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**Degree of Master of Science**

# The Aydar-Arnasay lakes system: formation, functions and future water management scenarios



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**Author's declaration**

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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**ABSTRACT OF THESIS** submitted by:

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The current development of the Aydar-Arnasay lakes system (AALS), which is one of the remarkable examples of the human-induced ecosystems, depends on numerous political and environmental factors. On the one hand, the political tensions and disagreements between Central Asian republics alter the implementation of the coordinated water policy in terms of agreed water discharges to the Aydar-Arnasay lakes. On the other hand, forecasting change of the regional climate has an uncertain influence on these lakes.

The main scientific methods applied in the present research are scenario approach, fostering the finding of alternative ways of the AALS future development; application of GIS technologies, contributing to the analysis of the AALS change dynamics in past; and environmental modeling assisting for simulation of the various development ways of the AALS future.

In order to achieve the main goal of the study which is identification of the most probable scenario of the AALS future development, a set of various water management scenarios has been elaborated in accordance with a level of regional cooperation between republics and significance of climate change. They are “Ready for Challenge”, “Fall Behind”, “Promising Future”, and “Business as Usual”.

Then, the AALS model aimed to test these scenarios has been created using STELLA software. Finally, the model created has been simulated for each water management scenario and results illustrating the change of the AALS volume in 2010-2040 have been obtained.

It was found that two of the elaborated scenarios, i.e. “Ready for Challenge” and “Promising Future” are unrealistic for the AALS development whereas another two, i.e. “Fall Behind” and “Business as Usual” stand big chances of being illustrative and plausible for the lakes’ future.



**Keywords:** Aydar-Arnasay lakes system, Uzbekistan, water discharges, Chardara reservoir, water management scenario, environmental modeling, Toktogul Reservoir, regional cooperation, climate change,

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***I would like to dedicate this thesis to my father who will forever remain in my heart…***

# 1. INTRODUCTION

The Aydar-Arnasay lakes system (AALS) is a system of lakes in Uzbekistan resulted from human-induced activity and currently one of the remarkable examples of artificially formed lakes playing a significant role in terms of fisheries development, maintenance of biodiversity, and recreational places for both the population and economy of the republic.

## 1.1 Background

The Aydar-Arnasay lakes system is situated in the south-eastern part of Uzbekistan on the territory of Navoi and Dzhizak provinces (Figure 1). In the north it is bordered by the Kyzyl-Kum desert whereas 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 lakes system includes lakes Aydarkul, Tuzkan, Arnasay or East Arnasay lakes and surrounding desert areas (Muminov and Poplavskiy 2006). The total length east to west of these lakes is 300 km and its north to south width varies from 30 to 50 km (Wahyuni, Oishi et al. 2009). The water level of the lakes system is about 240-242 m, water-surface area more than 3700 $km^2$ and volume about 44,3 $km^3$ (Nurbaev and Gorelkin 2004).

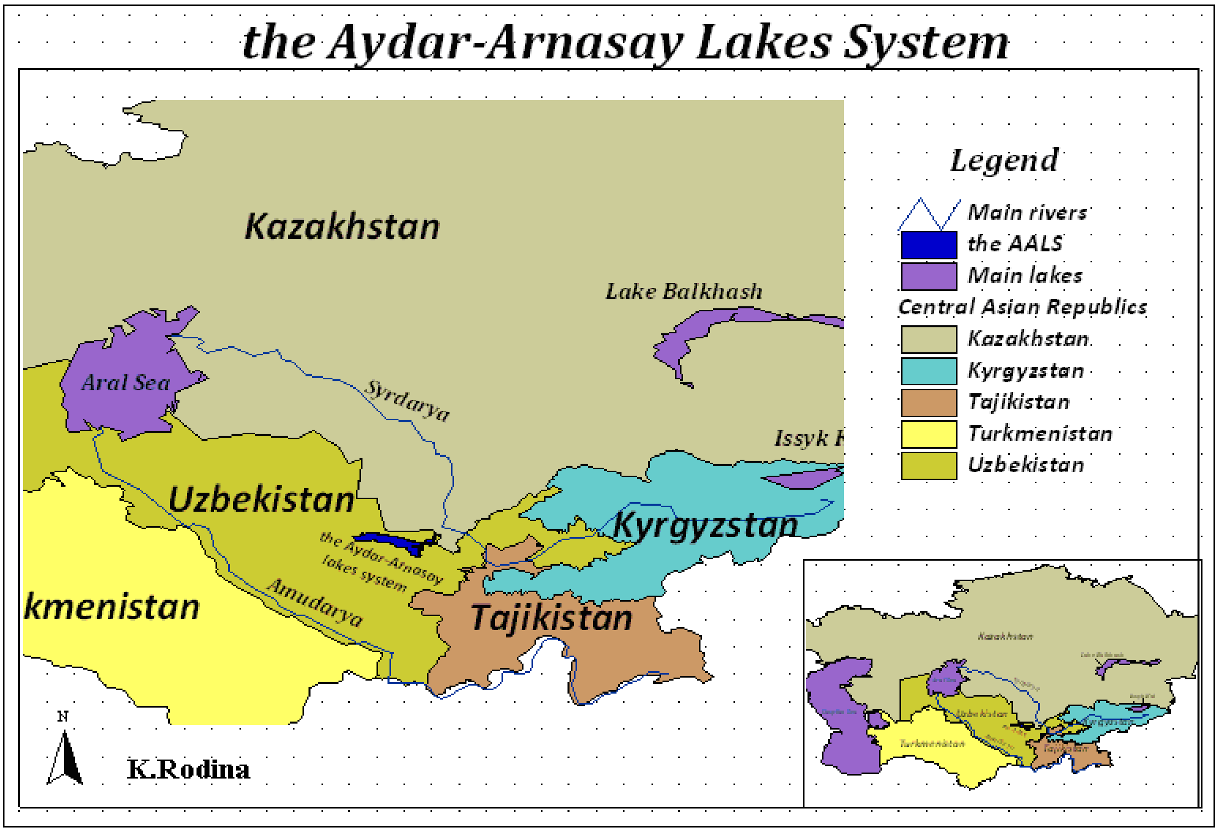


Figure 1. Location of the Aydar-Arnasay lakes system

## 1.2 Research

### 1.2.1 Problem statement

The current development of the Aydar-Arnasay lakes system (AALS), which is one of the remarkable examples of the human-induced ecosystems, depends on numerous political and environmental factors.

On the one hand, the political tensions and disagreements between Central Asian republics alter the implementation of the coordinated water policy in terms of agreed water discharges to the Aydar-Arnasay lakes. The republics concerned, i.e. Uzbekistan, Kazakhstan and Kyrgyzstan, are focused on their own national interests and are not trying to consult the neighbors' water needs.

On the other hand, forecasting change of the regional climate has an uncertain influence on these lakes. It is unclear, how the assumed climate change will impact the hydrological features of the AALS, such as volume water level, thermal regime and others in future.

Therefore, the future fate of this system is completely undetermined, including future of fisheries situated in these lakes, wetlands ecosystems designated as a Ramsar site, recreational activity and tourism which are directly related to the Aydar-Arnasay lakes.

### 1.2.2 Research aim

The overarching goal of the present research is to identify which of the elaborated water management scenarios is the most probable in terms of the future development of the Aydar-Arnasay lakes system.

The future development of the lakes system implies such important aspects as features of hydrological regime, including level of mineralization; maintenance of fisheries situated in these lakes, conservation of biodiversity, i.e. wetlands of international importance designated as a Ramsar site and various birds and fish species inhabiting these lakes, and recreation.

Besides, the future of these lakes directly depends on two factors: on the one hand, level of cooperation between Central Asian republics, basically, future relationships between Kazakhstan and Uzbekistan will define the policy of the water discharges from the Chardara reservoir located in South Kazakhstan; Kyrgyzstan in its turn will also have an influence on the Aydar-Arnasay lakes system in terms of the power-generation of the Toktogul Reservoir which releases a huge amount of water downstream during the winter time.

### 1.2.3 Research objectives

The following objectives were pursued in order to achieve the main goal:

- To describe the overall review of the Aydar-Arnasay lakes system (AALS), including preconditions of the lakes' formation, hydrological research conducted, current ecological conditions, and evolution of fish farming (Chapter 2);
- To analyze contemporary ICT as a tool for assisting environmental science and consider the successful worldwide examples and best practices of ICT application (Chapter 2);
- To analyze practical use of methods such as environmental modeling, scenario approach and remote sensing for data analysis (Chapter 2);
- To identify the main scientific methods for data collection and analysis which can contribute to the goal achievement (Chapter 3);
- To examine the past of the Aydar-Arnasay lakes system in terms of historical stages of the lakes' formation and change dynamics of the AALS water level and volume (Chapter 4);
- To examine the present development of the Aydar-Arnasay lakes from the socio-economic and environmental aspects (Chapter 5);
- To elaborate possible water management for the analyzing future development trends of the Aydar-Arnasay lakes (Chapter 6);
- To create the model of the Aydar-Arnasay lakes system for testing the elaborated scenarios using STELLA software (Chapter 6);
- To simulate model for each water management scenario (Chapter 6);
- To interpret the results obtained from the model simulation for achieving the main goal (Chapter 7).

## 1.3 Thesis structure

The thesis consists of seven chapters. The *first* introduction chapter considers background of the Aydar-Arnasay lakes system and defines the main goal and objectives of the present research. The *second* chapter reviews the existing academic discourse of the development of these lakes, including overview of the hydrological research conducted, assessment of the AALS ecological conditions and evolution of fish farming. Besides, this chapter describes contemporary ICTs as a tool for assisting environmental science. The *third* methodological chapter describes different techniques that have been employed during the research. The *fourth* chapter analyzes the Aydar-Arnasay lakes past in terms of examination of the historical development stages. Also, this chapter contains description of the practical exercise aimed to analyze change dynamics of the AALS hydrological parameters using GIS methods. The *fifth* chapter explores the present state of the Aydar-Arnasay lakes in the context of socio-economic and environmental aspects. The *sixth* research chapter consists of three main sections. The first section is devoted to the elaboration of the water management scenarios. The second one introduces the Chardara – Aydar-Arnasay model and its main characteristics. The third one describes the simulation of the model for testing the elaborated water management scenarios, conducting experiments and results interpretation. The main discussion and concluding points are provided in the last, seventh chapter.

# 2. LITERATURE REVIEW

The following chapter attempts to review literature related to the research conducted of the Aydar-Arnasay lakes system (AALS) and consider some successful examples of modern technologies and the methods utilized to carry out research of aquatic systems and other water-related issues. The literature review consists of three main sections.

The first section explains the main preconditions of the Aydar-Arnasay lakes formation, i.e. the Aral Sea crisis and its major consequences and disintegration of the USSR as a significant aspect in development of this lakes system.

The second section examines the Aydar-Arnasay lakes as a new subject of scientific inquiry. This section includes the overview of the AALS research conducted, i.e. consideration of the hydrological, hydrochemical and hydrobiological conditions of these lakes, including the main components of the AALS salt balance, mineralization. Besides, this section depicts the evolution of the AALS fish industry, i.e. fisheries development in the period of 1960-1990 and the AALS fisheries fate after the collapse of the USSR.

The third section considers the review of modern technologies broadly applied in environmental science, namely, environmental modeling combining with scenario approach, use of geographic information systems (GIS) and remote sensing. Moreover this section specifies many current examples demonstrating a worldwide and successful use of these methods.

It should be emphasized that because the Aydar-Arnasay lakes are relatively new human-induced system not so much scientific research has been conducted and not so many books, reports and articles concerning this topic have been published. For this reason, searching and analyzing of the existing information and data about the lakes system concerned was a quite complicated task for the author.

The most of the reports published concerning the Aydar-Arnasay lakes merely provide a brief explanation of their formation, shortly examine the major ecological features of this system and explain the main causes of environmental problems such as increase of mineralization and reduction of fish reproduction. We should pay attention that neither a deep scientific research nor the fresh journal articles and reports are existed at present time. Therefore, it is difficult to provide the current chapter with detailed and particular information about this lakes system.

Due to lack of deep information about the Aydar-Arnasay Lakes system in the English language, numerous scientific materials in Russian, including national reports, journal articles, archival materials, conference papers, and online databases have been used for writing of this chapter. The present chapter is a result of careful translation and compilation of the existing research conducted about the Aydar-Arnasay lakes; therefore, it has a high value in terms of the detailed review of this lakes' system in the English language.

## 2.1 Preconditions of the Aydar-Arnasay lakes formation

### 2.1.1 The Aral Sea desiccation

The disappearance of the Aral Sea is a well known and widely discussed human-induced catastrophe representing severe ecosystem changes. It is commonly accepted that the modern recession of the Aral has been triggered by the diminution of inflow from the two largest rivers feeding the Aral Sea, Amudarya and Syrdarya, for irrigation purposes in Central Asia (Micklin 1988).

In particular, since the 1960s the intensity of the water use has been enhanced by the following factors: the rapid population increase, industrial development and especially irrigation farming. According to the SIC/ICWC estimates (2002), water withdrawals in the Aral Basin for irrigation purposes doubled from 1960 to 2000, composing about 90% of the total water withdrawal in the region (Roll and Alexeeva 2005). The basic indicators of water and land use in the Aral Sea Basin during 1960-2000 are presented in Table 1.

**Table 1. Basic indicators of water and land use in the Aral Sea Basin during 1960-2000**[1]

| Indicator | Unit | 1960 | 1970 | 1980 | 1990 | 2000 |
|---|---|---|---|---|---|---|
| Population | million | 14,1 | 20,0 | 26,8 | 33,6 | 41,5 |
| Area under irrigation | million ha | 4,31 | 5,15 | 6,92 | 7,60 | 7,99 |
| Irrigated area per person | ha/person | 0,32 | 0,27 | 0,26 | 0,23 | 0,19 |
| Total draw-off | $km^3$/year | 60,61 | 94,56 | 120,69 | 116,27 | 105,0 |
| Draw-off for irrigation | $km^3$/year | 56,15 | 86,84 | 106,79 | 106,40 | 94,66 |
| Unit draw-off per ha under irrigation | $m^3$/ha | 12,450 | 16,860 | 15,430 | 14,000 | 11,850 |
| Unit draw-off per capita | $m^3$/person | 4,270 | 4,730 | 4,500 | 3,460 | 2,530 |

Source: (ICWC/SIC 2002)



[1] Excludes part of basin that lies in Iran and Afghanistan

From table 1 it can be analyzed that the population in Central Asia increased threefold in the period of 1960-2000. Moreover, the area under irrigation has almost doubled in the same period of time whereas the irrigated area per person has decreased from 0,32 ha/person to 0,19. Total draw-off, including draw-off for irrigation also increased significantly by 2000 (ICWC/SIC 2002).

The dramatic drying out of the Aral Sea has resulted in severe environmental, economic and social consequences. Roll and Alexeeva state that the Aral crisis has led to environmental degradation, including land and water salinization in the region. Besides, the adverse problems of salinization threatening the entire economy of the Central Asia gave rise to other problems such as:

- Increasing erosion and sedimentation that, in turn, alter the basin water regulation infrastructure;
- Soil contamination;
- Diminishing wetlands and biodiversity;
- Environmental issues in mountain regions, i.e. preservation of the glaciers, sustainability of mountain forests, and erosion of mountain slopes (Roll and Alexeeva 2005).

Roll and Alexeeva (2005) also add that human-induced desiccation of the Aral Sea has brought about some negative problems, such as desertification, dust and salt winds, changes in the regional climate, health problems of the population.

Generally speaking, the Aral Sea catastrophe primarily relates to the sharp shrinking of the Aral Sea, but meantime, we also should take into consideration a crucial issue: If the Syrdarya and Amudarya water does not reach the Aral Sea where this water is distributed?

It is widely known, that the drying out of the Aral Sea is mainly determined by human factors which contribute 80% to the shrinking of the Aral Sea. The remaining 20% is due to a natural factor, i.e. change of the regional climate. The human-induced factor primarily implies an excessive use of Syrdarya and Amudarya water for irrigation purposes (Mamatkanov 2001).

Apart from this, an inadequate efficiency of water resources for use in irrigation farming is an important issue for discussion. ICWC (2002) indicates that water losses occur in the on-farm delivery networks and directly in the fields. According to WUFMAS, water losses in these two cases can amount to 40% of the total supplies coming to the irrigation areas (ICWC/SIC 2002).

Additionally, due to obsolete condition of the irrigation channels and collector-drainage systems, a significant amount of water is discharged into the nearest depressions and lowlands. The Aydar-Arnasay lakes system, originally formed as a result of water discharges from the Chardara reservoir and fed by collector-drainage water from the Golodnaya Steppe irrigation area for a long period of time, is a distinct example of Aral water redistribution (Severskiy 2004). Summarizing, Severskiy emphasizes that namely insufficient use of water resources and very old collector-drainage network have resulted in shrinking of the Aral Sea and formation of the new artificial system such as the Aydar-Arnasay lakes in Uzbekistan.

### 2.1.2 Dissolution of the USSR

After the collapse of the USSR and proclamation of the Soviet republics' sovereignty, the geopolitical situation in Central Asia absolutely changed. As the result, the Syrdarya and the Amudarya River Basins were divided between new formed co-basin countries and the river became transboundary (Libert, Orolbaev et al. 2008). Furthermore, the new Central Asian countries began to launch completely independent management systems for water and energy consumption (Muminov and Poplavskiy 2006).

After declaring the sovereignty, new republics, i.e. Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan signed their first regional agreement. "Agreement on Cooperation in Joint Management, Use and Protection of Interstate Sources of Water Resources" was signed in February 1992. The 1992 Agreement stated the status quo of the Soviet water allocation arrangements between 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 other various water issues related to management of the Amudarya and Syrdarya River Basins (Weinthal 2006).

It is notable that the 1992 Agreement, however, did not condition the provision of the energy supplies to Kyrgyzstan for its use over the winter, when the energy needs there are highest. As Kyrgyzstan has become short of the previously delivered winter supplies of energy from Kazakhstan and Uzbekistan, it began to rely on their only readily available source of energy, i.e. hydropower (Libert, Orolbaev et al. 2008). In order to generate electricity, Kyrgyzstan actively started using its hydropower stations which are discharging large amounts of the water during the winter (Weinthal 2006).

In particular, Toktogul Reservoir[2], being a key element in the Syrdarya flow regulation, became the major source of the power generation after the dissolution of the USSR (Chembarisov and Shamsiev 2007). In other words, Kyrgyzstan transferred Toktogul Reservoir to power-focused regime based on huge amounts of water releases from the reservoir during non-growing period (up to 8 $km^3$ instead of 3 $km^3$) (Nurbaev and Gorelkin 2004).

As a result, the transition of the Toktogul reservoir to a distinctly different regime changed the water availability situation in the Syrdarya river basin. The maximum electricity generation was observed during the winter time whereas during the growing period the water releases were actually decreased that allowed accumulating water in the reservoir. Thus, downstream countries, Kazakhstan and Uzbekistan faced the water shortage for irrigation purposes (Shamsiev and Chembarisov 2007).

Besides, we should mention that winter flooding became a regular threat in the lower reaches of the Syrdarya in Kazakhstan as well as common in the Aydar-Arnasay depression in Uzbekistan as the result of spillover from the Chardara reservoir[3], situated in the border between Kazakhstan and Uzbekistan.

Among the main negative consequences of the Toktogul regime deformation the present research is mainly focused on flooding of the Chardara reservoir and followed by water releases to the Aydar-Arnasay lakes system. Nowadays, regional cooperation between Uzbekistan and Kyrgyzstan in terms of the Toktogul operation is a determinative point for the future development of the AALS.

## 2.2 Aydar-Arnasay lakes as a new subject of scientific inquiry

According to FAO classification (2004), all water bodies in the basin of the Aral Sea are grouped as follows:

- Natural waterbodies (rivers and lakes);
- Artificial freshwater waterbodies (irrigation channels, reservoirs, ponds);
- Artificial saline waterbodies (drainage channels, lakes for residual water storage) (FAO 2004).

Because the focus of the present research is on analysis of the artificial lakes formed by human activity in Uzbekistan, this work will basically consider the third group of

[2] See a map in section 4.1.5
[3] See a map in section 4.1.2

waterbodies, i.e. artificial saline waterbodies. The main attention will be paid to the analysis of the Aydar-Arnasay lakes system, playing an extremely important role for the whole economy of Uzbekistan as well as for population and attracting a high scientific interest nowadays. The next sections of the literature review will survey different aspects of the AALS development.

### 2.2.1 Overview of the AALS hydrological research conducted

Broadly speaking, some research of the Aydar-Arnasay lakes system (AALS) was conducted before the collapse of the USSR. Ivanov and Nikitin draw a conclusion about carrying out of the wide-ranging hydrological research of the Aydar-Arnasay lakes in 1970-1978. The main focus of these investigations was the examination of the hydrological AALS conditions, i.e. thermal regime, seasonal and diurnal water temperature fluctuations, and mineralization (Ivanov and Nikitin 1978).

During the literature searching, information focused on the research of soil, landscapes, biodiversity and ecological conditions in this period of time has not been found. Therefore, this section will mainly concentrate on the hydrological results of the research conducted on these lakes.

#### *2.2.1.1 Examination of the AALS thermal regime*

To start with, examination of the AALS thermal regime was a very important practical issue in the 1970s because these lakes were a very suitable place for development of the fish industry. During the year-round field research in 1973-1974, investigations focused on the study of the AALS thermal regime, components of the AALS thermal balance, and hydrothermal surveys aimed to trace the patterns of thermal regime formation in the lake's different parts were accomplished (Gorelkin and Nikitin 1976).

It has been found that presence of the numerous shallow zones from the north to the south extending more than 70 km in the East Arnasay as well as a large number of small bays in the Tuzkan lake and deep Aydarkul lake generates a distinctive thermal regime in these water bodies (Ivanov and Nikitin 1978).

#### *2.2.1.2 Seasonal fluctuation of water temperature*

Considering research of the seasonal fluctuations of AALS water temperature the following conclusions have been drawn:

- according to the classification of the thermal regime, this system of lake was classified as lakes of middle latitudes with periods of spring-summer warming up and fall-winter cooling (Nikitin 1991);
- temperature fluctuations between the bottom and surface of the deep-water Aydar lake make up 4-5˚C, increasing to 10-14˚C in June - July. Fluctuations of surface and bottom layers in the Tuzkan lake are 2-3˚C. Formation of homotermy conditions is often representative phenomena for the shallow-water East Arnasay lakes;
- maximum monthly average water temperature is observed in July-August – 25-27˚C. In the middle of August the period of fall cooling starts. At the beginning of this period the temperature changes are not considerable, whereas in October-November the temperature decreases to 10˚C. Termination of fall cooling period depends on the specific weather conditions, but actually November-December are the last months of termination. Subsequent lake cooling up to freezing takes about 15-30 days. Usually freezing can be observed with 1-2˚C average water temperature. Then, in March-April the water temperature begins to grow starting from 5-7˚C and in May-June and goes up to more than 20˚C (Ivanov and Nikitin 1978).

#### *2.2.1.3 Diurnal temperature fluctuations*

Along with seasonal fluctuations of the AALS water temperature, diurnal variations were also analyzed in 1970-1980. It is known that wide-ranging changes of the diurnal variations of water temperature are quite common for the arid and deserted areas with extreme continental climate where the Aydar-Arnasay lakes are situated.

Diurnal temperature fluctuations of the AALS surface layer can reach 9-11˚C on the certain days of the summer period. Constant winds promote good mixing and smoothing of diurnal variations of water temperature. For example, diurnal temperature amplitude in the Tuzkan lake makes up 2-3˚C. It was observed that fluctuations of water temperature diminish with depth; at the depth totaling 7m amplitude of diurnal variations of temperature is about 1˚C (Gorelkin 1977).

### 2.2.2 Mineralization as the one of the major research issue

In 1970s the expedition of the Central Asian Research Hydro-meteorological Institute examined that up to 97% of water resources of the whole Aydar-Arnasay system are concentrated in the main reaches of Tuzkan and Aydarkul lakes. According to the patterns of mineralization distribution in the lakes, three major zones were identified, i.e. western and eastern reaches of Aydarkul lake, and deep-water zone of Tuzkan lake. It was concluded that both wind-induced turbulence and delayed water cycle give rise to the smooth variation of mineralization within these zones (Nurbaev and Gorelkin 2004).

Regarding the research of the mineralization in these lakes, the expedition also confirmed that in 1972-1975 mineralization in the eastern part of the Tuzkan lake made up 4-4,5 g/l, while in the western part – 2-2,5 g/l.

Kamilov and Urchinov note the fact that in the 1980s practically there were no water discharges from the Chardara reservoir. It resulted in an increased evaporation and gradual growth of mineralization respectively, as well as a decrease of lakes' level, siltation, and deterioration of water quality in these lakes (Kamilov and Urchinov 1995). For instance, mineralization in the Aydarkul lake was 9-10 g/l and in the end parts up to 13-14 g/l, that had an adverse effect on fish reproduction (Nikitin 1991).

Recently, growth of the mineralization became one of the acute problems of the Aydar-Arnasay lakes (Nurbaev and Gorelkin 2004). Several national reports and articles have been devoted to this problem (Mahmudova 2004a). For this reason, we think it necessary to provide a scientific explanation of the mineralization process, i.e. to describe the main input and output components of the AALS salt balance, features of the hydrochemical regime, and different levels of mineralization in the AALS.

#### *2.2.2.1 The main components of the AALS salt balance*

The main input of the AALS salt balance is salt leaching from the ground. At the moment of inundation of the Arnasay depression, its bottom was occupied by saline lake or shors (13%), residual solonchaks (45%) and deserted alkaline soils (37,5%). The total salt content in the bottom layer at 0-1 m thickness was about 50,25 million tones (Mahmudova 2004a).

Besides, Kurbanov and Primov state that the south-east part of the Arnasay depression was occupied by salt Tuzkan lake, mineralization of which exceeded 90 g/l. According to the

Uzbek Hydrogeological Scientific Institute estimates, salt supply amounted to 0,85 million tones. It was concluded that in the process of flooding of the Arnasay depression by fresh water from the Chardara reservoir, an intensive interaction between salt contained in water and ground started and freely soluble chlorides, i.e. sodium and magnesium salts, washed away within a year. Therefore, more than half of all salts from the ground entered into the reservoir at the initial waterflood stage (Kurbanov and Primov 2006).

Chembarisov and Shamsiev consider salt inflow with collector-drainage water as the second input component of the salt balance of the Aydar-Arnasay lakes. Depending on dryness of the year and conditions of hydrotechnical melioration of irrigated areas, 7-10 thousand tones of water soluble salts comes to the AALS. During the collector-drainage water discharges from the Chardara reservoir to the lakes 2-8 thousand tones of salts enters in spite of the relatively low mineralization of the Chardara water (Chembarisov and Shamsiev 2007).

We are also interested in analyzing the main output components of salt balance. Exploring the literature, two main components were identified: a) settling out of hardly soluble salts and b) losses in the numerous shallow bays formed around the Aydar-Arnasay lakes system. Output components make up no more than 5% of the total input components. This results in the gradual salt accumulation in the lakes (Mamatov and Kurnanbaev 2006).

