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Environmental Security in Watersheds: The Sea of Azov

Edited by
Viktor Lagutov

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Environmental Security in Watersheds: The Sea of Azov

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Series C: Environmental Security

Environmental Security in Watersheds: The Sea of Azov

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Springer

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Foreword

Though the term “Environmental Security” is a widely used, well perceived and intuitively clear concept, it lacks a commonly accepted definition and methodologies. Definitions vary greatly depending on the institution or context in which it is discussed. Existing approaches to Environmental Security (ES) can be divided into two broad yet interlinked categories: (1) in which ES is a subject for international relations studies aiming to avoid violent conflicts over scarce resources; and (2) in which ES is a sign of sustainability in nature–environment interactions and, correspondingly, a part of national and human security.

According to the first approach ES is a process for effectively responding to changing environmental conditions that have the potential to reduce peace and stability in the world. Undoubtedly, this definition identifies an important issue. Changing environmental conditions cause harm and endanger societies depending on them, which in turn undermines peace and global stability. However, this approach suggests actions when changes have already commenced. At the same time most environmental changes which have affected human societies so far are human induced due to overexploitation of some ecosystem services and goods (e.g. overfishing) or their irrational usage (e.g. building in floodplains). Carefully planned patterns of natural resources consumption might assist in prevention of such changes to secure achieve in the functioning of ecosystems and societies. This observation brings up the need to consider the ecosystem services a vital component of the environmental security concept. Losing these services due to anthropogenic influence or natural hazards not only causes significant monetary losses, but also endangers human and societal well being. The second approach to ES definition is based on these considerations and allows the full complexity of human-environment interactions to be taken into account. At the same time, starting from this basis the perception of environmental security as an issue in international relations and conflict prevention/resolution can still easily be developed.

This approach also fits well with the traditional perception of environmental security in the former Soviet Union countries. In scientific and managerial communities in the region this term is understood in a much broader way than in the western tradition. As a rule Environmental Security is translated into Russian as “Ecologicheskaya

Bezopasnost" (Ecological Safety), which is perceived as a newer paradigm and logical development of the well known and long studied "Life and Industrial Safety" concept ("Bezopasnost' Jiznedeiatelnosti"). The latter, an assessment of anthropogenic activities on ecosystems and possible associated harm to humans, was an important discipline in the Soviet scientific arena for decades. Most educational programs on environmental management and policy that have appeared in the region since the 1980s have been launched by the mentioned academic departments. Undoubtedly, this fact has contributed to the formation of the perspectives and frameworks in which environmental security is being studied in the post-Soviet countries.

While almost every aspect of society-nature interactions can potentially be treated as an environmental security issue, threats originating from inadequate freshwater management constitute one of the most wide-spread and pressing problems. A perfect example of this feedback is the well-known Aral Sea catastrophe. The management policy oriented on economic growth and profit maximization (e.g. growing water withdrawal for irrigation) resulted in overexploitation of ecosystem resources and irreversible changes in the riverine and marine ecosystems. As a result of their degradation the regional economy has collapsed, causing social problems and international tensions. Prior to the disintegration of the Soviet Union the Aral Sea used to be an internal problem with little attention paid to it by international environmental communities. However, lately it has become an international issue with the risk of violent conflicts over the scarce resources in the area.

Unfortunately, this catastrophe has not led to radical changes in water management practices. The Sea of Azov, similar to the Aral Sea in many aspects, is following the same path. Neglected by most international environmental programs and suffering from a lack of national attention to environmental issues in development plans, the Sea of Azov is another example of ecosystem collapse due to water mismanagement and associated social-economic decline.

The Sea of Azov provides a perfect case study to consider environmental security issues from various perspectives. It has strategic importance for both basin countries (Russia and Ukraine) which depend on its ecosystem resources. Once one of the most productive seas in the world, it is now exposed to scarcity in water and aquatic resources. Some ecosystem services and goods are prioritized, while other needs are neglected. It is also increasingly high on the international political agenda, as the gateway to the landlocked and mineral-rich Caspian countries.

Analysis of these issues was given a major boost by the establishment in 2009 of the Azov Center for Watershed Cooperation (http://azovcenter.ru), which aims at studying the Azov's problems and contributing to ES threat mitigation. Based on the broad ES definition the Center's activities are diverse. One of the important areas of the Center's activities is an education and training program targeting water stakeholders and decision makers in the Azov region. Education facilitates environmental security through public awareness-raising not only because of the growing recognition of environment–security interdependences and negative consequences of unilateral decisions, but also due to stakeholders' exposure to points of view and needs other than those defined by their professional duties and daily routine.

The NATO Advanced Study Institute "Watershed Approach to Environmental Security: Fostering integrated water management in the Azov Sea Basin" has been carried out as a part of this program in September 2010. The Institute, co-financed by the NATO Science for Peace Program and the Black Sea Trust for Regional Cooperation, was attended by experts, researchers and practitioners from Governmental Environmental Agencies, NGO and business representatives from both basin countries (Russia and Ukraine), and representatives from relevant international organizations: the Food and Agriculture Organization of the United Nations, the Secretariat of the Wetland Convention (RAMSAR), the Secretariat of the Commission on the Protection of the Black Sea Against Pollution, the International Association on Danube Research, and many others representing a wide spectrum of Azov water stakeholders.

The current volume is based on the contributions made by the Institute participants, both faculty and students, who have learnt from each other during the Institute. Environmental security is a highly interdisciplinary subject regardless of the way in which it is defined or which approach is used for its assessment. The choice of these disciplines is always region-specific, depending on the problems, challenges, and available management options. Though the papers presented in this volume cover a wide range of disciplines, this is only an attempt to attempt to grapple with some aspects of the Azov Sea situation and does not pretend to be an exhaustive analysis of the threats to environmental security in the Azov basin. It is rather seen as an attempt to initiate a broad discussion over the fate of this important region and the first step towards productive international cooperation.

The volume consists of three distinct yet logically connected parts.

The first part introduces the Sea of Azov and its watershed, describing ecosystem services utilized by humans, both positive and negative feedbacks, as well as challenges arising and problems caused. Some threats to regional Environmental Security are identified here and some ways of mitigating them are also suggested.

The second part of the volume is devoted to the Black sea as the ecosystem hosting the Sea of Azov. These two seas are not only closely interconnected but also often considered as one system. Nevertheless, as a rule the Sea of Azov is excluded from the Black Sea's environmental agenda. Deeper insight into the processes taking place within the larger watershed is crucial for better understanding of the Azov processes and trends. Moreover, ES practices which have been successfully applied in the Black Sea situation will often be applicable to the Sea of Azov. One of the important considerations in this regard is habitat restoration for migratory species (e.g. sturgeon), which serve as a perfect bioindicator of an ecosystem's health.

At the same time reviewing international experience from other regions might also be useful to identify the ways to restore the Azov ecosystem's resilience and to secure a sustainable pattern of natural resources. The third part, devoted to available experience in transboundary basin management, starts with a chapter on the catastrophe of the Aral Sea. Numerous signs of the Azov Sea following the Aral's path can be already observed, and the largest manmade water-related catastrophe can serve as a perfect case study of the negative influence of prioritizing one ecosystem service (water for irrigation) over all others.

Stakeholder involvement is one of the most important prerequisites for successful water management, sustainable usage of water resources and developing mechanisms of environmental security. At the same time it is often one of the most challenging and controversial issues. The volume concludes with discussion of the best ways to secure stakeholder communication and active involvement in decision-making process.

All illustrations in this volume have been developed by the authors of the corresponding chapters unless otherwise indicated.

Prof. Viktor Lagutov

Preface

The issue of integrated watershed management for environmental security is extremely complex both scientifically and politically, especially given the additional factor of transboundary considerations. Notably, bringing together stakeholder representatives from national, regional, university organizations that deal with the Azov-Don watershed as well as international experts in multidisciplinary areas of scientific investigation and public policy expertise for this ASI was an excellent approach to addressing problems in the Azov-Don watershed. At the same time, the focus on this system makes important contributions to similar systems elsewhere in the world.

A myriad of economic development activities such as agriculture, manufacturing, dams, climate change, increasing coastal populations, waste management, transportation, and others all have impact on and an interest in the viability and health of watershed systems. Numerous important issues were addressed in this ASI. The over-arching issue of environmental security was a key focus, and component parts included ecosystem services, water usage issues, role of a variety of stakeholders, governance priorities and concerns, applicable scientific methodologies, monitoring techniques, predictive modeling tools, aquatic species (especially sturgeon) protection, problems analysis, and restoration efforts and successes.

It is gratifying to see the diverse roles represented by the participants in this ASI. When such a group comes together to address these important environmental security issues and collegially and knowledgeably discuss scientifically sound and economically practical solutions to problems, there is real hope for successful environmental protection side-by-side with economic development, not only in the Azov Sea Basin but across the world.

Rosemarie C. Russo, Ph.D.
International QSAR Foundation

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- Rostov Chamber of Commerce and Industry;
- Don Cossack communities.

The role of individuals in event organization and manuscript preparation always plays a major role. To stress this contribution personal thanks are expressed to

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The team of the colleagues from the Central European University (Kristina Rodina, Natalia Pervushina, Anar Mansurov) without whose selfless efforts and enormous energy a successful Institute would hardly have been possible.

[1] Opinions expressed in the written or electronic publications do not necessarily represent those of the Black Sea Trust, the German Marshall Fund, or its partners.

The help in preparation of this volume provided by Jovan Batancev and Nataliya Ilyashenko is highly appreciated. Their professional contribution and total dedication was essential for the entire project's completion.

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Contents

Part I The Azov Basin: Services, Drawbacks and Challenges

1 **The Azov Ecosystem: Resources and Threats** 3
Viktor Lagutov and Vladimir Lagutov

2 **Ecosystem Services of Rivers: The Don River (Russian Federation) and the Roanoke River (USA)** 63
Brenda Rashleigh, Viktor Lagutov, and Tobias Salathe

3 **Climate Change, Water and Agriculture in the Azov Sea Basin** 79
Nikolay Dronin and Andrei Kirilenko

4 **Ecological and Hydrogeological Assessment of Ukrainian Part of the Azov Sea Basin** 95
Svitlana Sytnik, Mykola Kharytonov, Anna Vagner, Victoria Lovinskaya, Elena Rabich, and Nataliya Ilyashenko

5 **Multipurpose Water Scheme Assessment of the Tsimlyansk Reservoir** 107
Elena Shavrak, Lev Fesenko, Irina Generalenko, and Nataliya Ilyashenko

Part II The Black Sea Experience

6 **Black Sea Environmental Status Improvement Through the Restoration of Wetlands Along the Danube River** 117
Dan Cogălniceanu

7 Fish Stock Management Cooperation in the Lower Danube Region: A Case Study of Sturgeons and Pontic Shad 127
Mirjana Lenhardt, Željka Višnjić-Jeftić, Ion Navodaru, Ivan Jarić, Milen Vassilev, Zoran Gačić, and Miroslav Nikčević

8 Distributed Geocomputation for Modeling the Hydrology of the Black Sea Watershed 141
Nicolas Ray, Gregory Giuliani, Dorian Gorgan, and Anthony Lehmann

9 Governance of the Protection of the Black Sea: A Model for Regional Cooperation 159
Violeta Velikova and Nilufer Oral

10 Vulnerability of the Black Sea to the Impacts of Climate Change 173
Gamze Celikyilmaz-Aydemir

Part III Transboundary Water Management

11 Spills of the Aral Sea: Formation, Functions and Future Development of the Aydar-Arnasay Lakes 183
Kristina Rodina and Ruben Mnatsakanian

12 Caspian Sea: Problems and Prospects 217
Anar Mansurov

13 Water Management and Use in the Amur-Heilong River Basin: Challenges and Prospects 223
Natalia Pervushina

14 Participatory Futures Research and Social Learning for Integrated Watershed Management 241
Andrew Segrave, Chris Büscher, and Jos Frijns

Abbreviations

AALS	Aydar-Arnasay Lake System
ADB	Asian Development Bank
ARC	Advanced Resource Connector
AzNIRH	Azovskij Nauchno-Issledovatelskij Institut Rybnogo Khoziaystva (Azov Sea Fisheries Research Institute)
AzovCenter	Azov Center for Watershed Cooperation
BASINS	Better Assessment Science Integrating Point and Non-point Sources
BSERP	Black Sea Ecosystem Recovery Project
DPSIR	Driving Forces-Pressure-State-Impact-Response framework
DWSI	Dutch Water Sector Intelligence
EEA	European Environment Agency
EGEE	Enabling Grids for E-sciencE project
EPA	United States Environmental Protection Agency
ES	Environmental Security
ESA	Environmental Security Assessment
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FWS	United States Fish and Wildlife Service
GIS	Geographic Information System
ICPDR	International Commission for the Protection of the Danube River
IES	International Institute for Environmental Security
IPCC	Intergovernmental Panel on Climate Change
IUCN	The World Conservation Union
IWRM	Integrated Water Resource Management
IWTS	Inland Water Transport System
MAC	Maximum Allowable Concentration
MEA	Millennium Ecosystem Assessment
mil, mln	million
MPC	maximum permissible concentration
NGO	Non-Governmental Organization
OECD	Organization for Economic Co-operation and Development

SD	Sustainable Development
SDI	Spatial Data Infrastructure
STELLA	Structural Thinking Experiential Learning Laboratory with Animation
SWAT	Soil Water Assessment Tool
TAC	Total Allowable Catch
TDA	Transboundary Diagnostic Analysis
UNDP	United Nations Development Program
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
WCMC	World Conservation Monitoring Centre
WFD	Water Framework Directive
WWF	World Wildlife Fund

Part I
The Azov Basin: Services, Drawbacks and Challenges

Chapter 1
The Azov Ecosystem: Resources and Threats

Viktor Lagutov and Vladimir Lagutov

Abstract The current unsustainable pattern of water resource use in the Azov Sea basin undermines regional environmental security. The damming of rivers followed by active utilization of aquatic ecosystem services has decreased freshwater influx to the sea by one third and there is a growing trend of irrevocable water abstraction. The water has been redistributed through the region causing changes in ecosystem resources and services consumption, greatly contributing to and at the same time threatening the regional economy and environmental security. As a result of irreversible changes the Azov Sea ecosystem is not capable of supporting many essential ecosystem services. Though the basin is a strategic area playing an important role in national and international development plans, it has been excluded from most regional environmental discussions. The already serious existing threats to both humans and ecosystems will be amplified by implementation of regional development plans (e.g. construction of new Azov Caspian shipping canal "Eurasia" and increase in transport intensity). Environmental and economic hardships could trigger political instability in the area inhabited by the reviving paramilitary Cossack communities. In this context, there is a need for integrated interdisciplinary analysis of the basin's environmental security. The paper aims at reviewing existing ecosystem services provided by the Azov ecosystem, historical paths in their utilization and corresponding challenges as a first step towards an integrated assessment of regional environmental security.

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1.1 Introduction: Environmental Security and Watersheds

1.1.1 Environmental Security

Although the concept of environmental security has been under careful consideration since the 1980s, there is still no commonly accepted definition [65, 100]. The definitions suggested by different institutions and authors are human-, state- or military-centric with some overlapping in approaches and methodology. Primarily two groups have been exploring the linkages between environment and security from different perspectives: (1) the environmental policy community and (2) the security community [164].

Traditionally the very term 'security' was affiliated with 'national security', especially during the Cold War, since the issues covered by it were supposed to be addressed by military authorities [16, 74]. Later, in the 1990s, many researchers started moving away from a narrowly militaristic understanding of threat, vulnerability and response mechanisms with regards to 'security' [100].

The fact that environmental stress can induce or amplify conflicts or instability has gradually become recognized by all the parties involved in the discussion. Environmental stress might include a variety of possible threats to society such as resource scarcity, ecosystem degradation or transboundary pollution. Often security institutions are called upon to protect resources and goods or gain control over them under conditions of escalating violence and wars. In case of environmental disasters the same organizations are requested to cope with the problems and mitigate negative consequences. The interlinkages between environment and security are numerous and have been actively explored by various scientific and managerial communities [1, 65, 66, 74, 100, 164]. For instance, Brown claims there are four main issues related to environment and security [16]: (1) resource scarcity as a cause for insecurity and conflict; (2) as an attribute of a society's transition to a market economy; (3) abundant resources as a source of conflict; (4) as one of the many "network threats". The environmental security concept is still being actively developed, articulating the need for a holistic integrated approach to human security, yet common definitions and methodologies are still to be found [65].

The Institute for Environmental Security (IES) has recently published (in 2011) a Methodology for Environmental Security Assessments which defines environmental security as:

> The current and future availability (determined by the factors – supply, accessibility and management) of life supporting ecosystem services and goods for human needs and natural processes which contribute to poverty alleviation and conflict deterrence [65].

This definition is clearly influenced by the well-known concept of Sustainable Development(SD):

> Sustainable Development meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland [129]).

However, unlike the SD concept the IES has some practical points and foundation for practical activities. The SD definition has been criticized for being too vague and general with little functional value [85]. It is often interpreted in a variety of ways suiting any needs of a person or institution speculating on it. Enriching the SD concept with ideas of considering ecosystem services and resources can provide a specific and practical foundation to help get the SD concept implemented in everyday management [85, 90]. This approach is getting increasingly recognized and some international organizations are already using definitions such as the following:

> SD is a pattern of resource[1] use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for generations to come.

Taking into account the notion of 'security' as a state and 'development' as a process it might be suggested that Environmental Security can be achieved assuring Sustainable Development through the rational usage of natural resources and ecosystem services. In this way both concepts and processes involved can be interlinked enhancing each other with existing approaches and methodologies.

Though 'ecosystem services' is another currently vague and actively developing concept lacking common definitions and methodologies it is nonetheless a more intuitively clear idea. The Millennium Ecosystem Assessment [104] defines ecosystem services as "the benefits people obtain from ecosystems. These include provisioning; regulating; supporting and cultural services" [104].

In particular, services provided by aquatic ecosystems can be identified and (to some extent) quantified. Human societies consume water for their own needs[1] in a number of ways which can be clarified, assessed and compared.

For instance, wetlands alone provide the following services in four types of ecosystem services:

- Provisioning (food, fresh water, fiber and fuel, biochemical genetic materials, etc.);
- Regulating (climate regulation, water regulation [hydrological flows], water purification and waste treatment, erosion regulation, etc.);
- Cultural (recreational, inspirational, aesthetic, etc.);
- Supporting (soil formation, nutrient cycling, etc.).

[1] Resources, natural resources, ecosystem services and goods are similar terms [65] and used interchangeably through this volume.

Water is utilized by every sector of a society and economy. Its shortage or low quality is a significant threat to all security types: environmental, national, personal, etc.

Water, aquatic resources and other services and goods affiliated with aquatic ecosystems are rapidly becoming an important issue on the international political agenda and in national development plans [40, 43, 66, 127, 155, 161]. The understanding that freshwater is a valuable but limited resource is becoming widespread, causing international conflicts and disputes.

At the same time, water ecosystems have undergone significant changes worldwide. In particular, according to the Millennium Ecosystem Assessment (MEA) 3–6 times as much water is stored in reservoirs as in natural rivers [104]. This is an unprecedented level of change and has already caused irreversible changes in many ecosystems. For instance, redistribution of the water in the Aral Sea has caused the sea's disappearance and loss of its unique ecosystem and biodiversity, which resulted in national-scale economic and social catastrophe [175]. The regional economy has collapsed, and many environmental refugees have fled the area causing political and economic instability in other regions. The linkage between unsustainable usage of natural resources for the sake of economic development and threats to all types of security (e.g., personal, food, national, even military[2]) is obvious. Unlike many other systems, the changes made to freshwater ecosystems can be irreversible. Most of the endemic species of the Aral Sea are extinct with no chance for restoration.

Thus, given exponentially increasing anthropogenic pressure on water ecosystems [104] and possible climate change [37, 68] the existing and prospective water management schemes and scenarios demand profound environmental security assessments. Services and goods in aquatic ecosystems provide a strong foundation for assessing environmental security. This assessment should not focus on military or personal security only, but rather use an integrated holistic approach. Following different interpretations of the ES concept alternative methods to assess its threats have been suggested [1, 3].

The method of Environmental Security Assessment (ESA) formulated by the IES most closely matches the criteria outlined above. The IES approach postulates the following principles:

- human beings are the referent object of environmental security;
- anthropogenic and naturally induced changes to life supporting ecosystems are the origin of a threat;
- providers of environmental security are stakeholders of ecosystem services, international organisations and other relevant institutions.

Using this foundation the IES has developed a methodology to work towards achieving global environmental security through *maintenance of regenerative*

[2]Many experts believe that scarcity of water resources in Central Asia and disputes over their redistribution as a vital component of national economies could trigger violent conflicts in the region [152].

capacity of life- supporting ecosystems (resilience) in order to secure the conditions for peace and sustainable development [65]. The approach consists of completing two main objectives:

1. Identification of threats to environmental security;
2. Examination of the ways to address and prevent these threats.

While the second objective (namely analyzing the ways to mitigate and prevent environmental security threats) is a questionable and controversial matter, the methodology for dealing with the first objective is more or less straightforward. According to the indicated methodology, threats to environmental security can be assessed through answering the following four questions:

- Are there ecosystems services and goods of global/high conservation value?
- Are there communities relying on these ecosystems for their livelihood?
- Are there changes in availability of ecosystem services and goods?
- Are these changes in availability expected to negatively impact the current and future availability of ecosystem services and goods?

Nevertheless, application of the ESA methodology to a specific aquatic ecosystem is still a challenging task. For instance, ecosystem services identification at the first stage is complicated by a number of issues such as the need for a potential service within an affiliated society. On the one hand, interlinkages between ecosystem and society and trends in their developments should be analyzed as broadly as possible. On the other, interests of stakeholder groups within society might conflict with or even completely contradict each other. The case of water management considered through the prism of environmental security illustrates this problem very well. In particular, flood protection is considered to be an important environmental security concern and one of the major functions of water management by some stakeholder groups [65], while other groups treat lack of flooding as a catastrophe for the river ecosystem and services provided by it [18, 60, 71, 177].

The tradeoffs among these stakeholder groups are addressed in the second stage of the ES threats assessment, yet in practical everyday water management, consensus in resources distribution cannot be accomplished without prioritizing some ecosystem services and neglecting other interests.

1.1.2 Watersheds

Some challenges in assessment of environmental security threats for an aquatic ecosystem and affiliated societies can be tackled in a more efficient manner compared to others. One of the problems that can be resolved is the delineation of ecosystem borders.

Ill-specified borders of an ecosystem might lead to the well-described and extensively discussed "tragedy of the commons" [62], where shared limited resources are depleted by stakeholders acting independently and rationally following their own self-interest, even when all the parties are concerned with long term resource sustainability. In many cases the proper borders of a system are difficult to establish.

This problem can be easily addressed by considering a watershed as the physical border for the ecosystem under consideration. One of the few principles accepted by alternative SD definitions and approaches is that a watershed can be considered as the most appropriate territorial unit for sustainable development [40, 55, 63, 162]. Watersheds were first identified as possible units for effective administrative division and management of economic activities a long time ago[3] [73] and this idea is still being actively promoted today [54, 125, 127].

In simple words, "a watershed is the area of land where all of the water that is under it or drains off of it goes into the same place" [40].

Using the watershed as a territorial unit for environmental security assessment brings together most relevant anthropogenic and natural processes to secure an integrated approach. This synthesis occurs literally, as water runoff brings all the traces of the human activities in a watershed to one single point.

As stated by John Wesley Powell, the US geographer who promoted the definition of US state borders according to watersheds in the nineteenth century:

> that area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community [40].

Moreover, successful application of the ES and SD concepts to a watershed can be secured by well elaborated Integrated Water Resource Management methodologies [54, 88, 89].

The consideration of watersheds also allows introduction of the ecosystem-wide integrated bioindicator, migratory aquatic species (i.e. sturgeon) which allows various aspects of ecosystem and social sustainability to be brought together [88, 91, 167].

A river watershed, therefore, seems in many ways to be a perfect object for environmental security analysis. However, it is still an open system. Consideration of processes occurring only within watershed boundaries cannot fully determine whether usage of ecosystem services (natural resources or goods) has a "sustainable pattern" securing ecosystem resilience and, correspondingly, ES.

The case of the Aral Sea shows that very effective and economically beneficial water consumption within a river basin resulting in economic growth and increasing (as it was believed) regional environmental security can end up as a catastrophe and one of the largest threats to environmental security known. To avoid this shortcoming in analysis, a watershed should be understood as an ecosystem including both water catchment area (river basins) and receiving waters (lake or sea).

There is another ecosystem similar to the Aral Sea case with a large freshwater catchment area and a more or less isolated small sea as a sink, namely the Sea of

---

[3] John Wesley Powell [1834–1902], the second director of the US Geological Survey, had been promoting the idea that the USA state borders should based on watershed areas to optimize agricultural activities.

Azov located in the southeastern part of Europe. There is a fear that this Sea might follow the path of the Aral Sea causing similar or even larger problems at the European scale. The Azov Sea basin incorporates a wide range of important human activities and provides a large number of ecosystem services. It can be used for discussing controversies and challenges of the environmental security concept and evaluating the perspectives of ES assessment methods.

The purpose of this paper is to give a short overview of the Azov ecosystem discussing selected services and goods as a first step towards a regional Environmental Security Assessment. The paper was not intended to provide an exhaustive detailed coverage of all the ecosystem services and threats to environmental security in the region, but rather to initiate discussion of environmental security issues on the watershed level among the regional and international communities.

1.2 The Azov Sea and Its Watershed

1.2.1 The Sea

The Sea of Azov (Fig. 1.1) is a unique ecosystem for a number of reasons. First of all, the Sea of Azov is the shallowest sea in the world with a maximum depth of only 14 m and an average depth of 7 m [11]. The large part of the sea, the Taganrog Gulf,

Fig. 1.1 The Sea of Azov and its watershed

has an average depth of only 1 m. Having an area of 39.1 th km^2 and a volume of 290 km^3, the Azov is the smallest sea in the world [138]. The water residence time in the sea is estimated at 10–20 years [13].

The climate in the region is continental with cold winters (mean temperature varies from −1°C to −5°C with minimum below −30°C) and hot dry summers (25°C with maximum above 40°C).

Historically[4], the average annual salinity of the sea of Azov was about 10.9‰ through almost the entire sea body[5] [11]. Nevertheless, the Taganrog Gulf has been almost fresh due to the large amount of freshwater brought by the tributaries. At the same time other parts of the Sea such as the Syvash, the lagoon in western part of the Sea, have been known as highly saline areas being traditional places for salt production. Sharp changes in average salinity level occurred in the second half of the twentieth century with an overall increasing trend to 14‰ and high stratification of salinity levels [138, 141]. Salinity and temperature conditions drive other characteristic features of the Sea.

Two main Azov Sea tributaries, the Don and Kuban Rivers, bring large amounts of sediments and nutrients from their vast and fertile catchments. Combined with the small sea volume, good water mixing and heating, low water salinity and long vegetation period, the nutrients provide favourable conditions for plankton and fish growth. The fauna of the Sea includes more than 300 invertebrate species and about 80 fish species including sturgeon, perch, bream, herring, sea-roach, gray mullet, minnow, shemaja, bullheads, sardines and anchovies[6] [14]. Black Sea Dolphins have often been observed in the sea.[7]

Historical biological productivity is extremely high for a sea. Allowing a sustainable fish harvest of more than 85 kg per ha of surface it has been proclaimed the most productive sea in the world [2, 36, 45, 140, 144, 151]. According to these assessments, other seas generate a much lower harvest.[8] The average annual catch used to be about 300 thousand tonnes during a 50 year period in the twentieth century [47, 86].

Another interesting feature of the Sea is the numerous spits along its coasts. The Arabat spit, one of the longest in the world, is 112 km long. The spits form shallow lagoons recognized as important sites for migrating birds [126] and recreation activities [58]. The sea and adjacent areas have one of the highest concentrations of Ramsar sites, e.g. wetlands of international importance, designated under the Ramsar Convention (http://www.ramsar.org). Of the ten largest wetlands in the Azov-Black sea region, seven are located in the Sea of Azov basin (Fig. 1.2) [103].

[4]Before the regulation of the river basins.

[5]Currently the Azov Sea salinity varies significantly depending on the region.

[6]Many species either already became extinct or have not been observed for a long time.

[7]Dolphins have disappeared from the Azov Sea lately [3].

[8]The Black and Mediterranean Seas produce 2 kg/ha and 0.5 kg/ha correspondingly [121].

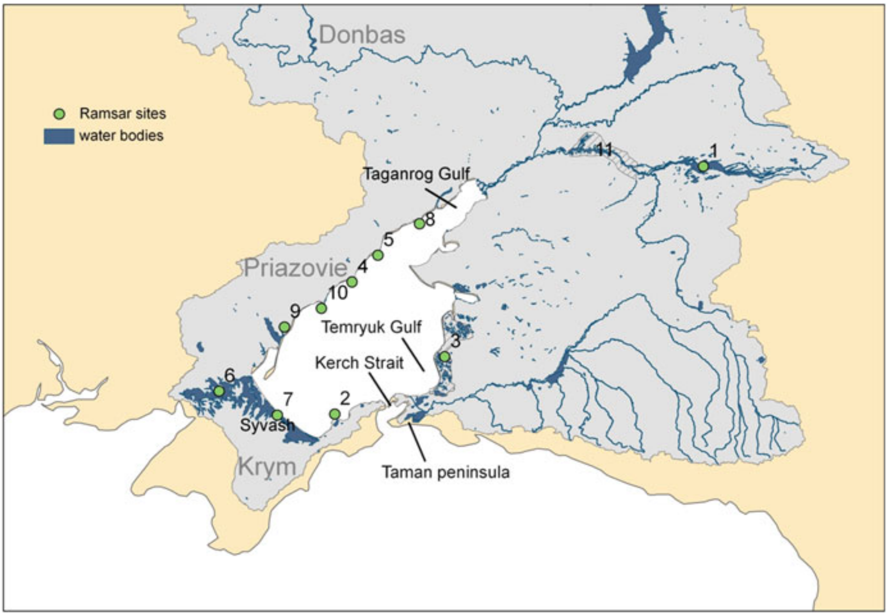

Fig. 1.2 The designated Ramsar sites in the Azov Sea watershed: *1* – Lake Manych-Gudilo, *2* – Cape Kazantyp, *3* – Kuban Delta, *4* – Berdianskaya Spit, *5* – Bilosaraiskaya Spit, *6* – Central Syvash, *7* – Eastern Syvash, *8* – Kryvaya Spit, *9* – Molochnyi Liman, *10* – Obytochna Spit, *11* – Veselovskoe Reservoir (Based on datasets from UNEP-WCMC [165])

Biodiversity of the Azov Sea is very rich not only because of the nutrients brought by the tributaries, but also due to diverse environmental conditions in the tributaries enhancing the biological diversity of the Sea. In particular, despite being geographically close rivers the Don and Kuban are clearly distinct in terms of native fauna.

The Sea is considered to be an internal water body of Russia and Ukraine, which is governed by bilateral agreements. Nevertheless, the border demarcation law was signed only in July, 2010 [130].

1.2.2 The Basin and Rivers

The Azov ecosystem and services provided by it strongly depend upon the quantity and quality of the freshwater runoff from its drainage basin. The Azov drainage area is 586,000 km^2, making the sea the world's leading water body in terms of basin to sea surface ratio (Fig. 1.3). This ratio, coupled with the rich biological life in the watershed, supports a large delivery of nutrients to the sea contributing to its high productivity [81]. The drainage ratio for the Sea of Azov (15 km^2 of watershed per 1 km^2 of sea surface) is three times as much as for the Black Sea (4 km^2).

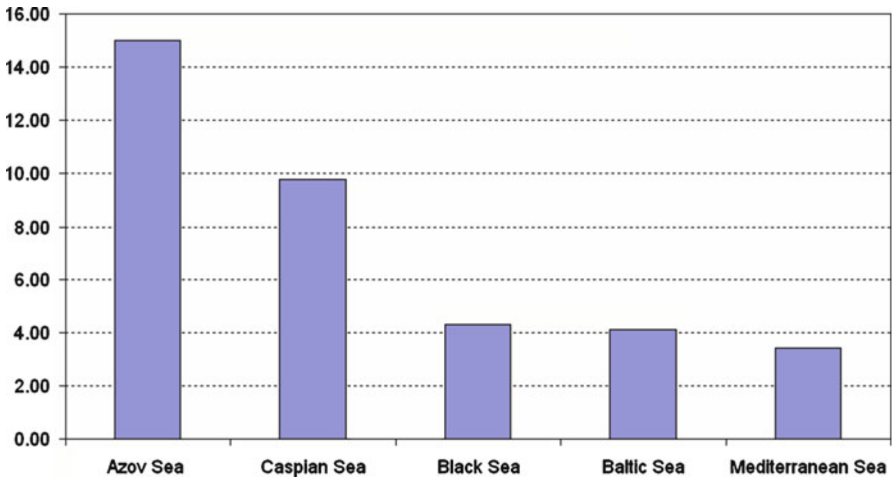

Fig. 1.3 The ratio of sea drainage area to sea surface *(calculated by the authors)*

The basin can be divided into three main sections: catchment areas of the (1) Don and (2) Kuban and (3) about 20 other smaller rivers (Fig. 1.4).

Annually the rivers provide about 35.7[9] km^3 of freshwater to the sea. The main influencing river is the Don, the largest basin river with an average natural annual flow around 26 km^3,[10] which provides around 60% of the total freshwater input to the sea. The Kuban delivers about 28% (12.8 km^3), leaving the rest to smaller rivers [13, 32]. Figure 1.5 presents the ratio among rivers' freshwater contribution.

The rivers experience high seasonal and yearly variations in water flow [48]. The Don River shows a higher dependence on the annual weather conditions than the Kuban, indicating higher amplitude in discharge (Fig. 1.6).

The Azov Sea basin, especially the lower Don catchment area, is one of the most productive economic regions with regards to industrial and agricultural sectors in both Russia and Ukraine [2, 82, 83, 109].

The most fertile soil, chernozem, located mostly in the catchment of the Sea of Azov, is accompanied by the most favourable climate conditions in Russia, supporting a high level of agriculture development. Though climate conditions vary within such a large territory, in terms of other Russian river basins they are similar. This defines similar land use patterns presented in Fig. 1.7.

It can be observed that not only almost the entire Azov watershed is cultivated, but it is mostly covered by various croplands. The only forested areas are located in

[9]According to the Russian State of the Environment report the freshwater influx in 2009 was 43 km^3 [138].

[10]Prior to the construction of the Tsimlyansk reservoir and the Volga-Don canal the average total annual flow in the river delta was 29.5 km^3 [36].

Fig. 1.4 Azov river network with largest dams indicated

the Caucasian mountains in the southern part of the Kuban basin, while some bare, sparsely vegetated areas occur in the eastern part of the Don basin.

The lower level of agricultural activities in the eastern part of the Azov drainage is explained by less favourable environmental conditions. For instance, Fig. 1.8

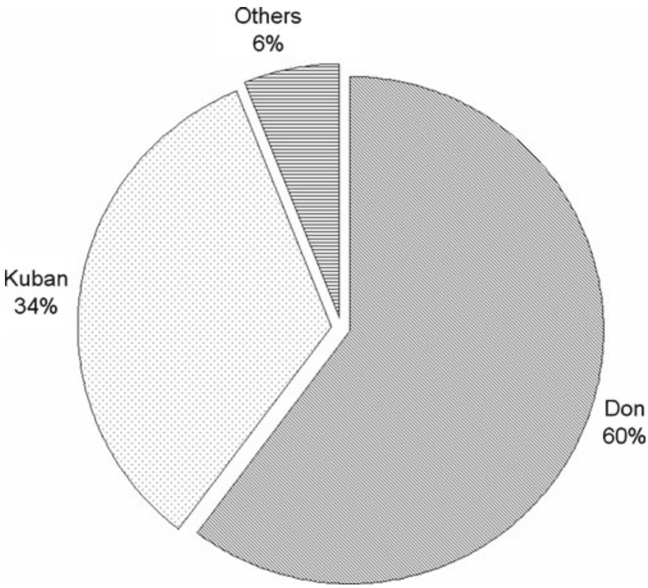

Fig. 1.5 Freshwater influx to the Azov sea by the main tributaries for the period 1953–1985 (Based on Borysova et al. [13])

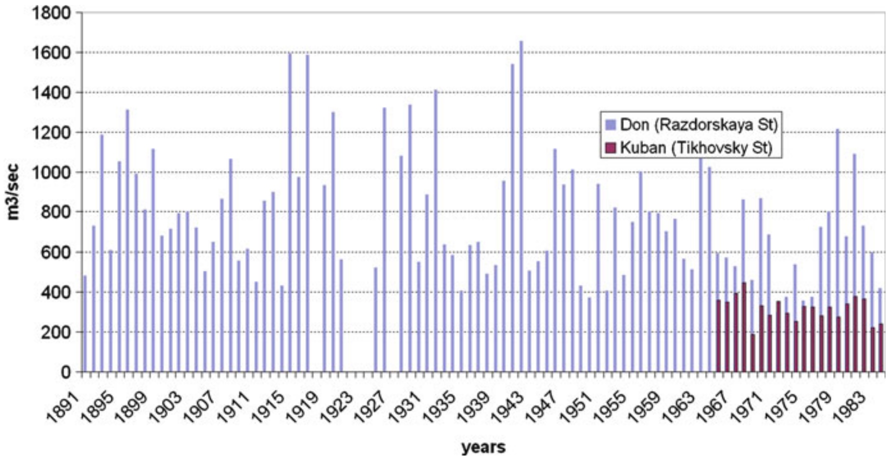

Fig. 1.6 Average annual discharges for the Azov rivers. The gauge stations are indicated in *brackets* (Based on Vörösmarty et al. [172])

depicts climatic conditions in the basin showing mean annual precipitation and temperature in the basin. Low precipitation is typical for the entire basin, while the eastern areas are exposed to even lower precipitation, causing desertification and low agricultural productivity. These areas are vulnerable to aridification [108, 156].

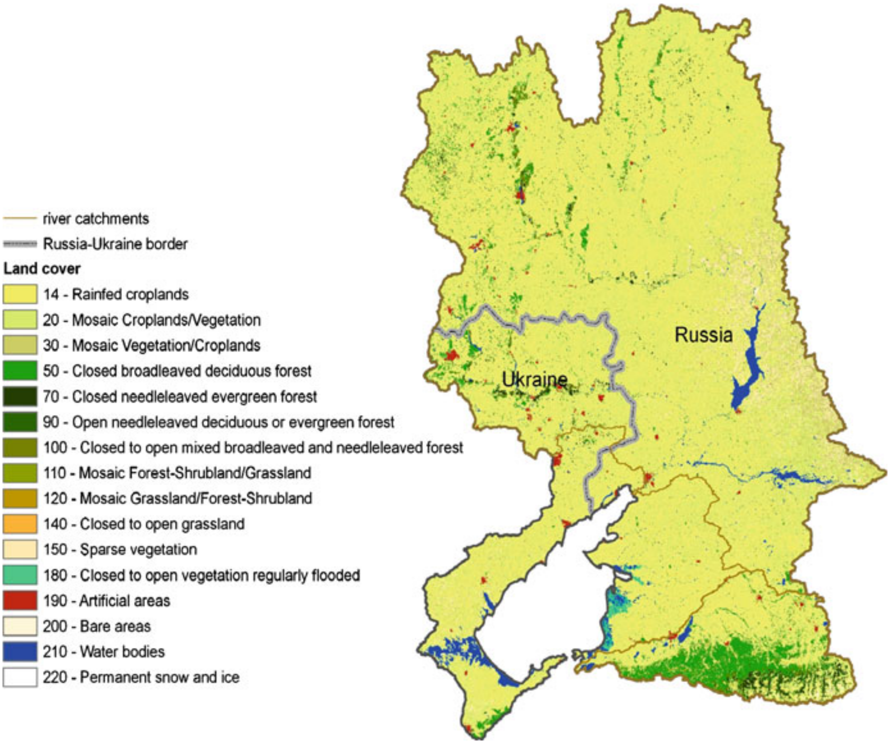

Fig. 1.7 Land cover in the Azov basin (Based on ESA [41])

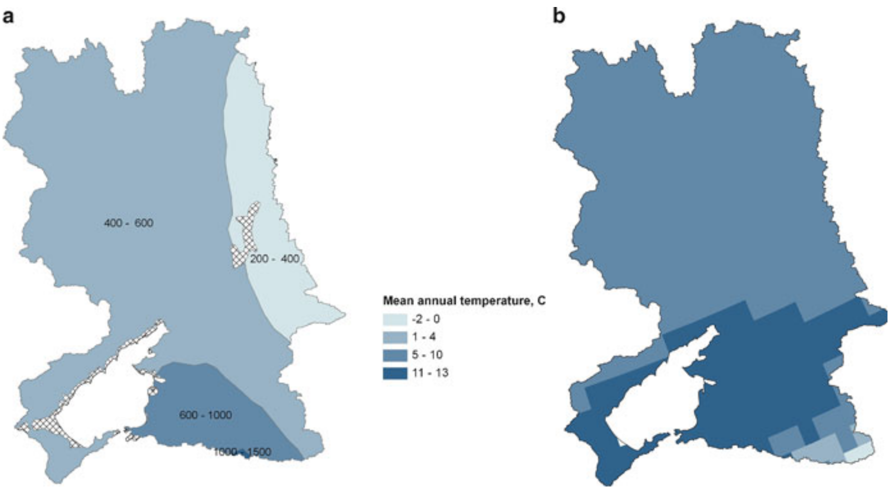

Fig. 1.8 (**a**) Mean Annual Precipitation (mm/year) and (**b**) Mean Annual Temperature (C) in the Azov basin (Based on UNEP [163] and Mitchell and Jones [106])

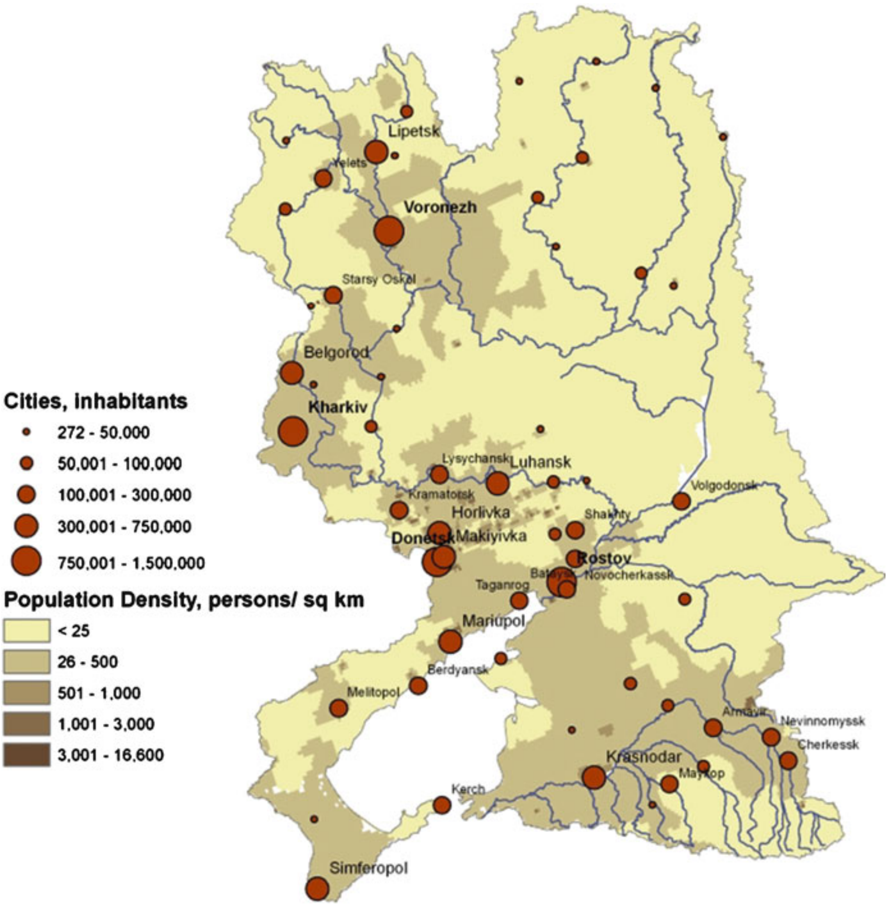

Fig. 1.9 Population density and largest settlements of the Azov basin (Based on UNEP [163])

The sea and its basin contain significant deposits of mineral resources (coal, iron, oil and gas, etc.) [58, 122].

The basin is one of the most densely populated areas in both Russia and Ukraine [138]. The total basin population calculated based on the Gridded Population of the World Version 3 (GPWv3) datasets is about 30 million inhabitants [22], out of which 18.8 million reside in the Don and 2.8 million in the Kuban basins. Figure 1.9 plots the population distribution through the basin and the largest urban settlements. It can be seen that the largest population share resides along the rivers. In particular, the most densely populated areas in the Azov basin are the Kuban River, Voronezh oblast and the Lower Don catchment including the largest Don's tributary Severskiy Donets.

Fig. 1.10 Administrative division of the Azov Basin

The basin is divided between Russia and Ukraine. It covers several regions (Fig. 1.10). Some of these regions in both countries are located completely within the Azov watershed (i.e., Rostov, Voronezh, Lugansk, Adygeya) or almost completely (i.e., Krasnodarskij Kray, Karachaevo-Cherkessiya).

1.2.2.1 The Don

The Don River (1,970 km) is the main source of fresh water in the basin of the Sea of Azov. It is the 4th longest river in Europe with a catchment area of 442 thousand km^2. The Don catchment area constitutes around 75% of the total Azov Sea basin, covering the most industrially developed areas. Thus, the processes occurring in the basin are the most important for the consideration of the environmental security of the Azov Sea basin.

The source of the river is southeast of Moscow near Tula and it enters the Gulf of Taganrog in the Sea of Azov (Fig. 1.1). The basin is shared by Russia and Ukraine with 87% and 13% of its territory respectively (Fig. 1.10).

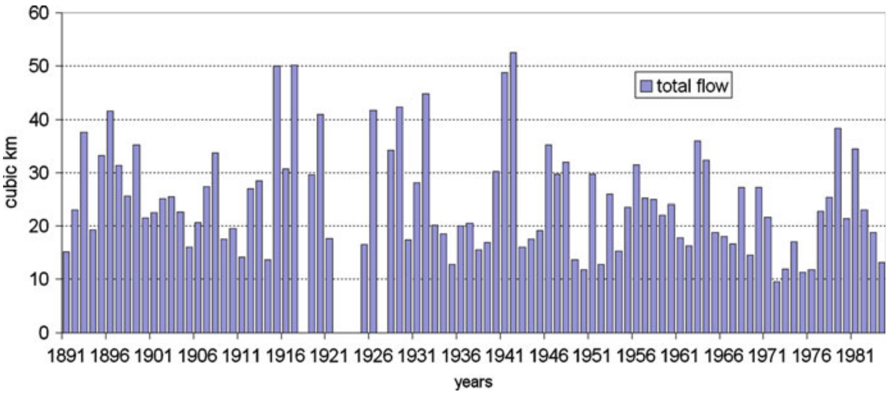

Fig. 1.11 The total Don annual flow for the period of observation 1891–1984 at the gauge station Razdorskaya (Based on Vörösmarty et al. [172])

The largest tributary is the Donets (the length – 1,016 km, catchment area – 99,600 km^2). Other important tributaries are the Voronezh, Khoper (1,008 km long, 61,000 km^2), and Medveditsa (764 km, 34,600 km^2). The river delta constitutes 340 km^2 with numerous arms and channels. The Don is a typical plain river with extended floodplain with numerous meanders along most of its tributaries. The upper river is confined to a narrow valley, while in the middle river the valley broadens to 6 km. In the lower course, from the Tsimlyansk reservoir to the river mouth, the Don valley is up to 20–30 km wide with large historical floodplain up to 12–15 km [45]. In this section the river can be up to 20 m deep.

The largest share of the river catchment area is covered by steppe with relatively low water availability (Figs. 1.7 and 1.8). The average annual river discharge is only 900 m^3/s or 2 l/s from 1 km^2 [150]. In this way, the relative water availability of the Don is 5–6 times lower than rivers in the Russian European North [137].

The natural hydrological regime is typical for steppe ecosystems and closely resembles other steppe rivers of Northern Eurasia such as the Ural River [90].

The Don starts to freeze in late November – early December and ice lasts for 140 days in the upper river and up to 90–100 days in the lower branches. Snowmelt is the main source for the total river flow, which depends on snow availability and the water content of snow cover in the winter period. The share of snowmelt in the total river flow is up to 70%. Other two minor sources are springs, ground waters and to a lesser extent rainfall. As a result, a characteristic feature of the Don's hydrological regime is an extreme fluctuation in the average annual discharge and total annual flow. Figure 1.11 illustrates the average total annual discharge at the Don River at the gauge station of Razdorskaya since 1891.

A more than fivefold difference in total annual water flow was observed during the period of river hydrology monitoring from 1891 to 1984s. The maximum total flow of 52.53 km^3 was recorded in 1942, while minimum comprised only 9.48 km^3 in 1972 (Fig. 1.11).

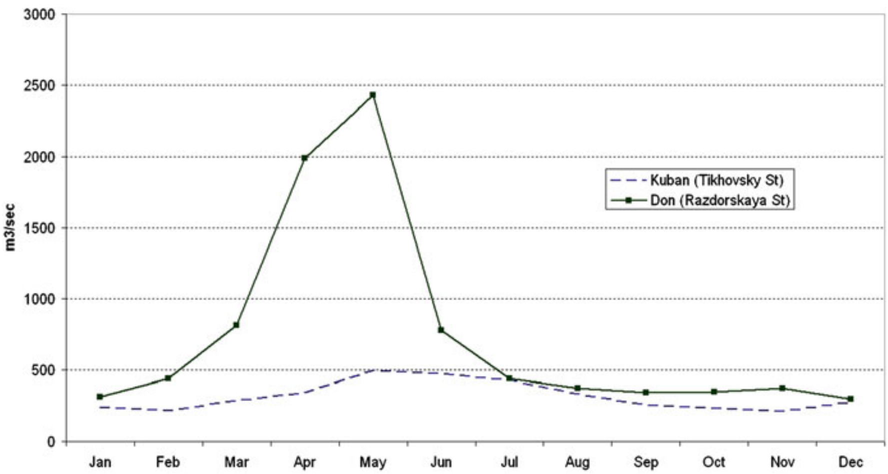

Fig. 1.12 The average monthly discharges by the main Azov rivers. The gauge stations are indicated in *brackets* (Calculations are based on Vörösmarty et al. [172])

The annual water distribution is also extremely uneven due to the high snowmelt proportion in the river flow. The monthly discharge for the average year based on the monitoring records for 1891–1984 is presented in Fig. 1.12 [172]. The high level spring flood with low or no summer and fall floods is a characteristic feature of the Don's hydrological regime, while the water flow during most of the year is very low (Fig. 1.12).

The fluctuation in water level during the flood period is significant along the entire river stream and amounts to 8–13 m [150]. Flood covers the wide floodplain especially in the lower river section.

An interesting feature of flooding in the lower Don is that it usually comes in two periods. The first one comes from snowmelt in the tributaries in the south called "golodnaya voda" ("hungry water"). The second wave "teplaya voda" ("warm water") arrives from the Northern branches. When snowmelt in the southern watershed is delayed and the two flows merge, high flood levels occur.

The Don River has 75 fish species considered indigenous to this watershed[11] [48].

1.2.2.2 The Kuban

The Kuban has a hydrological regime very different from that of the Don River. It originates on the slopes of Mt. Elbrus in the Caucasus, is fed by glaciers, and is a typical mountain river with rapid streams and canyons in its upper reaches.

[11] Many of these species are not present in the region anymore.

Halfway to the Azov Sea, the Kuban reaches the plain, forming numerous meanders, islands and rifts. In some places the river floodplain can reach up to 20 km wide while mostly it is only 3–4 km. Its drainage area is 61,000 km^2 and length is 906 km. The average annual discharge to the Sea of Azov is 12.8 km^3 [32].

An interesting feature of the river basin is the lack of any tributaries on the right side of the river with numerous watercourses originating in the Caucasus Mountains on the left.

The Adygeyskie (300 km^2) and the Zakubanskie wetlands (800 km^2) are situated close to the confluence of the Kuban tributaries, Laba and Afips rivers.

A characteristic feature of the Kuban River is an exceptionally developed delta that was once connected to both the Azov and Black Seas. The delta covers an area of 4,300 km^2 with an estuary of 1,200 km^2 area, 1.1 km volume and 0.9 m mean depth. These estuaries are important elements of the Kuban and Azov ecosystems serving as spawning and breeding grounds for many fish species.

Intensive glacier and snow melting during the warm season increases the water level in the Kuban for 5–6 months (Fig. 1.12). At the same time floods from intensive precipitation also occur in the region through the entire year [48]. The share of snowmelt in the annual flow is 49% in the upper river stretch and 34% in the lower stretch near the city of Krasnodar [45].

The Kuban River has records of 65 indigenous species that historically occurred in the lower and upper reaches [48].

The Kuban basin is fully located within the Russian administrative borders (Fig. 1.10).

1.3 Ecosystem Services and Their Utilization

The Azov basin can be characterized as one of the most productive regions in Russia and Ukraine with high levels of industrial and agricultural development. A major reason for such a blooming economic development is the abundance of services and goods provided by the Azov ecosystem.

As defined above, ecosystem services are “the benefits that people obtain from ecosystems”. These benefits include provisioning, regulating, supporting, and cultural services [104]. All four categories of the services are well articulated in the Azov basin. Services provided by the aquatic ecosystems are abundant in each category suggested: communities of the basin strongly depend on water and food provision by the water courses, water is actively used for industrial, navigation, energy generation, waste disposal and many other purposes. The ecosystem of the Azov Sea itself is defined by the supporting services provided by the basin rivers (nutrients, sediments delivery, etc.).

Furthermore, cultural and other nonmaterial functions play an important role in the region. In general, many societies have been formed next to water bodies and identify themselves as being affiliated with these ecosystems, and the local Cossack communities are among the best examples of this. Cossack Communities have always been settled in Russia along rivers and have traditionally been named after the corresponding rivers: Don, Ural, Terek, Kuban, Amur Cossacks [72, 87, 91].

Ecosystem services valued by societies change with time. In particular, one of the important river services valued by Cossacks earlier and no longer utilized was shelter against potential enemies. Some of the services and goods provided by the Azov ecosystem and actively exploited by humans have become obsolete over the centuries, others have been over-utilized so that they lost their value, while some are still actively utilized.

The list of material services which are currently utilized includes [14, 58, 83, 110]:

- Transportation;
- Food (i.e. fishery);
- Agriculture (irrigation for crops and livestock farming);
- Clean water access;
- Waste disposal (including both sewage water and cooling);
- Industrial needs and power generation;
- Recreation.

To satisfy these needs a significant amount of water has been extracted from the ecosystem. Having less then 1% of the total water runoff in Russia, the Azov basin has the least amount of available water resources in Russia [137]. At the same time the total water withdrawn in absolute values from the basin rivers comprises one fifth of the total Russian withdrawal from all water bodies, representing the second most utilized basin after the Caspian Sea. This trend had not only been maintained in recent years (2007–2009) but has even increased. In 2009 the water intake from the basin was 15.6 km^3 [138], what corresponds to half of the total freshwater inflow to the Azov.

1.3.1 Historical Paths: Don and Kuban Cossack Lands

Despite having high potential, the level of resources consumption in the basin had been relatively low until the beginning of the twentieth century. Most of the basin, in particular the lower and middle Don River basins and the Kuban River were pristine due to the traditional life style of the self-governed resident Cossack communities. Living in small villages (*stanitsas*) throughout the river floodplains, Cossacks relied on fishing and small-scale farming for food [25, 87, 90].

In exchange for military service they enjoyed exclusive rights to control natural resources on their territory (e.g. fish and water) and paid no taxes [15, 145, 170].

The level of the Don and Kuban Cossacks' control over the basin's water and aquatic resources was not as total and overwhelming as in the case of the Ural Cossacks Army where fishery was the main source of living for the entire community [12, 72, 90, 91]. However, usage of natural resources in the region was under careful community control.

Large portions of the Don and Kuban watersheds belonged to Cossack Communities with strictly regulated industrial and agricultural activities. In particular, 77.3% of the territory of the Don Cossacks Army Land and 78.8% of the Kuban Cossacks Army Land were under the Armies' ownership. At the same time Cossacks comprised 38% of the population in the Don and 42.8% in the Kuban regions [158]. The individual land shares for agricultural activities around the *stanitsas* were given to Cossacks and often rotated among them. No other citizens of the Russian empire were allowed to conduct any economic activities on the Cossacks' lands.

Any industrial or agricultural activity on their Lands had to be confirmed at Cossack gatherings (*Cossack Circles*), where the Cossacks also elected their commanders (*atamans*).

Large scale industrial activities began in the river basins only after the Cossack communities were deprived of their rights over the land and natural resources in 1917. Before that in the entire area of the Cossacks' territory there were only a few metallurgic factories and coal mines. Most of the territory was used for grain growing or livestock farming activities.

1.3.1.1 The World's First National Reserve

The establishment of the Azov Sea fish protected area can be used as a characteristic example of rational usage of natural resources within the region. Officially, the first state nature protected area in Russia ["Barguzinskij"] was established in 1916 in the areas close to the Lake Baikal [58]. Some authors claim that the first nature protection initiatives in Russia (i.e. Askania-Nova in the Azov Sea basin at the current territory of Ukraine) were undertaken by private land owners at the end of nineteenth century [4].

However, the official state-recognized protected area having all the features of a national reserve was established much earlier in the Azov Sea. This protected area was established even a half century before the Yellowstone National Park which is generally considered to be the first national park in the world [114].

Following Cossack demands, the Russian Ruling Senate issued a special Decree announcing strict limitations on the fishery in the Sea of Azov in 1819 [135] and established a no-fishing zone in 1835 [25]. The protected area was located in the delta of the Don River and sea areas adjacent to the Don Cossack territories. Protecting their rights and privileges, Cossacks enforced these regulations and limitations strictly. Special nature protection regiments were appointed to secure fish spawning and migrations not only during the spring and summer time but also during the winter time when a large portion of the sea was covered with ice.

Though the borders of the protected area have been changing, its official status has been preserved over the last century [2, 3, 78]. In particular, no fishing has been allowed in this zone.

1.3.2 Great Nature Transformation Projects

The efficient use of ecosystem goods and services in the region is complicated by uneven distribution of annual water flow in the rivers flowing into the Azov Sea (Fig. 1.12).

Since the Don, the largest basin river, is mostly snowmelt fed most of its annual flow (60–90% depending on the year) comes in two spring months [82, 83, 110]. Though the Kuban is fed mostly by glaciers and is thus characterized by more or less even water distribution, occasional large-scale rainfall-induced floods can occur any time of the year causing damage and complications in economic activities. Another factor hindering efficient economic development is that – as shown in Fig. 1.1, – the most applicable plain areas in the Kuban basin do not have natural water streams, undermining efficient agricultural activities. Water redistribution through the region and seasons was an important task to support the regional economy in both basins.

As a result the water courses in the Azov basin have been significantly altered in order to minimize dependence on uneven resource distribution and to secure the growing national economy in the twentieth century. A series of hydraulic constructions have been constructed on the Don and Kuban including the high pressure Tsimlyansk dam, barrage complexes, irrigation and navigation canals.

Though the first proposals on the Don impoundment were approved by the Russian Government at the beginning of the twentieth century, the construction works was halted due to the outbreak of World War I and the Revolution [86]. The massive scale alteration of the Azov basin rivers came into life only as a part of the Great Construction Projects of Communism, transforming Nature to support industrialization and economic growth. Figure 1.13 presents the development plan from the 1950s indicating the most important regional Great Projects including dams, irrigation and shipping canals.

Most of these proposals were successfully constructed, yet some had minor modifications. For instance, of the planned hydropower stations in the Don basin only the Tsimlyansk dam was actually built.

The original plan (Fig. 1.13) also indicates the proposed and successfully implemented large scale forest shelterbelt network covering the entire Azov Sea basin aimed at water yield increase, desertification and soil erosion prevention.[12]

The Kuban River modifications started in a later period, but also have had a great impact on the river ecosystem and affiliated communities [99, 163].

1.3.2.1 The Tsimlyansk Reservoir and Don Barrage Complex

The border between the lower and middle Don course is formed by the Tsimlyansk reservoir (Fig. 1.4). This large water body is 260 km long and has a full capacity of

[12]The forest shelterbelts still cover vast territories of the region yet many have been cut down without any restoration efforts [3]. See Sect. 1.3.5.1.

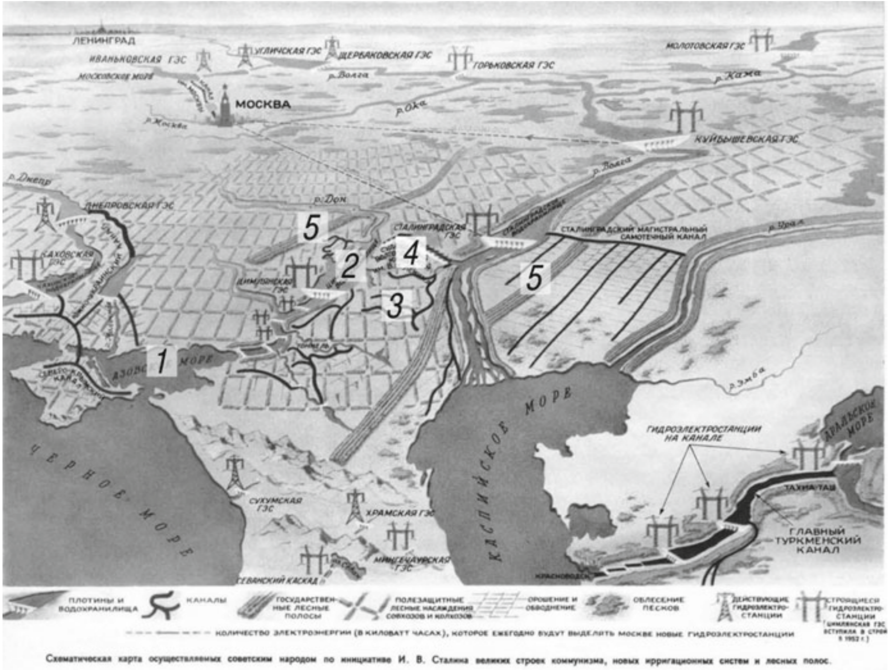

Fig. 1.13 Great construction projects of communism (*1* – Sea of Azov, *2* – Tsimlyansk reservoir, *3* – irrigation network, *4* – Volgo-Don canal, *5* – forest shelterbelts)

23.9 km^3. The amount of stored water is 9% more than average total annual flow in this section of the Don River (22.3 km^3), and the maximum depth reaches 36 m [3].