#### *2.2.2.2 Hydrochemical regime of the Aydar-Arnasay lakes*

Generally speaking, it is known that there is a strong connection between water and hydrochemical regimes of drainless lakes located in arid zones and it can be clearly observed on the example of Aydar-Arnasay lakes. The features of the water regime of these lakes basically are explained by the annual fluctuations of mineralization (Nurbaev and Gorelkin 2004). Summer-autumn increase of mineralization and its winter-spring decrease is recorded in lakes Tuzkan and Aydarkul. The significant increase of mineralization during the summer period is due to intensive evaporation, i.e. annual evaporation losses amount to 15-20% of total volume of water in lakes. This fact considerably influences the formation of their hydrochemical regime and patterns of mineralization distribution through the lake’s profile. Intensive evaporation promotes the regular increase of salt concentration in the surface layers of the lakes. The decrease of mineralization in Aydarkul and Tuzkan lakes during winter-spring time is primarily caused by increase of precipitation and decrease of mineralization of collector-drainage water (Chembarisov and Shamsiev 2007).

In the 1980s some investigations of the hydrochemical regime of these lakes have been accomplished. Mahmudova specifies that depending on the proportion of the balance's components, a distinct hydrochemical regime forms in different parts of the AALS (Mahmudova 2004a). Moreover, Ivanov and Nikitin in their book "Hydrometeorology of lakes and reservoirs in Central Asia" consider shallow zone of the Aydar-Arnasay lakes system which is distinguished by a particular hydrochemical regime. They describe that a huge number of shallow bays and small lakes formed around the whole Aydar-Arnasay system make the regime very heterogeneous. Taking into account the constant reduction of water level resulted from substantial evaporation, the majority of shallow bays of the coastal lake zone turn into separate tiny lakes, and subsequently into solonchaks (Ivanov and Nikitin 1978).

Summarizing, it should be outlined that a gradual increase of mineralization is observed in all Aydar-Arnasay lakes except East Arnasay lakes. This increase is caused by all types of salt inflow. Moreover, sharp reduction of water volume resulted from evaporation losses is also observed. Aydarkul and Tuzkan lakes are characterized by the most intensive increase of mineralization in recent years. The water regime and distribution of mineralization in the East-Arnasay lakes differ from the regimes of Aydarkul and Tuzkan. The principal distinction consists in the features of collector-drainage inflow. Increase of water inflow, which relates to entering of less mineralized water to the lakes, brings about the general decrease of mineralization with minimal amounts of salt concentration in the area of the Chardara water discharges (Nurbaev and Gorelkin 2004).

### 2.2.3 Overview of the AALS current ecological conditions

The current ecological condition of the AALS is considered to be visibly disturbed nowadays. Karimov outlines that due to a significant increase 44 $km^3$ of the Aydar-Arnasay lakes system volume in recent years this system has attracted a high scientific interest. Hydrological, hydrochemical, and hydrobiological conditions of these lakes were actively investigated by national and international experts dealing with water issues in recent years (Mamatov and Kurnanbaev 2006). Saving and protecting the Aydar-Arnasay lakes and their valuable ecological functions are now seen as a priority for Uzbekistan (Karimov 2008).

Contemporary research of these lakes is mainly related to examination of mineralization, water quality, and hydrobiological conditions (Mamatov and Kurnanbaev

2006). According to the research of the Institute of Water Problems and Institute of Zoology, among the most distinctive features of this lakes system the following should be specified:

- In the context of mineralization, water in the AALS is classified as moderately saline, i.e. 5-7 g/l; chemical composition is basically chloride-sulphate-calcareous (Chembarisov, Reumov et al. 2006);
- Annual water discharges from the Chardara and the collector-drainage run-off demineralize water in the lakes, a zone where Chardara water meets AALS water is characterized by lower mineralization of up to 2,0-3,5 g/l;
- Concentration of pollutants during spring time is lower than maximum allowable concentration calculated for the lakes. This fact makes these lakes suitable for fisheries development (Giniatulina, Mullabaev et al. 2004);
- The AALS is abundant of various species of phytoplankton (55 species); species of zooplankton range from 7,74 to 173,5 thousands species/m3 (Chembarisov, Reumov et al. 2006);
- In 2006 the total amount of bacteria ranged from 0,98 to 1,54 million cells/ml;
- The total amount of periphyton[4] was represented by 176 algae taxon, 136 from which are diatoms (Giniatulina, Mullabaev et al. 2004);

#### *2.2.3.1 The AALS water quality: experts' conclusions*

Based on the microbiological tests of the water quality, experts obtained the following conclusions:

- In the context of contamination by coliform bacillus, the AALS water is classified as clean;
- In context of total bacteria amount, the AALS water is classified as moderately polluted;
- Water pollution index[5] ranges from 30 to 50 which is indication of poor water quality in the AALS;



[4] ***periphyton*** - is a complex mixture of algae, cyanobacteria, heterotrophic microbes, and detritus that is attached to submerged surfaces in most aquatic ecosystems. It serves as an important food source for invertebrates, tadpoles, and some fish. It can also absorb contaminants; removing them from the water column and limiting their movement through the environment. The periphyton is also an important indicator of water quality; responses of this community to pollutants can be measured at a variety of scales representing physiological to community-level changes. (source: http://dictionary.reference.com/browse/periphyton)

- The hydrochemical analysis conducted demonstrated that in recent years about 7-8 compounds of various hazard classes exceeded maximum allowable concentration; experts state that the AALS hydroecological condition should be taken as visibly disrupted (Shamsiev and Chembarisov 2007);
- Assessment of the water quality for irrigation showed that water cannot be used for cotton and gourds irrigation due to high mineralization (8-10 g/l). Watering using this highly-mineralized water can cause soil salinization and sodium and magnesium soil alkalization; during low water years an insignificant amount of water can be used on small patches situated in the zone of Chardara water inflow for irrigation of salt resistant crops (Nurbaev and Gorelkin 2004).

### 2.2.4 Evolution of the fish farming

As it was mentioned above, the Aydar-Arnasay lakes play an important role for fisheries development. Karimov states that despite the active development of the AALS fisheries from the 1960s to the 1990s, there is no ample amount of publications and projects concerning this topic (Karimov 2008).

Currently, historical overview of fisheries in the Aydar-Arnasay lakes is briefly described by some national scientists such as Kamilov (1973, 1995), Karimov (2008), and Shohimardonov (2008, 2009). In their reports they are trying to underline the most important issues concerning the major trends in the development of fisheries in these lakes during 1960-2000.

#### *2.2.4.1 Fisheries development in the period of 1960-1990*

FAO Fisheries Technical paper "Fisheries in irrigation systems in arid Asia" demonstrates the situation in fisheries development in Uzbekistan in the period of 1960-1990. This paper outlines that until the 1960s fisheries were basically concentrated on the inshore water of the Aral Sea and the deltas of the main inflowing rivers, Syrdarya and Amudarya. During the 1960s fisheries existed only on the Aral Sea, totaling 25 000 tons of annual catch.

[5] ***Water quality index*** is a 100 point scale that summarizes results from a total of following nine different measurements temperature, pH, dissolved oxygen, turbidity, fecal coliform, biochemical oxygen, total phosphates, nitrates, and total suspended solids. The 100 point index can be divided into several ranges corresponding to the general descriptive terms: 90-100 excellent, 70-90 good, 50-70 medium, 25-50 bad, 0-25 very bad (source: http://www.water-research.net/watrqualindex).

It is important to point out that the majority of fisheries were in government ownership, but meantime, a few fisheries cooperatives were also operated on the Aral Sea. The fish captured were mainly the following species: carp (Cyprinus carpio), bream (Abramis brama), barbel (Barbus brachycephalus), roach (Rutilus rutilus) and shemaya (Chalcalburnus chalcoides aralensis). Less common were wels (Silurus glanis), pike (Esox lucius), asp (Aspius aspius), sturgeon (Acipenser nudiventris), pikeperch (Stizostedion lucioperca) (FAO 2004).

In the 1970s fishing fleets were transferred from the Aral Sea to the new formed lakes for residual water storage: Aydar-Arnasay lake system and the Lake Sarykamysh. During this period up to 6000 tons of fish were caught in these lakes (FAO 2004). Kamilov and Karimov emphasize that in the 1970s and the 1980s in the Aydar-Arnasay lake system the fish yields without stocking reached a maximum of 15 kg/ha, and after stocking they increased to a maximum of 25 kg/ha (Kamilov and Karimov 1994).

Because capture fisheries could not replace the quantity of fish lost from the Aral Sea the Ministry of Fisheries in Central Asia had to introduce a new program focused on the maintenance and development of fisheries in the new waterbodies. The Government of Uzbekistan implemented a large-scale development programme of pond fish culture and fisheries in inland waterbodies. That programme was primarily based on creation of new fish farms and fishing enterprises in all regions of Uzbekistan, testing and implementation of new efficient technologies, establishment of scientific centers, and specialist training (Kamilov and Karimov 1994). Starting from the 1970s fisheries in Uzbekistan started to develop very actively in lakes for residual water storage as in Arnasay lakes, in new pond farms and also in irrigation reservoirs (Kamilov 1973). For a while lakes for residual water storage, i.e. Aydar-Arnasay lake system and the Lake Sarykamysh, were more preferred for capture fisheries rather than irrigation reservoirs vulnerable to seasonal water level drawdown which has an influence on fish production (FAO 2004).

Later in the 1980s the Aydar-Arnasay lakes became the main fish provider of fresh fish for the population in Uzbekistan. They supplied a huge variety of fish such as carp, pikeperch, dream, roach, crucian carp, asp, phytophagous fish species, and even catfish. *Issue 4 of Ecological Herald of Uzbekistan* (2008) describes that in total, 3676 tons of commercial fish was produced in these lakes in 1987 while the total amount of commercial fish in whole Uzbekistan amounted to 7143 tons. In 1988 the situation was quite similar, i.e. 4616 tons of commercial fish in these lakes versus 8140 tons in the whole republic. In other words, commercial fish produced in the Arnasay lakes made up 51,4% of the total amount of commercial fish in Uzbekistan in 1987 and 56,7% in 1988 respectively (Karimov 2008).

Generally speaking, between the 1960s and the 1990s Uzbekistan fisheries, including fisheries located on Arnasay lakes functioned with well-organized management. One of the reasons for implementation of the program aimed at form fish pond farms was the development of an alternative fish supply to that which was lost from the Aral fisheries. During the 1970s and the 1980s, 20 fishing companies were created to manage the fisheries in all large lakes, reservoirs, and in lakes for residual water storage such as Arnasay lakes (Kamilov and Karimov 1994).

All capture fishery and aquaculture companies were state-owned and financed from the government budget. Special attention was paid to the production in fish farms of material for regular stocking of reservoirs as well as for production of market size fish. During those years there was a close cooperation between the All-union (i.e. USSR) Ministry of Fisheries and the government of the Republic of Uzbekistan (FAO 2004).

#### *2.2.4.2 The collapse of the USSR: the AALS fisheries fate*

After the collapse of the USSR in 1991, the Central Asian system of water management in the Aral Sea Basin became fragmented because each country obtained full independence. Disintegration of the USSR led to the conditions towards the free market economy and government of Uzbekistan decided to privatize the fisheries. Starting in 1994, it discontinued its financing. Fishermen working on the Aydar-Arnasay lakes found themselves in the new unfamiliar conditions of a market economy (Kamilov and Urchinov 1995).

The overall economic crisis and the loss of economic links with producers of fish equipment in the former USSR also adversely affected fisheries. Kamilov and Urchinov address the concerns about deterioration of the fish equipment over the last ten years. The number of fishing boats, set nets and seines dropped (Kamilov and Urchinov 1995). In the 1990s there were only 20 fishing boats with 130 horsepower engines, 40 boats with 20 to 60 horsepower engines, and 250 other types of motorized boats. All fishery companies together had only 5 000 gillnets and 36 beach seines, which are now worn out (FAO 2004).

To summarize, it should be emphasized that 1970-1980 was a successful period of time for Aydar-Arnasay lake system in terms of fisheries development. This period was characterized by well-structured management of the fish industry and close cooperation between countries. Later, after 1991 when the USSR was disintegrated, the situation in the fish industry completely altered. The considerable decrease of fish production and destruction of the whole fish management system and in these lakes was observing.

### 2.2.5 Main conclusions

Having analyzed the relevant literature about the Aydar-Arnasay lakes system and research conducted on these lakes, the following conclusions were combined by the author:

- Ineffective use of water resources and obsolete conditions of the irrigation channels and collector-drainage network resulted in huge water losses and the gradual shrinking of the Aral Sea. Besides, after the collapse of the USSR a poor condition of the collector-drainage network was one of the factors which led to formation of the new artificial system in Central Asia such as the Aydar-Arnasay lakes in Uzbekistan;
- Disintegration of the USSR has completely changed a geopolitical situation and caused the formation independent republics with own insights in terms of water and energy management. Therefore, transition of the Toktogul reservoir in Kyrgyzstan to power-focused regime has brought about the huge water discharges during the winter time and accumulation of water in Chardara reservoir with subsequent release to the Aydar-Arnasay system;
- The main focus of the investigations conducted on the Aydar-Arnasay system in the 1970s and the 1980s was the research of the hydrological conditions, i.e. thermal regime, seasonal and diurnal water temperature fluctuations, and mineralization;
- Other environmental topics of scientific concern such as soil, landscape, and biodiversity research have not been investigated in the 1970s and the 1980s;
- Increase of mineralization in these lakes has been defined as one of the severe problems in the 1980s as well as in recent years;
- According to the microbiological tests, the AALS water quality is poor and this water can be used neither for irrigation nor drinking purposes;
- 1970-1980 was a prosperous period of time for the Aydar-Arnasay lakes in terms of fisheries development and well-organized management and cooperation between All-union countries while after the collapse of the USSR the fish industry sank into degradation.

### 2.3 ICT as a tool for assisting environmental science

The section gives a detailed literature review of modern technologies broadly applied in environmental science, namely environmental modeling combining with scenario approach, use of geographic information systems and remote sensing. We should point out that application of the above mentioned technologies could provide deeper research of the Aydar-Arnasay lake system and give a more detailed analysis of the severe environmental problems specific to these lakes as well as provide some effective solution for alleviation of the existing problems.

Apart from this, this section also considers the successful worldwide environmental projects assisted by environmental modeling, scenario approach, GIS, and remote sensing.

#### 2.3.1 Use of modeling

Modeling has become a significant tool in the contemporary study of various environmental issues i.e. climate change, water management, land use, soil degradation, transport, population dynamics, and so on (Gotelli 1995). Smyth gives a clear definition explaining that a model is an abstract and partial representation of some aspects of the world "that can be manipulated to analyze the past, define the present, and to consider possibilities of the future". He outlines that models give an opportunity for researchers to explore issues concerning dynamics of ecological systems that cannot be checked in the field conditions because of reasons of logistics, political or financial issues (Smyth 1998).

Considering environmental models, Clark states that they cover a full range of geographic scales, i.e. from the local to the global. Furthermore, they cover a variety of input fields: human, natural, socioeconomic, and others. Because environment is considered to be a synthesis off all of these fields, environmental models very often incorporate several aspects from the areas given above (Clarke 2000). Clarke also adds that environmental modeling is mainly applied in the fields of significant societal importance.

Considering the properties of a good environmental model, Lee concludes that among the most important properties we should specify the following: transparency, robustness, reasonable data needs, appropriate spatial-temporal resolution, and the inclusion of enough key policy variables that allow policy issues to be explored (Lee 1973). Another interesting conclusion about the creation of a good conceptual environmental model provided by Hilborn and Mangel is focused on the fact that well-developed model forces ecologists to formulate hypotheses, establish what kinds of data are accessible, what data are necessary for research, and evaluate understanding of the key points of the system (Hilborn and Mangel 1997).

A variety of possible roles for the models  in environmental research, policy making and management, was suggested by various authors over the last decades (Brown 1993); (Frans 1987); (Irvine 2005); (Larocque, Mauriello et al. 2006); (Westerlvelt and Shapiro 2000). Consequently, a various classification of the roles of models can be proposed. Generally speaking, there are two main broad categories: a) research and b) decision-making support. The models with the first role assist scientists to build up in-depth understanding of the environmental system, whereas the second type models serve as mediators between scientists and decision-makers. In particular, the models in to environmental policy and decision-making the computer models can play four different roles. Van Daaten formulated them as following:

- Models as eye-openers;
- Models as arguments in dissent;
- Models as consensus building tools;
- Models as management tools (Van Daaten 2002).

In addition, King and Kraemer also consider three main roles which environmental model plays in policy context:

- firstly, models should be debatable and they should clarify results in a discussion;
- secondly, models should induce analysis and discourse among stakeholders concerned
- finally, models should draw a clear outcome for the politicians explaining the major advantages and benefits as well as risks and complications in a particular model (King and Kraemer 1993).



### 2.3.2 Successful worldwide projects assisted by environmental modeling

Modeling has arisen as a valuable tool for assisting environmental science and other relevant issues (Argent and Houghton 2001). Recent trends directed to management of natural resources have caused a demand for modeling approaches that can deal with various system aspects considered by managers, decision makers and stakeholders. These approaches require models of hydrology, land use, ecology, economics and other aspects of the natural and social to be modeled in an integrated outlook. To implement this, the concept of environmental modeling has appeared whereby models of different system components are linked and run together in a way which allows observing the modeled effects of a range of systems interventions on various system components (Rizzoli and Davis 1999).

Recently, environmental modeling has been applied in a variety of projects, i.e. *"Dynamic ecological-economic modeling for regional planning"* (Safonov 2000), *"MODULUS project"* (Oxley and Winder 2002), *"Integrated economic-hydrological water modeling at the basin scale: the Maipo river basin"* (Rosegrant and Ringler 2004), *"MULINO-DSS project"* (Giupponi, Mysiak et al. 2004), *"IWES project: development of an integrated decision support system for watershed management"* (Kralisch and Fink 2003), *"RIVERTWIN project"* (Gaiser and Printz 2003) and many others.

Let us pass to the description of some of the listed projects mentioned above and give some other contemporary worldwide examples of modeling used in environmental science, particularly in water management and other water-related areas.

#### *2.3.2.1 Dynamic ecological-economic modeling for regional planning in the Brussels-Capital region*

Safonov in his report "Dynamic ecological-economic modeling for regional planning" considers integrated modeling as a tool for analyzing the ecological aspects of mobility induced by major policy options in the Brussels-Capital region.

He explains that for this purpose a set of models was needed to be introduced. Introduction of models basically had three main implications in the project described in Safonov's article (Safonov 2000). Firstly, these models provided demographic forecasts of population dynamics and the situation in employment in the Brussels-Capital region and presented the spatial distribution of this prognosis. Secondly, these models provided scenarios of development of major economic sectors in the addressed region. Thirdly, taking into account the introduction of new regulations on vehicles in the region concerned, models were used for the economic forecast of future changes in the transport sector.

Summarizing, Safonov (2000) concludes that ecological-economic models made possible evaluation of the contribution to air pollution emissions of traffic and management scenarios which are based on the models generated several policy recommendations in transport sector (Safonov 2000).

#### 2.3.2.2 Mediterranean example: MODULUS project

Continuing, a Mediterranean example of modeling and decision support tools is also a good illustration of the application of modeling in environmental projects. Oxley and Winder (2002) give a remarkable example of MODULUS project in which ten constituent integrated models simulating hydrology, atmospheric conditions, vegetation, soils, and anthropogenic influence were introduced.

This project was aimed to elaborate appropriate measures for the problem of land degradation and assessment of policy options by integrated environmental modeling. It is notable that this project proved a success because it represented the feasibility of integrating distinct research models for policy support and decision making (Oxley and Winder 2002).

#### 2.3.2.3 The integration of ecological and economic modeling to manage water quality problems in Australia

Robinson (1997) in his article "The integration of ecological and economic modeling to manage water quality problems" gives an example of a project with successful application of the explicit ecological simulation model for evaluation of the potential economic impacts of policy interventions on the water quality of the Bremen river in Australia. The author explains that eutrophication being one of the most urgent problems in Australian coastal waterways can lead to degradation of ecosystem services and economic and social losses in future.

The main result of this project was development of economic model by using extended input-output data base incorporating a waste stream and effluent discharge sector. Policy interventions evaluated by this model gave information about the regional economic costs of biological oxygen demand (BOD) reduction in the river over long-term planning (Robinson 1997).

#### 2.3.2.4 STREAM instrument: use of a spatial distributed water balance model

The STREAM instrument is the next remarkable example of the application of modeling in environmental science. Aerts and Kriek in their article "STREAM (Spatial tools for river basins and environment and analysis of management options): set up and requirements" provide the detailed description of this instrument. They point out that STREAM uses a spatial distributed water balance model for simulating the water balance in larger river basins. The feasibility of this model relates to the fact that it provides a profound analysis of the impacts of climate changes and land use changes on the fresh water hydrology of a river basin. It is not surprising that STREAM instrument has been applied with success for several river basins such as the Rhine, Ganges/Brahmaputra, Amudarya, Yangtze and others (Aerts and Kriek 1999).

The core of the STREAM is a GIS-based rainfall runoff model demonstrating the simulation of river discharges and water availability in river basins. Furthermore, this instrument puts forward five spatial data output types, i.e. potential and actual evapotranspiration, soil water regime, aridity index, runoff regime, and snow cover. In addition, STREAM provides a scenario analysis enabling stakeholders to reveal main implications from the model simulation including all output types.

Therefore, they concluded that STREAM instrument has acknowledged being a complex and integral approach for management of river basins (Aerts and Kriek 1999).

#### *2.3.2.5 MULINO-DSS project: sustainable use of water resources*

Another worldwide example of environmental modeling is the MULINO-DSS project (Giupponi 2007). This modeling has been used for sustainable use of water resources at the catchment scale. MULINO-DSS is a project funded by the European Commission and aimed to using of Decision Support System (DSS) software for integration of socio-economic and environmental modeling with geospatial information and multi-criteria analysis. In DSS software integrated modeling allows assessment of the value of quantitative indicators that can be transparent and participatory decisions.

Furthermore, integrated analysis modeling makes use of three main modules. They are a) a mathematical hydrologic model (for surface flows of water in a catchment), b) a suite of mathematical models for simulations of land use changes resulted from management scenarios, and c) a suite of mathematical models for simulation of environmental impacts connected to water pollution and ground-water quality (Giupponi 2007).

Giupponi (2004) notes that despite the considerable complexity of the MULINO-DSS project in terms of application of such sophisticated software incorporating hydrologic models, scenario development and multi-criteria analysis, it became quite successful. The DSS software developed by the MULINO expert group became a practical application of a decision tool for sustainable management and quality of water. Elaborated by a large group of experts with distinct backgrounds, DSS software approved itself as software allowing to carry out complex integrated modeling in sustainable use of water resources at a catchment scale (Giupponi, Mysiak et al. 2004).

#### *2.3.2.6 FLUMAGIS project on water management in Germany*

The FLUMAGIS project is the next example demonstrating a successful application of environmental modeling in water management. Volk (2007) describes that this project was based on scale-specific modeling, the integration of methods for ecological and socio-economic assessment and techniques for visualization. One of the upsides of the respective project was the development of an interactive tool for the evaluation and visualization of the hydrological and ecological conditions in the Upper Ems river basin (Northwest Germany) and economic aspects of management actions.

GIS-based integrated ecological-economic modeling combining different scale of modeling, development of land use scenarios, floodplain assessment and model simulation of impacts of river basin management, and socio-economic assessment was the key part of the in this project (Volk 2007). The FLUMAGIS project was focused on integration of various simulation models in order to implement effective measures for river basin management as well as to predict the effect of proposed measures to the water quality and river habitat conditions.

As a result, the application of modeling in the FLUMAGIS project allowed decision makers to take several measures at river basin management on the different scale levels and ranked them according to their cost-efficiency (Volk 2007).

#### *2.3.2.7 RIVERTWIN project*

The last example of successful application of integrated environmental modeling described in the present work is the ongoing RIVERTWIN project focused on testing and implementing the integrated regional model MOSDEW for the strategic planning of water resources management in three river basins in Europe, Central Asia, and West Africa. Gaiser and Printz in their article devoted to the RIVERTWIN project outlines that modeling in the addressed project is based on integration of ecological, i.e. water availability and quality) and economic aspects (water use and water demand) of water management (Gaiser and Printz 2003). Simultaneously, integrated alternative water basin scenarios were created for each respective region.

The main application of these models is to promote sustainable, integrated water management, balancing economic constraints and ecological requirements, through several outcomes, for instance, developing integrated scenarios of economic growth, land use and climate change in cooperation with stakeholders and potential users in order to assess the implications for water management, or enhancing the mutual transfer of know-how and technology between European and Third World countries by the twinning of river basins (Gaiser and Printz 2003).

Drawing the conclusion, we should highlight that application of environmental modeling has become an essential tool of analysis in environmental projects. All examples provided above show a successful application of modeling in environmental science and other relevant spheres. For this reason, in the current research it has been decided to implement environmental modeling as a tool for analysis of the Aydar-Arnasay lakes system future development.

### 2.3.3 New way of thinking: scenario approach in environmental science

The scenario approach has become a widely used method of research in various fields such as the business sector, management, environmental science, economics and others. According to the United Nations Environmental Program (UNEP) definition[6], the scenario approach represents "descriptions of journeys to possible futures". This approach reflects various assumptions about how "current trends will evolve, how critical uncertainties will play out and what new factors will come into play" (IISD 2008).

For clarity, it is generally accepted that scenarios do not predict. Rather, they paint pictures of possible futures and explore the distinct outcomes that could result if basic assumptions are changed (UNEP/RIVM 2004). The main idea of the scenario approach or scenario thinking/planning is to incorporate known facts about the future, such as demographics, geography, military, political, industrial information, and mineral reserves, "with plausible alternative social, technical, economic, environmental, educational, political and aesthetic (STEEEPA) trends which are key driving forces" (Ringland 1998). It should be pointed out that this scenario approach is focused on creation and evaluation of alternative strategies or solutions that may be successful in an unknown future (Raskin, Banuri et al. 2002).

[6] More detailed description of the scenario approach is provided in sections 3.3.1 and 6.1.1

#### *2.3.3.1 Scenario approach in scientific publications*

Scenario approach is widely-spread as a strategic management tool for decision making process in environmental science (Lindgren and Bandhold 2003). A large number of international environmental organizations and institutions broadly use the scenario approach in the research of severe environmental problems such as global climate change, increasing growth of the world population, water scarcity, desertification, deforestation and others (IISD 2008). For instance, UNEP has published enormous amount of reports devoted to application of the scenario approach in environmental science, e.g. *"Four scenarios for Europe: Based on UNEP's third Global Environment Outlook"* issued in 2003 (UNEP/RIVM 2003), *"Global biodiversity scenarios for the year 2100"* (Sala, Chapin et al. 2000), *"GEO-2000 report: Alternative Policy Study: Water Resource Management in West Asia"* (UNEP 2000) and many others.

Among other international reports focused on scenario approach we should list a great amount of papers published by the International Panel on Climate Change (IPCC), for example, *"Emission Scenarios: summary for policy makers"* (IPCC 2000), and *"Special Report on Emissions Scenarios"* (IPCC 2001). Also, there are several reports published by less known institutions, for instance, *"Central Asia's Economy: Mapping Future Prospects to 2015"* published by Central Asia-Caucasus Institute (Dowling and Wignaraja 2006).

Furthermore, a huge variety of contemporary projects focused on the scenario approach are published in different scientific journals, namely:

- "Holistic aspects in landscape development: a scenario approach" in *Landscape and Urban Planning* (Patton 2002);
- "Scenario building as a tool for planning a sustainable transportation system" in *Transportation Research Part D: Transport and Environment* (Shiftan, Kaplan et al. 2003);
- "Scenarios as a tool in water management: Considerations of scale and application" in *Developments in Water Science* (Warwick, Bakker et al. 2003);
- "A formal framework for scenario development in support of environmental decision-making" in *Environmental Modeling & Software* (Mahmoud, Liu et al. 2009);
- "A DSS for water resources management under uncertainty by scenario analysis" in *Environmental Modeling and Software* (Pallottino, Sechi et al. 2005);

- "Scenarios of water resources management in the Lower Lusatian mining district, Germany" in *Ecological Engineering* (Koch, Kaltofen et al. 2005).

It should be noted that very often scenario approach is applied in collaboration with environmental modeling. There are several contemporary environmental projects in which environmental modeling and scenario approach are directly correlated, for example:

- "Participatory scenario analysis for integrated regional modeling" in *Landscape and Urban Planning* (Walz, Lardelli et al. 2007);
- "Combined ecological and economic modeling in agricultural land use scenarios" in *Ecological Modeling* (Monier, Birr-Pedersen et al. 2004);
- "Solving stochastic complementarity problems in energy market modeling using scenario reduction" in *European Journal of Operational Research* (Gabriel, Zhuang et al. 2009);
- "Modeling and multicriteria analysis of water saving scenarios for an irrigation district in the upper Yellow River Basin" in *Agricultural Water Management* (Gonzalves, Pereira et al. 2007);
- "Prospective scenarios for water quality and ecological status in Lake Sete Cidades (Portugal): The integration of mathematical modeling in decision processes" in *Applied Geochemistry* (Martins, Ribeiro et al. 2008).

Summarizing, it should be underlined that all scientific publications provided above demonstrate a very valuable practical application of the scenario approach in environmental science and show that this approach can be successfully used in the decision making process. Furthermore, application of scenario approach jointly with modeling provides a powerful framework for conducting the research as well as for decision-making process. In the present work we will attempt to use the integration of these two methods in order to reach the main research goal.



### 2.3.4 GIS technologies

#### *2.3.4.1 Definition*

Nowadays, Geographic Information System (GIS) technologies are widely used in various domains, such as cartography and geodesy, social and environmental sciences, urban planning, business and management sectors and others.

Currently, there are numerous definitions of GIS, but none of which explain it accurately and sufficiently. GIS incorporates three main aspects of modern world, i.e. geography, information, system, and offers new advanced methods of using them (Davis 2001). A typical GIS can be understood by the help of various definitions given below.

Steinberg considers definition of GIS in its simplest form pointing out that "GIS is a system designed to store, manipulate, analyze, and output map-based, or spatial, information" (Steinberg 2006). Davis defines GIS as "a computer-based technology and methodology for collecting, managing, analyzing, modeling and presenting geographic data for a wide range of application" (Davis 2001). Burrough considers GIS as, "set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes" (Burrough 1986).

Tomlinson gives an interesting definition of GIS explaining that GIS is "a particularly horizontal technology in the sense that it has wide-ranging applications across the industrial and intellectual landscape" (Tomlinson 2007). Longley indicates that GIS is a special class of information system which "keep track not only of events and activities, but also of where these events of activities happen or exist" (Longley, Goodchild et al. 2005). Arnoff defines GIS as, "a computer based system that provides four sets of capabilities to handle geo-referenced data: data input, data management (data storage and retrieval), manipulation and analysis, and data output" (Arnoff 1989). The definition provided by Arnoff contains a certain number of the important GIS functions. A full list of GIS functions is present in the next subsection.

#### *2.3.4.2 GIS functionality*

GIS has numerous functions which are dealing with geographic data from input to output. The main GIS functions are:

- Collection, i.e. gathering information from various sources, including global communication media; the illustration demonstrates a remote sensing satellite which can be treated as the prime data source today; the digitizing table is for converting paper maps into digital computer map data via electronic tracing (Davis 2001);
- Storage and management, i.e. administering and keeping track of data, including integration of different kinds of data sets into a common database; database management is replacing the physical map storage structure;

- Retrieval, i.e. easy and efficient selection and viewing of data in the diversity of ways, e.g. printed maps, computer monitor display, internet (Steinberg 2006);
- Conversion, i.e. change of data from one form to another or one map format to match another, for instance, converting from one geographic projection, reclassifying, recalling and other computer options which make data more useful and valuable for users;
- Analysis, i.e. analyzing data to produce new outcome and insight; using distinct techniques for data research, statistical procedures and other methodologies (Tomlinson 2007);
- Modeling, i.e. generalization of a data or a simple explanation of real things and processes; simplifying the data to figure out how things works and explain what the data means;
- Display, i.e. presenting data by a variety of ways, e.g. maps, graphs, reports for better understanding (Davis 2001).

##### *2.3.4.3 GIS technologies as a tool for environmental research: examples*

GIS technologies are quite widespread used tool in different fields of science. Regarding interactions between GIS and science, GIS involves complete understanding about patterns, space, and processes or methodology needed to approach a scientific problem. It is a tool acting as a means to attain certain objective quickly and efficiently (Tomlinson 2007).

Longley explains that GIS in the context of computerized mapping and spatial analysis have been developed simultaneously in several related fields. The present status would not have been achieved without intimate interaction between various fields such as utility networks, cadastral mapping, topographic mapping, thematic cartography, earth science, geography, surveying and photogrammetery remote sensing, image processing, computer science, rural and urban planning (Longley, Goodchild et al. 2005).

According to Shamsi (2000), the GIS technologies are rapidly becoming standard tools for management of natural resources. The effective use of large spatial data volumes is dependent upon the existence of an efficient geographic handling and processing system to transform this data into usable information. The GIS technology is used to assist decision-makers by indicating various alternatives in development and conservation planning and by modeling the potential outcomes of a series of scenarios (Shamsi 2000). Shahab describes the major areas of GIS application, they are:

- **Different streams of planning**: urban planning, housing, transportation planning architectural conservation, urban design, landscape;
- **Street Network Based Application**: it is an addressed matched application, vehicle routing and scheduling: location and site selection and disaster planning;
- **Natural Resource Based Application**: management and environmental impact analysis of wild and scenic recreational resources, flood plain, wetlands, aquifers, forests, and wildlife;
- **View Shed Analysis**: hazardous or toxic factories, siting and ground water modelling, wild life habitat study and migration route planning;
- **Land Parcel Based**: zoning, sub-division plans review, land acquisition, environment impact analysis, nature quality management and maintenance;
- **Facilities Management**: location of underground pipes and cables for maintenance, planning, tracking energy use (Shahab 2008).

There are a huge variety of environmental projects assisted by various GIS (Tomlinson 2007). GIS are broadly applied in investigation of meteorological and hydrological issues; research of land use and water management, climate change and biodiversity y as well as in socio-economic sphere, i.e. demography, transport and industry sectors and others (Davis 2001). Let us list some interesting examples of projects assisted by different variations of GIS technologies. They are:

- "GIS-based decision support system for regional eco-security assessment and its application on the Tibetan Plateau" in *Journal of Environmental Management* (Xiaodan, Xianghao et al.);
- "Linking conceptual and simulation models of the Cooum River: collaborative development of a GIS-based DSS for environmental management" in *Computers, Environment and Urban Systems* (Bunch and Dudycha 2004);
- "An integrated GIS-based analysis system for land-use management of lake areas in urban fringe" in *Landscape and Urban Planning* (Liu, Lv et al. 2007);
- "A GIS-based model to estimate the regionally distributed drought water demand" in *Agricultural Water Management* (Satti and Jacobs 2004);
- "GIS tool for hydrogeological water balance evaluation on a regional scale in semi-arid environments" in *Computers & Geosciences* (Portoghese, Uricchio et al. 2005);

- “Application of a GIS-based simulation tool to illustrate implications of uncertainties for water management in the Amudarya river delta” in *Environmental Modeling and Software* (Schluter and Roger 2007);
- Assessing water quality management options in the Upper Litani Basin, Lebanon, using an integrated GIS-based decision support system” in *Environmental Modeling & Software* (Assaf and Saadeh 2006).

##### *2.3.4.4 Remote sensing*

Remote sensing is an extensive science, drawing from many areas for support and development. Satellite and digital imagery play an important role in remote sensing; providing information about the land studied (Lillesand and Keifer 1994).

The field of remote sensing has been defined many times (Campbell 2002). Davis explains that remote sensing is “the art or science of telling something about an object without touching it” (Davis 2001) . Lintz and Simonnet describe it in the same way pointing out that remote sensing is “an acquisition of physical data of an object without touch or contact” (Lintz and Simonett 1976). Barrett and Curtis consider remote sensing as “an observation of a target by a device separated from it by some distance” (Barrett and Curtis 1992).

Campbell give a very comprehensive and complete description, i.e. remote sensing is “the practice of deriving information about the earth’s land and water surface using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth surface” (Campbell 2002).

Sabins considers remote sensing as an interesting and exploratory science, because it provides images of areas “in a fast and cost-efficient manner, and attempts to demonstrate what is happening right now in a study area”. While airphotos and fieldwork remain critical as sources of information, the cost and time to carry out these methods sometimes could not be feasible for the research. Satellite and digital imagery acquired recently, provide more overall detail to assist the researcher in the classification process (Sabins 1994).

Nowadays, remote sensing is widely used as a tool for environmental science. It should be emphasized that the present thesis mainly is interested in consideration of remote sensing for the water research. For instance, Jensen mostly examines remote sensing in context of its application in hydrological research (Jensen 2007). Rango states that remote sensing data are being used operationally in precipitation estimates, soil moisture, measurements for irrigation scheduling, snow water equivalent and snow cover extent assessments, seasonal and short term snowmelt runoff forecasts, and surface water inventories (Rango 1994). Miller studies Remote Sensing of coastal aquatic environments and examines its various technologies, techniques and applications (Miller, Del Castillo et al. 2005).

In order to illustrate the great importance of remote sensing method in water area let us list several water research projects by application of this method.

To start with, several projects directed to water management in terms of irrigation farming have been accomplished and published in the various scientific journals. Some of them are, as follows: “Combining remote sensing-simulation modeling and genetic algorithm optimization to explore water management options in irrigated agriculture” in *Agricultural Water Management* (Ines, Honda et al. 2006); “Using remote sensing data for water depletion assessment at administrative and irrigation-system levels: case study of the Ferghana Province of Uzbekistan” in *Agricultural Water Management* (Chemin, Platonov et al. 2004); and “Remote sensing for irrigation water management in the semi-arid Northeast of Brazil” in *Agricultural Water Management* (Folhes, Renny et al. 2009).

In common with the projects above, some research in other water related areas by using remote sensing has been accomplished and also issued, i.e.:

- “Review of remote sensing applications in hydrology and water resources management in India” in *Advances in Space Research* (Bhavsar 1984);
- “Remote sensing application to the management of agricultural drainage water in severely arid region: A case study” in *Remote Sensing of Environment* (Abderrahman and Bader 1992);
- “Sustainable fresh water resources management in northern Kuwait--A remote sensing view from Raudatain basin” in International Journal of Applied Earth Observation and Geoinformation (Ud Din, Al Dousari et al. 2007);
- “A multi-scale remote sensing approach for monitoring northern peatland hydrology: Present possibilities and future challenges” in *Journal of Environmental* Management (Harris and Bryant 2009);
- “The role of remote sensing in hydrological modelling of the Okavango Delta, Botswana” in *Journal of Environmental Management* (Milzow, Kgotlhang et al. 2009).

Concluding, all examples provided above clearly demonstrate that remote sensing is a powerful method for the water research and it can be applied for wide-ranging aspects of water area.

### 2.3.5 Main conclusions

Having examined modern methods as a tool for assisting different areas of environmental science we should conclude that all above mentioned methods, i.e. environmental modeling, scenario approach, use of GIS technologies, and particularly, remote sensing are advanced and powerful for scientific analysis. Furthermore, these methods are considered to be suitable and very practical for examination of water management systems. Application of the methods concerned[7] would give deeper and meaningful understanding of the current state of the Aydar-Arnasay lakes system.



[7] Application of the methods concerned is described in details in third methodological chapter

# 3. RESEARCH METHODOLOGY

The chapter provides the detailed description of the methods used for the data collection and analysis in the course of the research. The present thesis represents a combination of qualitative and quantitative study of the Aydar-Arnasay lakes system (AALS). Various methods for data collection and analysis were applied in the research. For the purpose of better understanding of the methods used, let us primarily consider the research design and subsequently describe each method in details.

## 3.1 Research design

In order to achieve the main goal of the present course of the study, a complex of different research methods was applied to ensure that this study meets its objectives.

Analytical methods were used to review and analyze information about the research conducted of the Aydar-Arnasay lakes system and worldwide practices of modern ICT use. Comparative methods were applied for investigations of the AALS past, i.e. the AALS water surface area and volume during 1969-2009 were calculated. These methods include comparison of the different land use datasets and comparison of the USSR military maps. Along with this, GIS methods for the calculation of the AALS area were used, namely, application of the Digital Elevation Maps (DEM) created in the Arcview program and Remote Sensing (RS) conducted by MultiSpec program.

The research trip to Moscow greatly assisted in provision of valuable information about the Aydar-Arnasay lakes system and expert opinions, especially about the situation concerning the cooperation between Central Asian republics. Furthermore, this trip provided high-quality datasets for conducting environmental modeling by the STELLA software.

Summing it all up, the general steps of the present research design are as follows:

- Reviewing and analyzing the existing sources of literature relevant to the Aydar-Arnasay lakes system and use of modern ICT for scientific purposes;
- Elaboration of the AALS water management scenarios and their visualization by the scenario conceptual graph;
- Assess the elaborated AALS water management scenarios using the model in the STELLA software;

- Interpretation of the results, i.e. analysis of the prime implications of each water management scenario and finding of the possible water management scenario indicating the AALS future development closer to reality.

## 3.2 Methods of data collection

The main methods for data collection include literature review, unstructured interviews, and GIS data mining. To begin with, data collection consisted of two main temporary stages:

- Preliminary conduction of data collection before the planned research field trip; this stage included gathering of many-sided information about Aydar-Arnasay lakes system from national reports, books, journal articles and other relevant materials;
- Detailed screening of the particular information about the Aydar-Arnasay lakes system based on the content of the tentative thesis chapters during the research field trip.

### 3.2.1 Literature review

To start with, the initial steps undertaken were to review the academic literature and documents in the research area. Evaluation of the relevant literature builds a logical framework for the study and demonstrates that the researcher is aware of how the issue in question has been studied before and consequently, the researcher has a particular viewpoint about the known and even the unknown problems of the study.

The review of existing literature assists in collecting the relevant information, opinions, and findings of different authors about the conditions and features of the Aydar-Arnasay lakes system. Therefore, literature review in the present thesis includes evaluation of various materials such as national reports, books, journal articles, programme documents, action plans, and others. On-line electronic resources were also used mostly from such international organizations as United Nations Environmental Program (UNEP), World Bank, Interstate Commission for Water Coordination (ICWC), and Food and Agriculture Organization (FAO). Furthermore, particular consideration was given to the literature in relation to fisheries development in the Aydar-Arnasay lakes and historical stages of the AALS formation. It is worth mentioning that this literature was gathered in Russian, and was translated into English by the author.

Due to lack of resources on the thesis topic in the library of the Central European University (CEU), there was a need to visit and search in the libraries of the Faculty of

Geography (Moscow State University) and Institute of Geography (the Russian Academy of Science), which offer a collection of relevant literature, especially information about the historical stages of the Aydar-Arnasay lakes system.

The literature review is based on such topics as the consequences of the Aral Sea desiccation, hydrological research conducted, and overview of the fisheries evolution in the AALS (Chapter 2). Besides, the literature review gives a detailed description of scenario approach and environmental modeling, outlines the remarkable examples of the projects related to these methods (Chapter 2), and provides an overview of GIS technologies, including remote sensing, one of the main methods used in the present work to analyze change dynamics of the AALS water surface area (Chapter 4). Finally, the review of contemporary literature about the AALS ecological conditions and main problems provides a good background for the elaboration of the AALS water management scenarios (Chapter 5).

Apart from using various books, journal article and other sources of information listed above, the bulk of information derives from archival research. The most important information, which was found in the archives of the VASKhNIL library (the acronym stands for *Lenin All-Union Academy of Agricultural Sciences*), was about the evolution of the Aydar-Arnasay lakes system and prime stages of its historical development.

### 3.2.2 Unstructured Interviews

One of the methods for data collection in the present research is conducting unstructured interviews. For the purpose of clarity, the main idea of unstructured interview is introduced and the suitability of this type of interview for the present research is demonstrated.

Unstructured interviews are most useful when the researcher wants to gain an in-depth understanding of a particular phenomenon within a particular cultural context. In addition, they are most appropriate when the researcher is working "within an interpretive research paradigm, in which they would assume that reality is socially constructed by the participants in the setting of interest" (Patton 2002). Based on this underlying assumption, the researcher wants to understand the phenomenon of interest from the individual perspectives of those involved.

Minichiello defines unstructured interviews as interviews in which neither the question nor the answer categories are predetermined. Instead, they rely on social interaction between the researcher and the informant (Minichiello, Aroni et al. 1990). Punch describes unstructured interviews as a way to understand the complex behavior of people without "imposing any *a priori* categorization, which might limit the field of inquiry" (Punch 1998). Patton (2002) describes unstructured interviews as a natural extension of participant observation, because they so often occur as part of ongoing participant observation fieldwork.

During the research trip in Moscow, a few unstructured interviews with experts working on water issues in the Central Asian region were conducted. The purpose of these unstructured interviews was to get familiar with the existing relationships between Central Asian countries, namely, between Uzbekistan and Kazakhstan in terms of regulations on water discharges to the AALS and the main disagreements with regard to present water policy. Another aim of these interviews was important to understand the roots of the current problems and discontent.

The main reasons for choosing unstructured interviews in the present research are the following:

- good possibility for researcher to generate questions in response to the interviewees' narration, that results in deeper understanding of the area concerned;
- the researcher's control over the conversation is intended to be minimal, but nevertheless the researcher tries to encourage the interviewees to relate experiences and perspectives relevant to the problems of interest to the researcher;
- the unstructured interview is especially useful for studies attempting to find patterns, generate models, and implement information system design; in the present case these interviews help to understand patterns of water distribution and water discharges between Uzbekistan and Kazakhstan.



### 3.2.3 GIS data mining

Data mining is the essential ingredient in the more general process of Knowledge in Databases (KDD). The idea is that by automatically sifting through large quantities of data it should be possible "to extract nuggets of knowledge" (Read 2005). Data mining can be defined as a process of analyzing data which is already presented in database (Witten and Frank 2005). Currently, data mining is becoming an increasingly important "tool to transform this data into information". It is commonly used in a wide range of "profiling practices, such as marketing, scientific discovery, surveillance", and others.

In the present research, data mining was used for searching the different aerial satellite images of the Aydar-Arnasay lakes system in numerous databases of such international organizations and institutions as the US Geological Survey (USGS), Satellite and Information Service of National Oceanic and Atmospheric Administration (NOAA), the database of The National Aeronautics and Space Administration (NASA), the US Berkley Earth Science and Map Library, and others. During data mining, a set of high-quality AALS satellite images starting from the 1970s was found. The method of data mining of the aerial satellite images allows us to accurately analyze the changes of the AALS water surface area during 1969-2009, thus contributing to the present research.

### 3.3 Methods of data analysis

Among the main methods for data analysis, the following have been applied:

- scenario approach for elaboration of the water management scenarios;
- environmental modeling assisted by the STELLA software;
- GIS methods using the Arcview program;
- Remote Sensing using the MultiSpec program.

#### 3.3.1 Scenario approach as an analytical method for predicting

The scenario approach is one of the methods used of analyzing data in the course of the study. For the present research it is important to outline that the scenario approach was used in combination with environmental modeling assisted by the STELLA software. To clarify why this method has been chosen for data analysis in the present research, let us firstly briefly repeat the concept of scenario approach and its features.

The scenario approach, introduced by the Shell Planning Group in the 1970s, has developed as a powerful method which provides a simple concise tool for "*painting a picture*" of how actors (clients), components and messages act together to complete one or more system goals (Foster 2006). Defining the "scenario approach" we should emphasize that it is primarily a structured process of thinking about and anticipating the unknown future, "without the pretense of being able to predict the future or being able to influence the environment" in a major way. Instead, this approach "navigates through the uncertainties and large-scale driving forces" that are impacting on the future (Schoemaker 1995). The main goal of the scenario approach is to examine possible future developments that could impact on individuals, organizations or societies, in order to find directions for decisions that would be most "beneficial no matter how the future unfolds" (Schoemaker and Van der Heijden 1992).

In the current research we will try to apply the scenario approach as the major analytical method for presenting the future development of the Aydar-Arnasay lakes system. Scenario approach let us elaborate a number of possible future water management scenarios which propose completely different development ways of the AALS. In other words, in our research we have assumed that this method will demonstrate a wide range of possible environmental changes in the Aydar-Arnasay lakes in future, varying from imperceptible and harmless changes to severe and destructive ones.

### 3.3.2 Environmental modeling

To find the answer to the research question, which is built on the identification of the most possible water management scenario for the future development of the AALS, the environmental modeling was conducted by the STELLA Software. The purpose of environmental modeling was to develop a conceptual model of the AALS and then, to assess elaborated AALS water management scenarios using this model.

#### *3.3.2.1 Stella Software*

STELLA software was chosen because it is a powerful tool for constructing mathematical models of physical, chemical, ecological, and other systems. Furthermore, in comparison with the majority of computer languages, STELLA enables the majority of time and effort to be spent on understanding and investigating the features of a dynamic system, rather than writing a program that must follow some complex syntax. STELLA has a friendly graphical interface that aids in laying out, constructing, and utilizing a model. Models can be configured to run independently with set inputs (either numerically or graphically specified) or in an interactive "flight simulator" mode. Model output can be observed by numerical readouts, tables, and graphs.

In terms of technical implementation, STELLA has three levels covered different aspects of model building. The upper level, *mapping,* is focused on creating the conceptual model of the system and shows the main blocks of the systems to be modeled and the relationships between them. The second one, *modeling,* is used for direct model building by basic blocks. The third one represents a full list of equations that connect the model blocks.

In other words, the STELLA software is easy to use for environmental modeling and it does not require deep technical skills for working.

Working in the STELLA software consisted of the following steps:

- Development of the conceptual model of Aydar-Arnasay lakes system (AALS);
- Description of the AALS conceptual model and its input and output parameters and examination of the primary factors which influence the Aydar-Arnasay lakes' volume fluctuations;
- The model simulation based on the elaborated water management scenarios;
- Interpretation of the results obtained.

### 3.3.3 GIS methods

GIS methods have been applied for the calculation of the AALS water surface area and volume during 1969-2009 as one of the important parts of the present research. For the calculation of the AALS water surface area in various time periods the following GIS methods of data analysis have been applied:

- Comparative method based on the analysis of the land use datasets;
- Comparative method based on the analysis of the USSR military maps;
- Use of Digital Elevation Maps (DEM);
- Remote sensing provided by the MultiSpec program.

#### *3.3.3.1 Arcview program*

The Arcview program has been chosen for the practical exercise, i.e. calculation of the AALS water-surface area and volume during 1969-2009. The main reason of using this program is a presence of a certain amount extensions which enable to calculate water-surface area easily. Another reason is convenient and understandable toolbar in the Arcview program which makes working process very effective.

The Arcview program has been used for the first three methods listed above. In the first method, comparative method based on the analysis of the land use datasets, use of the Arcview has been basically related to the working with land use datasets during all exercise's steps. Application of the Arcview program in the second method, comparative method based on the analysis of the USSR military maps, was necessary only for the final step of the exercise, namely, for the calculation of the AALS water-surface area. Use of the Arcview in the third method was appropriate for the creation of the AALS Digital Elevation Maps succeeded by calculation of the water-surface area.

### 3.3.4 Remote sensing

As mentioned above, remote sensing is one of the GIS methods applied for the AALS calculation of the water-surface area during 1969-2009. Characterized by two major peculiarities, it has been decided to present the method concerned separately from another methods used. In general, the main features are:

- it is more sophisticated and time-consuming method in comparison with first three methods;
- it allows research to occur on time scales, both in duration and frequency, that were previously impossible;
- it often allows the investigation of portions of the Earth that are difficult or dangerous to reach;
- specific softwares are required for this method; MultiSpec program has been selected for the present research (Sabins 1994).

#### *3.3.4.1 MultiSpec program*

MultiSpec program is a processing system for interactively analyzing Earth observational multispectral image data such as that produced by the Landsat series of Earth satellites and hyperspectral image data from current and future airborne and spaceborne systems such as AVIRIS. In particular, Landsat satellite images have been used for the present research.

This software has been selected because it is a very valuable tool and is a much faster method than using the aerial photo methods. It is quite accurate and it makes possible to achieve higher levels of accuracy with better resolution.



## 3.4 Limitations of the Research

There were several factors that hampered the present research. One of them was the failed research trip to Uzbekistan, which was due to two main causes. On the one hand, the complicated political situation in the Central Asian region affected the organization of the planned research trip. On the other hand, lack of possibility to organize a number of meetings with experts in water management and other water-related issues also influenced the preparation for the research trip.

# 4. AYDAR-ARNASAY LAKES SYSTEM: LOOKING INTO THE PAST

The following chapter analyzes historical features of the Aydar-Arnasay lakes system (AALS) development based on the documentary research, i.e. literature found in the archives, valuable information received during the unstructured interviews in Moscow, and use of different satellite images obtained from GIS data mining. The main methods for the data analysis, described in the research methodology chapter, have been applied for working on this chapter.

The present chapter consists of two main sections. The first section focuses on analysis of the main historical stages of the Aydar-Arnasay lakes formation. Having considered all relevant archive materials, the AALS historical stages have been combined and described by the author. Moreover, in order to show the lakes' historical development more demonstrably, a set of maps using GIS methods has been created by the author.

The second section examines the change dynamics of the AALS water-surface area and volume in 1969-2009. This section contains the description of the practical exercise accomplished by the author. The main idea of this exercise is to calculate the AALS water-surface area and volume during 1969-2009 using GIS methods and examine change dynamics during these years. This exercise has provided valuable data about water-surface area and volume of these lakes in the period 1969-2009 which allow conducting extensive analysis of change dynamics of these characteristics.

## 4.1 Historical stages of the AALS formation

This section depicts the main historical stages of the Aydar-Arnasay lakes system formation proposed by the author and the main peculiarities of each stage examined in the archives. The stages of the AALS historical development are as follows:

- the 1920s- 1960 (1963): the Aydar-Arnasay solonchak;
- 1960 (1963)-1969: the Chardara reservoir construction (Gorelkin and Nikitin 1976);
- 1969-1970: inundation of the Aydar-Arnasay depression (Muminov and Poplavskiy 2006);
- 1970-1991: the AALS as the lakes for residual water;
- 1991- Present (Ryabcev 2005).

### 4.1.1 Aydar-Arnasay solonchak (the 1920s – 1960(1963))

According to Gorelkin and Nikitin (1976), the first stage of the AALS formation is the period before the reclamation of the Golodnaya Steppe irrigation area in 1918-1920. In this period of time the area of the present-day Aydar-Arnasay lakes system was occupied by the Aydar-Arnasay depression with dried alkaline soils and wet salines.