Put into operation in 1953, the Tsimlyansk reservoir was aimed at maintaining uninterrupted use of various ecosystem services including hydropower generation, water supply for settlements and industries, irrigation, navigation and fishery [3, 36].

The primary purpose of the reservoir was to secure navigation through the Don River as an essential component of the Inland Water Transport System (IWTS)[13] developed in the Soviet Union. The System has connected the Black and Mediterranean Seas to the Baltic and White seas as well as inland industrial centers through a network of canals and river streams.

The Tsimlyansk high-pressure dam has allowed access to the Volga-Don canal in the upper middle course of the river and redistributed uneven annual water flow to secure the navigation downstream the dam in the lower stream. Three low pressure dams were also built in this river segment to secure navigation (Fig. 1.4).

[13] Also known as the United Deep-Water System of Waterways [51].

1.3.2.2 The Kuban Impoundment

The same situation has occurred on the Azov's second largest tributary, the Kuban River. A series of dams and stream alteration works have been completed over the second half of the twentieth century aimed at power generation, irrigation, fishery and securing flood control (Fig. 1.4).

The largest reservoir on the Kuban River, Krasnodarkoe, with a full capacity of 2.4 km^3, was constructed in 1975. Its length is 45 km, the maximum depth 20 m and the mean depth 5.5 m. A number of smaller dams have been constructed to support irrigation and industry in the region by diverting the Kuban water into two canals: the Nevinnomysky canal constructed in 1948 and the Big Starvopolsky canal constructed in 1967. In total, more than 3 km^3 of water is withdrawn from the Kuban River through these canals for irrigation and irrevocable transfer to other basins.

1.3.3 Transport

This region has always played a strategic role in terms of both terrestrial and marine-based transport. However, following the disintegration of the Soviet Union the importance of the region in the Russian national economy has significantly increased. It is geographically located at the crossroads of many transportation routes both east-west and south-north for many means of transportation: in particular, all railways and highways to the Caucasus pass Rostov-on-Don, located in the Don River mouth.

The Azov Sea itself is an important transportation means, providing a navigable entrance to the inland Russian industrial and economic centers through a network of canals and rivers. Moreover, this area is the only Russian exit to the southern seas.

Though Ukraine currently has better access to the Black Sea than through the Azov Sea ports, the region plays a significant role in Ukrainian transport infrastructure as well due to the proximity of the many metallurgic and mining industries to these ports.

As a result, a number of sea and river ports have been active for many years in the region causing significant environmental problems. The most important ones are the ports of Taganrog, Rostov, Mariupol and Azov (Fig. 1.14).

The Azov ports obtained a special importance after the construction of the railways linking the coast with inland Russia in the second half of the nineteenth century. One third of the total grain export by sea from the Russian Empire was transported through these ports by 1919. They were also active in metal and coal transportation due to their proximity to the Donbas coal region (Fig. 1.2).

The strategic location of the Sea of Azov has stimulated the rapid development of transport infrastructure in the Russian part of the basin. The large multimodal transport logistics complex Rostov Universal Port (Rostovskij Universalny Port) connecting the Russian industrial inland areas and the Caspian sea with Europe and

Fig. 1.14 The ports of the Sea of Azov and adjacent Black Sea coast (Based on FAO [44])

Mediterranean countries is scheduled to be completed in 2013[14] [67]. This project is a practical implementation of the Russian President's[15] concern over the fact that the main Russian cargoes pass through foreign ports. As stated in the project description, the aim of it is to "create competitive conditions for switching of export cargo from the ports of Ukraine and the Baltic States to Russian ports" [159]. The port is aimed to transship 20 types of cargo including coal, metal, mineral fertilizers, etc. with a total annual turnover of 16 MMT per year.[16] The first terminal has already been put into operation having transshipped one million tonnes of goods: coal, metal and grain [139]. The planned annual capacity of the first terminal will be up to 3 MMT per year.

Meanwhile, freight traffic volumes through the ports in the Azov-Don basin area already indicate steady growth from 10% to 45% over a year depending on cargo [123].

The shallow character of the Sea of Azov does not allow large vessels to approach the inner ports, obstructing effective trade. To overcome this problem the Taman Handling Complex was built in 1999 in the Strait of Kerch (Port Kavkaz) (Fig. 1.14)

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[14] According to other sources in 2016 [139].

[15] At the timeVladimir Putin when the decision on the port was made.

[16] Million metric ton per year.

providing a facility for transferring goods (mainly oil, sulfur and fertilizers) from small ships, capable of Azov Sea navigation, to larger oceanic vessels, and vice versa [134].

Moreover, regional development plans suggest constructing another large cargo transfer facility at the Taman peninsula (Fig. 1.1) for goods reloading for shipping within the Internal Water Transport System [77].

1.3.3.1 Volga-Don Shipping Canal

The distance between the river Don and the Volga tributaries at the Don's middle course is insignificant, and was often used for boat portage from the Don to the Volga in medieval times.

The first attempts to connect both rivers with navigable waters in order to secure passage from the Caspian and to the Black Seas were undertaken by Peter the Great by the Kamiishinski canal project [133]. The project lasted through the eighteenth century, but was not completed [120].

Currently the Don River is linked to the Volga River by a canal near Volgograd at the place of the old portage way. This canal built in just 3 years from 1949 to 1952 is an essential part of the United Deep-Water System of Waterways and the only waterway connecting the Caspian countries with Europe [51]. It is capable of handling ships up to 5,000 tonnes and its total carrying capacity is 16.5 million tonnes of cargo per year [49]. The 100 km canal contains 13 dams with their own ship locks, 22 shipping canals, and 96 hydraulic constructions [30, 150].

The transit time along the 1,300 km navigation route through the Don and Volga rivers and Volga-Don shipping canal takes on average 7 days and involves passage of 18 sluices [3].

1.3.3.2 "Eurasia" and Volga-Don 2 Canals

Increase in trade volume and goods transportation throughout the region is forecasted [123]: for instance, UNECE forecasts a 2.0–2.3 fold increase in trade volumes between the Caspian Sea and the Danube-Black Sea countries alone [77]. Following the need "to transport Russian goods through Russian ports"[17] and to secure trade of inland Russian areas and landlocked Eurasian countries with the rest of the world, there is a need to upgrade the regional navigation facilities to modern standards [77]. Many experts claim that the main reason for such an improvement and capacity increase is oil transportation from the Caspian Sea. Such construction is actively supported by the Kazakhstan and Azerbaijan authorities willing to diversify their oil

[17] As proclaimed by the former Russian President Vladimir Putin.

transportation routes [51]. The proposed route is also often seen as a new Silk Road, an important geopolitical trade route linking Europe and Asia, a window of opportunity for landlocked Central Asia, especially since China and India have shown interest in the Project [107].

However, the existing Volga-Don Shipping Canal cannot support increasing traffic demand due to a number of factors such as limited carrying capacity due to the shallow depth of some waterway paths, limited capacity of ship locks, short navigation period, etc. [51]. Its operation is also hindered by outdated equipment [30, 50, 77].

There are currently two alternative proposals for building a new canal: the Volga-Don 2 and Eurasia Canals.

The Volga-Don2 project envisages construction of new canal near the Volgo-Don 1 to increase the annual traffic capacity from 16.5 million tonnes of cargo annually to 30 million tonnes by allowing the passage of larger vessels [30]. Several alternative routes parallel to the existing Volga-Don Shipping Canal exist, but the most popular proposal suggests renewal of an abandoned Soviet project [53]. Construction of the canal started in the 1980s but was cancelled due to the economic crisis of 1990s [75]. According to some assessments 20% of the construction has been completed [50].

The Eurasia project suggests building an almost straight 650 km canal using the previously created reservoirs and natural landscape features such as Manych-Gudilo Lake, Kuma-Manych depression and the river Kuma through the territory of Dagestan, Kalmikiya, Stavropol and Rostov provinces [10, 30, 49].

In development of this initiative the President of Kazakhstan, Nursultan Nazarbaev, proposed in 2007 resuscitating the abandoned Soviet plan of connecting the Azov and Caspian seas directly (Fig. 1.15). The attempt to connect two seas was undertaken in the 1930s and a part of the proposed canal with remaining navigable reservoirs was constructed [107]. Nearly 300 km of the Manych waterway with three water and ship locks were constructed connecting the Lower Don with the Manych-Gudilo Lake before the construction was interrupted by World War II. The remains of that attempt, the Proletarskoe reservoir (constructed in 1939) and the Veselovskoe reservoir (constructed in 1951), are presented in Fig. 1.15.

The technical proposal, feasibility study and project documentation have not yet been developed. At the moment, different proposals exist indicating alternative canal characteristics: width varies from 28 to 110 m, depth from 4 to 6.5 m, traffic capacity from 45 to 75 MMT per year, and ship capacity from 5,000 tonnes to up to 10,000 tonnes [10, 28, 49, 51, 67, 77, 124].

There are extensive debates over this proposal among political elites and scientific communities [3]. The canal opponents not only indicate the ecological consequences of this construction but also its economic inefficiency and engineering hardships of its implementation.

Negative environmental impacts on the Azov Sea ecosystem are foreseen for both project construction and maintenance stages [3, 28, 128]. The possible risks include, but are not limited to

- Water to support canal functioning will be abstracted from the Don River, which is already suffering from a water deficit. Other river ecosystems in the region, the

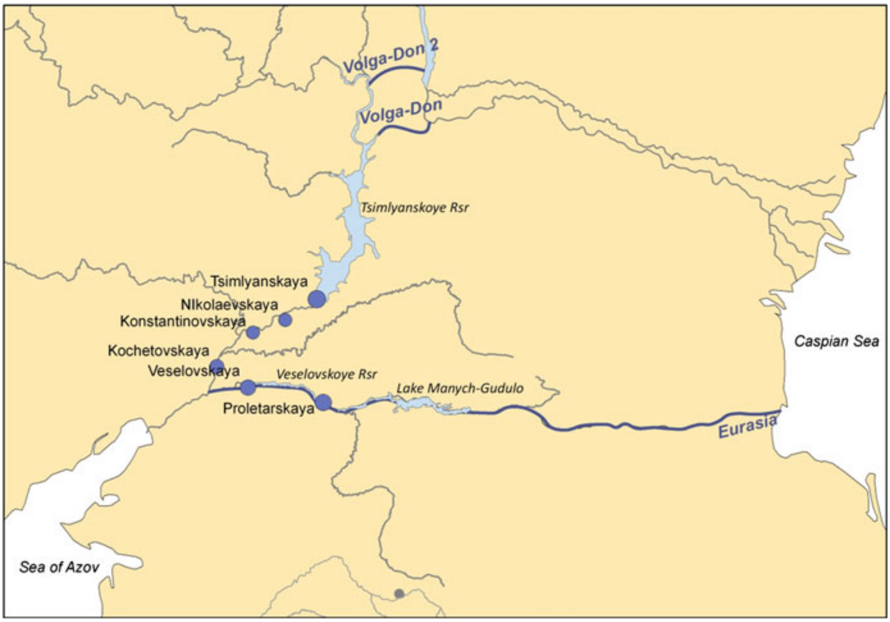

Fig. 1.15 Alternative proposals for new Azov-Caspian shipping canal: Volga-Don 2 and Eurasia

Kuban and Terek Rivers, are already exposed to high levels of water withdrawal causing significant environmental impact and economic losses. Additional water removal will result in their degradation with all the negative consequences that entails. In particular, an increased deficit of freshwater in the Sea of Azov will be compensated by influx of the Black Sea water characterized by high salinity, causing degradation of the Azov Sea ecosystem;

- oil pollution of both aquatic and terrestrial ecosystems; The sea suffers already from a high level of oil pollution originating from existing tanker navigation [109] and accidents [23, 154]. The canal construction and increased intensity of oil transportation will cause additional and substantial oil pollution not only to the navigable canal and surrounding land, but also to the Azov and Caspian Seas;
- the proposed route goes through a number of ecologically important and protected areas such as Ramsar sites, the Veselovskoe reservoir and the lake Manych Gudilo, the unique steppe zapovednik[18] Rostovskiy (the only steppe zapovednik in Russia), the natural park Donskoy;
- habitat fragmentation for many protected steppe species such as saiga antelope;
- soil salinization along the canal;
- possible pathway created for invasive species.

[18]Zapovednik – a protected area which in the Russian classification system corresponds to the highest degree of environmental protection of designated areas that are strictly protected and usually restricted to public.

The project's economic grounds have also been challenged, and numerous engineering challenges have been identified, including:

- Building of 650 km long canal is an unprecedented scale project. The existing part of the proposed route also requires expansion and modification. Such a project demands substantial investment;
- Canal operation requires a large amount of freshwater to be taken from the Azov basin, which is not available in the region (even in case of Kuban and Terek irrigation systems will be connected to the canal as sometimes suggested). Calculation of water balance should also take into account the high level of evaporation due to the arid conditions in the area of planned construction;
- According to most climate change scenarios, the Azov Sea region will experience a decrease in precipitation and increase in temperature [37] causing higher evaporation and, correspondingly, higher water abstraction from the Azov basin;
- There is a fear that Kazakhstan simply will not be able to secure a sufficient volume of oil and other goods transportation to justify such a large scale investment [124]. The capacity of existing pipeline systems and Volga-Don shipway are still underutilized [107].

As a result, current negotiations on the shipway construction have been halted until sufficient Kazakhstan's cargo base is quaranteed.

Comparing the two projects, the "Eurasia" shipway is considered to be the more desirable option in terms of logistics: it is a shorter route by 600–800 km, a shorter transit time, the navigation period is 10 months vs 8 months for Volga-Don 2, and it has a higher annual transit capacity (45 MMT per year vs 16 MMT) [51]. Both projects have been started but not completed. A significant environmental impact on river ecosystems is foreseen for both projects, mainly caused by lack of water in the region. Economic justification for both is also challenged [50, 75].

Though Russia seems to be determined to launch this geopolitically ambitious project of linking Europe and Asia with one more canal, the decision on which shipway to be developed has not been made yet[19] [3, 67, 124]. Both options have supporters among the Russian national elite, regional governors and authorities, Caspian partner countries as well as India and China[20] [107]. Some experts suggest that both proposals will be implemented as serving different purposes [30, 77].

1.3.4 Fishery

Until some 20 years ago the Azov Sea had been referred to by many authors as the most productive sea in terms of fishery [2, 3, 35, 81, 82, 111, 113, 140, 144, 173, 174]. The unique productivity of this water body was well known far away from the region

[19] According to the Minister of Transport of the Rostov Oblast the decision has not been made by June 2011 [67].

[20] China is willing to fund the canal construction [107].

Table 1.1 Annual release of hatchery-reared sturgeon into the Azov Sea (Kuban and Don River estuaries) (Source: Chebanov et al. [21])

Years of stocking	Russian sturgeon		Stellate sturgeon		Great sturgeon	
	Kuban	Don	Kuban	Don	Kuban	Don
1956–1968	–	3.7	–	2.1	–	0.8
1969–1972	1.6	4.2	4.5	2.5	–	1.3
1973–1985	6.3	8.0	16.4	1.8	2.7	0.4
1986–1990	8.6	5.1	17.3	0.3	–	0.01
1991–1995	13.7	2.1	11.4		0.1	0.01
1996–1998	16.1	1.8	11.8	0.2	0.2	0.01
1999	13.5	3.3	14.8	0.4	0.5	0.1
2000	17.7	3.4	9.9	–	–	–

thousands of years ago. In particular, The Greek name of the Azov, Meotida, is believed to be derived from "feeder" or "provider". The Azov was called the "bream sea" by Nomads and Hanseatic League and the "fish sea" by Turks [144, 157].

The highest harvest was recorded in the second half of the nineteenth century. At the peak of the Azov fishery, the harvest reached 300 thousand tonnes with the largest share represented by sturgeon, bream, pike perch, roach, zanthe and other valuable fish species. The harvest of these species alone was about 150 thousand tonnes [119].

During the first half of the twentieth century the Azov Sea alone secured 18% of the total fish harvest in the Soviet Union [11].

1.3.4.1 Aquaculture

The consequences of dam construction on migratory fish stocks were well understood and fish farming in the newly constructed reservoirs was planned to compensate the anticipated decrease in valuable fish such as sturgeon. After the completion in 1953 the Tsimlyansk reservoir was intensively used for fish stocking. Moreover, the entire Azov Sea was considered to be a pasture for valuable fish. Having lost spawning grounds cut by basin dams and decreased flooding areas in the river floodplains these fish types are not capable of natural reproduction [81, 86, 90]. At the same time with barrage complex construction numerous hatcheries have been established on the Azov and Caspian Seas for artificial sturgeon and other valuable fish propagation and consecutive release for maturing and feeding in the open sea until it might be harvested [20, 21, 143]. In this way, the sea was considered as a large fishing pond and referred to as a fish "pasture" in the literature [91].

While aquaculture based on the stocking of normal fish ponds with low value, often invasive species can result in a good harvest [9, 43], the efficiency of sturgeon hatcheries have been challenged by many researchers [45, 81, 90, 91, 174]. The fact that the Soviet (and later Russian) hatchery-based sturgeon restocking programs in the Caspian Sea and the Sea of Azov have not contributed to stock replenishment has been increasingly recognized [109, 176].

The failure to sustain sturgeon population is well illustrated by the Azov hatchery programs. Table 1.1 shows the average annual release of sturgeon by the

Azov hatcheries led by fishery affiliated institutions such as AzNIIRKh. Since 1990 five sturgeon hatcheries have been releasing up to 30 million juveniles of Russian, stellate and Great sturgeons annually [20, 21].

The official reports by these institutions claim that hatchery-reared fish released only in the Kuban River area account for over 90% of the total harvest in the Azov basin [20, 174]. If this were the case in the 2000s, the number of sturgeons at the Sea of Azov should be much more than in the 1990s due to the ban on commercial fishery introduced in 2000. Depending on species, most of the juveniles released by the end of 1990s should have reached their reproductive age (7–14 years) by now. If the fish was not detected within the rivers where they spawn due to the lack of *homing*[21] fidelity they should at least be found in the open sea. However, only a few dozen mature sturgeon specimens have been found in the sea recently[22] [3, 57, 98, 109, 144, 176].

1.3.5 Agriculture

The regional fertile soils and the best climate conditions in Russia have supported a high level of agricultural development. On top of this, the basin environmental conditions are the best available for growing various crops and performing agricultural activities throughout Russia. The region is considered to be the national "breadbasket". Numerous crops cultivated only in the region are important nationwide.

However, climate conditions are not favourable for agriculture in all parts of the region. The basin is located on the border between arid Central Asian and mild European climate zones and has features of both. This peculiarity should play an important role in analysis of regional environmental security with special attention paid to food security and water availability. There are numerous methods to assess aridification and desertification levels [156], one of the most commonly used involving calculation of Mean Potential EvapoTranspiration (PET) followed by the construction of humidity/aridity indexes [33]. This method has been successfully used for assessment of desertification risks for the last few decades [59].

The Humidity Index for the Azov Sea basin based on a ratio of annual precipitation and potential evapotranspiration is shown in Fig. 1.16. As can be seen from the figure a significant area in the eastern part of the basin is characterized by semi-arid conditions, making it vulnerable to aridification and desertification.

The influence of harsh Central Asian environmental conditions is also well captured by another widely used indicator, the Length of the available Growing Period (LGP) [163]. The LGP concept combines temperature and moisture considerations to determine the length of time crops are able to grow, hence excluding periods which are too cold or too dry, or both. Figure 1.17 depicts LGP for the Azov basin.

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[21] Homing fidelity phenomenon is the ability of sturgeon species to identify proper direction for migration into their natal river and to find a designated spawning site according to seasonal changes.

[22] See Sect. 1.4.5 later in this chapter.

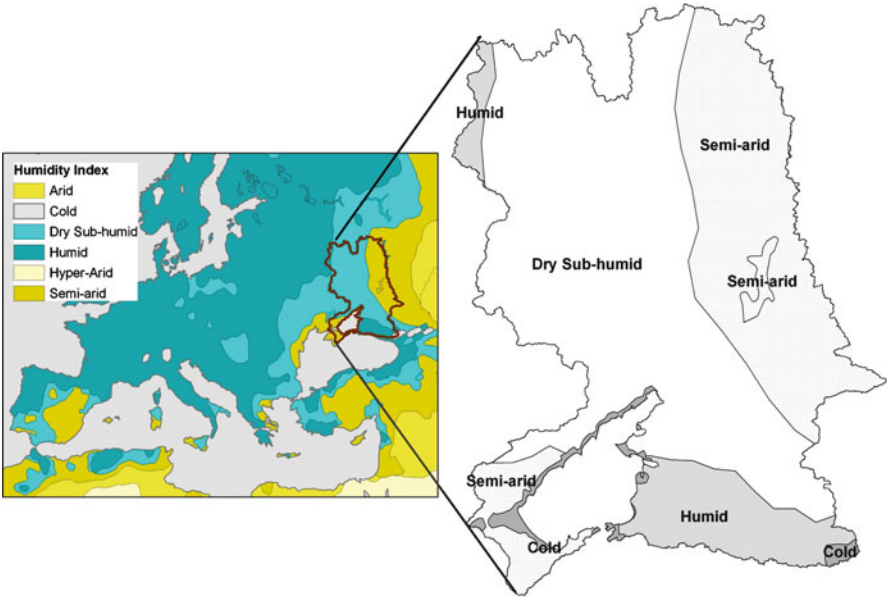

Fig. 1.16 Humidity index for the Azov Seas basin (Based on Trabucco and Zomer [156])

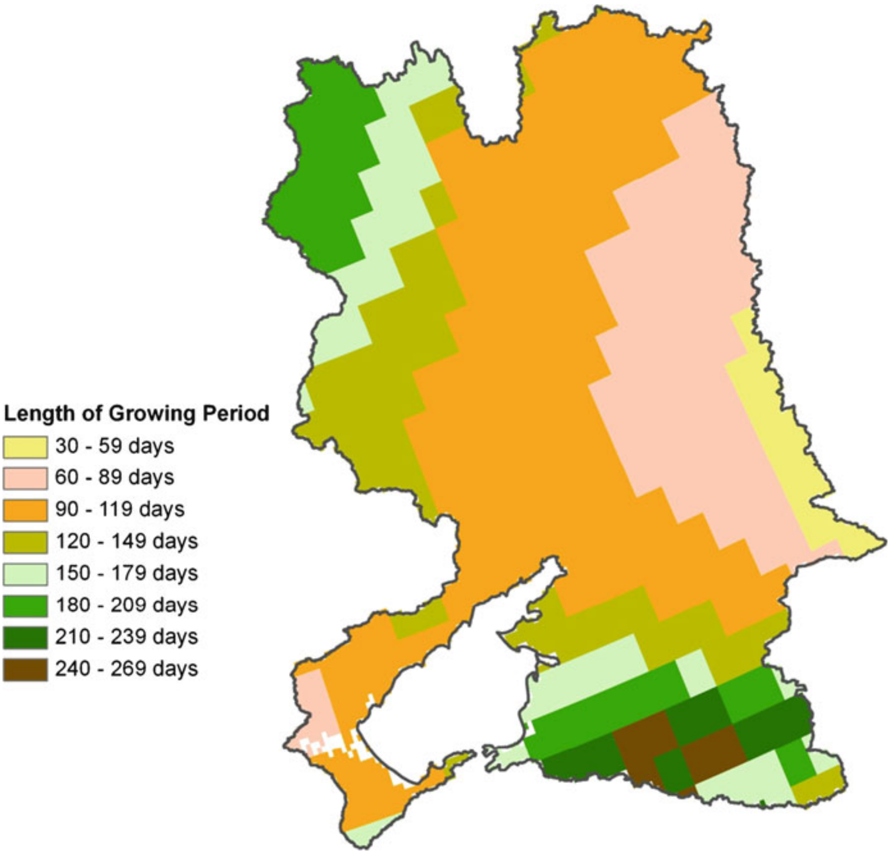

Fig. 1.17 The Length of growing period for the Azov Sea Basin, days per year (Based on FAO [44])

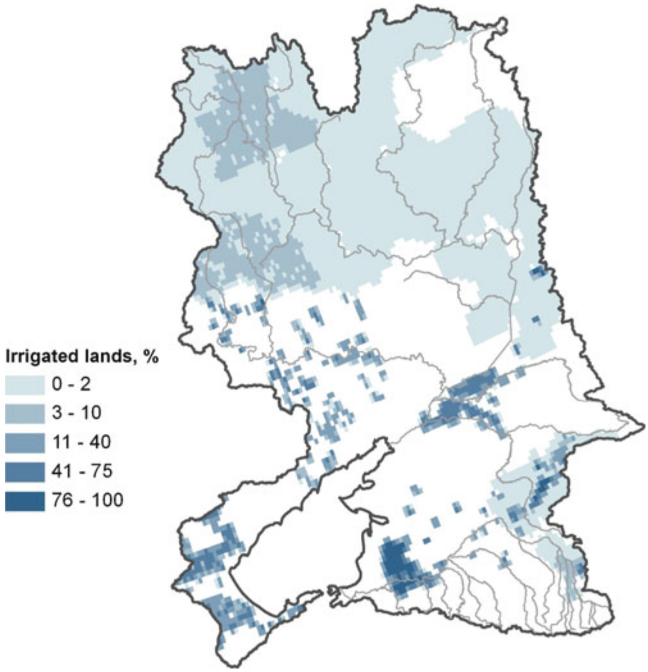

Fig. 1.18 Areas equipped for irrigation in the Azov Sea basin[23] (Based on Siebert et al. [147])

As can be seen, the eastern part of the basin is exposed to unfavourable conditions for agriculture. This peculiarity was well known for many years and numerous attempts to improve agricultural conditions were undertaken. The Great Constructions in the region were focused partly on solving this problem and increasing ecosystem resilience as well. In particular, irrigation was one of the major justifications for the construction of the Tsimlyansk reservoir [36].

As a result of these massive scale nature transformation and irrigation activities the current agriculture in the region greatly depends on the water withdrawal from the basin rivers. Figure 1.18 depicts the basin areas equipped for irrigation based on the data published by UN FAO [147]. Though this map should be considered as an approximation only, it captures the large scale of water diversion activities in the region.

Economic efficiency of basin agricultural activities such as rice production in the Volga, Kuban and Don floodplains have been repeatedly challenged by many authors [36, 45].

Livestock farming has always played an important role in the region [58, 157]. Many important stocks (e.g. cattle) were based almost exclusively on the vast Don River floodplain [36].

[23] In percentage of the total area of raster with a resolution of 5 min.

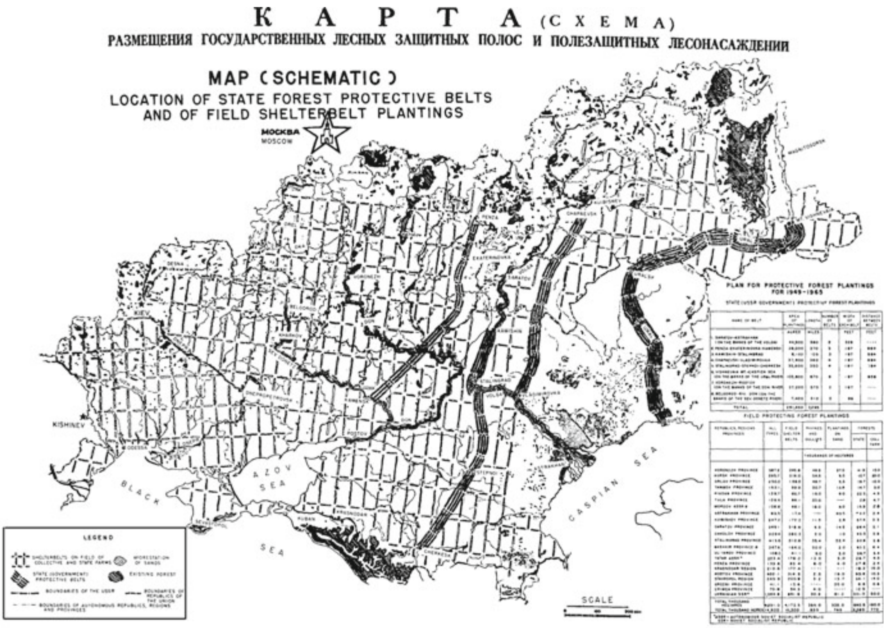

Fig. 1.19 The state forest protective belts (major) and field shelterbelts (grid through the entire European part of the Soviet Union)

1.3.5.1 Land Reclamation

One of the most important and influential projects aimed at agricultural improvement and land reclamation was the development of a forest shelterbelt network in 1940s–1950s as a part of the Great Plan for the Transformation of Nature launched in 1948.[24]

This plan was developed as a result of the drought and famine of 1946–1947 which resulted in an estimated one million deaths in the southern regions of the Soviet Union [169].

A large network of forest belts was developed through the entire South of the country. The entire plan had to be implemented within 15 years. Around two million hectares of forest was planted with a total length of the belts up to 5,000 km [118]. The major state forest protective belts consisting of several forest strips have a parallel structure from southwest to northeast with a length up to 900 km each. The scheme of the network is shown in Fig. 1.19.

[24] Similar plans to improve agricultural quality of steppe areas by planting forest stripes were suggested and implemented in Russia much earlier by many researchers and managers such as Peter the Great, Russian agronomist Andrey Bolotov in 1767 [118], the father of soil science Vasiliy Dokuchaev and others. Based on these ideas protective forestation in steppe areas was developed and began to be implemented in Russia before 1917 [58].

Fig. 1.20 The second 600 km forest zone (out of 8 existing) consists of three parallel 60 m wide belts [56]

The primary purpose of the network was to protect arable lands from the dry hot winds carrying sand from the south east. The network of natural and artificial water bodies had to be surrounded by forest belts as well. The bulk of the network was built by 1956 when the program was shut down. Figure 1.20 shows a satellite image for a typical rural area in the Rostov oblast [56]. Three parallel 60 m wide with 300 m interval forest belts can be clearly identified in the image. These belts are part of the 600 km Kamensk-Penza State Forest Protective Zone. The forested areas along the water bodies and gullies are also visible.

In modern terms, this unprecedented large-scale project can be considered as combating desertification, controlling erosion, building ecosystem resilience and providing additional restoration. According to Voitsekhovskiy [169] as a result of the planting efforts the area of forest shelter belts constitutes up to 5% of the total Russian forest area. The belts are so common and have now been around for so long that they are considered by many as a part of the natural landscape.

After the drought of 1967, when the areas protected by the existing network suffered the least, maintenance of forest strips was recognised as important, and after that time the belts were maintained until the Soviet Union's collapse. However, the system has not only been abandoned recently, but also actively reduced due to uncontrolled deforestation by local communities and companies. For instance, in 1995 about 19.8 thousand hectares of forest belts were replanted while in 2007 this dropped to 0.3 thousand hectares only [169].

The project has undoubtedly had a significant impact on the entire ecosystem of the Azov Sea basin, in particular the water balance was affected. For instance, the pattern of snowmelt in the watershed has been changed due to increased water storage capacity within the areas protected by the forest belts.[25] However, an impact assessment of the land use pattern change on the Sea of Azov is a challenging task considering the construction of large reservoirs on the rivers Don and Kuban undertaken at the same time.

The network has direct implications for environmental security in general: crop yield has been increased, food security has improved, erosion levels have decreased, etc. [58, 118].

1.3.6 Domestic and Industrial Water Use

The basin is characterized by low water availability: it holds only 1% of the total water available through Russia [138].

The population and economy strongly depend on a centralized water supply. For instance, the Rostov oblast, located at lower Don basin with relatively good water supply, is divided into four zones of water availability [79, 110]:

1. high availability zone occupies 1.7% of the region;
2. average zone – 16.8%;
3. low zone – 29.3%;
4. no water available – 52.2%.

As a result basin water resources are actively withdrawn and redistributed through the region for other essential purposes such as municipal and industrial usage. For instance, more than 60% of the annual flow of the river Don has been withdrawn for the regional economy [110].

Treated drinking water from surface reservoirs is used by 70% of the area's population. The water withdrawal from the Don for municipal needs is typical for the entire densely populated lower basin [138].

Despite high population density and large developed industrial centers, urban stormwater is not treated in some regions including the highly populated Ukrainian part of the basin [142, 160]. Moreover, municipal wastewater in most cities of the densely populated Seversky Donets basin and numerous chemical plants discharge wastes to the river directly [160]. Storing of wastewater in special ponds for release during the flood is widely practiced by many industries. Most of these industries discharge untreated or under-treated industrial sewage to the basin rivers [138].

1.3.7 Energy Generation

Power generation is another ecosystem service actively utilized in the region. The development of hydropower generation started in the region at the beginning of the

[25] It is estimated that 80% of snow cover retained by the belts protected agricultural fields, while areas lacking belts loose 50–80% of snowmelt with runoff [169].

Table 1.2 Energy generation capacity and production of the largest hydropower complexes in the South of Russia [149]

Hydropower cascades	Capacity, MWt	Production in 2010, MWt
South Russia, total	5462,7	3,390
Volga (Caspian basin)	2582,5	1,893
Chirkeiskaja (Caspian basin)	1,000	589
Irganayskaya (Caspian basin)	400	199
Miatlinskaya (Caspian basin)	220	111
Tsimlyanskaya (Azov basin)	209	131
Kubanskaya (Azov basin)	184	139

twentieth century. The first hydropower stations were constructed in the region before World War II on the Kuban River. Presently, there are several cascades of small-scale hydropower stations on the Kuban and only one relatively large one (the Tsimlyansk Station on the Don). The difference in the number of hydropower generation projects is explained by the landscape features: mountains in the Kuban tributaries and flat steppe in the Don basin. Despite the high number of stations, the energy produced is insignificant. Table 1.2 shows energy generation capacity and actual electricity production by the largest hydropower stations in the south of Russia [149]. As can be seen, energy generated by the entire basin is many times less than the amount of energy generated by the stations in the Caspian basin.

Water from the basin is also used in other sectors of energy generation such as thermal power plants. For example, a lot of water is required to secure operation of the Novocherkassk Thermal Power Station (one of the largest in Russia) and cooling of the Volgodonsk Nuclear Power Station [80].

Water has also been extensively used in other regional industries such as mining, metallurgy, chemical, food and others [3, 58, 102, 116, 122, 142, 171, 173].

1.3.8 Recreation

The Azov Sea area has been a popular tourist resort for many years. Water-related tourism has developed in various areas of the basin including both the sea and its basin. For instance, one of the unique features of the Azov Sea is the presence of mud volcanoes on the southern coast of the Sea, the Taman peninsula. The mud volcanoes, which have been actively used for curing numerous diseases, are rare, with only a few found in Europe, while dozens are available in this region.

Russia has limited access to warm seas (Azov, Caspian and Black Seas only) and the demand for such resorts is consequently very high. Taking into account that tourism infrastructure is not developed on the Russian coast of the Caspian Sea and all transportation routes to the Black Sea coast pass the Azov basin, tourism plays a significant role in the region. Moreover, the shallow warm Azov Sea itself has been positioned as a place for family vacations and attracts many tourists from the inland Russia areas. Apart from this, river-based tourism is also well-developed in both the Don and the Kuban basins.

As a result, tourism support infrastructure constitutes a substantial share of the regional economy. The Azov ecosystem's degradation is likely to lead to the region losing its attractiveness for tourists, with corresponding economic losses.

1.4 Waterborne Threats to Environmental Security

The Azov Sea ecosystem provides many services essential to coastal and inland communities including water, food, energy supply, transportation, and climate regulation. As discussed above, endangering these services might cause threats to environmental security. However, the unsustainable pattern of water resources usage undermines environmental security of the region.

Despite its important strategic role, the Azov basin has not been considered as a subject for most regional environmental processes and discussions [3, 17]. In particular, the Sea is excluded from the Bucharest Convention, the major regional document focused on protection of the Black Sea. As a result no comprehensive independent analysis of environmental security risks in the basin has been conducted, nor indeed has any particular study been conducted by specific stakeholders or scientists with regard to their own interests [77].

The total freshwater inflow delivered to the Azov Sea before damming the basin rivers was about 42 km^3. The damming followed by active utilization of ecosystem services has decreased freshwater influx to less than 33 km^3 per year [144]. The water has been redistributed through the region causing changes in the pattern of ecosystem resources and services consumption. The existing and emerging patterns should be assessed with regard to their sustainability and possibly corrected to identify and eliminate threats to regional environmental security.

1.4.1 Aquatic Ecosystems

1.4.1.1 Freshwater

The impact of dams on river ecosystems has been studied and well analyzed worldwide [27, 69, 70, 95, 96, 101, 112, 167] as well as from a Russian regional perspective [2, 36, 81, 86, 91, 166].

First of all, dams change the hydrological regime of the rivers completely in terms of both water quantity and annual discharges. In particular, the volume of irreversible withdrawal from the Azov rivers varies between 11 and 13 km^3/year. Abstracted water is mostly used for irrigation [38, 144]. The remaining water flow is redistributed fairly evenly through the year.

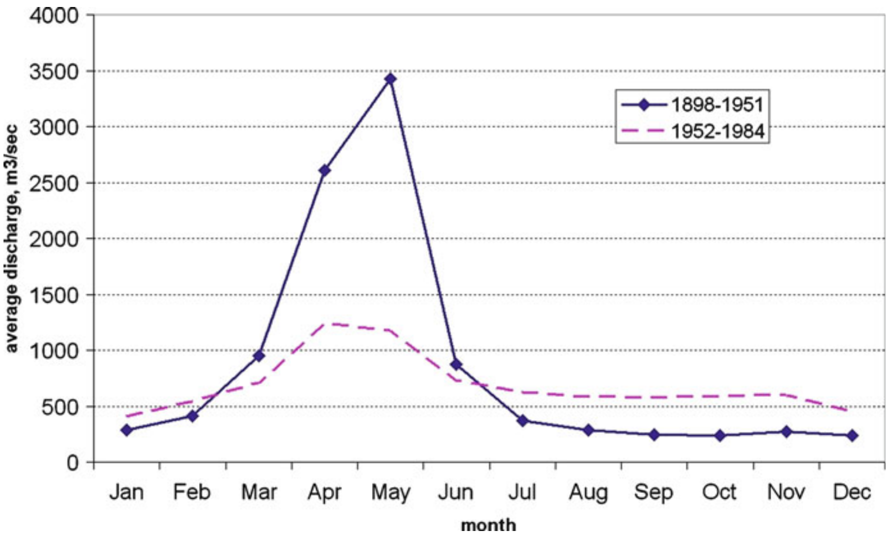

Fig. 1.21 Changes in the Don River hydrological regime after completion of the Tsimlyansk reservoir (Statistics based on Vörösmarty et al. [172])

As can be seen from Fig. 1.21, the Don hydrological regime has been reformed, and the natural pattern of annual water distribution with high water in spring and low water during other periods has ceased to exist. These statistics were calculated for the gauge station Razdorskaya with an annual average flow rate of 935 m^3/s. The annual average discharge has dropped to 687 m^3/s between the two time periods (Fig. 1.21).[26] Flooding of the Don floodplain has ceased, causing significant economic losses for agriculture and fishery.

Regulation of the Kuban for irrigation purposes has also drastically affected its flow and hydrological regime. For instance, total river discharge during the spawning period (May–August) has almost halved from 3.5 to 2 km^3 [45].

Not all water diverted from the river streams is being used efficiently for ecosystem service generation. According to official assessments, water losses during transportation are greater than 3 km^3 per year. In absolute values the Azov basin is second in Russia after the Caspian basin with regard to water losses [138].

Taking into account the fact that the basin contains only 1% [138] of total water available in Russia, the ratios of water abstracted and water losses to available water in the Azov basin is the highest in Russia.

Water is not only being lost due to irrigation and ineffective transportation, but also due to evaporation from the large surface area of reservoirs constructed in

[26] According to some authors the annual average discharge after the Tsimlyansk construction has dropped down to 160 m^3/s [45].

arid zones [36, 84]. According to assessments by the Russian Ministry of Natural Resources [137] water lost due to evaporation from reservoirs in the region constitutes up to 9% of water inflow to the reservoirs [137]. The large amount of evaporated water has also significantly changed the regional climate, by increasing humidity around the Tsimlyansk reservoir [31].

There are other significant problems and threats to security connected to reservoirs in the region. Both the Don and Kuban Rivers carry a lot of sediments which have accumulated in the reservoirs and drastically decreased their effective water storage capacity [3]. Euthrophication and siltation of the Tsimlyansk reservoir is increasingly becoming an important issue since this is the only source of water for nearby settlements and industries [3, 45]. High rates of swamp formation and coast destruction are reported around the reservoir [110].

Excessive amounts of water used for irrigation cause soil salinization and substantial damage to agriculture [36].

1.4.1.2 Sea

Anthropogenic activities in the basin rivers have not only drastically changed river ecosystems but also had a significant impact on the shallow Azov. In particular, the salinity of the Sea has drastically increased. Average sea salinity was 10.9‰ from 1923 to 1951, but has rapidly increased by almost 30–13.8% during the period 1952–1976 [11]. According to the Russian Report on State of the Environment the salinity of the sea in 2009 was 12–14‰ [138]. The salinity stratification has also increased: homogeneous salinity through the water body has given way to a differentiated salinity levels, thus fragmenting sea habitats. This factor actively contributes to changes in biota, collapse of fishery, unemployment, and, correspondingly, threats to environmental security.

1.4.2 Soil Degradation

Another threat to environmental security is the high degree of soil degradation throughout the entire Azov basin. The primary type of soil degradation in this region is loss of topsoil and terrain deformation, which has significant implications for agriculture.

Figure 1.22 depicts human induced soil degradation according to the GLASOD Project [117]. Apart from mountain territories in the Kuban basin in the South and a small area with “moderate” degradation level, the soil in the entire basin is classified as “highly” or “very highly” degraded. Salinization is also considered to be a significant threat in certain areas with high level of irrigation. This correlation can be visually traced by comparing Fig. 1.22 and the map of irrigated basin lands in Fig. 1.18.

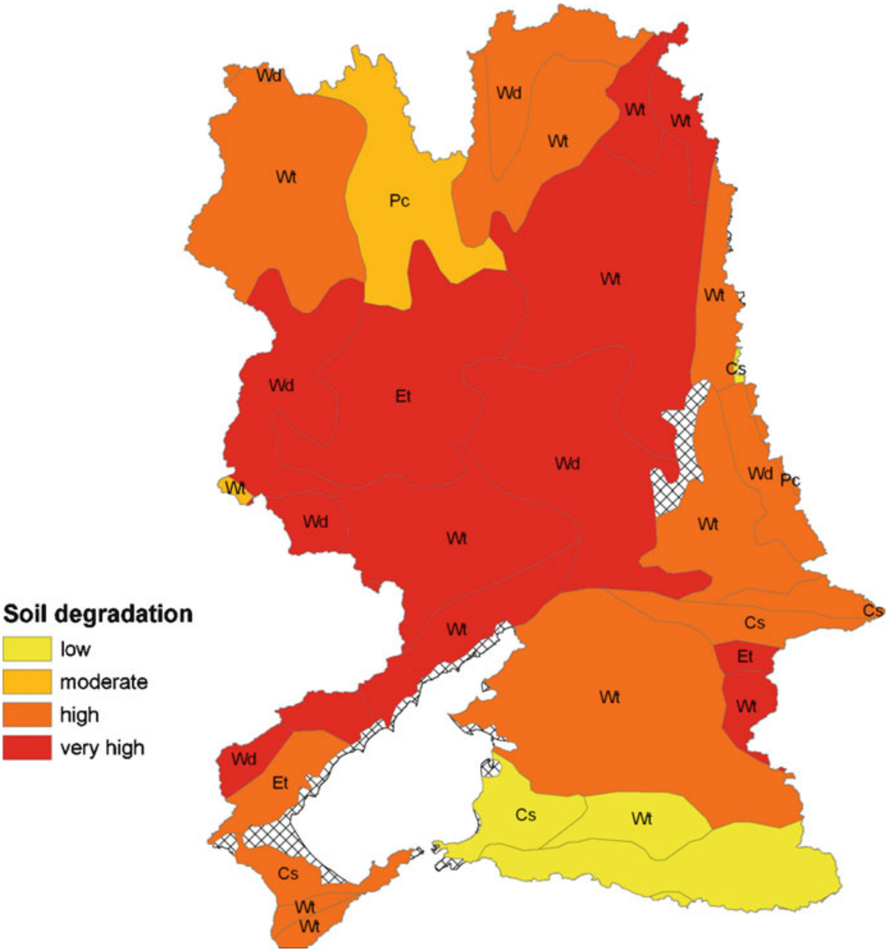

Fig. 1.22 Severity of soil degradation in the Azov basin. The abbreviations indicate the types of soil degradation: *Wt, Et* Loss of topsoil, *Wd* Terrain deformation, *Cs* Salinization, *Pc* Compaction (Based on Oldeman et al. [117])

1.4.3 Pollution

The Sea of Azov serves as an endpoint for pollutants collected from the large terrestrial catchment area, which is exposed to high levels of anthropogenic influence and generates a significant load of diverse pollutants due to economic activities and high population density. The Sea was polluted from multiple sources for many years. Heavy volumes of waste-water from industry, households and agriculture were regularly discharged into the Sea and the rivers of its basin [32]. The shallow sea has limited water exchange with the Black Sea, meaning that most of the pollutants are accumulated in its water and sediments.

Taking into account the high level of anthropogenic activities in the Azov Sea basin and the deterioration of state nature-protection mechanisms and institutions, a gradual increase in pollution of the sea tributaries and, consequently, the sea itself can be foreseen. At the same time many regional industries causing point source water pollution (i.e. chemical plants, heavy industry, engineering, mining) have collapsed both in Russia and Ukraine [46, 116]. Many factories were even disassembled and sold as scrap metal. There has also been a significant decline in both crop cultivation and livestock management [46, 105].

Nevertheless, an increase in pollution of the basin rivers can be observed in recent years. For example, there has been a significant increase in the total dissolved solids in the Don water. According to Fashchevsky [45], concentrations of sulphates in the Don River have increased by a factor of 2.6–2.8, chlorine and magnesium by 2, sodium and potassium by 2.3–3.1, and total dissolved solids (TDS) by 1.6 [45]. Irregular occasional monitoring shows that the concentration level for many pollutants is many times higher than the Maximum Allowable Concentration (MAC). In particular, the concentration of oil products, heavy metals, pesticides and phenols is higher than MAC by a factor 6–8 [92, 141, 176]. Furthermore, the river Donets, the largest Don tributary, has been proclaimed the most polluted river in Europe [13].

Pollutants have been delivered to the Azov ecosystem with river discharges and direct pollution from the ports, dockyards, oil refineries, coastal municipal sewage systems, and other sea–based sources. According to the results of monitoring conducted by the Russian State Oceanographic Institute, both pathways contribute significantly towards the sea's pollution [142]. In particular, significant levels of pollution have been detected in several sea areas caused by a wide range of point and non-point sources. As a result, pollutants are not evenly spread through the territory of the sea. In particular, the TDS in the Taganrog Gulf, adjacent to the Don River delta and the crossroad for most Azov navigation routes, have increased by a factor of 4.6, largely due to the increase in chlorine (6), sulphates (2.8) and sodium (5).

It should be noticed that the system of monitoring and control over sewage and industrial waste discharges does not work properly. For example, the waste water discharges in the Kuban as well as the coastal cities of Taganrog and Eisk in 2006 are unknown because the water treatment and other industrial organizations simply have not provided this information [141].

Nevertheless, official statistics shows that untreated sewage from the two largest oblasts of the basin, Rostov and Krasnodar, constitute about 10% of total discharges to surface water bodies for the whole of Russia [46]. Coupling this fact with the significant level of pollution coming from the Ukrainian part of the basin and low water availability in the area, the Azov Sea can be proclaimed as the most polluted water body in Russia. The statistics also indicate no improvement in percentage of untreated sewage over the last 20 years (Fig. 1.23).

Pollutants from irrigation water (fertilizers, pesticides, etc.), stormwater runoff and other anthropogenic activities upstream the rivers influence mainly the deltas of the Don and Kuban as well as the Taganrog and Temryuk Gulfs.[27]

[27] Gulfs adjacent to the Don and Kuban River deltas respectively.

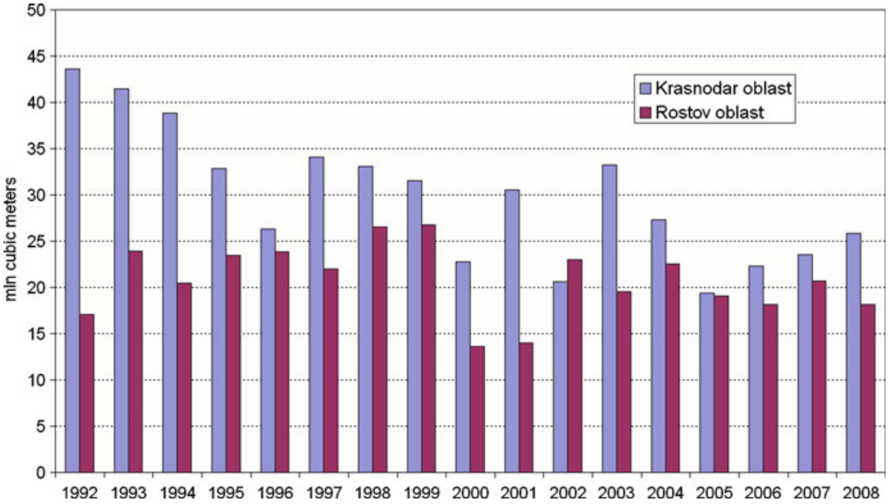

Fig. 1.23 Percentage of untreated sewage in the largest oblasts of the basin (Based on statistics by Federal State Statistics Service [46])

Intensive agriculture provides a significant contribution to river and sea pollution in the region. For example, agricultural land comprises around 80% of the Ukrainian part of the catchment. Depending on soil type and cultivated crop in the basin, washout of nitrogen and phosphorus from 1 ha of Don and Kuban agricultural land can be up to 22.5 and 1.1 kg respectively [168].

Donbas (Fig. 1.2), one of the most populated, agriculturally and industrially developed areas of the entire basin, hosts multiple industries including mining, metallurgy, chemical, and food production. It contributes greatly to the overall pollution of the Azov sea and the tributaries [153, 160]. The most polluted river, the Severskiy Donets, crossing the Russian-Ukranian border upstream of Rostov, the capital of South Russia, has a concentration of iron almost 3 times as high as the MAC (0.26 and 0.1 mg/l correspondingly), copper is 10 times the limit (0.01 and 0.001 mg/l), nitrites are 2.4 times the limit (0.195 and 0.08 mg/l); zinc is 120 times the limit (0.001 and 0.127 mg/l); oil products are 10 times the limit (0.05 and 0.5 mg/l); and chromium is 6 times the limit (0.001 and 0.006 mg/l). Many other pollutants (manganese, ammonia, sulphates, calcium, etc.) can also be found in the river water in concentrations close to or exceeding the MAC [160].

Another significant threat to public health and regional environmental security is associated with mining activities in the Middle Don basin [122].

A large amount of radionuclides has been recorded in recent years in the Lower Don and the Taganrog Gulf. The contamination has traditionally been blamed by officials on the Chernobyl accident, and the possibility of pollution by the Volgodonsk Nuclear Power Plant located upstream the Don River on the Tsimlyansk reservoir has been denied [136]. Meanwhile, risks of accidents at this station make the most densely populated areas downstream the Don vulnerable with regard to environmental security [80]. The project contained numerous technical and engineering shortcomings [80] and accidents are very probable – problems connected with radionuclides leakage are reported regularly from this site [132, 136].

1.4.3.1 Oil Pollution

There is a major concern connected to the constantly increasing petroleum and heavy metal pollution in the basin water bodies [52, 109], since the concentration of these pollutants is already many times higher than the MAC. This increase in pollution concentration despite industrial and agricultural decline is a very interesting phenomenon and deserves separate profound research. However, according to some assessments this increase has been caused by growing activity of the energy sector in the region under conditions of diminishing state control over its environmental impact [92].

There are different possible pathways for oil products appearing in the marine environment: accidents during oil extraction and transportation, ordinary leakage from vehicles within the watershed with consequent transfer to aquatic systems, with runoff or snowmelt, leakage from vessels, deposition with precipitation. All these pathways are applicable in case of the Sea of Azov.

There is a danger of increasing pollution by oil products due to the growing transportation trends in the region. The most significant threat of oil pollution originates from intensifying oil tanker transportation and the recently initiated oil extraction in the offshore area [3, 92]. One of the recent environmental disasters occurred when more than four freighters sank and two oil tankers were damaged in the Strait of Kerch during a storm. As a result more than 1,300 tonnes of oil and 7,000 tonnes of sulfur were spilled into the water [23, 154]. According to Russia's environmental authorities it would take 10–15 years to clean up the strait and its coastline. The Strait is characterized by complicated navigation conditions and in the case of intensive traffic the risk of such disasters will increase [134]. If constructed, the Eurasia and Volga-Don 2 canals will increase oil pollution risks in the region manyfold.

1.4.4 Biodiversity

Following wide-scale changes in aquatic ecosystems throughout the region, biodiversity has greatly deteriorated [47, 113, 144, 151]. Many species have not been observed for many years and are believed to be extinct in the region. In particular, the sturgeon has not only lost its commercial value but is on the brink of extinction: not a single specimen can be found in the region for hatchery-based restocking needs [93, 151].

The primary causes of decline are habitat degradation and fragmentation due to river regulation. Regularly flooded large areas in the river deltas and lower river branches are critical for maintaining biodiversity [36, 86]. However, in recent decades flooding is only possible during the years with extremely high water availability (namely 1963, 1979, 1981, 1994 only) [119], which resulted in biodiversity loss. Increasing river-sea transportation through the region with associated dredging activities and harbour reconstructions has also contributed considerably to biodiversity loss.

Another factor causing changes in biota is substantial water pollution. A high level of contamination has been observed in the tissues of fish caught in the Sea of Azov [102, 109].

Due to the life cycle characteristics and long time span, long lived species are subject to *bioaccumulation*[28] and *biomagnification*[29] processes. The longer the organism's life span the greater the risk of chronic poisoning, even if environmental levels of the toxin are very low. In this way low concentrations of pollutants can be accumulated, affecting health and reproductive abilities. Valuable long-lived fish species are especially vulnerable to water pollution due to bioaccumulation and long distance migrations [64, 90, 92, 146]; they have been proposed as natural bioindicators of ecosystem health and sustainability [89, 91]. Bioaccumulation and biomagnification not only threaten aquatic species population survival and sustainability but also endanger humans consuming them as food. Being on the top of food web, humans are very susceptible to the biomagnification process.

Biological products (i.e. fish) harvested from the sea (in case their stocks are replenished at some point) impose a significant threat to human health and environmental security as well [3, 113, 144].

Another factor actively contributing to the ecosystem changes are the invasive species, which have already caused significant damage to the Azov. In particular, in the late 1980s, the jellyfish Mnemiopsis, which inhabits Atlantic Ocean coastal waters in the USA, was introduced to the Sea of Azov. The jellyfish depletes the available zooplankton stock, causing food shortage and altering food webs [32].

1.4.5 Fish Stock Depletion

According to the official assessments by the Russian Federal Fishery Agency, the regional fishing industry has collapsed and the condition of Azov fish stocks is considered to be critical [119, 151].

At the peak of the regional fishery, the Don and Kuban fishing zones alone secured sustainable harvest of valuable fish in 1.7 million centners[30] annually.

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[28] Bioaccumulation is a process when species absorbs toxic substances at a rate higher than that of substance loss.

[29] Biomagnification is a process of increase in toxin concentration in organisms on higher trophic levels that occurs through the food chain.

[30] One metric centner = 100 kg. This way, valuable fish harvest was 170 thousand tonnes.

Table 1.3 Average total annual harvest[a] in the Sea of Azov [32, 157]

Period	Average annual harvest, th tonnes		Ratio of valuable fish in harvest, %
	Total	Valuable fish	
1927–1936	174.7	89.8	51.4
1937–1949[b]	192.9	63.8	33.1
1950–1959	166.4	30.4	18.4
1960–1970	172.3	19.6	11.4
2005	5	0	0

[a]The harvest size does not include unrecorded harvest
[b]During the World War II (1942–1944) the regional harvest is unknown

The primary target of fishing efforts by that time was valuable fish species (Beluga sturgeon). At the beginning of the twentieth century the harvest is estimated to have dropped tenfold, to 162 th centners [157].

The trend of fish harvest decrease has continued through the twentieth century. As can be seen from Table 1.3 the ratio of valuable fish in harvest has been gradually decreasing. This decline is explained by overexploitation of long-living migratory fish stocks spawning in the rivers. Efforts to sustain the sea's productivity by applying more efficient technologies and gears were unsustainable and caused stock depletion even prior to the major hydraulic works on the basin rivers and the general degradation of the Azov's ecosystem. The same pattern of overexploitation and decline of various species can be observed in the Caspian Sea as well [90, 91].

The analysis of fishing statistics shows that the regional fish harvest pattern was not sustainable even though fishery was a highly regulated sector of the Soviet economy. The corresponding state institutions such as the Azov Sea Fisheries Research Institute (AzNIIRKH) existed in all fishing zones of the Soviet Union and were responsible for fish stock assessments and total allowable catch calculation. According to the fishing quotas recommended by these organizations, the official removal rate for the valuable fish stocks in the Azov fishing zone was 80–90% [157]. This is almost 10 times as high as the traditional 10–12% removal rate for long-lived species (e.g. sturgeon) [81, 90]. The Azov Sea is not unique with regard to the high unsustainable official fishing quotas: 70–80% of sturgeon spawners were officially removed from migrating spawning populations in the Ural River [90]. Moreover, unlike the fishery in the Caspian Sea where sturgeon harvest was allowed only in the river streams,[31] the Azov fishery in accordance with official recommendations was active through the entire basin: river streams, deltas and open sea. Many recommendations given to fishery were later abandoned as ineffective. For example, the proposal by the Azov Fishery Research Institute to transport sturgeon fingerlings and larvae from the Caspian basin for their release in the Azov Sea basin has

[31]Fishing Caspian migratory species at the bottleneck of their life cycle, on their spawning runs, is discussed in another Environmental Security Series book "Rescue of Sturgeon Species in the Ural Basin" ([90]).

come to be seen as a costly initiative with zero efficiency by the very same intuition [76, 176]. Nevertheless, during the last decades substantial investments have been made with significant numbers of larvae transported.

The work of these fishery-affiliated institutions has been criticized by many authors for decades without major consequences [2, 81, 140].

As a result of unsustainable fishing, the Azov Sea fishery has collapsed. The harvest of valuable species in the Azov basin as well as any commercial fishing in the Don River has been banned since 2000. Unfortunately, these activities have not resulted in any observed stock recovery so far [3, 86, 91, 98, 113]. In particular, according to reports by the Azov Branch of the Federal Fishery Agency, the number of reproductive females in sturgeon populations in the Sea of Azov in 2008 was the following: Russian Sturgeon – 100 specimens, Sevryuga – 15 specimens [151]. This population size confirms the inefficiency of costly hatchery–based restocking programs according to which millions of sturgeon juveniles were released 10 years ago[32] [19–21]. Having approximately 10 years maturation period and total ban for sturgeon fishery in the region, the released juveniles should reach their reproductive age only now and be abundant in the Sea. If illegal poaching had occurred, sturgeon should have been available on the regional black market, which has not been the case for many years [76, 109, 113, 171].

Many factors have contributed to regional fish stock depletion and collapse of the regional fishery. However, the largest irreversible damage to migratory and other valuable fish stocks was caused by river damming and unsustainable commercial fishery resulted in overharvesting.

Taking into account that fishery was an important sector of the regional industry providing essential food source for local communities and world famous export goods (e.g. black caviar), depletion of this resource alone significantly threatens regional environmental security.

1.4.6 Freshwater Supply

A significant threat is also imposed by the inadequate availability of freshwater resources for municipal needs. As mentioned above, the region strongly depends on surface water bodies for drinking purposes.[33] High levels of water pollution, uneven water resources distribution and lost ecosystem services in water purification are already causing significant public health threats in the region.

The entire region has experienced water shortages. For instance, the water deficit of one of the main basin administrative and industrial centers, Voronezh, is currently 150 th m^3 per day [138]. Around 100 thousand people in the Rostov oblast

[32] See the chapter's Sect. 1.3.4.1.

[33] Mainly the Don basin, the situation in the Kuban region is better due to availability of small mountain rivers and springs.

consume only car transported water, while more than 10 thousand use for drinking purposes untreated water the from surface water bodies [138].

Moreover, the level of biological contamination of freshwater used for drinking purposes is the highest in Russia, occurring in 7.6% of all water samples through the region [138]. As a result, outbreaks of infectious diseases have become common problem in the region [102]. The water supply situation is already characterized as critical by the Russian Ministry of Natural Resources.

The primary reasons for water supply problems are water deficit, technological aging of the equipment and high level of surface water pollution [138].

1.4.7 Economic Cooperation and Social Stability

The Russian economy has been converted from a centrally planned to some version of a free market system which thus far has not provided adequate management of environmental problems. Superprofit obtained by monopolies coupled with a weak legislative system and underdeveloped civil society has led to maximizing short-term economic benefits at the expense of other nature-society needs. For instance, the low efficiency Tsimlyansk hydropower station with outdated equipment was purchased in 2005 by the world's second largest oil company Lukoil [47]. Such a purchase seems to be a strange investment unless the company will use this investment to secure Caspian-Azov transportation of oil tankers by creating favourable water discharges along the navigation route. It might also assist in cleaning oil spills in case of accidents and within the river stream and river delta where oil extraction is planned.

Ironically, environmental protection measures were more possible under the Soviet administrative system. For example, the last and the only successful sturgeon spawning in the Don River occurred in 1991 when the Department of Nature Protection of the Council of People's Deputies of Rostov Oblast[34] issued a decree to the regional water management authorities to create favourable conditions for sturgeon migration by securing water discharge from the Tsimlyansk reservoir and opening sluices downstream. The result of this spawning was observed in 2005 when these sturgeon reached reproduction age[35] and reappeared in the Don River. After 1991 the sluices have never been opened and no other large scale attempts of sturgeon spawning migrations in the river have been observed [119]. Such an administrative resource does not exist in today's economic and political situation and security prospects from the point of view of ecosystem resilience and diversified ecosystem services are low. Effective cooperation among stakeholders in water management is not possible due to inefficient or absent legislative acts and procedures [3, 110].

The majority of regional industries including fishery have collapsed during the last two decades [39, 116], and increasing unemployment has contributed to social

[34] Chaired by Vladimir Lagutov who has launched this initiative.

[35] Reproduction age for sturgeons varies from 7 to 14 years.

inequality and instability. The situation is complicated by the regional historical and anthropological peculiarities associated with the reviving Cossack Communities. Having always been self-sustaining, Cossacks heavily relied on river ecosystems and affiliated services and resources. As discussed above, they have historically enjoyed property rights over natural resources on their Lands, in particular fish resources [26, 29, 72, 135, 170] and their revival has led to some moves to regain control over these resources [87, 94]. The first Cossack organizations established in the Azov region in the end of 1980s-beginning of the 1990s were closely linked to the first environmental NGOs which appeared at the same time [80].

Shrinking resources and the diminishing quality and quantity of ecosystem services for local communities at the expense of superprofit for national and international monopolies (i.e. oil transportation needs over fishery and regular floods) induces regional separatism. Being supported by powerful Cossack communities this trend represents a significant threat to national security unless the potential is used for social benefits [6, 42, 87, 91, 93, 94, 131, 148]. For example, the newly formed Cossack organization "Don Cossack Republic" is actively demanding establishment of a new administrative unit within the Russian Federation. The unit would comprise territories of Rostov and Volgograd provinces within the historical borders of Don Cossacks Army Land (which also includes substantial territories of modern Ukraine), be named "Don Cossacks Republic" and have a higher level of economic and political autonomy [3]. The organization is openly supported by many local Cossack communities.

Set against this, running waterways and migratory fish stocks are considered to be federal property and any attempts to revise that fact may be perceived as anti-constitutional activities by the Federal Government and regional authorities [151]. The organization has already been warned for its extremist activities by the regional Prosecutor's Office [61].

High demand for diminishing ecosystem goods (sturgeon products) stimulates criminal activities in the region. The situation with poachers and illegal trade is already considered to be a significant threat to national security [24, 76, 109, 115]. It is also causing transboundary conflicts because many well-equipped poachers are crossing the border in search of a higher catch [171].

1.4.8 Infrastructure Security

Many Great Nature Transformation Projects have been developed in the basin. Some have had positive impacts on ecosystem services use and aided regional environmental security. However, at the moment these constructions are presenting a threat. For example, a high level threat to regional environmental security is imposed by the inadequate conditions of hydraulic structures and facilities. Many of these facilities do not have any organization or entity responsible for their maintenance and renovation [110]. Only the largest facilities employ permanent staff for monitoring and technical support.

The life operation period of most hydraulic facilities in the region has either expired or nearly expired [110]. However, being constructed for the needs of vanished Soviet organizations (i.e. kolkhoz) they are currently abandoned and their ownership as well as their status is uncertain [79]. Special concern is connected to aging waste storage facilities that were constructed without proper design and planning (e.g. missing dampproofing) after World War II during the period of Great Constructions [110].

The modern system of technological monitoring and quality control has been questioned. The accident at the largest Sayano-Shushenskaya Hydropower Plant in Siberia [7], which has been associated with defective turbine and questionable maintenance practices [97], challenges existing procedures and reliability of technical control at Russian strategic sites.

On the other hand, the well-developed Soviet system of weather monitoring and forecasting has been collapsing due to aging equipment and overall decrease in the number of monitoring stations. At the same time weather forecast is essential for optimized and safe functioning of hydraulic facilities such as reservoirs. Inadequate management of facilities lacking consideration of weather conditions already causes regular devastating floods in the Kuban River with numerous casualties and considerable economic damage [34]. Moreover, harsh weather conditions coupled with aging, poorly maintained facilities might result in collapse of abandoned and supported dams and hydraulic structures, endangering local and regional communities.

Potential terrorist activities also endanger the security of hydropower facilities. For example, a group of terrorists stormed a hydroelectric power station located at the river Terek in close proximity to the Kuban watershed in 2010, killing two guards and detonating four bombs [8].

A security breach at the Tsimlyansk facilities due to any reason could be devastating due to the high population density, industries and infrastructure concentration through the floodplain downstream the dam and in the Don River delta.

The same considerations apply to the Volgodonsk Nuclear Power Plant located at the Tsimlyansk reservoir, which uses its water for cooling purposes. The Plant design and project has been challenged and several shortcomings that increase technological failure risks have been indicated [80]. Accidents at the Plant followed by radionuclide leakage would cause water contamination of the reservoir and downstream areas highly dependent on this freshwater source. The Plant relies on the water level in the reservoir and its decrease will result in endangering plant operation with subsequent environmental and economic fallout.

1.5 International Relations

For a long time the border delineation in the Sea of Azov has been a sensitive issue in relations between Russia and Ukraine, causing political tensions and direct conflict in the summer 2003 [5]. Ukraine unilaterally established a maritime border with Russia in the 1990s, taking over control of the Strait of Kerch and depriving

Russia of an the exit to the Black Sea. The claim was based on the discrepancy between the Soviet-era administrative border between the two republics and actual administrative management. The situation around the Tuzla peninsula, the core of the dispute, has been one of the bitter problems in Russia-Ukraine relations and one of the symbolic signs of controversy between the two countries.

Another factor contributing to tensions is the collapse of the regional fishery. In both countries the Azov fishery has been a substantial sector of the regional economy and disputes over the use of the common fish stock might induce newer conflicts. For example, following reluctance of the Ukrainian partners to impose a temporary ban on fishing of valuable and protected species, a proposal on separating the still productive Taganrog Gulf, fully located on the Russian territory, from the open sea shared by both countries has been put forward [3].

Apart from the pure "matter of principle", classic national pride and depleting fish stocks, the maritime border delimitation in the Sea of Azov is a matter of gas and oil deposits available in the region.

At the moment the agreement is signed and ratified, yet opposition in both countries has been challenging this decision and taking into account the unstable political situation the dispute might start again in near future [130].

The problem of transboundary watercourse pollution is another significant stressor in Russian-Ukrainian relations [109, 160]. The Ukrainian share of the basin is one of the most populated, agriculturally and industrially developed areas of the entire basin. It hosts multiple industries including mining, metallurgy, chemical, food production and others. The economic crisis and depression in Ukraine has minimized environmental concerns in the region [153, 160], causing a lack of investment in environmental protection. As a result, concentrations of various dangerous pollutants (oil, copper, iron, nitrites, zinc, chromium, manganese, ammonia, sulphates, calcium, etc.) in the Severskiy Donets, the river crossing the Russian-Ukrainian border upstream of the most highly populated Russian areas (i.e. Rostov-on-Don), is many times higher than the MACs, causing significant threats to the local population and overall environmental security.

The broader international community also has an interest in the region as the "water gateway" to the Caspian Sea and its mineral resources.

1.6 Conclusions

Environmental security with regard to water resources should be understood as the current and future availability of life supporting services and goods of aquatic ecosystems for both human needs and ecosystem processes, which can be achieved through integrated watershed wide management and securing resilience of the aquatic ecosystem. At the same time environmental security is closely linked to other security dimensions such as international relations and infrastructure security.

The Azov Sea watershed is a good case study for showing the need to consider environmental security as an integrated, holistic, interdisciplinary concept including many interconnected aspects of national, human and other relevant traditional security types.

The Sea of Azov is a unique ecosystem and is not only an essential component of regional security; it is also a region of high national and international concern. It performs functions and provides services and goods crucial for diverse sectors of the basin countries' national security including food provision, economy, transportation, and political stability.

At the same time the high level of anthropogenic pressure on the Sea and basin ecosystems has caused irreversible changes in them by over-utilizing some of the resources available.

This fragile system is losing its resilience and is deteriorating at an alarming rate, losing many of the services it has traditionally offered society (fishery, freshwater supply, etc.).

The largest irrecoverable damage to the ecosystem has been inaugurated with the basin rivers impoundment aimed at securing economic growth. The multipurpose barrage cascades on the basin rivers have been constructed with a view to economic goals (primarily navigation for the Don River and irrigation/flood control for the Kuban River) and neglecting other needs.

As a result serious threats to environmental security in the Sea of Azov and its basin can already be identified. The unsustainable pattern of resource use has already caused a collapse of the regional fishery, which had been a significant sector within the basin economies and an important component of national food security. The consequent unemployment and other negative effects have contributed to socio-economic and political instability in the region as well as heightening international tensions.

Existing regional development plans aim at giving priority to further utilization of the strategic location of the Azov Sea through development of the transportation network and the construction of new Azov-Caspian shipping canals. Additional water abstraction from the Azov basin will undermine ecosystem resilience and stability, diminishing the role of other ecosystem services. Further ecosystem changes coupled with population growth, economic development and likely climate change effects will amplify the present threats to environmental security. causing unavoidable biodiversity loss and significantly undermining national food security, the existing development plans will trigger other threats to security such as clean water deficit, disease outbreaks, interruptions in agricultural and industrial processes, and higher pollution concentration. Special concern is connected to ageing equipment and the expiring operation time of numerous hydraulic facilities in the region.

Recommendations and strategies for mitigation of these threats have been repeatedly communicated to the national and regional authorities [2, 36, 140, 151, 173], yet further development and management plans contradicting these recommendations are still on the political agenda.

Many experts believe that the actions required are politically unrealistic and foresee the fate of the Aral sea for the Azov ecosystem [52]. Literally speaking, the disappearance of the Sea of Azov is not possible due to the connection to the Black Sea. However, water loss will be compensated through the Strait of Kerch by high salinity Black Sea waters, destroying the Sea of Azov ecosystem as it is known now and dramatically altering the ecosystem services it provides.

According to some assessments the highly productive ecosystem of the Azov still has recovery potential [35, 38, 83]. To utilize it, an independent interdisciplinary assessment of environmental security in the region has to be carried out; any existing best water management practices should be carefully considered for possible application in the region, taking account of regional peculiarities. The existing water protection legislation hindering effective and equal cooperation among water stakeholders should be improved. The current legislation requires effective mechanisms for securing sustainable use of natural resources without prioritizing most profitable sectors of economy (e.g. oil transportation). In addition, watershed-wide bilateral and international cooperation is urgently needed to develop and enforce environmental security.

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Chapter 2
Ecosystem Services of Rivers: The Don River (Russian Federation) and the Roanoke River (USA)

Brenda Rashleigh*, Viktor Lagutov, and Tobias Salathe

Abstract The concept of ecosystem services recognizes the services, and benefits, provided to people by ecosystems. River systems provide many services to people, including freshwater provisioning, carbon storage, fisheries, recreation, transportation, and biodiversity. Here, we review the services provided by rivers and describe a conceptual model relating services to drivers, pressures, ecosystem state, and management responses. This approach allowed us to highlight how policies and decisions can lead to trade-offs among services, which must be considered for sustainable watershed management. We have used this conceptual framework to compare two rivers, the Don River in the Russian Federation and the Roanoke River in Virginia/North Carolina, USA, to demonstrate the usefulness of the ecosystem services approach. Future science needs for ecosystem services in rivers are to identify service indicators and map services, link drivers/pressures to services with models, and relate natural systems to social and economic systems.

Keywords Ecosystem services • Rivers • Fisheries • Trade-offs • Don River • Roanoke River

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2.1 Introduction

Ecosystem services are the benefits that people obtain from ecosystems. Although an understanding of services has been in existence for some time, the Millennium Ecosystem Assessment (MA) in 2005 raised awareness of the ecosystem service paradigm for both scientists and the general community. The concept of ecosystem goods and services is of value to managers and policy makers as it allows the linkages between human and ecological systems to be understood by non-scientists, stakeholders as well as other interested parties. The benefits that these ecosystems generate are threatened by society's own activity [36]. For the sustainable management of environmental resources, identifying and quantifying ecosystem goods and services are increasingly required [55]. River systems provide many services to people, including carbon storage, fisheries, recreation, transportation, and biodiversity. Vörörsmarty et al. [57] found that 80% of the world's population is exposed to high levels of threat to water security and habitats associated with 65% of continental discharge are classified as moderately to highly threatened.

Here, we review the services provided by rivers and describe a conceptual model relating services to drivers, pressures, ecosystem state, and management responses. This approach allowed us to identify trade-offs between services, and also highlight where services respond similarly to pressures, and may be bundled, or considered together. Tradeoffs may occur among services (e.g., [53]), and an understanding of these can better outline effects of decisions for single endpoints or services. We have considered two rivers, the Don River in the Russian Federation and the Roanoke River in Virginia/North Carolina, USA, in the context of our conceptual model, to demonstrate the usefulness of the services approach. Future science needs for ecosystem services in rivers are to identify service indicators and map services, link drivers/pressures to services with models, and relate natural systems to social and economic systems.

2.2 Defining Services for Rivers

Streams and river ecosystems provide significant services to humans [42]. The MA [32] provided a general list of ecosystem services, which has continued to evolve and be refined for different ecosystems. A full understanding of services for rivers is still an open research question (e.g., [46]). We propose a set of services provided by rivers in Table 2.1. Some studies recognize habitat and biodiversity as supporting services; other studies (e.g., [30]), consider services and biodiversity together in their assessment. We have assumed that the habitat and biodiversity values, mainly for fish and birds, are encompassed in final services related to recreation, and in some cases, food provisioning [5]. Fish, in particular, support the provisioning of services from rivers. Services supported by fish include the regulation of food web dynamics and recycling of nutrients; linkages within aquatic systems and to terrestrial ecosystems; food production and recreational activities; and information services,

Table 2.1 Final services provided by river ecosystems

Watershed ecosystem services	Examples (considerations to maintain the services)
Food, fiber, and fuel	• Fish/shellfish consumed by humans • Hydropower (water quantity and timing)
Clean water	• Water used by humans for drinking, agricultural, and industrial uses (water quantity, quality, and timing) • Assimilation of waste (water quality and quantity)
Climate resilience	• Carbon sequestration capacity (integrity of soil, wetlands, and riparian areas)
Flood/storm protection	• Avoidance of damages from flood and storms (aerial extent of functioning floodplains)
Recreation	• Boating, swimming (water quality and pathogens) • Bird watching (habitat quality, habitat connectivity)
Biodiversity	• Sustainability of iconic species for existence value (habitat suitability, migratory routes)

including assessment of ecosystem stress and resilience [22]. Vescovi et al. [56] distinguish between tourism (e.g., river viewing), and existence values (personal satisfaction from free-flowing rivers).

2.3 A Conceptual Framework for Watershed Ecosystem Services

Conceptual models can demonstrate the linkages among management actions, environmental stressors, and ecological and societal effects, and provide the basis for developing and testing hypotheses to explain current conditions [17]. We have used the Driver-Pressure-State-Impact-Response (DPSIR) framework to create a conceptual model for a river system (Fig. 2.1) with the IHMC CmapTools software [7]. The Drivers, or Driving Forces, are human influences and activities, as well as the natural conditions, affecting ecosystems. For rivers, the drivers encompass those typically found on a landscape. The drivers encompass those typically found on a landscape. These were taken from the United Nations International Standard Industrial Classification of All Economic Activities (http://unstats.un.org/unsd/cr/registry); The Pressures are the direct stresses affecting ecosystem function and condition, i.e., pollutant release. Physical alteration, as a pressure, is often due to dams. Additional interactions occur among pressures, for example, emissions of greenhouse gases relate to altered precipitation and flow. The State reflects the current environmental (physical, chemical, and biological) conditions of an ecosystem. The Impact is the measure of the effects due to changes in the state of a system; here we equate these to ecosystem services (Table 2.1). The impact reflects the societal values associated with the system state. The Response is the societal response to solve environmental problems in terms of management strategies and policies. More description of the DPSIR framework can be found in Pirrone et al. [41] and Maxim et al. [31].

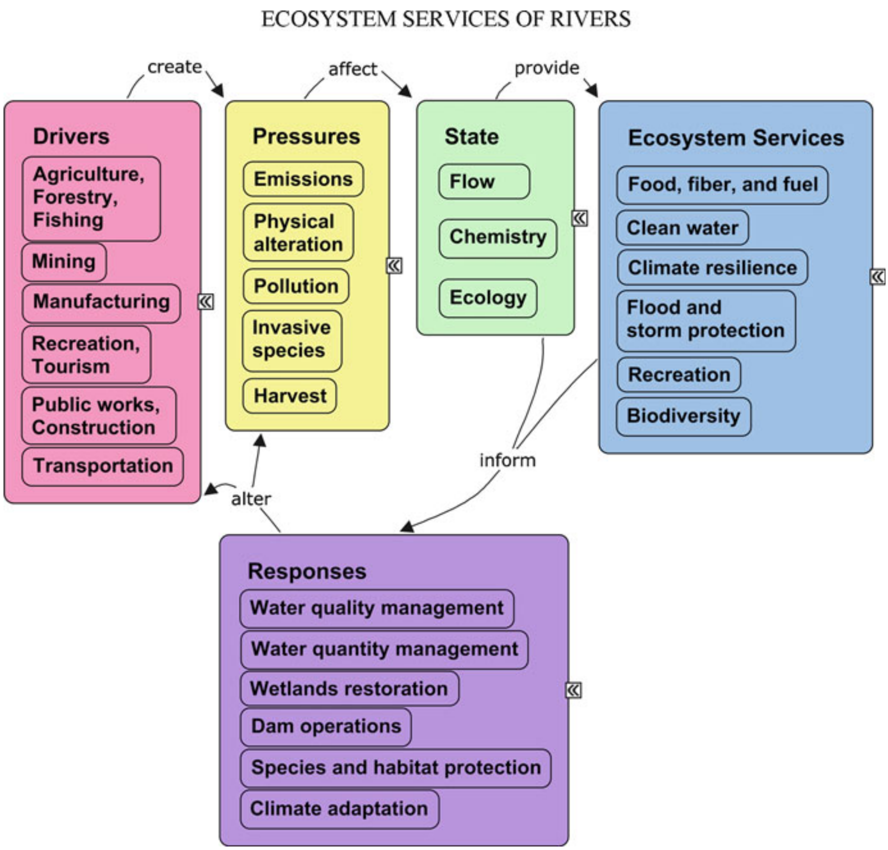

Fig. 2.1 Conceptual model for river ecosystems, where drivers are socioeconomic and natural forces influencing the ecosystem; pressures are stresses that human activities place on the ecosystem; the state is the condition of the ecosystem; services are benefits that ecosystems provide to humans (Table 2.1); and responses are the environmental management actions and decisions by society

For rivers, managers and decision-makers have several factors to consider in their response. Decisions related to water quality include setting standards, diagnosing causes of impairment, and optimizing actions to reduce pollutants. Water quantity decisions relate to control of major water withdrawals and diversions. Considerations include dilution of waste, habitat for species, and salinity in receiving waters. Of particular importance are decisions relating to dam building, removal, and operation. Stormwater/flooding regulation is a consideration. Managers must also consider species and ecosystem protection, including habitat and passage for fishes, and protection of wetland ecosystems and the services they provide [43]. Finally, decision-making must recognize the need for adaptation to climate change, and an understanding of the changes occurring in temperature, storms, and water flow and timing. Including the concepts of ecosystem services can inform these management decisions [11]. For example:

- Services provided by dams – flood control, power generation – can be in conflict with biodiversity, through the restriction of fish passage. Dugan et al. [16] evaluated the effects of dams in the Mekong Basin, and concluded that major investment is required in innovative technology to reduce the loss of ecosystem services.
- Different types of wetlands (including rivers) provide several services, including flood control, habitat, and support of water quality. The consideration of multiple ecosystem services provided by wetlands may change the character of the market [14].

Nelson et al. [33] have found that tradeoffs occur between biodiversity conservation and commodity production. For river systems, trade-offs are most likely to occur between service provided by fish and services of drinking water provisioning, withdrawal of water for industrial and consumptive uses, and waste assimilation.

2.4 Science Needs for the Study of Services for Rivers

In order to use ecosystem services to manage river systems, a first step is to identify service indicators and map services [55]. The mapping of services depends on the distribution of resources, and the quality of these resources, as represented by the state of the system (Fig. 2.1). Translation of the state of the system to services, by production functions, is an area of ongoing research. Some indicators are listed in Table 2.1. Because the delivery of services is spatially explicit [5], it is necessary to view services through the creation of a map, or an atlas of the services provided by a given region. For rivers, innovative approaches that consider river reaches or subcatchments as map units may be needed (e.g., [54]). Luck et al. [30] found that even for the same ecosystem services, the relationships among these in watersheds varied spatially. The temporal provisioning of services, and the accumulation of services over large time scales, must also be considered [20].

A second category of research needs for ecosystem services in rivers is to link drivers/pressures to services with models. Conceptual models (e.g., Fig. 2.1) can be used to support the development of mathematical models. A next step will be to identify the types of mathematical models and decision tools needed to represent the steps of the conceptual model [45]. Gentile et al. [17] have noted that for the Everglades and South Florida systems in the USA, the conceptual models are used in the initial development of performance criteria for system recovery, for those stressors that are determined to be most important in shaping the landscape, and to guide the use of numerical models used to develop quantitative performance criteria in the scenario analysis. Models can be used to assess the success of river protection and rehabilitation ∕ restoration. Models for relationships between hydrological patterns, fluvial disturbance and ecological responses in rivers and floodplains are needed [2].

A third needed research area is the relation of ecosystem services to management decisions, through social and economic analysis. Banzhaf [3] emphasized the need to communicate the results of environmental economic analyses to policy makers to help inform their decisions. In general, a valuation approach is necessary for putting services in terms that can best inform decisions. Some services (e.g., fisheries and forestry) already have monetary value; other services can be valued by employing different environmental economics valuation methods, including hedonic pricing, the travel cost method, and contingent valuation. An extensive literature exists to describe valuation methods for ecosystem services, including work in river ecosystems [29]. Wetland valuation has also been well-studied [12], however, wetlands need to be considered within the framework of water systems, and the full range of costs and benefits from wetlands creation and destruction occurs within the context of the water system. Buijse et al. [6] have noted that rehabilitation schemes in large rivers should consider economic impact, as well as environmental impact. Luck et al. [30] concluded that worldwide conservation efforts could best be prioritized by including the human need for services, which they represented as human population density in a watershed and the capacity to pay for human-derived alternatives to ecosystem services, rather than simple dollar metrics for ecosystem services.

2.5 Two River Examples

For this analysis we will consider two rivers: the Don River in the Russian Federation, and the Roanoke River in Virginia/North Carolina, USA (Fig. 2.2). Both rivers rise in forested areas, cross large areas with agriculture and large cities, and empty into valued receiving waters. This international perspective allows us to focus on shared characteristics, rather than country-specific management.

2.5.1 The Don River

The Don River rises in the town of Novomoskovsk, 60 km southeast of Moscow, and flows for a distance of about 1,950 km to the Sea of Azov, draining an area of 425,600 km^2. From its source, the river first flows southeast to Voronezh, then southwest to its mouth. The Tsimlyansk Dam, forming the Tsimlyansk Reservoir, raises the water level of the Don in this area. For the next 130 km below the Tsimlyansk Dam, water depth in the Don River is maintained by the sequence of three dam-and-ship-lock complexes; the sufficient depth of the lower waterway is maintained for navigation by dredging. At its easternmost point, the Don comes near the Volga, and the Volga-Don Canal (length ca. 105 km), connecting both rivers, is a major waterway. The main city on the river is the industrial city of Rostov-on-the-Don, with a population of one million. The river splits into several channels and creeks, forming a delta upon entry into the Azov Sea.

Fig. 2.2 Location maps of two rivers

Waters of the Lower Don system are used for municipal and industrial needs, and for irrigation of crops. However, the water from the reservoir has been widely used for irrigation in the region and downstream, unsuccessful agricultural policies, such as attempts to grow cotton and rice in the region, have limited the effectiveness of irrigation. Besides, the basin is one of the most densely populated areas in Russia. The Don River and the downstream Azov Sea have always been important tourist attractions on the both regional and national scale.

The Don River basin is an intensively exploited region with respect to agriculture and industry, leading to many pressures in the system. In the Don River, water abstracted for irrigation is a major pressure, which increases downstream salinity and impacts fish populations [15]. The annual water withdrawal from the 28 km^3 total annual Don flow is 21 km^3, out of which 9 km^3 are withdrawn irrevocably [13]. Physical stream alteration has also caused water losses in the basin through large-scale evaporation from the Tsymliansk reservoir located in the arid zone and water withdrawal for Volgo-Don Canal maintenance. The water withdrawal and physical stream alterations have drastically changed hydrological regime and caused significant ecosystem changes: total flow during the flood has been reduced threefold; flood duration was reduced by a factor of 4, flood area by a factor of 3, flood frequency by a factor of 2 [25, 50].

Treated drinking water from surface water resources is used by 70% of the area population, and these resources are subject to contamination with Giardia and

Cryptosporidium parasites resulting from fecal contamination [24]. Nikanorov et al. [35] have demonstrated toxicity of the sediments in the lower Don River basin to biotic organisms, and contamination of Cs-137 from the Chernobyl Incident may exist in the system [18]. Eutrophication is also an issue for the Lower Don River, where high turbidity also occurs, which may extinguish light and limit plankton growth [34].

The primary purpose of the Tsymliansk reservoir construction was to secure navigation through the snowmelt fed Don River characterized by high spring flood and very low water in summer. Aimed to redistribute river water discharge through the year more evenly and to create navigable depth upstream the Tsymliansk dam was essential to secure access to the Internal Water Transport System,, which links the .Black and Mediterranean Seas and Caspian Seas together through network of canals and rivers [51]. At the same time, it was an attempt to utilize some other ecosystem services such as energy generation, fisheries, irrigation and water supply for settlements and industries. For instance, the reservoir is currently being used for cooling purposes at the Volgodonsk Nuclear Power Plant.[1] The benefits from the Tsymliansk hydropower station with an average annual power output of 663 million kWh is considered insignificant.

As a result, the very active and efficient efforts to utilize some ecosystem services have caused significant deterioration in quality of others. Flood control with a sequence of dams and annual water redistribution has resulted in reduced floodplain productivity due to lack of flooding, collapse of the regional fishery due to loss of spawning grounds and habitat degradation in both the river and the shallow Sea of Azov. The salinity of the Sea of Azov, deprived of its largest freshwater influx from the Don River, is gradually increasing due to the Black Sea water inflow through the Strait of Kerch [15]. As a result, habitat degradation coupled with massive scale overfishing over the second half of the twentieth century has brought many fish populations to the brink of extinction [60]. Many species abundant in the Don river two decades ago cannot be observed any longer despite the fact that the harvest of valuable fish stock have been banned since 2000 [48]. For example, the Deputy Director of the Federal Fishery Agency stated that the reproductive population of the Azov sturgeon in 2008 was only about 100 specimens, while at the end of 1990s the population was estimated to be 17 billion [52]. The total degradation of the sturgeon spawning habitats is claimed to be the reason for this situation.

In the Don River, there are two Wetlands of International Importance, designated under the global Convention on Wetlands ("Ramsar Sites"): Veselovskoye Reservoir and Manytch-Gudilo Lake further upstream on Manitsch River, a left-bank tributary entering the Don upstream of Rostov sites. Both are extremely important for biodiversity. The former harbors several tens of thousands of wintering waterbirds, and the latter a comparable number of wintering and breeding birds. Both also serve as important refueling areas for migratory birds along the Western Siberian-Eastern European-Eastern African flyway. Lake Manytch-Gudilo

[1] Sometimes referred to as Rostov Nuclear Power Plant.

furthermore provides important hydrological functions in the context of the arid Eurasian steppe habitats and the typical wildlife and flora that surround this aquatic ecosystem (cf. [44]).

Management responses in the Don River basin are varied. A monitoring network exists in Russia, although there are some issues associated with network design, choice of parameters, and data handling [59]. Shubin [49] notes that the aims and methods of river restoration for small and large rivers in the Volga-Don basin are different, but they must be achieved through a common scheme of coordinated arrangements. In Russia, basin authorities used to be some of the best examples of the watershed approach [27]. Newer, more efficient sewage treatment facilities have been installed in the major basin settlements.

The first state protected area in Russia was established in the Don river delta in 1835[2] for protecting fish spawning and feeding grounds, after strict limitations were imposed earlier in 1819 [8, 9, 47]. The borders of the protected area have been changing, yet the no fishing zone has been preserved for more than 150 years. There are also several Ramsar sites in the Don River network and discussions among regional authorities, local communities and national government on establishing the protected area along the main river stream are ongoing [28]. The Azov Center for Watershed Cooperation (Novocherkassk) in cooperation with State Fishery Agencies and the Don Cossacks Community has initiated official requests to the national and regional governments to develop water management scheme taking into the account environmental flow and fish population needs. In the Don River, efforts are underway to secure appropriate flows for the 2-week migration period of sturgeon [26]. For that purpose, larger discharge should be secured from the Tsimlyansk reservoir, and the three dams downstream that support navigation should be modified to allow through-migration for sturgeon.

Integrated basin wide water management involving cooperation among different stakeholders and aimed at the environmental flow needs has to be introduced. Environmental flow needs are still neglected in the region. Moreover, navigation through the Don River is increasing and new plans on enhancing the regional water transportation network have been developed. One of the under-utilized responses in responding to the ecosystem degradation and the resulting loss of ecosystem services is cooperation with local communities and stimulation of community based nature protection. The Don Cossacks, the largest and the oldest Cossack community in the Russian Empire, historically inhabited almost the entire Don River basin and had enjoyed self-government privileges and control over the natural resources. Severely oppressed by the Bolsheviks, these groups are recovering recently claiming back their rights and privileges; the regional and national authorities take into account the growing potential of the Don Cossacks and delegate them certain nature protection functions [28].

[2] The state-recognized protected area was established several decades earlier than the famous Yellowstone National Park which is considered to be the world first protected area.

2.5.2 The Roanoke River

The Roanoke River is a 660 km long river draining 15,418 km^2 in Virginia and North Carolina, in the southeastern United States. This river drains from the eastern edge of the Appalachian Mountains southeast across the Piedmont and coastal plain to Albemarle Sound. The Roanoke was a historically important river, where early settlement in the Virginia Colony and the Carolina Colony were located. It is impounded along much of its middle course to form a chain of reservoirs. The river has its headwaters in the Blue Ridge Mountains in southwestern Virginia where the North Fork and South Fork of the river merge. The combined stream flows northeast between mountain ridges through the Roanoke Valley, then east through the city of Roanoke, emerging from a gorge in the Blue Ridge Mountains southeast of Roanoke. The river flows generally east-southeast across the piedmont and coastal plain ecoregions, to enter the western end of Albemarle Sound. The river is impounded twice in Virginia, with three high dams forming reservoirs in North Carolina: Kerr Lake along the North Carolina border; Lake Gaston reservoir, which stretches upstream to the Kerr Dam; and Roanoke Rapids Lake.

In the Roanoke River basin, 360 stream kilometers are negatively impacted by instream habitat degradation, including sedimentation, streambank erosion, channelization, lack of riparian vegetation, loss of pools or riffles, loss of woody habitat, and streambed scour [37]. These pressures are typically a result of land development and human activities on the landscape. The dams along the river mainstem have contributed to bank erosion and sedimentation [23]. Bosch et al. [4] estimated a 12% watershed decline in groundwater recharge in a coastal watershed in the Roanoke basin, because of suburban development. Livestock contribute to fecal pollution [10].

Despite these pressures, the state of the system is mostly high quality, providing several ecosystem services. The dams along the river are operated for hydroelectric power generation as well as recreation, flood control, and water supply [37], and associated lakes support fish, wildlife, and recreation. The lower Roanoke River floodplain contains some of the best remaining river floodplain communities known in the southeastern United States. The floodplain extends 209 km along the lower Roanoke River and varies in width from 5 to 8 km. The Roanoke River is ecologically significant and diverse, with 36 species of fish, mussels, and crayfish with conservation priority in the basin [38]. The lower Roanoke River is important habitat for migratory American shad [21]. The river historically supported the Atlantic sturgeon, although their numbers have been negatively impacted by overfishing [1].

Several management responses are underway in the Roanoke River. In 1990, the US Fish and Wildlife Service and the NC Wildlife Resources Commission began acquiring property within the floodplain; the Roanoke River National Wildlife Refuge and the Roanoke River Wetlands Game Land now protect over 130 km^2. In addition, The Nature Conservancy, a private conservation organization, manages about 85 km^2 of land within the floodplain owned by a private forestry company [37]. Pearsall et al. [39] proposed reasonable, flexible, and economically sustainable adaptive management strategies for the Roanoke River to enable the bottomland hardwoods to regenerate and support their associated biota. This Roanoke River is the focus of collaborative work between the U.S. Army Corps of Engineers and the Nature Conservancy, to consider balanced flows [58]. Wetlands protection is accomplished through the Nature Conservancy and conservation easements to the state of North Carolina.

Several restoration activities are being conducted for fisheries. Shad are being trapped and transported provide access to historical spawning habitat above dams. However, transported individuals may have reduced effective fecundity and post-spawning survival compared with non-transported fish that spawn in the lower Roanoke River [19].

2.5.3 Parallels Between the Don and Roanoke Rivers

The drivers shown in Fig. 2.1 are relevant for both river systems, and will likely be found in most developed watersheds. Both the Don and Roanoke Rivers face similar pressures – flow alterations, and elevated sediment, nutrients, toxics, and pathogens. Chains of dams are found in both river systems, and considerations for dam management were important issues in both rivers. Both support similar ecosystem services, as outlined in Fig. 2.1, although the Don River is more important for shipping, due to its large size, population center, and the role-played in the national navigation network. For both the Don and Roanoke Rivers, migratory fish runs are important. Many migratory fisheries are in decline worldwide, and improved population and habitat management is needed for these species [40].

Management responses varied across the two river systems. Land is protected in both systems under local, state, and federal jurisdictions, including state parks and national wildlife refuges. Wetland habitats protection is also an important issue in these rivers; some wetland sites in both basins are protected, and additional protection may be needed. In the Roanoke, non-governmental organizations have organized within these watersheds to promote education, river recreation, land protection, and watershed planning, while in the Don River basin, local Cossack communities with cultural ties to the land have organized to support sustainable watershed and fisheries management. Many fisheries management options are being considered in both basins, however, recovery efforts face many challenges.

2.6 Conclusions

Our vision is that the application of ecosystem services science to river ecosystems can lead to better watershed management decision-making, and ultimately benefit human and ecological well-being. The DPSIR model allows for the consideration of the many relationships that occur in an ecosystem, and demonstrate the different human influences on the system, Although a more detailed DPSIR model will be needed to explicitly represent the many system pathways, there is value is conceptualizing these overall links (Fig. 2.1), The scale of the study is an issue for consideration. Here, we focused on the river systems, but a broader view would consider the upland watershed, the watersheds of the tributary rivers of the main river, and the downstream estuary, as well as the linkages between them. We believe that the DPSIR conceptual model can serve as the basis for integrated, holistic management that allows for consideration of all consequences of management decisions. In particular, the "critical path" approach developed by the Scientific and Technical Review Panel of the Ramsar Convention [43] is a practical tool to link water catchments basin planning with local site management decisions and interventions. We conclude that the set of drivers, pressures, and services in river systems are quite similar and, although their relative importance can vary, and studies across large systems in different countries can provide new perspectives on management responses.

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Chapter 3
Climate Change, Water and Agriculture in the Azov Sea Basin

Nikolay Dronin and Andrei Kirilenko

Abstract The provinces of Russia and Ukraine located within the Azov sea basin are important producers of grains, sugar, sunflower, meat, and milk. Nineteen Russian provinces of the region together harvest almost half of all grain in Russia; agriculture contributes 28% to their total GDP. In Ukraine, four provinces collect 15% of grain harvested in the country. Because of heavy dependence of regional economics on agriculture, and major effects of regional agriculture on food security of the entire countries, climate change impacts on food production and water resources constitute major threats to the food security of both Russia and Ukraine. Historically, major droughts frequently affected the agriculture of the region, with resulting crop failures affecting the entire population of Russian Empire and USSR. The recent climate change seems beneficial for agriculture of the region: warmer temperatures extend growing season and elevate the accumulated heat. At the same time, further warming is not likely to be matched by higher precipitation, with negative impacts from the increasing aridity of climate. The most effective adaptation option, expansion of irrigation, is limited with high pressure on water resources, which is already high in many parts of the region.

Keywords Climate change • River basin • Droughts • Agricultural performance • Water deficit • Adaptation of farming

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3.1 Introduction

The Azov Sea basin includes more than 20 administrative units (oblasts, krays, etc., further referred to as "oblasts") of European Russia and Ukraine. This chapter concentrates on 19 of these units, leaving those with relatively minor area inside the watershed outside the scope of analysis (Fig. 3.1). All but two of the 19 units at least partially belong to the watershed of the river Don (Fig. 3.1). Further, we combined these administrative units into five regions: Chernozem (which roughly corresponds to the Central Chernozem economic region of Russia), North Caucasus, Middle Volga, Lower Volga, and East Ukraine (Fig. 3.2). Agriculture is one of the main activities in the area: the percentage of land under crops varies between 48% in Middle Volga region and 69% in East Ukraine (Fig. 3.2; see [24]). In Russia, agriculture contributes on average 23% (Lower Volga), 27% (Middle Volga), 29% (Chernozem), and 33% (North Caucasus) to the GDP of the oblasts [11], much higher than the share of agriculture in national GDP (11%; mean value of relative contribution of agriculture to oblast GDP computed over all administrative units of Russia is 19%).

Between these five regions, Central Cherozem is an important producer of grains, sugar, sunflower, meat, and milk, with 82% of agriculture land (11.1 million ha) used for crops (with 6.0–6.2 million ha under grains, 0.8–0.9 million ha under sugar beets, and 0.4–0.5 million ha under sunflowers), 12% by pasture, and rest by hey production. Similarly, rich Chernozem soils of East Ukraine allow for growing a variety of crops, including winter wheat, sunflower, beets, potatoes, fruit, berries,

Fig. 3.1 The region of study with the borders of 19 administrative units of Russia and Ukraine and their principle cities. The watershed of the Don River is shaded in *grey*

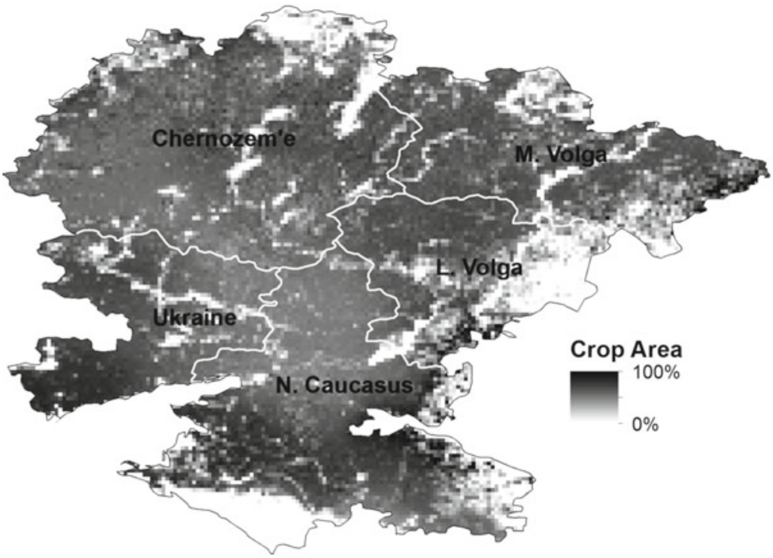

Fig. 3.2 The main agricultural lands in the region of study. The percentage of crop area is shown according to [24]

and also cattle grazing, with 83% of agricultural land under crops and 14% under hayfields and pastures. North Caucasus is an important producer of corn, sunflower, sugar beet, vegetables and fruits, grapes, and livestock, with 58% of the arable land allocated for cereals, 30% for forage, 9% for technical crops and 3% for vegetables. Within the region, Krasnodar and Stavropol krays and Rostov oblast are important producers of corn, rice, and winter wheat; the latter is grown on half of the farmland under grains; this is where Kuban, one of only two rice farming regions in Russia, is located. Middle Volga has a more continental and dry climate; the main crops here are wheat (50–70% of all land under crops), rye (10%), corn, millet, barley, sugar-beet, sunflower, mustard, flax and vegetables. Cultivated lands occupy about 85% of the entire territory of the region. Finally, in Lower Volga (represented in the basin by Volgograd oblast) agriculture takes 78% of the total land, including 52% under crops: durum wheat, vegetables, vines, sunflower, potato and mustard. Agriculture here also includes dairy and meat cattle grazing, poultry and bee keeping.

Because of the economics dependence on its agricultural performance, with major impacts on food security of the entire countries [6], climate change impacts on food production and water resources constitute major threats to population of the region. Multiple climatic factors that affect the farming include short growing period, late spring and early fall frosts, lower accumulated temperatures, highly variable precipitation and frequent droughts. GCM integrations hint at a possibility of significant increase of the temperature (by 1–3°C in 2020s and 3–6°C in 2080s) and moderate increase or decrease of precipitation over the principle agricultural lands of European Russia and Ukraine with notable decrease of summer precipitation [16,18,19]. The effect of such climate change is twofold. On one hand, higher temperatures will increase the length of vegetation period and reduce the risks connected with spring and winter frosts. On the other, temperature increase, when it is not followed by higher precipitation, may lead to more frequent agricultural and hydrological droughts. Lower precipitation may negatively affect the runoff in the basins of the rivers of Southern European Russia, such as Don [2,16], with 5–15% runoff decrease leading to 10% water deficit. In some of the oblasts of North Caucasus and Lower Volga regions, runoff decrease, combined with increasing water demand, will further complicate already existing high pressure on water resources [2,16], restricting irrigated agriculture. In this chapter, we investigate these and other impacts of climate change in detail.

3.2 Agricultural Climate

3.2.1 Temperature and Precipitation

Highly productive Chernozem (Black Earth) soils explain the historical significance of the Azov sea basin oblasts as the "bread basket" of the USSR. At the same time, cold temperatures and insufficient summer precipitation severely limit the agricultural production in the basin. Large-scale summer droughts are frequent and heavily impact the yields on rainfed land, while irrigation is not wide-spread: irrigated lands occupy only 3.4% of the agricultural area in the Azov Sea basin, ranging from 1.7% in Central Chernozem region to 6.3% in North Caucasus [10]. In the coldest Chernozem region, the growing season is only 130–160 days long with the accumulated temperature 1,200–1,600°C (base 10), and the last spring and first fall frost dates are highly variable [31]. Similarly, in East Ukraine the growing period is limited to 130–160 days. Overall, the length of the growing season in the region trails the 260–300 day growing seasons of the main agricultural areas of Western Europe.

Further south and east, in North Caucasus and Lower Volga regions, growing period extends to 165–200 days with accumulated temperatures above 2,000°C, however precipitation here is more limiting (see section 3), especially during the summer period. Winter crops are able to return reasonable yield even in dry summers if moisture reserve in soils was sufficient. E.g., in Ukraine summer precipitation supplies only 25–30% the required water. Climate variability results in highly variable yield. The variability of grain production ranges from 15% to 20% in the Chernozem and North Caucasus regions to 25–35% in Middle Volga to 35–50% in Lower Volga [13].

3.2.2 Droughts

The Azov Sea basin is very vulnerable to droughts. During the last century, these droughts led to multiple catastrophic impacts on the agriculture (Table 3.1). Between

Table 3.1 Agricultural performance of different sub-regions of the Azov Sea basin in years of major droughts in the twentieth century [5]

Year	East Ukraine (EUk)	North Caucasus (NC)	Chernozem (CH)	Middle Volga (MV)	Lower Volga (LV)
1891	Failure	No data	Failure	Failure	Failure
1906	Excellent	Excellent	Average	Failure	Failure
1911	Excellent	Average	Excellent	Average	Failure
1920	Average	Average	Failure	Failure	Failure
1921	Failure	Failure	Average	Failure	Failure
1924	Failure	Failure	Failure	Failure	Failure
1931	Excellent	Excellent	Average	Failure	Failure
1934	Failure	Failure	Failure	Excellent	Average
1936	Average	Average	Failure	Failure	Failure
1946	Failure	Failure	Failure	Failure	Failure
1960	Failure	Average	Failure	Average	Failure
1963	Failure	Average	Failure	Failure	Failure
1965	Excellent	Failure	Average	Failure	Failure
1972	Excellent	Failure	Failure	Failure	Failure
1975	Failure	Failure	Failure	Failure	Failure
1979	Failure	Failure	Average	Average	Average
1981	Failure	Average	Failure	Failure	Failure

the regions, the agriculture of Middle and Lower Volga is the most vulnerable to drought. Out of 17 major droughts that impacted the basin since late nineteenth century, only two had not destroyed the yield in these two regions. The least vulnerable to drought is North Caucasus, which has always played a role of food production buffer during the years of poor harvest [5]. This region has not been impacted by half of the major droughts in the region. The synoptic situation in western and eastern parts of the Azov Sea basin may be very different; as a result, it had been very important for food security of the USSR that East Ukraine had frequently produced excellent harvests during the years when the other regions of the basin were hit by major droughts. During five major droughts of 1906, 1911, 1931, 1965, and 1972, the effect of disastrous harvest loss in the Middle and Lower Volga regions was mediated by the above average harvests in East Ukraine. On the opposite, in 1934 and 1979 the East Ukraine suffered from severe crop failures, while the eastern part of the basin collected an average harvest. However, in 1891, 1921, 1924, 1946 and 1975 a major crop failure struck the entire Azov Sea basin, including East Ukraine, Middle and Lower Volga.

The first of these drought patterns, with very good harvest in Ukraine and extremely poor harvest in other regions of the basin, coincides with an invasion of dry arctic air over the European Russia, with a quasi stationary anticyclone over the Volga river basin. The dry hot winds spreading along the southern and south-western periphery of the anticyclone are especially damaging for crops. The same anticyclone blocks western humid masses, which bring excessive moisture to Ukraine. The drought is typically localized to a smaller area, but has high intensity and frequently completely destroys the crops. Occasionally, the drought can affect extensive territories of North Caucasus, Central Chernozem region, and even northern regions of European Russia. The 1911 drought makes a good example of this spatial heterogeneity of drought impacts. In spring, a cyclone over the north of European Russia and a very stable anticyclone in the middle and southern regions of Western Siberia resulted in prolonged (May–June) dry conditions in an extensive territory of Volga river basin, southern Urals, and the southern part of Western Siberia; to the east of Volga river there were no precipitation until late July. In this area crop failure was catastrophic. At the same time, many provinces of Ukraine and Central Chernozem region had excellent harvests, even though they were affected by somewhat excessive precipitation during the harvest season [30].

The other type of drought, which affects the crops in the entire area, is also triggered by spring or early summer invasion of arctic air, which forms dry hot air mass. The effect of this meteorological drought is, however, aggravated by weather conditions during the previous year. Prospects for good harvests strongly depend on the moisture stored in the top soil layer at the beginning of the growing period. The unusually dry autumn or extremely severe winter of the previous year can lead to an enormous area of crop failure, similar to that observed in 1891. The 1891 drought was a remarkable historic event, which affected a gigantic territory: Middle and Lower Volga, almost entire Central Chernozem region, south-west and north-east Volga-Vyatka region, North Caucasus, Crimea and southwest Ukraine [30]; it brought Russian Empire into a deep social and economic crisis. In Central Chernozem region, winter crops were already damaged during an unusually dry autumn of 1890. The winter of 1890–1891 was extremely cold. Additionally, strong winds swept away snow from the soil surface, which remained bare for weeks in many regions. In spring, fast snow melt stored little soil moisture. In spring and summer, meteorological drought was triggered by an invasion of arctic air. Until mid-June this dry warm weather was however interleaved with returning frosts, which additionally damaged winter crop and prevented sowing of spring cereals. The drought spread from the parts of Volga river basin south of the city of Saratov and the basin of the Urals River to East Ukraine, Rostovskaya and Volgogradskaya oblast and to Crimea. In the Central Chernozem region, strong dry sukhovei winds elevated air temperature above 40°C, while lowering air moisture below 20%. The resulted agricultural drought killed the entire harvest in Volgas, Central Chernozem and Urals regions [30].

3.2.3 Observed Climate Change

Recent climate change looks rather favorable for at least some regions of the Azov Sea basin. During the last 40 years of the twentieth century, average annual air temperature has increased by 0.8–1.3°C, adding 300–500°C to the annual accumulated temperature above 10°C. The temperature increase mostly affected the cold period, with an exception of North Caucasus, where the summer temperature increased higher, than the winter temperature. In Chernozem and Volga regions, the frequency of winters with soil temperatures hazardous to winter crops has been reduced from 18–22% to 8–10%, and in North Caucasus – from 10% to 4%, as compared with period up to 1990 [27]. During the same period, the cold period has shortened by 2–4 weeks, considerably widening crop growth period. In Ukraine, between 1980 and 2002 summer temperature was increasing by 0.78°C per decade, and declining between 1958 and 1979; overall temperature trend was 0.12°C per decade [26].

As the climate becomes warmer, precipitation is also increasing in the four Russian regions of the watershed; the annual precipitation during 1998–2007 period has been 10–50% higher than the 1961–1990 climatic mean. The precipitation increase is higher during winter, summer, and fall, and lower during spring, except for North Caucasus [4], with precipitation over the dryer regions exhibiting smaller increase. Overall, this increase in precipitation has compensated for the increased evapotranspiration in a warmer climate. Contrary to that, in Ukraine between 1980 and 2002 summer precipitation has been decreasing by 5.52 mm per decade; between 1958 and 1979 precipitation was increasing, so that the overall trend is −0.31 mm per decade. At the same time, soil moisture has been increasing over 1958–1979, and leveled between 1980 and 2002 [26].

Recent climate change is beneficial for agriculture of the region. Simulated climate-related yields of cereals in Stavropol oblast (North Caucasus region) show 30% increase over the past 20 years (1985–2005); similar changes in agricultural climate in many other regions has also led to improved wheat growth [27]. However, the main driver of crop yields seems to be economic rather than climatic one; during the first decade of Ukraine gaining independence, its mean 5-year yield of cereals fell by 16% (1992–1996 and 1997–2001 mean yields are compared according to FAOSTAT 2010 [7], with other authors giving similar estimates [32].

3.2.4 Future Climate Change

We estimated the current and future climate in the region from the University of Eastern Anglia's Climate Research Unit (CRU) climate datasets [17,20]. The monthly gridded values for temperature, precipitation, air humidity, and incoming solar radiation were processed using a stochastic weather generator [8] to obtain daily dynamics and to produce the missing monthly and yearly data such as the number of growing degree days baseline 10°C (GDD 10) and aridity indices. For future climate, we used simulations of five general circulation models (GCMs): CGCM2, HadCM3, CSIROmk2, ECHam4, and DOE PCM, for three pre-set time periods: 2020s, 2050s, and 2080s [17], for four "marker" SRES scenarios: A1FI, A2, B1, and B2 [12]. Multiple samples of climate parameters were computed for each combination of SRES scenario, GCM, and time period [6].

Agriculture is the major activity in the Azov Sea basin; it is also likely to be the economic sector with the major dependence on the climate. Because of that, to characterize current and future climate of the five regions of the basin we used the weighted arithmetic mean of the spatially distributed climate parameters, with the weights equal to the relative area of agriculture in a location [24]; we also did not take into account the locations where the agriculture takes less than 10% of land.

The GCM simulations show an increase in temperature as compared to the 1961–1990 base climate. In 2020s, this increase, averaged over five GCMs, varies between 1.3°C and 1.6°C for Ukraine and 1.6–1.9°C for Middle Volga. By 2050s, simulated temperature increase varies between 2.5°C and 3.0°C for North Caucasus and 2.7–3.7°C for Middle Volga. Finally, by 2080s, the temperature increases by 2.8–5.0°C for North Caucasus and 3.5–6.2°C for Middle Volga. The highest temperature increase is simulated by the model driven by the A1FI scenario; the lowest – by B1 and B2 scenarios (Table 3.2). Between the models, HadCM3 simulates the highest changes in the temperature, while PCM output is the lowest. This major temperature increase results in higher potential evapotranspiration.

The change in precipitation is very variable: while PCM projects a major increase in precipitation (up to 100 mm in 2080s), other GCMs' precipitation projections increase moderately, or even decrease. Averaged over GCMs, precipitation increase by up to 18 mm in 2020s, up to 30 mm in 2050s, and up to 42 mm in 2080s; this increase is highly variable across the scenarios and the regions, with the highest increase in precipitation in Chernozem, and the lowest increase in North Caucasus (Table 3.2). When the warm season (April–September) is taken alone, the projections are similar: PCM projects an increase in precipitation (up to 40 mm in 2080s), while other GCMs' precipitation projections slightly increase, or decrease. On average, however, all regions demonstrate small decrease in the warm season precipitations over all scenarios (Table 3.3).

Higher precipitation cannot compensate for increasing evapotranspiration. The difference between the potential evapotranspiration (computed according to [3]) and precipitation increase in all regions, with the highest increase in Lower Volga and Chernozem, and the smallest increase in Ukraine and North Caucasus (Table 3.2). When the current difference between precipitation and evapotranspiration is taken into account, Lower Volga region has the highest increase. Overall, this change should result in major increase in crop water requirements. Taking into account that summer precipitation is responsible only for 25–30% of water available for crops, water deficit exceeding the amount summer precipitation by roughly two times could be regarded as dangerous. Among all regions of Azov watershed, Lower Volga and Middle Volga are under threat of aridization by 2020.

Increasing temperatures in the region lead to better crop growing conditions. The accumulated temperature above 10°C (GDD10, growing degree days base 10) increases substantially, by 213–302°C in 2020s, by 213–302°C in 2050s, 384–609°C in 2050s, and 515–1,005°C in 2080s, with the lowest increases under B1 scenario and in Chernozem region, and the highest increase under A1FI scenario and in Volga and North Caucasus (Table 3.4). The substantial increase in accumulated temperatures, combined with a longer growing period potentially results in better agricultural potential of lands, higher yields and a possibility of growing new crop varieties. However, these positive changes are unlikely to be realized without

Table 3.2 Historical (1961–1990) and future climate for five regions of the Azov sea watershed: mean annual temperature (°C), annual precipitation (mm), and the difference between the estimated reference evapotranspiration and precipitation

		Temperature					Precipitation					EP0-Precipitation				
Scenario	Time	CH	LV	NC	MV	EUk	CH	LV	NC	MV	EUk	CH	LV	NC	MV	EUk
1961–1990		5.7	7.4	10.0	5.4	8.7	572	408	550	479	516	63	440	495	272	373
A1	2020s	7.2	8.8	11.3	7.0	10.0	581	413	553	490	523	266	661	542	475	436
A2		7.2	8.9	11.3	7.0	10.0	584	410	551	491	518	256	656	535	463	434
B1		7.2	8.9	11.3	7.0	10.0	586	415	561	490	527	263	659	533	480	434
B2		7.4	9.1	11.5	7.3	10.3	590	414	556	494	522	261	665	542	475	442
A1	2050s	9.2	10.8	13.0	9.1	11.8	594	421	558	505	533	372	802	677	597	535
A2		8.8	10.5	12.7	8.7	11.4	596	413	552	503	521	328	760	632	545	509
B1		8.2	9.9	12.1	8.1	10.9	595	419	568	497	534	311	725	591	539	481
B2		8.6	10.3	12.5	8.5	11.3	602	418	559	505	527	312	741	611	537	499
A1	2080s	11.5	13.1	15.0	11.6	13.8	608	430	565	522	546	507	970	833	745	655
A2		11.0	12.7	14.6	11.1	13.4	613	418	554	521	525	441	914	772	670	623
B1		8.9	10.6	12.8	8.9	11.6	601	423	573	503	540	351	778	639	588	519
B2		9.8	11.5	13.5	9.7	12.4	614	422	563	515	532	367	817	680	601	557

Four SRES scenarios are presented (A1FI, A2, B1, and B2). Each of the values is a weighted mean of the values in all cells inside the region, with the weights equal to the percentage of the cell under crops. The results were then averaged across five GCMs

Table 3.3 Change of summer temperature, precipitation, and the difference between the reference evapotranspiration and precipitation for the Azov sea watershed, for summer period

		Temperature					Precipitation					EP0-Precipitation				
Scenario	Time	CH	LV	NC	MV	EUk	CH	LV	NC	MV	EUk	CH	LV	NC	MV	EUk
1961–1990		14.9	17.3	18.4	16.0	17.1	329	220	304	259	276	284	563	578	467	471
A1	2020s	16.4	18.8	19.7	17.5	18.5	325	216	297	258	273	400	688	574	576	514
A2		16.3	18.8	19.7	17.5	18.5	325	214	296	256	273	398	689	574	573	514
B1		16.4	18.9	19.8	17.6	18.5	325	216	300	253	274	402	690	568	583	512
B2		16.6	19.0	19.9	17.7	18.7	326	216	298	255	273	406	698	579	584	521
A1	2050s	18.3	20.8	21.6	19.7	20.3	320	211	287	257	270	485	789	676	672	593
A2		17.8	20.3	21.2	19.1	19.9	321	209	287	253	269	460	769	652	644	575
B1		17.4	19.8	20.7	18.7	19.4	322	213	297	249	273	444	739	614	632	549
B2		17.7	20.2	21.0	18.9	19.8	323	213	294	253	271	453	756	633	637	566
A1	2080s	20.5	23.0	23.7	22.1	22.3	314	207	277	256	266	587	903	790	780	683
A2		19.8	22.4	23.2	21.3	21.8	315	202	276	249	264	551	880	760	743	661
B1		18.2	20.6	21.4	19.5	20.1	319	211	295	246	272	478	778	649	671	579
B2		18.8	21.3	22.1	20.1	20.8	321	211	291	251	269	500	813	686	689	611

For additional explanations see Table 3.2

Table 3.4 Change in growing degree days (base 10°C) and aridity indices (UNEP 1992 Aridity Index AIU and Thornthwaite's 1948 Aridity Index AIT) for the Azov sea watershed

		GDD base 10°C					AIU					AIT				
Scenario	Time	CH	LV	NC	MV	EUk	CH	LV	NC	MV	EUk	CH	LV	NC	MV	EUk
1961–1990		1,057	1,449	1,647	1,226	1,410	0.94	0.54	0.52	0.68	0.61	0.57	0.77	0.78	0.71	0.70
A1	2020s	1,278	1,695	1,911	1,467	1,660	0.71	0.40	0.52	0.53	0.56	0.56	0.73	0.65	0.68	0.65
A2		1,609	2,067	2,302	1,830	2,019	0.65	0.36	0.47	0.48	0.52	0.60	0.75	0.68	0.70	0.67
B1		2,031	2,540	2,784	2,293	2,471	0.59	0.33	0.42	0.44	0.48	0.63	0.77	0.71	0.72	0.70
B2		1,270	1,697	1,909	1,460	1,660	0.72	0.40	0.52	0.53	0.56	0.56	0.74	0.65	0.68	0.65
A1	2050s	1,513	1,981	2,204	1,727	1,929	0.67	0.36	0.48	0.50	0.52	0.59	0.75	0.67	0.70	0.67
A2		1,892	2,414	2,652	2,136	2,337	0.62	0.33	0.43	0.46	0.48	0.62	0.77	0.71	0.72	0.70
B1		1,283	1,704	1,916	1,475	1,663	0.71	0.40	0.52	0.52	0.56	0.56	0.73	0.64	0.68	0.64
B2		1,441	1,881	2,103	1,650	1,838	0.68	0.38	0.50	0.50	0.54	0.58	0.75	0.66	0.70	0.66
A1	2080s	1,572	2,029	2,258	1,798	1,977	0.66	0.36	0.49	0.48	0.53	0.60	0.75	0.67	0.71	0.67
A2		1,307	1,732	1,949	1,495	1,697	0.72	0.39	0.52	0.53	0.55	0.56	0.74	0.65	0.68	0.65
B1		1,490	1,951	2,175	1,695	1,905	0.68	0.37	0.49	0.50	0.53	0.58	0.75	0.67	0.69	0.66
B2		1,685	2,177	2,403	1,907	2,116	0.66	0.35	0.47	0.48	0.51	0.60	0.76	0.68	0.71	0.68

For additional explanations see Table 3.2

applying adaptation measures due to a general increase in climate aridity. The increasing water deficit negatively impacts all regions, with lesser impacts on Chernozemny region and Ukraine, and very high negative impacts on Lower Volga, as indicated by the changes in the [29, 32] dry index (AIT) and UNEP (1992) index of aridity (AIU) (Table 3.4). Because of these negative changes, yield reduction is likely in absence of adaptation measures. Our modeling of the agricultural production in Russian part of the region under the same scenarios [2] has demonstrated reduced yields of major crops (for each administrative unit, two most important crops were simulated). The major driver for this harvest reduction is a dramatic increase in the frequency of agricultural droughts. For example, for Stavropolsky kray (in North Caucasus region), current drought frequency is 28 dry years in a century, but for the 2020s under the A1FI scenario it increases to 64, and for the 2070s to 89 years per century.

3.3 Conclusions

Higher temperatures during the growth season may have already modified the yield in the Azov sea region. Lobell and Field [14] suggest that the warmer temperatures between 1981 and 2002 reduced the trend of increasing yields of six principal crops: wheat, rice, soybean, barley, maize and sorgos. Similarly, in the countries of the Former Soviet Union (FSU), the yields of main crops (wheat, corn and barley) were negatively affected: e.g., Lobell and Field [14] computed that between 1981 and 2002 climate change reduced the observed 0.85 t/ha increase in wheat yield by 10%; increase in barley yield was reduced by 30%, and observed maize yield increase was reduced by 7%. Other authors, concentrating on regional effects of climate change, estimated that the recent climate change was beneficial for the region of study; however, the authors believe that further warming would not be matched by increasing precipitation, and increasing aridity of climate would negatively impact the region. In this chapter we demonstrated that in the Azov basin, especially in the Low and Middle Volga and North Caucasus, water deficit will increase dramatically, thus leading to more arid environment. Alcamo et al. [2] estimated that climate-related production of grain in the Middle and Lower Volga, Central Chernozem, North Caucasus would drop by 7–29% in the 2020s, and by 23–41% in the 2070s relative to 1961–1990. They also estimated that under A2 HadCM3 climate projections computed for the Russian part of the Azov sea basin the frequency of food production shortfall years will increase from current 0–2 to 1–4 years per decade by 2020s and to 1–6 years per decade by 2070s.