Ivanov (1957) highlights that in the 1910s and 1920s the Tuzkan depression dried up on a regular annual basis, flooding during the spring period and shrinking by the fall period up to 10 km and served as a place for salt production. 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 the cotton monoculture. Consequently, starting from the 1950s salt deposition and production was terminated due to increasing Tuzkan water recharge.

Figure 2 shows a historical map of Uzbekistan illustrating how the Aydar-Arnasay lakes looked in 1954. Particularly, the red circle demonstrates the location of the Aydar solonchak and the blue circle – the location of the future Chardara reservoir which would be completed in 1964, and green one – Golodnaya Steppe irrigation areas.

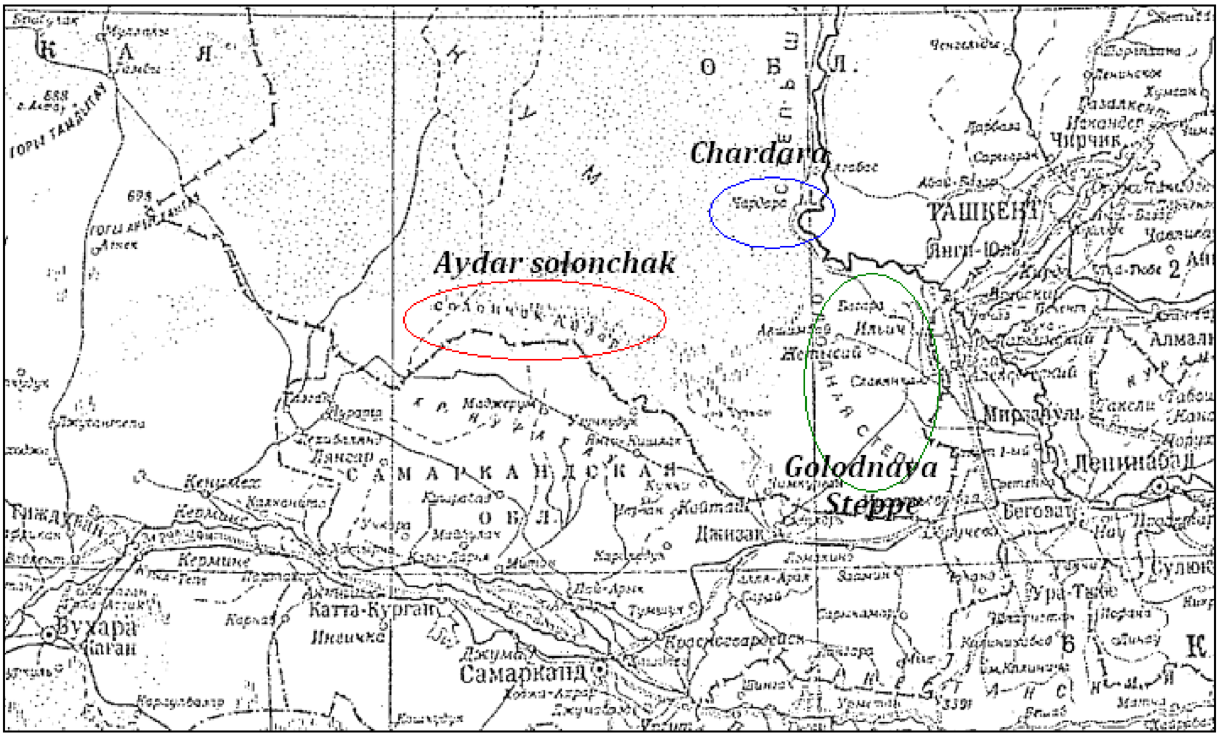


Figure 2. The Aydar-Arnasay lakes system in 1954 (The Uzbek Soviet Encyclopedia, volume 14, 1971-1980)

It should be emphasized that beginning of the Golodnaya Steppe reclamation was identified by the author as the main precondition of the lakes system development and as the first historical stage. Namely, collector-drainage water from the Golodnaya Steppe irrigation areas considerably contributed to the lakes' evolution. This will be accurately seen in the consequent stage of the AALS development. The early sixties were proposed by the author as the period of termination of the first stage mainly because of construction of water facilities, i.e. Chardara reservoir, which was erected in 1963.

### 4.1.2 Chardara reservoir construction (1960(1963)-1969)

The large scale irrigation and drainage construction in Central Asia started after launching a program for the USSR land reclamation on the Plenum of Central Committee in May 1966. Based on this program, each five years it was planning to introduce thousands of new irrigation lands, building of the waterworks facilities such as reservoirs, dams, pumping stations, water catchment systems and others (Ryabcev 2005). Initially, erection of the cascade of artificial water reservoirs on the Amudarya and Syrdarya rivers, extensive-irrigation network and collector-drainage systems in the 1960s was basically related to the issue of water redistribution security (Ivanov and Nikitin 1978).

In the period of 1965-1985 a large number of reservoirs of seasonal and over-year regulation on the Syrdarya River was built. The largest and most important reservoirs are Toktogul (Kyrgyzstan), Chardara (Kazakhstan), Kayrakumskoe (Tajikistan), Charvak and Andijan (Uzbekistan) ((EDB) 2009).

Gorelkin underlines that the construction of the Chardara reservoir is a determinate stage in the evolution of the Aydar-Arnasay lakes (Gorelkin 1977). Ivanov and Nikitin describe that the impounding seasonal Chardara reservoir[8] was set in operation in 1964. Situated in the end part of the Syrdarya middle stream the Chardara, reservoir is responsible for the seasonal run-off regulation for irrigation and energy purposes in Kazakhstan (Figure 3). The reservoir occupies the Syrdarya river alluvial terraces formed by loamy sand and loam at 0.5-5.0 m thickness (Ivanov and Nikitin 1978).



[8] ***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 (McGraw-Hill 2002)

The main component of the Chardara reservoir water balance is the inflow of the Syrdarya surface water amounting to 74-93% of total inflow. Side inflow coming from the Borsu channel, the Keles and Kurukkeles rivers and several collectors makes up 6-25% in the annual balance. Water release from the Chardara reservoir goes downstream through Chardara waterworks facility and is estimated as 86-97% of all releases (Ivanov and Nikitin 1978).


Figure 3. The Chardara reservoir (adopted from Google Earth and modified by the author)

Among important characteristics of the Chardara reservoir it is necessary to point out the following: its volume (5,88 $km^3$), water-surface area (900-915 $km^2$) and net capacity (4,7-5,0 $km^3$). Ivanov (1978) analyzes that the Chardara reservoir water regime is characterized by three main phases: fall-spring filling up (October-March) spring equilibrium – level standing close to normal maximum operating level (April-June) and summer drawdown (June-September).

It should be mentioned, that 1963-1969 as duration of the second stage was assumed by the author nearly. This stage was proposed by the author due to the following factors:

- All relevant archive materials somehow have underlined that construction of the Chardara reservoir is a significant point in terms of the AALS evolution;
- In particular, the water discharges from the Chardara reservoir were responsible for to the Aydar-Arnasay lakes origin.

### 4.1.3 Inundation of the Aydar-Arnasay depression (1969-1970)

Increase of collector-drainage water from the Golodnaya Steppe and experimental discharges from the Chardara reservoir to the Aydar-Arnasay depression in mid-to late 1960s gave rise to instant formation of the Aydar-Arnasay lakes. Drainage water surpluses from the Arnasay lakes were discharged to the Aydar depression (Nasrullin, Chembarisov et al. 2007). According to Gorelkin's estimates (1976) the lakes' water surface amounted to 110 $km^2$ and the volume to 300 million $m^3$ by 1969.

During the archives' analysis it was concluded that the Aydar-Arnasay lakes system mainly fed by the collector-drainage water from the Golodnaya Steppe eventually formed in the extremely wet 1969 as a result of 21 $km^3$ water discharges from the Chardara reservoir. Inundation of the Aydar-Arnasay depression precluded huge damage in the downstream part of the Syrdarya River on the Kazakh territory (Mahmudova 2004a). At the same time, a substantial part of Uzbek grasslands was flooded and restructuring of the Arnasay lakes' hydrographic network took place, including flooding of the Aydar depression and its connection with the Tuzkan lake in 1970.

Having examined the different archive materials and scientific national reports concerning the respective topic, the author assumed that the inundation of the Aydar-Arnasay depression became a crucial period of early formation of these lakes and therefore 1969-1970 can be identified as an important development stage of these lakes.

### 4.1.4 Lakes for residual water (1970-1993)

For current research we should emphasize that inflow of collector-drainage water from the Golodnaya Steppe was the primary inflow component of AALS water balance during 1970-1993. In the 1970s 98% of the water mass was concentrated in the Aydarkul and Tuzkan lakes while the Arnasay lakes characterized by the regime of collector-drainage network did not concentrate a large water volume (Ivanov and Nikitin 1978).

Most of the literature analyzed (Mahmudova 2004a; Ivanov and Nikitin 1978; Gorelkin, 1976 and 1977; Kamilov, 1973) showed that the Aydar-Arnasay lakes had a particular hydrological regime during 1970-1993 basically due to collector-drainage water. Besides, the main function of these lakes was the accumulation of this residual water from the irrigation. Thus, based on the literature review, the author concluded that this period of time can be treated as a milestone in the AALS evolution and classified as the one of the historical stages. Figure 4 demonstrates the Aydar-Arnasay lakes system in 1993.


Figure 4. The Aydar-Arnasay lakes system in 1993 (adopted from Google Earth and modified by the author)

In addition, the bulk of the national reports examine some general trends of the AALS development in 1970-1990. After the careful review of these reports and translation of the relevant issues the author combined the following conclusions:

- The main function of the AALS during 1970-1993 is to store collector-drainage water coming from the Golodnaya Steppe irrigation areas;
- In the 1970s constant decrease of lakes' level, increase of mineralization and concentration of biogenic substances resulted in gradual eutrophication of the Arnasay lakes (Ivanov and Nikitin 1978);
- During 1975-1977 such water quality characteristics as water purity, coloration and oxidation, concentration of biogenic and organic substances sharply changed. In 1975 and 1976 during the summer period an increased number of phytoplankton was observed in the Tuzkan lake (Ivanov and Nikitin 1978);
- In the 1970s practicing of the low-mineralized water discharges from the Chardara reservoir was the crucial issue for maintenance of the lakes' regime during the summer period as well as for favorable conditions during the winter period (Nikitin 1991);
- In case of not having the water discharges from the Chardara reservoir the gradual fall of the AALS level and growth of mineralization would be continued;

- Increase of mineralization will cause decrease of the lakes' freezing point to - 0,3-0,6˚C. Therefore, the probability of more intensive cooling before freeze-up period will take place. The formation of freeze-up under the low level of lake will have influence on hydrochemical regime of lakes and increased content of organic substances could probably give rise to suffocation killing fish species (Giniatulina, Mullabaev et al. 2004).

#### 4.1.5 1993- present

The present stage of the AALS development is characterized by two very important features.

The first feature is that after the collapse of the USSR, the new Central Asian republics began to launch independent systems for water and energy consumption. Namely, the coordinated operation of the Naryn-Toktogul cascade was disrupted. In these conditions Kyrgyzstan started to increase consumption of its electricity due to lack of fuel resources. Starting from 1993 Kyrgyzstan began to use the Toktogul Reservoir (Figure 5) located in the Naryn River for energy production rather than for irrigation purposes. Energy production in the Toktogul Reservoir entailed substantial water discharges from the Chardara reservoir to the Aydar-Arnasay lakes during winter and spring times, 6,0-8,5 km$^3$ on average (Kurbanov and Primov 2006).


Figure 5. The Toktogul Reservoir

According to the Central Asian Research Hydro-meteorological Institute, 38,64 $km^3$ of water was discharged to the AALS during 1993-2006, i.e. the largest discharges were observed in 1994 – 9,3 $km^3$, 1995 – 4,0 $km^3$, 1998 – 3,14 $km^3$, and 2000 – 4,76 $km^3$. These discharges led to increase of lakes' overall volume and made the Aydarkul lake the third largest in Central Asia with a volume amounting to 41 $km^3$ (in contrast, the Aral Sea – 109 $km^3$, Sarykamysh Lake – 46 km $km^3$ ) (Mahmudova 2004a).

The second feature is the very complicated relationships between Central Asian republics, in particular, between Kazakhstan, Uzbekistan, and Kyrgyzstan are being observed after the dissolution of the USSR. Despite several agreements concluded in 1995-2000 focused on the rational use of water and energy resources in the Basin of the Syrdarya River, the republics concerned still cannot manage the issues about how much water should be discharged to the lakes and how much water should be used for irrigation purposes (Shamsiev and Chembarisov 2007). In other words, water discharges to the AALS are conducted without any coordinated actions of the republics, i.e. amount of water that should be discharged to the lakes and used for irrigation purposes is not agreed on and it is not clear how the system of water management works (Ryabcev 2005).

Additionally, seasonal water distribution for irrigation and energy purposes without considering the complex approach steadily results in decrease of water supply in the Toktogul Reservoir. For instance, by the 1998 vegetation period, the Toktogul volume reduced to 7,2 billion $m^3$. Besides, between 1999-2001 vegetation periods volume of drawdown from the Toktogul Reservoir increased up to 3 billion $m^3$ due to additional charge of the Naryn-Toktogul cascade. Thus, it caused additional water discharges from the Chardara reservoir to the AALS (Ryabcev 2005).

In reliance on these two AALS features, the author suggested that this period of time should be attributed a high importance and therefore, it can be identified as a new development stage.



#### *4.1.5.1 Water discharges as the main indicator of the AALS volume increase in 1993-2009*

As it was analyzed above, starting from 1993 water discharges from the Chardara reservoir played a significant role in the AALS development. In our analysis we deem it necessary to consider how much water was discharged to the AALS during 1993-2009, including mean amount of water releases as well as releases during dry and wet years. Thus, we will examine Figure 6 which demonstrates the dynamics of the annual water discharges from the Chardara reservoir to the AALS during 1993-2005.

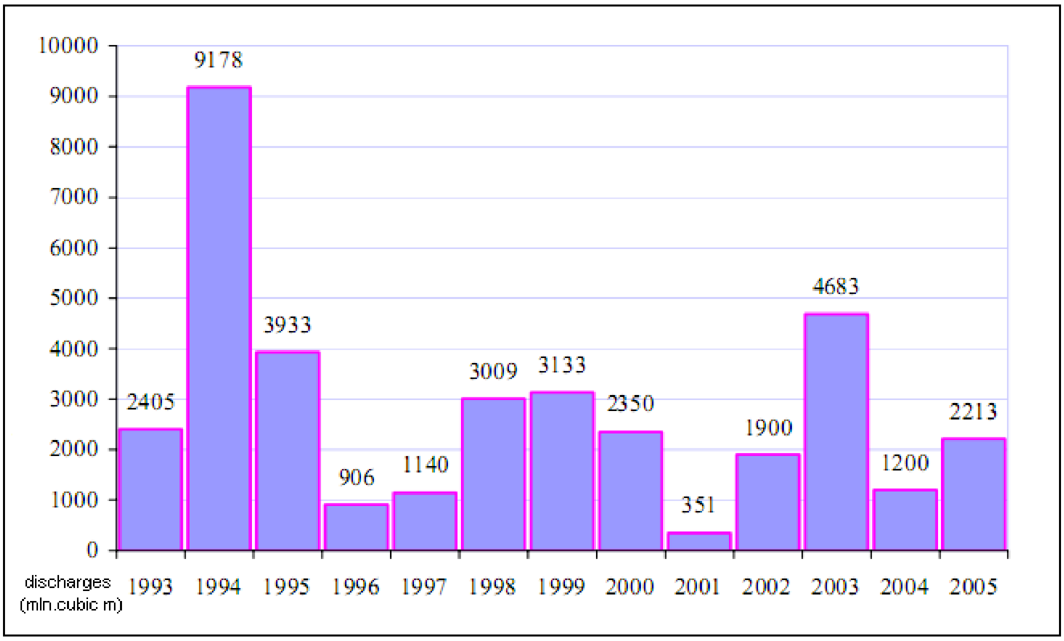


Figure 6. Water discharges from the Chardara reservoir to the AALS in the period of 1993-2005 (Mamatov and Kurnanbaev 2006)

From Figure 6 it can be seen that the water discharges coming from the Chardara reservoir to the AALS varied greatly during 1993-2005. Such huge variations can be explained by the different amount of the precipitation which depends on either wet or dry year. As can be observed from the figure, 1994 was an extremely wet year, and the water releases were extremely high, whereas 1996 and 2001 were dry years and water releases in these years were minor consequently. In total, water releases ranged from 0,35 $km^3$ (2001) to 9,1 $km^3$ (1996).

According to the experts' estimations, starting from 2005 and to present days, water discharges from the Chardara to the AALS make up 2-2,5 $km^3$ on average. Actually, this amount of the releases basically considers as an essential for the stable condition of the AALS regarding volume and water level of these lakes (Mamatov and Kurnanbaev 2006). Later we will simulate the model[9] in order to find out how much water is needed for the AALS maintaining taking into account various temperature conditions.

Having analyzed the water releases from the Chardara, for the present research it is also important to examine how the AALS water-surface area and volume have been changing

[9] Model simulation can be found in the section 6.3.1

during these years. In order to analyze this, it was decided to accomplish a practical exercise by using GIS technologies in order to calculate the following parameters of the AALS:

a) Water-surface area during 1969-2009;

b) Volume during 1969-2009.

The full description of this practical exercise and methods used is presented in the next section.

## 4.2 Practical exercise: Change dynamics of the AALS water-surface area in 1969-2009

### 4.2.1 The main idea of the practical exercise

Before going into the main research of the future development trends of the Aydar-Arnasay lakes system (AALS), we should analyze how this system has been evolving since 1969. In particular, according to one of the established objectives of the research, we will investigate how the water-surface and volume of the AALS have been changing. For this reason, it has been decided to calculate the AALS water-surface area starting from 1969 to present time.

It should be emphasized that finding of the valid method for the calculation was one of the intractable questions in the exercise. Generally speaking, four main GIS methods were found for the calculation of the AALS water-surface area:

- Comparative method based on the analysis of the different land use datasets by Arcview program;
- Comparative method based on the analysis of the USSR military maps using Google Earth and the Arcview program;
- Using of Digital Elevation Maps (DEM) in the Arcview program;
- Remote sensing provided by the MultiSpec program.

It can be observed that all methods in this exercise were based on application of the modern GIS technologies which are an effective tool for investigation of various environmental issues[10]. However, in the course of the exercise it was identified that three of them has the rigid limitations that make the calculation of the parameters concerned impossible. In order to show the whole process of exercise accomplishment, we consider it necessary to go step by step describing the basic ideas and limitations of the methods used.



[10] See section 2.3.4

### 4.2.2 Analysis of the main methods applied

#### *4.2.2.1 Comparative method: land use datasets*

To begin with, the comparative method based on the analysis of the different land use datasets by Arcview program was the first in the exercise. The basic idea of this method was taking two land use maps, e.g. for 1970 and 1990 and comparison of the AALS water-surface areas for the respective years by using some special extensions of the Arcview program.

At first view, this method seemed quite simple and suitable for our exercise because it did not require a complicated procedure. But, in the process of GIS data mining, i.e. searching land use datasets for various time periods, we only managed to download the contemporary datasets (for 2004 and 2009). Therefore, the principal limitation of this method was the unavailability of the land use datasets for the 1970s and the 1980s.

Another limitation of the method was impossibility to examine dynamics of the AALS water surface changes during 1969-2009. In case of availability of the old land use datasets, we only could compare the AALS water-surface area for two years taken. Thus, we should conclude that this method does not detect the change dynamics of the water-surface area from year to year; it merely demonstrates the absolute value of the water-surface area in each year and indicates relative changes between two years. Summarizing, the major downsides of this method are:

- unavailability of old land use datasets;
- time-consuming process of the water surface calculation (in case of availability of old land use datasets);
- impossibility to examine the change dynamics through the entire time line.

#### *4.2.2.2 Comparative method: USSR military maps*

Comparative method based on the analysis of the USSR military maps was the second method applied in the exercise. The principal idea of this method was similar to the first one, i.e. analysis of the two USSR military maps concerning calculation of the AALS water-surface area. We should clarify that despite the supposed time consuming process of the calculation, the USSR military maps are considered to be more accurate with relation to demonstration of the AALS water-surface area in the various time periods. For this reason it was decided to try this method in the present research.

In order to demonstrate and make it and understandable for the reader, a part of the exercise procedure of the water-surface calculation is illustrated. Figure 7 shows some initial steps undertaken for the water-surface area calculation. The left picture displays the process of adjustment of the AALS represented on UUSR military map with the AALS on Google Earth. The right picture shows the next step, namely, image interpretation. After these two steps this method assumes working with annotated images in the Arcview program for the purpose of the water-surface area and volume calculation.

Notwithstanding the above, in the course of the work we encountered some serious limitations which forced us to reject this method. The main limitation we identified was the

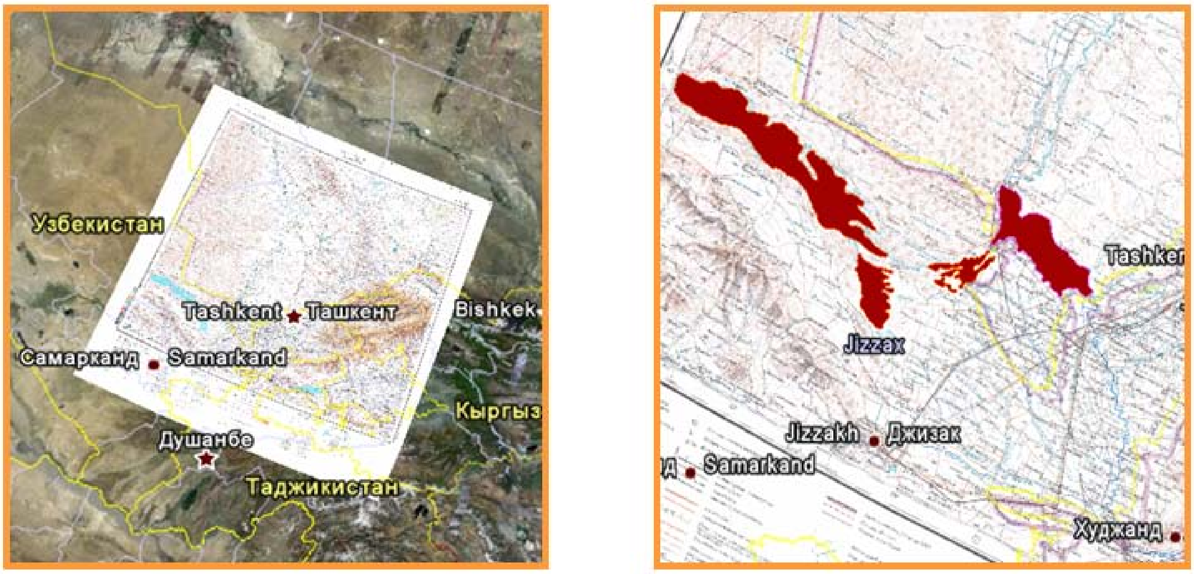


Figure 7. Initial steps taken for the AALS calculation (screenshot from Google Earth)

uncertainty of the creation time of the USSR maps. Specifically, some maps were created in 1975, but then were revised in 1985; others were composed in 1982 and revised in 1985. Consequently, it was impossible to calculate the AALS water-surface area precisely for a certain year and results obtained could be with low accuracy. For this reason this method was omitted.

#### *4.2.2.3 Use of Digital Elevation Map (DEM)*

The next method examined for the AALS water-surface calculation was based on the application of the Digital Elevation Map (DEM). The method assumed the following steps:

- Creation of the Digital Elevation Map (DEM) of the AALS by integration of the 6 Shuttle Radar Topographic Mission (SRTM) images in the Arcview program (Figure 8);
- Working with the DEM map in Arcview program (Figure 9); the main idea here was to gradually fill the DEM of the AALS depression with water until the historic level of water table is reached; this level is defined by analyzing the old satellite images. Thus we could examine the water-surface area and volume of the AALS for the different years;
- Comparison of the AALS water-surface in the Arcview program.

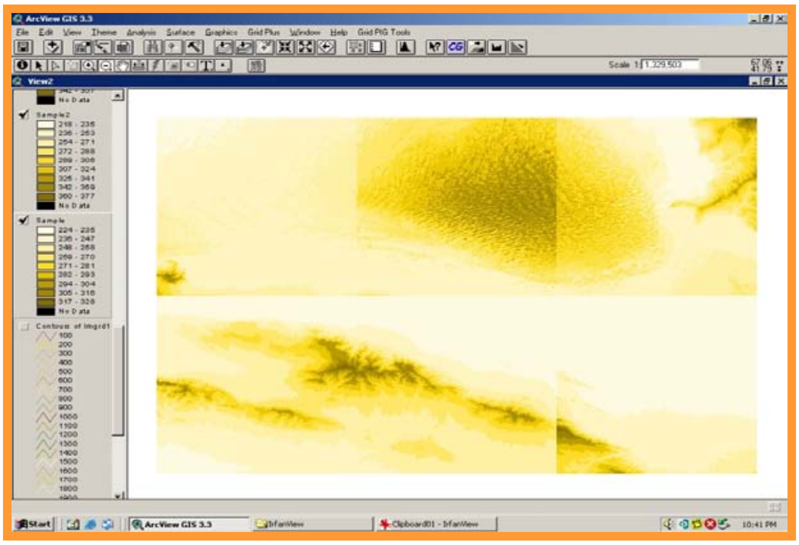

Figure 8. Integration of six SRTM images in the Arcview Program

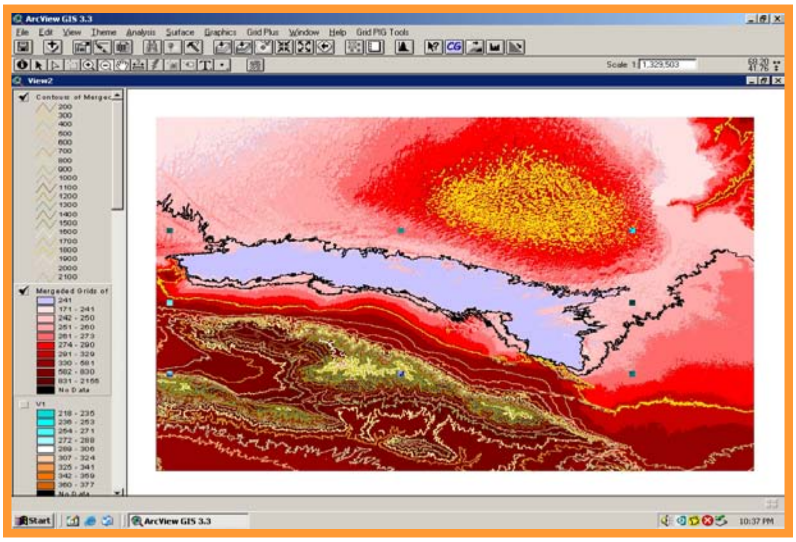

Figure 9. Digital Elevation Map (DEM) created by Arcview Program

Relative to the previous two methods, this method is supposed to be more complicated in terms of technical skills needed for working in the Arcview program. In the process of using this method one crucial disadvantage, that brought us to reject this method, was identified. After the DEM creation it was revealed that the AALS depression on the DEM has been already filled with water, and consequently, the procedure of analyzing the AALS water-surface area depending on the different levels of water table was not possible. Consequently, this method was not suitable for our exercise as well as the previous two.

#### *4.2.2.4 Remote sensing*

The last method used for the present exercise was based on remote sensing assisted by the MultiSpec program. Among all methods described above, this method can be undoubtedly considered as the most sophisticated because:

- It requires advanced technical skills in working with remote sensing needed, including reading of the special literature and tutorials;
- It is extremely time-consuming method;
- It is a combination of several software programs for the water-surface calculation.

Despite all complications, remote sensing was acknowledged to be very accurate and convenient method of the AALS water-surface calculation. To prove that, let us explain the main working steps taken here. They are:

- Downloading the AALS satellite images for the various time periods, starting from 1969 to 2009. There were two complications. One the one hand, not all satellite images were downloadable; for the exercise we managed to download the images for the following years: 1968, 1973, 1978, 1983, 1988, 1993, 1998, 2003, 2008 and 2009. But, at the same time, we should highlight that images obtained enabled to examine the change dynamics of the AALS water surface. On the other hand, process of satellite images preparation to remote sensing was time-consuming because several images consisted of two parts and they had to be integrated into one image (Figure 10);
- Processing of the satellite images in the MultiSpec program; in total, 10 satellite images from the all given periods were processed;
- Working with the processed satellite images in the Arcview program; Figure 11 shows the process of working with the image in the Arcview program, namely, calculation of the AALS water-surface area for 1993 by using a special Arcview extension called

*Grid Analyst*. The same procedure was conducted for all respective years considered in the exercise.

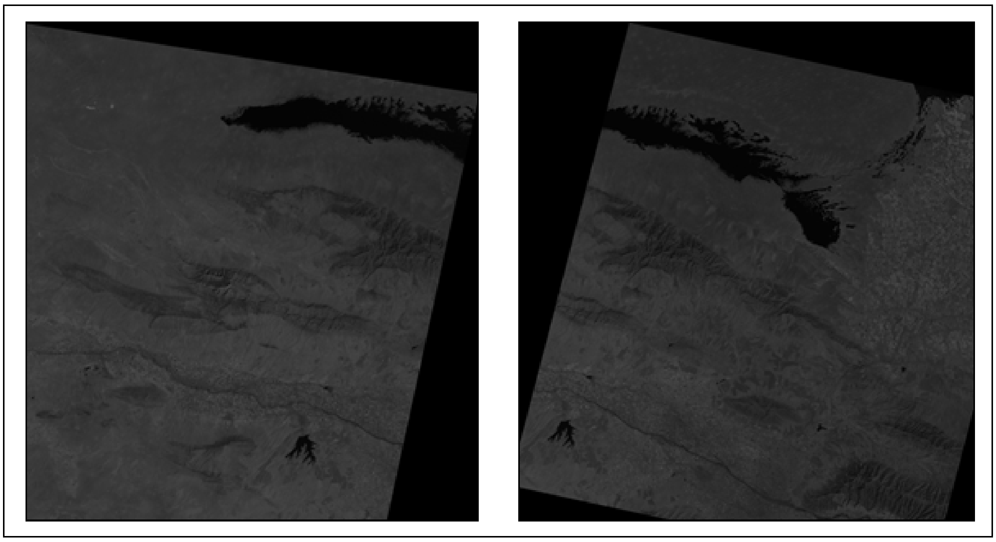

Figure 10. Preparation stage: integration of the satellite images

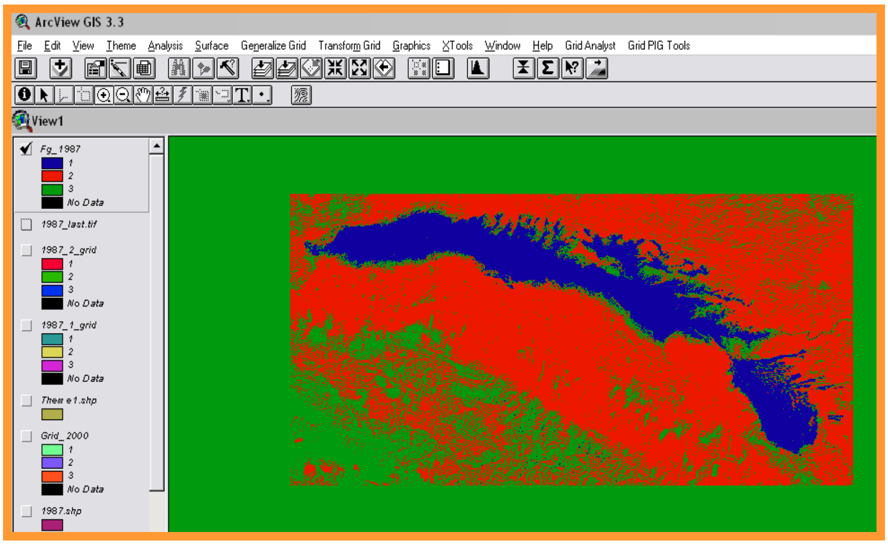


Figure 11. Working with the AALS processed image in the Arcview Program

### 4.2.3 Results obtained

After calculations of the AALS water-surface during 1969-2009, impressive results have been received. The results of the calculations and their illustrative representation are presented in Table 2 and Figure 12. Also it should be noted that along with the calculation of the water-surface area, the Arcview program enabled calculation of the AALS water volume.

Table 2. Change dynamics of the AALS water-surface area and volume during 1969-2009[11]

| | 1969 | 1973 | 1978 | 1983 | 1988 | 1993 | 1998 | 2003 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Water surface,** $km^2$ | 2180 | 1959 | 1630 | 1771 | 2143 | 2504 | 2890 | 3500 | 3640 | 3752 |
| **Volume,** $km^3$ | 17,5 | 15,6 | 12,3 | 13,4 | 17,7 | 25,0 | 28,7 | 36,9 | 41,2 | 44,3 |

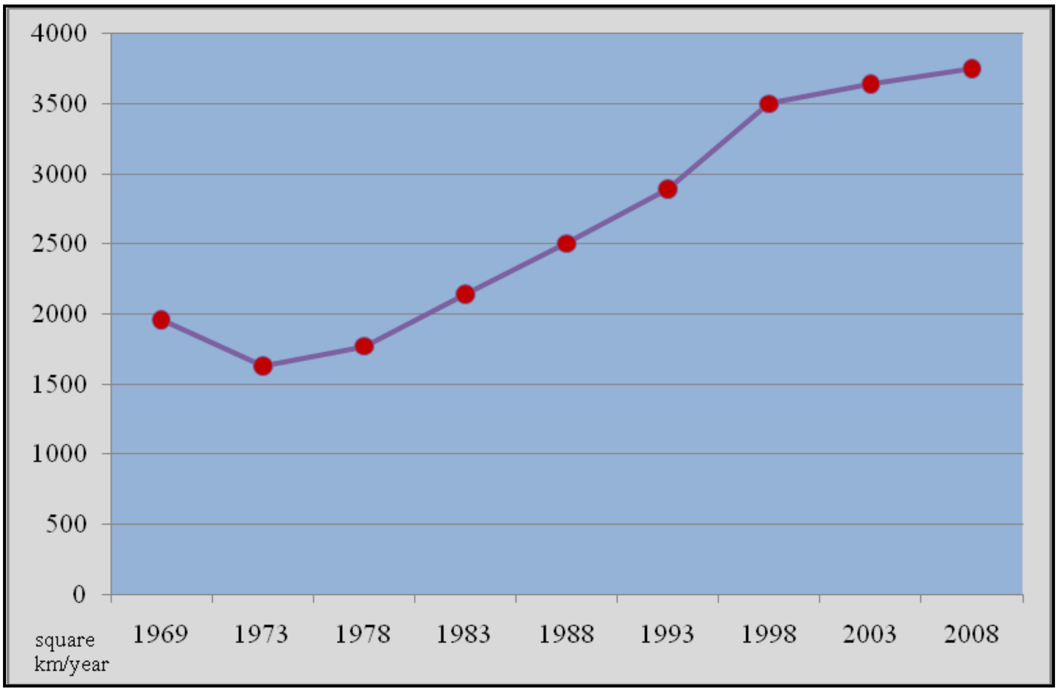


Figure 12. Change dynamics of the Aydar-Arnasay lakes system during 1969-2009[12]

Figure 12 clearly demonstrates trends of the AALS historical development which was described in the first section of the present chapter. In this graph we can observe that 1969-1993 was a period when these lakes existed as for the storage for collector-drainage water coming from the Golodnaya Steppe irrigation area and the water-surface of the lakes system was increasing slowly. Table 1 indicates that during 1969-1993 the water surface area increased by 300 $km^2$ while during 1993-2009 – by 1200 $km^2$. Such huge increase was caused by the change in the Toktogul regime operation, i.e. electricity generation during the winter time resulted in increased water discharges from the reservoir. Concerning volume changes, the same trends can be identified. In the period of 1969-1993 the volume did not increase significantly, from 17,5 $km^3$ to 25 $km^3$. In contrast, we can examine that since 1993 volume has been increasing more rapidly, from 25 $km^3$ to 43,4 $km^3$ in 2009.

[11] The following calculations were made using the Arcview program
[12] Based on the results obtained the graph has been created in the Excel program by the author

Summing it all up, this exercise let us visualize the historical stages of the Aydar-Arnasay lakes system development. Furthermore, we could analyze how this system was evolving during forty years in terms of water-surface area and volume changes. This exercise has laid a significant groundwork for our further research, namely, elaboration of the water management scenarios and the creation of the AALS model.

Based on the literature found in the archives, results obtained from the unstructured interview and use of different satellite images the major historical features of the Aydar-Arnasay lakes system (AALS) development have been examined, i.e.:

- The main historical stages of the Aydar-Arnasay lakes have been identified and described by the author;
- Change dynamics of the AALS water-surface area and volume in 1969-2009 has been examined by accomplishment of the practical exercise using the various GIS methods;
- The present chapter has attained one of the objectives established by the author and laid a significant groundwork for the following research chapters.

# 5. AYDAR-ARNASAY LAKES: ANALYSIS OF THE PRESENT DEVEPOMENT ASPECTS

The present chapter aims to analyze the current state of the Aydar-Arnasay lakes system (AALS) and define what high-priority ways of contemporary development are. The main methods used for data analysis in the present chapter are review of numerous literature and unstructured interviews. The chapter chiefly is based on the analysis of the existing scientific national and international books, reports and journal articles and other materials associated with the AALS current conditions.

The chapter consists of four main sections. The first section depicts the general overview of the AALS current state, including some quantitative features of these lakes and ecological conditions of this aquatic system.

The second section considers socio-economic aspects of the AALS development. Among the primary socio-economic aspects the following chapter considers fisheries which are situated on shoreline of these lakes and recreation. These aspects have been selected due to the following reasons. On the one hand, fisheries and recreation are basically two priority-oriented ways of development for these lakes nowadays. On the other hand, availability of information was important issue in the consideration of these aspects. It should be noted that majority of the relevant literature more or less contained some information about respective aspects of development. For example, all national reports determined have outlined a special significance of the fisheries for both Jizakh and Navoi provinces in which these lakes located and the whole republic. This section examines such important issues of the fish farming as analysis of the fisheries legal framework, existing acute problems, e.g. stealage of fish production and main future benefits from the fisheries well-being. Also the section considers the main types of recreational activity which are developed around these lakes.

The third section is devoted to analysis of environmental aspects of the AALS development. The main aspect of the AALS environmental development is biodiversity conservation, i.e. wetlands of the international importance. This aspect has been selected because the Aydar-Arnasay lakes were designated as a Ramsar site in 2007. This section analyzes the prime criteria for identifying wetlands of international importance and then justifies application of these criteria for the AALS.

### 5.1 The AALS current ecological situation

According to the experts, the current ecological condition of the Aydar-Arnasay lakes system is highly disturbed (Khamidov 2004). Due to extremely high mineralization in certain parts of the lakes, the water is suitable neither for irrigation purposes nor drinking and cooking. According to the calculations (Nurbaev and Gorelkin 2004), reduction of the water releases from the Chardara by up to 1,5-2 $km^3$ will give rise to the gradual shrinking of the lakes system. In case of water closure from the Chardara, over the first three years the AALS water level will fall by 0,4-0,6 m a year. Then, it will lead to the growth of mineralization (up to 15-20 g/l) and ceasing of the spawning season.

Taking into account this situation, the Uzbek Government has recently decided to place under control these lakes proposing to conduct a set of scientific researches of this vulnerable system as well as to implement some protective works in the AALS area (Kulmatov pers.comm.).

In order to maintain fish reproduction in the Aydar-Arnasay lakes, there is a need to control the water quality and take active measures to make these lakes flow-through ones. A program, aimed to initiate a flow regime, includes construction of a dam near the Baumurat village and dam-protective works near the Arnasay lake (Kulmatov pers.comm.). In order to make these lakes flow-through, it has been decided to erect outlet works in the western part of the Aydarkul lake which could carry 3,0 $km^3$ water away. Discharged water would probably have a low mineralization (2,0-3,5 g/l) and could be used for irrigation and flooding of pastures (Mahmudova 2004a).

Summarizing, for maintenance and conservation of the stable condition of the Aydar-Arnasay lakes the following aspects should be considered:

- To define the condition of water and ichthyologic resources as well as supply of fish resources;
- To monitor the current hydrological, hydrochemical and hydrobiological features of these lakes in order to assess their influence of fish resources;
- To monitor the current ecological condition of vegetation cover, in particular, to evaluate condition of the wetlands of international importance included in Ramsar list;
- To control the water releases from the Chardara reservoir ((FAO) 2004).

### 5.2 Socio-economic development: consideration of the main aspects

Nowadays, Aydar-Arnasay lakes represent not only a significant system in terms of commercial fishing, but also the system with a strategic importance for Navoiy and Jizzakh provinces as well as for Uzbekistan. This system of lakes performs significant socioeconomic functions for the population of the nearest residential areas. These lakes provide the population with employment, the fish industry, and places for recreation (Kurbanov 2008).

#### 5.2.1 Fisheries: assessment of the AALS current trends

##### *5.2.1.1 Impact of the USSR disintegration on fisheries*

It is well known from the literature review examined[13] that after the dissolution of the USSR the situation in Uzbekistan the fish industry changed significantly. As was mentioned above, the government of Uzbekistan privatized all state-owned fish farms and fisheries enterprises, including farms located on Arnasay lakes and stopped their government financial support. As a result fish production dropped to one third and large-scale fishing in water reservoirs such as Aydar-Arnasay lakes system (AALS), Lake Sarykamysh, Charvak, Chimkurgan and several others was virtually stopped or significantly reduced (Thorpe and van Anrooy 2009).

By the end of the 1990s partial recovery of fisheries in the Aydar-Arnasay lake system started on account of private farmers began to be better acquainted with the new economy (Thorpe and van Anrooy 2009).

Figure 13 illustrates the comparison of amount of fish captured (tons) in the AALS and whole Uzbekistan during 1987-2005. Figure 13 clearly shows a sharp decline of fish production in these lakes as well as in Uzbekistan in the period of USSR collapse. In 1991, after disintegration of the USSR, 2430 tons of fish were produced from the lakes while in 1988 fish production had been 4616 tons. Then, starting from 1997, slow recovery of the fish industry can be observed in both these lakes and Uzbekistan. During 2003-2005, about 800 tons of fish was captured from these lakes.



[13] See section 2.2.4

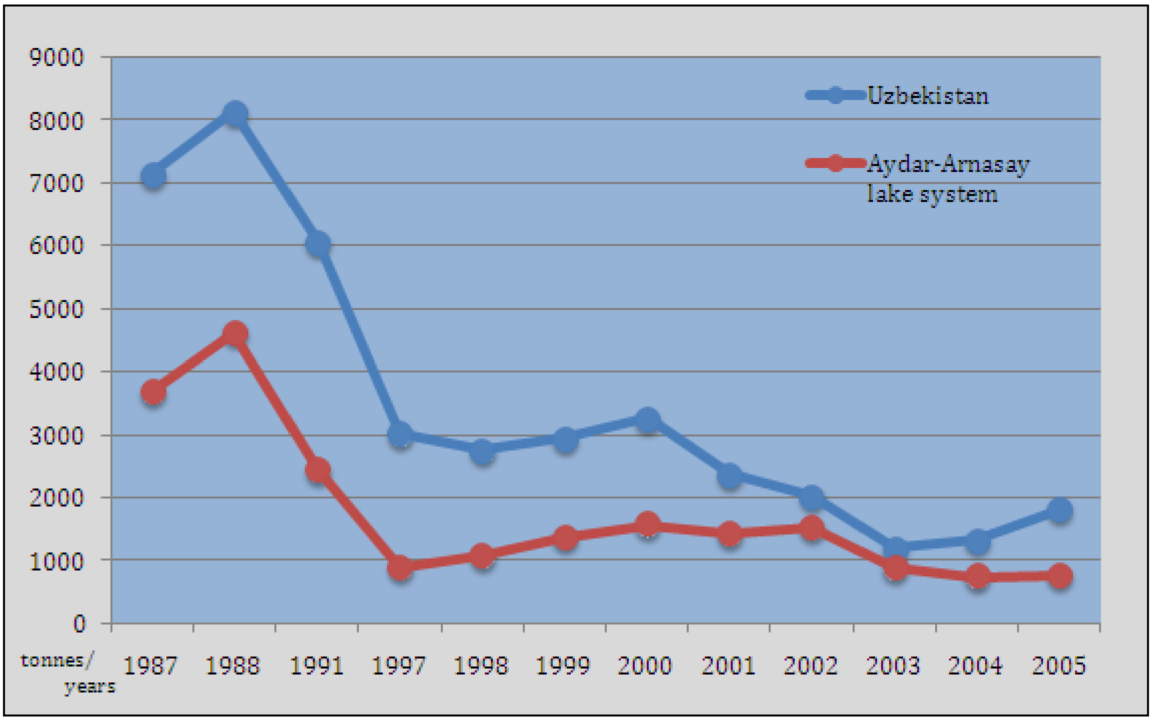


Figure 13. Time changes of amount of fish captured in the Aydar-Arnasay lakes and Uzbekistan in 1987-2005[14]

Figure 14 presents changes in carp catch as one of the most important captured species in the Aydar-Arnasay lakes system and Uzbekistan in 1987-2005. Similarly to Figure 13, from Figure 14 it can be distinctly noticed that carp catches sharply decreased in the period of the USSR collapse. In 1987 carp production in the Arnasay lakes made up 1868 tons and then decreased to 1083 tons in 1991.

The lowest carp catches were observed in 1997 totaling 402 tons. Later, starting in 1997 slow recovery of carp capture can be seen. During 2000-2005 carp captures were lower in comparison with the 1990s amounting to 230 tons on average (Karimov 2008). So low carp captures in 2000-2005 are related to lack of financial support of fisheries provided by government, lack of measures aimed at maintenance and development of the fish industry at the high level.



[14] The graph has been created by the author using data adopted from Ecological Herald of Uzbekistan, 2008

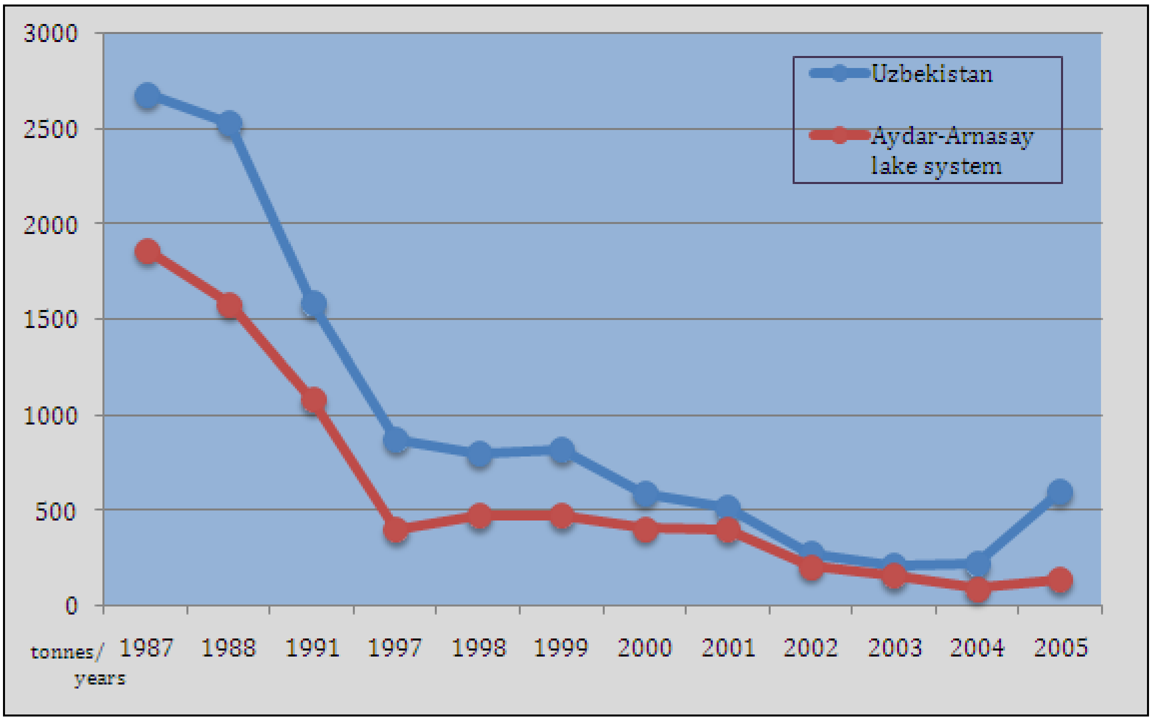


Figure 14. Time changes of carp catch in the Aydar-Arnasay lakes and Uzbekistan in 1987-2005[15]

#### *5.2.1.2 Assessment of the AALS current fisheries trends: 2000-2009*

Currently, commercial catch in the Aydar-Arnasay lakes is basically represented by three main species, carp, pikeperch, and roach. Such species as dream, asp, phytophagous fish species, and catfish are not found in the catches. According to the Ministry of Fisheries, Aydar-Arnasay lakes provided 51.4% catches in 1987 of the total amount of produced fish in Uzbekistan, 56.7% - 1988, 75.1% - 2002, 73.5% - 2003, and 41.6% - 2005 (Kurbanov and Primov 2006).

According to the FAO Fisheries Technical paper (2004), by today the fish production in the Aydar-Arnasay lake system has decreased to one fifth in comparison with 1987, i.e. from 3667 tons in 1987 to 759 tons in 2005. Along with reduction of fish production, all fisheries have been privatized. Privatization has caused the decline of the formerly well-developed fisheries and management structures ((FAO) 2004). Coordination between fisheries institutions that are responsible for maintaining sustainable fish yield in these lakes has been undermined. Linkages between the irrigation and fisheries institutions have been lost as well.



[15] The graph has been created by the author using data adopted from Ecological Herald of Uzbekistan, 2008

Support of the fisheries by the government is minimal. Education and training of specialists has also stopped, and the research network has come to an almost complete standstill (Kamilov and Karimov 1994).

Today, Uzbekistan has no national programs or specific fishery development projects supported by the government or international assistance. Private initiative focuses only on exploitation of rich fish stocks in the Aydar-Arnasay lake system using small fishing teams. In other words, the situation described above has resulted in deterioration of the fish industry fisheries in the Aydar-Arnasay lakes as well as in whole Uzbekistan. Depletion of fish production, lack of measures directed at maintenance and development of fisheries and absence of the determinate policy in the fish industry are remarkable characteristics of the contemporary condition of the fish industry in the republic (Thorpe and van Anrooy 2009).

Depletion of fish production in the Aydar-Arnasay lakes from the perspective of species variety and amount of fish is observed. Based on analysis of the article *"Development of the capture fisheries and aquaculture in Uzbekistan"* dedicated to Aquaculture and capture fisheries development policy and strategy of Uzbekistan and published in the special issue of the "Ecological Gerald of Uzbekistan" the author was trying to generalize the main causes of fish supply reduction in the Aydar-Arnasay lakes. According to the analysis conducted, they are:

- Lack of stocking with fish;
- Overexploitation and unreasonable use of fish resources; fish capture exceeds the natural reproduction;
- Lack of monitoring and effective measures pointed at the maintenance and development of fisheries;
- Lack of scientific justification, i.e. in the process of fish catch, farmers do not take into consideration data about the current conditions of fish supply on their rented plots;
- Weak resource-and-technical base, particularly, there are no methodological recommendations regarding the fish capture level, reproduction rates and other important characteristics;
- Lack of government financial support and any kind of its participation in fisheries development (Karimov 2008).

Examination of other important article regarding fisheries in Uzbekistan, i.e. *"Inland fisheries livelihoods in Central Asia: Policy interventions and opportunities"* additional important reasons related to the deterioration of fisheries have been found, namely:

- increase in cost price of commercial fish causes an increase of concealed fish produced in the Arnasay lakes; amount of fish captured is not registered anywhere and taxes are not paid;
- the problem of stocking with fish species such as carp, catfish, pikeperch, bream, and asp is not solved; there is no opportunity for farmers to realize fish stocking due to lack of finances and absence of breeding stock in Uzbekistan. Lack of breeding stock primarily relates to the fact that breeding stock propagation was not developed on these lakes last ten years;
- initiation of fish farm enterprises gives rise to the additional problems related to provision of breeding stock because re-created fish farms will not be able to deal with breeding stock propagation by themselves followed by fish stocking of their plots; the main causes of that are as follows:

a) underdeveloped resource base of fish farms;

b) lack of scientific base and experts involved in breeding stock propagation;

c) expenses on breeding stock propagation will be not paid off for a few years;

d) fish stocking will be conducted spontaneously with various fish species and probably with low-quality breeding stock (Thorpe and van Anrooy 2009).

Finally, having examined results of contemporary scientific investigations (Shamsiev and Chembarisov 2007); ((FAO) 2004); (Kamilov and Karimov 1994), the author has revealed some environmental reasons of depletion of fish resources. The major reasons are:

- an increase of mineralization in the lakes;
- the unsteady water level of the lakes;
- spontaneous development of fish fauna resulting in unstable and low reproduction;
- absence of natural reproduction of several commercial fish species, such as silver carp and grass carp, and undeveloped benthos being the main feed stuff for benthos eaters.

#### *5.2.1.3 Analysis of fisheries legal framework*

According to the Uzbek Scientific and Research Center at fisheries development, special laws about fisheries in Uzbekistan have not been adopted. Nowadays, governance and control for fisheries development is regulated by the following important laws and regulations:

- Fisheries governance is regulated by "Law on Joint-Stock Companies and protection of shareholder's rights", "Law Concerning Limited Liability Companies", "Law about Farm Enterprises";
- Fisheries management is directly regulated by "Internal Revenue Code", "Land Code", "Nature Conservation Law", and "Water Law";
- Regulations of the Cabinet of Ministers: Regulation № 350 08/13/2003 "Measures on enhancing of demonopolization and privatization in the fish industry", Regulation № 289 06/07/2001 "About fisheries system development".