One factor that can significantly change these projections is "carbon fertilization". Field experiments demonstrated that under the double concentration of carbon dioxide in the atmosphere (as compared with the pre-industrial concentration), C3 crop yields are elevated by 10–20% [1,9,15]. Higher water use efficiency of crops grown in environment with elevated carbon oxide concentration [33] may lead to better resistance to atmospheric droughts. Other authors, however, note that in the regions where summer temperatures are already high, such as observed in the Azov sea basin, higher temperature will moderate photosynthesis enhancement [34], and that the higher CO_2 environment is more favorable for weeds, than it is for crops [35]. However, even under the optimistic projections, climate change – modulated reductions of the rate of yield increase will negatively affect the food demand/balance, propagating into high impacts on food security. Adaptations to new agricultural climate can moderate the impacts of these changes.

The prime source of adaptation to the expected climate change is an expansion of irrigation. Agricultural lands that eventually became part of FSU have long history of developing irrigation systems, starting in the sixth to thirteenth centuries, when irrigation first appeared in isolated arid lands of Lower and Middle Volga River, North Caucasus, and southwestern Siberia. In the 1950s and 1960s, large irrigation projects were completed in the region [28]. Tsimlyansk reservoir, completed in 1952, contributed to rapid expansion of irrigation in Don river basin, which grew from about 50,000 ha in 1950 to nearly one million ha by 1980 [28]. In the upper basin of the Don River, an extensive network of ponds provides water for irrigation. In North Caucasus, the longest in the Europe Great Stavropol Canal (480 km), was constructed to supply rice fields with water from Kuban river [28]. Gigantic water management projects of the mid-1980s, which were not finished, targeted water transportation from low water stress regions of European North, e.g. North Dvina river; despite severe pressure from the government, especially from the former Ministry of Water Resources of the USSR, these projects were halted due to public outcry over its negative environmental and social impacts. Similar, in the end of 1980s costly Volga-Chogray channel, projected to transport 1.9 km^3 of water to Stavropol kray, was put to stop under public pressure [28].

A major factor limiting irrigation is, however, the already existing high pressure on water resources. Further, with warmer temperatures later this century, water availability for irrigation may decrease, and water demand increase. Using WaterGap model to estimate water resources of Russia, Alcamo et al. [2] found that all Russian regions of the Azov sea basin are currently experiencing middle or severe pressure on water resources (middle pressure was determined as water withdrawal-to-availability ratio between 0.2 and 0.4; the ratio above 0.4 was classified as severe pressure); in future their GCM projections disagree on the trend of water availability. Due to an elevated water demand from the industrial and residential sectors under higher air temperature, improved water management will be required.

Irrigation and other changes in agricultural practices have high potential as a measure of adaptation to future climate. Olesen and Bindy (2002) [22, 24] estimated that in the European part of FSU potential yield increase due to changes in management can exceed the climatically-driven yield decrease by a factor of 4.5. According to Russian Grain Union's estimates current yield of cereals in the south of European Russia can be increased from 2.8 to 9 t/ha, and in Volga region from 1.7 to 6.4 t/ha, mainly through better used of fertilizers [21]. Other measures include a shift to drought-tolerant crops and crop varieties, such as corn (including winter corn), and sunflower, shifting sowing time, expansions of the areas under winter crops and thermophilic spring crops, etc.

The important uncertainty in defining the best adaptation measures is the rate of climate change. The farmers are able to effectively and quickly adjust to new climate conditions, perhaps not realizing that the changes in practices are associated with climate [21], e.g. when the adaptations to water shortage are included into a new water management plan. If the ongoing change of temperature and precipitation is slow, the autonomous adaptation can be exercised at low costs during the normal cycle of replacing the equipment and updating the practices, discarding those made obsolete by climate change [25]. However, if climate change is accelerated, as projected by GCMs for this century, reactive adaptations may carry high costs, requiring planned adaptations.

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Chapter 4
Ecological and Hydrogeological Assessment of Ukrainian Part of the Azov Sea Basin

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Abstract Water resource potential of the Priazovie territory of Ukraine consists of the total water flow of rivers and aquifer reserves that are not hydraulically connected to the surface flow. The problem of the Azov Sea preservation and recovery of its commercial fishing value can be primarily achieved through restoring its natural characteristics such as volume and duration. The ecological state of this water ecosystem is characterized as unsatisfactory since it is subjected to a considerable level of anthropogenic load. Thus, there is an urgent need for immediate management decisions that will help stabilize the state of the ecosystem and neutralize the consequences of the anthropogenic load exerted on the ecosystem.

Keywords Water use • Resources • Balance • River • Sea • Eco-hydrogeological conditions

4.1 Introduction

Excessive anthropogenic load that was historically exerted onto various water bodies as a result of extensive water management resulted in a critical reduction of rivers' self-purification capacity and a consequent depletion of water resource potential.

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Present critical condition of Ukrainian water ecosystem results from significant contamination of water bodies that originates due to the following factors:

- Unregulated disposal of waste waters from urban settlements, economic entities and agricultural lands;
- Wide-scale radiation pollution of many river basins after the Chernobyl NPP catastrophe;
- Inadequate economic mechanisms of water use and implementation of water-control practices;
- Low efficiency of the existing regulation system regarding protection and use of water resources that results from poorly organized regulatory and legal framework and organizational structure of administration;
- Lack of continuous automated monitoring of the ecological state of basins within the areas of the Black Sea and the Azov Sea.

4.2 Environmental Policy and Water Use in Ukraine

Long-term policy objectives needed for the rational use and recovery of water resources and ecosystems should encompass the following concepts:

- Controlled decrease in the anthropogenic load exerted onto the water bodies;
- Achievement of the environmentally safe use of water bodies and water resources in order to meet economic needs of the society;
- Provision of ecologically stable functioning of a water body as an element of the natural environment; controlled preservation of the water ecosystems in order to restore water quality;
- Creation of an efficient control system and mechanisms for economic regulation of resource protection and use.

In order to improve the regulating system for the water resource protection and use and to develop relevant water-control practices, it is necessary to employ systemic and integrated methods for evaluating the effects of the anthropogenic load, based on the basin approach to the water body.

Major drawbacks of Ukraine's governing structure are complex multilayered factors, such as macroeconomic policy oriented toward extensive use of natural resources, investment policy aimed at development of the resource-intensive sectors of economy, unstable legislation that is not harmonized with the European legislation; lack of ecologically-balanced long-term economic strategy, natural-resource characteristics of export strategy and finally existence of significant incentives to obtain quick returns from the sale of natural resources.

This being the case, the main focus points for stabilizing the state of natural environment should be preservation and recovery of marine, coastal-marine, river, floodplain and lake ecosystems, as well as ecological rehabilitation of urban landscapes and other territories where the economic activity is carried out intensively.

Table 4.1 Cost of special water use in Ukraine

Special water use	Cost			
	UAN	RUB	EUR	USD
The Danube basin	0.02	0.77	0.0018	0.0025
Basins of the rivers on the Priazovie territory	0.12	4.62	0.011	0.015

Additionally, it is imperative to promote the concept of "greening" the agricultural landscapes and agro-technologies. The key economic mechanisms of the natural resources management in Ukraine should include the fixed fee application for charging special water use to prevent any type of pollution act (Table 4.1).

All of the above mentioned factors are crucial since water resources that are available within the territory of Ukraine are limited. Surface waters occupy 4% of the country's territory, i.e. the area of 24.1 thousand km². Annual flow makes 52.4 km³/year. Total volume of the river flows in Ukraine, without the river Danube during a year of average water content makes 87.1 bln. m³, where this number decreases to 55.9 bln. m³ during a low-water year. Directly on the territory of the country the average annual water flow of 52.4 and the low water flow of 29.7 bln. m³ are formed and the rest is obtained from the adjacent territories. The Danube water resources yield on average approximately 123 bln. m³ of water per year [1].

Ukraine is a water-deficient country where the value of river flow constitutes 1 thousand m³/year per person. For Canada this value is equal to 94.3 thousand m³/year and for Russia – 31 thousand m³/year, while Sweden has approximately 19.7 thousand m³/year, the USA – 7.4 thousand m³/year, Belarus – 5.7 thousand m³/year, France–3.4 thousand m³/year and Poland – 1.6 thousand m³/year.

Overall, over 63 thousand natural water bodies exist in Ukraine. Mainly, these are streams (less than 10 km long) and small rivers (up to 100 km long). There are 81 average size rivers (from 100 to 500 km), and only 9 large rivers of more than 500 km long (Dnepr, Danube, Tisa, Dnester, Yuzhniy Bug, Pripyat, Desna, Seversky Donets, Zapadniy Bug).

The rivers of Ukraine belong to two marine basins such as the Azov-Black Sea and Baltic basins, and feature essential differences in their characteristics. Almost all rivers of Ukraine are related to the Azov-Black Sea basin. Only the Syan and Zapadniy Bug rivers located to the west of Ukraine flow to the Baltic Sea. Total length of Ukrainian rivers constitutes 248 thousand km.

The basic element of enriching water balance of Ukraine is the atmospheric precipitation, which volume comprises 366–377 km³. Since the considerable amount of water is consumed by evaporation (more than 80% of water balance), about 50 km³ of water precipitates during the average year.

Condition of water ecosystems depends on the degree of anthropogenic load, which consists primarily of heavy consumption of the river flow and discharge of wastewaters of various content. Volume of water withdrawal in Ukraine is represented by the following data: from surface waters of dry land – 11.3 bln. m³, including those in the basins of the Dnepr – 60%, the Seversky Donets – 12%, the Danube – 8%, the Dnester – 5%, the Yuzhniy Bug – 3%; underground waters – 2.5 bln. m^3; sea waters – 0.9 bln. m^3. For example, water intake from the Azov Sea for the production needs of the "Azovstal" Metallurgical Plant comprises 780 mil. m^3/year.

Consumption of freshwater in Ukraine per unit of production output greatly exceeds similar indices in the developed countries of Europe. For example, consumption of France is exceeded by 2.5 times, Germany – 4.3 times and Great Britain and Sweden – by 4.2 times. Water use by Ukrainian branches of economy is distributed in the following manner: industry allocates 4.5 bln. m^3 for its purposes, municipal economy – 2.6 bln. m^3, agriculture – 1.9 bln. m^3 and irrigation – 0.9 bln. m^3. Water supply for the average consumption per person accounts for 262 l per day.

Anthropogenic contamination of water bodies originates from large amounts of untreated water released by industrial enterprises of Ukraine, as well as by sewerage networks of the cities. In Ukraine, total annual wastewater discharge to water sources comprises 8.6 bln. m^3, including contaminated waters (3.3 bln. m^3). Water used for direct consumption makes 4.3 bln. m^3. Percent of recycled water supply and recurring water supply in gross consumption volume is equal to 83%.

Water resources of Ukraine are distributed in a non-uniform manner, failing to correspond with the location of water-dependent economic complexes. The least amount of water resources is located in places where high-capacity consumers are concentrated, i.e. in Donbass, Krivoy Rog area, the Autonomous Republic of Crimea, and in the southern regions of Ukraine.

For replenishing water deficit in the regions of Ukraine, a decision was made to create a network of canals such as the North-Crimean canal – 402 km, the Dnepr-Donbass canal – 263 km, the Seversky Donets-Donbass canal – 131.6 km, the Dnepr-Krivoy Rog canal – 35.4 km and the Kakhovsky canal of 130 km long.

We have analyzed the water fund of the Priazovie territory of Ukraine, which unites the following regions: Autonomous Republic of Crimea (11.4 thousand km^2 or 25% of the area of this territory), Kherson region (8.1 thousand km^2 or 18%), Zaporozhye region (12.8 thousand km^2 or 28%), Donetsk region (11.4 thousand km^2 or 25%) and Lugansk region (1.8 thousand km^2 or 4%), including 25 administrative districts, 33 cities and towns, 121 rural settlements, and 1,600 villages. Population of this area is 5 mil. people, including 4.4 mil. citizens (88%) and 0.9 mil. rural inhabitants (22%).

4.3 Water Resource Potential of the Priazovie Territory of Ukraine

Water resource potential of the Priazovie territory of Ukraine consists of the annual river flow and aquifer reserves that are not hydraulically connected to the surface flow. During the average year the water potential constitutes 1.87 km^3.

Water bodies occupy more than 8% of the Priazovie territory. Total area of the river basins is 45.5 thousand km^2. There are 5 medium rivers (total length – 865 km), 2,213 small rivers which comprise 8.7 thousand km in total length, including

Table 4.2 Distribution of ponds and water reservoirs in river basins of the Priazovie territory of Ukraine

Regions	Ponds			Water reservoirs			
	Quantity, units	Water surface area, thousand ha	Capacity, thousand m³	Quantity, units	Water surface area, thousand ha	Capacity, mil. m³ Total	Capacity, mil. m³ Useful
Crimea	684	4.07	79.47	13	2.54	209.4	193.2
Donetsk region	343	2.45	67.20	55	6.95	374.1	329.6
Zaporozhye region	270	2.71	57.85	16	1.24	43.9	37.8
Lugansk region	43	0.45	8.79	10	0.76	22.6	19.5
Kherson region	36	1.15	17.50	3	15.23	7.8	5.5
Total	1,377	10.8	230.81	97	26.72	653.8	585.3

194 rivers of more than 10 km long (5 thousand km). Average density of the river network is 0.20 km/km² [1].

Prospective aquifer reserves are estimated as 1.05 km³/year, which makes 5% of total aquifer reserves in Ukraine. 29% of water is hydraulically connected with the surface flow and 71% is represented by waters of deep aquifers.

Water reserves are heavily utilized by such industrial complexes of Priazovie as coal industry, metallurgy, chemical industry, machine building, and useful minerals development. Every year the Ukrainian part of the Priazovie territory withdraws about 1.4 km³ of water from the natural resources for the needs of highly developed industrial-agrarian complex: 58% of the above volume is drawn from the surface sources, and 42% come from the subsurface sources. Volume of water that is discharged to the network of river basins exceeds the available water resources. Rivers of this region feature high mineralization since considerable part of the river flow is created by the mine drainage. Due to the great demand for water the river flow is heavily regulated (Table 4.2).

Considerable degree of the natural flow regulation, intensive anthropogenic load exerted onto the rivers of the Priazovie territory of Ukraine and their basins resulted in noticeable changes in the eco-hydrogeological conditions of the coastal part of the Azov Sea. The problem of preservation of the Azov Sea as a natural resource and recovery of its commercial fishing value can be achieved through restoration of the natural flow characteristics such as volume and duration.

The Azov Sea is one of the smallest seas in the world. Its area comprises approximately 37,800 km². Maximum length from the Arabatskaya Strelka Spit to the Don River delta constitutes 360 km, and maximum width between top parts of Belosaray and Temryuk Bays is 180 km. It is a shallow-water sea, with an average depth of 8.5 m, and a maximum depth of approximately 13 m. The Azov Sea volume is nearly 320 km, 1,678 times less than the Black Sea volume [2].

The Azov Sea is connected to the World Ocean through the Black Sea and Mediterranean Sea – therefore, its level is relatively constant. Maximum interval of fluctuations from the average sea level is 32 cm. The highest level of the sea is reached in June, and the lowest one can be observed in November.

Natural environment of the Azov Sea is characterized by specific conditions, which define the peculiarities of biocenoses' existence. Fish fauna of the Azov Sea includes 103 fish species and subspecies related to 76 classes and 36 families. Majority of fish species (77%) inhabit the near-bottom layers of the sea, and the rest 23% are pelagic fish [3].

Water balance of the sea is formed by the inland fresh-water flow, inflow of the Black Sea waters and Sivash waters, atmospheric precipitation, water evaporation from the sea surface and flow of Azov waters to the Sivash and the Black Sea. Total volume of water input and output estimates 82 km^3 per year. Consequently, 25% of Azov waters are replenished annually. The main share of water input falls at inland flow (43.8%), the Black Sea waters (39.2%), and atmospheric precipitation (16.6%). Regarding water output, the first place is given to Azov waters' flow into the Black Sea (55.3%), evaporation losses come second (43.0%), and the flow to the Sivash accounts for only 1.7% [4].

There are three main reasons that drive currents in the Azov Sea such as (1) the effect of winds that is applicable to the whole sea or its considerable part, (2) the compensation phenomena, which restore the normal level surface of the sea; and (3) the coastal water flow. The first factor is a decisive one since it determines both the system of currents and mean circulation of water masses. Compensating currents result from the regional wind surge phenomena, which are very important for certain areas of the sea. Effect of the coastal flow dominates only during long-term conditions with no wind or low speed of winds, or given the presence of the ice cover.

The main constant current in the Azov Sea follows a counterclockwise direction and is created by the flow of the river Don. At the same time, the constant current is often leveled by the Northeastern and Southwestern winds. In particular, this phenomenon is observed during autumn and winter seasons. Current in the Kerch strait is usually directed towards the Black Sea, since its level is somewhat lower than that of the Azov Sea. However, when wind direction varies the Black Sea current appears as well. Variability of currents is a specific feature of the Azov Sea hydro geological conditions. They arise quickly; set the entire water column into motion, which can sometimes register relatively high speeds. At the same time, these currents subside also very quickly, when the action of motion triggers (mainly, winds) is terminated.

The Azov Sea has unstable gas content conditions. Main sources that supply oxygen into the water column are photosynthesis and atmospheric aeration. The output part of the oxygen balance includes consumption of oxygen by aquatic organisms for breathing, oxidation of the organic matter and also evaporation of oxygen from the surface layers into the atmosphere [4]. The oxygen content in the Azov Sea waters is characterized by seasonal variability, which is determined by temperature and intensity of biological processes. As a rule, due to the shallowness of the water body there may be high and stable oxygen content in the water column, whereas oxygen content may vary in the near-bottom layer. During autumn, winter and spring the oxygen conditions are favorable for hydrobionts, while summer is characterized by short-time oxygen deficit that sometimes comprises as much as 75–83% of the bottom area. During the recent decade the summer periods were characterized by an increase in the areas with oxygen deficit (hypoxia), first of all due to the impact of high temperatures at which oxidation and decomposition of contaminants of organic and inorganic origin is more intense and demands more oxygen. On the other hand, occurrence of hypoxia is promoted by intensive development and decomposition of phytoplankton, decay of bottom deposits, saline and temperature stratification preventing water from mass mixing and oxygenation given low wind activity [3, 4]. Nowadays, practically every year shows signs of biota extinction in large areas in the Azov Sea, which is caused by oxygen deficit both in near-bottom layers and in the middle layers of water.

Physical and geographical location of the Azov Sea, its low volume and shallowness stipulate variability of its hydrogeological conditions, primarily salinity and degree of stratification of its water masses. Salinity of the Azov Sea is influenced by the incoming river flow and additional inflow from both the Black Sea and Sivash. The Azov Sea salinity depends on the water flow exchange through the Kerch straight. Average annual salinity of the Azov Sea before the river regulation was equal to 10.6%. Introduction of the Don River regulation in 1952 changed this value dramatically. During the spring of 1953 the salinity of the sea increased to 12.4%. Withdrawal of river water for the purposes of filling the Tsymlyansk water reservoir aligned with the period of low total humidity of the Azov basin and resulted in a high level of salination. This high salination period lasted for over 30 years. In 1976 salinity of the sea reached 14.2%. Gradual increase in total humidity of the basin resulted in overall desalination of the sea that continued for 6 years due to the full inflow of the rivers Don and Kuban. In 1982 salinity of the sea was equal to 10.0%, but in 1983 new period of the Azov Sea salination began. In 1987 the average annual salinity was equal to 11.8%. Since 1992 new desalination period for the sea began yet again and was characterized by the salinity value that decreased to the level that existed before the river control was introduced. Salinity of the Azov Sea is distributed in a non-uniform manner by the aquatic area, where its value steadily increases in percentage from the western to the eastern part.

The Don River delta is the most desalinated part, while the highest salinity values are observed in the Kerch strait. In recent years, a reduction of the Black Sea impact in the formation of salinity values of the Azov Sea was observed. Increase in the Azov Sea water salinity resulted in changing the fauna of this water body. The Black Sea species that were not previously found here populated the sea. Therefore, natural habitat of some local species was altered considerably. Such drastic changes caused overall decrease in the quality of the oxygen conditions, reduction of food supply for fish, and aggravated the conditions for reproduction of herrings, sturgeons and other fish species [5].

Hydro geological conditions of the Azov Sea are influenced by the wind. On one hand, wind activity promotes mixing of water masses and leveling of spatial and vertical gradients of salinity and temperature in the sea. On the other hand, long-term effect sometimes causes mixing of surface waters of the sea and activates water exchange through the Kerch strait. As a result, both spatial and vertical gradients of salinity and temperature increase. The key factor that determines changes in salinity and stratification of water masses is the annual flow pattern. River flow is reduced at the expense of growing consumption of water resources. River water quality is impaired because of its consequent contamination. As a result of irreversible water consumption and control of the flow, the Azov Sea ecosystem is actually functioning in average-to-low-water conditions [3]. Methods for restoration of the natural and ecological balance in both the Azov Sea and in ecosystems of the Azov Sea river basins as well as creation of the conditions for safe water use will be only possible when the overall assessment of their real ecological state is carried out. This knowledge would allow for an opportunity to perform hydro-economic and ecological zoning on the territory of the basin, to develop organizational provisions for solving the river basin problems, and to implement nature-oriented and resource-saving measures.

Currently, the list of the State normative documents that serve as the base for the legitimate assessment of the state of natural water ecosystems and anthropogenic load includes the following: Decrees of the Cabinet of Ministers of Ukraine "On Approval of Regulations on the State System of Environmental Monitoring" and "On Approval of the Procedure of the State Monitoring of Water Bodies". The State System of monitoring in Ukraine is implemented for 1,496 control points of surface waters of dry land, 96 points of seawaters and 5,907 points of underground waters.

4.4 Water Ecosystem Assessment Methods

The main drawback of the available methods for water ecosystem assessment is the lack of ecosystem approach. At present, there are methods available for anthropogenic load calculation and determination of ecological state of small river basins, which assume the basin approach and include analysis of the components described below [6] (Fig. 4.1). According to the input data for classification of the condition of the subsystem "Radioactive Pollution of the Territory", the concentrations of Cs-137, Sr-90, and Pt-239 and Pt-240 radioactive isotopes were determined.

The data presented above was acquired with the help of the informational maps of radiation pollution of the territory of Ukraine. The local executive authorities should provide the input data for evaluation of the land use close to the river basins and calculations within the subsystem "Land Use". The land audit data has to contain information about the following characteristics:

- Forest land percentage referring to the part of total area of forests, forest belts, tree and shrub vegetation within the river basin;
- Degree of natural state of the river water-shed area referring to the part of total area of lands remaining in a natural or close to a natural state (swampland, lands

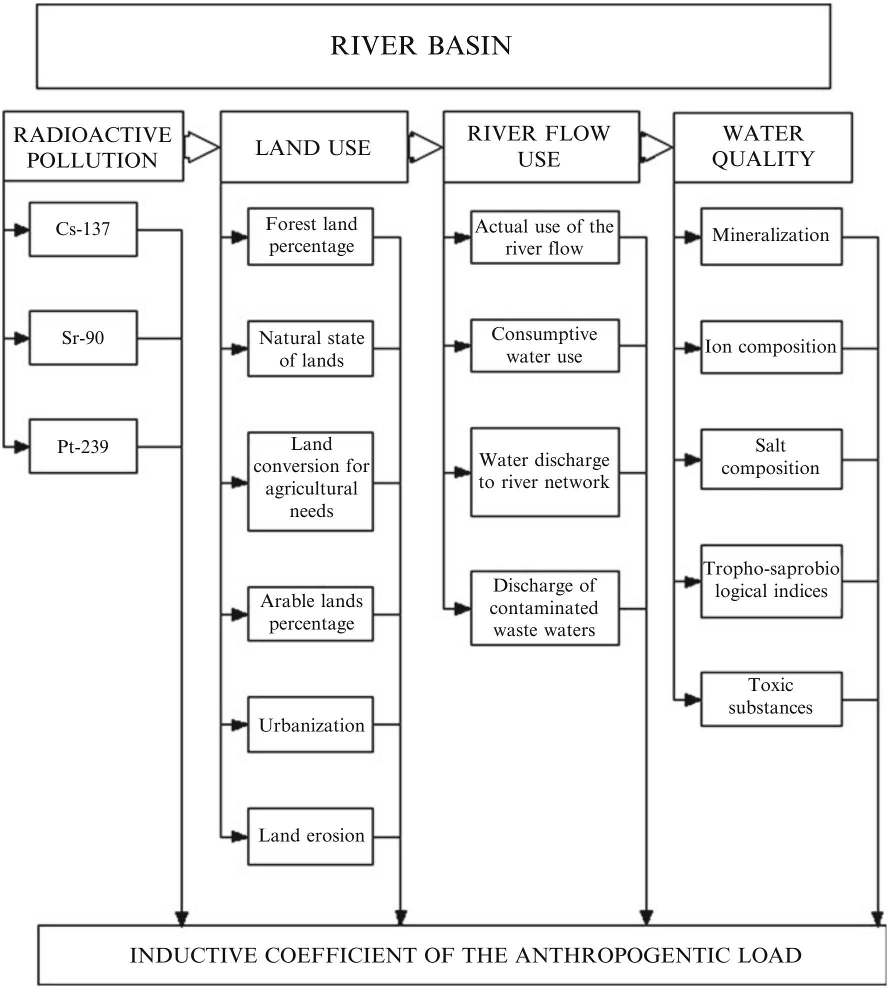

Fig. 4.1 Illustration of methods used for anthropogenic load calculation and determination of ecological state of small river basins

under water, natural forests, protective water-control plantings, conservation districts, pastures, hay-fields) within total area of the basin;

- Land conversion for agricultural needs referring to the part of all agricultural area on the territory of the basin (arable land, perennial plants, garden plots) within the total area of the basin;
- Arable land percentage referring to the part of total area of arable land and gardens within the total area of the basin;
- Urbanization referring to the part of total area of lands occupied by cities, objects of industry, transport and communication within total area of the basin;
- Land erosion referring to the value of soil loss per year in the river basin.

Table 4.3 Evaluation of the anthropogenic load exerted onto water ecosystem of the Karatysh river

Index	Condition
Radioactive pollution	
Cs-137 Ki/km²	0.3 – within normal limits
Sr-90 Ki/km²	0.01 – within normal limits
Pt-239 Ki/km²	0.005 – within normal limits
River basin land use	
Forest land percentage, % of the basin area	5.3 – significant
Land conversion for agricultural needs, % of the basin area	86.8 – significant
Lands occupied by natural ecosystems, % of the basin area	23.2 – significant
Arable lands percentage, % of the basin area	71.0 – significant
Urbanization, % of the basin area	2.3 – very low
Soil erosion, t/ha per year	15 – significant
River flow use	
Actual use of the river flow, %	16.8 – significant
Consumptive water use of the river flow, %	16.8 – above normal limit
Water discharge to river network, %	0.1 – insignificant
Contaminated waste water discharge to river network, %	0.01 – insignificant
Water quality*	
Total mineralization, mg/l	2,352
Mineral compounds of nitrogen, MPC excess	34 MPC
Petroleum products, MPC excess	1–7 MPC
Zinc MPC excess	1–7 MPC
Phenol MPC excess	1–3 MPC

*The indices featuring excess of values of minimum permissible concentrations, of all the required indices characterizing water quality, are included only

The input data used for determining the degree of river flow use in the river basin under the subsystem "River Flow Use" include: index of real use of the river flow, index of consumption of the river flow; index of water discharge to river network and index of contaminated waste water discharge to river network. The set of indices for determining the class and quality category of surface waters includes general and specific indices that are grouped according to the following three blocks:

- Salt composition indices: concentration of chlorides, sulfates, calcium, magnesium;
- Block of tropho-saprobiological (eco-sanitary) indices: suspended matter, transparency, pH, ammonium nitrogen, nitrate nitrogen, nitrite nitrogen, phosphorus of phosphates, dissolved oxygen, biochemical consumption of oxygen;
- Indices of content of specific toxic substances: concentration of copper, zinc, chromium, iron, manganese, petroleum products, phenols, synthetic surfactants.

We have analyzed all characteristics and indices for evaluation of the anthropogenic load and assessment of the ecological state of the basin of the Karatysh river relating to the Azov Sea basin, which flows on the territory of Donetsk and Zaporozhye regions of Ukraine (Table 4.3).

The Karatysh river is a typical representative of small rivers and is characterized by the indices listed below: length – 41 km; area of the basin – 458 km²; river gradient 5,4 m/km. The river valley up to 3 km wide is of a trapezoid shape; flood plain is of low significance. The river channel is moderately twisted of up to 5 m wide. Surface waters of the Karatysh river are used for technical water supply and irrigation. Therefore, upon the assessment and analysis of characteristics of the basin of the Karatysh river, which relates to the Azov Sea basin, we may draw the conclusion that the ecological state of the given water ecosystem can be characterized as unsatisfactory with a considerable level of impact of the anthropogenic load. Thus, this condition stipulates the necessity to produce immediate management decisions aimed at stabilization of the ecosystem state and neutralization of the consequences of the anthropogenic load exerted on the ecosystem.

4.5 Conclusions

The system analysis of the current environmental situation of the Ukrainian river basins, development of the methods for evaluating the anthropogenic load and establishment of the efficient system for controlling protection and use of water resources should become the most important issues on the state water policy agenda.

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Chapter 5
Multipurpose Water Scheme Assessment of the Tsimlyansk Reservoir

Elena Shavrak, Lev Fesenko, Irina Generalenko, and Nataliya Ilyashenko

Abstract This paper presents a comprehensive research of the processes and activities associated with the Tsimlyansk reservoir multipurpose water scheme. Both quantitative and qualitative assessment of the reservoir has been performed using the data obtained in order to secure research quality. Based on water silt characteristics we assessed possible operation time of the Tsimlyansk reservoir. In attempt to analyze water balance of this reservoir we managed to integrate a set of changes into the processes of water resource formation and its exploitation. This report presents composite index results of reservoir water pollution for the period 2000–2009. Additionally, this assessment investigates the influence of the various reservoir processes on the water quality. Based on the analysis of results we identified the preconditions for sustainable development of multipurpose water scheme of the Tsimlyansk reservoir together with the coefficients that could reduce the intensity of siltation process.

Keywords Tsimlyansk reservoir • Siltation • River Don

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5.1 Introduction

Artificial reservoirs are an important part of the Russian water resources due to uneven water availability across the country. There are more than 2,000 reservoirs in the Russian Federation with approximately 109 water bodies with the total volume equal to 760 km^3 [1]. The Tsimlyansk reservoir belongs to these large reservoirs. Its construction was completed in 1952 in the middle course of the River Don [2].

The Tsimlyansk reservoir is shared by the Rostov and Volgograd regions. The main purpose of reservoir construction was to secure navigation and deep-water thoroughfare between the Volga River and the Azov Sea. Traffic intensity through the Volgo-Don canal significantly increases every year. For example, in the year 2000 5,022 ships passed through the Tsimlyansk reservoir, whereas it was 6,799 ships in 2007. About half of all ships passing through the reservoir are oil tankers. Reservoir territory hosts around 457.5 thousand people, approximately 156.8 thousand hectares of farmlands and 37.2 ha of forests [1, 3]. The banks of the reservoir host well-developed infrastructure that consists of numerous economic objects such as Rostov nuclear power plant (RNPP), the Tsimlyansk hydro power plant, the ports of Volgodonsk and Kalach on Don, tank farms, fish factories, fishing companies, hunting farms and wildlife sanctuaries.

At the moment public interest towards this region is growing due to the recreation potential of the Tsimlyansk reservoir. There are more than 50 sanatoriums and recreation centers in the neighborhood of Volgodonsk and Tsimlyansk, where more than 10,000 people enjoy recreational services every year [3].

Morphological characteristics of the Tsimlyansk reservoir underwent many changes through time due to the operation of the multipurpose water scheme infrastructure that was built next to the reservoir and has been functioning for approximately 57 years.

This assessment characterizes this multipurpose water scheme of the Tsimlyansk reservoir and analyzes the background of its development.

Water supply of the local town and surrounding villages is the primary concern for the Tsimlyansk multipurpose water scheme. Annually 30–40 million m^3 of water are extracted for these purposes. Water supply is characterized by high provision and significant amount of the irrecoverable water withdrawal (about 3.4% from the total water supply point [1]). Irrigation purposes are an important part of the water use of the Tsimlyansk reservoir. Key irrigated lands comprise about 323 thousands ha and are situated on the Lower Don River in Rostov region. The volume of water used for the irrigation purposes usually constitutes around 2 km^3 per year. The regional energy infrastructure is represented by the Tsimlyansk hydro power plant (204 MW) and the Rostov (Volgodonsk) nuclear power plant (RNPP), which began to generate electricity in 2001. Currently, 2 power blocks (with 2,000 MW) operate on RNPP and additional 2 power blocks are under construction. Water reservoir cooler (WRC) with the area of 18 km^2 is activated by the circulating water system of NPP. The nuclear power plant was installed on the bank of the Tsimlyansk reservoir. A water reservoir cooler is constantly pumped by water motion into the power

Table 5.1 Main sections of the multipurpose water scheme (MWS) of the Tsimlyansk reservoir

Sections of MWS of TR	Water consumption, million m³/year						
	1988	2003	2005	2006	2007	2008	2009
Municipal needs	68	62	33	32	31	36	31
Irrigation	2,370	1,925	1,622	1,923	1,923	1,850	1,800
Hydro power	11,245	14,798	18,653	12,051	12,051	12,051	10,443
Nuclear power	–	28	32	36	39	27	33

plant in order to support its cooling needs. An average injection consists of 38.78 million m³ [3] of water given the NPP power of 2,000 MW.

The data presented in Table 5.1 represents the scale and production dynamics associated with the main sections of the multipurpose water scheme of the Tsimlyansk reservoir (TR).

Recently, the amount of water allocated for engineering and irrigation purposes has been declined. Municipal services focused on reducing both industrial and farmland production and boosted their control over the water consumption patterns. In contrast, we can see a steady development of the nuclear power. Due to the climatic conditions and river flow, we can monitor annual changes in water consumption patterns [1].

The future pattern of the Tsimlyansk reservoir water use is determined by a complex set of factors. It is crucial to make an assessment of the possible operation time for the Tsimlyansk reservoir. We will be able to identify both quantitative and qualitative indicators for the water source characteristics.

5.2 Estimating Operation Time for the Tsimlyansk Reservoir

As the main criteria for establishing potential exploitation period of the reservoir we analyzed the characteristics of the silting factors and the so-called reservoir's "dead volume". The state authority responsible for the regulation of the Tsimlyansk reservoir water management strategy clarified the volume of silt which comprised 0.822*109 m³. Additionally, as the state provided values for full and useful capacities of the reservoir together with its overall area that constituted 22.97*109 m³, 11.54*109 m³ and 2,624 km² respectively. Based on this information we calculated the siltation speed and also the time projection for the sediment to fill both the entire reservoir and it's the dead volume.

On average about 15.8 million m³ of mud accumulated annually at the reservoir bottom. If we assume that the silt deposited annually at an even rate we can calculate that the average deposition speed was approximately 6 mm³ of mud per m² per year. Given this speed, we can estimate that the difficulties associated with the water intake should be expected within the foreseeable future. It is necessary to underline that the siltation happens in an uneven fashion. We established the average speed of this process, the approximate height of the siltation and also the degree to which silt is expected to accumulate in different reservoir sections (Table 5.2).

Table 5.2 The silting characteristics of the Tsimlyansk reservoir

Reservoir section	Area km²	Siltation million m³	Siltation rate mm³/m²/year	Siltation deposits, m	Section depth, m	Section siltation, %
Upper	304	100	6	0.330	4.5	7
Chirskoy	400	150	7	0.375	6.0	6
Central	1,040	212	4	0.204	8.8	2
Priplotinnaya	880	360	8	0.410	12.2	3

The silting process of the Chirskoy and Priplotinnaya (near the dam) sections of the reservoir is twice more intense than the analogous process observed in the Central section. In some places of the Priplotinnaya section we observed an increase in the sediment layer from 2 to 4 m high which led to the consequent siltation of the usable part of the Tsimlyansk reservoir. The main factors responsible for such phenomenon are the specific features of various water processes.

Thus, we can conclude that the reservoir might exhaust its water reserves for the anthropogenic use in not so distant future. Due to the uneven distribution of siltation process, nowadays there is a necessity to mechanically remove the bottom sediment. The primary target that has an urgent need for these drastic measures is the Priplotinnaya section of the Tsimlyansk reservoir.

5.3 Qualitative Characteristics of the Water Sources

The usable reservoir volume currently constitutes 11.54 km³. Water volume located between the levels of 36.0 and 33.5 m (total volume 6.27 km³) is required for the seasonal control regulation and is annually restored in spring. The lower part of the prism control (between levels 33.5 and 31.0 m and volume of 5.27 km³) is considered a reserve stock which is used for supporting water consumption during water-deficient years [1].

The dynamics of reservoir's water quantitative indicators is determined by the water exchange between the reservoir and the atmosphere. The Tsimlyansk reservoir belongs to the continental climate zone that is characterized by hot and arid summers with low rainfall [2]. That is why the volume of the reservoir water depends on both climatic conditions and inflow of the Don River to the Tsimlyansk reservoir. Table 5.3 shows the averaged value of the Don River flow into the reservoir and the air temperature in the Priplotinnaya section of the Tsimlyansk reservoir. For the last 25 years the average annual air temperature increased by 1.7°C or by 20%. Given these conditions we should expect an increase in the overall water loss due to the increased evaporation process.

The water balance that shows changes in water inflow and withdrawal for the last several years is demonstrated in Table 5.4. The balance analysis allows drawing several conclusions which are:

- Waste discharge to the reservoir decreased in volume and diversion capacity for irrigation and drinking was reduced. These changes were triggered by the

Table 5.3 The average Don inflow and the air temperature (the Priplotinnaya section of the Tsimlyansk reservoir) calculated for different periods

Period	The Don inflow, km³/year	Average annual air temperature, °C
1967–1972	15.6	9.0
1973–1978	14.3	8.7
1979–1984	18.8	9.4
1985–1990	17.1	8.8
2002–2009	18.6	10.5

Table 5.4 Water balance of the Tsimlyansk reservoir (million m^3)

	1988	2007	2008	2009
Inflow				
Total increment to the reservoir, including surface precipitation	19,348	17,661	18,560	13,220
Water intake with sediment removal	21	15	4	3
Total inflow after sediment removal	19,369	17,676	18,564	13,223
Withdrawal				
Evaporation	1,648	2,457	1,718	1,835
Evaporation, % from inflow	9	14	4	14
Filtration through dam	950	943	943	839
Drinking purposes	68	36	32	35
Irrigation	2,370	1,885	1,850	1,800
Nuclear power energy generation	–	39	27	33
Water transport	555	500	502	498
Hydro power energy generation	11,245	12,051	13,135	10,442
Total withdrawal	16,836	17,899	16,777	15,507
Accumulation	2,527	–235	347	–2,284

structural reorganization of the multipurpose water scheme of the Tsimlyansk reservoir and regulation of the water consumption.

- Water loss through evaporation constituted 11% of water input from 1953 until 1987. During the observed period (2000–2009) water loss through evaporation repeatedly increased up to 14%. Together with the low water supply of the region and the location of the Tsimlyansk reservoir [2], this observation indicates a potential for destabilizing the water balance of the Tsimlyansk reservoir.

5.4 Water Grade Estimation

It is imperative to have the appropriate quality of water supply in order to allow for the uninterrupted and effective functioning of the multipurpose water scheme. In order to maintain and assess the water quality, water indicator named specific combined water pollution index (SCWP) is used in this research.

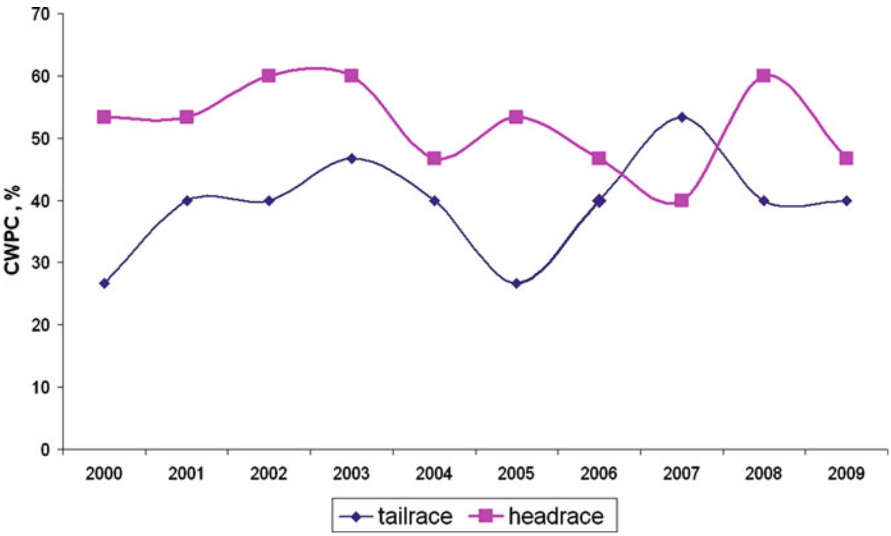

Fig. 5.1 Changing dynamics of CWPC. *1* – headrace, *2* – tailrace

We analyzed the water monitoring database which was constructed by the Federal Government Agency «Tsimlyansk Reservoir Water Management» for the period of 2000–2009. This Agency provided a specific list of 15 substances that are characteristic for the water surface pollution on the entire territory of the Russian Federation: dissolved oxygen, phenols, mineral oil, nitrites, nitrates, ammonium nitrogen, phosphates, chlorides, sulfates, iron, copper, zinc, manganese and nickel.

Additionally, we performed a preliminary water quality assessment by taking into account the coefficient of water pollution complexity (CWPC), which is a trustworthy assessment of the anthropogenic load and is widely used by RosHydromed. CWPC is described in percentage and changes from 1% to 100% according to the gradual decrease in water quality. Increase in CWPC indicates contamination of the analyzed reservoir with new pollutants.

Figure 5.1 demonstrates the change in dynamics of CWPC for the headrace and tailrace of the Tsimlyansk reservoir for the last 10 years.

According to 10 years of observation the CWPC changes within the range of 25–60%. Figure 5.1 indicates a dynamically changing contamination complexity. Contamination is characterized by 9 substances such as iron, copper, manganese, nitrite and ammonium nitrogen, phosphates, sulfates and different organic compounds. It should be noted that for the 9 out of 10 years the CWPC in the tailrace was lower than in headrace. Potentially this finding points to the natural self-purification capacity of water. Yet it is imperative to realize that the anthropogenic load cannot be completely neutralized by the natural purification.

We calculated a relative complexity exponent of the specific combined water pollution index (SCWP) in order to establish water quality category according to [1]. This exponent aims to estimate the pollution effect of one substance of interest that

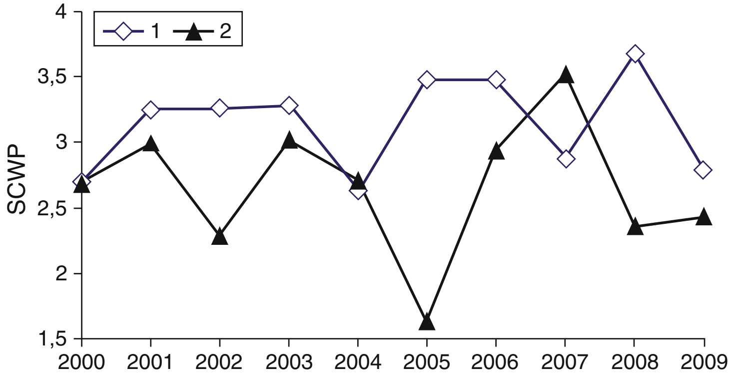

Fig. 5.2 The changing dynamics of SCWP: *1* – head water, *2* – tail water

was selected from the other compounds. Calculation of this exponent allows us to take into account repetitive cases of increased maximum permissible concentration (MPC) and high pollution values for all substances of the scheme. Thus, we are able to test critical substances that significantly contribute to the degradation of water quality.

Figure 5.2 demonstrates changing dynamics of SCWP for headrace and tailrace of the Tsimlyansk reservoir for the last 10 years.

According to [1] water pollution of the Tsimlyansk reservoir could be referred to as the third class of contamination for the whole observation period. The dynamics of the SCWP together with the CWPC indicators (Fig. 5.1) show the process of natural self-purification of water. The quantitative water pollution concentrations in tailrace for 9 out of 10 years are less or equal to the ones in the headrace. There is one critical ingredient found throughout the entire Tsimlyansk reservoir that keeps the level of contamination high – Manganese. The concentration of Manganese in tailrace was 2–5 times higher than the MPC for the period of 2000–2009; the MPC values were detected in more than half out of the entire set of calculations.

Hence, the conducted water quality analysis indicated that the steady level of high pollution caused by various important compounds such as Manganese is characteristic for the Tsimlyansk reservoir. The multipurpose water scheme influences the overall water quality, especially the river characteristics. Results presented in Figs. 5.1 and 5.2 indicate the efficiency of the water natural self-purification process on the territory of the Tsimlyansk reservoir.

5.5 Conclusions

Given the assessed issues of using the water resource of the Tsimlyansk reservoir, we established not only the preconditions for the sustainable development of the multipurpose water scheme of the Tsimlyansk reservoir but also the factors that decrease the possibility of the siltation process. Analysis of the Tsimlyansk reservoir functional characteristics for the years 2000–2009 allows us to conclude the following:

- Tsimlyansk reservoir will still be able to satisfy anthropogenic needs for several generations; this timeframe was forecasted based on the calculation of the average siltation speed;
- As a result of the enhanced regulation practices, we observed a decrease in waste discharge into the reservoir.

The effectiveness of water natural self-purification process ensures the improvement of the water quality in the tailrace of the Tsimlyansk reservoir in comparison with the headrace.

It is also imperative to account for all the negative factors that interfere with the development perspectives of the multipurpose water scheme of the Tsimlyansk reservoir, such as:

- Partial siltation of the usable capacity of the Tsimlyansk reservoir of the Priplotinnaya section that endangers traffic routes and fish farming;
- Increase in the water loss due to evaporation creates an issue for the water balance of the Tsimlyansk reservoir;
- Steady level of increased reservoir water pollution by various compounds such as heavy metals, specifically Manganese.

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Part II
The Black Sea Experience

Chapter 6
Black Sea Environmental Status Improvement Through the Restoration of Wetlands Along the Danube River

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Abstract The Black Sea is heavily impacted by human activities, and a large contribution is made by the rivers. The Danube River provides almost 70% of the river inflow to the Black Sea and changes within the river basin are having an important contribution to the status of the sea. The once extensive floodplain of the Danube was severely diminished during the last two centuries. The Danube Delta is the largest wetland left along the Danube and acts as a buffer zone between the river basin and the sea, regulating the sediment and water transfer. The river, delta and marine basin function as a single geosystem. Restoration of the former wetlands will improve the quality of the aquatic resources, both freshwater and marine. Re-establishing the hydrological dynamics and connectivity is essential, since all other processes are influenced by the flow regime. The restored wetlands along the Danube floodplain and delta will then limit the carrier effect of the river and reduce the load of pollutants and nutrients transported to the sea.

Keywords Wetlands • Black Sea • Danube • Ecosystem improvement • Restoration • Impact

6.1 Introduction

Humanity has a long history of mismanaging aquatic systems throughout the world, be it marine or freshwater. While many issues related to water shortages, deterioration, overexploitation and overall decrease in the quality and quantity of goods and

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services provided seem local, they are in fact global in scale [21]. Improving the management of aquatic resources requires understanding and accepting the complexity of the processes involved and their different time-space scales. Already large scale approaches are being implemented in water management: the integrated river basin management, based on the ecosystem approach developed under the Convention on Biological Diversity, and the regional seas programme of the United Nations Environment Programme (UNEP). For example the European Union (EU) has implemented the river basin management concept since 2000, within the EU Water Framework Directive. River basin and regional seas management approaches are an important step towards achieving proper us and status of aquatic resources. The river with its unidirectional flow connects even remote areas within the river basin with the sea and acts as a carrier for the outputs of most human activities (e.g. pollutants). Water discharge is the main factor controlling matter transfer from land to sea by rivers. These river basin-sea interactions require a large time-scale conceptual framework in planning and management.

One of the best examples documenting the impact of rivers on the coastal areas is represented by the Black Sea basin and its main tributary, the river Danube. The Black Sea was less than two decades ago considered a major environmental disaster [13], and this has triggered extensive studies and management and conservation measures. This included signing in 1992 the Convention on the Protection of the Black Sea against Pollution (Bucharest Convention). In a similar way, the Danube River benefited from a major regional conservation approach, the International Commission for the Protection of the Danube River (ICPDR). While both initiatives are encouraging, proper management requires a combined approach for the Danube River and Black Sea. In this chapter I will briefly discuss the need for a joint management program for the Danube River and Black Sea, and how restoring the functions of the wetlands associated with the floodplain helps to improve the status of the sea.

6.2 The Black Sea

The Black Sea is the largest land-locked sea, connected to the Marmara Sea by a narrow strait 35 km long, the Bosporus. There are three major parameters that characterize an enclosed sea: (1) the water budget, (2) the water retention time, and (3) the load of contaminants. The general nature of the enclosed seas depends on the water budget, i.e. the outputs of freshwater through evaporation versus the inputs from rain and runoff from land. If the evaporation rate is higher than the input, the surface waters become denser and sink, resulting in considerable vertical mixing of the water and in oxygen transport towards the deeper water bodies (e.g. the Mediterranean Sea). When freshwater inputs exceed evaporation the lighter water bodies remain floating over the higher density water bodies. Oxygen is not replenished and becomes depleted or even absent in the deeper parts. This is the case of the Black Sea that receives more freshwater than is lost through evaporation resulting in a positive budget. The differences in the density of water bodies results in a highly stratified water column that causes steep physical and chemical gradients. Thus, the largest proportion of the Black Sea waters (87%) lack dissolved oxygen [15].

The water retention time refers to the time period required to replace completely the water from a water body, as the sum of the inputs and outputs. The retention time is of major importance in how contaminants are retained or accumulated in the water body. If the retention time is short, contaminants do not accumulate, while for high retention time the load of contaminants can become significant. Of equal importance in estimating the water quality and impact of pollution is the load of contaminants. This parameter is influence by both the amount (i.e. contaminant load) and the persistence and toxicity of each compound. The total amount of contaminants entering a sea depends on the population size within its catchment, on the industrial and agricultural development, and on the level of treatment of wastewater treatment. The Black Sea has a huge drainage basin of 2,405,000 km^2 that includes parts of 21 countries, with over 170 million inhabitants. This means that the load of contaminants reaching the sea is extremely high. The ration between the sea surface and drainage basin is about 1:6, indicating that each square km of sea drains 6 km^2 of land, indicating a major contribution of surrounding ecosystems.

The Black Sea suffered numerous changes in size, salinity, and connectivity during the geological periods: initially it was an arm of the ocean, then part of a large inland sea, it then almost dried out and after being refilled became a deep freshwater lake [10]. During the last Ice Age it was a shallower freshwater lake until the rising ocean level reconnected it through the Marmara Sea to the Mediterranean and then to the Atlantic Ocean. There are still debates regarding the timing and way the connection was made. The gradual inflow model suggests that the first connection was made about 9,000 years ago, with the depth of the Bosporus Strait deepening slowly, causing an increased exchange of water with the Black Sea that gradually became brackish [27]. The catastrophic flood model states that about 7,160 years ago the connection was abruptly made and water from the Marmara flooded the present day Black Sea basin [28]. The reconnection of the Black Sea to the ocean triggered both an increase in the sea level and an increase in salinity that reached rapidly the present concentration of 18–22‰, making it a brackish sea, well below the ocean salinity level of 35%.

Presently the Black Sea (excluding the Azov Sea) covers an area of 436,400 km^2, has a water volume of 547,000 km^3 and a maximal depth of 2,212 m. After the initial increase in salinity, it achieved the mineral budget equilibrium about 1,000 years ago and natural changes still take place. Therefore it is difficult to separate natural processes from man-induced ones.

The Black Sea is heavily impacted by human activities that resulted in heavy pollution and eutrophication [16], overexploitation of fish stocks, introduction of alien species [8], coastal wetland destruction and coastal erosion and the subsequent coastal engineering works [34], off-shore oil and gas production [26]. High levels of riverine nutrient input during the 1970s and 1980s caused eutrophic conditions in nearby coastal areas. This in turn triggered frequent and intensive algal blooms resulting in hypoxia and the subsequent collapse of benthic habitats on the northwestern shelf [16]. Coastal areas are one of the most important and valuable areas from a human perspective. They provide nonrenewable (e.g. oil, gas, sand, gravel) and renewable resources (e.g. food and animal feed, raw materials for pharmaceutical industry), transportation, waste disposal and recreation. Coastal erosion and degradation require extensive restoration measures, usually at high costs [14, 34].

Some of the human-induced impacts are related to marine shipping and coastal development, but others are carried by rivers (e.g. pollutants and nutrients). Thus changes within the river basin are having an important contribution to the status of the sea. My focus will be on the Danube River which provides almost 70% of the river inflow to the Black Sea [11].

6.3 The Danube River

The Danube River is the second largest European river after the Volga. It is 2,860 km long and has a drainage basin of 801,500 km^2 that includes territories of 19 countries, with more than 83 million inhabitants. The average water flow of the river upstream the delta is 6,300 m^3/s, ranging between extreme values of 1,500 and 19,000 m^3/s. The Danube, unlike the other European rivers, is only slightly developed, especially downstream Vienna (Austria). This constitutes one of the river's most valuable assets.

Humans have always settled along large rivers that provided water, food, shelter, construction materials and a transportation route. For centuries humans attempted to control flood levels and erosion to protect their settlements and agriculture fields [9]. Impacts along river banks are old and huge transformations occurred along the Danube River.

Draining a territory almost twice the Black Sea area, the Danube River is the most important sediment provider of the sea, its influence extending down to the deep sea floor [25]. The freshwater input of the Danube River and its associated contaminants are transported by gyres throughout the Black Sea. Thus the river acts as a "carrier" of human impacts over large distances, finally impacting the sea.

The connectivity of the Danube River and its tributaries was disrupted by more than 500 larger dams and reservoirs with a capacity over five million m^3 [23]. In the nineteenth century before the major rectification and dam building started along the Danube and its main tributaries, the river carried an estimated 65 million tons of sediments per year, of which almost 5 million tons (7.5%) were retained in the delta [4]. After the construction of the Iron Gates dam was completed in 1971, sediment discharges diminished by 30–40% [24], creating a sedimentary deficit in the littoral zone. Combined with the extended damming and rectification works along the Danube and its tributaries, the sediment load transported and reaching the Black Sea littoral zone was reduced to 38 million tons (58%) [24]. These changes affected not only the amount but also the quality of the sediments, with average sediment size shifting from large to small sized particles [4]. The construction of the Iron Gate Dam also contributed to a reduction in the dissolved silicate load of the river by 2/3.

This caused a similar decrease in wintertime dissolved silicate in central Black Sea surface waters [11]. Due to the gentle slope of the lower floodplain of the Danube, the construction of dams below the city of Turnu Măgurele is not possible, thus at least 850 km (30%) are free flowing, but still impacted by levees and draining of associated wetlands. Over the 1960–2000 periods, river freshwater discharge to the Black Sea remained more or less constant [18].

Floodplain Rivers are non-equilibrium systems, depending on the shifts in water level. Their ecological integrity depends upon a certain level of disturbance. Flood events are vital in shaping and maintaining the complex landscape structure of terrestrial, aquatic and semi-aquatic ecosystems [33]. The hydrological connectivity facilitates the exchange of matter and energy between different landscape elements and promotes the functioning of the system. In addition, the floodplain provide shelter for the biota during harsh conditions (e.g. drought, pollution events, high floods) while riparian corridors play a key role in facilitating migration [17].

The Danube had a large floodplain that expands into a delta before reaching the Black Sea. The large floodplain of the Danube provided a huge water storage capacity in the associated wetlands, where water was retained during high floods and slowly released afterwards. The associated wetlands also ensured water purification, sediment and pollutant trapping, greatly improving the quality of water that reached the Black Sea. Almost two centuries of channelization, damming, confining by levees and draining of associated wetlands have severely diminished it. Presently most of the length of the main stem of the Danube River and the major tributaries are confined by flood control dikes [23]. For example, over the past 50 years more than 90% of the Upper Danube and its major tributaries have been dammed for hydropower production [29]. Thus there are virtually no free-flowing sections left upstream Vienna [29]. Only during the last 50 years the natural alluvial flood plain areas have declined from about 26,000 km^2 to a mere 6,000 km^2 (about 23%) [23]. This has resulted in a severe reduction in surface connectivity and the fragmentation of the once continuous riparian and floodplain ecosystems (Table 6.1). At present, later exchange processes of matter are restricted to short-term flood pulses, while most of the year backwater processes are disconnected from the river system [33]. The reduction of wetlands associated to the floodplain coupled with an increase in the load, diversity and toxicity of pollutants, resulted in an additional impact for the Black Sea already affected by coastal, shipping and off-shore activities.

6.4 Danube Delta

The Danube Delta is one of the main components of the Danube River system and is of recent origin, perhaps less than 7,000 years ago, starting after the reconnection of the Black Sea to the ocean. Its genesis and later rapid expansion are due to the low tidal oscillation of the Black Sea (5–7 cm), the large and shallow continental platform, the strong North-South littoral current and the high sediment load transported by the Danube. The delta was described as diverse, dynamic and fragile [2].

Table 6.1 Major human activities and impacts in the Danube river floodplain

	Type of activity	Purpose	Impact	Ecological services lost or diminished
1	Wetland drainage	Agriculture and urban development	Destruction of wetlands and fragmentation of floodplain connectivity	Sediment retention Water storage Maintaining high biodiversity Nutrient retention and cycling Pollutants retention and breakdown Climate regulation Recreational and aesthetic
2	Dykes	Protecting localities and economic activities from floods	Isolation and fragmentation of wetlands associated with the floodplain	Sediment retention Water storage Maintaining high biodiversity Nutrient retention and cycling
3	Channelization	Navigation, flood control, erosion prevention, infrastructure	Disrupts the floodplain structure and destroys the riparian habitats	Diffuse pollution control by riparian vegetation Maintaining high biodiversity Water storage
4	Dam construction	Water supply and hydroelectric power	Creation of reservoir disrupts the connectivity of the river and limits dispersal of biota	Sediment transport Maintaining high biodiversity
5	Water abstraction	Water for domestic, industrial or agricultural use	Decrease in water flow and floodplain water table, increased salinity at sea level	Biological productivity of aquatic habitats Aquifer recharge
6	Dredging	Gravel and sand extraction, facilitating navigation	Bank instability, increased erosion and water flow	Sediment retention Maintaining high biodiversity
7	Fishing, forestry and reed harvesting	Food and animal feed, wood and timber, construction materials	Decrease in biodiversity, overexploitation	Maintaining high biodiversity Carbon sequestration
8	Introduction of alien species	Improve yields in fisheries and forestry	Decrease in biodiversity	Maintaining high biodiversity

Adapted after Mant and Janes [19]

Activities 1–3 cause deterioration, destruction and fragmentation of natural habitats, while activities 4–8 represent exploitation of natural renewable resources

It is a disturbance-dominated system, with seasonal floods covering large areas within the delta and controlling most of its processes and functions. The delta has a typical triangular shape, having 65–85 km from the apex to the coast, and is up to 70 km wide between the branches. There are about 3,500 km of natural channels and artificial canals, connecting more than 450 lakes.

The Danube Delta represents the interface between the Danube River Basin and the Black Sea and acts as a buffer area by regulating the water and sediment transfer. These three factors combined: river, delta and marine basin function as a single geosystem [25]. The delta has an area of 5,500 km^2 that represents only 0.67% of the Danube River Basin and only 1.2% of the Black Sea area. The delta fulfills a number of important ecological services: hydrological, biological productivity, high biodiversity, ethno-cultural diversity, tourism and recreation. With regards to the Black Sea the delta provides important ecological services by purifying, detoxifying and overall improving the quality of the Danube waters reaching the sea.

6.4.1 Human Impact in Time

For over 150 years the Danube Commission has supervised, regulated and controlled navigation. In the nineteenth century, the Danube Commission dredged and enlarged the Sulina arm for navigation. At the beginning of last century two canals were dredged to increase the influx of freshwater in the Razelm lagoon. Later, during 1938–1940 3,400 ha of Tataru Island were dyked and in the early 1950, the industrial exploitation of reed was started. During 1983–1989 the most complex and destructive activities in the delta started under the "Programme for the remodeling and integral use of the natural resources in the Danube Delta". The Danube Delta was affected by increased pollution and accelerated eutrophication, habitat destruction due to hydro-engineering works that decreased the ecotonal areas along the river branches and channel banks, overfishing, and introduction of alien species. The dyked areas represented 97,408 ha, of which 39,974 were drained for agriculture [31]. These negative effects were amplified by the destruction of almost 450,000 ha of wetlands associated to the floodplain upstream the delta of a total floodplain area of 540,000 in Romania only [30]. Hydro-engineering works also impacted water flow throughout the delta. The total length of the channels doubled as a result of hydrotechnical works from 1,743 to 3,496 km [7], causing an increase in the discharge of the river from an estimated 167 m^3/s before 1900 to 620 m^3/s in 1989 [3]. This induced the siltation of lakes and accelerated eutrophication. Thus the ability of the delta to cope with the increasing load of contaminants was severely diminished by the huge engineering works. The Danube Delta is divided between Romania (80%) and Ukraine (20%). The cooperation between the two countries for the proper management of the delta and nearby coastal areas are hindered by a conflict over territorial water delimitation around the Snake Island, and the alleged environmental impacts of the construction of the Bastroe canal by Ukraine.

6.4.2 Wetland Restoration

Wetlands and coastal areas are some of the most valuable ecosystem types of the world [6], with estuaries valued at 22,832\$ ha^{-1} $year^{-1}$, followed by wetlands with 14,785\$ ha^{-1} $year^{-1}$, lakes and rivers with 8,498\$ ha^{-1} $year^{-1}$ and coastal areas 4.052\$ ha^{-1} $year^{-1}$. For comparison grasslands were valued at only 232\$ ha^{-1} $year^{-1}$. The value of a wetland varies largely and one of the important parameters that must be accounted for is the hydrogeomorphic location, with connected wetlands having higher values than isolated ones [22].

In the past, the wetlands associated with the Danube floodplain including the delta contributed to the improvement of water quality. To improve the status of the Black Sea, restoration of the wetlands upstream and within the delta is needed. Restoring wetlands along the Danube floodplain and delta will limit the "carrier effect" of the river. The necessity and feasibility of different restoration projects are considered for different former wetlands (e.g. [5, 12, 29, 32, 33]). Re-establishing the hydrological dynamics and connectivity is considered the most important step, since all other processes are influenced by the flow regime [33].

After 1990, several major restoration projects were started in the Danube Delta, promoting the restoration of wetlands dyked and dammed in the past: Babina, 2,100 ha (polder for agriculture), Cernovca, 1,580 ha (polder for agriculture), Holbina-Dunavat, 5,630 ha (ponds for fish farming), Fortuna, 2,115 ha (polder for agriculture/forestry), Popina, 3,600 ha (ponds for fish farming) [31]. Most of the restoration activities were focused on reconnecting the area to the river by rehabilitating the hydrological system. This in turns allows the rehabilitation of the transformed ecosystems and the reintegration into the complex natural landscape. The restoration of the natural resources and ecological functions should enable the local populations to proceed to their traditional and sustainable use. Restored wetlands have generated important direct economic benefits, resulting in higher yields of fish, reed, medicinal plants and increased value for tourism [30].

The economic collapse of the former Socialist countries followed by improved wastewater management, and the recent restoration of wetlands has lead to a decrease in the loads of pollutants and nutrients entering the Black Sea. Signs of recovery became evident rapidly, within 5 years after the intensive farming ended [20]. Nevertheless, a recent study has forecasted that if regional development follows as predicted, the Black Sea ecosystem will likely return to its highly eutrophic state of the 1980s and the recent recovery will be reversed [16]. The Black Sea states made considerable progress in coastal planning and management leading to more sustainable use of the coastal zone (e.g. [1]). The Black Sea countries have agreed on the necessity of reconstruction of existing management systems in compliance with ICZM principles in the Ministerial Declaration on the Protection of the Black Sea, Odessa Declaration (1993), the Strategic Action Plan for the Rehabilitation and Protection of the Black Sea, Istanbul (1996), and in the new Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea, Sofia (2009). Environmental management of the Black Sea is further complicated by the fact that 9 of the 16 countries comprising the majority of its catchment are non-EU states. Nevertheless the progresses made so far have paved the road for an integrated management of rivers and seas.

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Chapter 7
Fish Stock Management Cooperation in the Lower Danube Region: A Case Study of Sturgeons and Pontic Shad

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Abstract The Danube River is 2,857 km long and navigable along the major part of its flow (2,411 km). Human activities have started to influence Danube River flow more significantly since the sixteenth century, through the flood prevention, navigation and hydropower plant construction activities. Two largest dams in the Danube, located at 943 river km ("Iron Gate I", constructed in 1970) and 863 river km ("Iron Gate II", constructed in 1984), have formed a large accumulation lake. These dams represent obstacles for migratory fish species, such as sturgeons and shads. Beside the negative impact of dams and the river flow regulation, common stocks of these species in the Lower Danube Region (LDR) are also impacted by unsustainable and illegal fishery and pollution. Major obstacle to an efficient common management of these fish stocks by LDR countries is a lack of management harmonization and coordination, as well as lack of common management plans that would be based on coordinated monitoring and research efforts in all LDR countries. Guiding principles for a good management plan for sturgeons and shads in the LDR should include efficient public and stakeholder participation, and a long-term vision that would be harmonized with the short-term social, cultural and economic needs.

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Availability of timely scientific information, provided through the broad and long-term monitoring and research activities, could determine the state of sturgeon and shad stocks and the efficiency of their current management.

Keywords Anadromous fish • Sturgeon • Shad • Danube River • Fishery

7.1 Introduction

The Danube River Basin (801,463 km²) is shared by 18 countries, with a population of about 83 million people. The Danube River is 2,857 km long and is navigable from the Black Sea up to 2,411 river km in Germany (www.icpdr.org). Due to a wide spectre of activities related to hydropower production, flood prevention and the improvement of navigation, the natural Danube River flow suffered significant modifications since the sixteenth century. These changes have significantly influenced Danube ecological quality, leading to degradation and loss of fish spawning and nursery grounds, and severely impacting fish migrations. The largest hydropower dam and reservoir system along the entire Danube is located at the 117-km-long Djerdap Gorge (Iron Gate I and II dams). The second largest dam system, situated at Gabčikovo downstream from Bratislava, is operational since 1992 (Fig. 7.1).

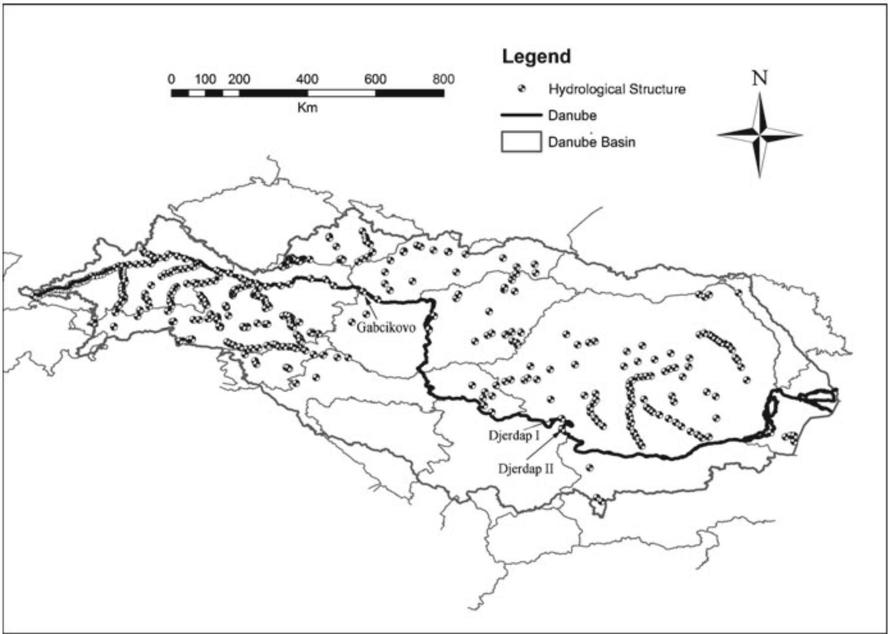

Fig. 7.1 Map of the Danube River basin with locations of hydrological structure; three largest hydropower dams in the region are emphasized: Iron Gate I, Iron Gate II and Gabcikovo

The Danube River Basin can be divided into the three major regions according to Bacalbasa-Dobrovici [2]: Upper, Middle and Lower Danube. The Upper Danube comprises the upstream segment of the river, from its spring down to Vienna (890 km in length). The Middle Danube is situated between Vienna and the “Iron Gate I” dam (993 km), while the Lower Danube stretches between the “Iron Gate I” dam and the Danube Delta (942 km). Due to a number of negative anthropogenic impacts, certain fish populations have experienced a severe decline or have reached endangered status. Degradation of spawning areas, through the changes in the river bed type, river hydrology and water and sediment pollution, represents one of the key problems in the Upper Danube. Beside the presence of a significant fishing pressure, the Middle Danube is severely impacted by the dam construction which is blocking passage of migratory fish species, due to a lack of fish passes. The Lower Danube is also facing the problem of dams without fish passes (“Iron Gate II”), as well as unsustainable and illegal fishery and pollution, which are also characteristic negative factors in the Black Sea. The Upper Danube is completely regulated, with 35 dams located in this region (Fig. 7.1), while there are three dams downstream from Vienna: “Gabčikovo”, “Iron Gate I” and “Iron Gate II”. All these dams represent migration barriers and migratory fish species, such as sturgeon, shad and medium distance migrants, are particularly affected, being unable to move up or downstream between their spawning grounds and areas used at other times throughout their life cycle.

These negative anthropogenic influences have especially impacted anadromous fish species, which migrate from the sea into rivers to spawn, sometimes moving for several hundreds of kilometres. Beside the provision of their unhindered migration and suitable spawning localities, it is also necessary to preserve their wintering habitats in rivers, as well as nursery habitats for juveniles during their downstream migration towards the sea. Since they are dependent on a complex system of habitat requirements for their successful reproduction, these species can represent good indicators of the degree of habitat degradation. Anadromous species of the greatest economic value in the Danube are sturgeons and shads. In the past, sturgeons used to migrate upstream in the Danube up to Bavaria, while some shad specimens have been recorded up to Budapest (1,650 river km) [4]. Regulation of the river flow in Djerdap Gorge for navigation purposes, conducted in the nineteenth century, and the construction of “Iron Gate I” and “Iron Gate II” dams, all contributed to the shortening of migration routes of these species to 863 km, except for a small number of individuals that managed to pass through the locks.

The Danube River basin and the Black Sea, originally inhabited by six sturgeon species, are considered as the key habitat of European sturgeons [19, 42]. Nowadays, European sturgeon (*Acipenser sturio*) and ship sturgeon (*Acipenser nudiventris*) have almost disappeared from the region [10], while beluga (*Huso huso*), Russian sturgeon (*Acipenser gueldenstaedtii*), stellate sturgeon (*Acipenser stellatus*) and sterlet (*Acipenser ruthenus*) are experiencing severe decline [19]. Three anadromous sturgeon species (beluga, Russian sturgeon and stellate sturgeon) are still entering Danube for spawning, while the sterlet represents potamodromous species.

There are three species of the genus *Alosa* which are present in the north-western part of the Black Sea, including the Sea of Azov: Pontic shad (*Alosa immaculata* Bennett 1835), Caspian shad (*Alosa caspia* Eichwald 1838) and Black Sea shad (*Alosa maeotica* Grimm 1901). Only two of these species migrate to Danube, with Pontic shad being the dominant one according to the abundance of migrants. The Pontic shad is a migratory species which is distributed in the Black Sea and Sea of Azov [26], as well as in the Sea of Marmara [8]. It migrates for spawning into the Danube, Don, Dnieper and other major rivers of the Black Sea basin. Despite barrages, pollution and exploitation, Pontic shad persisted and preserved their economic and cultural value within the Lower Danube Region (LDR) [25].Caspian shad is being only occasionally registered in the Danube, and according to Antipa they can migrate up to the 931 river km of the Danube River, which was recently confirmed by a record of Caspian shad specimen at the 864 river km [28].

Improvement of the state of migratory fish species in the Danube will require coordinated activities between the countries that are sharing common fish stocks. Their activities would have to become harmonized to achieve optimal fish stock management and a sustainable exploitation. Countries that are considered to belong to the LDR are: Serbia, Romania, Bulgaria, Moldavia and Ukraine. Moldavia was not considered in this study, because it has only a small part of the Danube River located on its territory (800 m), and it did not participate in regional fishery management meetings. This chapter presents two examples of common fish stocks in the LDR where the coordinated management among all countries in the region is needed: the case of sturgeon and shad stocks management. We have made a comparison of the measures and management activities that were applied on sturgeons and shads according to their economic value.

7.2 Sturgeon and Pontic Shad Catch in the LDR

Unsustainable and illegal fishery have both led to a severe decline of sturgeon species populations in the LDR. This is probably not surprising, bearing in mind that the Black Sea region is, after the Caspian Sea, the major region in the world regarding the sturgeon catch and caviar production [38]. At the beginning of the twentieth century, the annual sturgeon catches in the LDR were about 1,000 t, but they have dropped significantly by the end of the century [34]. The state and the trends of sturgeon stocks are well represented by the example of beluga catch, recorded during 1920–2005, where the maximum was reached during the first half of the twentieth century (more than 900 t annually), and consequently decreased to 200 t in 1974 and to only 10 t in 2005 [30]. This could be explained by the impact of the dam constructed in 1970 at the 943 river km. According to Vassilev and Pehlivanov [39], the total annual catch in Bulgaria decreased from 64 t/year during 1920–1940 to 25 t/year during the period 1995–2002, with the ratio of different species in the catch considerably changing during the studied period. While the Russian and stellate sturgeon used to make the major part of the catch in Bulgaria in the past,

Table 7.1 Overview of the literature related to the catch and scientific investigation of sturgeons and shads in the Lower Danube Region, and the status of these fish species on different lists – Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), Convention on the Conservation of Migratory Species of Wild Animals (CMS, or Bonn Convention)

Sturgeon	Shad
Catch related sources of Center in the LDR	
LDR – Bacalbasa-Dobrovici and Patriche [3]; Navodaru and Staras [27]; Vassilev [38]	LDR – Lenhardt et al. [22]
Romania – Patriche et al. [31]	Romania – Navodaru and Waldman [28]; Ciolac [5]; Ciolac and Patriche [6]
Bulgaria – Vassilev and Pehlivanov [39]; Hubenova et al. [9]	Bulgaria – Kolarov [13]
Serbia – Lenhardt et al. [15, 16, 19]	
Scientific research Center	
Age determination and Sr:Ca ratio in fin rays – Jarić et al. [12]	Age determination – Visnjic-Jeftic et al. [40]
Tagging – Suciu et al. [36]	Seaward drift of the Pontic shad larvae – Navodaru [26]
Spawning ecology and places – Vassilev [37]; Suciu et al. [35]	Biological characteristics and population dynamic – Kolarov [13]
Molecular genetic analysis – Cvijanovic et al. [7]; Suciu et al. [36]	Shad as natural indicator of pollution – Visnjic-Jeftic et al. [41]
Viability analysis – Jarić et al. [11]	
Sturgeon as natural indicator of pollution – Lenhardt et al. [23]	
Status on lists Center	
IUCN Red List of Threatened Species – from Vu (vulnerable) to critically endangered (CR)	IUCN Red List of Threatened Species – Vu (vulnerable) with population trend stated to decrease
CITES – Appendix I and II	
Natura 2000 (Annex II, IV and V of the European Habitats and Species Directive)	Bern Convention – Appendix III (protected fauna)
Bern Convention (Appendix III)	Natura 2000 (Annex II and V of the European Habitats and Species Directive)
Bon Convention (Appendix II)	
Action Plan Center	
Danube River Basin – Action Plan [1]	There is no Action Plan for shads in the Danube River
Bulgaria – Raikova et al. [33]	
Serbia – Lenhardt et al. [18]	

beluga became the dominant sturgeon species in the catch during the last years. The change in sturgeon catch in the Serbian part of the Danube River during 1960–1997 was mainly induced by the construction of two dams. Stellate sturgeon became only rarely caught by the time "Iron Gate I" dam was finished, and the same happened with Russian sturgeon after the completion of the "Iron Gate II" dam [15]. A list of references related to the sturgeon catch in the LDR is presented in Table 7.1.

Annual landings of Pontic shad from the Romanian part of the Danube River varied greatly and appear to be cyclic, with several strong years being followed by several low ones, which is evident in the catch in Romania for the period 1920–2000

[28]. The maximum annual catch of Pontic shad during this period was 2,500 t (in 1975), while the lowest one was 23 t (in 1999). A list of references related to the Pontic shad catch in the LDR is presented in Table 7.1.

Sturgeon species have received greater attention in the LDR countries. This was mostly due to their greater economic value, especially of caviar, as well as due to their specific life history, such as delayed maturity, which contributes to their greater population vulnerability and slower population recovery potential [11]. Inclusion of all sturgeon species in the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) list initiated increased cooperation among LDR countries and, during regional meetings aimed at the establishment of sturgeon catch quotas, experience and knowledge exchange was intensified. At the first regional meeting, organized in 2001, the Black Sea Sturgeon Management Action Group (BSSMAG) was established, and in 2003 the "Regional Strategy for the Conservation and Sustainable Management of Sturgeon Populations of the NW Black Sea and Lower Danube River in accordance with CITES" was developed [20]. After the introduction of sturgeon fishery moratorium in Romania in 2006, information exchange among Romania, Bulgaria, Ukraine and Serbia was somewhat diminished.

In contrast to the described sturgeon fishery management, there was no coordination of the Pontic shad fishery activities within the LDR. During the period 1958–1989, monitoring and management of commercial fisheries, especially of sturgeons and the Pontic shad, were regionally regulated by the "Convention concerning fishing in the waters of the Danube" signed by Romania, Bulgaria, former Yugoslavia and the Soviet Union, but after the collapse of the socialism in the region, only a weak impact of the Convention remained.

7.3 Scientific Research of Sturgeons and the Pontic Shad

By the end of 1990s and during the last decade, a number of international projects dealing with the sturgeon research and management issues has been initiated or realized in the LDR countries:

- GEF/WB/DDBRA No. 131/1997 (1997–2000) "Location of essential habitats of Danube River sturgeon populations in the river and their genetic structure"
- GEF/WB/DDBRA project OGCA 97A0706 (1998–2000) "Migration and habitats of Danube sturgeons in Romania"
- Grant of the Royal Society, London (1998–2000) "Genetic population structure of endangered sturgeon species of the Lower Danube"
- Norwegian Research Council (2000–2001) "Endangered Species: Oocyte maturation of the beluga sturgeon (*Huso huso*) – Evolutionary significance of egg yolk proteins"
- European Agency for Reconstruction (EAR) (2007–2008) "Sustainable use of sterlet and development of sterlet aquaculture in Serbia and Hungary"

- Norway through the Norwegian Cooperation Programme for Economic Growth and Sustainable Development in Romania and by the Romanian Ministry of the Environment and Forestry (2009–2011) “The BEST COMBAT project (BEluga STurgeon COMmunity BAsed Tourism)”

As a part of activities within some of the projects, internet presentations dealing with these issues have also been developed:

- “BEST COMBAT” presentation (www.bestcombat.cc-intro.info);
- “Sturgeons of Romania and CITES” (http://www.indd.tim.ro/rosturgeons/index1E.htm);
- “Sturgeons in Serbia” (http://www.sturgeons.info).

As opposed to the large amount of available data on sturgeon species on the Internet, the data on the state of shad species in the Black Sea and the LDR are scarcer, and there are no specialized Internet presentations for these species.

Results of investigations on beluga, Russian sturgeon and sterlet (the biometry, gravimetry and protein contents of the oocytes) suggest that, despite the difference in size of both female and oocyte, water content and protein levels are conservative aspects of the reproductive biology of sturgeons [17]. Due to the protected status of beluga, Russian and stellate sturgeon populations in Serbia, most of the research was conducted on sterlet, where some recent studies have indicated the possibility of the use of certain sterlet related parameters as biomarkers [21]. Recent research has also indicated levels of heavy metal accumulation in sterlet populations and indicated causal relationship of the presence of these pollutants in the environment and pathological changes in sterlet organs (gills, liver and skin; [32]). Endangered status of sturgeon populations in the LDR and the diminished access to sturgeon populations, imposed by moratoria, has also stimulated studies involving the population viability analysis, through simulations of virtual sturgeon populations [11]. In Romania, where sturgeons are more abundant, a regular monitoring of juvenile sturgeon downstream migration, established in 2000, has indicated that the natural spawning and annual recruitment in beluga and sterlet have varied within natural limits, while they were alarmingly low in Russian and stellate sturgeon [30]. Age structure of adults is also monitored regularly, and an effort has also been made to analyse Sr:Ca ratio in sturgeon pectoral fin rays as a proxy to habitat water salinity, and thus as a tool for the research of sturgeon migration dynamics [12]. Special attention was given to investigations of sturgeon migrations and habitats, where some novel methods involving tagging and satellite tracking have been recently introduced. These satellite tags were surgically attached on beluga specimens and set to be detached after a certain period of time. After detachment and rising to water surface, they were set to transmit all stored information to a satellite receiver (www.bestcombat.cc-intro.info). Sturgeon spawning ecology and places were investigated by Suciu et al. [35] in Romania and by Vassilev [37] in Bulgaria. Investigations of the genetic structure of Danube sturgeon populations were conducted in both Romania and Serbia [7, 36].

Pioneer research of Pontic shad in the LDR countries was made by Ukraine and Romania in 1950s and 1960s. More recent research, conducted in Romania, was mostly focused on Pontic shad exploitation [24, 25, 28], population structure of Pontic shad spawning migrants [5, 6] and Pontic shad larvae drift [26]. The major investigation of Pontic shad in Bulgaria is related to the work of Kolarov [13], who introduced morphological investigation, analysis of growth, migrant structure and catch in Bulgaria. The lowest extent of Pontic shad related research was performed in Serbia, even though this species is placed under protection in Serbia since 1993. One of the more recent studies was focused on Pontic shad age determination methods [40], while there are still ongoing geometric morphometry and histopathological analyses (Višnjić-Jeftić et al., unpublished). Recent research efforts were also focused on the estimation of heavy metal accumulation in tissues of Pontic shad specimens caught at the 863 river km of the Danube River. These investigations have revealed unacceptable concentrations of Cd and As in muscle tissue of the Pontic shad [41].

To introduce more efficient management in the LDR countries, there is a need for more research and collaboration among these countries. These efforts should be mostly focused on the monitoring of fish stocks, investigation of factors that influence changes in stocks, molecular and genetic investigations of migrants, identification, protection and restoration of spawning and nursery grounds in the Danube River and its floodplains, as well as in the Danube Delta and on the costal shelf in the Black Sea.

7.4 Overview of the Cooperation Within the Common Management of Sturgeon and Shad Stocks

Based on the above presented information, it can be concluded that the cooperation within the common management of sturgeon and shad stocks in the LDR was formally established through two international conventions. Before the political changes in the LDR countries, the major legal basis of cooperation was the "Convention concerning fishing in the waters of the Danube", which was mostly based on regular meetings of the commission, consisted of representatives from all LDR countries. After the political changes in the region, the most important cooperation regarding sturgeon species stocks was achieved within the CITES. A number of regional meetings have been held within the CITES, with the participation of both the management authorities and scientific authorities from the LDR countries. In this way, a certain networking between governing and scientific institutions was accomplished. Following 11 years of poorly regulated sturgeon fishery (1990–2000), Romanian fishery and CITES management authorities implemented adaptive management of sturgeon stocks during 2001–2005 [30]. Common management of shad stocks in the LDR was similarly established through the "Convention concerning fishing in the waters of the Danube", but with the cessation of meetings at the turn of the century there was a complete lack of coordination among the LDR countries regarding this common resource.

Beside the formal cooperation among the LDR countries through the implementation of international and regional agreements, there is also a scientific cooperation and the exchange of data and experiences within the scientific community in the region. This cooperation has resulted in a number of common publications (e.g. [12, 22, 40]).

As a recognition of the importance of sturgeon species and their protection in the Danube River basin, the "Action Plan for the Conservation of Sturgeons (Acipenseridae) in the Danube River Basin" was developed, as a result of a major collaborative process engaging sturgeon stakeholders from across the Danube River Basin [1]. There are still no action plans for Pontic shad in the Danube, although this species is placed under protection in Serbia and listed in the Red List of endangered species in Bulgaria (Table 7.1).

7.5 Present Problems Within the Common Fish Stock Management in the LDR

In 2006, Romania has introduced total moratorium on sturgeon fishery for the period of 10 years, except for the catch of specimens for artificial spawning and supportive stocking efforts. Serbia has also imposed total ban on beluga, Russian and stellate sturgeon fishery, and sterlet is the only sturgeon species that is allowed to be caught. In Bulgaria, sturgeon fishery is currently not prohibited, except during the period of their spawning. There were no common meetings held since 2006, and no harmonization efforts among the LDR countries regarding catch and supportive stocking. Illegal fishery still represents an important problem in the LDR, and its extent is very difficult to be estimated. According to Bacalbasa-Dobrovici and Patriche [3] and Navodaru et al. [29], illegal fishery in the region used to make up even about a half of the total catch (and up to 90% of the sturgeon catch). Although there was a number of international and regional scientific projects conducted in the region, which were focused on the assessment of the state of sturgeon populations, their duration was rarely more than 1–2 years, so there was often a lack of follow-up after the completion of these projects, and therefore a lack of funding for continuous activities.

Pontic shad conservation and management status differs among the LDR countries. In Serbia, it is protected since 1993 by the Decree on the Protection of Natural Rarities. In Bulgaria, it is included in the new Red Book of Endangered Species (in press) as a vulnerable species (VU), due to a significant decline it experienced in this country during the last decade. The prohibited period for the Pontic shad catch in Bulgarian part of the Danube River lasts from 15 April to 15 May. In Romania, Pontic shad is not considered to be threatened and it is not included in the Red Romanian Book of vertebrates. The prohibited period of catch in Romanian part of the Danube River depends on the river kilometre: between the Black Sea and the 43 Marine mile, prohibition lasts for 5–7 days in April; between the 43 Marine mile and 238 river km, prohibition is established in April–May and lasts for 20 days; between the 238 and 845.6 river km, it lasts for 30 days during April–May.

In Ukraine, Pontic shad has a Data Deficient status (DD). Such a large difference in the status of Pontic shad in the LDR countries often leads to absurd situations on the river stretches where the Danube represents a border between countries, where fishermen are allowed to catch shad on one side of the river, while the fishery is at the same time prohibited on the other side of the river.

7.6 How to Overcome the Current Situation and Enable Sustainable Exploitation of Sturgeon and Shad Stocks in the LDR?

To overcome present problems related to sturgeon and shad populations in the LDR countries, it is necessary to take into consideration socio-economic situation in these countries, to determine major drivers of illegal fishery and its extent. It is also important to assess potential factors that could diminish the extent of illegal fishery, harmonize relevant legislation among the LDR countries and improve the fishery control in the field. Research efforts should be focused both on the evaluation of the potential use of sturgeons and shads as indicators of ecosystem integrity and on the assessment of major endangering factors:

- Pollution – through research activities focused on genotoxicity, histopathology and the accumulation of heavy metals, PAHs and PCBs;
- River regulation (impact of dams and embankments) and gravel exploitation – through the identification, monitoring and restoration of spawning, nursery, feeding and wintering grounds, and development of feasibility studies for the construction of fish passes on existing dams;
- Unsustainable and illegal fishery – monitoring of population characteristics, development of aquaculture and supportive stocking projects, monitoring and development of measures for the diminishment of illegal fishery.

In order to accomplish such broad spectre of research efforts, it will be crucial to involve all stakeholders in the process – all relevant governmental institutions, managers of fishery waters, fishermen and fishermen organizations, scientific institutions and private enterprises that are involved or are interested to become involved in sturgeon aquaculture.

Through the habitat fragmentation by dam construction, emission of industrial and communal wastewaters and the runoff from agricultural lands, humans have significantly impacted anadromous fish populations in the Danube. Furthermore, unsustainable management (through unsustainable and illegal fishery) have led to a severe decline of their populations, especially of sturgeon species. As species with greater economic value, sturgeons have received greater attention from both the scientific community and fishery managers, so there is a need for additional research to assess the status of shad populations in the LDR. These species could be used as natural indicators and as the incentive for transboundary cooperation, as it was suggested in the case of Caspian sturgeons [14]. Active involvement of local

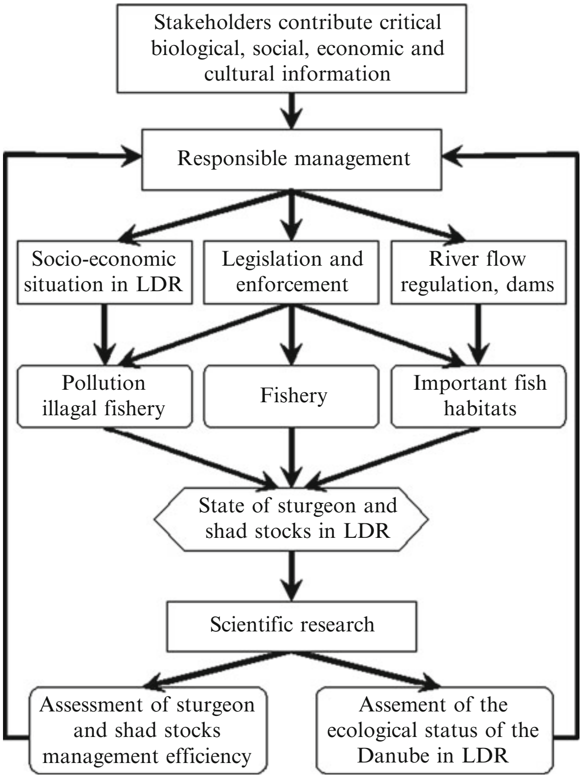

Fig. 7.2 Flow chart with necessary parameters and factors for the achievement of responsible management of sturgeon and shad stocks in the LDR

communities and international organizations is also very important. In this sense, the "Best Combat" project is a good example of the efficient involvement of local communities. This project combines biology, sociology and tourism with the aim of conserving beluga population in the LDR by providing support and education to local communities to develop new sources for livelihood (with a focus on community-based tourism), as an alternative to the unsustainable and illegal fishing of the endangered beluga (http://www.bestcombat.cc-intro.info).

Responsible management of sturgeon and shad species in the LDR countries could be only achieved through the integration of information from different fields (biological, social, economic and cultural) which would comprise assessment of the socio-economic situation in the LDR countries, legislation harmonization and improvement of the catch control, as well as the diminishment of the impact of river flow regulation on sturgeon and shad stocks (Fig. 7.2). Beside the efficient control of the pollution and fishery, it should comprise measures for the diminishment of illegal fishery and wetland protection. Scientific research of sturgeon and shad populations would provide the estimation of the status of their populations in the LDR as an evaluation of the efficiency of the applied management plans, as well as of the ecological status of the Danube in LDR.

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Chapter 8
Distributed Geocomputation for Modeling the Hydrology of the Black Sea Watershed

Nicolas Ray, Gregory Giuliani, Dorian Gorgan, and Anthony Lehmann

Abstract The surface of the Black Sea watershed amounts to about 2 mil. km^2 with a population of 160 mil. Inhabitants over 25 countries. In light of the current and forthcoming climate, land cover and population changes in this region, it is becoming extremely important to better understand how the quantity and quality of waters will vary in the catchment over the coming decades. To model the hydrology of this catchment, three steps are needed: (1) a large transnational data collection effort, (2) adequate management and sharing processes of the environmental data in a dedicated Spatial Data Infrastructure, and (3) distributed computing in order to allow running a high-resolution model. The EU/FP7 enviroGRIDS project (running 2009–2013) is addressing these steps with a 30-partner consortium mainly located in the Black Sea region. In this paper we are discussing how enviroGRIDS is approaching the various data-related challenges of the project. We particularly address the important issue of sharing data through international initiative such as GEOSS, the specificity of the hydrological modeling tool SWAT (Soil and Water Assessment Tool), and the technical requirement for using Grid computing infrastructures to optimize computationally-intensive simulations.

Keywords Black Sea • Hydrological modeling • SWAT • Web Processing Service • Grid computing • Geospatial data • Spatial Data Infrastructure

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8.1 Introduction

Climatic change is becoming a worldwide concern that will affect many areas of human activities. The last report of the Intergovernmental Panel on Climate Change [29, 30] predicts important changes in the coming decades that will not only modify climate patterns in terms of temperature and rainfall, but will also drastically change freshwater resources qualitatively and quantitatively, leading to more floods or droughts in different regions, lower drinking water quality, increased risk of water-borne diseases, and irrigation problems. These changes may trigger socio-economic crises across the globe that need to be addressed well in advance of their occurrences in order to reduce their associated risks.

One region that could particularly be affected by these water-related problems is the watershed of the Black Sea (or Black Sea hydrological Catchment – BSC) (see Fig. 8.1). This catchment has a surface amounting to about 2 mil. km^2 with a population of 160 mil. Inhabitants over 25 countries. This large watershed is subject to numerous environmental pressures and threats. Inadequate management of wastewater/solid waste, ecological unsustainable industrial activities, inadequate land management, and improper agricultural practices have greatly affected the region in many places [51], and notably the Danube catchment area [44]. These pressures generate several direct consequences such as pollution of surface/groundwater, eutrophication, and accelerated runoff/erosion. These consequences have, in turn, the following main effects: decline in quality of life, human health risks, degradation of

Fig. 8.1 The Black Sea watershed

biodiversity, economic decline, and reduced availability of water. Even if some signs of recovery have been observed in the last years, the Black Sea itself is also affected by severe environmental degradation [8] and eutrophication remains a severe problem.

The European Community is addressing the crucial problem of water quality and quantity by adopting the Water Framework Directive (WFD) [9, 31]. A key aspect of the WFD is the consideration of the river basin as the working unit, moving away from administrative boundaries such as communes, provinces, districts or countries that often cross across water-related boundaries. This requires the installation of a regulating body for the whole river basin. For many transboundary rivers, these bodies unite representatives of different countries. One extreme case within the Black Sea watershed is the river Danube, which is now regulated by the ICPDR (International Commission for the Protection of the Danube River). The ICPDR is driven by the interests of 19 riparian countries and of the European Union (EU).

Despite efforts to date, the vulnerability of different areas of Europe and beyond to climate change remains poorly addressed. Moreover, there is a strong need to integrate information on land cover and demographic changes in order to better assess population vulnerability to water scarcity. Building spatially-explicit integrated scenarios of climate, land cover and demographic changes for the entire Black Sea catchment is therefore a necessity if one wants to fully understand the future trends in water quantity and quality in this region. However, before exploring the impacts of these scenarios, one needs a good quality spatially-explicit hydrological calibrated with appropriate and sufficient input data.

The aim of this paper is to discuss the enviroGRIDS approach to modeling the hydrology of the entire Black Sea catchment, and especially the two important technical and institutional issues that arose from such an endeavor: (1) the transnational environmental data collection, standardization, and dissemination process, and (2) the need for distributed computing in order to achieve high-resolution hydrological modeling.

8.2 The EnviroGRIDS Project and the Modeling of the Black Sea Catchment

The EnviroGRIDS project (http://www.envirogrids.net), funded by the EU 7th Framework Programme for a period of 4 years (April 2009–March 2013) with a consortium of 30 partners, aims at building capacities in the Black Sea region on new international standard to gather, store, distribute, analyze, visualize and disseminate crucial information on past, present and future states of this region in order to assess its sustainability and vulnerability. The project focuses on the terrestrial part of the catchment and one of its main scientific objectives is to assess how the sustainability of water usage in this catchment may evolve in the future (at 20, 30 and 50 years time horizons). To achieve this, the project aims at building the first full hydrological model for the Black Sea catchment that will allow one to explore the outcomes of integrated scenarios of change (climate, land cover and demography) on the water quality and quantity of all rivers basins in a comparative way.

To model the hydrology of the catchment, the Soil Water Assessment Tool (SWAT: http://swatmodel.tamu.edu) [3] model is used. SWAT is a widely used basin-scale, continuous-time model that integrates various processes such as hydrology, climate, chemical transport, soil erosion, pesticide dynamics and agricultural management. SWAT accounts for variable soil and land cover conditions by subdividing the simulated catchment into sub-areas. The model uses a daily to sub-hourly time step and can perform continuous simulation for a 1–100 year period. SWAT has an ArcGIS (ESRI, Redlands) interface that takes layers of information such as soil, land cover, elevation, and calculates hydrology, erosion and chemical transport both inland and in-stream. About 50 peer-reviewed papers discussed the application of SWAT on pollution loss studies for a wide range of small and large river catchments [17].

SWAT was already used to simulate the hydrology of large-scale body masses such as the African continent [46], the entire U.S. with river discharges data at around 6,000 gauging stations [4], and of 12 large river catchments in India [28]. SWAT is recognized by the U.S. Environmental Protection Agency (EPA) and has been incorporated into the EPA's BASINS (Better Assessment Science Integrating Point and Non-point Sources).

In the enviroGRIDS project, SWAT will be used to apply a high-resolution (i.e., sub-catchment spatial and daily temporal resolution) water balance model to the entire BSC. The BSC model will be calibrated and validated using river discharge data, river water quality data, and crop yield data [1]. As part of the modeling work, uncertainty analysis will also be performed to gauge the confidence on all model outputs. Subsequent analyses of land use change, agricultural management change, and/or climate change can then predict the consequence of various scenarios.

To achieve the building and calibration of the BSC SWAT model, an initial data collection phase (ended in mid-2010) over the catchment was necessary. This data collection phase was a keystone process to ensure the best possible informed model and to discover data gaps. The main outcome of this endeavor was that the transnational nature of the Black Sea catchment makes it very difficult to get the same quantity and quality of data in all areas of the catchment. Raw environmental monitoring data are often limited to distribution because of their commercial value at the national level or to their sensitive nature (as perceived by the national agency owning the data). As a result of this data collection phase, the available data from the enviroGRIDS Consortium were gathered to construct and calibrate a coarse-resolution SWAT model for the full catchment. Recent results obtained with this model (Abbaspour 2010, personal communication) include long-term averages of river discharge, precipitation, actual and potential evapo-transpiration, soil moisture and aquifer recharge over the entire catchment. In the ongoing second phase of the project, data policies or agreements are being sought with a maximum of regional institutions in order to access additional high-resolution temporal and spatial data sets. How to best access and make available these data sets to the largest audience possible through international standards is the subject of the following section.

8.3 Sharing Environmental Data in a Transnational Setting

Environmental managers are regularly facing the problem of having to take sound decisions with only partial information, which can translate into inaccurate and inefficient management decisions. Gathering and integrating the vast amount of environmental data generated on a daily basis, but often operated in isolation, therefore appears as an essential and fundamental effort to be taken in order to make sound decisions at all levels, from global to local [40].

Understanding and modeling a hydrological system such as the Black Sea watershed is very complex due to the highly interconnected and continuously evolving interactions at many spatial and temporal scales. These interactions require gathering and integrating different sets of environmental data (e.g., physical, chemical, biological) (GEO [19]). Currently, data accessibility, availability, compatibility, and lack of sufficient resources to analyze these data are among the most frequent difficulties that are negatively influencing the way that scientists, researchers, decision-makers and the general public are accessing and using these data [7, 48]. This is mainly due to the fact that geospatial data are voluminous, geographically distributed, and heterogeneous in term of format. All these factors influence the way that data providers store, publish and deliver environmental data. Moreover, users are often lacking the appropriate computational resources to analyze these data. Current environmental research projects regularly need to handle several terabytes of data and accessing high-performance hardware and specialized software is expensive. This explains why currently data sources are often fragmented, integrating geospatial data to answer a scientific problem is difficult and expensive, and diffusion of geospatial information is problematic and not applied efficiently.

Thus, making sense of the vast amount of data and information, and turning them into understandable information is a challenging, but necessary task [26]. Enhancing access to data benefits the wide usage of it and enables scientists to compare results and methods more easily, which improves scientific accountability, credibility and potentially the quality of data. Having environmental data in digital form is essential as it greatly facilitates storage, dissemination, data exchange and sharing, while allowing for faster and easier updates, and giving the users the ability to integrate data from multiple sources. Consequently, digital geospatial data can be thought of as a shared resource that can be maintained continuously [40].

To address the need of sharing environmental data, the concept of Spatial Data Infrastructure (SDI) appears to be an interesting framework [38, 45]. An SDI encompasses data sources, systems, network linkages, standards and institutional issues in delivering geospatial data and information from many different sources to the widest possible group of potential users [11]. SDIs intend to avoid duplication of efforts and expenses by enabling users to save resources and time when trying to acquire or maintain data sets [35, 45]. SDIs can be seen as an integrated information highway which links together environmental, socio-economic and institutional geospatial data resources to provide a movement of data from local to national and global levels [36, 37].

One essential component of SDIs is interoperability: an open science framework allowing scientists and researchers to publish, discover, evaluate and access data [42]. The Open Geospatial Consortium (OGC) aims to develop and provide such standards enabling communication and exchange of information between different systems of different types operated with different software [43]. A SDI committed to interoperability permits widely and effectively exchange of data, maximizes the value and reuse of data and information under its control, and is able to exchange these data and information with other interoperable systems, which allows new knowledge to emerge from relationships that were not envisioned previously.

Different initiatives at the regional and global levels are influencing and promoting the creation of SDIs. These initiatives coordinate actions that promote awareness and implementation of complementary policies, common standards and effective mechanisms for the development and availability of interoperable geospatial data and technologies to support decision making at all scales and for multiple purposes. Such an initiative is the Global Earth Observation System of Systems (GEOSS), a worldwide voluntary effort coordinated by the Group on Earth Observation (GEO) aiming at connecting already existing SDIs and Earth Observation infrastructures. GEOSS is foreseen to act as a gateway between producers of geospatial data and end users, with the aim of enhancing the relevance of Earth observations for the global issues and offering public access to comprehensive information and analyses on the environment (GEO [18, 20, 21, 24]). To support the nine defined Societal Benefit Areas (SBAs, see Fig. 8.2), various mechanisms for data sharing and dissemination are presented in a 10-year Implementation Plan Reference Document (GEO [18]). Any GEO member is volunteer, must endorse data sharing principles, and seeks to agree on “interoperability arrangements” (GEO [20, 21]) to allow its SDIs to communicate with others.

The establishment and implementation of initiatives such as GEOSS follows a more generic approach, the so-called System of Systems (SoS) approach [39]. This approach underpins a multi-disciplinary framework built on existing systems. It allows recognizing the heterogeneity of systems reflecting the diversity of stakeholders involved, while recognizing and specifying arrangements in order to federate these systems that can be very different. Such framework provides interesting features: (1) each component can operate independently (e.g., in order to match their own objective) and can be connected to others component by agreeing and specifying interoperability arrangements, providing flexibility (the overall framework will not fail done if one or more components disappear), (2) it increases the capacity to turn data into information by sharing resources, (3) it provides a holistic approach, (4) it supplements but not supplant existing systems, (5) it is based on Service Oriented Architecture principles, and (6) it can incrementally incorporate new components/systems. However, one of the major benefits of the SoS approach is to allow users to perform functions that cannot be made with any single component [6]. This means that such a system is more than the sum of its parts and it offers the possibility to better understand the complex relationships between the different components of the Earth system. Consequently, such a framework can then offer possibilities for SDIs to extend complement and benefit from capabilities offered by

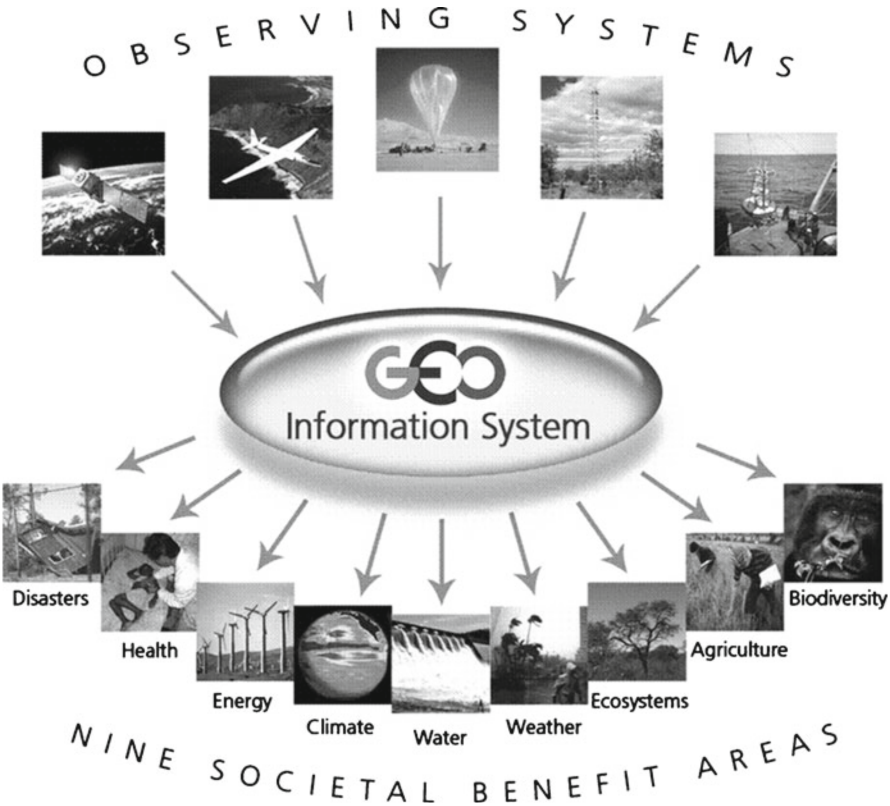

Fig. 8.2 The global earth observation system of systems

other type of infrastructures. For example, distributed computing infrastructures such as Grid architecture can be really beneficial for data processing and management of an ever-increasing amount of high-resolution data.

One of the goals of the enviroGRIDS project is to push for wide adoption of GEO data sharing principle in the Black Sea region, and therefore to register in GEOSS many new environmental data sets on the Black Sea watershed. During the first year of the project, an analysis of data sets and observation systems available within the Black Sea catchment against the enviroGRIDS project requirements revealed spatial and temporal gaps in data coverage, gaps in observation systems, and problems with data accessibility, compatibility and interoperability. It highlighted that large amount of data sets relevant to the project and end-users data needs are available at different scales, from national to regional, European and global. It was also found that access to data is often limited or restricted, particularly at national level, so data accessibility appears to be the main problem preventing effective data usage. With respect to hydrology, major identified problems concerned (1) data gaps on pollution loads to the Black Sea from land based sources, including rivers, (2) missing observation system to monitor pollutants deposition from atmosphere, (3) gaps on availability of data on pollutants deposition from atmosphere, (4) scarce data from river stations in some regions, (5) limited or restricted access to pollution discharges and water quality data, particularly in non-EU countries, and (6) unsatisfactory spatial resolution of crop yield data from available global data sets, while access to more detailed national agriculture data is limited or restricted. Additionally, the analysis of available data sets revealed the problem of data compatibility at different scales (e.g., European and global land cover classifications) requiring significant efforts, particularly when it is necessary to combine in one application data from different scales. Finally, the fact that most of reported national data sets are not accessible through the Internet and do not have relevant metadata available, points to the necessity of bringing project partners' data and metadata to interoperability standards (e.g., OGC and ISO). This required developing a capacity building strategy on Earth Observation Systems in the Black Sea catchment through improved data collection, management, storage, analyses and dissemination.

For the large adoption, acceptation and commitment to SDI philosophy, enviroGRIDS is therefore seeking to build capacities at human (e.g., education and training of individuals), infrastructure (e.g., installing, configuring, and managing the needed technology) and institutional (e.g., enhancing the understanding within organization and governments of the value of geospatial data to support decision-making) levels. Of particular importance is to show and prove the benefits of sharing interoperable data/metadata through appropriate examples, best practices and guidelines. This will help to strengthen (1) existing observation systems, (2) capacities of decision-makers to use it, and (3) capacities of the general public to understand important environmental, social and economical issues at stake in the region. Additionally, capacity building efforts should aim to convince a maximum of data owners/providers that sharing their data is very good opportunity to become more visible nationally and internationally by joining the effort of GEOSS.

8.4 Distributed Modeling of the Hydrology of the Black Sea Watershed

The push for large-scale high-resolution SWAT modeling, as is foreseen in the enviroGRIDS project, comes at the expense of very large computational needs. This expense proves even greater if there is a need to iteratively run such large models for common practices in modeling such as calibration and uncertainty analysis. However, the very nature of a SWAT hydrological model makes it theoretically possible to split the full computation into sub-units of computation that can be run independently on many computers. A distributed computing architecture can provide the necessary computational and storage resources to achieve the parallel computation of these sub-units.

8.4.1 Grid Based Computing Infrastructures

The Grid architecture is one of the main solutions that provide many potential benefits for the modeler:

- it reduces total computation time to get results more rapidly;
- it enables running models for larger geographical area;
- it enables the development and processing of higher-resolution models;
- it allows better assessing model uncertainty and sensitivity by running a larger number of model iterations;
- it supports user scalability by simultaneously running a large number of models.

Altogether, these benefits can participate to a much higher accuracy in model outputs, and can therefore increase the quality of watershed management decisions based on these model outputs.

The term grid computing originated in the 1990s as a metaphor for making computer power as easy to access as an electric power grid [16]. A grid can be defined as a layer of networked services that allows users single sign-on access to distributed collection of resources not centrally controlled. Another, task-oriented, definition of a grid is a cluster of loosely coupled, networked computers acting in concert to perform very large tasks. There are basic concepts lying behind grid: long term collaboration, user and provider communities and security. To use a grid infrastructure, users belonging to different administrative organizations are typically grouped into a specific user community, called a Virtual Organization (VO), a group of people who share a data-intensive goal. This group of users wants to share geographically distributed resources in a secure way. Users as well as resources must be authenticated by a certification authority before acceptance in the VO (for users) or in the Grid infrastructure (for resources). The acceptance in a VO authorizes users to access the resources based on the policies of the VO. Moreover, an application that is intended to be run on the grid must go through a so-called "gridification" process. This process intends to generate a grid application that interacts with grid services to achieve requirements that are specific to a particular VO or user.

Many different Grid infrastructures exist and are available for scientists worldwide. These grids can be classified in international, national, or field-specific sets (see http://www.gridcafe.org/grid-powered-project.html). In the enviroGRIDS project, we are using the Worldwide LHC Computing Grid [50]. The WLCG was implemented within the framework of The Enabling Grids for E-science (EGEE) series of projects funded by the European Commission and that started in March 2004 and officially ended on April 2010 [13]. The coordination of the Grid infrastructure is now taken over by the European Grid Initiative (see [14]), which is the future sustainable computing Grid infrastructure in Europe. The goal of the establishment of EGI is to move from a project-based funding of the European grid infrastructure (as was the case in the EGEE project) to a sustainable country-based funding. Currently, the majority of users of the WLCG come from the High Energy Physics (HEP) community for which the WLCG is a necessity to analyse the data generated by the Large Hadron Collider

(LHC) experiment at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland. However, a growing number of WLCG users come from many other scientific disciplines, such as the biomedical field, earth science, astrophysics, fusion science, etc. In late 2010, the WLCG had about 260 resource centres in 55 countries, with more than 150,000 CPU cores, 28 PB of disk storage, 38 PB of tape storage, more than 14,000 registered users, and more than 300,000 jobs/day. These figures are likely to increase considerably over the coming months/years.

8.4.2 EnviroGRIDS Computing Infrastructure

The time dedicated to the gridification of particular software is only one of the several aspects to take into consideration before deciding to engage project resources into Grid computing. In enviroGRIDS, an important issue was to ensure the sustainability of the pool of computing resources that enviroGRIDS partners could use during, but also beyond, the project duration. Two mitigation actions were taken to minimize the risk of losing access to computational resources. First, we decided to build a dedicated enviroGRIDS VO. This VO is composed of computational nodes belonging to enviroGRIDS partners either already part of the WLCG or willing to join after appropriate software installation. The current enviroGRIDS VO has started the first experiments on developing tools and applications on resources provided by the Technical University of Cluj-Napoca (512 core processors and 12 TB storage), but additional resources provided by enviroGRIDS partners, universities and research institutes (UPB, ICI, UVT from Romania) should join soon. An advantage of the enviroGRIDS VO is that it may facilitate incorporation of new computing resources in the EGEE from the Black Sea countries. Some institutions in this region may indeed be more willing to share their resources for their use in a dedicated Black Sea project, rather than joining a more generic VO (e.g., Earth Science Research VO). Finally, administrating its own VO permits more flexibility in term of software installation and resource allocations within the VO.

The second mitigation action was to ensure not to be restricted to a given Grid platform or Grid middleware (i.e., the software running Grid services). The new European Middleware Initiative (EMI) aims to improve and standardize the dominant existing various middleware in order to produce one simplified and interoperable middleware [15]. EMI attempts to unify a few Grid platforms such as ARC [2], gLite [33], Unicore [47] and dCache [12]. The EMI platform will empower the EGI infrastructure with more stable, useable and manageable software.

8.4.3 SWAT Model Parallelization for Distributed Processing

Although a recent survey [32] indicates that Grid technology in hydrology has been successfully tested to improve flood prediction and ground-water resources management, only minimal efforts on reduction of computation time have been made in the past for SWAT modeling [49]. However, the intrinsic model representation in SWAT makes it theoretically well suited for gridification. A watershed modeled using SWAT is indeed partitioned into different required and/or optional objects of subunits such as sub-basins, reaches/main channel segments, impoundments/reservoirs on the main channel network and point sources. Watershed sub-basins are the first level of the subdivision. These sub-basins are defined by geographical positions in the watershed and are spatially related to one another [41]. All sub-basins drain into the river network where water is routed from upstream to downstream reaches. The land area in a sub-basin may be divided into hydrologic response units (HRUs) that are portions of a sub-basin that possess unique land use, management, or soil attributes [41]. Unlike in the case of sub-basins, no spatial relationship or interaction can be specified among HRUs. Sediment, chemicals or nutrient loadings from each HRU are computed independently and then summed up to determine the total load from a sub-basin. A watershed model should also incorporate one reach or main channel associated with each sub-basin. This channel carries loadings from the sub-basin or outflow from the upstream reach segments into the downstream network of the watershed in the associated reach segment.

By simulating each sub-basin independently on a separate Grid node and ensuring proper hydrological network routing at the end, it is therefore possible to decrease the total simulation time. We recently explored various ways of achieving this with SWAT running on the WLCG infrastructure [52]. Our results showed a clear potential for using SWAT on the Grid, but only with large models. For smaller models, the various overheads of running on the Grid (e.g., splitting of the model, submission time, queuing in remote nodes, merging of results) are costly in term of total computational time, and in such case running the model locally is more efficient.

In parallel, we also developed gSWAT [5], a web-based application that will be accessible through the project main portal (see below). This application allows the calibration of SWAT models and the executions of different scenarios. The development of such a web interface is extremely important if one seeks wide adoption of Grid technology by the SWAT and other user communities. User-friendly interfaces to the Grid must indeed be developed to mask the underlying complexity of the Grid architecture.

8.4.4 BSC-OS Portal

One challenge of the enviroGRIDS project is the interoperability between geospatial and Grid infrastructures. The geospatial technologies offer very specialized functionality for Earth Science oriented applications, while the Grid oriented technology is able to support distributed and parallel processing. The enviroGRIDS system resources are accessible to the large community of users through the BSC-OS (Back Sea Catchment Observation System) Portal that provides Web applications for data management, hydrological models calibration and execution,

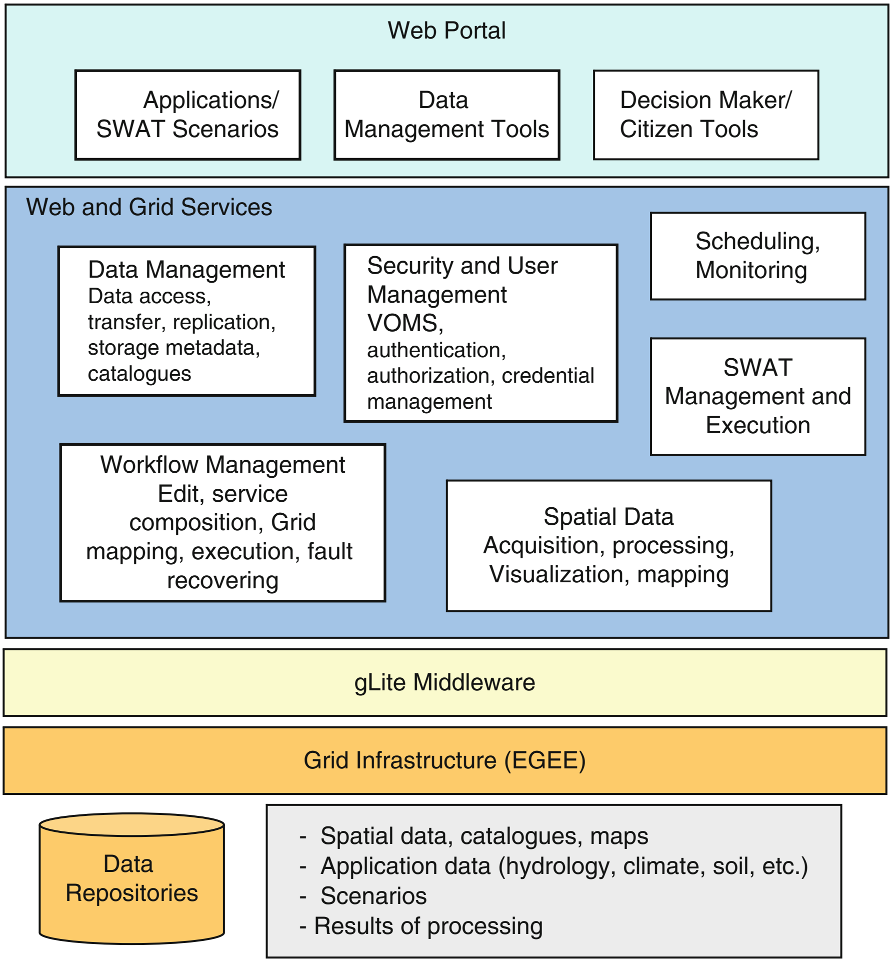

Fig. 8.3 EnviroGRIDS functional Layers. The lower level is the data level. The Grid system is provided by the EGEE infrastructure, on which the gLite middleware is running. The middle levels consist of a set of various services and platforms supporting the basic functionality. The upper level provides tools and applications to end users with appropriate graphical user interfaces

satellite image processing, report generation and visualization, and virtual training center (see Fig. 8.3).

The portal consists of a set of Web applications through which the users access the system resources such as spatial data, hydrologic models, environmental scenarios, data processing tools, visualization facilities, environmental reports, and training materials. There are five categories of users: data providers, earth science specialists, decision makers, citizens, and system administrators.

The main user application categories provided by the portal are:

- Data management – provides the user with spatial data management and operations. The user may enter data and metadata, visualize, modify, update, and remove spatial data from the data repositories;
- Hydrological model management – provides the Earth Science specialists with hydrologic model configuration, scenario and model development, model calibration and scenario running;
- Satellite data processing – the specialist may process satellite data and images in order to search for relevant information (e.g. land cover, vegetation, water, soil composition, etc.);
- Data visualization and report – the specialists visualize various spatial data in different formats and views and compose environmental reports for decision makers and citizens;
- Decision maker and citizen applications – provide the decision makers with the interactive and graphical tools to access the private environmental reports. The user may visualize data that make possible statistical analyses and predictions;
- Virtual Training Center – supports the development of Earth Science oriented training materials based on the Grid processing.

The BSC-OS Portal provides a set of tools and applications to the users interested in environmental studies and predictions. The regular users visualize the reports generated by the specialists as results of executing environmental scenarios. The input materials for the reports are built up by the specialists by running hydrological models of the Black Sea catchment area and by processing related satellite data. All data sets required for building up the hydrological models, environmental scenarios, and spatial models are provided and entered into the system by the data providers. The portal gathers services provided by various technologies such as gSWAT [5], Collaborative Working Environment (CWE) [34], Uniform Resource Management (URM) [10], gProcess and ESIP Platforms [27].

Finally, Grid technology can promote the use of applications modules by several teams, an efficient cooperation among them, and economies of scale to assemble a critical mass of people and investments [32]. In the enviroGRIDS project, the use of the Grid infrastructure has been a driving force in the standardization processes of many data sets currently found in various formats in different countries of the Black Sea Catchment area. This standardization process is enabling regional organizations to take advantage of EnviroGRIDS to analyze large trans-boundary environmental data sets in a harmonized way to support the conceptualization and implementation of environmental and relevant sustainable development policies.

8.5 Some Remaining Challenges

Several challenges are foreseen in the second part of the enviroGRIDS project (ending in 2013). We have discussed in this paper the necessity and benefits of sharing environmental data through interoperable SDIs. We have also examined how Grid computing can help in tackling large spatially-explicit hydrological models such as the Black Sea watershed. If we want the joint benefit of achieving optimized data management and massive data processing, we need to address the real challenge of integrating SDIs and Grid computing. As we discussed previously (see [23]), this integration means developing a Grid-enabled SDI (or gSDI), and it is not straightforward because Grid and SDI architectures differ in many ways. To take full advantage of a gSDI, research and development is necessary in order to: (1) develop so-called mediation mechanisms [25] to be able to launch simulations on different computing back ends (e.g., local computer, local or remote cluster, Grid infrastructure) through standardized procedures, (2) develop plugins for various GIS clients such as ArcGIS and GRASS to allowing users to seamlessly access different computational resources depending on the task (e.g., data retrieval, processing or map making), (3) evaluate the capabilities offered by Desktop Grids that provide access to unused resources of desktop computers (CPU and storage) within a local network, (4) evaluate the potential of Grids in term of data management because Grids offer capabilities that are currently not (or only partially) provide by SDIs (e.g., distribution storage, data replication, data stored as close as possible to components that access them, security, and efficient data moving protocols). This last point requires making Grid middleware spatially-enabled, and then implementing OGC standards and interfaces directly into them.

Another challenge stems from the world of social media/networks (e.g., Facebook, LinkedIn, Twitter, Flickr, YouTube) that allows users to share information and rapidly proliferate content, which is currently changing the field of Science (see [22] and references therein). Social media users can now easily share any report, image, map or any other geospatial information with their network. It can be expected that this kind of medium becomes an increasingly important way to communicate information on the environment, and potentially also to generate new data. The latter is exemplified by the geotagging capabilities of pictures published on Flickr (e.g., identifying pictures on a map) or mapping of tweets (i.e., Twitter messages) in order to spatially analyze this data and make sense of it (e.g., in a crisis situation). In the context of enviroGRIDS, we are exploring ways in which social media could help in building capacities and knowledge in the field of data sharing principles. These media can potentially foster communication, sharing and collaboration around emerging problems, help disseminate best practices, and influence the development of new methodologies and tools.

At the global and regional levels, initiatives such as GEO/GEOSS need the support and engagement of different stakeholders from the different communities involved. However, with the growing availability of server/client tools to set up a local SDIs, the risk is high to see a growing number of unconnected systems. Hence, promoting and raising awareness on GEO/GEOSS and their related benefits is essential in order to concentrate and coordinate efforts on joining the vision of standardized and interoperable SDIs. To achieve this objective, commitment, capacity building, interoperability, harmonization, and answering the needs and requirements of communities are essential elements to strengthen the engagement of all stakeholders.

Finally, environmental security linked to water quantity and quality in the Black Sea watershed is bound to the scientifically sound forecasting of its state under forthcoming climatic, land cover and populations changes. This forecasting needs a well-calibrated hydrological model, which can only be achieved through sufficient availability of data from river stations. Moreover, the Water Framework Directive needs a lot of observational data to assess the quality of the rivers based on water and biodiversity samples. Obtaining these data is still problematic in many of the non-EU countries on the Eastern side of the Black Sea watershed. Focusing our efforts in these countries, while understanding the institutional particularities of each of them, is a big challenge in the enviroGRIDS project. However, communicating the data sharing principles and benefits to these countries' stakeholders is important because the information shared by different water authorities across Europe should find its way to the Water Information System for Europe (WISE) and the Biodiversity Information System for Europe (BISE). This would be able to present the water-related environmental quality in all regions of Europe in a comparable way, which could greatly facilitate research and enhance the quality of environmental management. The unique natural features and identity of the Black Sea region well disserve a concerted effort and a state-of-the-art information system in order to preserve its value and assess its vulnerability to the global changes we are facing.