Among the documents provided above, Regulation № 350 08/13/2003 "Measures on enhancing of demonopolization and privatization in the fish industry" is one of the principal documents defining the current state of affairs in the fish industry (Shohimardonov 2008). Let's analyze the main points of this regulation and main implications related to it.

Shohimardonov (2009) in his presentation "Overview of fisheries development in Uzbekistan" showed on the FAO and Regional Eurofish Workshop in Bulgaria highlighted that Regulation № 350 08/13/2003 "Measures on enhancing of demonopolization and privatization in the fish industry" was accepted in order to reinforce the privatization process and develop the private property in the fish sector as well as to implement the market principles and mechanisms for the organization of fishing enterprises, catch regulations and marketing of the fish production. This regulation outlines that natural fish reservoirs such as Aydar-Arnasay lakes are rented on a competition basis by fish farms for ten years at least. Fish farms in these lakes settled a lease agreement can carry out fish capture in these reservoirs without quota basis, but relying on the available biological resources, maintenance of fish yielding capacity and reproduction of fish resources at appropriate level (Shohimardonov 2009).

Also this regulation specifies that money received from the rent of natural fish reservoirs is directed, as follows: 60% - to the local budget, including measures focused on fisheries development; 25% - to the Fish Development Fund under the Uzbek Scientific and

Research Center at fisheries development; and 15% - to the Uzbekistan National Committee for nature protection (Karimov 2008).

It has been assumed that the respective regulation could improve the situation in the fish industry, give an opportunity for small and medium-sized businesses to implement rational use of fish resources. After several years of adoption of addressed regulation some omissions related to absence of action plan for fisheries improvement at the appropriate level and lack of measures at maintenance of fish reproduction and rational use of fish resources have been identified (Kurbanov 2008).

Considering the major contemporary failings and omissions in the fish industry the following should be pointed out:

- There is no any agency which could coordinate work between farms dealing with extraction of fish resources from the natural reservoirs and farms involved in the process of fish stock growing, reproduction and implementation of measures concerning replenishment of fish stock, i.e. stock of pike, catfish, bream, and asp whose supply are actually eliminated in Uzbekistan;
- Absence of material and technical resources for the fishing farms and factories in Uzbekistan, including Aydar-Arnasay lakes;
- The regulation № 350 08/13/2003 “Measures on enhancing of demonopolization and privatization in the fish industry” adopted by Uzbekistan’s Cabinet Council does not envisage provision of information for the State Environment Committee about species variety and amount of fish captured by farmers from the natural reservoirs. Not having information about extraction of bioresources from the natural water bodies and materials about measures in the context of conservation and bioresources reproduction on the rented reservoir plots, the The State Environment Committee has no opportunity to introduce the timely measures aimed at preventing depletion of fish resources in the natural reservoirs;
- Existing statistical accounting documentation is inadequate. Approved statistical documentation does not make available information about species variety and amount of produced fish. This fact complicates the work of the State Environment Committee in the field of appropriate control of business enterprises dealing with fisheries in the natural reservoirs;

- Despite the fact that according to the regulation № 350 08/13/2003 “Measures on enhancing of demonopolization and privatization in the fish industry”, 60% of financial resources received from rental payments are transferred to local budget and 25% to the Fish Development Fund, the Uzbek Scientific and Research Center at fisheries development does not provide any elaborated measures at increase of fish resources in the natural reservoirs, i.e. such species as carp, pikeperch, asp, and catfish;
- Farmers dealing with commercial fishery in the natural reservoirs do not comply with the treaty commitments concerning conservation, reproduction and rational use of fish resources and also a set of other requirements explicated in the regulation № 350 08/13/2003 “Measures on enhancing of demonopolization and privatization in the fish industry”;
- Concealment of commercially produced fish from its registration in the final documentation; this fact results in depletion of fish resources in the natural reservoirs (Shohimardonov 2008).

#### *5.2.1.4 Concealment of fish production*

Nowadays, concealment of the fish production in the Aydar-Arnasay lakes and other natural reservoirs in Uzbekistan is one of the large-scale urgent problems of the fish industry. A huge gap between the expenditure and revenue sides is considered to be one of the central reasons of the concealment of commercial fish from its registration in the final documentation.

Specifically, this has become noticeable over the last two years (Karimov 2008). Based on calculated expenses attributed to fisheries in the Arnasay lakes (Kamilov and Kurambayeva 2008) the author has reviewed that the expenses consisted of two main parts: a) revenue side received from commercially extracted fish, and b) expenditure side related to the rental payments for reservoir use. Calculations demonstrated that rental payments amounted to 31% in 2004, 33.8% - 2005, 39.6% - 2006, and 72.8% - 2007 (Kamilov and Kurambayeva 2008).

Also it has been discovered that if the additional expenses such as salary, fish equipment, alimentation, different taxes and allocations are taken into consideration, expenditures will increase even more and farmers will not have floating assets for conducting measures stated in the regulation № 350 08/13/2003 "Measures on enhancing of demonopolization and privatization in the fish industry" (Kamilov and Kurambayeva 2008).

From the Kurbanov' article "The importance of development the fishery farms with high potential in the system of the Ministry of Agriculture of the Republic of Uzbekistan" it has been analyzed that farmers need to have floating assets for the rental payments next year, equipment purchase, salary and other expenses. To cover these expenses farmers have to conceal commercially produced fish from its registration in the final documentation. It is notable that the additional expenses are paid by farmers not from the private means, but from their unaccounted fish catch. All additional expenses connected to the rental reservoir payments could be used for fish farms construction, growing of breeding stock, and stocking of lakes (Kurbanov 2008).

Summarizing, the author found out that to conserve fish resources in Aydar-Arnasay lakes it is necessary to introduce strictly limited volume of fish catch. Besides, payments for fish caught should be accomplished in accordance with the procedure described in Annex №1 of the regulation № 508 04/28/2004 "On strengthening control for rational use of biological resources and its import and export" adopted by Uzbekistan Cabinet Council (Chembarisov, Reumov et al. 2006). Taking into account all expenses provided above, it is essential to emphasize that introduction of limited volume of fish catch in Arnasay lakes will merely allow to set up control of fish extraction and reduce a part of expenses, but the main problem, i.e. large scale fish theft will remain (Shohimardonov 2008).

#### *5.2.1.5 Farmers' problems*

Analysis of the article "Development of the capture fisheries and aquaculture in Uzbekistan" showed that today farmers are facing numerous problems related to maintenance of fisheries in the Aydar-Arnasay lakes and they have to find an effective solutions by themselves.

It also has been found that each farmer has various cost price of one kg produced fish; the primary reason of that is different distance of farmer's rented plots. Some farmers have lake plots close to transportation routes and populated areas whereas other farmers' plots are located in the remote areas (Karimov 2008). All incremental costs are paid by the owners. Uzbek government does not provide any financial support for farmers with remote plots and they have to pay much more of their own money for fish delivery. Thus, it can be seen that cost price of produced fish differs depending on distance to residential areas and roads (Thorpe and van Anrooy 2009).

Another problem examined by the author is farmers' responsibility for conservation, rational use of fish resources in the Arnasay lakes. Farmers have to adjust to the fluctuations of water level in the Aydar-Arnasay lakes. It is notable that water level in these lakes has been increasing continually over the last years. Because of sharp increase of water level, fishermen have suffered from a huge damage. Fish facilities, utility rooms and other implements were inundated. Nobody bears responsibility for material and fishermen's moral damage. The government will not make amends for farmers in case of increase or decrease of lake level (Kamilov and Kurambayeva 2008).

Furthermore, it has been concluded that fish equipment, i.e. fishing gears, floating crafts and other implements purchased by farmers are characterized by low quality and this will consequently lead to increase of costs. The government does not get involved in provision of centralized supplies, including netting materials, floating crafts, replacement parts for outboard motors and boats and other implements. Farmers have to buy all equipment as well as breeding stock at their own expenses (Shohimardonov 2008). If demand for breeding stock increases, fish farms producing such material will dictate terms to farmers due to their monopolistic activity. Due to inability to pay, farmers will purchase a low quality breeding stock, but at lower price.

Consequently, poor quality breeding stock will cause even earlier inevitable degradation of fish resources in the Aydar-Arnasay lakes; the main problem here focuses on the fact that the government has no concerns about developing fish farms (Shohimardonov 2009). Specifically, Karimov (2008) states that the government must accept responsibility for elaboration of scientific and economically feasible fish stocking in the Aydar-Arnasay lakes. Also government must defray expenses of implementation of respective measures.

It has been concluded that in order to initiate favorable conditions for both farmers and fish farms and replenish fish resources in the AALS, Uzbek government must take obligatory part in the solution of problems examined above. In addition, to provide conservation, rational use and reproduction of fish resources in the Aydar-Arnasay lakes, measures aimed at alteration and amendment of regulation № 350 08/13/2003 "Measures on enhancing of demonopolization and privatization in the fish industry" adopted by Cabinet Council of the Republic Uzbekistan are required (Shohimardonov 2009).

#### 5.2.1.6 *Fate of the Aydar-Arnasay lakes*

Having analyzed current situation in the AALS fisheries development, we consider it necessary to discuss what could happen with the fish industry in future. Based on the examination of the literature associated with fish farming on these lakes, we will demonstrate several possible future trends.

According to the FAO forecasts (2009), there are two possible ways of fisheries development in the Aydar-Arnasay lakes in future. On the one hand, in case of increase of lake's level fish farms and approached roads will be flooded. By reason of farmers' movements from one place to another, cost price of produced fish will go up. On the other hand, if a decrease of lake level takes place, mineralization will increase and natural reproduction of fish resources will slow down. There will be a need to replenish fish resources by purchase of breeding stock (Thorpe and van Anrooy 2009). Farmers dealing with growing of breeding stock will surely raise the price for their production. Increase of cost price will again cause concealment of produced fish by farmers. This is a situation of catch-22, i.e. one unsolved problem generates another. As a result, farmers will suffer from losses as well as fish fauna of the AALS will be eliminated.

The literature analyzed demonstrated that in case of losing the socio-economic and ecological functions of the Aydar-Arnasay lakes, Uzbekistan will face serious and long-terms difficulties such as:

- Cheap fish production totaling today 5-10 thousand tons will not be available for the population;
- Fish growing in the pond farms will require additional expenses; for instance, to produce 5250 tons of fish more than 28 000 tons of food stuff to the value of 3 million dollars will be needed;
- Local population engaged to the fish industry will lose jobs;
- Taking into account constant decrease of water level in these lakes, major part of lake's coast line will turn into small shallow bays followed by formation of solonchaks;
- Because lake's bottom is difficult to recultivate, the respective area will not be effectively used for agricultural purposes for a long time;
- Annual fish growing in the pond farms will require a huge amount of additional water supply (Kurbanov 2008).

To prevent all possible difficulties given above we should understand the important functions of these lakes from the economic perspective as well as the population's needs and to analyze future benefits from fisheries development.

According to Shohimardonov (2008), the government investing 1 uzbek sum in the fish industry of the Aydar-Arnasay lakes will gain 8,5 uzbek sum of net profit. In case of growing 5250 tons of fish, savings on the feeding stuff needed for breeding stock propagation will make up 21,7 thousand tons priced at more than 3 billion uzbek sum. Annual savings on the fishfood will amount to 2,5 million dollars. Total revenue annually received from savings on feeding stuff for 5250 tons of fish, will compose 8,5 billion uzbek sum. If more fish is grown in the Aydar-Arnasay lakes, savings in water required for growing fish in pond farms will amount to 157 million $m^3$.

If mineralization increases up to 10 g\l and higher, natural growth of fish supply will be actually ceased. Consequently, need for artificial replenishment of the Aydar-Arnasay lakes by young commercially produced fish growing in the pond farms will take place. To get 5250 tons of annual fish production, it will be necessary to grow and stock 35 million commercially produced fish units to these lakes. Difference in costs of fish growing in the pond farm and the lakes has made up 525 uzbek sum, i.e. 1 kg of fish grown in pond farm is 525 uzbek sum in comparison with 1 kg grown in the lakes (Shohimardonov 2008).

To sum up, comparative estimates demonstrate that breeding commercial fish in the Aydar-Arnasay lakes is much more economically feasible than breeding in pond fish farms. Earned profit from raised fish in the lakes is more than twice higher versus the same amount of fish produced in the pond fish farms. Taking into consideration that selling price of pond fish is 50% higher than of fish grown in the lakes, profit earned from fish reared in the lakes will increase even more (Thorpe and van Anrooy 2009).



### 5.2.2 Recreation

Recreation is the second important socio-economic aspect of the Aydar-Arnasay lakes development. Recreational activity developed on the Aydar-Arnasay lakes system is represented the following types:

- **Camping** (the Aydar Yurt Camp)

The most popular place for camping is "the Aydar yurt Camp" which is situated in the area of the Navoi region in the center of the Kyzylkum desert, around 10 km from the Aydar-

Arnasay lakes system. The camp is characterized by complete recreation infrastructure, which provides services both for individuals and special groups from 10 to 100 persons. Short walks around the area of the camp and to the Aydarkul lake, long Bactrian camel safaris along the Kyzylkum desert and also jeep tours to the Aral Sea are organized from the yurt camp (partnership 2006);

- **Ecological and ethnographic tourism** (on the territory of Nuratau-Kyzylkum Biosphere Reserve)

The development of ecotourism in the territory of the buffer zone of the Nuratau State Nature Reserve has the objective of stimulating the local population to conserve wildlife nature. Nowadays ecotourism is seen in Uzbekistan as one of the powerful options to link economic and ecological sustainable development (UNDP 2007);

- **Sightseeing**

Sightseeing includes visiting cultural and historical sites such as native Uzbek homes near the Aydar-Arnasay and Alexander the Great Fortress;

- **Fishing**

Summing it all up, Figure 15 demonstrates distribution of the various types of recreational activity developed in the Aydar-Arnasay lakes.

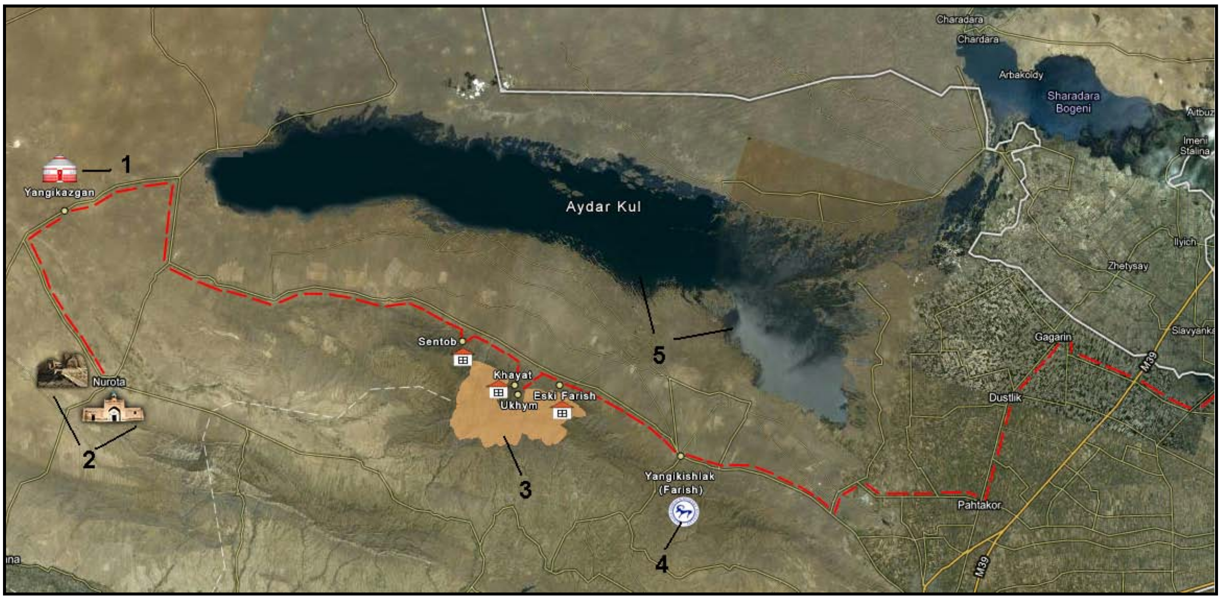


Figure 15. Recreational activity in the Aydar-Arnasay lakes system (adopted from World database on protected Areas and modified by the author)

(Legend: 1- Aydar yurt Camp; 2- historical sites, i.e. Alexander the Great Fortress, Ok Namaz Mosque; 3- territory of the Nuratau-Kyzylkum Biosphere Reserve; 4- visiting center of the Nuratau-Kyzylkum Biosphere Reserve; 5 – fishing tourism)

### 5.3 Environmental development: biodiversity conservation as the top priority for the AALS

Among various environmental aspects of the Aydar-Arnasay lakes system development the present research considers biodiversity conservation which is high-priority direction for these lakes nowadays. Primarily, the present section examines the project at initiation of the Nuratau-Kyzylkum Biosphere Reserve which includes the Arnasay Ornithological Reserve on Lake Tuzkan as the bright example of the environmental model for biodiversity conservation. Secondly, the section analyzes the Aydar-Arnasay lakes in terms of Ramsar Convention, including consideration criteria for identifying wetlands of international importance and finding of the appropriate criteria for the AALS.

Considering the conservation measures taken, according to Project UNDP/GEF/ Government of Uzbekistan "Creation of Nuratau Kyzylkum Biosphere reserve as a model of preservation of a biodiversity of Uzbekistan", the most part of the Aydar-Arnasay lakes located in the territory is included into the Nuratau-Kyzylkum biosphere reserve those features will be described in the next section.

Furthermore, in 1983 under the decision of the Government, the Arnasay ornithological *zakaznik*[16] (type of protected area) covering 63,000 hectares was created on the territory these lakes (Mahmudova 2004a). This zakaznik unites three reservoirs: Tuzkan, Arnasay, and Aydarkul. In accordance with IUCN list of protected areas category (2003), this zakaznik was treated as category IV, i.e. *Habitat/Species Management Area:* protected area managed mainly for conservation through management intervention. It means that the area of land and/or sea is subjected to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of specific species (Chape, Blyth et al. 2003).

Recently, “Action Plan for maintenance of stability of ecological conditions and effective use of Aydar-Arnasay Lakes System for the Republic of Uzbekistan for 2008-2015 years” was developed in Governmental level and also approved by the government. The main idea of this plan is to preserve and maintain the stable conditions of Aydar-Arnasay water

[16] Zakaznik - is a type of protected area in Russia and other former Soviet republics that meets World Conservation Union's (IUCN) category III, or more frequently category VII criteria. Zakazniks are the areas where temporary or permanent limitations are placed upon certain on-site economic activities, such as logging, mining, grazing, hunting, etc. They correspond to *sanctuary* in UNESCO World Heritage terminology Chape, S., S. Blyth, et al., Eds. (2003). United Nations List of Protected areas, UNEP World Conservation Monitoring Center.

ecosystem as an ecosystem carrying valuable ecological and socio-economic functions for Uzbekistan. Among proposed conservation measures, the wetland's management plan for the Aydar-Arnasay lakes is being elaborated. These lakes are under the protection of the state bodies of nature protection (International 2008b).

### 5.3.1 Nuratau-Kyzylkum Biosphere Reserve as a model for biodiversity conservation

#### *5.3.1.1 Background*

The Nuratau Mountains with adjacent Kyzylkum desert and Aydar-Arnasay lakes system are extremely unique and vulnerable ecosystems. Taking into account the increasing environmental threats such as desertification, biodiversity degradation, unsustainable use of water resources and land use, the Government of Uzbekistan with support of the members of Nature and Biodiversity Conservation Union (NABU) had been working on research in the respective topic since 1993. The preparation of the Global Environment Facility (GEF) project proposal focused on biodiversity conservation started in 1998 and approval was received in 2000 (UNEP 2007).

#### *5.3.1.2 Strategy*

The main goal of the project was to elaborate a new, more durable approach to biodiversity conservation in Uzbekistan by directly linking wildlife conservation with rural development. It should be noted that the project, focused on initiation of this biosphere reserve, has been implemented by the government of Uzbekistan, Global Ecology Fund and UN Development Program. The Project is also co-financed by German Union of Nature Protection.

The project was completed in 2007 and nowadays it is planning to include this biosphere reserve in the UNESCO global net of biosphere reserves. Currently, the experience gained from organizing this reserve is taken into account for the further research in founding biosphere reserves in the Central Kyzylkum Desert, in the Southern Ustyurt Desert, in the tugai woods of the river Amudarya and in other unique locations of Uzbekistan.

#### *5.3.1.3 Description*

Creation of the Nuratau-Kyzylkum Biosphere Reserve in 2007 was one of first projects in Uzbekistan that was intending to integrate conservation and local communities needs.

Basically, this biosphere reserve is considered to be a very remarkable example of contemporary environmental model of protection in both Uzbekistan and Central Asia.

The Nuratau Nature Reserve is one of fifteen nature reserves of Uzbekistan. It is located in the Nuratau-Mountains at the semi-desert edges of the Aydarkul-Lake (Figure 16). The Nuratau mountain area reaches an altitude up to 2,200 meters. It should be pointed out that the Nuratau-Kyzylkum Biosphere Reserve is integration already two functioning reserves: Nurata Reserve, and Arnasay Ornithological Reserve on Lake Tuzkan.

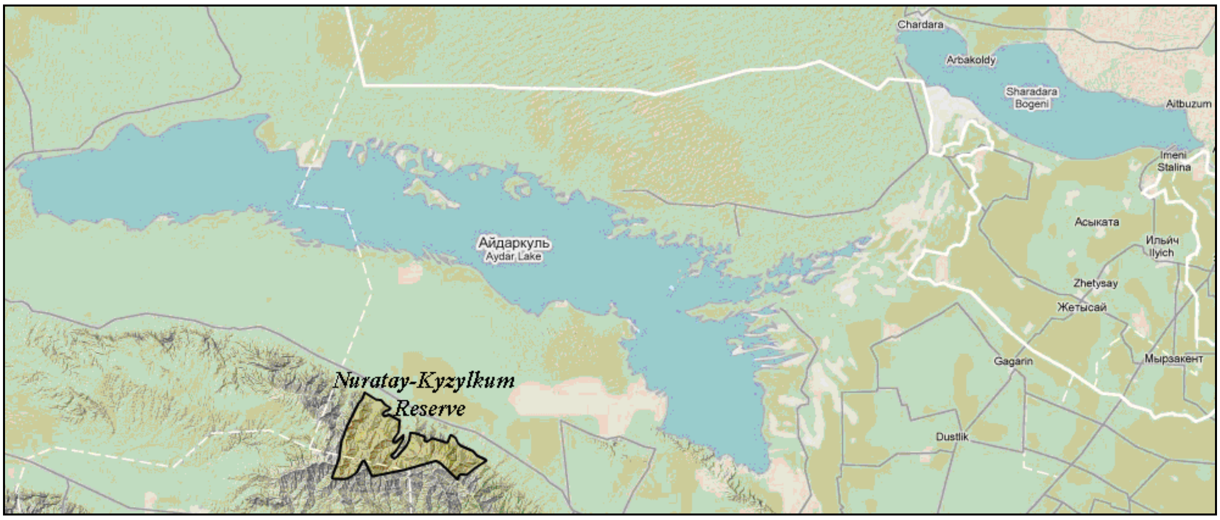


Figure 16. Geographical location of the Nuratay-Kyzylkum Biosphere Reserve (UNEP 2007)

The mountains, the semi-desert, the lake and the desert form a unique landscape with an extremely varied biodiversity of flora and fauna. The flora and fauna of the biosphere reserve, many species of which are included into the Red Book of Uzbekistan, are under strict control. The area is therefore composed of four different ecosystems that are representative for the Central Asian region. There are 1,200 plant families native to the mountain area and about 300 to the desert area. The fauna is composed of more than 250 bird, 29 reptile and 35 different mammal species, among them species that are threatened by extinction. For example, among the birds from the Red Book the following species are the rarest: golden eagle, bearded vulture, black griffon-vulture and other rare birds (Tacis programme 2006).

The biosphere reserve Nuratau-Kyzylkum is physically structured into three zones. A 57,100 hectare core zone is dedicated for long-term protection of nature and landscape without any human use. In the 164,524 hectare adjoining buffer zone only considerate land use by humans, which is compatible with the proposed goals of the biosphere reserve, is allowed. In the outer 851,524 hectare development zone procedures for sustainable resource management are to be developed and promoted.

Besides having their distinctive features, these zones have the features typical both of the wildlife and of the populated areas of Central Asia. They represent various historical and archeological monuments, cultural and natural realms, traditional economy methods and living standards (UNEP 2007).

#### *5.3.1.4 Success*

The initiation of this reserve had five major outcomes:

- The unique national and global biodiversity value and the mosaic of natural and cultural landscapes in the project area conserved;
- Local authorities and communities have a better awareness and valuation of biodiversity resources and services and an understanding of the principles of sustainable development;
- The capacity of local authorities and communities to play an active role in the planning and management of natural resources and development of sustainable livelihoods in place;
- Types of land use reduced within the project area with negative effects on ecosystems and the basis established for the long-term sustainable development of the area in place;
- New "inclusive" and sustainable human development-oriented approaches to the conservation of biodiversity in Uzbekistan developed and tested (UNEP 2007).



### 5.3.2 Ramsar Convention

The Ramsar Convention on Wetlands came into force for Uzbekistan on 8 February 2002. Nowadays, Uzbekistan has two sites designated as Wetlands of International Importance, with a surface area of 558,400 hectares, i.e. the Aydar Arnasay Lakes System and Lake Dengizkul (Mahmudova 2004b).

Figure 17 shows boundaries of Aydar-Arnasay lakes site from the Ramsar Convention perspective. Ramsar boundaries are shown in light green.