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Chapter 9
Governance of the Protection of the Black Sea: A Model for Regional Cooperation

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Abstract The Black Sea is a semi-enclosed sea ecologically linked to the Mediterranean Sea through the narrow Turkish Straits system. The regional Black Sea institutional framework for the protection of the marine environment involves two regional organizations: the Commission on the Protection of the Black Sea against Pollution (Black Sea Commission, BSC), established through the United Nations Environmental Programme in 1992, and the Black Sea Economic Cooperation (BSEC), also established in 1992. The BSC is the body responsible for the implementation of the Convention on the Protection of the Black Sea against Pollution (Bucharest Convention) and its protocols, and the Black Sea-Strategic Action Plan (BS-SAP). The legal framework for the protection and preservation of the Black Sea against pollution is based on the Bucharest Convention and its implementing protocols. These legal instruments were subsequently supplemented with four Ministerial Declarations: the Odessa Declaration (1993), the Sofia Declaration (2002), the Bucharest Declaration (2007) and the last Sofia Declaration (2009). Most of the environmental problems in the Black Sea are of transboundary character and as such cannot be efficiently regulated by individual states. Moreover, many Black Sea resources are shared and need common regional policies. A new Black Sea Strategic Action Plan was adopted by the Black Sea States in 2009 (BS-SAP).

Keywords Black Sea • Cooperation • Region • Framework • Policy • Environment • Pollution

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9.1 Introduction

The Black Sea, with the adjoining Azov Sea, forms an enclosed basin with a catchments area of over two million km^2. Each year approximately 350 km^3 of river water flows into the Black Sea from an area encompassing nearly one-third of continental Europe. The surface area of the Black Sea is approximately 386,000 km^2 with a maximum depth of 2,206 m. The Black Sea shoreline stretches for a total of 4,340 km.[1]

The Black Sea is a semi-enclosed or enclosed sea as defined under Article 122 of the United Nations Law of the Sea Convention ("UNCLOS").[2] The Black Sea is connected to the Mediterranean Sea by narrow Turkish Straits system, consisting of the Straits of Istanbul (Bosporus) and Çanakkale (Dardanelles). The Strait of Istanbul, which connects the Black Sea to the Marmara Sea, measures a mere 700 m at its narrowest channel. The abundance of fresh water flowing into the Black Sea from a multitude of rivers from the European and Asian continents,[3] coupled with inflow of the dense saline world ocean waters through the narrow Turkish Straits creates an extremely slow rate of water exchange and vertical mixing for the Black Sea, which in turn has generated one of the most anoxic bodies of water and also one of the most vulnerable. The marine life of the Black Sea is supported by a narrow layer of surface water, underneath which a 2,000 m column of hydrogen sulphide prevents the sustainability of marine life at lower depths. The precarious water margin within which the Black Sea biodiversity must survive has been further eroded by the anthropogenic impacts, which began during the 1970's with the so-called green revolution that introduced toxic run-offs from agricultural pesticides and the rapid industrialization that marked this period. The influx of nutrients, pesticides, industrial waste from the surrounding countries, and to a great extent introduced by the Danube River, together with the overfishing, introduction of alien species and habitats destruction brought the Black Sea marine environment to the precipice of almost irreversible damage by 1991, when the UNEP regional sea programme became involved.[4] Over the past two decades there has been significant efforts and progress in furthering the governance of the Black Sea at the regional level for protection and preservation of the marine environment.

This paper will examine the development of the governance structure for the protection and preservation of the Black Sea at the regional level and present an overview of recent developments, including the role of new environmental management approaches such as Integrated Coastal Zone Management (ICZM), the Ecosystem

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[1] Coastal length on the Black Sea: Bulgaria 300 km; Georgia 310 km; Romania 227 km; Russia 475 km; Turkey 1,400 km and Ukraine 1,628 km.

[2] The United Nations Convention on the Law of the Sea, adopted in Montego Bay on 10.12 1982, entered into force on 16.11 1994; 1833 UNTS 3.

[3] Shalva Jaoshvili, "Rivers of the Black Sea", Technical Report no. 71 (EEA, 2002). Available online at http://reports.eea.europa.eu/technical_report_2002_71/en/tech71_en.pdf

[4] State of the Environment of the Black Sea Pressures and Trends 1996–2000 (Commission on the Protection of the Black Sea against Pollution, Istanbul, 2002). Available online at http://www.blacksea-commission.org/Publications/SOE_Eng.htm

Approach and Integrated River Basin Management (IRBM), which became the core of the new BS-SAP adopted in 2009.[5]

9.2 Regional Governance Framework for the Black Sea

9.2.1 Institutional Framework

The Black Sea (Fig. 9.1) regional institutional framework for protection of the marine environment involves two regional organizations: the Commission for the Protection of the Black Sea against Pollution (BSC),[6] established through the United Nations Environmental Programme in 1992,[7] and the Black Sea Economic Cooperation (BSEC),[8] also established in 1992.

Fig. 9.1 The Black Sea

[5] The new BS-SAP2009 is often named "the revised BS-SAP", as this document is based on the revision of the previous BS-SAP, which was adopted in 1996.

[6] www.blacksea-commission.org

[7] The UNEP Regional Programme includes UNEP administered regional seas and non-UNEP administered. The Black Sea falls into the latter category. See also http://www.unep.org/regionalseas/programmes/nonunep/blacksea/default.asp

[8] http://www.bsec-organization.org/Pages/homepage.aspx

International institutions that have also activities related to the protection, preservation and rehabilitation of the Black Sea marine environment are the European Union,[9] GEF/UNDP,[10] International Maritime Organization (IMO),[11] Memorandum of Understanding on Port State Control in the Black Sea Region (MoU PSC),[12] International Commission for the Protection of the Danube River (ICPDR),[13] United Nations Economic Commission for Europe (UNECE),[14] United Nations Environment Programme (UNEP),[15] Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and continuous Atlantic area (ACCOBAMS),[16] Organization for Security and Co-operation in Europe (OSCE),[17] NGOs,[18] and others.

The Black Sea Commission was established expressly and exclusively for the protection of the Black Sea marine environment, whereas the function of BSEC is primarily to promote economic and trade activities in the wider Black Sea area.[19] Yet, environment protection is one of the fields of cooperation of BSEC countries in the region.[20]

9.2.2 BSEC

In BSEC actions reference is made to the Summit Declaration on Black Sea Economic Cooperation,[21] requesting the BSEC member states:

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[9] E.g. Danube Black Sea Task Force (DABLAS): set up in 2001 with the aim to provide a platform for cooperation to ensure the protection of water and water-related ecosystems in the Danube and the Black Sea.

[10] http://www.thegef.org/gef/

[11] http://www.imo.org/Pages/home.aspx

[12] http://www.bsmou.org/

[13] http://www.icpdr.org/

[14] http://unece.org/

[15] http://www.unep.org/

[16] http://www.accobams.org/

[17] http://www.osce.org/index.php

[18] http://www.bseanetwork.org/

[19] See http://www.bsec-organization.org/Pages/homepage.aspx. See also, V. Chchelashvali, "BSEC: The Way from the Regional Economic Initiative to the Full-Fledged Regional Economic Organization," Turkish Review of Eurasian Studies, Turkish Review of Middle East Studies, Vol. 1 p. 5 (OBIV, 2001).

[20] The area includes the following states: the Republic of Albania, the Republic of Armenia, the Republic of Azerbaijan, the Republic of Bulgaria, Georgia, the Hellenic Republic, the Republic of Moldova, Romania, the Russian Federation, Serbia and Montenegro, the Republic of Turkey and Ukraine.

[21] Istanbul, 25 June 1992, http://www.bsec-organization.org/documents/declaration/summit/Reports/Istanbul1992.pdf

> to take appropriate steps, …, for the protection of the environment, particularly the preservation and the improvement of the environment of the Black Sea, and the conservation, exploitation and development of its bio-productive potential (paragraph 15).

In this spirit, the BSEC participating states have also established a Working Group on Environmental Protection, which met for the first time in Varna, on 3–4 November 1993, and agreed that:

> Environmental protection has emerged as a priority in the BSEC region, and that immediate and concerted action should be taken in order to combat pollution.

The environment is addressed in a project-oriented manner in the BSEC Economic Agenda. Over the years this commitment of the BSEC to act in favor of the environment of the region has been confirmed at the political level,[22] though the implementation actions have not been always forthcoming. Recently, joint Declaration on combating climate change in the wider Black Sea area was adopted at the 23rd Meeting of the Council of Ministers of Foreign Affairs of BSEC (November 2010).[23] In this Declaration the BSEC countries commit themselves to transform the BSEC region into a model of clean energy, develop policies to mitigate climate change, strengthen cooperation in increasing safety, increase public awareness on ecological issues, and others – an ambitious agenda, which properly implemented would definitely contribute to good governance of environment protection in the wider Black Sea area.

Affiliated bodies of the BSEC include Parliamentary Assembly of the Black Sea Economic Cooperation (PABSEC),[24] the Black Sea Trade and Development Bank, and the International Center for Black Sea Studies (ICBSS),[25] whose focus is research only.

9.2.3 *Commission on the Protection of the Black Sea Against Pollution*

The BSC is the body responsible for the implementation of the Bucharest Convention and its protocols, and the Black Sea-Strategic Action Plan (BS-SAP). The Commission is made up of one representative from each of the Black Sea coastal states, parties to the Bucharest Convention (Bulgaria, Georgia, Romania, Russian Federation, Turkey and Ukraine). The Commission meets annually and adopts an annual work program.

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[22] See the Ministerial Declaration, Bucharest, 3 March 2006, http://www.bsec-organization.org/documents/declaration/ministerial/Reports/AnnexVIBucharestStatement%20final.pdf and the Action Plan it endorses.

[23] http://www.bsec-organization.org/documents/declaration/ministerial/Reports/Annex%20VI%20-%20Thessaloniki%20Joint%20Declaration.pdf

[24] http://www.pabsec.org/

[25] http://www.icbss.org/

The ultimate goal of the Commission is to "rehabilitate" the Black Sea, and 'to preserve it as a valuable natural endowment of the region, while ensuring the sustainable use of its marine and coastal resources for the economic development, well-being, health and security of the population of the Black Sea coastal States.[26]

In order to achieve this goal, the Istanbul-based Black Sea Commission has been given a number of functions under Article 18 of the Bucharest Convention, which include:

1. Promoting the implementation of this Convention and informing the Contracting Parties of its work.
2. Making recommendations on measures necessary for achieving the aims of this Convention.
3. Considering questions relating to the implementation of this Convention and recommending such amendments to the Convention and to the Protocols as may be required, including amendments to Annexes of this Convention and the Protocols.
4. Elaborating criteria pertaining to the prevention, reduction and control of pollution of the marine environment of the Black Sea and to the elimination of the effects of pollution, as well as recommendations on measures to this effect.
5. Promoting the adoption by the Contracting Parties of additional measures needed to protect the marine environment of the Black Sea, and to that end receiving, processing and disseminating to the Contracting Parties relevant scientific, technical and statistical information and promoting scientific and technical research.
6. Cooperating with competent international organizations, especially with a view to developing appropriate programmes or obtaining assistance in order to achieve the purposes of this Convention.

The actual day-to-day responsibility of implementing the work programs to fulfill the functions of the Commission falls upon its Permanent Secretariat, which is also based in Istanbul. Six acting Advisory Groups advise to the Commission and the Secretariat. An Advisory Group consists of two representatives from each of the six Black Sea countries, functioning also as an intermediary between the Commission and the national authorities and other stakeholders in their respective countries. The Advisory Groups are an integral part of the institutional structure of the Commission and function as specialized subsidiary bodies. In many ways, they are to serve not only as specialized technical bodies but also as the "eyes and ears" of the Commission so as to promote more harmonious implementation of policy and consequently advance the objectives of the Bucharest Convention and the BS-SAP. The BSC has six functioning advisory groups at present working in the fields of land-based sources of pollution (LBS), environment safety aspects of shipping (ESAS), integrated coastal zone management (ICZM), biodiversity protection and conservation (CBD), management of living resources (FOMLR) and pollution monitoring/assessments (PMA).

[26] The Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea 2009, adopted in Sofia, Bulgaria, on 17 April 2009, available at http://www.blackseacommission.org/_bssap2009.asp

9.2.4 Legal Framework

The Black Sea legal framework for protection of the marine environment at the regional level was established under the UNEP Regional Seas programme in 1992. The 1992 Convention for the Protection of the Black Sea against Pollution (Bucharest Convention) is a framework convention, which sets out the overall objectives and obligations of the Parties.[27] The Bucharest Convention, in general, provides for the obligations to be fulfilled by all the Contracting parties, which include, in particular, "the prevention, reduction and control of pollution".[28] The Convention further imposes a positive duty on each Party to take domestic action to prevent, reduce and control pollution from land-based sources,[29] vessel-based sources,[30] and dumping,[31] as well as to cooperate in order to prevent, reduce and combat pollution due to emergency situations.[32] The Convention requires that the Contracting Parties, as soon as is possible, adopt laws and regulations to prevent, reduce and combat pollution for activities in the continental shelf[33] and atmospheric pollution including vessels flying their flags and aircraft under their registry.[34] In addition, the Convention acknowledges that the Contracting Parties in taking measures consistent with international law, have the duty to cooperate in preventing pollution of the marine environment due to hazardous waste in transboundary movement.[35] The Parties further undertook to cooperate and harmonize laws for liability for damage caused to the marine environment of the Black Sea to ensure the highest degree of deterrence and protection for the Black Sea as a whole.[36]

And where the Bucharest Convention sets out the overall objectives and obligations of the Parties, the actual implementation of each of these is to be done through

[27] Done at Bucharest 21 April 1992. In force 15 January 1994. 32 International Legal Materials 1101 (1993).

[28] Article V (2).

[29] Article VII and in accordance with the Protocol on the Protection of the Black Sea Marine Environment against Pollution from Land-Based Sources. For a recent analysis of UNEP land-based activities in the Black Sea, see The Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities, 1999 UNEP – United Nations Environmental Programme. Available at http://www.gpa.unep.org

[30] Article VIII.

[31] Article X and in accordance with the Protocol on the Protection of the Black Sea Marine Environment by Dumping. The dumping of matter classified as "noxious" in Annex II requires a special permit for each case from the national authorities whereas matter classified as "hazardous" requires only a general permit.

[32] Article IX and in accordance with the Protocol on Cooperation in Combating Pollution of the Black Sea by Oil and Other Harmful Substances in Emergency Situations.

[33] Article XI.

[34] Article XII.

[35] Article XIV.

[36] Article XVI.

more detailed and specific protocols. To date, the Black Sea States have ratified or adopted the following implementing protocols:

- The Protocol on Protection of the Black Sea Marine Environment against Pollution from Land-Based Sources[37] and the revised 2009 Protocol;
- Protocol on Cooperation in Combating Pollution of the Black Sea Marine Environment by Oil and Other Harmful Substances in Emergency Situations (Emergency Protocol)[38];
- Protocol on the Protection of the Black Sea Marine Environment against Pollution by Dumping (1994 ratified)[39]; and
- The Black Sea Biodiversity and Landscape Conservation Protocol to the Convention on the Protection of the Black Sea against Pollution, which was signed in Sofia, Bulgaria in 2003[40] but has not yet entered into force.

These legal instruments were subsequently supplemented with three Ministerial Declarations: the Odessa Declaration (1993), the Sofia Declaration (2002), Bucharest Declaration (2007) and, lastly, the Sofia Declaration (2009). The Odessa Declaration incorporated the emerging principles of international environmental law adopted in Agenda 21 by governments at the 1992 Rio Conference on Environment and Development (Earth Summit). The Declaration underscored the dire state of the Black Sea marine environment and openly declared that existing efforts were insufficient to maintain a sustainable development of the Sea emphasising the need for urgent, comprehensive, consistent and coordinated action at all levels. Furthermore, in addition to the objective of the protection and preservation of the Black Sea, the Declaration also included the rehabilitation of the Black Sea where necessary. In order to meet the goals of protecting, preserving and where necessary rehabilitating the Black Sea, the Ministers of Environment declared their commitment to integrated management and sustainable development, in line with Agenda 21. In addition, the Ministers agreed that national policies would be based on the precautionary approach, use of low and non-waste technologies, integrated marine environmental protection with other areas of policy, use of economic incentives for the use of low and non-waste technologies, as well as the polluter pays principle and user fees and apply environmental impact assessment procedures to all sectors.

However, by 2002 it became evident that progress would be slow in the Black Sea region and this was reflected in the Sofia Declaration, which was in essence a

[37] Adopted in Bucharest 21 April 1992. Entry into force 15 January 1994, 32 International Legal Materials 1122 (1993).

[38] Adopted in Bucharest on 21 April 1992. Entry into force on 15 January 1994. 32 International Legal Materials 1127 (1993).

[39] Adopted in Bucharest on 21 April 1992. Entry into force on 15 January 1994. 32 International Legal Materials 1129 (1993).

[40] Signed by Bulgaria, Romania, Turkey and Ukraine in 2003, by Georgia in 2009. Ratified by Bulgaria, Georgia, Turkey and Ukraine so far. It will enter into force when Ukraine sends a Notification to the depository in Romania about ratification.

diplomatically-worded criticism of the lack of progress. It referred to the need for prompt adoption of the Regional Black Sea Contingency Plan to the Emergency Protocol, noting the considerable delay in the implementation of the Strategic Action Plan for the Rehabilitation and Protection of the Black Sea, and the lack of commonly agreed upon indicators to assess the efficiency of measures implemented. The Sofia Declaration (2002) also served as the political foundation for the amendment to the timetable dates that had originally been agreed to and adopted by the Black Sea coastal states, which gave impetus to a fundamental revision of the Strategic Action Plan initiated a few years later.

A comprehensive and thorough review of the achievements and gaps in the Black Sea region in terms of protecting and rehabilitating the Black Sea ecosystem was presented in the report on the Implementation of the Black Sea Strategic Action Plan 2002–2007,[41] approved by the Ministers of Environment of the Contracting Parties to the Bucharest Convention in 2009. A further acknowledgement of the achievements and awareness of the need for a stronger political action and commitment to the protection of the Black Sea was expressed in the Declaration of the Ministers of Environment of the Contracting Parties to the Convention adopted in Sofia 2009.

9.3 Recent Developments

Most of the environmental problems in the Black Sea are of transboundary character (inter-state externalities), and as such cannot be efficiently regulated by individual states. Besides, many Black Sea resources are shared and in need for a common regional policies. Of course, there are plenty of pollution sources of local impact, such as abandoned hazardous waste sites, small WWTP, local air pollution and others, where national governance is sufficient. However, for any emerging environmental problem since the 1970s decision-makers in all Black Sea states have relied on a combination of national legislative and administrative procedures accompanied by sets of standards to foster improvements in the natural environments of the Sea, which at that time looked already seriously damaged. The regulations were answering questions like:

- How stringent should our water quality standards be?
- How clean is clean enough?

Nonetheless, there was little reason to believe that the resulting environmental policies were efficient enough, as in the 1980s the Black Sea was already considered to be the most threatened sea in the world. Consequently, new approaches were sought in the late 1980s looking for the weakest link in a system, for instance oxygen in a eutrophicated environment, and protecting also 'the most sensitive member

[41] http://www.blacksea-commission.org/_publ-BSSAPIMPL2009.asp

of a population with an adequate margin of safety', such as dolphins, for instance. Recently new paradigms in environmental protection emerged, incorporating "market-based" instruments – principally pollution taxes and tradable permits – rather than so-called "command-and-control" instruments, and designing standards, which require the use of clean technologies and phasing-out high waste and waste-generating technologies, including the use of BAT[42] and BEP.[43] Besides, it became clear that the rational for a successful strategy in environmental protection of a sea with transboundary problems lies in the regional approach, uniform understanding of environmental quality objectives and joint efforts to achieve them. New environmental management approaches were identified, these are:

- Integrated Coastal Zone Management (ICZM);
- The Ecosystem Approach;
- Integrated River Basin Management (IRBM).

All these new visions became a core of the new Black Sea Strategic Action Plan, based on sound understanding of the priority transboundary environmental problems and consequent formulation of ecosystem quality objectives.[44] The BS-SAP2009 also includes short-, mid- and long-term targets to tackle the sources of possible degradation – municipal, industrial and riverine discharges, overfishing, habitat destruction, ballast waters, illegal discharges from ships and other ship-related threats, climate change, lack of integrated coastal zone management and spatial planning, and others. The intention is to reach 'Good environmental status' of the whole Black Sea and to sustain it as likewise stated in the EC Marine Strategy Framework Directive (MSFD).

An assessment of the state of the Black Sea ecosystem (SoE),[45] recently carried out by scientists and experts for the Black Sea Commission showed a steady improvement of the Sea ecosystems during the last years in comparison to previous periods of investigations (often covering more than 50 years). However, the increased vulnerability is still there, yet many habitats are fragile and in need for "no use" protection, fish stocks are not recovered and urge for ecosystem-based management.

The challenges today remain four priority transboundary problems expressed previously in the BS SAP 1996 and confirmed by the last diagnostic analyses. These are: eutrophication/nutrient enrichment; changes in marine living resources; chemical pollution (including oil); and biodiversity/habitat changes, including alien species introduction.

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[42] Best Available Techniques.

[43] Best Environmental Practice.

[44] The 2009 BS-SAP has been formulated through careful consideration of inter alia the BS-SAP1996, the 2008 Black Sea Transboundary Diagnostic Analysis (http://www.blacksea-commission.org/_tda2008.asp) and the 2007 Report on the BS-SAP1996 Implementation Gap Analysis. The latter report was later developed to include the achievements also and it was electronically published at: http://www.blacksea-commission.org/_publ-BSSAPIMPL2009.asp, as mentioned already in the text.

[45] SoE2009, http://www.blacksea-commission.org/_publ-SOE2009.asp

The Ecosystem quality objectives in the BS-SAP2009 were formulated to address the major environmental problems in the Black Sea region and they are:

- EcoQO 1 Preserve commercial marine living resources through:
  - Sustainable use of commercial fish stocks and other marine living resources;
  - Restore/rehabilitate stocks of commercial marine living resources.
- EcoQO 2 Conservation of Black Sea Biodiversity and Habitats through:
  - Reduce the risk of extinction of threatened species;
  - Conserve coastal and marine habitats and landscapes;
  - Reduce and manage human mediated species introductions.
- EcoQO 3 Reduce eutrophication through:
  - Reduce nutrients originating from land based sources, including atmospheric emissions.
- EcoQO 4. Ensure Good Water Quality for Human Health, Recreational Use and Aquatic Biota through:
  - Reduce pollutants originating from land based sources, including atmospheric emissions;
  - Reduce pollutants originating from shipping activities and offshore installations.

Presently, as a result of the efforts of the countries signatories to the Convention on the Protection of the Black Sea Against Pollution, numerous coastal and marine protected areas have been designated and new protected areas are assigned continuously, hot spots are addressed, environmental safety aspects of shipping are better ensured, the populations of endangered species are given time to recover while applying different measures of protection, sensitive areas are identified to proceed thoughtfully to spatial planning, dumping is prohibited, in fishery bans, fishing-free zones, prohibited gears and other protection measures are in place (Table 9.1). Decreasing trends in emissions and atmospheric deposition of pollutants are observed and the amount of insufficiently treated or untreated waters decreases during the last years.

At the national level changes in legislation and policies take place to transpose international regulations and adopt new approaches. Romania and Bulgaria are in

Table 9.1 Protection measures in the fishery

States	BG	GE	RO	RU	TR	UA
Complete ban	x	x	x	x	x	x
Periodic ban	x	x	x	x	x	x
Total allowable catch (TAC)	x	x	x	x	–	x
Total permitted catch = limit	–	–	–	x	–	x
Minimum admissible size	x	x	x	x	X	x
Periods for fishing bans	x	x	x	x	X	x
Fishing free zones	–	x	x	x	–	–
Prohibited fishing gears	x	x	x	x	x	x
Allowable mesh size for nets	x	x	x	x	x	x

Table 9.2 Estimates of annual nutrient loads to the Black Sea (tonnes)[a]

Nutrient source	DIN	PO4-P
Direct discharges from municipal waste water treatment plants serving >5,000 people	6,120	2,150
Direct discharges from Industrial sources discharging >1,000 m^3/day	1,180	250
River loads	497,590	20,043
Istanbul Strait	58 total N	12 total P
Atmospheric deposition	203,040–431,460	

[a] TDA2008, www.blacksea-commission.org

process of drafting National Action Plans for the implementation of the MSFD and outlining programmes of measures to achieve good environmental status of the Black Sea. The "EU Integrated Environmental Approximation Strategy" for the years 2007–2023 of Turkey will be a key tool to develop program of measures and accelerate the sustainable use of environmental resources where the biological diversity will be protected, natural resources will be managed in a rational manner with an approach of sustainable development, and finally the rights to live in a healthy and balanced environment will be ensured. Ukraine has a program for the protection and rehabilitation of the environment of the Black and Azov Seas acting in the period 2001–2010. In Russian Federation, the Federal Law "On Fishery and Conservation of Water Biological Resources" (2004) and the Federal Law "On Environmental Protection" (2002) ensure the conservation of living resources and its sustainable use and protection of the Black Sea as a whole. There are no special management plans for the Black Sea in Russia, however, there are no major polluting land-based sources along the Russian Black Sea coast, the designation of protected areas is advanced and environmental safety aspects of shipping are well recognized and paid attention.

During the last years the Black Sea Protocol for Combating Pollution from Land Based Sources (LBS Protocol) was in process of revision and in April 2009 the Black Sea coastal states signed this revised legal document. One of the main aspects of the revised Protocol is the extended geographical scope of its application and its emphasis on cooperation with States sharing transboundary watercourses that drain into the Black Sea. Inspired by different EU[46] examples, the revised BS-LBSA[47] Protocol attempts to replace the limited 'shoreline' coverage evident in the previous 1992 BS-LBS Protocol with a significantly broader approach. The Protocol provides the legal ground and presents opportunities to enhance our cooperation with States and international bodies concerned with the protection and rehabilitation of the rivers draining into the Black Sea, and hence, influencing on the well-being of its ecosystems. This is of great importance for the Black Sea into which more than 300 rivers flow and where 80% of the pollution is recognized to come from activities carried out on land, either in coastal areas or further upstream in the proximity of rivers, which then transport the pollution to the sea. And the rivers remain the largest source of nutrients in the region (Table 9.2).

[46] European Union.

[47] LBSA – land-based sources and activities.

9.4 Conclusions

The Black Sea states are now in a period of time when they have to face new and more ambitious challenges, ‘acting nationally' and thinking ‘regionally', embracing adaptive management as a progressive approach. Committing themselves to fulfilling the objectives and carrying out the measures in the new Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea adopted in Sofia, 2009, the states showed their political will to provide good governance; one that will lead to preserving the Black Sea ecosystem as a valuable natural endowment of the region, whilst ensuring the protection of its marine and coastal living resources as a condition for sustainable development of the Black Sea coastal states, well-being, health and security of their population.

The Black Sea states actively participate in the rehabilitation of the Black Sea and endeavor to ensure that the “Sea that nearly died” will never go back to the state of the “most threatened sea in the world”, as referred to in media and publications on the Black Sea from the late 1980s and early1990s.

The existing cooperation today in the Black Sea region confirms the dedication of the region to conserving the global value of the natural resources and biodiversity, and the common desire for the sustainable management and protection of the Black Sea, achieving balance between the rapidly developing economy of all involved States and well-being of the Environment.

Chapter 10
Vulnerability of the Black Sea to the Impacts of Climate Change

Gamze Celikyilmaz-Aydemir

Abstract Climate change has effects on the world's coastal zones in varying degrees. The most common negative impacts of climate change have been the sea level rise, coastal erosion, sea water acidification, water temperature increase, increased frequency of storms, and several associated impacts. The Black Sea and its coastal regions get their share of damage in various degrees in different parts, mainly through coastal erosion and related consequences. Unfortunately, it is often the human activity that increases the vulnerability of the ecosystems to those negative impacts. This paper aims to make an overview of the existing climate change impacts, and to highlight the vulnerability of the ecosystems with some examples from the region. Finally, the existing activities for adaptation to the climate change impacts and associated challenges are given briefly.

Keywords Climate change • Black Sea • Impact • Ecosystem • Vulnerability

10.1 Introduction

Coastal ecosystems are ecologically vital, and economically valuable due to the services they provide with their diverse and highly productive nature. However, they are under constant stress due to climate change impacts which are exacerbated by anthropogenic activities.

According to IPCC 2007 Report, world seas and coastal areas will be exposed to increasing risks due to climate change and sea-level rise. Sea-levels are projected to rise by up to 0.6 m or more and sea surface temperature by up to 3°C by 2100 [11].

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Black Sea's coastal areas take their share of the global climate change impacts. Increasing number of people and ecosystems on the coastal area are at risk from climate change impacts, and are subject to additional stresses due to land-use and hydrological changes in catchments. Populated deltas and urban areas at the low-lying coastal regions are the most vulnerable regions along the Black Sea coasts [10].

Impacts of climate change on coasts have been so far been exacerbated by increasing human pressures, which are expected to continue in near future. Low income local economies' dependence on natural resources and tourism, and the urge for regional development have moved the environmental concerns down to the bottom of the priority list in many of the countries of the Black Sea.

It is not possible to avoid the impacts of climate change, but it is possible to decrease the vulnerability, and to increase the resilience of the ecosystems and economic sectors to those impacts. However, adapting to the impacts of climate change poses scientific, financial, political and institutional challenges for the Black Sea countries. On the level of single countries, scientific, financial and institutional capacities are limited, and often clear national policies to adapt to the impacts of climate change are lacking. On the international level, well developed cooperation should be present for overcoming the challenges.

Over the last decade promising steps have been made in terms of international cooperation, in order to overcome the challenges for adapting to climate change. So far, the Black Sea Commission has been considered to be the one of the major internationally set up institutional bodies that has an agenda to develop resilience to the impacts of climate change on the Black Sea Coasts.

Climate Change is a problem with several challenges and various dimensions. It is not only the ecosystems that are at stake; sectors that are vital for the local and national economies are also at risk. Therefore, the solution will not be a single answer, nor will it be short term. The unavoidable impacts can only be handled by adapting to the changing climate and its associated conditions. Furthermore, internationally driven efforts can only be a part of the solution. National and individual awareness for the upcoming threads and determination to overcome the barriers will be the key to survive the climate change challenge with the least possible damage.

10.2 Economic Activities in the Region

The Black Sea catchment area has a population of around 160 million people [3] and encompasses some of Europe's major economic centers. In addition to its six littoral countries (Bulgaria, Georgia, Romania, Russia, Turkey and Ukraine), the Black Sea catchment area covers Austria, Belarus, Bosnia and Herzegovina, Croatia, the Czech Republic, Germany, Hungary, Moldova, Slovakia, Slovenia and Serbia. The Black Sea has become an important transit corridor for energy supplies from east to west, and a commercial transportation route facilitated by large ports such as Varna (Bulgaria), Constanta (Romania), Odessa and Sevastopol (Ukraine), Novorossiysk (Russia), Batumi, Poti and Sokhumi (Georgia), and Istanbul (Turkey).

Agriculture plays an important role in the economies of all the countries that border the Black Sea. The most important crops in Romania and Russia are grain, wheat, sugar beet, sunflowers, vegetables, potatoes and fruits; while the coastal areas of Georgia and Turkey produce tea, citrus fruits, hazelnuts and grapes.

The local economies around the Black Sea are often dependent on tourism and fishing. Various invertebrates and fish from the Black Sea coastal wetlands are the main food source for the local population.

Despite intense commercial activity in the neighboring countries, annual per capita GDP in the region is low, ranging from USD 2,450 in Georgia to USD 8,700 in Russia [19]. All the Black Sea countries are experiencing rising rates of unemployment (year 2009): 6.8% in Bulgaria; 6.9% in Romania; 8.8% in Ukraine; 8.2% in the Russian Federation; 16.5% in Georgia (year 2008); and 14% in Turkey [19]. Many people work in the black and grey economies in the region and poverty is widespread.

Countries neighboring the Black Sea have interfered to the natural ecosystems for urban development along the coastal zone for several years. Wetlands have been renovated for agricultural, forestry and fishing purposes; river beds have been deepened; and canals, roads, housing, industrial facilities and water dams have been constructed.

10.3 Biodiversity and Ecosystems

The Black Sea hosts 1,983 species of invertebrates; 168 species of fish; and four species of mammals, besides hundreds of species of plants, some of which are already rare or endangered [18]. The upper 150-m layer of sea water sustains the biological life of the Black Sea ecosystem [5], while deeper water layers are saturated with hydrogen sulphide. The unique geomorphology and hydro-chemical conditions allow the growth of specific organisms (protozoa, bacteria and some multi-cellular invertebrates). Disturbances to the natural balance between the two layers may cause irreversible damage to this complex ecosystem.

The Black Sea coastal zone wetland ecosystems occupy large areas and act as a form of transmitting mechanism, linking the river catchment area with the seawater. The largest Black Sea wetlands are situated in the coastal plain areas of Romania, Ukraine and the Russian Federation, in the deltas of large rivers such as the Danube, the Dniester, the Dnieper, the Don and the Kuban [18].

Black Sea ecosystems are threatened mainly by anthropogenic impacts, which result in the eutrophication of shelves and coastal waters. Fertilizers from agricultural land, discharges from animal husbandry, and municipal sewage are the main sources of pollution, especially near estuaries and deltas. Also, intensive marine transportation has led to the introduction of invasive species and oil pollution from the discharge of ballast water.

Black Sea waters are very isolated from the open oceans. The Black Sea's only connection with the Mediterranean Sea is through the Bosporus Strait, the Sea of

Marmara and the Dardanelle. Every year the Black Sea receives about 350 km^3 of river water, from a 1.9 million km^2 basin which equals to nearly one-third of the continental Europe [5]. All these circumstances cause the Black Sea to be vulnerable to anthropogenic impacts. Indeed, the land-based anthropogenic pressures, combined with the Black Sea's natural circumstances, have led to radical changes in Black Sea ecosystems, and had major transboundary impacts on biological diversity, and economic and social life (such as fisheries and recreational areas), over the past three decades, [7].

10.4 Observed and Expected Climate Change Impacts

The world's coastal zones are affected to varying degrees by the impacts of climate change. The main impacts of global climate change on the Black Sea region are sea level rise, coastal erosion, surface water temperature rise, increased wind velocity and frequency of storms, and changes in vertical structure and nutrient loads. In addition, increased concentrations of CO_2 in the atmosphere are driving more CO_2 into the ocean, increasing the water acidity [4]. Unfortunately, anthropogenic activities are exacerbating the coastal erosion, seawater intrusion and groundwater salination.

Over the last 85 years, the average rise in the level of the Black Sea was indicated to be between 2.5 and 2.8 mm/year [2], while Shuisky reported 3.5–4.5 mm/year rise from 1949 [15] along the northern Black Sea coasts.. There are several parameters to be considered when determining the basis of rise in sea level, such as surface freshwater flux, changes in river run-off and surface pressure, and the subsidence of surrounding land. In his 2004 study, Tsimplis et al. concluded that around two-thirds of the long-term rise in the level of the Black Sea during the twentieth century was due to increased water volume [17].

Higher water temperatures are seen as the most pervasive of the current impacts of climate change on the marine systems of the Black Sea. A warming trend of 0.25°C was observed in the Black Sea over the last century. The most significant warming phase was between the early 1960s and the 1980s, a period dominated by steady positive water temperature irregularities above the long-term average [14].

Although no detailed research has been carried out to determine changes in the level of acidity, storm frequency and vertical structure in the Black Sea, the negative impacts on local ecosystems and coastal areas are already visible.

There are no clear trends in precipitation patterns resulting from the impacts of climate change in the river catchments of the Black Sea [13]. The only observable impact of climate change between 1960 and 2000 was a slight increase in the mean temperature of the drainage basins.

The research to determine the real climate change impacts and vulnerabilities have several handicaps for the Black Sea Region. Often, there is either limited or no data available on long term trends of several parameters (water temperature, precipitation, rise in sea level rise etc.), and the existing ones are rather fractioned. This limitation generates difficulties for scientists for making models and scenarios of projected impacts. Also, it is often difficult to identify accurately the main source of the damage in the coastal zones, since the level of vulnerability to climate change impacts greatly depends on human activities.

10.5 Vulnerabilities: What Is at Stake?

Vulnerability is the function of exposure, sensitivity and adaptive capacity. The different geographical areas of the Black Sea coasts are naturally exposed to different types of physical climate change impacts, which vary in intensity. The degree of sensitivity and resilience of the unique environment and ecosystem to the new climatic conditions in each region of the Black Sea is also highly variable.

Studies indicate that combined multiple impacts, such as sea-level rise, seawater acidification and the expansion of oxygen-deficient "dead zones", may create negative synergistic effects, to which organisms and ecosystems may have little resistance [12]. In addition, the vulnerabilities of coastal ecosystems are exacerbated by human activities, such as uncontrolled urban and industrial development, and the building of dams.

To date, coastal erosion and groundwater salinisation are the most important consequences of the rise in the sea level of the Black Sea. Taking into account anthropogenic activities related to industrial and urban development, the coastal lowland plains are particularly vulnerable [10]. Coastal erosion and salt-water intrusion also have negative impacts on local economies, especially on the tourism and agriculture sectors, residential buildings and public welfare.

Several coastal areas have already been damaged as a result of erosion [6]. The Romanian coast, for example, has faced serious erosion problems for several decades. In the last 35 years, the northern shoreline has retreated inland by between 180 and 300 m, and 80 ha of beach have been lost each year [9]. Human activities have drastically changed the natural evolution of the coastal strip between Sulina and Sf. Gheorghe Danube mouths, where the highest erosion and substantial accumulation rates can be observed compared to the entire Romanian Black Sea coast [16]. In Bulgaria, erosion poses the greatest threat to coastal zones, with almost half of the coastline being subject to erosion [9]. In Kizilirmak River Delta (Turkey), coastal retreat along the eastern side is between 2.5 and 5.0 m/year and is mostly attributed to decreasing sediment supply, resulting from the construction of dams for electricity generation, together with intensive agriculture and illegal sand extraction [1].Therefore, significance of coastal erosion and its associated effects are expected to increase in the Black Sea's coastal areas, partly due to climate change impacts, but largely due to the lack of effective coastal planning regulations.

Habitats and ecosystems on the low-lying Black Sea coasts are vulnerable to sea-level rise due to their low tidal range and limited scope for on-shore migration [1]. Studies suggest that coastal plains with elevations of up to 1 m are at high risk of inundation. Examples include the Danube delta in Romania, and Terkos Lake (Istanbul) and Kizilirmak delta (Bafra/Samsun) on the Turkish coast [8]. Sea-level rise has also been recognized as a threat to numerous ports and towns on the coasts of Ukraine, Russia and Georgia. However, coastal flooding has so far been due to heavy rainstorms and rivers draining into low-lying coastal areas, rather than sea-level rise. Tides are non-existent and currents are very weak [9].

Periodic flooding due to storm surges has already caused increased salinity in the low-lying coastal areas of the Black Sea. This has led to the degradation of agricultural land and groundwater in several Black Sea coastal areas, including the Burgas region of Bulgaria. However, no action has yet been taken to address this problem. The altitude of many coastal areas makes the risk of coastal flooding less severe. Besides the flash floods along the Romanian coastline, droughts and desertification are among the most serious climate change–related threats to the country as a whole. Unfortunately, [11] Report forecasts locally increased frequencies in storms along the Black Sea coasts [11].

Climate change also has direct impacts on the fish stocks, through changing their physiology and behavior, and altering growth patterns, reproductive capacity, mortality and distribution. These impacts, combined with overfishing, can alter the productivity, structure and composition of the ecosystems on which many other fish species depend.

10.6 Efforts to Adapt to the Impacts of Climate Change

Prior to the 1990s, relatively little action had been taken to protect the Black Sea. In 1992, the Black Sea countries signed the Bucharest Convention, which was followed by the first Black Sea Ministerial Declaration (the Odessa Declaration) in 1993. This inspired the Global Environment Facility (GEF) and other donors, particularly the European Union to formulate the longer-term Black Sea Strategic Action Programme, which was signed in October 1993 at a ministerial conference in Istanbul.

Following the signature of the action plan, GEF has funded several projects, supporting the regional aspects of the Black Sea Partnership for Nutrient Control and assisted and strengthened the role of the Black Sea Commission. Black Sea Strategic Action Programme embodied specific actions (policy and legal actions, institutional reforms and investments) that can be adopted nationally, usually within a harmonized multinational context, to address major priority transboundary problems and, in the longer term, enable the sustainable development and environmental protection of the Black Sea.

The Black Sea Commission's involvement in climate change matters has started in October 2008, when it organized a conference aimed at improving understanding and dealing with the consequences of climate change impacts through science, information technology and policy. The Commission involves control of climate change aspects into its activities mainly through monitoring biodiversity loss.

At national level, institutional, political and financial constraints are among the main handicaps for effective adaptation measures. There is also a significant lack of data regarding the costs and benefits of adaptation, as well as uncertainty surrounding future climate impacts. Projects to protect coastal areas from erosion are being undertaken in Bulgaria and Romania, although coastal strategies/legislation does not exist in either country. In Romania, the Danube Delta Biosphere Reserve Authority published a master plan for its protection in 2005. In addition, the International Commission for the Protection of the Danube River, which was established to implement the Danube River Protection Convention, works to ensure the sustainable and equitable use of waters and freshwater resources in the Danube River basin.

There are projects to integrate climate change adaptation efforts into decision making processes (e.g. PEGASO), however number of such projects are limited compared to those for other world seas. There are modeling tools available for assessing climate change impacts and vulnerabilities in the world seas (e.g. GVA, DIVA Tool, SimCLIM Model, FUND Model), and they can be downscaled and utilized for research projects in the Black Sea Region.

10.7 Conclusion

The unavoidable impacts of climate change have been getting more and more obvious in the Black Sea Region countries. The negative impacts have already affected ecosystems as well as economical sectors, which are important for national economies. The urgency of addressing the problem has already alerted the countries of the region and gave way for seeking solutions on international platforms over the last decade. However, the multidimensional nature of the problem and the challenges that lay under each step of the solution make it very difficult to take actions for many countries. Although international support and guidance exist to a certain level, the national governments have the biggest role for the solution with their determination to intervene before tipping points are reached. The major drive for taking action will be protecting the national economies as well as protecting the ecosystems of the Region.

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Part III
Transboundary Water Management

Chapter 11
Spills of the Aral Sea: Formation, Functions and Future Development of the Aydar-Arnasay Lakes

Kristina Rodina and Ruben Mnatsakanian

Abstract The Aydar-Arnasay lake system (AALS) is located in the Republic of Uzbekistan and represents one of the most remarkable examples of anthropogenic (human-made) aquatic ecosystems. The system plays an important role in the regional economy such as fisheries, biodiversity maintenance and conservation since the system is a designated RAMSAR site in 2007 and finally recreation and tourism. Anticipated regional climate change might have an impact on the activity of this fragile ecosystem in the near future. At the same time the current AALS functioning can be hindered due to the complicated political situation in the Central Asia and the policy of self-interest and self-sufficiency applied by the regional States. Research presented in this paper reviews the process of AALS formation and analyzes its historical development. Based on the contemporary situation analysis of the four main water management scenarios for the AALS were introduced. These scenarios were tested and analyzed using the STELLA® software and the most realistic and plausible future of the AALS has also been assessed and discussed. As a result, this research concluded that the most probable scenario of the AALS fate and functioning is characterized by the lack of interstate cooperation and a negligible regional climate change.

Keywords The Aral Sea • Water resources • Irrigation • Republic of Uzbekistan • The Aydar-Arnasay lake system (AALS) • Water discharge • The Chardara Reservoir • Water management scenarios

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11.1 Background

Central Asia is a vast region located between 35–55° North latitude and 48–87° East longitude. The region includes five former USSR Republics, i.e. Kazakhstan, Uzbekistan, Tajikistan, Turkmenistan and Kyrgyzstan (Fig. 11.1). The total area of the region is more than four million km^2 with the population of approximately 57 million people [3].

Significant elevation differences between the areas below the sea level and the highest mountain peaks create an extraordinary diversity of landscapes and climate types within the region. In general, Central Asia is regarded as the region with the arid landscape types characterized by an extreme unevenness of the geographical phenomena and processes. All local climactic conditions share the main regional feature such as high continentality associated with the large amplitude fluctuations of air temperature, low amount of precipitation and prevalence of the steppe landscape in the north compared to the semi-desert and desert landscape in the central and southern parts.

Despite the arid climatic conditions, Central Asia is a region with abundant water resources. However, more than 80% of the water resources are concentrated in the

Fig. 11.1 Central Asian region (Source: Maps of the world: http://mapsof.net/static-maps/jpg/central-asia-political-map-2003)

Table 11.1 Water resources of the Aral Sea Basin (average water flow of the Aral Sea Basin rivers (km^3/year)) [3]

	River basin		Total for the Aral Sea basin	
Country	Syrdarya	Amudarya	km^3	%
Kazakhstan	4.5	–	4.5	3.9
Tajikistan	1.1	62.9	64	55.4
Turkmenistan	–	2.78	2.78	2.4
Uzbekistan	4.14	4.7	8.84	7.6
Kyrgyzstan	27.4	1.9	29.3	25.3

mountains that belong to the territories of the two upstream countries – Kyrgyzstan and Tajikistan (Table 11.1). Two major rivers of the region such as Syr Darya and Amu Darya that supply the Aral Sea originate in these two countries, whereas three other countries such as Uzbekistan, the single largest consumer of water, Kazakhstan and Turkmenistan are situated downstream of these rivers [39]. Furthermore, 25.3% of the region's water resources are concentrated only in Kyrgyzstan and 55.4% in Tajikistan [3].

Moreover, most of these water resources are used for irrigation in the downstream areas of Kazakhstan, Uzbekistan and Turkmenistan, where more than 83% of the region's arable land is concentrated [3].

Water resources are vital for the Central Asian countries and the process of coordinating the shared utilization of water is getting more complicated. In particular, allocation and use of the water resources became the most difficult issues that arose after the collapse of the USSR. The natural interdependence of the Central Asian Republics that appeared after 1991 experienced major changes which had a negative impact on the previously well-organized water resource management. Self-interest and self-security became the most important factors that shaped the countries' policies from then on. Besides, geopolitical changes and transformation of the regional economy dismantled stable systems of water utilization and energy exchange within the region [9].

Seasonal differences in demand for water have generated conflicting approaches to the utilization of transboundary river resources in two groups of countries. The first group incorporates the countries located downstream that use water resources mainly for irrigation purposes during summer months whereas the second group includes the upstream countries that apply water for energy generation during winter time.

This problem is aggravated by the well-known Aral Sea crisis, which is famous for such global consequences as the Aral water redistribution and excessive reservoir drainage due to the winter floods phenomenon. Among other problems, the region experiences catastrophic flooding in the downstream areas in winter and major droughts during summer time together with acute power shortages in the upstream countries during winter and surplus energy generation in summer, which unfortunately goes to waste since it is neither stored nor sold to other consumers in need [33].

11.2 Human Activity in the Aral Sea Basin

Irrigation plays a significant role in the economies of Central Asia. Due to the arid climatic conditions of the region, most of the crops are cultivated by irrigation [39]. Widespread *furrow watering* (or surface watering) is a traditional method of irrigation in this region and is applied to approximately 76% of the Kazakhstan arable land whereas Tajikistan utilizes this method in irrigating almost 100% of its land [14]. It is worth mentioning that the agricultural output that results from such heavy irrigation efforts makes up 11% of GDP in Kazakhstan, 19% in Tajikistan, 27% in Turkmenistan, 33% in Uzbekistan, and 38% in the Kyrgyzstan.

Many irrigation and drainage (I&D) schemes in Central Asia are the creations of central planning in the 1950s–1980s. That period was characterized by designing the large-scale projects for building massive schemes to irrigate desert or steppe areas. In addition to this, hundreds of thousands of people moved into the areas in order to work in the agricultural field. During the 1970s–1990s the irrigated area expanded by 150% and by 130% in the Amu Darya and Syr Darya river basins respectively. Such an expansion of the irrigated area required a large quantity of water to be used. For instance, Uzbekistan's annual intake of water grew from around 35 to 60–63 km^3. In general, an average water withdrawal in the region accounts for 14.000 m^3/ha for irrigation, whereas rates in countries such as Pakistan and Egypt that do not employ efficient irrigation schemes average around 9.000–10.000 m^3/ha [39].

Due to the tradition of excessively large withdrawals of water per irrigated hectare in Central Asia water for irrigation purposes has become increasingly scarce. Additionally, another main problem of the growing insecurity of water supply system is characterized by the deterioration of irrigation infrastructure.

The vast network of I&D systems constructed during the 1960s–1980s has fallen into decay since the collapse of the Soviet Union. Most of I&D systems were created within the earthen channels, allowing for huge water losses during its delivery. It is worth saying that in Kyrgyzstan out of 160.1 km of inter-farm canals, 158.6 km (99%) are earthen, and 61.6% of these are in an unsatisfactory condition. These canals are clogged with silt, sand, stones, and, therefore, the rate of movement of water through the canal is minimal, about 1 m/s. The efficiency of delivery ranges from 40% to 80%, which is very low. Additionally, the delivery efficiency of on-farm canals currently performs in a much worse manner [34].

The deterioration of irrigation canals has caused lower conveyance efficiency[1] in Central Asia. For example, in Kazakhstan the conveyance efficiency of the main channels has declined since 1996 by 7–24%. The current average conveyance efficiency for Central Asia is 48% [19]. Moreover, the drains experience even worse issues compared to the fate of canals. In Uzbekistan, villagers complained that large collectors are not of sufficient depth and are clogged with weeds which leads to the

[1] The conveyance efficiency – typically defined as the ratio between the water that reaches a farm or field and that diverted from the irrigation water source [7].

blockage of the closed drainage and occasional burning of the vertical drainage pumps, resulting in inefficient operation of the system [39].

11.2.1 Environmental Effects of Irrigation

Development of irrigation has a profound negative impact on the environment of Central Asia, primarily by bringing large quantities of water to areas where nature does not provide for it and thus allowing for human settlement where it otherwise would not be possible. Practices of unsustainable construction of irrigation systems and channels and mismanagement of water dominated during the 1960s–1980s under the auspices of the former USSR Ministry of Water Management [9]. This triggered an aggravation of the well-known Aral Sea crisis in the 1990s.

The Aral Sea catastrophe represents a good case study demonstrating the devastating impact of the human activity on the Aral Sea that resulted in complete sea drainage and the consequent disruption of environmental security within the region. The crisis clearly implicates a strong collision between the diminishing capacity of ecosystem services[2] and growing human society needs. Ecosystem services stand for maintenance of the Aral ecosystem, regulation of the Syr Darya and Amy Darya runoffs and control of the local climate, support of nutrient dispersal and water cycling. Human society needs, in turn, imply constant consumption of valuable natural resources. In case of the Aral Sea ecosystem services mean the consumption of water resources for irrigation of vast arable lands. Extensive anthropogenic activity, being observed during the past decades in the region, has disrupted the balanced development of the Aral Sea ecosystem and further aggravated its ecological functions.

It is commonly accepted that the modern recession of the Aral Sea has been triggered by the diminution of inflow from the two largest rivers feeding the Aral Sea, Amu Darya and Syr Darya, for irrigation purposes. In 1960 the Aral Sea had a surface area of about 68.000 km^2 and a volume of 1.061 km^3 [21]. Before 1960, the Syr Darya and Amu Darya rivers annually discharged into the Aral Sea about 56 km^3 of water, and a further 8 km^3 came in the form of precipitation, and as ground water flow. The mean annual evaporation from the sea surface was 63 km^3. The water level of the Aral Sea was about 53 m above sea level (a.s.l.). As a result of the intensive uptake of water for irrigation until the 1990s, the annual water run-off reaching the Amu Darya and Syr Darya river deltas was reduced to 5 km^3, and in some years the rivers virtually stopped flowing into the sea. By 1992 the Aral Sea water level had dropped to 37 m a.s.l. and the surface area was reduced to 34.100 km^2 [11]. Figure 11.2 illustrates the satellite images representing the change of the Aral Sea

[2] Ecosystem services – the benefits which people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth (Source: http://www.greenfacts.org/glossary/def/ecosystem-services.htm)

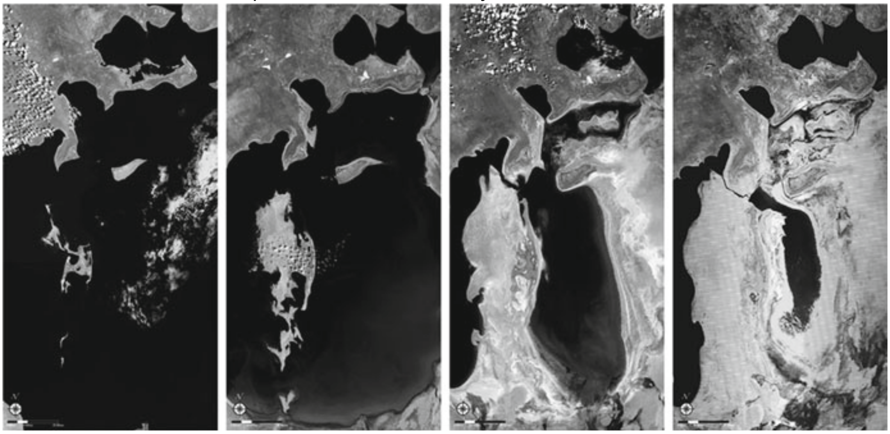

Fig. 11.2 The vanishing Aral Sea (Source: http://landsat.usgs.gov/about_LU_Vol_3_Issue_4.php)

water surface in 1977–2009. The following figure clearly confirms the situation of the Aral Sea described above.

11.2.2 Consequences of the Aral Sea Crisis

The dramatic drying out of the Aral Sea caused by excessive use of water for irrigation has resulted in severe environmental, economic and social problems. Among the most negative environmental problems the following should be mentioned:

- salinization threatening the entire economy of Central Asia,
- waterlogging,
- increasing erosion and sedimentation that, in turn, altered the basin water regulation infrastructure,
- soil contamination,
- desertification,
- dust storms,
- the change of the regional climate,
- decrease of biodiversity and etc.

Salinization is one of the widespread negative environmental consequences that hamper agricultural productivity in the region in several ways. On the one hand, it increases water requirements for the crop cultivation. On the other hand, increasing salinity decreases ability of the plants to absorb water and thus alters their growth. According to the Central Asian Scientific-Research Institute for Irrigation, estimate of the loss in cotton yields is 20–30% on slightly salinized land, 40–60% on moderately salinized land, and up to 80% and beyond on severely salinized land [39].

Along with salinization, waterlogging is another notable consequence of the Aral Sea catastrophe. Water tables in the Aral Sea Basin have risen considerably in the past decades. The area of irrigated land with a water table of 2 m or less expanded by 35% between 1990 and 1999. Waterlogging is responsible for the contamination of the drinking water sources with bacteria, salts, and agrochemicals with subsequent increasing risk of health problems.

Apart from the health problems caused by contaminated drinking water, anthropogenic activity has brought about many other negative social changes in the Aral region such as lack of fresh water, deficit of water for irrigation purposes, increase of unemployment rate due to degradation of the fish industry and general drop in life quality. High rates of several forms of cancer and lung diseases are observed nowadays. Respiratory illnesses include tuberculosis and cancer, digestive disorders, and infectious diseases, which are rather common ailments. Health concerns associated with the region are the main cause for an unusually high fatality rate amongst vulnerable parts of the population, especially among the young and elderly population [30].

The Aral Sea crisis also has led to hindering of the regional economic development due to the fish industry breakdown. Increased salinity caused by the irreversible changes of hydrological and hydrochemical sea cycles negatively influenced the fish population. The formerly flourishing Aral Sea ecosystem supported 24 species of fish in 1960–1970s [13]. By the mid 1970s the average salinity of the sea exceeded 14% and the natural reproduction patterns of the Aral fish were completely destructed. In the late 1970s several species of fish did not reproduce at all. Such factors as fall of the USSR, the complicated period of economic reforms, privatization and cutting off state financial support has led to the substantial reduction of both fish catches and overall aquaculture production in the 1990s [12].

11.3 Appearance of Human-Induced Aquatic Ecosystems

It is widely known that the Aral Sea crisis is mainly determined by human factor which causes 80% of the Aral Sea drainage. According to these estimations the remaining 20% is lost due to a natural factor, i.e. changes in the regional climate [21]. The human factor primarily implies an excessive use of Syr Darya and Amu Darya water for irrigation purposes [18]. Due to obsolete conditions of the I&D systems a significant amount of water is discharged to the nearest depressions and lowlands succeeded by formation of new artificial aquatic ecosystems. The formation of such ecosystems play an essential role in economic, social and environmental development of Central Asia and has been observed for several decades [39].

The following article aims to present a remarkable example of such artificial ecosystem and to examine the history of its formation, main functions and future development pathways. The referred ecosystem is called the Aydar-Arnasay lake system (AALS). The system originally formed as a result of water discharges from the Chardara Reservoir (located at the Kazakh-Uzbek border) and received

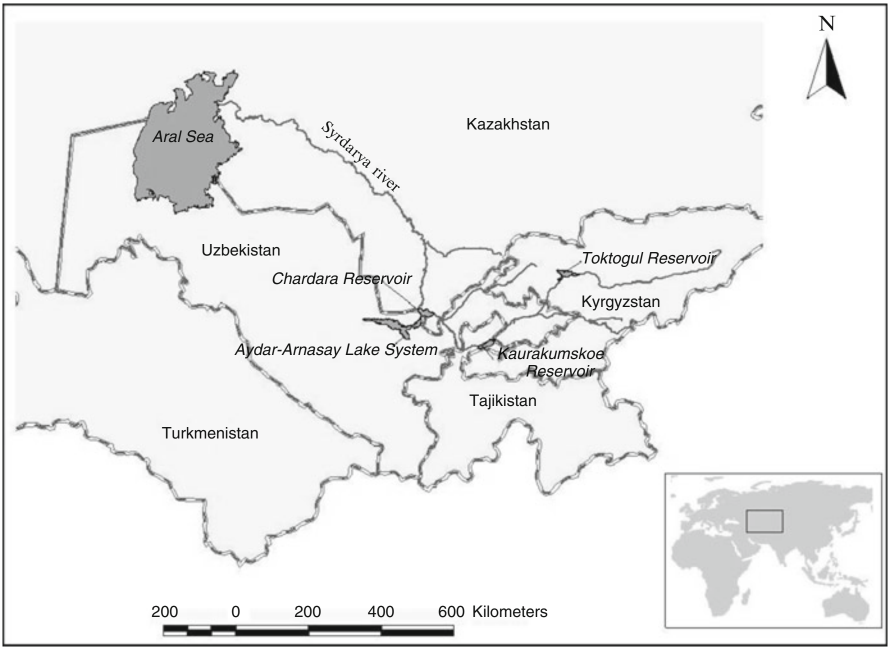

Fig. 11.3 The Aydar-Arnasay lakes system (AALS)

collector-drainage water from the Golodnaya Steppe irrigation area for a long period of time thus being a distinct example of Aral water redistribution.

11.3.1 The Aydar-Arnasay Lake System: Formation, Current State and Functions

The Aydar-Arnasay lake system (AALS) is situated in the southeastern part of Uzbekistan on the territory of Navoi and Dzhizak provinces (Fig. 11.3). In the north it is bordered by the Kyzyl-Kum desert, in the south – by the foothills of the North-Nuratau Mountains and extensive irrigated areas of the Golodnaya steppe in the east.

The Aydar-Arnasay lake system includes Aydarkul, Tuzkan, Arnasay or East Arnasay lakes and surrounding desert areas [23]. The total length of these lakes is 300 km and its north to south width varies from 30 to 50 km [36]. The water level of the lakes system is about 240–242 m, water surface area is more than 3,700 km^2 and volume is about 44.3 km^3 [26].

The lakes represent one of three most important places of fish production in Uzbekistan. According to the Ministry of Fisheries, Aydar-Arnasay lakes provide 41–43% catches of the total amount of produced fish in the Republic. Currently, the three main species, i.e. carp, pikeperch, and roach constitute the commercial catches in the Aydar-Arnasay lakes [12].

Besides, these lakes maintain high biodiversity, including a great variety of waterfowl bird species inhabiting the wetlands (located around the lakes). The lake system was proclaimed an official designated RAMSAR site in 2008 [38].

Alongside with a rich biodiversity, the lakes are also very well suited for developed recreational activity such as camping (i.e. the Aydar Yurt Camp), ecological and ethnographic tourism (on the territory of Nuratau-Kyzylkum Biosphere Reserve), sightseeing that includes visiting cultural and historical sites such as native Uzbek homes near the Aydar-Arnasay and Alexander the Great Fortress and fishing [17].

Despite its high economic and environmental values little is known about this artificial ecosystem. Bringing together numerous pieces of available information from different sources and disciplines, the following article aims to make a coherent multidisciplinary review of the Aydar-Arnasay lakes.

The author used different literature sources such as national and regional reports, journal articles, program documents, action plans and other available literature in order to conduct the analysis of the AALS historical formation. On-line electronic resources were also used and originated mostly from such international organizations as United Nations Environmental Program (UNEP), World Bank, Interstate Commission for Water Coordination (ICWC), Food and Agriculture Organization (FAO), Eurasian Development Bank (EDB) and many other sources. Together with using the sources of information listed above, the bulk of information related to the lakes' historical development was derived from the archival materials published in original (Russian) language. The GIS methods, including compiling the maps in Arcview software and remote sensing completed in MultiSpec® program were used for the analysis of the AALS formation.

The scenario approach was used as the major analytical method for analysis of the future development of the Aydar-Arnasay lake system. This approach was used since it allowed the researchers to consider alternative and completely different potential fates of the lake system. It was assumed that this method will demonstrate a wide range of probable environmental changes in the Aydar-Arnasay lakes in the future, varying from imperceptible and harmless changes to severe and destructive ones.

As a result, four alternative water management scenarios have been elaborated and then tested by the AALS model using the STELLA® software. Finally, the model created has been simulated for each water management scenario. The analysis outcome yielded representative results that illustrated the changes within the AALS volume for the period of 2010–2040 and allowed for further discussion with relation to the most plausible scenario.

11.3.2 Change of the AALS Water-Surface Area in 1969–2008

In the course of the AALS historical development the author made an accurate observation related to the change of the water-surface. The AALS water-surface area has been steadily changing since the emergence of the lakes. In order to examine the evolution of lakes it was crucial to calculate the water surface (km^2). For this purpose the following methods were used:

Table 11.2 Dynamics of change of the AALS water surface area and volume in 1969–2008 [29]

Year	1969	1973	1978	1983	1988	1993	1998	2003	2008
Water surface, km^2	2,180	1,959	1,630	1,771	2,143	2,504	2,890	3,500	3,640
Volume, km^3	17.5	15.6	12.3	13.4	17.7	25.0	28.7	36.9	41.2

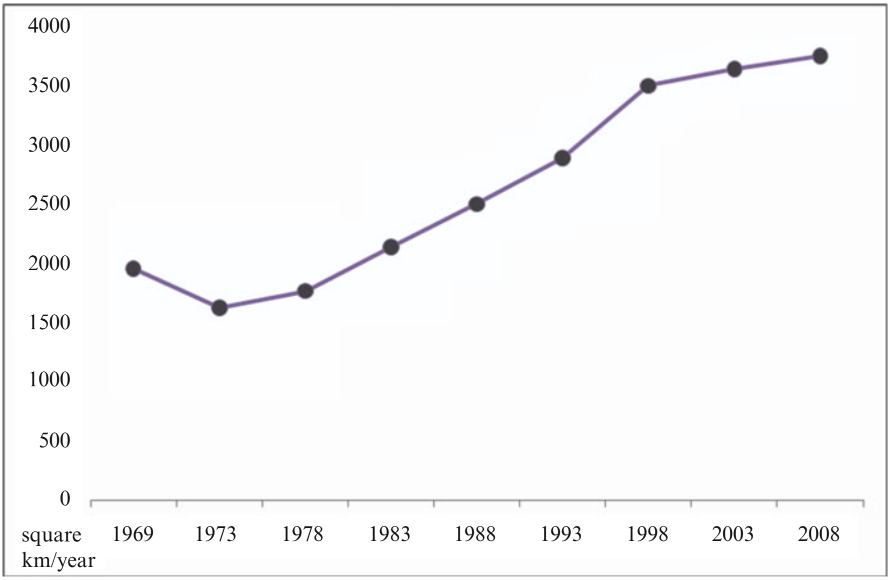

Fig. 11.4 Change of the Aydar-Arnasay lakes' water surface in 1969–2008 (Note: the years shown were chosen due to the availability of high quality satellite images. These images allowed for accurate identification of the lakes' border and calculation of their physical parameters)

- a comparative method based on the analysis of the different land use datasets (Arcview software);
- a comparative method based on the analysis of the USSR military maps;
- creation of Digital Elevation Maps (DEM) (Arcview software);
- remote sensing (MultiSpec) [29].

The results of the calculations and their illustrative representation are presented in Table 11.2 and Fig. 11.4.

Figure 11.4 demonstrates stages of the AALS historical development, which will be discussed in detail in the next section. The graph shows that 1969–1993 was a period when the lakes' water surface was slowly increasing. It was related to the fact that these lakes existed as storage for collector-drainage water discharged from the irrigated area. The amount of water coming to these lakes varied from year to year and overall, water discharges were not high. Table 11.2 shows that during 1969–1993 the water surface area increased by 300 km^2 while during 1993–2008 by 1.200 km^2. Such a significant increase was caused by the change of water management system in Central Asia due to collapse of the USSR with subsequent change of the countries' priorities in terms of water resources use.

Concerning the volume changes, the similar trends can be identified. In the period of 1969–1993 the volume increased from 17.5 to 25 km^3. In contrast, since 1993 volume has been increasing more rapidly, from 25 to 41.24 km^3 in 2008. In 2009 the volume made up 44.3 km^3 [29].

11.3.3 Review of Historical Stages

According to the brief analysis above, the emergence and further formation of these lakes passed through a multistage historical process characterized by the complex water management evolution and. Furthermore, the lakes acquired the valuable ecological and economic functions during each historical stage. Among the primary factors influencing the transformation of AALS water management both the Aral Sea crisis and collapse of USSR should be underlined. Undoubtedly, these two factors have played a substantial role in the AALS fate and have determined trends of the AALS functioning. With the help of archival materials and the analysis conducted the author was able to identify the following historical stages:

- The Aydar-Arnasay solonchak (the 1920s – the 1950s);
- Lakes as a collector of irrigation water (the 1950s – 1964);
- The AALS emergence (1964–1970);
- Lakes as a storage of residual water (1970–1991);
- The current lake system (1991– present) [29].

11.3.3.1 The Aydar-Arnasay Solonchak (The 1920s – The 1950s)

The history of the AALS formation originates from the period of the reclamation of the Golodnaya Steppe irrigation area (located in Kazakhstan) in 1918–1920. Efforts that began as early as in the end of the nineteenth century gradually transformed the Golodnaya Steppe area from a desert into an intensively irrigated agricultural area, which nowadays represents one of the major cotton and grain producing regions of Uzbekistan.

In 1918–1920 the area of the present-day Aydar-Arnasay lake system was occupied by the Aydar-Arnasay depression with dried alkaline soils and wet salines. The Tuzkan depression, which is a part of the AALS, dried up on a regular annual basis. Spring time was characterized by heavy flooding while during the fall period it was continuously shrinking by almost 10 km and served as a place for salt production. In general, the present-day lakes were occupied by a vast solonchak covered with halophytes[3] [6].

[3] Halophyte – A plant that is adapted to live in soil containing a high concentration of salt. Such plants are abundant in salt marshes and mud flats. Halophytes must obtain water from soil water with a higher osmotic pressure than normal soil water. To achieve this the root cells of some halophytes have a very high concentration of salts and so are able to take up water by osmosis (Source: http://botanydictionary.org/halophyte.html)

11.3.3.2 The Lakes as a Collector of Irrigation Water (The 1950s–1964)

Later in the 1950s, reconstruction of the North Kirov irrigation channel and building the Central and South-Golodnostepninskiy irrigation channels resulted in extensive flooding of the Golodnaya Steppe areas and development of cotton monoculture. Starting from the 1950s salt deposition in the AALS was terminated due to increasing Tuzkan water recharge[4] [5].

Collector-drainage water from the Golodnaya Steppe irrigation areas considerably contributed to the evolution of lakes during this period of time. In 1950s the lakes mainly existed as storage for irrigation water from the Golodnaya Steppe area.

11.3.3.3 The AALS Emergence (1964–1970)

The large-scale irrigation and drainage construction in Central Asia started after launching a program for the USSR land reclamation during the Plenum of Central Committee in May 1966. Based on this program, each 5 years it planned to introduce thousands of new irrigation lands, building waterworks facilities such as reservoirs, dams, pumping stations and water catchment systems [31].

Creation of the cascade of artificial water reservoirs on the Amudarya and Syrdarya rivers, extensive irrigation network and collector-drainage systems in the 1960s were basically related to the issue of water redistribution security [8]. During the period of 1965–1985 a large number of reservoirs for seasonal and all-year regulation was introduced on the Syr Darya River. The largest and most important reservoirs are Toktogul (Kyrgyzstan), Chardara (Kazakh-Uzbek border), Kayrakumskoe (Tajikistan), Charvak and Andijan (Uzbekistan) [4].

The construction of the Chardara Reservoir predetermined the future evolution of the Aydar-Arnasay lakes [5]. The impounding[5] seasonal Chardara Reservoir was set in operation in 1964. Situated in the end part of the Syrdarya middle stream the Chardara Reservoir was responsible for the seasonal run-off regulation of irrigation and energy purposes in Kazakhstan.

The main component of the Chardara Reservoir water balance was the inflow of the Syrdarya surface water amounting to 74–93% of total inflow. Water released from the Chardara Reservoir traveled downstream through the Chardara waterworks facility and is estimated to be 86–97% of all releases [8].

Increase of collector-drainage water from the Golodnaya Steppe and experimental discharges from the Chardara Reservoir in mid-to late 1960s gave rise to the gradual formation of the Aydar-Arnasay lakes. Drainage water surpluses from the Arnasay lakes were discharged to the Aydar depression [24].

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[4] The water recharge means a hydrologic process where water moves downward from surface water to groundwater with its subsequent replenishment (Source: http://www.science-dictionary.com/definition/groundwater-recharge.html)

[5] Impounding reservoir – (*civil engineering*) a reservoir with outlets controlled by gates that release stored surface water as needed in a dry season; may also store water for domestic or industrial use or for flood control. Also known as storage reservoir [20].

During the analysis of archives it was found that the AALS mainly received the collector-drainage water from the Golodnaya Steppe. Eventually, 21 km^3 of water discharges from the Chardara Reservoir in the wet year of 1969 was responsible for real lakes' emergence.

Inundation of the Aydar-Arnasay depression precluded a huge damage in the downstream part of the Syr Darya River on the Kazakh territory [17]. At the same time a substantial part of Uzbek grasslands was flooded and restructuring of the Arnasay lakes' hydrographic network took place. This restructuring resulted in flooding of the Aydar depression and its connection with the Tuzkan lake in 1970. Starting from 1970 the lake system incorporated three water bodies, i.e. Aydarkul, Tuzkan and Arnasay lakes.

11.3.3.4 The Lakes as Storage of Residual Water (1970–1991)

In the 1970s 98% of the water mass was concentrated in the Aydarkul and Tuzkan lakes while the Arnasay lakes that were regulated by a regime of collector-drainage network did not hold a large water volume [8].

Most of the reviewed literature identified that the Aydar-Arnasay lakes had particular features during 1970–1991 basically due to the fact that they were supplied by the collector-drainage water [6, 8, 10, 17]. Firstly, a decrease of water level in the lakes was caused by inconstant water discharges, increase of mineralization and concentration of biogenic substances and eventually resulted in a gradual eutrophication of the Arnasay lakes [8]. Secondly, such water quality characteristics as water purity, coloration and oxidation and concentration of organic substances sharply changed [8]. Finally, in the 1970s practices of the *low-mineralized* water discharges from the Chardara Reservoir contributed to the maintenance of the lakes' regulation during the summer period as well as to the provision of favorable conditions during the winter period [25].

Overall, the main function of these lakes for the period of 1970–1991 was the accumulation of the residual water from the irrigation areas. The end of this phase was caused by the aggravation of geopolitical situation in Central Asia with subsequent collapse of the USSR in 1991. Such circumstances completely changed the system of water management within the region, causing severe consequences such as overall transformation of the lakes and alteration of their core functions. Figure 11.5 demonstrates the morphology of these lakes during the year of 1991.

11.3.3.5 The Current Lakes System (1991– Present)

After the USSR officially collapsed and the Soviet Republics proclaimed their sovereignty the geopolitical situation in Central Asia experienced a radical change. As a result, the Syr Darya and the Amu Darya river basins were divided among the newly formed co-basin countries and the rivers became transboundary. Furthermore, the new Central Asian countries began to launch completely independent management systems for water and energy consumption [23].

Fig. 11.5 The Aydar-Arnasay lakes in 1991

After declaring their sovereignty, the new Republics such as Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan signed their first regional agreement. The "*Agreement on Cooperation in Joint Management, Use and Protection of Interstate Sources of Water Resources*" was signed in February of 1992. The 1992 Agreement stated the status quo of the Soviet water allocation arrangements among the countries until new modalities for water cooperation could be agreed upon. The Interstate Commission for Water Coordination (ICWC) was launched to implement the Agreement and decide upon other water issues related to the management of the Amy Darya and Syr Darya River Basins [37].

It is important to say that the 1992 Agreement did not condition the provision of any barter relations[6] among the countries that used to be implemented before. As Kyrgyzstan has become short of the previously delivered winter supplies of energy from Kazakhstan and Uzbekistan, it began to rely on its readily available source of energy, i.e. hydropower energy [16]. In order to generate electricity Kyrgyzstan started actively using its hydropower stations, which has significantly changed the river's hydrologic regime[7] [37]. The Toktogul Reservoir as the key element in the Syr Darya flow regulation became the major source of the power generation in Kyrgyzstan after the collapse of the USSR [1].

[6] Barter relations imply gas/water exchange with regard to countries' needs. Kyrgyzstan provided water resources for the downstream countries, Kazakhstan and Uzbekistan, mainly for irrigation purposes. In return, these counties provide gas needed for energy production.

[7] Hydrologic regime – "changes with time in the rates of flow of rivers and in the levels and volumes of water in rivers, lakes, reservoirs, and marshes. The hydrologic regime is closely related to seasonal changes in climate. In regions with a warm climate, the hydrologic regime is affected mainly by atmospheric precipitation and evaporation; in regions with a cold or temperate climate, the air temperature is a leading factor. The hydrologic regime of lakes is determined by the relationship between the amount of precipitation reaching the lake's surface, evaporation, surface and underground flow into the lake, and surface and underground outflow of water from the lake, as well as by

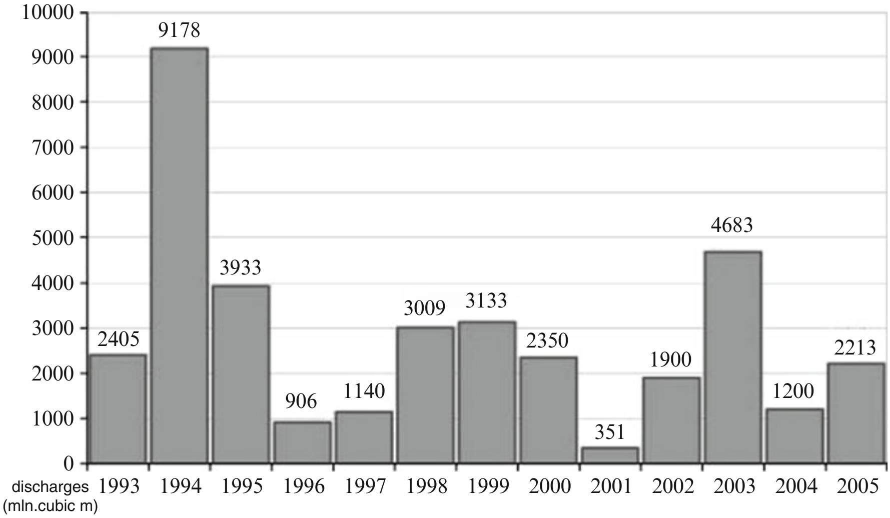


Fig. 11.6 The Chardara water discharges to the AALS in 1993–2005 [19]

Kyrgyzstan transferred Toktogul Reservoir to power-focused regime characterized by substantial water releases from the reservoir during the winter season (up to 8 km^3 instead of 3 km^3) [26]. As a result, the transition of the Toktogul Reservoir to a distinctly different regime changed the water availability in the Syr Darya river basin. The maximum electricity generation was observed during winter time whereas during summer time the water releases were actually decreased. This allowed for water accumulation in the reservoir. Thus, the downstream countries, Kazakhstan and Uzbekistan faced the water shortage for irrigation purposes [32].

Additionally, winter flooding became a regular threat for the lower reaches of the Syr Darya in Kazakhstan as well as for the Aydar-Arnasay lakes in Uzbekistan as the result of spillover from the Chardara Reservoir, situated on the border between Kazakhstan and Uzbekistan.

Among the main negative consequences of the Toktogul regime deformation the present paper is mainly focused on flooding of the Chardara Reservoir and followed by the water releases to the AALS. Figure 11.6 demonstrates the dynamics of the annual water discharges from the Chardara Reservoir to the AALS in 1993–2005.

After the collapse of the USSR the regional cooperation between Uzbekistan and Kyrgyzstan in terms of the Toktogul operation became a crucial point for the future AALS development [15].

According to the Central Asian Research Hydro-meteorological Institute 38.64 km^3 of water was discharged to the AALS during 1993–2006, with the larg-

the size and shape of the lake, the pattern of change in the surface area with change in level, and wind activity, which determines the size of the waves and the extent to which the level rises and falls. Fluctuations in the lake level may be seasonal, annual, or short-term. Man's economic activities are introducing ever greater changes in the hydrologic regime." (The Great Soviet Encyclopedia 1979).

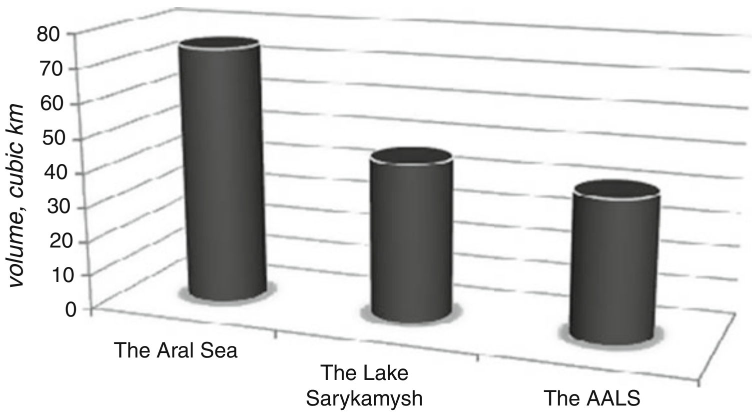


Fig. 11.7 The largest water bodies in Central Asia

est discharges occurring in 1994 – 9.2 km^3, 1995 – 4.0 km^3, 1999 – 3.14 km^3, and 2000 – 4.7 km^3 [15].

These discharges led to the increase of an overall volume and made the Aydarkul Lake the third largest in Central Asia with a volume amounting to 44.3 km^3 as presented in Fig. 11.7 (in contrast, the Aral Sea – 75 km^3 in 2008 [22], and Sarykamysh Lake – 46 km^3) [17].

Another important aspect to be analyzed is the complicated interstate relations that were observed after the USSR ceased to exist.

Despite several agreements established between 1991 and 2000 that focused on the rational use of water and energy resources in the Syr Darya river basin, the concerned Republics still cannot decide upon the amount of water to be discharged to the AALS and used for irrigation purposes [32]. Water discharges to the AALS are conducted without any coordination on behalf of Republics and it is still unclear how the system of water management will work [31].

Additionally, experience showed that designing seasonal water distribution for irrigation and energy purposes without considering the complex approach results in a steady decrease of water supply in the Toktogul Reservoir. For instance, by the 1998 vegetation period, the Toktogul volume reduced to 7.2 billion m^3. Between 1999 and 2001 vegetation periods volume of drawdown from the Toktogul Reservoir increased to about 3 billion m^3 due to the additional discharge of the Naryn-Toktogul cascade. Thus, it caused additional water discharges from the Chardara Reservoir to the AALS [31].

11.4 Possible Future of the Lakes System

The future functioning of the Aydar-Arnasay lake system plays an essential role for Uzbekistan in terms of the economic, social and environmental values and currently is compromised. The prosperous functioning of the lakes directly depends upon the effectiveness of the Central Asian Republics' decision-making processes regarding the determination of the national water policy principles. In fact, Kyrgyzstan and Kazakhstan, the main lakes' water supplies undoubtedly predetermine the Aydar-Arnasay lakes current functioning. Taking into account the longstanding tensions and lack of compromise among Central Asian Republics, the lakes' future does not seem very promising.

To examine the future fate of the lakes, scenario approach was implemented as a method that allows for description of several realizable or desirable futures. In particular, the water management scenarios have been elaborated in order to depict the alternative pathways of the lakes' future. The AALS model was created that tested the respective scenarios. Last but not least, results obtained from all of the above-mentioned methods were presented in a discussion regarding the most plausible scenario.

11.4.1 Building the Aydar-Arnasay Lakes Model

The main goal of the Aydar-Arnasay lakes model is to test the elaborated AALS water management scenarios using the STELLA ® software in order to detect the most probable scenario for the lakes' future development. The model has three main blocks and can be operated in two modes. The description of the blocks and modes is presented below.

11.4.1.1 The Model Modes

The model can be operated in two main modes:

- Mode I *"Model optimization"*. This mode is designed to determine the amount of water needed for the Aydar-Arnasay lakes' maintenance taking into consideration present and future climatic changes. The results obtained will lay the groundwork for the elaboration of the quantitative characteristics of the water management scenarios. Further on, these characteristics will be put into the model.
- Mode II "*Scenario analysis*". This mode is designed to test the elaborated water management scenarios to determine the most probable AALS future.

11.4.1.2 The Model Blocks

The Chardara – Aydar-Arnasay model has three main blocks:

- *The Chardara-Aydar-Arnasay lakes system*; this block represents the main input and output parameters of the Aydar-Arnasay system. The input parameters are as follows: (a) water discharges from the Chardara Reservoir, (b) water discharges from the drainage network, and (c) inflow from rainfalls. The output parameters are as follows: (a) evaporation, (b) percolation, and (c) the storage changes which are represented by the AALS volume fluctuations. Figure 11.8 shows visual representation of the Chardara-AALS model block.

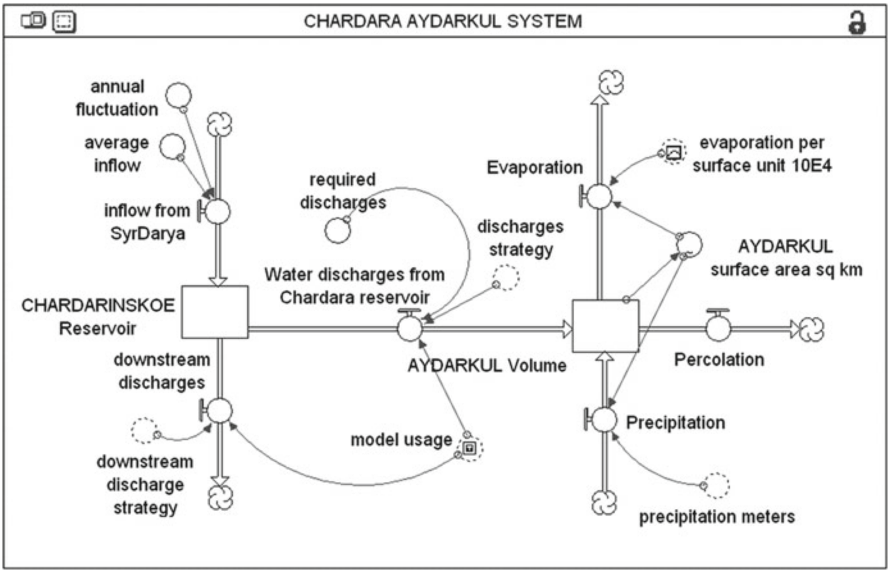
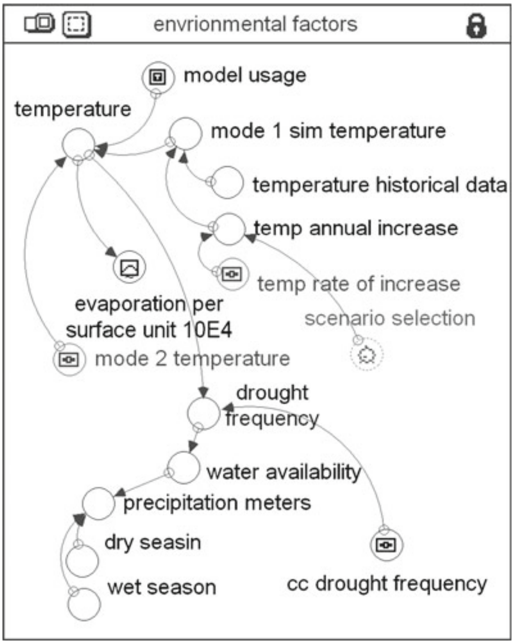


Fig. 11.8 "Chardara-Aydar-Arnasay lakes system" block

Fig. 11.9 "Environmental factors" block



- *Environmental factors*; this block is focused on consideration of the important environmental parameters of the Aydar-Arnasay lakes, i.e. temperature, evaporation and precipitation. Figure 11.9 shows the model block simulating the respective environmental parameters.

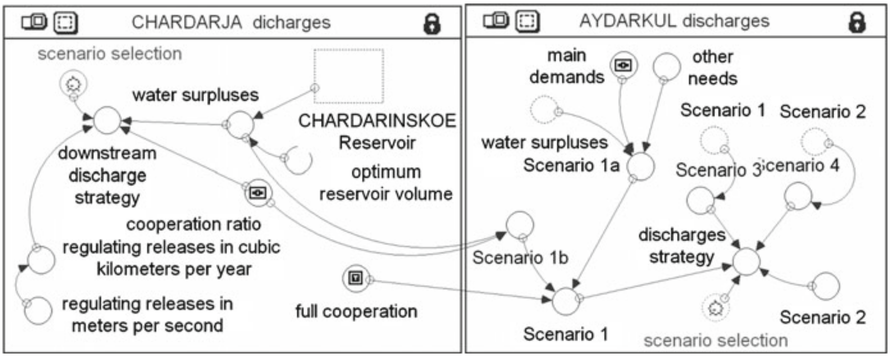


Fig. 11.10 "Scenario analysis" block

It should be mentioned that "The Environmental factors" block is used for the two regimes described above. In case of Mode I, the block is used for temperature simulation in order to find out how much discharged water will be needed in the future for the AALS maintenance in the context of climate change. In case of Mode II, the block is responsible for temperature simulation according to the climate change conditions considered in the water management scenarios.

- "*Scenario analysis*"; this block consists of two subblocks: (1) the Chardara downstream discharges and (2) scenario analysis with relation to the water discharge strategy. Figure 11.10 shows simulation of the water discharges according to the selection of water management scenario.

The left subblock in Fig. 11.10 illustrates the downstream discharge strategy. Downstream discharge strategy contains two management options: (a) a high regional cooperation which means that the lakes will get a necessary amount of the Chardara water, (b) a low regional cooperation which implies that the Chardara water is released to the downstream areas excluding the supply of the lakes.

The right subblock in Fig. 11.10 represents simulation of the four considered water management scenarios.

11.4.1.3 Model Simulation

The process of model simulation consists of three main parts:

- Model simulation: Mode I "Model optimization";
- Development of the quantitative assumptions needed for the elaboration of the water management scenarios;
- Model simulation: Mode II "Scenario analysis". A series of experiments was conducted for the purpose of testing the alternative water management scenarios [29].

Overall four water management scenarios were tested using the Chardara – Aydar-Arnasay model. The developed model interface with a range of control parameters such as the rate of temperature increase, drought frequency and a level of regional cooperation allows for running several alternative situations within each scenario. The model was executed ten times for each scenario in order to analyze a range of the volume change. The description of the water management scenarios and results of the model simulation are presented in the next sections.

11.4.2 Designing the Water Management Scenarios

As part of its third Global Environment Outlook (GEO-3[8]) Report, the United Nations Environment Programme (UNEP) developed a set of four alternative scenarios depicting development for the period of 2002–2032. These scenarios were intended to stimulate thinking about different possible trends in the environment at the global and regional level.

The GEO-3 scenario concept has been applied to the elaboration of the AALS water management scenarios. This concept was chosen because the GEO-3 scenarios:

- are acknowledged to be an efficient analytical tool successfully applied on the regional level;
- represent a holistic approach to sustainable development; they provide environmental window by emphasizing environmental descriptions and policies;
- have a wide range of driving forces, i.e. demographic, economic, social, technological, environmental, cultural and political (governance) drivers;
- contain qualitative and quantitative assessment [35].

GEO-3 scenarios are defined by two main criteria: (1) regionally/globally oriented development and (2) economically/environmentally oriented development. There are four alternative GEO-3 scenarios: *Market First, Policy First, Security First*, and *Sustainability First*. The concept of GEO-3 scenarios is presented in Fig. 11.11.

Designing the AALS scenarios consisted of reviewing contemporary political, economic, and environmental situation in Central Asia followed by elaboration of the main criteria to be used for the AALS scenarios building. The following criteria have been chosen:

[8] UNEP's third Global Environment Outlook (GEO-3) Report was published in 2002. The report presents four scenarios of sharply contrasting futures, looking ahead over the next thirty years. The four contrasting visions have many implications for policy – from hunger to climate change, from freshwater issues to biodiversity and from waste generation to urbanization. GEO-3 Report quantifies the impacts of the scenarios for all 19 GEO 'sub-regions', such as Eastern Africa, South Asia and Central Europe. Regional impacts are discussed in the context of sustainable development. The report summary compares the impacts of the four scenarios across regions – and for the world as a whole – in the light of internationally agreed targets including those in the Millennium Declaration where applicable [35].

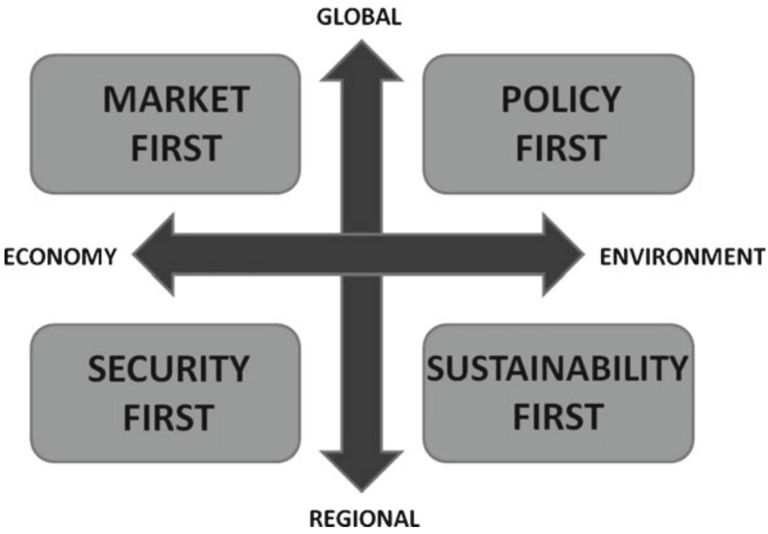


Fig. 11.11 GEO scenario conceptual scheme

1. *regional cooperation* focused on the water policy with regard to the water discharges coming to the AALS. In particular, Kazakhstan and Kyrgyzstan were considered the chief players defining the further lakes' functioning.
2. *regional climate change* addressed through the change of the annual average temperature and evaporation.

11.4.2.1 Main Criteria

Regional Cooperation

Regional cooperation among Central Asian republics is the first criterion which was set for the scenario elaboration. This criterion was selected due to the contemporary significance of the interstate relationships determining the development of the overall water situation in the whole region. The regional water situation is focused on the questions of water distribution among the Republics, building water policy with focus on sustainable and integrated water use and development of legislative environmental base.

Regional cooperation among the republics is examined from the two perspectives. They are as follows:

Uzbekistan and Kazakhstan
In the context of the Aydar-Arnasay lakes' functioning regional cooperation among the Republics principally focuses on the amount of water discharged from the Chardara Reservoir located on the Kazakh-Uzbek border.

Based on the detailed analysis of the legal documentation,[9] national policy papers and other relevant reports, the conclusion about absence of any coordinated water policy between countries above has been made. The current water discharges from the Chardara Reservoir are not regulated at all. They are being implemented without any agreements and regulations that could ideally be proposed by the concerned Republics.

Contemporary situation between the two Republics encounter several problems such as the unsteady water discharges from the Chardara, leading to the gradual alteration of the lakes' hydrologic regime, including growth of mineralization and enhancing the process of eutrophication, changes of local climatic conditions and disruption of previously flourishing fish industry. Therefore, the relations between Kazakhstan and Uzbekistan should be taken into account.

Kyrgyzstan

A special emphasis should be paid to the interstate relations of both Uzbekistan and Kazakhstan with Kyrgyzstan. This is a requirement due to the necessity to operate the Toktogul Reservoir, which is one of the most important strategic objects in terms of provision of both water and energy to the population and industries.

According to the literature review, transfer of the Toktogul Reservoir into a power-focused regime, which resulted in huge amounts of water releases during the non-growing period changed the relationships with the downstream countries, Uzbekistan and Kazakhstan [2]. At present, they experience a lack of water resources during the growing periods. Moreover, the functioning of the Aydar-Arnasay lakes directly depends on the Kyrgyz position with regard to the amounts of water released from the Toktogul for the needs of the downstream countries [9].

Therefore, the consideration of the Kyrgyz policy plays a significant role for the downstream republics and should also be taken into consideration during the elaboration of the scenarios phase.

Regional climate change

Regional climate change is the second criteria to be applied to the AALS scenario building. Change in the regional climate has been observed in the region during the

[9] Some documents analyzed are listed below:

The Water Code of Kazakhstan(2003)

The Water Code of Kyrgyzstan (2004)

The Water Law in Kyrgyzstan (1994)

The Law "*Interstate use of water resources, bodies and facilities in Kyrgyzstan* " (2001)

The Law "*Water and water use in Uzbekistan*" (1994)

"Agreement among Kazakhstan, Uzbekistan and Kyrgyzstan on water and energy resources of the Syrdarya River Basin" (1998)

"Agreement among Kazakhstan, Uzbekistan and Kyrgyzstan on joint water use of Narun-Syrdarya cascade of reservoirs" (1998)

"Agreements between Uzbekistan and Kyrgyzstan on joint water and energy resources" (2000 and 2001)

International Water Law in Central Asia: Commitments, Compliance and Beyond

(Ziganshina D, The Journal of Water Law).

last century. For example, in Kazakhstan the annual average temperature grew by 1.3°C, in Kyrgyzstan – by 1.6°C, and in Uzbekistan – by 0.6–1°C for the period of 1990–2000. Nowadays, the region is facing a high number of drought periods, lack of water for irrigation and domestic needs and many other problems caused by regional climate changes [28].

The Central Asian Republics experience radical economic transitions that have a great impact on many sectors likely to be affected by climate change. In this region, agricultural production has already decreased in some commodity groups. Additionally, quantities and qualities of water resources are at risk of potentially severe effects of climate change. Water resources were intensively abused for the agricultural purposes and were transferred unsustainably from several river systems [27].

In future the regional climate change may result in serious future threats to the fragile water ecosystems in Central Asia including the growing stress exerted on the Aydar-Arnasay lakes. Such problems as an alteration of the hydrological cycle, unstable water-level, high mineralization and fisheries deterioration could appear within this region in the nearest future [27]. Furthermore, climate change might bring changes to the maintenance of AALS biodiversity, including habitat changes and necessity for species to adapt the new living conditions. In particular, the overall maintenance of the AALS wetlands that are designated as a RAMSAR site due to a great variety of waterfowl bird species might be hampered [29].

11.4.2.2 The Water Management Scenarios

Proceeding from the GEO scenario conceptual scheme, the author developed a similar conceptual scheme for the Aydar-Arnasay water management scenarios.

Four alternative scenarios were formulated and evaluated using the AALS model described above. According to Fig. 11.12, four main AALS water management scenarios can be identified:

- The first scenario *"Ready for Challenge"* is based on a high level of regional cooperation and a substantial change of the regional climate.

This scenario assumes that a high level of cooperation among Uzbekistan, Kazakhstan and Kyrgyzstan will give rise to the integrated water management. Such cooperation will encourage the countries to take into account the neighbors' interests. In particular, joint Kazakh and Kyrgyz policy will contribute to the balanced development of the Aydar-Arnasay lakes succeeded by a gradual increase of its volume during the period of 2010–2040.

Kazakhstan will take into consideration the Uzbek needs in terms of providing the necessary amount of the Chardara water for the lakes' maintenance, i.e. keeping them at the same volume and water surface area. At the same time, water surpluses within the Chardara Reservoir will be used by Kazakhstan for national economy needs, mainly for irrigation agriculture as well as for housing and community amenities. Kyrgyzstan, in turn, will pay attention to the interests of the downstream

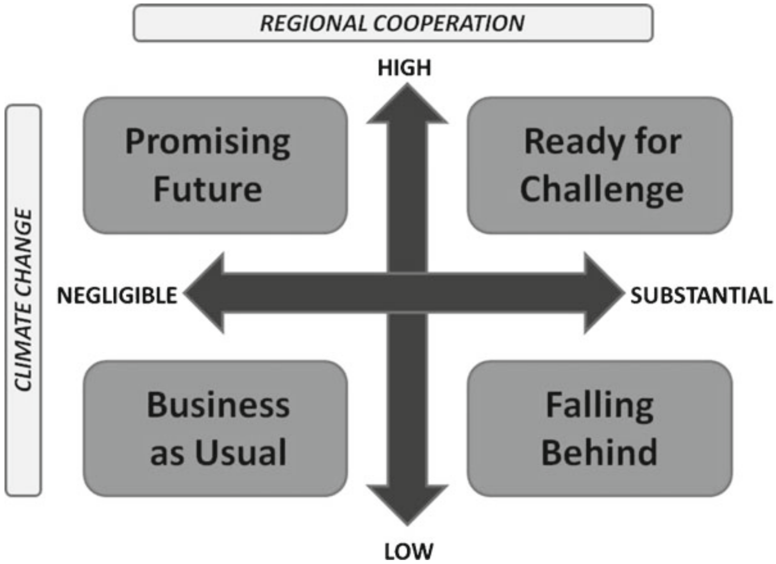


Fig. 11.12 Conceptual scheme of the water management scenarios [29]

countries by regulating the Toktogul Reservoir operation, allowing for the necessary amount of water to be discharged during the summer season.

Close cooperation between Kyrgyzstan and Kazakhstan may have a positive result in terms of renewal of the barter relationships based on gas and water exchange. Consequently, Kyrgyzstan will diminish its currently heavy impact on the Toktogul Reservoir in its power-focused regime thus bringing about the decrease of the water released during the winter time. Uzbekistan will stop suffering from unexpected and severe flooding during the winter time. Thus, such fruitful beneficial cooperation will provide for a successful and sustainable maintenance of the AALS, enhancing fisheries development, recreational activity and biodiversity conservation.

Assumed severe climatic changes in this scenario might have no negative consequences for the AALS functioning. Potential increase of the annual average temperature over the next 30 years might have an adverse effect neither on the AALS water level nor on its volume. A high level of the regional cooperation, which was considered the key driving force in this scenario, will compensate for the substantial climatic changes. As it was previously mentioned, the AALS volume will be increasing over the next 30 years. It is quite unclear how the volume growth will influence the fisheries development and maintenance of biodiversity, in particular habits of endangered bird species, recreational activity and tourism. According to the modeling results, the volume will increase by 4–6 km^3 during the period of 2010–2040 (Fig. 11.13) [29].

It is assumed that an increase in the volume will negatively affect the AALS functioning and disrupt environmental security of these lakes and surrounding

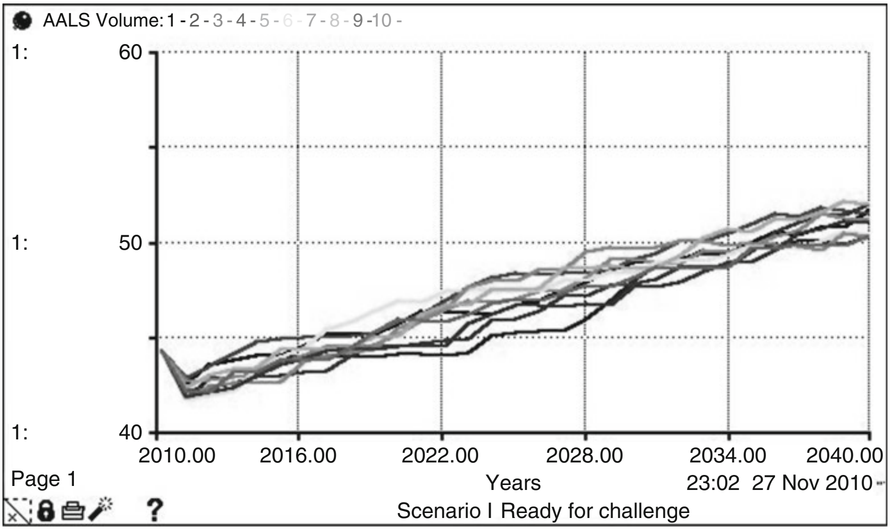


Fig. 11.13 Scenario "Ready for Challenge": the AALS volume change[10] [29]

ecosystem. There are three conclusions to be made with regard to "Ready for challenge" scenario:

- Due to the probable increase of the AALS water level, fisheries situated along the lakes could be flooded and fish production benefiting the republics' economy could be impeded with subsequent drop of the economic profit;
- Future of the Aydar-Arnasay wetlands and their wildlife inhabitants is uncertain. There is a high level of probability that the volume change will trigger habitat disturbances. In order to evaluate how the AALS volume change will influence the wetland conditions, a detailed research using modern GIS techniques and modeling is highly recommended;
- There are some uncertainties with relation to any possibility for recreation and tourism to be successfully developed in the future. On one hand, future change of the AALS hydrological conditions should be taken into account while constructing or redesigning the recreational facilities. On the other hand, existing recreational facilities situated along the lakes' shoreline could be vulnerable to the increase in water volume. The risks associated with the changes of lakes' hydrological conditions should be carefully assessed [29].
- The second scenario *"Fall Behind"* is based on a low level of regional cooperation and a substantial change of the regional climate.

Compared to the first scenario, "Fall Behind" assumes a completely different pathway for the Aydar-Arnasay lakes' future. The countries will take into consideration only their own interests disregarding those of the neighbors. There will be no

[10] In order to get a representative picture, the model was simulated several times for each water management scenario. The lines on Figs. 11.13, 11.15–11.17 present a range of lakes' volume change.

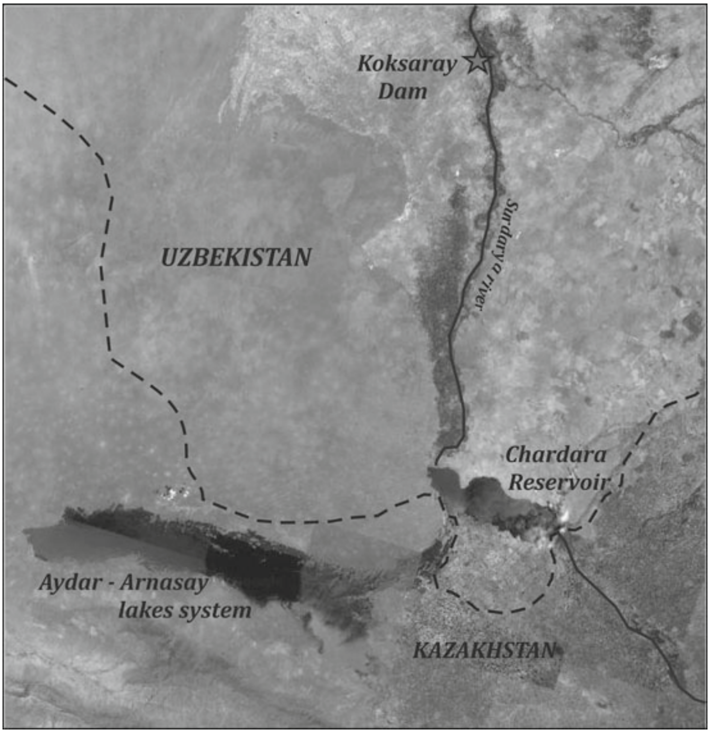


Fig. 11.14 The Koksaray dam (Note: a *dashed line* is a state border between Uzbekistan and Kazakhstan)

regional cooperation at all that may bring about the aggravation of environmental security at the regional level as well as at the local one.

It might happen that Kazakhstan will block the water access from the Chardara Reservoir to the AALS by closing the dam located close to the border. The water surpluses will be accumulated in the Koksaray dam that was launched in March 2010 in the downstream Syr Darya instead of the Aydar-Arnasay lakes (Fig. 11.14).

Hence, the Aydar-Arnasay lakes will lose the supply source and will start drying out. The model simulation demonstrates that the AALS volume will be gradually decreasing next 30 years. The AALS volume will range from 19.3 to 23.09 km^3 in 2020 and from 3.4 to 6.7 km^3 in 2030. By the years 2032–2034 the Aydar-Arnasay system will dry out entirely (Fig. 11.15) [29].

Disappearance of such a meaningful aquatic ecosystem will disrupt the surrounding ecosystems' functioning and aggravate environmental security. The following conclusions concerning "Fall Behind" scenarios can be underlined:

- Fisheries as a significant item of national income will be completely ruined;
- Wetlands situated around the AALS will be entirely destroyed and their dwellers will have to find a new suitable habitat;
- Recreational activity and tourism will be abolished.

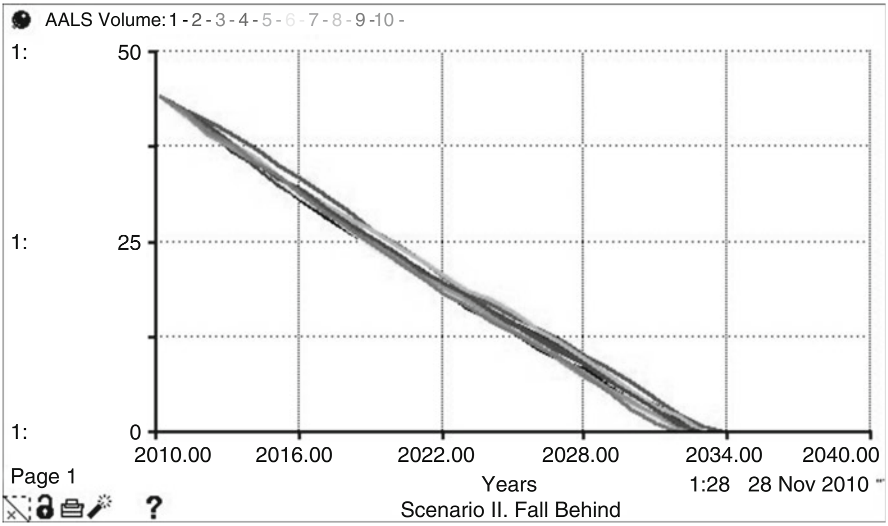


Fig. 11.15 Scenario "Fall Behind": the AALS volume change [29]

Regional climatic changes might considerably affect the AALS hydrologic regime. An increase of the annual average temperature may trigger the increase of evaporation from the AALS water surface and plant species transpiration. Also it might have an effect on the growth of mineralization and deterioration of the living conditions for fish. Future probable climatic changes may become one of the main disturbance factors for the AALS functioning [29].

- The third scenario *"Promising Future"* is based on a high level of regional cooperation and a negligible change of the regional climate (or even absence of any climatic changes).

This scenario assumes a high level of the regional cooperation as in the Scenario *"Ready for Challenge"*. The countries will be concerned with the mutual beneficial interests in terms of integrated water management. They might come up with launching the interstate water policy with respect to the water discharges to the AALS.

According to the modeling results, around 2.11 km^3 of water discharges will be needed for the AALS maintenance in future. Taking this fact into account, Kazakhstan could probably give this amount of Chardara water to the Uzbek lakes and use only the remaining water surpluses for its own needs. Kyrgyzstan might probably renew the barter relationships with Kazakhstan followed by the consequences described in the *"Ready for Challenge" Scenario*.

The experiments with the model identified the stable AALS volume over the next 30 years. This result is well justified by a high level of regional cooperation and the minor climatic changes in future.

As it can be seen from the Fig. 11.16, the AALS volume will range from 41.7 to 45.1 km^3 in 2020, 41.9 – 44.9 km^3 in 2030, and 42.5 – 45.6 km^3 in 2040. On average,

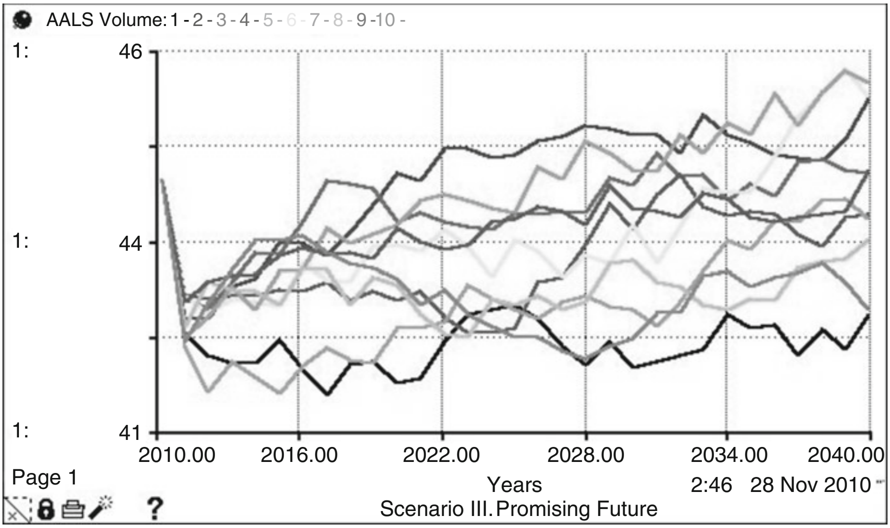


Fig. 11.16 Scenario "Promising Future": the AALS volume change [29]

the AALS volume will be around 43.4 – 44.5 km^3 for the period of 2010–2040 that corresponds to the current value [29].

The AALS future development will answer the lakes' development described in the first scenario. A minor change of the regional climate is the only factor which distinguishes this scenario from the first one. Climate change might have a certain influence on the lakes' hydrological processes. But this influence will not be tangible for the lakes' functioning. This scenario is characterized by a balanced and prosperous development of the lakes system in the future and seems to be the most idealistic. Yet, in real world situation, it might have no chances for successful implementation.

Analysis of the present scenario yielded the following conclusions:

- The volume and water-level will remain at the same level in comparison with the contemporary values;
- Fisheries and recreational activity will be gradually thriving, making their financial contribution to the national economy;
- Conservation measures, especially protection of the AALS wetlands and their inhabitants will be accomplished.

The fourth scenario *"Business as Usual"* is based on a low level of regional cooperation and a negligible change of the regional climate (or even absence of any climatic changes).

The scenario assumes that the AALS future functioning will have well-defined current trends. According to the modeling results, two stages of the AALS functioning were identified for the period of 2010–2040 (Fig. 11.17).

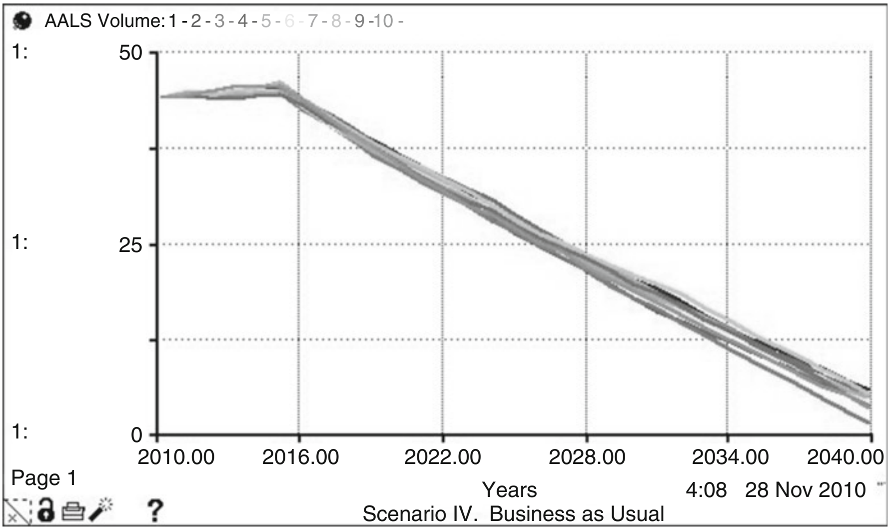


Fig. 11.17 Scenario "Business as Usual": the AALS volume change [29]

The first stage implies that the AALS volume will remain at the same level during the years 2010–2015. According to the obtained results the volume will range from 43.3 to 44.7 km^3 in 2010–2015 and the system will function in a balanced manner.

Such results could be explained by the fact that Kazakhstan will still continue to release water to the Chardara Reservoir followed by supplying the lakes, thereby keeping their balanced functioning. For its own needs, Kazakhstan will use only the Chardara water surpluses. It is possible that the use of water surpluses will be needed for testing the newly operating Koksaray dam located in the downstream Syr Darya.[11] With the present course of development, the AALS functioning will be kept during the period of 2010–2015.

The second stage will begin after 2015 when the gradual decline of the Aydar-Arnasay lakes' volume will take place. The results obtained from the model simulation show that the volume will vary considerably ranging from 33.2 to 35.4 km^3 in 2020, from 15.9 to 19.5 km^3 in 2030. By the years 2039–2040, the volume will be about 1.3–3.4 km^3. After 2040 the Aydar-Arnasay lakes will ultimately dry out (Fig. 11.17) [29].

The main reason for designing the second stage of the scenario past the year 2015 is based on the predicted change of the Kazakh priorities. From 2015, there is a high probability that Kazakhstan will start using the Koksaray dam in full operating mode. Consequently, the Chardara water will be mostly used for irrigation of the southern Kazakh areas.

[11] See Fig. 11.14.

Kyrgyzstan will also undertake the policy of self-interests course. The Republic might carry on using the Toktogul in the power-generated regime, releasing a huge amount of water downstream and flooding areas located there.

According to this scenario, the future climatic changes will be negligible and will have no impact on the lakes' hydrologic regime. Therefore, the conclusion is such that the climate change will have a minor effect in terms of changing the AALS operation.

In the light of the current trends observed within the region, the *"Business as Usual*" scenario has the largest chances to be plausible in the future.

11.5 Discussion

Nowadays all Central Asian Republics tend to conduct the policy of independency and take into account only their own interests. Kyrgyzstan continues using the Toktogul Reservoir for energy generation and discharges the excess water during the winter time [4]. Uzbekistan and Kazakhstan are trying to store water coming from Kyrgyzstan as much as they can [30].

The operation mode of the Aydar-Arnasay lakes still depends on the following factors:

- The Kazakh policy in the context of amount of water discharged from the Chardara Reservoir;
- The Kyrgyz policy in relation to the Toktogul operation.

Water management in Central Asia is an issue that is entirely based on the Republics' decision. There is no close cooperation among countries with respect to the integrated water use. There are neither existing agreements signed nor modifications in environmental legislation focused on joint use of water resources. Self-interests and self-sufficiency are prevailing in the countries' concern.

Having simulated the AALS model for each water management and analyzed the results, the Scenario "Business as Usual" based on a lack of regional cooperation among the Republics and negligible climatic changes turned to be the most realistic and plausible for the fate of the lake system. There are two main reasons for that:

- The issue of water availability and self-sufficiency will be the top priority for the Kazakhstan in the near future. Construction of the Koksaray dam in the lower Syrdarya supports this point very well. Kazakhstan will start using the Koksaray dam in a full operational mode, meaning that no water will be discharged to the Aydar-Arnasay lakes from the Chardara Reservoir. The functioning of the entire lakes' system will be compromised. Correspondingly, the fisheries that bring substantial financial benefits to the Uzbek economy and contribute to the regional food security will be ruined. Maintenance of biodiversity will be difficult to achieve and the scale of recreational activities and tourism will be diminished.

- Minor cooperation between Kazakhstan and Kyrgyzstan will not give rise to the renewal of the barter relationships. The Toktogul operation in the power-focused regime will be kept. Taking into account this fact, no water will be available for the AALS maintenance. The political disagreements, being currently observed in the region, will probably hinder the beneficial interstate relations in terms of implementation of the coordinated water management. The rigorous interstate relations will bring about transboundary water conflicts aggravating environmental security in the region as well as in the Aydar-Arnasay lakes.

11.6 Conclusion

This paper analyzed the historical formation of the Aydar-Arnasay lake system. The five main historical stages have been identified. The calculation of the AALS water surface area was performed for the period of 1969–2008 and was followed by interesting findings. Two main criteria that were crucial for the application in the scenario building were identified such as the level of regional cooperation and climate change factor within the region. Based on the identified criteria, four alternative scenarios for the system operation for the period of the next 40 years were formulated and evaluated using the AALS model.

Although there is a high level of uncertainty associated with regional policies and environmental situation, the most probable scenario for establishing the lakes' future is characterized by the system's disappearance due to a lack of regional transboundary cooperation and controversial decision-making process among the regional states over their legal share of the limited natural resources, water and gas.

The disappearance of the AALS will result in significant economic and environmental damages to the Republic of Uzbekistan. Fisheries will probably be ruined and Uzbekistan will lose a significant item of national income. Wetlands situated around the AALS will be entirely destroyed and their dwellers will have to find new suitable habitats. Recreational activity and tourism will fall into decay. Therefore, an uncertain future of the Aydar-Arnasay lakes undermines environmental security in the whole region.

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Chapter 12
Caspian Sea: Problems and Prospects

Anar Mansurov

Abstract The Caspian Sea is one of the most unique and fragile ecosystems in the world. Having been affected by centuries of human activities including fishing, management of the feeder rivers and hydrocarbons extraction, it currently suffers significant environmental pollution and deterioration. The main aspects of the current environmental problems in the region are attributed to severe oil and heavy metals pollution, decrease in biodiversity, flooding and water level fluctuations. Urgent measures need to be taken immediately by all littoral states to end the current degradation of the Caspian Sea and to rehabilitate its flora and fauna.

Keywords Caspian Sea • Oil pollution • Caspian ecosystem • Caspian biodiversity

12.1 Introduction

The Caspian Sea is the world's largest body of inland water with a total surface area of 386,400 km^2 and approximate volume of 78,700 km^3. Salinity of the water in the Caspian is approximately one-third than that of the oceanic water [2]. Despite the fact that in most of the literature and media it is usually referred to as the "Caspian Sea", from the scientific point of view, it should more properly be referred to as the biggest lake in the world [5]. The Volga River, draining area of 1,400,000 km^2, contributes roughly 75% of the total inflow to the Caspian. The other four major rivers (out of approximately 130 inflowing rivers and streams) that contribute an additional 15% to the inflow are the Kura, Ural, Terek and Sulak rivers. Water level of

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the Caspian fluctuates significantly over time. Between 1978 and 1995, water levels rose by approximately 2.5 m, but it has still not reached the highest recorded level of 1880. Significant decrease in water level happened between 1920s and 1977. These fluctuations of the water level are attributed to the longer precipitation and runoff cycles that are, in turn, influenced by long-term patterns in atmospheric circulation over the North Atlantic Ocean [5]. Five states share access to the Caspian Sea: Azerbaijan, Iran, Kazakhstan, Russia and Turkmenistan. From a geopolitical point of view, the legal status of the Caspian is not yet agreed between littoral states, and sea surface as well as water column resources are still to be demarcated. The entire Caspian Sea region is geologically unstable with frequent sinkholes, mudslides, mud volcanic activities, seismic and surge events and geotectonic dislocations [6]. The long history of isolation of the Caspian aquatic environment has had a strong influence on its biodiversity. The Caspian Sea is home for around 400 endemic aquatic taxa, including 115 species of fish some of which are anadromous, migrating to the rivers for spawning. The most famous are seven species and subspecies of sturgeon and the Caspian seal – one of two freshwater seal species occurring worldwide [2]. It is clear therefore that the Caspian Sea is one of the Earth's unique ecosystems – but due to continuous mismanagement of human activities and naturally occurring degradation it currently faces significant environmental deterioration.

12.2 Human Impacts and Current Environmental State

Environmental impacts on the Caspian Sea itself and the surrounding region could be generally grouped under the following categories:

- Pollution of the water body and sea-floor sediments pollution due to oil exploration and production – both offshore and onshore, transportation and navigational activities, underwater pipelines;
- Direct discharges of highly contaminated effluents from industrial enterprises situated on the coastline;
- Discharges of improperly treated and raw sewage and urban effluents;
- Industrial, agricultural and domestic pollution brought in by rivers from the upstream states;
- Impact on surface runoff, and river dynamics – construction of dams and barrages (especially on Volga River) resulting in flooding and altered water cycle;
- Overfishing and poaching, illegal trade of caviar;
- Emergence of invasive species from improper management of ballast water, migration through Volgo-Don channel (e.g. *Mnemiopsis leidyi* ctenophore from the Black Sea) and past purposeful introduction of commercial alien species (e.g. humpback salmon – *Oncorhyncus gorbuscha*);
- Naturally occurring seepages of hydrocarbons from the seabed.

Aspects listed above and corresponding impacts have resulted in severe degradation of the coastal area, depletion of the fish stocks and significant decrease in biodiversity [6]. Due to the close relationship between humans and the Caspian, the

Table 12.1 Total pollution load to the Caspian Sea

Criteria:	BOD	N	P	E. Coli	Oil	Hg	Cd
Sources	kt/year	kt/year	kt/year	10^15 C/y	kt/year	t/year	t/year
Rivers	641	827	88	145,000	75	14	141
Municipalities	80	24	6	5,000	19	1	2
Industries	25	2	1	0	28	2	6
Atmosphere	0	39	0.8	0	0.35	0	0
Total	746	892	95.8	150,000	122.35	17	149

Data source: CEP [3]

oil and heavy metals pollution of the water had significant impacts on human health in the coastal communities. Table 12.1 below displays total pollution loads to the sea from main sources according to the Caspian Environment Program data for 2003.

Despite shut-down of a significant part of the major industrial facilities (mainly chemical plants and refineries) during the last 20 years, the level of environmental pollution remains very high. This is mainly caused by aging of pollution control and wastewater treatment facilities and obsolete underwater piping systems, as well as lack of emergency control equipment especially on old offshore oil production facilities. Rivers bring all kinds of industrial, agricultural and domestic pollutants to the Caspian. The Volga River alone accounted for 2.5 billion m^3 of raw sewage discharges and for 7 billion m^3 of treated sewage discharged annually, while Kura and Araz rivers are contributing approximately 500 million m^3 of sewage annually [7]. Discharge of untreated sewage from urban areas along the shore raises risk of spread of infectious water born diseases among human populations and diminishes the value of the Caspian coast as a recreational area. High loads of nitrogen and phosphorus cause severe eutrophication both in rivers and in estuaries as well as in adjacent wetlands.

Oil pollution in the Caspian Sea is attributed to human activities in oil exploration and development (in all five littoral states) as well as natural oil and gas seepages from the sea bed. The area around Absheron peninsula is considered to be the most affected because of the legacy of more than 150 years history of oil production, and the proximity of Sumgayit chemical production factories and oil processing facilities. According to the Blacksmith Institute [1] Sumgayit area was ranked in the top 10 of the most polluted places in the world. Recent studies of the sediments from the Baku Bay and Chirag offshore oil field revealed concentrations of 270–2,100 and 19–3,860 mg/kg of petroleum hydrocarbons respectively. Such high concentrations of oil pollution lead to complete loss of benthic fauna and consequently fish populations feeding on benthos [7]. Improperly capped and abandoned wells, leaking underwater pipelines, vessels discharging used oil to the sea, precipitation of oil particles discharged to the air by the onshore industry facilities – are the main contributors to human induced pollution of the Caspian.