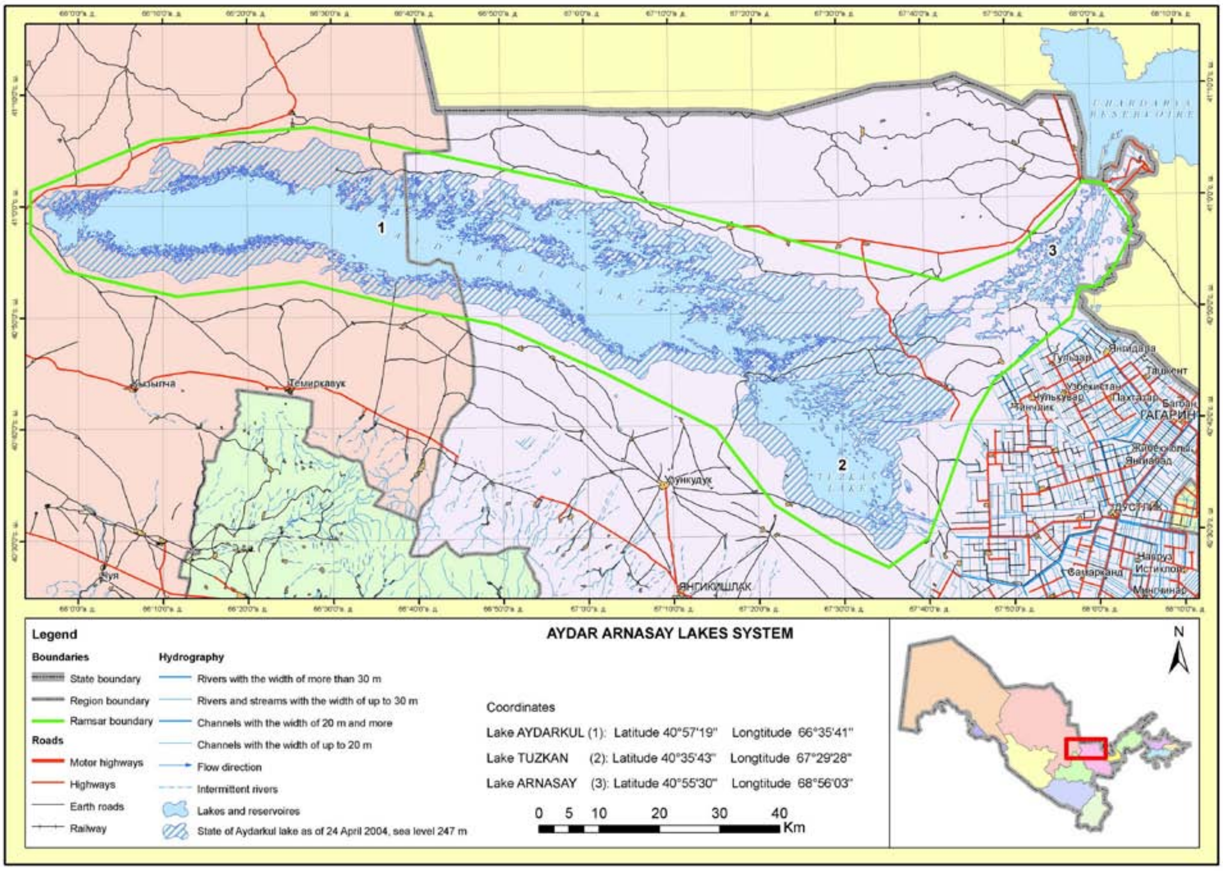


Figure 17. Ramsar boundaries of the Aydar-Arnasay lakes site (http://ramsar.wetlands.org/Database/Searchforsites)

#### *5.3.2.1 Criteria for Identifying Wetlands of International Importance*

Among the main Ramsar criteria for identifying wetlands of international importance, the Aydar-Arnasay lakes site has been selected based on five main Ramsar criteria (International 2008b). To begin with let us consider a list of criteria for identifying a wetland of international importance and then to justify appropriate criteria for wetlands in Aydar-Arnasay lakes.

Article 2.2 of the Ramsar Convention states that “Wetlands should be selected for the List on account of their international significance in terms of ecology, botany, zoology, limnology or hydrology” and indicates that “in the first instance, wetlands of international importance to waterfowl at any season should be included” (International 2006).

It has been discovered that there are two main groups of the criteria for the designation of wetlands of international importance. Group A of the criteria focuses on the sites containing representative, rare or unique wetland types (International 2006). Only one criterion is included in this group, i.e.

- Criterion 1: Wetlands are supposed to be internationally important if they are representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographical region. The group B focuses on the sites of international importance for conserving biological diversity. Four main subgroups of the criteria are included in this group, namely:

*Criteria based on species and ecological communities:*

- Criterion 2: Wetlands should be considered internationally important if they give support for vulnerable, endangered, or critically endangered species or threatened ecological communities;
- Criterion 3: Wetland should be considered internationally important if they support populations of plant and/or animal species which are important for maintaining the biological diversity of a particular biogeographical region;
- Criterion 4: Wetlands should be considered internationally important if they support plant and/or animal species at a critical stage in their life cycles, or provide refuge during severe conditions (International 2006).

*Specific criteria based on waterbirds:*

- Criterion 5: Wetlands should be considered internationally important if they constantly support 20,000 or more waterbirds;
- Criterion 6: Wetlands should be considered internationally important if they constantly give 1% support to the individuals in a population of one species or subspecies of waterbirds.

*Specific criteria based on fish:*

- Criterion 7: Wetlands should be considered internationally important if they support a large proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contribute to global biological diversity;
- Criterion 8: Wetlands should be considered internationally important if they are an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.

*Specific criteria based on other taxa:*

- Criterion 9: Wetland should be considered internationally important if they constantly support 1% of the individuals in a population of one species or subspecies of wetland-dependent non-avian animal species (Wetlands International 2008a).

#### *5.3.2.2 Justification for the application of Criteria for Identifying the AALS as Wetlands of International Importance*

As was mentioned above, the Aydar-Arnasay lakes site has been selected in accordance with five main Ramsar criteria. Justification of all five criteria for identification of the Aydar-Arnasay lakes as wetlands of international importance is provided below.

According to Criterion 2 this site is a very important habitat of threatened bird species. Table 3 demonstrates the variety of bird species which inhabit the respective site, including their threatened status in accordance with International Union for Conservation of Nature (IUCN), Convention on Migratory Species (CMS), and National statuses (Wetlands International 2008b).

Table 3. The threatened list of bird species in the Aydar-Arnasay lakes

| Species | | [1]IUCN Threatened Status | [2]CMS Status | [3]National Status |
|---|---|---|---|---|
| English name | Scientific name | | | |
| Whity Headed Duck | Oxyura leucocephala | En | - | En |
| Ferruginous Duck | Aythya nyroca | NT | I/II | En |
| White Tailed Sea Eagle | Haliaetus albicilla | LC | I/II | En |
| Siberian White Grane | Grus leucogeranus | - | - | En |
| Pallid Harrier | Circus macrourus | NT | - | En |
| Sociable Lapwing | Chettusia gregaria | CR | I/II | En |
| Little Bustard | Tetrax tetrax | - | - | En |
| Asian Dowitcher | Limnodromus semipalmatus | - | - | En |
| Dalmatian Pelican | Pelecanus crispus | Vu | I/II | Vu |
| White Pelican | Pelecanus onocrotalus | - | - | Vu |
| Pygmy Cormorant | Phalacrocorax pygmaeus | LC | I/II | Vu |
| White Spoonbill | Platalea leucorodia | - | - | Vu |
| Mute Swan | Cygnus olor | - | - | Vu |
| Whooper Swan | Cygnus cygnus | - | - | Vu |
| Red Breasted Goose | Rufibrenta ruficollis | En | I/II | Vu |
| Lesser White Fronted Goose | Anser erytropus | Vu | I/II | Vu |
| Osprey | Pandion haliaetus | - | - | Vu |
| Imperial Eagle | Aquila heliaca | Vu | I/II | Vu |
| Pallas Sea Eagle | Haliaetus leucoryphus | Vu | I | Vu |

(Source: Ramsar Sites International Service. Information Sheet on Ramsar Wetlands 2008b)
**Legend:**
1= IUCN Red List of Threatened Animals (Abbreviations: CR= critically endangered; EN= Endangered; VU = Vulnerable; NT= near threatened; LC= Least Concern);
2= Convention on Migratory Species (CMS) (Abbreviations: I=Appendix I species; II=Appendix II species);
3= National Red Book of Threatened Species (Abbreviations: EN= Endangered; VU= Vulnerable).

According to the Important Birds Areas survey, about 220 bird species of 14 orders have been recorded in the Aydar-Arnasay lakes system since the 1970s. Among all lakes in this system Aydarkul is considered to be the largest habitat with more than 100 species of waterbirds in Uzbekistan. Among them 24 species are included in the Red Book of Uzbekistan and 13 of them are included in IUCN International Red List, and 10 of them directly related to wetlands (Bird Life International 2007).

We should emphasize that the Aydar-Arnasay lakes site is located at the crossroads of the East-Asian Australian and Central-Asian Indian flyways (Figure 18). The Central-Asian Indian flyway of migratory birds covers the a big continental zone of Eurasia and the Arctic open spaces up to the Indian Ocean, unites some important migratory routes of waterbirds, the majority from which reaches from northern regions of Russia up to the most southern wintering territories in Western and Southern Asia, in Maldives and the British territories in the Indian Ocean (Figure 19). The Central-Asian Indian flyway unites 274 populations of the migrating waterbirds belonging to 175 species, including 26 global endangered and threatened species. Thus, located in the Central-Asian Indian flyway of migratory waterbirds, the Aydar-Arnasay lakes play a significant role as a place of large-scale wintering of waterbirds.

These lakes provide habitat for the following waterbirds: Grebs (Podicipediformes), Totimplate (Pelrcaniformes), Ciconiformes (Ciconiformes), Swans, Geese, Ducks (Anseriformes), Rails (Rallidae), Shorebirds (Charadriiformes) and other species. Around these lakes the following species were also observed: Wild Boar (Susscrofa), Badger (Melesmeles), Jungle Cat (Felis chaus), Golden or Indian Jackal (Canis aureus), Muskrat (Ondatra zibethicus), Nutria (Myocastor coypus), Ciconiformes (Ciconiformes), Rails (Rallidae), Pheasant (Phasianus colchicus), Diesed Snake (Natrix tessellate), Marsh Frog (Ranaridibunda) (UNEP 2005). The coastal vegetation mostly consists of reed associations and habitat for the above specified animals. Therefore, Criterion 4 is observable in the Aydar-Arnasay lakes because this site, i.e. reservoir and its shallow bays are habitat of numerous species of flora and fauna (Wetlands International 2008b).

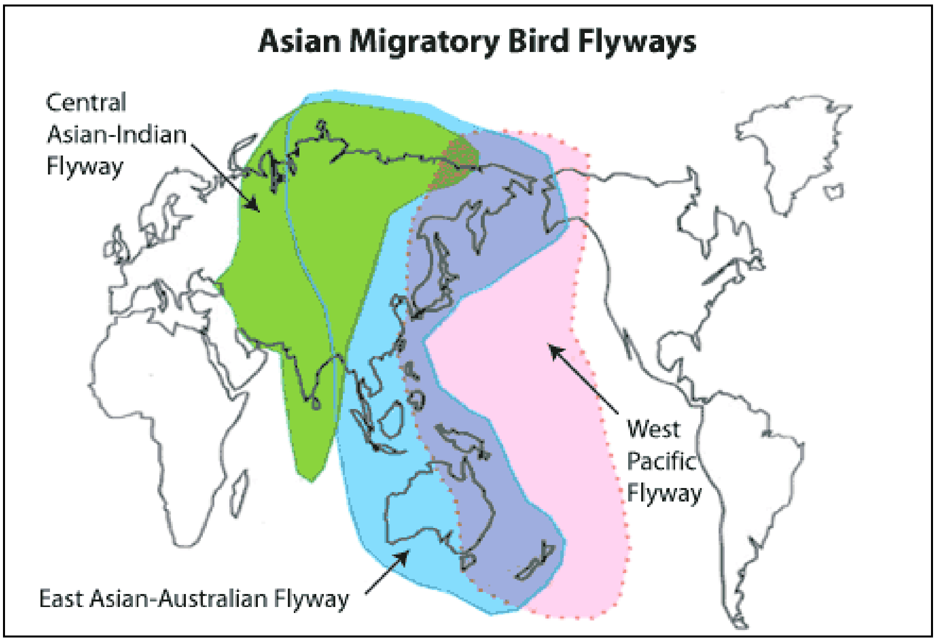


Figure 18. Asian Migratory Bird Flyways (Source: U.S. Fish and Wildlife Service)

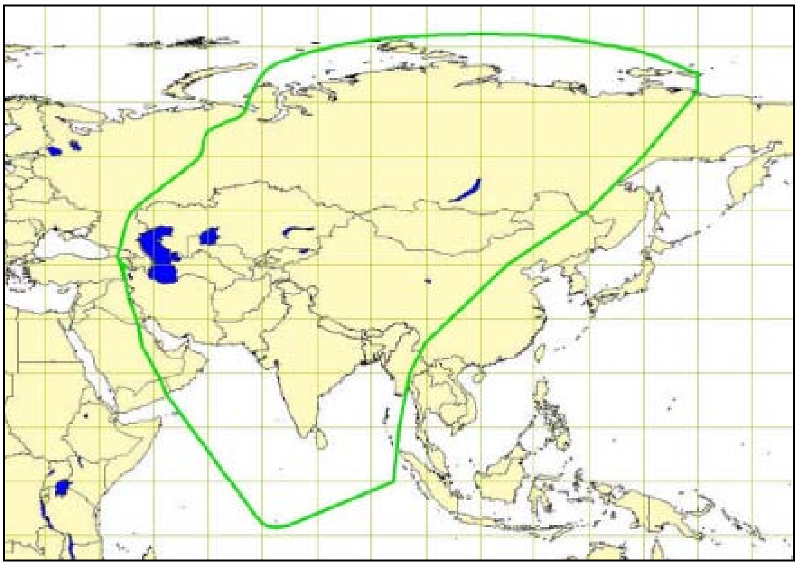

Figure 19. Indicative map of the Central-Asian Indian Flyway region (Source: UNEP 2005)

According to the wintering waterfowl estimates since 1989, the total number of wintering waterfowl has met with Criterion 5, as it exceeded 20,000 waterbirds. In 2003 the estimates showed that around 96,000 birds of 37 species were recorded. Later in 2004, 61,000 of birds of 45 species were identified, i.e. 19 species of Anseriformes (Anseriformes), 6 species of birds of prey (Falconiformes), Marsh Owl (Asto flammeus) and Pheasant (Phasinuscolchicus), and 4 species of gulls (Laridae) (UNEP 2005).

The Aydar-Arnasay lakes also have met with Criterion 7, harboring 28 species of fish, including 14 food fishes. The following species were observed: Pickerel (Esoxlucius), Carpbream (Abramis brama), Zherekh (Aspiusaspius), Crucian Carp (Carassius auratus), Grass Carp (Ctenopharyngogon idella), Carp (Cyprinus carpio), Silver Carp (Hypophthalmichthys molitrix), Spotted Silver Carp (Aristichthys nobilis), Sabrefish (Pelecus cultratus), Roach (Rutilus rutilus), Wels (Silurus glanis), and Zander (Ctizostedion lucioperca). This site is very important from the perspective of its contribution to global biological diversity and maintenance of a huge variety of indigenous fish species.

Finally, Criterion 8 is also fulfilled because the respective place is a significant source of food for fish species given above, spawning ground, nursery, and migration path. On the Aydar-Arnasay lakes 14 species of fishes continually live and reproduce. 7 species of fish have commercial importance, namely: Carp (Cyprinus carpio), Silver Carp Hypophthalmichthys molitrix), Wels (Silurus glanis), Mudfish (Channa argus), Zherekh (Aspius aspius), Crucian Carp Carassius auratus), and Carpbream (Abramis brama) (Wetlands International 2008a).

#### *5.3.2.3 Wetlands types*

Concerning wetland type, it can be pointed out that Aydar-Arnasay lakes widely represent various types of inland wetlands. Among all inland wetlands included in the Ramsar classification for wetland types, the following types were found on these lakes:

- M - Permanent rivers/streams/creeks; includes waterfalls;
- O - Permanent freshwater lakes (over 8 ha), includes large oxbow lakes. These wetlands are found in some parts of the Arnasay lake, approximately 2-3 thousand hectares;
- P - Seasonal/intermittent freshwater lakes (over 8 ha), includes floodplain lakes. These wetlands are found in some parts of the territory between Arnasay and Tuzkan lakes;
- Q - Permanent saline/brackish/alkaline lakes. These wetlands represent the major part of the lakes;
- R - Seasonal/intermittent saline/brackish/alkaline lakes and flats. These wetlands represent small part of the lakes;
- W - Shrub-dominated wetlands; shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils (Wetlands International 2006).

Among human-made wetlands the following types were identified on the addressed site:

- 1 - Aquaculture (e.g., fish/shrimp) ponds;
- 3 - Irrigated land; includes irrigation channels and rice fields;
- 4 - Seasonally flooded agricultural land (including intensively managed or grazed wet meadow or pasture);
- 5 - Salt exploitation sites; salt pans, salines;
- 6 - Water storage areas; reservoirs/barrages/dams/impoundments (generally over 8 ha) (Wetlands International 2006).

The Aydar-Arnasay wetlands also include hunting and fish farm facilities. Active measures are taken to improve the lakes' habitat and farming efficiency as well as actions aimed to conserve various species. Besides, these lakes are extensively used for recreational purposes. Reed vegetation is used by the local population for building some temporary constructions. It is very important to note that the ecological character of the wetlands in these lakes directly depends on the interaction with local communities and indigenous people (Wetlands International 2008b).

The Information Sheet on Ramsar Wetlands (2008) summarizes that in 2000-2003 international counts of wintering waterbirds were conducted in these lakes. During the last five years scientific research has been carried out on the cadastres of flora and fauna, some national and international scientific reports about the Aydar-Arnasay wetlands were published. The State Committee for Nature Protection and Academy of Sciences of the Uzbekistan has elaborated projects directed at scientific research, management and protection of the Aydar-Arnasay lakes (Wetlands International 2008b).

To sum up, the Aydar-Arnasay lakes system represents a place of great significance concerning the wetlands of international importance as well as place of fisheries development. Therewith, situated in the crossroads of the East-Asian Australian and Central-Asian Indian flyways, these lakes is a valuable place of large-scale wintering of waterbirds.

# 6. AYDAR-ARNASAY LAKES SYTEM FATE: POSSIBLE FUTURE DEVELOPMENT TRENDS

The following chapter is concerned with the analysis of the possible future ways of the Aydar-Arnasay lakes system (AALS) in order to achieve the main goal established in the thesis. For clarity, let us recall that the overarching goal of the present research is the identification of the most representative water management scenario in terms of the AALS future development which directly depends on environmental (change of the regional climate) and political (regional cooperation) factors. The main methods applied for the prediction of the AALS future trends in this chapter are the integration of the scenario approach and environmental modeling assisted by the STELLA software.

The present chapter has three main sections. The first is devoted to elaboration of the possible AALS water management scenarios. In order to devise the scenarios, the following steps are taken: development of the major scenario criteria, demonstration of the conceptual scheme of the elaborated AALS water management scenarios, and detailed description of each scenario.

The second section is concentrated on the development of the AALS model assisted by the STELLA software. The development includes assigning the model objective and description of the model structure, i.e. geographic and temporal scale, basic assumptions, and input and output parameters and main blocks of the model.

The third section attempts to carry out modeling of the elaborated water management scenarios and explicate the results obtained.



## 6.1 Possible water management scenarios of the AALS future development

### 6.1.1 Background

As indicated in the literature review, the scenario approach is acknowledged as a powerful strategic management tool for the decision making process in environmental science[17]. The majority of contemporary environmental research is based on the application of

[17] See section 2.3.3

the scenario approach. In practice, the scenario approach is a set of various stories built around "carefully constructed plots" (Mietzner and Reger 2005).

Before going further we deem it important to explain the main concept and characteristics of the scenario. In general, the concept of the scenario approach can be shown by a simple conceptual image presented in Figure 20.

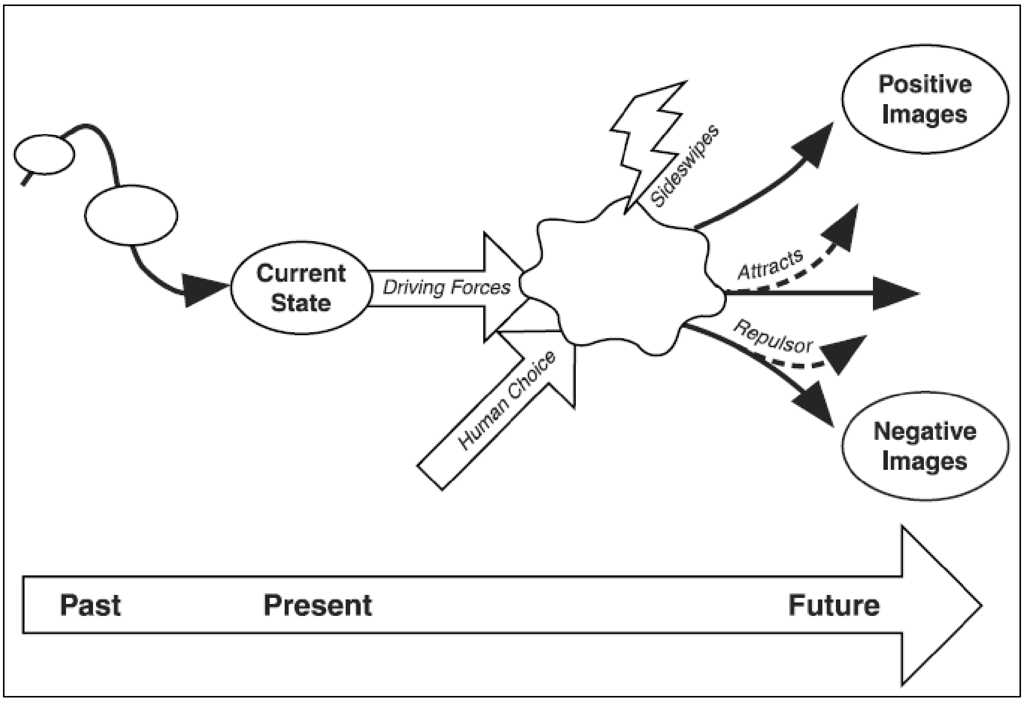


Figure 20. Scenario dynamics (Mietzner and Reger 2005)

From the picture it can be observed that the current state is a result of historical processes. This state could change due to driving forces which condition the future development. This approach depicts alternative ways of future development. *Positive images* might include their consistence with sustainable development. *Negative images*, in turn, play a significant role because they can raise awareness and provide some effective alternative to eradicate some present perilous conditions. Additionally, we should note *sideswipes* which can be explained as surprising and extreme occurrences (natural disasters, wars, global epidemic and others) that can influence future development (Mietzner and Reger 2005).

Among the most distinct characteristics of the scenario approach the following should be listed:

- It depicts alternative ways instead of extrapolating trends from the present;
- It anticipates future trends and opportunities (Ratcliffe 2002);

- It creates holistic images of how future could develop;
- It reframes existing decisions by providing a new context of decisions;
- It embraces both qualitative and quantitative information;
- It requires decision makers and other stakeholders to question their basic assumptions (Neilson and Wagner 2000).

There are different types of scenarios and ways of classifying them (Martelli 2000). For example, scenarios can be classified in relation to distinct aspects, i.e. aspects of representation (complete formulated or sketchy), topic (global or specific), time (short, mid or long-term and others. Depending on the action aspects, scenarios could be forward or backward scenarios. Also they can be mission scenarios, action scenario or issues scenarios (Maleska 1995). Besides, scenarios can demonstrate results of the forecasts in a consistent or compelling way. Thus, they might be exploratory or normative. Explorative scenarios are scenarios based on the demonstration of future starting from analyzing past and present trends and leading to decent future. Conversely, normative scenarios suggest various visions of the future, i.e. from desired to dramatic (Faley and Randell 1998). Summarizing, such variety of scenario classifications underline that this approach is actively developed today and used in different domains.

### 6.1.2 GEO-3 scenarios as an example of successful scenario building

Based on the examination of the literature devoted to the scenario approach, for the development of our own water management scenarios for the AALS future, it has been decided to use the concept of the UNEP scenarios developed for the Global Environmental Outlook (GEO) as a good example for scenario building. GEO-3 scenarios have been focused on the framework of Global Scenario Group (GSG) and then applied to six UNEP regions and 21 UNEP subregions (UNEP 2002). The main idea of GEO scenarios is that they are based on the two following criteria:

a) Globalization/regionalization;

b) Economy/ Environment (Figure 21);

According to these criteria, there are four main types of GEO scenarios, namely:

**The Market Forces (or Market First) scenario** envisages a world in which market-driven developments coverage on the values and expectations that prevail in industrialized countries;

- **The Policy Reform (or Policy First) scenario** considers a world where strong actions are undertaken by governments in an attempt to reach specific social and environmental goals;
- **The Security First (or Fortress World) scenario** assumes a world of great disparities, where inequality and conflict prevail, brought about socio-economic and environmental stresses;
- **The Great Transition (or Sustainability First) scenario** pictures a world in which a new development paradigm emerges in response to the challenge of sustainability, supported by new, more equitable values and institutions (UNEP 2002).

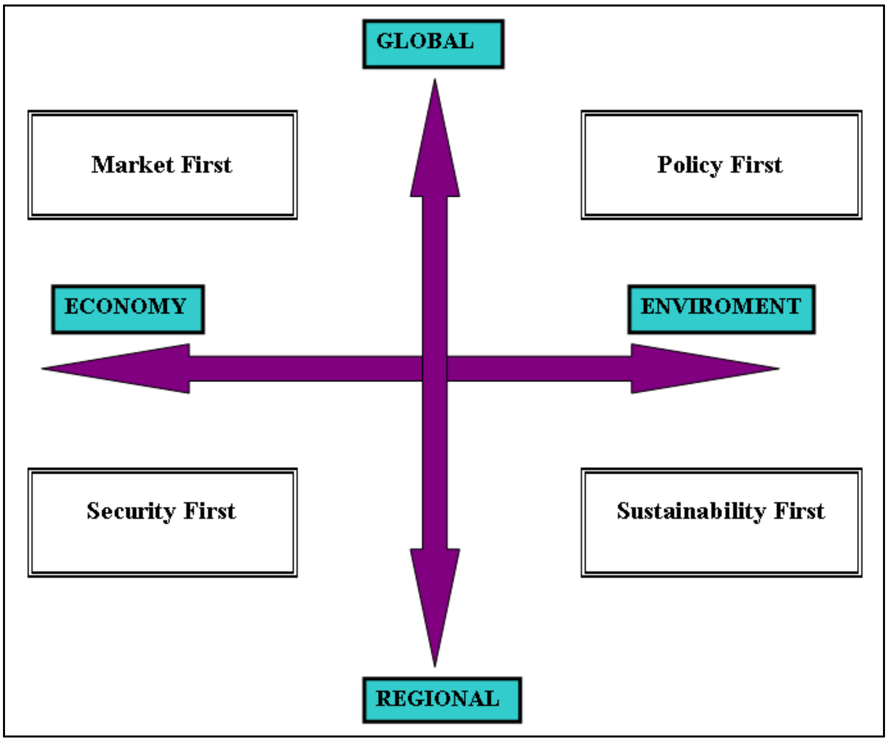


Figure 21. Conceptual scheme of GEO-scenarios

In our opinion, the concept of GEO scenarios seems to be coherent and suitable for scenario creation. There are a large number of positive moments of the GEO concept. Some of them are:

- GEO scenarios take into consideration a large variety of driving forces, i.e. demographics, economics, environment, geopolitical, social, cultural aspects, and technological changes.
- GEO scenarios can be readily visualized by a simple conceptual scheme which makes them more comprehensive and easily available for stakeholders and decision makers (Figure 21);
- GEO scenarios represent a successful combination of qualitative and quantitative scenarios. “Qualitative narratives take a central position with the quantitative tools playing a supporting role” (UNEP/RIVM 2003). From the qualitative perspective, GEO scenarios explore relationships, trends, situations for which few or no numerical data are available. They can more readily incorporate human motivations, insights, values and behavior and explain alternative ways of development by creation holistic qualitative picture. From the quantitative perspective, GEO scenarios provide greater consistency and precision. Their assumptions are explicit and their conclusion can be traced back to the assumptions. They can provide estimates of past, present and future trends, for instance, population growth or resource use (UNEP 2002).

### 6.1.3 Elaboration of the water management scenarios

To begin with, we should briefly explain the reason of developing **water management scenarios** in the present research. The prime reason of our choice is the fact that we are dealing with a complicated human-induced lakes system whose development directly depends on management decision making and political cooperation. It is known that the water policy of Kyrgyzstan and Kazakhstan undoubtedly predetermines the Aydar-Arnasay development ways. In the present work, the water management scenarios will reflect different water discharges strategies which will be used for depiction of alternative ways of the lakes development. Moreover, these ways can be either suitable or unacceptable for the decision making process.