Population of the Caspian seal are also significantly affected directly by oil and heavy metals pollution of water, accumulation of parasitic infections, diseases, loss of breeding habitats and indirectly through decline of fish populations. Populations of Caspian seal had decreased from approximately one million in early twentieth century to 30,000 by the 1990s [2].

Another important problem is overfishing. Although governments of the littoral states significantly reduced quotas for fisheries, poaching impact on the fish stock is hard to estimate. According to the Caspian Scientific Research Institute of Fisheries, Russian Federation, [4] the current total unofficial catch exceeds legal quotas 11-fold. In the 1980s annual catch of sturgeon was around 20–25,000 tones. In 1990s total harvest declined by 90% and in 1998 annual catch did not surpass 1,500 tones annually. Pollution and overfishing are not the only problems for the sturgeon population. Construction of dams and barrages especially on Volga and Kura rivers raises serious obstacles for populations of fish to go up the river to spawn. Competing invasive species introduced for commercial harvesting to the Caspian during the soviet period also pose additional burdens on the food stock thus limiting populations of the endemic species. Recent instances of hybridization of Caspian sturgeon and Black Sea sturgeon have been recorded but the implications of this phenomenon on overall sturgeon species diversity, and thus on the Caspian environment is still to be assessed [2].

The history of human attempts to manage water levels of the Caspian Sea could be visualized by the example of Kara-Bogaz Gol bay. Kara-Bogaz Gol is a large shallow water, highly saline, lagoon in the eastern part of the Caspian Sea, separated from the main water body by natural sand bars. It acted as a natural evaporative sink and thus was deemed to be a major contributor to overall decrease in water level during the twentieth century. In 1980 a dam was constructed to prevent water from entering Kara-Bogaz Gol bay (approximately 30 km^3 annually). Almost immediately sea levels started to rise. But this increase was rather a consequence of naturally occurring fluctuations than a result of Kara-Bogaz Gol blockage. According to estimates, isolation of the bay contributed only 11 cm out of 25 m of total sea level rise during the next 10 years [2]. Overall rise of the sea level had a disastrous effect on the coast line, resort and industrial facilities along the shore. In 1992 dam was completely removed.

Other impacts from human activities such as degradation of the coastline due to mismanagement of construction and development activities, and acidification caused by air emissions from industries onshore have impacted wetlands as habitats for migratory birds sand should be considered for immediate intervention.

12.3 Measures to Suspend Environmental Degradation of the Caspian Sea

Since the Caspian Sea is a landlocked body of water the primary natural means for pollutants removal is biodegradation and, to a lesser extent evaporation and chemical breakdown. Thus urgent measures should be taken to stabilize the situation, cease pollution of the reservoir and attempt to rehabilitate the Caspian:

- Introduction of strict international standards and control measures in offshore and coastal oil and gas exploration and production industry. Implementation of zero discharge strategy in respect to the discharges of produced water, drill cuttings, fluids and chemicals as well as other hazardous materials;

- Proper decommissioning of all redundant hydrocarbons production, accumulation and transportation (underwater pipelines) facilities as well as improperly capped exploration wells and structures to avoid human induced hydrocarbons seepages;
- Introduction of international navigational standards and compliance regulations such as MARPOL to control pollution arising from the marine vessels;
- Reconstruction of all onshore sewage and wastewater treatment facilities in accordance with current technological and regulatory developments to comply with Caspian specific domestic and industrial effluents discharges criteria;
- Strengthening of control on occasional direct discharges of untreated sewage from the onshore and offshore facilities;
- Regulation and restriction of use of agricultural chemicals, fertilizers and pesticides in coastal zones and upstream the rivers. Strengthening of regulations for all land-based activities impacting runoff water and groundwater table. Establishment of interstate communication and control over discharges to rivers. Common internationally accepted standards should be introduced for immediate implementation in regards to agricultural, domestic and industrial discharges to the rivers;
- Poaching-control measures and restriction of fishing quotas for all endangered species. Detailed monitoring of fish spawning in the rivers and effects caused by human introduced barriers to fish migration. Control of populations of invasive species where practicable;
- Minimization of impacts from onshore oil processing industries through introduction of emission treatment equipment and control of adherence to discharge standards;
- Regulation of construction and development activities along the Caspian shores in all littoral countries;
- Implementation of the Conservation of Caspian Biodiversity Strategy [2];
- Control of river flow and freshwater management activities in upstream states, consideration of impact to Caspian Sea in all upstream developments and environmental assessments;
- Improve public access to information and community participation in regards to all Caspian environment related aspects;
- Introduce educational programs to raise public awareness on emerging environmental issues for the entire Caspian region.

Immediate implementation of the measures mentioned above will slow, if not completely stop, continued deterioration of the Caspian Sea, allowing it some time to rehabilitate itself from past deterioration.

12.4 Conclusion

People living around Caspian Sea were benefiting from its bounty since ancient times, but not always treating it as the precious and very fragile asset that it is. The real disaster started to emerge during the ninteenth century with the beginning of oil production from early offshore and coastal oilfields. Peaking in the middle of twentieth century, oil production brought enormous revenues but triggered environmental disaster that we are facing now. Now it is not only a threat to biodiversity, it is also a threat to human health and human well-being. It is also a real threat to the entire region. The example of the Aral Sea should be a constant reminder to us of where disrespect to the delicate environment could lead. Possible future effects of the current magnitude of human impacts on the Caspian are very hard to predict. Environmental quality of the region is decreasing very rapidly. Maybe it is already too late to save certain species and Caspian will never be like it was before. However we can still slow or stop its total degradation and help nature to rehabilitate itself.

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Chapter 13
Water Management and Use in the Amur-Heilong River Basin: Challenges and Prospects

Natalia Pervushina

Abstract The Amur-Heilong River is the longest water body in the Eastern Hemisphere and is also known as the eleventh largest river basin in the world. The river passes through the neighboring territories of Russia, China and Mongolia and represents an important transboundary water body. Analysis conducted in this paper examines the most crucial Amur-Heilong watershed characteristics and problems. The discussion pays particular attention to the regional water management strategies and specifically to water quality and quantity concerns. Additionally, this article identifies a number of potential threats to environmental security and focuses on their implications for human health and chances of transboundary conflicts escalation.

Keywords Amur-Heilong • Songhua • Sungari • River basin • Watershed • Transborder water conflicts • Water quality • Water quantity

13.1 Introduction

The Amur-Heilong River is the longest water body in the Eastern Hemisphere, which is also known as the eleventh largest river basin in the world [14]. Unlike many Siberian rivers that flow in a north-south direction, Amur-Heilong River has a west-east orientation and extends into the Tatar Strait of the Okhotsk Sea. The River passes through three neighboring countries such as Russia, China and Mongolia.

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Since the largest sections of the basin are located on the territories of Russia and China, their impact on the entire system of water management and use is the greatest. The conducted analysis pays particular attention to the regional water management strategies and focuses specifically on water quality and quantity. Additionally, this paper identifies a number of potential threats for environmental security and focuses on their implications for human health and increasing chances of transboundary conflicts.

13.2 General Description of the Amur-Heilong River Basin

The Amur-Heilong is one of the world's longest rivers that functions as a border between Russia and China and stretches for over 3,000 km (Fig. 13.1). The basin characteristics on Russian and Mongolian sides are very similar to those of other big Russian rivers such as the Lena and the Yenisey, however these similarities are lost at the border with China. Poorly inhabited territories around the river basin on both Russian and Mongolian sides are drastically different from the over-populated Chinese side.

The basin is geographically located in the temperate climate zone, which has monsoon characteristics in the eastern and continental climate characteristics in the western parts. Thus, the basin expresses different characteristics throughout the

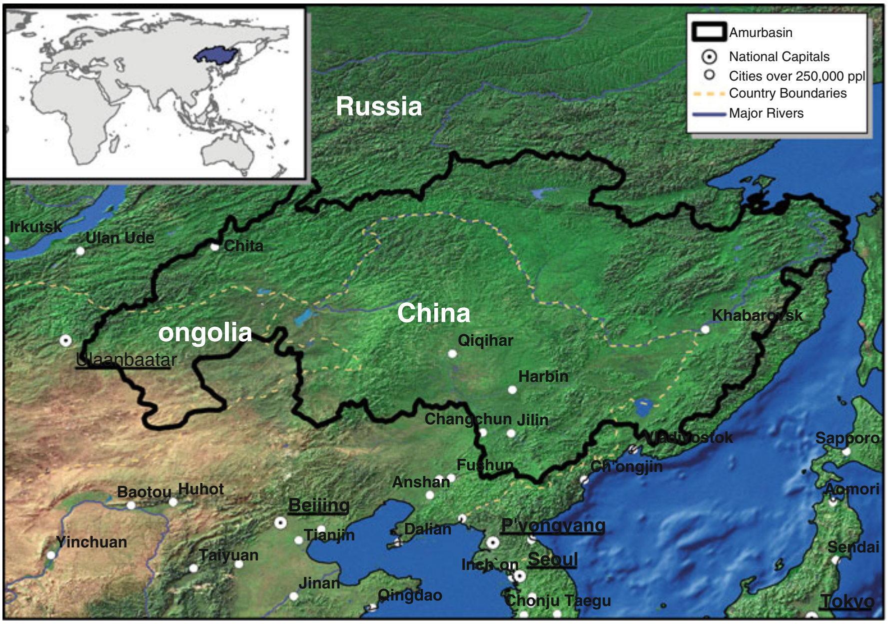

Fig. 13.1 Map of the Amur-Heilong River basin (WWF Russia)

course of the river. Russia has the largest hydrographic network in this river basin with 172 thousand watercourses and more than 60 thousand lakes [17]. China has much less available water resources due to the climate characteristics and the desert area at the Chinese-Mongolian border. The Chinese side is exposed to extensive agricultural activity that results in consequent land degradation. As for Mongolia, it possesses four main rivers with more than 400 tributaries.

The Amur-Heilong River basin is home to some of the world's most outstanding ecosystems and most charismatic plants and animals many of which originated due to the favorable conditions of the regional environment. Genetic intermixing of species occurred mainly in places where different habitats happened to intercross, for example in places where the Amur-Heilong valleys and tributaries have different types of landscapes: desert, steppe, grassland, taiga, mix-broadleaved coniferous forests and tundra. This diversity of species contributes to the Amur-Heilong biodiversity. The flora of the basin includes 9,000 species of vascular plants and fauna is characterized by approximately 700 species of vertebrate animals and around 135 species of fish including the biggest freshwater fish in the world – Kaluga (*Huso dauricus*). Many wildlife species that are characteristic for the Amur-Heilong appear on the Red List of the World Conservation Union as globally threatened. Four of the world's top-priority endangered ecoregions outlined by the World Wildlife Fund (WWF) are located in the Amur-Heilong River basin [14]. The most diverse temperate forests, vast grasslands and extensive fertile belts of wetlands are specific for the Amur-Heilong. The regional ecosystem on the Russian Far East possesses about 5% of all species living on the planet [2] and contains some of the most biodiversity-rich temperate forests in the world [3].

The Amur-Heilong is a unique transboundary region between the booming economy of Northeast China and the industrially under-developed region of the Russian Far East and Mongolia. The total population of the basin is approximately 80 million people according to various estimates. Around 75 million reside on the Chinese side where the population density is high and settlement is relatively recent. The rest of the area is relatively sparsely populated on both Russian and Mongolian sides. Around five million people reside in Russia and around 50 thousand people reside in Mongolia [17]. The basin has the following administrative division: five administrative units on the Russian side (Primorsky province, Khabarovsky province, Evreiskaya Autonomous Province, Amur Province and Zabaikalsky province). Three administrative units are located on the Chinese side: Heilongjiang, Jilin and Inner Mongolia, two of them continuously suffer from desertification since the 1980s. Only two provinces, Hentiy and Dornod, are located on the Mongolian side.

Although history of human settlement in the basin is relatively short, damage done by excessive resource exploitation in the twentieth and twenty-first centuries has severely depleted not only natural resources, but also the capacity of some renewable resources, i.e. fisheries, wetlands and forests to recover [14].

Being an important source of water supply and a strategic resource for all three countries associated with the basin, the Amur-Heilong has become the site of long-term large-scale investment projects. The projects are connected with gas and oil extraction, mineral material extraction, power generation through construction of hydroelectric stations, timber harvesting and primary processing. The key actors and investors that utilize the basin are Russia and China who have recently strengthened their collaboration in development of natural resources. The collaboration has been enforced by signing two recent development programs in Russia and China: "Social-economic development strategy in the Far East and Baikal region until 2025" (further referred to as "Strategy") and "Plan of Revitalizing Northeast China".

Scientists identify the current ecological condition of the Amur-Heilong basin as close to critical, whereas the situation in the lower regions to a certain degree can qualify as critical [9]. The critical condition is caused by high vulnerability and low level of resilience of water and wetland ecosystems and forests due to high anthropological pressure. Extensive use of nature, water, timber logging and fishing destroy natural resilience of the basin system.

The following anthropogenic factors significantly contribute to creation of ecological problems across the basin [17]:

- high population density and uneven population distribution;
- water pollution by untreated or not properly treated waste water from agriculture;
- activities of industrial and community services;
- development of urbanized landscapes;
- industrial and agricultural constructions;
- timber logging, fishing and hunting;
- non-environmentally friendly economy and forest/water management;
- forest fires;
- underdeveloped network of protected areas. According to the last WWF estimates 16% of the total river basin area is considered to be protected areas on the Chinese side, 13% – on the Mongolian side and only 9%-on the Russian side [12].

The main ecological problems in the basin are transformation and destruction of historically created ecosystems, low level of ecosystem resilience, productivity and biological diversity. This leads to the decreasing quality and low ecological capacity of the natural resource potential in the Amur-Heilong basin.

13.3 Water Use

Approximately 80% of the Russian-Chinese border mimics the course of the Amur-Heilong River and is the area of major environmental concern. Considering the necessity to preserve the natural boundary, Russian-Chinese environmental issues should be analyzed mainly from the perspective of water resource management and use. Russia and China have common interests related to water such as water supply for economic activity, water quality improvement in accordance with certain norms and standards and damage prevention from flooding [10]. Problems related to biodiversity and ecosystem conservation with natural watercourse regime tend to be of secondary importance.

Fig. 13.2 The hydrographic network of the Amur-Heilong basin

13.3.1 Water Quality

At present Russia is concerned with the Amur-Heilong water quality as it is currently placed in a more vulnerable position than China due to the country's large water intakes and the need to address the pollution. The most developed Amur-Heilong tributaries and upper reaches of other watercourses are located on the Chinese side, plus the overall level of anthropogenic pressure is much higher in China and is expected to increase in the future. The water resource network is much more extensive on the Russian side of the basin with exception for the Khanka/Xinkai lake region in the Primorsky province in Russia (Fig. 13.2).

Amur-Heilong is one of the rivers with the highest level of pollution caused by natural contaminants (phenols, irons and other metals resulting from natural hydro chemical reactions). The river annually discharges around 24 million tonnes of suspended sediments, with the average water pollution density is 90 ppm. However, when comparing the average drainage of suspended sediments under equal water flow during the last 15–20 years the result shows that drainage has increased by 10–15% since then [13]. This phenomenon happens due to the rise of anthropogenic pressure in Northeast China and tilling in particular. The Songhua/Sungari River, one of the main tributaries of the Amur-Heilong River on the Chinese side also discharges tonnes of sediments into the river. According to various estimates, its share in the entire Amur-Heilong pollution ranges from 60% to 90% [14].

Table 13.1 Industrial and municipal water discharges in the Songhua/Sungari river basin in 2003 [1]

Type	Total waste water discharge m^3/day	Total waste water, discharge km^3/year	COD kg/day	COD tonnes*10^3/year	NH3-N kg/day
Industrial	3,334,323	1.217	563771	206	41,803
Municipal	6,083,740	2.221	2,387,613	872	197,510
Total	9,418,063	3.438	2,951,384	1,078	239,313

The developing economies of Russia and China were little concerned with problems of pollution during the socialist industrial development period. With the collapse of the Soviet Union Russia lost the political will to increase industrial production around the basin. On the south river bank the situation was worse due to intense development of environmentally dangerous industries. The water quality problem was further complicated by the absence of transboundary pollution prevention standards and countries' mutual inability to discuss their responsibilities towards preserving the environment of the basin [14].

Both Russia and China pollute the basin, however their level of pollution is different. At the same time Mongolia's impact on water pollution is much lower than that of China or Russia. The main pollutants found in the river are ammonium nitrate, lead and hydrocarbons [10]. Industrial point-source pollution, industrial spills, agricultural non-point run-off and sewage from urban areas are widely considered to be the key sources of water pollution in the basin [16].

While discussing Russian monitoring reports, Karakin indicates that Russia annually discharges around 1 km^3 of wastewater from point pollutants into the river [10]. Most discharged wastewater is not treated in accordance with standard requirements. There is some amount of wastewater from the non-point pollutants on the Russian side but it is small due to the low level of agricultural activity.

The most conservative Chinese estimates of wastewater discharge from the point sources suggest that China discharges 4–5 km^3 annually. However, simple calculations based on China's water intake figures suggest that even if 50% of water were taken irreversibly, these figures would still be underestimated [10]. Up to 90% of wastewater is discharged to the Songhua/Sungari River on the Chinese side.

Table 13.1 shows the findings of the Asian Development Bank (ADB) report written before Songhua/Sungari spills in 2005. The aim of the report was to develop pollution prevention measures in the Songhua/Sungari River [1].

The same ADB report shows that non-point agricultural wastewater discharge exceeded the volumes of point source industrial wastewater discharge in the Songhua/Sungari river during 2005 (Table 13.2). This means that the growing population density in Northeast China will lead to an increase in volumes of the non-point wastewater discharge in the future.

Unfortunately, the numbers do not give an accurate picture for the entire basin, nor do they give information regarding the overall volumes of pollutants and their distribution. Therefore, we can neither make any specific predictions of ecosystem

Table 13.2 Percentage of point/non-point sources of wastewater discharge on the Songhua/Sungari river basin [1]

COD	Nonni, %	2nd Songhua, %	Songhua/ Sungari, %	Total basin of Songhua/Sungai, %
Point sources	22	70	54	47
Non-point sources	78	30	46	53

response to the pollution nor estimate pollution's potential effect on human health. However, it is clear that the problem of transboundary basin pollution will become even more complicated in the future, where non-point sources of pollution will be the key polluting agents.

13.3.1.1 Implications of Water Quality Problem: Human Health

The main sources of water pollution in the river basin are the industrial point sources, industrial spills, agricultural run-off and sewage from urban areas. One of the cases connected with industrial spills was the accident on the Songhua/Sungari River in a petro-chemical plant of the Jilin Petrochemical Corporation located in Jilin city of Jilin Province in November 2005. The accident has become one of the largest trans-boundary chemical spills in a river system in recent years [15]. As UNEP expert group report shows, the explosion on a plant led to the spill of an estimated 100 tonnes of toxic substances containing benzene, aniline and nitrobenzene [15]. The pollution spread to the Songhua/Sungari River followed by flowing of the contamination plume downstream towards the Russian side. In a week the plume reached Harbin in the Heilongjiang province (population four million) where the peak concentration of nitrobenzene was 0.581 mg/l (33.15 times the permissible level). The city water supply was shut down for several days after the spill. The Jiamusi monitoring station recorded that the stretch of the plume was 80 km while it was passing through Harbin and furthermore it extended to 150 km long when passing through Jiamusi [15]. Five days after the accident, the Chinese State Environmental Protection Administration (SEPA) issued emergency monitoring instructions to its provincial counterparts in Heilongjiang and Jilin provinces. The instructions enabled different levels of authorities to take appropriate mitigation and timely measures. Within a short period of time Chinese authorities communicated the information regarding the spill to the international community and the highest governmental levels in Russia. Monitoring results were provided to the Russian side on a daily basis. Later the two sides signed the Joint Emergency Response Monitoring Plan on Water Quality on the Songhua/Sungari River.

A research project "Ecological Impact Assessment of the Major Water Pollution Accident in the Songhua River and its Countermeasures" that was initiated by China started in December 2005. The goals of the project were the (1) assessment of the ecological and environmental impacts of the accident and (2) identification of

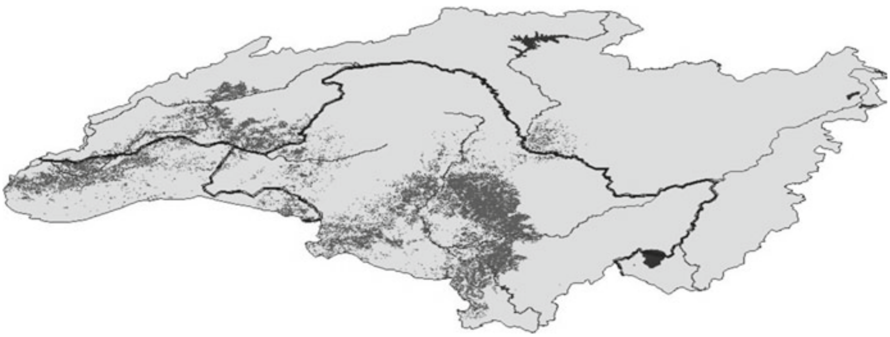

Fig. 13.3 Cropland area in the Amur-Heilong (Source: ESA GlobCover [6])

long-term aquatic ecology pollution risk [14]. The project findings were officially announced by SEPA and showed the following:

- secondary pollution from nitrobenzene in the ice or sediments is minimal;
- nitrobenzene concentrations in the fish of the Songhua River meet the permissible standard and fish are safe to eat;
- groundwater is safe to drink;
- using water for irrigation in spring 2007 would not affect the growth of crops;
- active carbon powder proved effective in removing nitrobenzene from the water [14].

Other research on the ecological effects of the spill by Chinese Research Academy of the Environmental Science showed similar results that the effect of the incident on the Songhua River ecosystem was only temporary [22].

The Songhua spill was not the only recent large-scale accident on the river. The most recent accident happened in July 2010 when 1,000 tanks with 160 tonnes of easily inflammable highly explosive chemicals were flushed by floodwaters into the river in Chanchun city, Jilin province. Most of the tanks were taken out of the water. Chinese experts claim that these tanks did not have any effect on the environment; however no special impact assessment was ever performed.

Russian experts consider pollution from non-point sources from small Chinese farms to have the most negative effect [10]. This factor is hard to assess, however GIS tools allow for estimating the level of anthropogenic pressure in the region. Figure 13.3 shows a cropland area in the river basin and gives a picture of the cropland area distribution in all three basin countries where evidently China's share is the largest.

Regardless of the neutral official Chinese position on pollution effects on the ecosystem and human health, water regional experts express another opinion, which is stated in the Amur-Heilong Reader [14]. The book gives an overview of the basin and collects various specialists' expert opinions with an analysis of human health in the Khabarovsky province where about 70% of the population uses the Amur-Heilong water for drinking and household purposes. According to the data based on sanitary and epidemiologic service reports within the last 5 years, cholera has been regularly detected near Khabarovsk in Russia. Around 23% of water samples from the Khabarovsk water supply system contain bacteria that cause diseases of the digestive system. About 10% of water samples contain antigens of viral hepatitis A. The level of dysentery and hepatitis A in Khabarovsky province is double the national average [14]. Eating fish has the same risks as drinking water. Pollutants are metabolized in the ecosystem by microorganisms and algae and then accumulated by fish that feed on algae and benthic organisms. Fish-eating birds, mammals, and people are impacted by exposure to high concentrations of heavy metals and organic contaminants accumulated in fish tissues [14]. Results of fish microbial analysis showed that all fish in the main channel of the basin, especially from the Songhua/Sungari River downstream, is highly contaminated by bacteria and does not comply with the existing epidemiological standards for human consumption [14]. Gas chromatography found the following volatile organic compounds: ethanol, methanol, acetone, acetaldehyde, ethylacetate, isopropanol, and butyric acid esters. The analysis after the Songhua/Sungari spills in 2005 showed noticeable concentrations of different pollutants in the Amur-Heilong fish (only mercury concentrations were few dozen times higher than normal).

Analysis of development strategies in the Russian provinces shows strong concern for the regional government with regard to river pollution. Below are the main trends of regional development strategies:

- "Social-economic development strategy in the Far East and Baikal region until 2025" indicates that having a water border with China is not seen as a competitive advantage but a problematic factor, which leads to real threats and challenges.
- Khabarovsky province development strategy indicates that there is a high probability of ecological and nature disasters due to the transboundary pollution of the Amur-Heilong River. Special political and social attention should be paid to the problem of transborder river pollution.
- Evreisky province development strategy indicates that the main ecological security threat is a transboundary pollution of river surface waters by pollutant spills from the Chinese side. The region suffers the most severe damage of nature and public health, the condition of most streams is officially declared catastrophic.
- Primorsky province development strategy indicates that having a border with China may become an issue. This province has the least damage in the basin.

China has also performed official assessments and prognosis of the affects of pollution and potential human activity in the Northeast region. Special recommendations for regional development were laid out by the Chinese Engineering Academy in the project named "Revival of all industrial bases in Northeast China". The title of the document indicates that Chinese government is primarily interested in industrial development rather than ecology conservation. The project report mentions that the Northeast region has come to the edge of ecological catastrophe within a 100 years; however the general ecological situation is better than in other Chinese regions [4]. The deplorable ecological condition resulted from the resource mismanagement rather than natural resources limitations. The document provides detailed plans for regional revitalization on the national level and overlooks the ecological effect on neighboring states with a focus on better access to their natural resources.

A number of investigations have been done by international experts in recent years with regard to the growing number of cancer cases and deaths all over China since the breakneck acceleration of economic growth. Nationwide cancer rates have risen since the 1990s becoming the nation's largest killer. In 2007 the disease that was responsible for one in five deaths eventually grew up to causing 80% of the cases since the start of economic reforms 30 years earlier [18]. Many toxic industries have been moved to impoverished, poorly regulated rural areas, where according to the World Bank reports farmers are almost four times more likely to die of liver cancer and twice more likely to die of stomach cancer than the global average [18]. Over the last years, the Chinese media has been full of stories of "cancer villages". In 2010 a journalist posted an online Google map showing more than a hundred "cancer villages". Recent findings indicate that their number has reached four hundred and some of them are located in the Amur-Heilong basin.

13.3.2 Water Quantity

China is currently preoccupied with the problems of water quantity since its main interests are connected with the maximization of water use for social-economic purposes. The problem of water quantity will be getting more important due to the following factors:

- growing tendency for aridification in Northeast China;
- growing demand for provisions – one of China's principal problems of social-economic development.

The first factor is due to extensive human activity and climate change conditions in the region. Precipitation has been greatly reduced and average temperature has significantly risen in Jilin, western Heilongjiang and Inner Mongolia provinces since the 1980s [23]. This has led to an excessive degradation in grazing land and steppes. Reservoir construction in the lower river also causes water shortage and draughts. Total reservoir volume in Jilin province is 40.4 km^3 (more than a half of it is located in the Amur-Heilong), 9.62 km^3 in Heilongjiang province. The largest reservoirs in Russia are located in the Amurskaya province with a total volume of 42.4 km^3 [9].

According to the estimates of Karakin total volume of available water resources in Russia is sufficient for satisfying its needs in the foreseeable future [9]. The volume of water intake for direct consumption amounts to 1% of available water resources. The share of water intake for agricultural needs is not more than 4.5% of all water intakes [9]. Water intake in China in Heilongjiang province reaches almost 40% of available water resources where the share of agriculture is more than 70%. The water volume for irrigation purposes only in Heilongjiang province

Table 13.3 Average annual water use per person in Chinese provinces and Russia [9, 10]

	Inner Mongolia	Jilin	Heilongjiang	Russian side, total volume
Annual water use volume per person, m^3/person	734.5	349.8	712.9	216

is 500–1,000 times more than in the south of the Russian Far East [9]. At the same time the situation in the basin is less intense than in other Chinese provinces where the population has to be evacuated because of desertification (the river basins of Liao, Yellow and Huai). Approximately 10 projects on water runoff diversion from the Amur-Heilong tributaries have been implemented and 20 more are planned to be implemented in China. For comparison, the volume of annual water intake in China is up to 36 km^3, whereas in Russia it reaches only 1.18 km^3 [9]. Thirty-fold difference is mainly due to agricultural activities. The difference in water use per person in Chinese provinces and Russia is presented in Table 13.3.

As observed by Russian scientists, the level of water in the Amur-Heilong River has significantly decreased since the 2000-s, which has led to development of wind erosion processes, drying of lakes and tributaries, and overall degradation with resulting decrease in productivity of flood-plain ecosystems [13]. Incredibly low water levels were observed in 2000, 2001 and 2002. Low water levels led to sharp temperature rise and consequent development of eutrophication processes in channels and lakes. The following large amounts of water flow due to extensive precipitation after a dry period in 2009 that happened due to anthropological pressure and global climate change conditions led to flooding and death of many plants and contamination of the fiver flow with large amounts of organic substances. The processes described had a significant effect on the chemical composition of water in the river.

13.3.2.1 Implications of Water Quantity: Potential Transboundary Conflicts

Shortage of natural resources often results in international conflicts. Water resources were named a key factor leading to intense political pressure and threatening potential sustainable development [20]. Water ignores boundaries, evades institutional classification and eludes legal frameworks. Decrease or scarcity in water quantity, in other words water stress, may have a disturbing effect on the stability in transboundary basins.

The Amur-Heilong basin has a potential for triggering transboundary conflicts due to diminishing amounts of water on the Chinese side. Although there have been no clear signs that the water supply has reached its critical limits, some conflict situations have already taken place.

China's extensive development in the Inner Mongolia has led to gradual desertification. As a response, Chinese government attempted to use water resources in neighboring provinces in order to stimulate the construction of hydro-technical equipment and water transfer projects. One of these projects was the water flow transfer from the upper Argun (or Hailar River in Chinese Language) to Dalai Lake, which is the fifth largest Chinese freshwater lake (Fig. 13.2). The lake is severely shrinking due to human activity influence and climate change. According to media reports, satellite surveys calculated the area of the lake to be 2.370 km^2 in April 2000. By June, 2010, it had shrunk to 1.850 km^2 demonstrating a severe loss of 520 km^2 [19]. The canal connecting the Hailar River and the Dalai Lake was built in 2009 despite the fact that it came into conflict with the Ramsar Convention principles and international agreements on wetlands protection. The initial plan was to transfer 1.05 km^3/year (30% of river flow) to a lake, which would have a negative effect on the upper transboundary River Argun, particularly on flood-plain lands on the Russian side [9]. Ecologists expressed their concerns, however China considered Argun to be its national inner river and therefore it did not see the necessity to inform the Russian government about its redevelopment plans [9]. Additionally, this project was not discussed on the international level either.

In summer 2009, the head of the Zabaikalsky province officially appealed to the Russian Minister of Natural Resources and Minister of Foreign Affairs with a concern regarding the Dalai-Hailar project [11]. The project was later officially discussed, however unfortunately it was not given a proper attention during the official discussion. Later in 2009, the Dalai-Hailar project was launched and raised a lot of concern among ecologists in Zabakailsky province. At present, the water level in the River Argun remains stable due to atypical extensive precipitation, yet the river was suffering from extensive draughts in 2002–2009 [4]. The Dalai-Hailar channel still continues its operation, while ecologists on the both sides are observing a constant decrease in the river water levels.

The case shows that the problem of water quantity has the potential of developing into a larger transboundary conflict. Additionally, Russian water experts officially evaluate the Argun River as the worst polluted water object in the Zabaikasly province [8]. Provided the strategy of Chinese economy development is unchanged, coupled with low-level precipitation in the Argun basin the situation of water supply in the region might run out of control.

13.4 Russia and China Efforts to Deal with Water Related Problems

Surprisingly, the 2005 Songhua chemical spill became a starting point for a new greener and cleaner mode of development in China as well as for better ecological cooperation among the basin-sharing countries. Within several months after the spill, the Chinese government managed not only to strengthen environmental policies in the basin, but also to exploit the incident to support a nation-wide policy reform and increase pollution-prevention investments [14]. This can be justified by the allocation of 12.2 RMB billion for the Songhua/Sungari water treatment in China's 11th 5-year development plan [10]. The agreement on the use and protection of transboundary waters between the Government of the Russian Federation and People's Republic of China was signed in January 2008. The agreement commits two countries to take measures against transboundary environmental pollution. Since then China has already started meeting its commitments by finance allocation, whereas no major actions were observed from the Russian side [5]. The agreement also suggests developing transboundary water quality monitoring and information sharing. The document touches upon the industrial pollution sources only, thereby leaving agriculture non-point pollution sources behind.

Despite the countries' intentions to monitor and share, nothing practical have been done to create the preconditions for successful water management in the basin. There is an absence of transboundary pollution prevention standards; no infrastructure for proper water treatment on both sides; no program or agreement among China, Russia and Mongolia that could serve as a useful ground for transboundary strategic assessment. The Strategic Action Programme (SAP) for the Lake Xinkai/Khanka implemented by Beijing UNEP office in 2006 showed that countries used different methods for water quality assessment (different types of COD) [21]. Five years have passed since the report was written but nothing has been done for the methodology and standards harmonization. At present, China has five water quality standards for surface waters, whereas Russia has seven; the description of water quality according to these standards is also different. Several transborder commissions have been created within the last years in the basin; however they have a low capacity due to reluctance to deal with controversial issues and environmental problems.

Another recent document is the "Collaboration Plan between the Far East and Siberian regions of the Russian Federation and Northeast provinces of the People's Republic of China (2009–2018)". The document was signed by the President of Russia Dmitry Medvedev and the President of China Hu Jintao on September 23, 2009 and covered 205 mutual projects in the transboundary region. The main activities in the document include modernization of industry and accelerated use of nature. Russian projects are mostly connected with extraction and preprocessing of natural resources, whereas Chinese projects are connected with processing final products and technological modernization. The overall plan of actions is of great concern for ecologists who already named the document as "colonization of the Russian Far East and Siberia by China" [5]. Nevertheless, the document refers to environmental issues such as joint monitoring of air quality, joint monitoring of water surface and biological resources, creation of joint protected areas, exchange of ecologically safe technology, technological waste treatment and utilization and exchange of ecological experts. Unfortunately, more detailed measures to deal with environmental issues are not included.

13.4.1 Prospects for Water Use and Management

A limited number of environmental projects covering prospects for basin development have been implemented in the Amur-Heilong. One of these projects was the

GEF project implemented by the UNEP Beijing office. The project was aimed at producing two reports: the Transboundary Diagnostic Analysis (TDA) for the Amur-Heilong and Strategic Action Programme (SAP) for the Lake Xinkai/Khanka [7]. The TDA report is still incomplete; however the SAP report for Xinkai/Khanka Lake was published. It was anticipated that the Xinkai/Khanka SAP framework and findings should be used as the basis for the TDA elaboration for the Amur-Heilong. The SAP report identified the lack of unified authority to manage the lake and its resources as the main obstacle for successful water use and management. Not only do the citizens of each side speak different languages, but even the scientists use different methods for water quality assessment resulting in disorganized management attempted in the lake basin [21].

A group of international experts has elaborated several scenarios on the future prospects of the basin [14]. These scenarios are laid out in the Amur-Heilong basin reader. One of these scenarios is the most hypothetical "business-as-usual" (BAU) scenario based on the effective common environmental policy that will not be developed or rigorously implemented. The basic justification for BAU approach was that none of the countries were ready to solve ecological problems caused by extensive economic development. Nor were they ready to foresee ecological outcomes while planning their future social-economic activity. The authors conclude that the degradation of the ecosystem, water quality and fish resources was inevitable, whereas the existing Russian-Chinese projects on complex use of water resources were named as "ecologically destructive" [4].

Russian water experts pay special attention to the problem of water quantity. They express concern that quantity issues might be ignored [10]. According to their opinion, inner water demand in China for communal and fishery needs in the basin will be solved solely by the Chinese side without taking Russia's interests into account. Table 13.4 provides the information on the present situation and the prognosis for the water intake in Northeast China up to 2030 and serves as the basis for the argument. Although there are no clear signs that water supply has reached critical limits, the growing tendency in water use in China shows that water supply has a great potential for growing concern. It may have a larger impact due to climate change influence and human activities resulting in aridification and desertification processes. Simultaneously, there is a water supply problem on the Russian side in basin areas of the Zabaikalsky province. These areas are already exposed to a regular catastrophic flow decrease as a result of climatic cycles.

Indeed, water quantity problem turned out to be transboundary, leading to serious rivalry for water similar to the case of the Argun crisis. More developed Chinese provinces with rising population density and industrial activity will evidently need more water. China will accelerate river development plans and expand irrigation areas along the riverbanks in the basin having an irrevocable influence on water supply. Provided this tendency is continued, China's development will be restrained by water shortage problem, which will be solved at the expense of water intake from the Amur-Heilong.

Table 13.4 Water resources and water intake in the Amur-Heilong on Chinese territory in 2003 and prognosis till 2030 [10]

Indicator	Area							
	Nonni	2nd Sungari	Sungari total	Argun	AH main channel	Ussuri	Transborder area total	Basin total
Average long-term precipitation, km^3	138.45	51.07	301.5	59.03	60.06	32.93	170.37	471.88
Total water resources, average long-term; km^3	29.38	16.42	81.77	12.03	21.19[a]	7.86[a]	47.8	129.57
Irrigated land, 2003; *10^3 ha	–	–	2,610	–	–	–	801	3,412
Irrigated land, 2030; *10^3 ha	–	–	4,051	–	–	–	1,495	5,545
Surface water intake, 2003; km^3	5.3	4.4	17.6	0	0.6	2.7	4.0	21.6
Surface water intake, prognosis, 2030; km^3	11.0	7.3	27.8	0.6	2.3	4.7	8.5	36.3
Irrigation, 2003; km^3								
Irrigation, 2030; km^3	–	–	30	–	–	–	11.9	41.9
Industry and cities, 2003; km^3								
Industry and cities, 2030; km^3	–	–	126	–	–	–	2.6	15.2
Total water intake, 2003; km^3	9.53	5.84	27.19	0.2	1.6	5.7	8.3	35.5
Water demand prognosis, 2030; km^3	17.3	9.8	42.6	1.01	4	8.5	14.5	57
Total increase, 2003–2030; km^3	7.77	3.96	15.41	0.81	2.4	2.7	6.2	21.5

*Numbers on Amur and Ussuri main channels imply flow share from China side only

13.4.2 Recommendations for Water Management and Use

Regional water experts Simonov and Dahmer [14] discussed various recommendations for the Amur-Heilong River basin with regard to water management and use. The recommendations are aimed at sustainable basin development and "greening" of existing industries and agreements. These recommendations included:

- development of the trilateral international committee on complex basin management that would create opportunities for successful water use and management;
- development and adoption of transboundary program on basin adaptation to human and climate change impacts on water;
- harmonization and adoption of water quality standards and threshold levels of water pollution in transborder water objects;
- reinforcement of existing commissions on water quality control and pollution prevention;
- adoption of environmental impact assessment mechanisms in both countries on national and transborder level (e.g. mechanisms suggested by the Convention on Environmental Impact Assessment in a Transboundary Context, 1991; however China and Russia have not ratified the Convention);
- adoption of obligatory state ecological expertise of any industrial/economical activity in the basin at least in transboundary regions;
- reinforcement and proper implementation of existing transborder agreements such as the Agreement on use and protection of transboundary waters (2008) and the Agreement on nature protection of the Argun River basin (2006);
- use and application of general international ecological standards developed by international conventions with regard to transboundary water problems (e.g. Convention on the Protection and Use of Transboundary Watercourses and the International Lakes, 1992, however China has not ratified the Convention);
- development and adoption of ecosystems services' evaluation for long-term investment/development projects.

13.5 Conclusion

Problems of water quantity and quality are very interrelated. This interrelation is well shown when countries have to supply the water needs for economic and industrial activities and to simultaneously comply with the existing legal framework. The Amur-Heilong River basin is very similar to other world river basins in terms of the nature of problems that concern both quality and quantity. Nevertheless, these problems are usually unique for the basin geographical location and socialistic heritage in the water management practices.

As argued in the article, the water quality issues have a long history and gained special attention from both Russia and China. This problem could be solved by the means of providing adequate financial inflow and strengthening political decision-making process within the states located on both sides of the basin. Another issue concerning water management strategy relates to the water quantity and this particular issue might have an even greater impact on the basin. There is an urgent need to account for this potential threat to environmental security and use extra efforts to enforce transboundary cooperation between China and Russia.

In order to address the issues of water management and use in the basin it is necessary to consider the structure and characteristics of the region in order to adapt the world's best available practices to the local watershed management. This would allow for creation of an effective management strategy for the entire transboundary region, yet the precursors for this improvement would be a strengthened political will and successful cooperation between all three basin-sharing countries.

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Chapter 14
Participatory Futures Research and Social Learning for Integrated Watershed Management

Andrew Segrave, Chris Büscher, and Jos Frijns

Abstract Watersheds encompass diverse social, economic, technological, and ecological systems that are interrelated in complex ways. Stakeholders in watersheds and the ecosystems that support them are intricately interconnected. Increasing acknowledgment of these interdependencies has been accompanied by widespread recognition that water management needs to become more integrated, adaptive, and participatory. But difficulties associated with stakeholder participation along with the uncertainty inherent to planning processes have hindered the implementation of Integrated Watershed Management since its conception. This chapter discusses the use of participatory futures research and social learning to actively explore watershed management issues from different perspectives and collectively set goals with diverse stakeholders. This interdisciplinary approach can improve the sustainability of management interventions and ultimately increase the longer term environmental security of watersheds. Whether it's for strategic learning within the water sector, or facilitating genuine participation for Integrated Watershed Management, futures research and social learning are advocated as valuable approaches to involving stakeholders from the framing of problems onwards.

Keywords Wicked problems • Participatory futures research • Social learning • Adaptive • Integrated • Participatory • Resilient • Environmental security

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14.1 Introduction

Watersheds, being natural hydrogeological units, often extend across administrative and national borders. The resources and services provided by ecosystems within a watershed are also commonly used by various stakeholders. Any one group's actions may have consequences for others, and the combined effect of the activities of different groups can also influence the ecosystem itself.

Stakeholders and the ecosystem that supports them are interconnected. For this reason, Integrated Watershed Management (IWM) essentially begins with identification of the different stakeholders. Once these actors have been identified, the next step usually involves collective identification of the issues of concern and goal setting. The EU Water Framework Directive (WFD), for example, explicitly stipulates participative processes.

Such planning processes are inherently complex, especially if diverse stakeholders and longer term goals are involved [38]. It is also widely recognised that practical implementation of IWM has been problematic since its conception. This paper describes an approach to the IWM process whereby participatory futures research and social learning are used to involve stakeholders in maximising the sustainability of management interventions and environmental security.

14.2 Integrated Watershed Management

Rather than restating a general definition of Integrated Water Resources Management (IWRM) or Integrated Watershed Management (IWM),[1] as given elsewhere, the broader significance of these concepts is briefly explored below. It is through understanding the motives behind these ideas, and the problems that impede their implementation, that such principals and models (e.g. Fig. 14.1) might eventually be emulated in practice.

The main incentive for change in water resource management practices was widespread recognition during the late 1970s that environmental security cannot be achieved by focusing on the natural, physical characteristics of watersheds alone. Social and economic factors also need to be taken into account. Water management responsibilities were typically divided between various organisations, who essentially executed their respective tasks independently. A narrow technocratic approach was common, whereby insights from the natural and technological sciences dominated. This fragmented and one-sided approach meant that water management activities were generally limited to the design and control of the natural and physical characteristics of watersheds. Interventions often disregarded important linkages between water quality and quantity, for instance, overlooking the impacts of

[1] In this paper IWRM and IWM are grouped. Although practices differ slightly, both concepts rest on similar premises, namely integrated and participatory management of water resources.

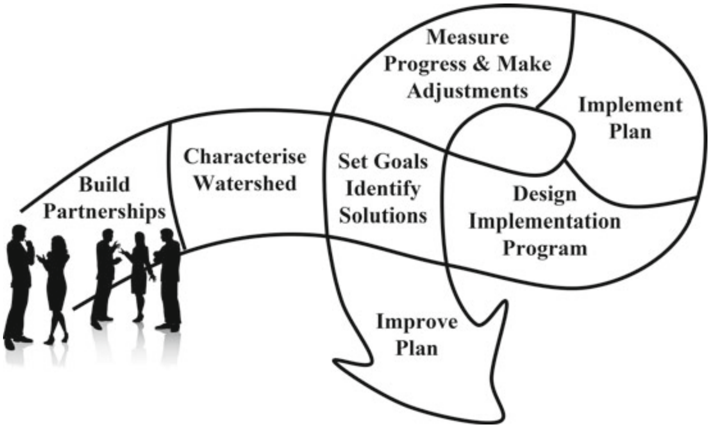

Fig. 14.1 Steps in the watershed management process (Adapted from: US EPA http://www.epa.gov/owow/watershed/watershedcentral)

upstream interventions for downstream areas and leaving social inequities undiscussed ([29]: 132). Advocates of IWRM argued that social and economic perspectives should supplement the standard approach to water management that focused on input from the natural sciences and technology.

The second premise that grounds IWRM is that management should be participatory; involving all relevant parties. Integrated management called for the coordination and harmonisation of the various responsibilities and tasks of public bodies together with those of the stakeholders in the watershed. These principles were integral to the concept of IWRM that was proposed several decades ago. IWRM would bring stability and coordination to the management of watersheds [3, 29, 30].

This promising outlook fueled the popularity of IWRM. It was soon embraced globally by the most powerful water institutions and promoted as the panacea to water management problems [29]. IWRM became a ‘sanctioned discourse’ in the international water sector, i.e. “…the prevailing dominant opinion and views, which have been legitimised by the discursive and political elite” [19]. IWRM also opened the floor for discussions concerning the fundamental shortcomings of the management styles that previously dominated, which in itself can be considered a significant step forward [30].

What remains problematic is the actual implementation of the theories [3]. Propagating notions of integration, participation, good governance, and empowerment IWRM became widely popular. These ideals are now generally ‘squeezed’ into a framework that includes a series of cooperative, iterative steps (e.g. Fig. 14.1). But even after two decades of IWRM, implementation and institutionalisation remains rare [9, 30].

Accomplishment of stakeholder participation in actual decision-making processes has proven particularly difficult. The dominant management model to be implemented under IWRM has been a monocentric one, whereby a limited number of organisations oversee the implementation of IWRM in a centralised way. In practice, participation may even become an end in itself rather than a means of benefitting from the diversity of views available. The means of engaging stakeholders is ideally "…not just one of participation but rather one of creating effective processes and procedures of learning and reflexive decision making by the engaged actors" [50]. The approach put forward in this chapter addresses precisely this point.

Taking the Don River watershed as an example, the general complexities associated with IWRM are illustrated. The Don River watershed is one of Russia's most populous regions and the economic centre of Southern Russia. The Don River is also a busy navigation route surrounded by vital agricultural areas, and an industrial hub for coal and steel production. One main tributary of the Don River, the Donets, flows through the north-eastern corner of the Ukraine. Such diversity regarding the human systems that are entwined with the water system is one aspect of what makes IWRM exceedingly difficult. But besides human stakeholders there are ecological stakes, such as the dependence of the ecosystem on biodiversity, which need to be represented in decision making.

The Don River watershed comprises diverse physical features and provides a variety of ecosystem services that need to be considered in management systems. Management of landuse in the watershed needs to account for various aspects of the water system such as drainage and stormwater runoff, water supply, and water quality. Landowners, farmers, environmental specialists, and a range of other public and private parties all have vested interests and responsibilities concerning how this watershed is managed. In the case of quantitative shortages or qualitative pollution of water, political decisions need to be made concerning the allotment of water rights and the enforcement of environmental regulations.

Besides the parties with economic interests, local communities should have the right to frame the problems and attribute value to the resources in their watershed from their own worldview. This is an especially important consideration when indigenous communities are involved whose worldview has coevolved with their environment generating unique local knowledge.

This is the case in the Don River basin where the Don Cossacks have established a unique lifestyle and culture since the fourteenth century. These people developed a relationship with the river ecosystem reflected in, for example, fishing laws ([25, 47]). The need to achieve agreement between groups that have fundamentally different value systems is what makes IWRM a social and political challenge.

14.3 Watershed Problems Are Wicked Problems

The characteristics of watersheds that make their management so difficult are seldom accounted for in the existing approaches to planning and framing potential problems. Ironically, the framing of problems is perhaps the most crucial phase in planning adaptation to contextual change. The standard approach is for scientists to identify and quantify thresholds for crucial variables and monitor lists of (generic) indicators [7]. Next, deterministic models are used to make projections of trends (e.g. [5]). But transitions in natural systems are mostly nonlinear and characterised by irreversible tipping points [40].

Traditional approaches to planning rest on certainties and knowledge of initial conditions to make probabilistic predictions. This is the all too familiar pitfall of assuming historical determinism [43]. Theorists have acknowledged that "interconnectedness, interdependence and seemingly acausal connections place this eminent and hugely successful system under pressure" [2].

As outlined above, water resources management generally dealt with technical problems in isolation and systems were designed with high predictability and controllability in mind. But this "command-and-control" approach is progressively considered inapt because of changes in how water management problems are perceived [34]. Water management has undergone a fundamental shift to involve what are called 'wicked' planning problems [24].

Wicked problems are characterised by complexity, uncertainty, and diverse views and interests. There is no definitive solution and different values and views can lead to conflicting strategies [17, 38]. The interrelatedness of anthropogenic and natural systems in watersheds make issues complex, and the transboundary nature of watersheds amplifies this complexity [14, 21].

Besides the complexity of the systems themselves, the diverse perceptions and stakes involved make the problem space ambiguous. In the quest to objectively establish water management models it is often wrongly assumed that there is an overriding social ethic or collective problem perception [18]. There are actually multiple frames of reference and interpretations at play, which lead to divergent understandings and values attributed to the watershed [12]. World views and values are obviously integral to the concept of sustainability and imposing generic classifications may have little practical use [25].

In addition to the ambiguity that is introduced by diverse perceptions, managers, developers, researchers, and policy makers need to conceptualise the future to work proactively. The future is inherently uncertain and people perceive and deal with this uncertainty in fundamentally different ways [8].

14.4 Sustainability Implies Continuity and the Future Is Uncertain

The most prevalent definition of sustainable development is that of the Bruntland Commission: "development which meets the needs of the present, without compromising the ability of future generations to meet their own needs." Thus, sustainability implies continuity into the future. But the needs of future generations are indeterminate and there is fundamental and uncertainty concerning the effects of current activities on future circumstances. Uncertainty is inherent to sustainable development and the environmental decision making that is necessary for watershed management. This realisation led to the emergence of the Precautionary Principal, which states that uncertainty should not be used as a reason for postponing measures to prevent degradation. Even so, the focus on quantifying risks with probability assessments remains dominant.

On paper, risks are defined by the product of the probability and the consequences of the occurrence of a specified hazardous event. But stakeholders can weight and respond to potential risks in fundamentally different ways [1, 41]. Objectively quantified risks are known to be amplified or attenuated by social processes (Busby 2009). More critically, they do not account for indeterminacy or even the uncertainty that does not have a known probability distribution and involves subjective perceptions. Furthermore, when multiple stakeholders with multiple frames are involved, the issues which are at stake become ambiguous [12]. One logical first step is to identify and analyse location, level, and nature of the different types of uncertainty [28]. Nonetheless, once uncertainty is reduced to risks it is no longer a source of anxiety: “It may become a source of fear, but it may also be accepted as routine, such as the risks involved in driving a car or practicing a dangerous sport”[16].

The knowledge and methods needed to address these issues are largely lacking [34]. But besides the difficulties uncertainty and ambiguity bring, they can be seen as a source of diversity for reframing issues as a step towards more suitable responses [45]. Through its dealings with risk, today’s ‘Risk Society’ is confronted with itself [6]. Risks reflect our actions and omissions and thus embody the norms and values of the decision makers. Giddens [13] argues that political decisions regarding wicked problems should not be constrained by uncertainties pertaining to the possible implications for society. Adaptation must be proactive and forward planning is required [13].

14.5 Futures Research Is Important to Sustainable Watershed Management

The challenge associated with sustainable development is to preserve the quality of the natural ecosystems while meeting the needs of the various human stakeholders. When considering the aspect of sustainability that concerns the prospects for maintaining a certain anthropogenic system, ‘future-proofing’ and ‘resilience’ are often mentioned.

The resilience of anthropogenic systems may be increased by investing in time, flexibility, robustness, or knowledge [28]. When an adaptive approach is feasible, strategies are likely to focus on improving flexibility and knowledge. But if frequent adaptation is costly, as with investments in infrastructure, robust solutions are needed. A robust solution implies that it will remain effective within the range of projected scenarios concerning the internal and external pressures it may face in the future. Intelligent watershed management makes use of the best scientific information and the knowledge and ambitions of the local stakeholders to design sustainable strategies.

The science system of the water sector generates new knowledge and technologies to improve the resilience of the anthropogenic systems and make them more sustainable in their natural context. But research costs time, so potential problems need to be defined before the solutions are required. Futures research is thus essential to programming a precompetitive research agenda to generate the necessary knowledge. Similarly, investing in robustness or flexibility also relies on futures research. The meaning we attribute to 'futures research' in this chapter is the investigation of images of the future and exploration of the inherent uncertainty. The future itself cannot be studied because it does not exist [48].

Any claim that a system is sufficiently robust or flexible rests on assumptions concerning likely future circumstances. Futures research is needed to ground such assumptions and is thus essential to making robust investments and defending them as such. Besides this, futures research is an ethical exercise, since it involves exploring hopes, values, choices, and responsibilities. Masini [27] argues that it is a moral duty of managers to explore possible futures with the relevant stakeholders.

The futures research referred to here is not based on extrapolation of trends and postulation of predictions. It recognises the plurality of possible futures and emphasises exploring the uncertainty and what different stakeholders deem normatively preferable. Dilemmas often appear when policy-makers and resource-users concentrate on the short-term goals of a specific sector. This type of thinking generally results in two-dimensional trade-offs, like financial gain versus biodiversity, which reflect the assumptions behind oversimplified models rather than the real complexity of the interrelated systems. Collective futures research, using methods such as participatory scenario planning and backcasting, is one way of employing the diversity of perspectives and the openness of the future beneficially [35].

14.6 Social Learning and a New Adaptive, Integrated Approach

The widespread acceptance of IWRM principals means that, somewhat parallel to the social scientists, engineers and natural scientists are developing methods for increasing stakeholder participation. For example, Van Buuren [44] designed a method for practically implementing participatory learning and decision making for drainage and sanitation planning. Suitable approaches to tackling wicked problems are also being sought on various levels from post-normal science as a form of mode 2 knowledge production, to social learning [15, 37, 39, 42]. These approaches tend to emphasise transformative learning and democratic processes by explicitly recognising human perception as a key variable. Several recent European research projects (e.g. HARMONICOP, NEWATER, SWITCH, and CONVERGE) have developed and tested knowledge and methods for applying these approaches.

Social learning, in particular, has been recognised as a "transitional and transformative process that can help create the kinds of systematic changes needed to meet the challenge of sustainability" [49]. It is also an approach that has been well tested in practice [23]. The idea of social learning is developing quickly and different definitions exist. Broadly speaking, social learning involves collective interaction among different individuals and groups to gain insight into their environmental circumstances by intelligence gathering and reflection so that they can anticipate and act to improve the management of human and environmental interrelations [22, 31].

Social learning is generally associated with systems thinking and a reflexive approach. The emphasis is on co-learning, whereby individuals collectively develop new knowledge by making use of the diversity of perspectives and understandings at hand [11]. If the focus is not on developing new knowledge, then hierarchical and non-hierarchical learning may also be included. Hierarchical learning is the traditional teacher-student relationship whereby an amateur learns from an expert. Non-hierarchical learning, on the other hand, takes place when two experts learn from each other but do not generate any new knowledge. Besides these different types of learning, some theorists also distinguish between intentional and accidental learning and active or passive learners.

Different types of learning can lead to different types of insight. These may be referred to as single-, double-, and triple-loop learning. Most learning is single-loop, whereby skills, practices and actions are developed within an existing paradigm. Double-loop learning results in a paradigm shift by challenging the assumptions and models that underlie existing actions and behaviour patterns [32]. The most transformative form of learning is triple-loop, which involves fundamental changes in values, norms, and the worldview as a whole [4]. Participatory processes that facilitate multiple-loop learning thus provide a deeper understanding of the wicked problems that watershed management really entails.

Through the development of social learning theory and practice several important lessons have been learned. Creation of a suitable learning environment and facilitation of the desired learning process have proven essential [20]. The facilitator should be an external expert who is given the authority to lead, imposing clear rules and roles, and can generate an environment of trust and act as a 'neutral' mirror when necessary [51]. Transparency needs to be maximised so that the different stakeholders can take advantage of their differences and mutual dependence. The size of the learning group should be kept relatively small, to facilitate continuous feedback, and the subject matter must be as concrete as possible. Those involved should be stimulated to think in systems and to critically analyse their own norms, values, and assumptions explicitly.

While a focus on the local stakeholders is important, changes in understanding that are realised at local or regional level may not be reflected at a higher institutional level. Social learning thus necessitates new roles for governmental actors. Existing management structures can provide resistance to demand-led systems, particularly when this introduces uncertainty about how financial resources will be allocated [46]. Finally, it is important not to overemphasise the learning process. It is essential to recognise the central role of uncertainty, but it is equally important to differentiate between wild speculations and intelligent scenarios. The future should be treated as if it is open, but not empty [43]. Dutch Water Sector Intelligence

(DWSI) is a strategic learning alliance that was designed using the ideas and lessons summarised above.

14.7 A Case Study: Dutch Water Sector Intelligence

Dutch Water Sector Intelligence (DWSI) was launched in 2009 by KWR Watercycle Research Institute and a team of pioneers from drinking water companies, water boards, and other organisations in the Dutch water sector. It is a strategic learning alliance, geared towards signalling important developments and providing strategic input for setting agendas and programming research questions for the science system of the water sector. DWSI was designed based on the premise that both futures research and social learning are essential to successful integrated water resource management. The sector is investing in flexibility and knowledge to increase the sustainability and resilience of its activities.

Planners and decision makers from throughout the water sector meet three times per year to develop strategic insights that they use as conceptual building blocks for their individual organisations and for groups of partners collectively. This supports the adaptive capacity of the sector and, by bringing the strategists from the different organisations together; the potential for more integrated activities is increased.

The objective of DWSI is more abstract than practical integrated watershed management, for which social learning alliances have also been successfully applied in various cases [23]. But the success of any form of social learning depends on explicating the similarities and differences between the norms, values, interests and goals or visions of the different stakeholders [49]. The lessons learned may thus be generalised.

At the heart of DWSI is a group of futures researchers who continuously examine and report on social, economic, political, technological, ecological, and demographic trends in the context of the Dutch water sector (Fig. 14.2). (Inter)national futures studies are analysed and translated to the sectoral level in an integrated fashion.

The futures research team also participates in various networks, such as the World Future Society, and attends conferences to tap into the most important current developments. The knowledge acquired through this research is used to design think-tank sessions with strategic thinkers and decision makers from each of the partner organisations and external experts who fuel the strategists with new insights.

DWSI thus facilitates hierarchical learning, providing external input of fresh ideas, followed by active, intentional co-learning in smaller groups. Debate and (inter)discursivity are used to provoke reflexivity. Carefully tailored group processes reveal and test participant's assumptions and facilitate generation and analysis of alternatives to ascertain whether or not adaptation is needed for changing circumstances in the SEPTED dimensions listed in Fig. 14.2. The outcomes also provide input for programming the research agenda of KWR as water cycle research institute of The Netherlands.

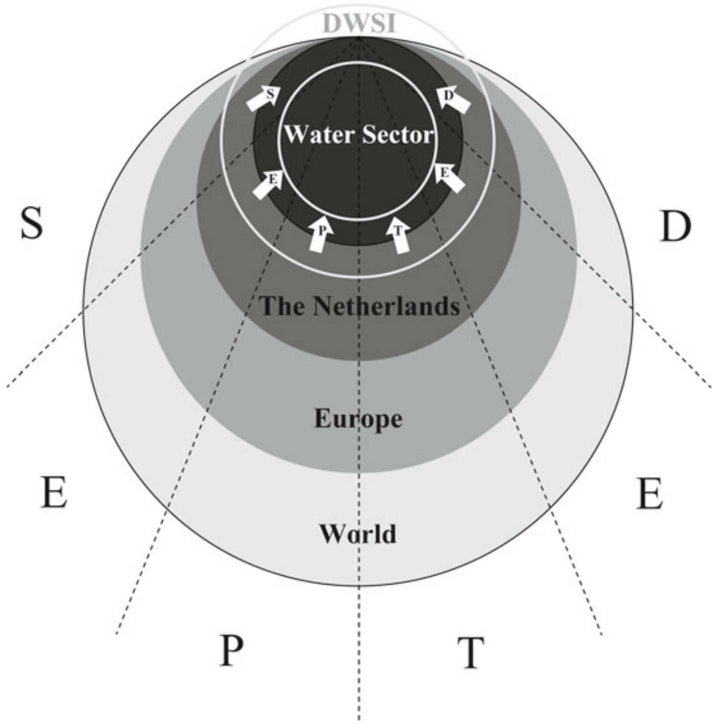

Fig. 14.2 Translating social (*S*), economic (*E*), political (*P*), technological (*T*), ecological (*E*), and demographic (*D*) trends to opportunities and threats for the Dutch water sector

14.8 Improving IWM Through Participatory Futures Research and Social Learning

Longer term water management problems on a watershed scale generally involve significant uncertainty, complexity, and diverse interests and views. In response, there is a call for water management to become more integrated, adaptive and participatory [33, 36, 42]. Although IWM is designed to involve the different stakeholder groups, its implementation faces difficulties when it comes to dealing with uncertainties and participation in the decision making process. A participatory futures research and social learning approach is advocated for the management of watersheds such as the Don River Basin (see Table 14.1).

Participatory futures research can play a key role in improving the sustainability of the water sector by allowing participants to anticipate future opportunities and threats in an intelligent and systematic fashion and collectively set normative goals. Through social learning, making use of different perspectives and views, new knowledge and understanding is developed and building blocks for a shared watershed management process can be established.

Table 14.1 Key characteristics of watershed problems, IWM and a participatory futures research and social learning approach

Watershed problems	IWM elements	Participatory futures research and social learning approach
Complex	Integrated	Collective interaction (cross sectoral)
Uncertain	Adaptive	Strategic anticipation (explore visions and uncertainty)
Diverse interests and views	Participatory	Reflection and co-learning

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