Having considered the concept of the GEO scenario, it has been decided to develop a similar concept for our scenario building. However, in order to make water management scenarios more realistic and feasible, completely different criteria have been established.

The procedure of the elaboration of the water management scenarios consists of the following steps:

- Establishment of the main criteria which are the unchanged basis for the AALS water management scenarios;
- Creation of the conceptual scheme backbone demonstrating of the arrangement of these elaborated criteria;
- Detailed description of each AALS water management scenario, including its main concept and assumptions;
- Spatial arrangement of the scenarios according to the elaborated criteria on the conceptual scheme;

#### *6.1.3.1 Development of the criteria for the water management scenarios*

To begin with, let us describe how the main criteria for the water management scenarios have been selected. The main steps of criteria selection are:

- A huge amount of literature devoted to driving forces of the Aydar-Arnasay lakes development has been analyzed;
- In order to define which factors are the most important for the AALS development the literature analysis of the driving forces such as population, economics, environment, technologies, political and social aspects has been conducted;
- Particular attention has been paid to the contemporary geopolitical situation in Central Asia, i.e. a large amount of journal articles and newspapers concerning political relationships has been reviewed;
- Particular attention has been also paid to the analysis of existing environmental problems in Central Asia, e.g. lack of water resources, change of the regional climate, poor water quality;

As the result, two main criteria for the water management scenarios have been chosen:

1) regional cooperation between republics;

2) change of the regional climate.

**Regional cooperation between republics**

Regional cooperation between the republics, namely between Uzbekistan, Kazakhstan and Kyrgyzstan, is the first criterion defined for the scenarios. Generally speaking, this criterion has been selected because nowadays the interstate relationships between the republics concerned determine the development of many environmental aspects in the whole region, such as distribution of water resources between the republics, and development of legislative environmental base.

Regional cooperation between the republics is examined from two positions:

- **Regional cooperation between Uzbekistan and Kazakhstan**; In the context of the Aydar-Arnasay lakes development regional cooperation between the republics in question principally focuses on the amount of water discharges from the Chardara reservoir located in Kazakhstan; Based on the previous research chapters we know that today there is no coordinated water policy between the countries to determine the exact amount of water discharges from the Chardara to the AALS and to the downstream Syrdarya. Current unsteady water discharges from the Chardara which is the main feed source of the Aydar-Arnasay lakes cause the gradual alteration of the hydrological regime of the lakes, aggravation of the ecological situation, including growth of mineralization and deterioration of the fish industry. Therefore, consideration of the relationships between these republics seems necessary.
- **Regional cooperation from the perspective of Kyrgyzstan**; Interstate relationship with Kyrgyzstan is a particular question which should not be excluded from the present analysis. The main reason relates to the situation in the Toktogul Reservoir operation. As it was described in the literature review and then in the research chapters, transferring the Toktogul Reservoir to a power-focused regime based on huge amounts of water releases during the non-growing period changed the relationships with downstream countries, i.e. Uzbekistan and Kazakhstan. At present, they experience a lack of water resources during the growing periods. Moreover, the fate of the Aydar-Arnasay lakes directly depends on the Kyrgyz position regarding water releases from the Toktogul. Therefore, the analysis of the relationships between Kyrgyzstan and Uzbekistan is necessary for the elaboration of the water management scenarios.

It has been decided by the author that regional cooperation as one of the basic criteria for the elaboration of the water management scenarios will be expressed by the water discharges in the conceptual model. The quantitative description of the water discharges depending on the level of regional cooperation will be introduced in the section on model simulation.

**Change of the regional climate**

Change of the regional climate has been proposed by the author as the second criterion for the elaboration of the AALS water management scenarios. This criterion has been selected because the change of the regional climate as one of the current problems for Central Asia as well as for Uzbekistan represents serious threats for the environment, ecological, and socio-economic systems. During the last decades it has been observed that the quantity and quality of water resources are at high risk of acute effects of climate change (Perelet 2008).

Climate change issues are closely connected with issues of water resources in Uzbekistan. Change of the regional climate in future will give rise to considerable variations of the whole Aydar-Arnasay system, including environmental and socio-economic. Such problems as alteration of the hydrological cycle, unstable water-level of the lakes, the problem of high mineralization, fisheries deterioration and others could aggravate the future functioning of this vulnerable lakes system.

Many experts believe that the climate in Uzbekistan will considerably warm up causing major environmental, economic and social disturbances. Besides, climate change will affect the maintenance of biodiversity in terms of protection of Aydar-Arnasay wetlands designated as a Ramsar site and all endangered species living there (Perelet 2008).

Therefore, in our viewpoint the change of the regional climate could be an appropriate criterion for the elaboration of the water management scenarios. Under the change of regional climate, in the present research change of the average annual temperature will be considered. Quantitative description of this criterion will be given in the model simulation section.

#### *6.1.3.2 Development of the scenario conceptual scheme based on elaborated criteria*

As described in the previous section, two determinate criteria for the water management scenarios have been elaborated and proposed by the author. They are:

- **Regional cooperation** which will be expressed by water discharges in the AALS model;
- **Change of the regional climate** which will be demonstrated by change of annual average temperature and evaporation.

Proceeding from the GEO scenario conceptual scheme[18], a similar conceptual scheme for the water management scenarios has been devised. Figure 22 demonstrates the backbone of the conceptual scheme based on two criteria concerned.

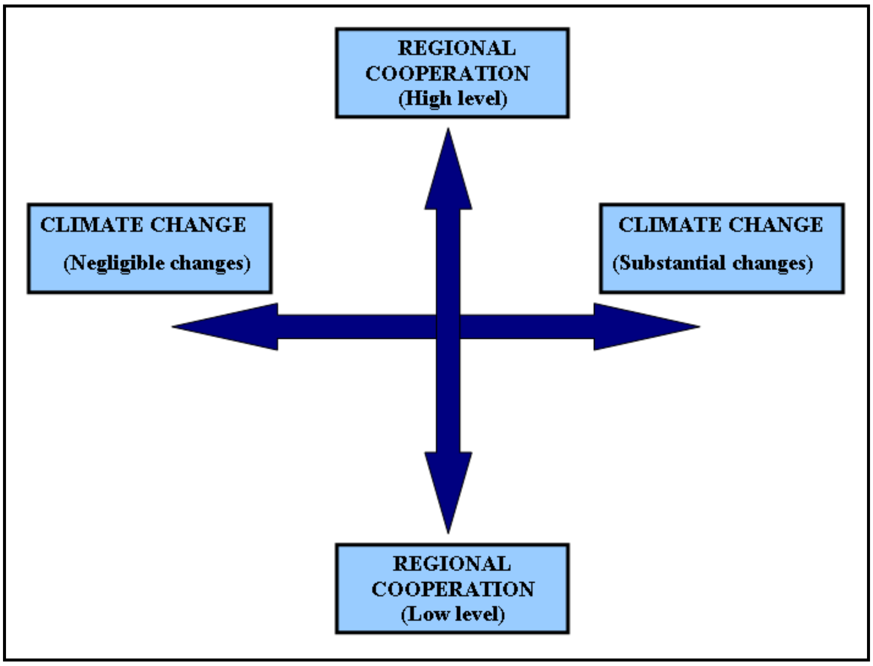


Figure 22. Backbone of the water management scenarios conceptual scheme

Analyzing Figure 22 four alternative scenarios can be identified, namely:

- The first scenario is based on high level of regional cooperation between republics concerning the Aydar-Arnasay lakes and substantial change of the regional climate;
- The second scenario is based on low level of regional cooperation between republics concerning the Aydar-Arnasay lakes and still substantial change of the regional climate;
- The third scenario is based on high level of regional cooperation between republics concerning the Aydar-Arnasay lakes and negligible change of the regional climate or even absence of any climatic changes;
- The fourth scenario is based on low level of regional cooperation between republics concerning the Aydar-Arnasay lakes and negligible change of the regional climate or even absence of any climatic changes;

The next section will introduce the name of the scenarios concerned and describe their concept and main assumptions.

[18] See Figure 21 as an example

### 6.1.4 The water management scenarios: description

The present section considers a full description of the water management scenarios elaborated for the testing by the STELLA software (Table 4) and demonstrates a conceptual scheme of these scenarios (Figure 23). Figure 23 presents the conceptual scheme filled with our scenarios, namely, Scenario I “Ready for Challenge”, Scenario II “Fall Behind”, Scenario III “Promising Future”, and Scenario IV “Business as Usual”.

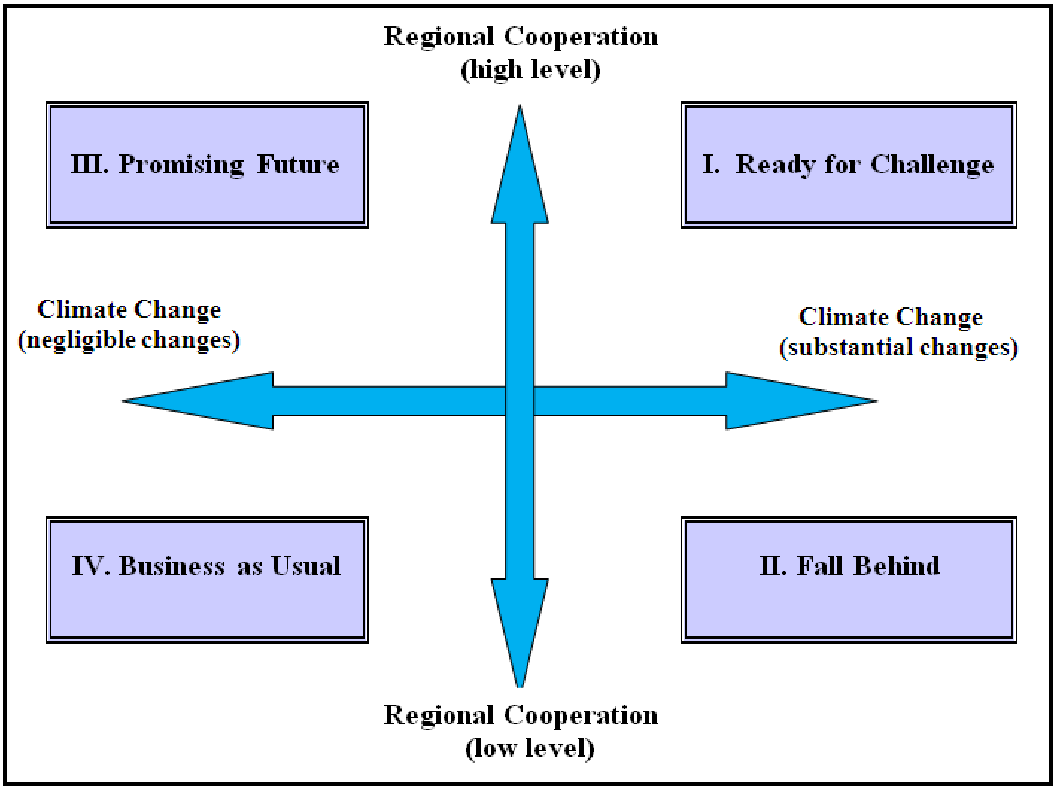


Figure 23. Conceptual scheme of the elaborated water management scenarios

Table 4. Description of the water management scenarios

| Scenario | Regional cooperation | Climate Change | Assumptions |
|---|---|---|---|
| **I. Ready for Challenge** | High Level | Substantial Changes | Consulting interests: coordinated and comprehensive water policy between Kazakhstan and Uzbekistan in terms of water discharges to the AALS;<br>Consulting interests: close cooperation between Uzbekistan and Kyrgyzstan in terms of coordinated the Toktogul reservoir operation;<br>The AALS fate: stable development, i.e. stable water-level, sustained volume, maintenance of biodiversity, the fish farms, recreational activity;<br>Climate Change influence: there is a high probability that regulated water discharges will compensate severe climatic |

| | | | |
|---|---|---|---|
| | | | change in future;<br><br>General trends: balanced and gradual development of the AALS; |
| **II.**<br><br>**Fall**<br><br>**Behind** | Low<br><br>Level | Substantial<br><br>Changes | Kazakhstan policy: accumulation of the Chardara water surpluses in the new launched Koksaray dam;<br><br>The AALS fate: losing of the main feed source (Chardara reservoir) and a progressive destruction of the system;<br><br>Kyrgyzstan policy: use of the Toktogul Reservoir in the power-focused regime and releasing a huge amount of water during the non-growing season;<br><br>Fate of the downstream countries (Uzbekistan and Kazakhstan): high probability of flooding during the winter time and lack of water during the summer time;<br><br>Severe climate change impact: increase of temperature and evaporation followed by the increase of mineralization, probable shrinking of the AALS;<br><br>General trends: aggravation of the AALS future situation due to lack of regional cooperation and severe climatic changes, i.e. situation in fisheries development, maintenance of biodiversity, and recreation; environmental and socio-economic functions of the AALS will be diminished; |
| **III.**<br><br>**Promising**<br><br>**Future** | High<br><br>level | Negligible<br><br>changes | Consulting interests: elaboration of the coordinated policy between republics based on regulated water discharges to the AALS;<br><br>Implementation of the joint projects aimed to conserve wildlife nature of the Aydar-Arnasay lakes; maintain fisheries, enhance tourism development, including construction of transport and resort infrastructure;<br><br>Upsides of minor climatic changes in future:<br>a) minimal fluctuations of the AALS water-surface area and volume;<br>b) probable increase of the lakes' size;<br><br>The AALS fate: prosperous future and sustainable development;<br><br>General trends: active development of the AALS fisheries, i.e. sustainable fish reproduction, fish production growth and modification of fish facilities; |
| **IV.**<br><br>**Business**<br><br>**as**<br><br>**Usual** | Low<br><br>Level | Negligible<br><br>Changes | Main assumption: continuing current trends in the AALS development;<br><br>Self-interests: no coordinated policy in terms of water discharges to the AALS; irregular water releases;<br><br>Climate change influence: minor climatic changes have no impact on the AALS development;<br><br>The AALS fate: despite absence of climate change, there is a probability of slow decrease of the AALS water-level and volume mainly due to low level of regional cooperation;<br><br>General trends: indeterminate state of the AALS, including fluctuations of the hydrological lakes' conditions, lack of coordinated measures aimed to maintain biodiversity, fisheries development and recreational activity; |

## 6.2 The Aydar-Arnasay lakes model development

The following section focuses on the description of the model of the Aydar-Arnasay lakes using the STELLA software. As it was described in the methodology section[19], this software seems to be a suitable tool for development of the Aydar-Arnasay lakes model.

Before introducing the main idea and structure of the model, we deem it reasonable to reiterate the primary research question. Our overarching goal is to identify which of the elaborated water management scenarios is the most probable for the future development of the Aydar-Arnasay lakes system.

"The AALS future development" directly depends on the level of regional cooperation between Central Asian republics and some environmental factors, such as change of the regional climate. These factors will influence the future characteristics of these lakes, including the hydrological features, maintenance of fisheries, conservation of biodiversity, i.e. wetlands of international importance designated as a Ramsar site and various birds and fish species inhabiting these lakes.

### 6.2.1 Model structure and basics

The main goal of the model is to test the elaborated water management scenarios of the Aydar-Arnasay lakes system future using the STELLA software in order to find the most probable scenario for the future development of these lakes system.

Research resulting in creation of the model consisted of two main stages. They are:

- The "desk-based" stage of the research was focused on literature review and unstructured interview with experts; this stage gave rise to the detailed analysis of the AALS and identification of the factors most influential on its development.
- The "field study" stage was aimed to gather more particular information about factors and processes important for the Aydar-Arnasay lakes development. Analysis of the archival materials was also conducted at this stage.

As the result of these stages, the simulation model was constructed using the STELLA software. Finally, series of experiments were carried out to test the elaborated water management scenarios.



[19] See section 3.3.2.1

Figure 24 shows the model screenshot presenting the basic structure of the AALS model.

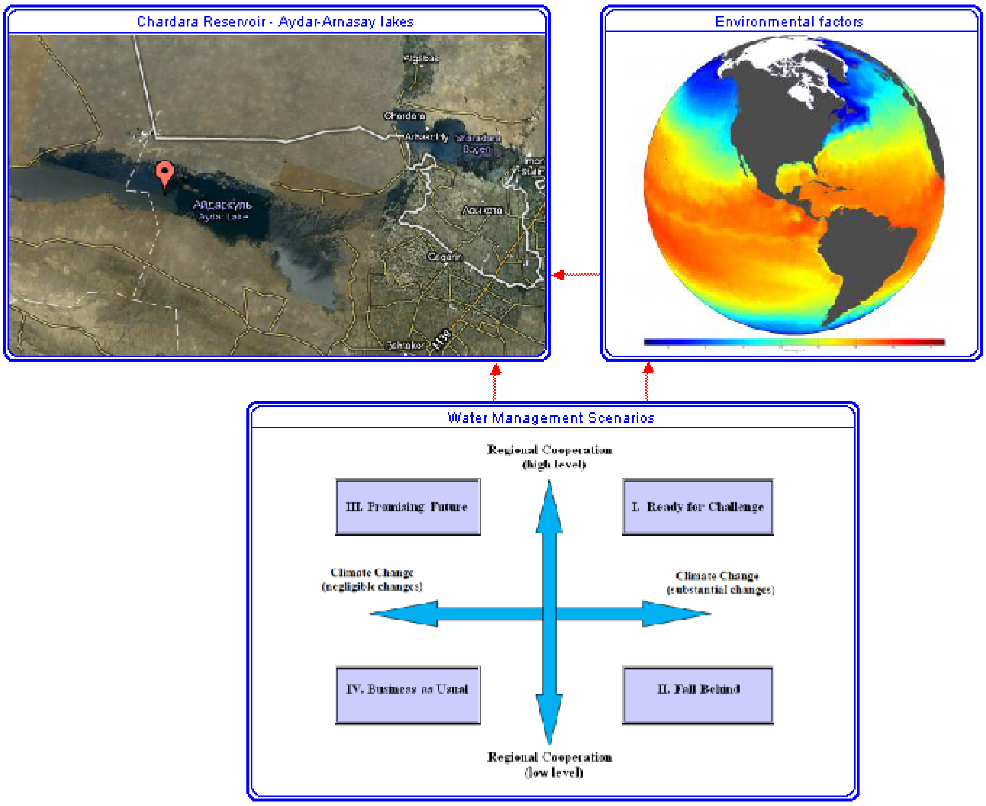


Figure 24. The model screenshot demonstrating the basic block of the model

The present model contains two main modes:

- Mode I "Model optimization"; this mode is designed to find out how much water discharge is needed for the maintenance of the Aydar-Arnasay lakes taking into account future change of the regional climate; the results obtained will lay a groundwork for the elaboration of the quantitative characteristics of the water management scenarios which will be put into the model;
- Mode II "Scenario analysis"; this mode is designed to test the elaborated water management scenarios in order to find the most probable one for the future development of the AALS.

The present model is formulated through quantitative assessment of the inflows, i.e. water discharges from the Chardara reservoir, water discharges for the drainage network and inflow from rainfall; outflows, i.e. evaporation and percolation, and storage changes which are represented by AALS volume fluctuations.

#### 6.2.1.1 *Geographic and temporal scale*

To begin with, let us start with a description of the geographic and temporal scale of the Aydar-Arnasay lakes model. The present model is one-dimensional, i.e. it includes only one space dimension. The model considers the Chardara reservoir situated in the middle stream of the Syrdarya River and the Aydar-Arnasay lakes system fed by the Chardara water (Figure 25).

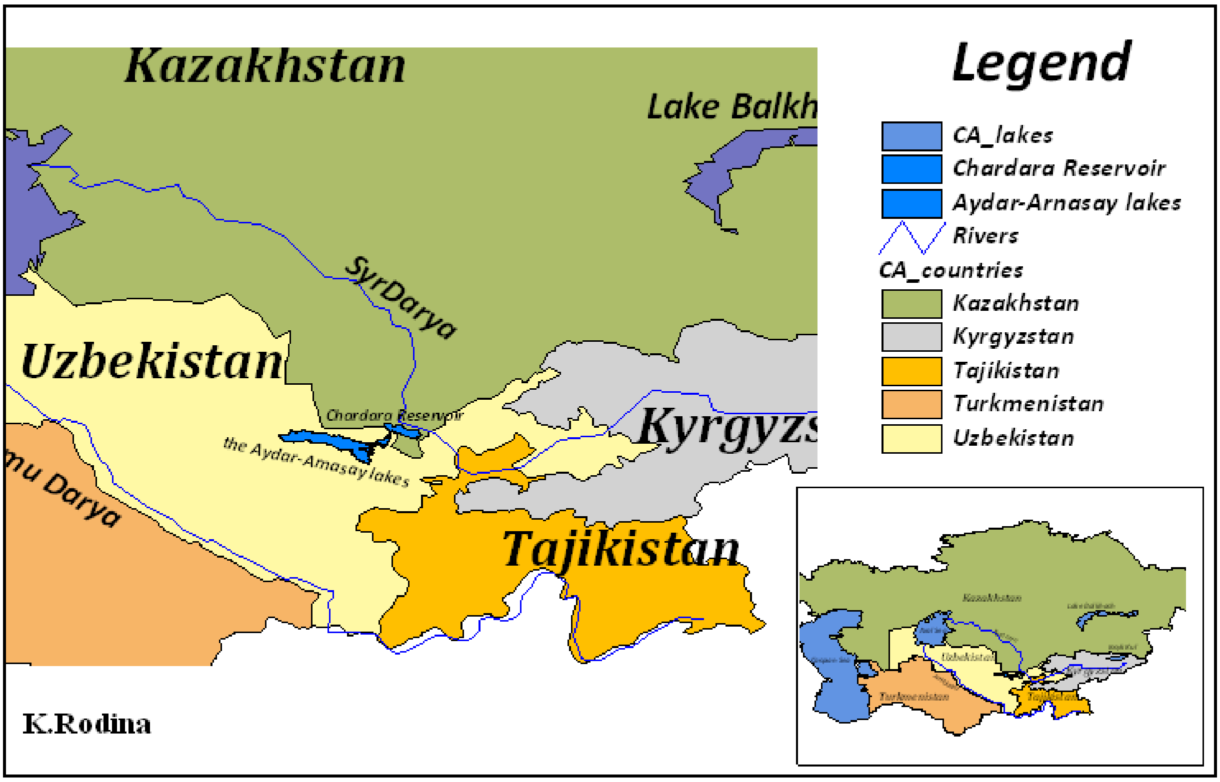


Figure 25. Geographical location of the simulated area[20]

The quantitative value of the model's parameters is basically determined by availability of reliable data. The most precise data for the model's parameters have been found for 2000-2008. These data have been obtained from the current field research, scientific calculations, experts' estimations and national reports. Therefore, all quantitative data which we will put in the model will be average mean calculated for 2000-2008.

Simulation of the developed water management scenarios using the model will be conducted for the period 2010-2040. Consequently, the future development of the Aydar-Arnasay lakes will be analyzed for this period of time.



[20] The present map has been made by the author using the Arcview program

#### 6.2.1.2 Basic assumptions

The Chardara- AALS model is based upon the following basic assumptions:

- The model assumes that the most important input parameters for the Aydar-Arnasay lakes system are water discharges from the Chardara reservoir, inflow from drainage network, and inflow from the rainfall;
- Water losses from the Aydar-Arnasay lakes basically occur only through the outflow from evaporation and percolation;
- The model takes into consideration changes on average annual temperature based on historical records. It has been concluded that average annual temperature made up 13-16 C degrees during 1970-2010. Random coefficient composes about 0-0,6 C degrees;
- At present, the annual average temperature is 14,8 ºC and evaporation is 2,7 $km^3$ (EDB 2009);
- The model supposes that the amount of precipitation in dry periods is 100-200mm, in wet periods - 300-400 mm; the proportion between dry and wet years is 7:3 (Mamatov and Kurnanbaev 2006).

These assumptions are valid and justified by the analysis of the Aydar-Arnasay lakes system carried out by the national experts and research results published in scientific papers.

The list of assumptions provided above is not exhaustive. More assumptions used for the development of a particular model block are considered in corresponding sections below.

#### 6.2.1.3 Input parameters

The present model contains two types of input parameters:

- Environmental factors such as annual average temperature, evaporation, precipitation and percolation;
- Control parameters such as water discharges to the AALS, downstream water releases, and cooperation ratio which can be regulated depending of the scenario selected.

#### 6.2.1.4 Main blocks

The Chardara – Aydar-Arnasay model has three main blocks:

- The Chardara – Aydar-Arnasay lakes system;
- Environmental factors;

- Scenario analysis, including Chardara downstream discharges.

The description and illustration of each block is presented below.

**The Chardara – Aydar-Arnasay lakes system**

Figure 26 demonstrates the first block of the model, called the Chardara – Aydar-Arnasay lakes system. This block represents the main input and output parameters of the Aydar-Arnasay system and their correlation.

Concerning the main input parameters, the present model considers the following:

- *water discharges from the Chardara reservoir*; the average inflow to AALS during 1993-2008 made up 2,56 $km^3$ or 67% of the total inflow of AALS; considering inflow during the cultivation period (April to September) it can be outlined that the inflow occurred only during water abundant years, i.e. 1993-1994, 1998 and 2002-2005; in the period of 2007-2009 water discharges were 2,20 $km^3$ on average;
- *inflow from drainage network;* the drainage network gathers collector-drainage water from the irrigated areas of Golodnaya Steppe; in the period of 1993-2008 inflow from drainage network ranged from 0,63 to 1,4 $km^3$ year. On average, the collector-drainage inflow made up 0,88 $km^3$ or 21% from the total inflow of AALS and therefore, this is a indication of an important role of collector-drainage water in the AALS water balance; it was calculated that during 1993-2006 about 12,09 $km^3$ of collector-drainage water from the Golodnaya Steppe was discharged to the AALS;
- *inflow from the rainfall;* their contribution to the AALS is about 0,2-0,7 $km^3$/ year; in average, the annual inflow is about 0,47 $km^3$/ year of 12% of he total inflow of the AALS (Wahyuni, Oishi et al. 2009).

The Aydar-Arnasay lakes lose its water mainly due to:

a) *outflow from evaporation*; evaporation plays major losses in the AALS as typical losses in arid regions; the annual evaporation rate is 2,7-2,9 $km^3$; the highest portion of the evaporation losses is estimated in May to September, i.e. 84% of the annual rate (Wahyuni, Oishi et al. 2009);
b) *percolation*[21]*;* the annual outflow is about 0,5 $km^3$ (Kurbanov and Primov 2006).

[21] Percolation - a hydrologic process where water moves downward from surface water to groundwater (Allison, G., G. Gee, et al. 1994)

Inflow from the Syrdarya River, being the main feed source of the Chardara reservoir is calculated as average inflow (5 $km^3$) + annual fluctuations. Annual fluctuations range from -1 to 1(Wahyuni, Oishi et al. 2009).

In order to simulate the Chardara – Aydar-Arnasay system in a more realistic way, downstream discharges to South Kazakhstan were taken into account. Besides, this block embraces the downstream discharge strategy which is used in the second mode, i.e. analysis of the water management.

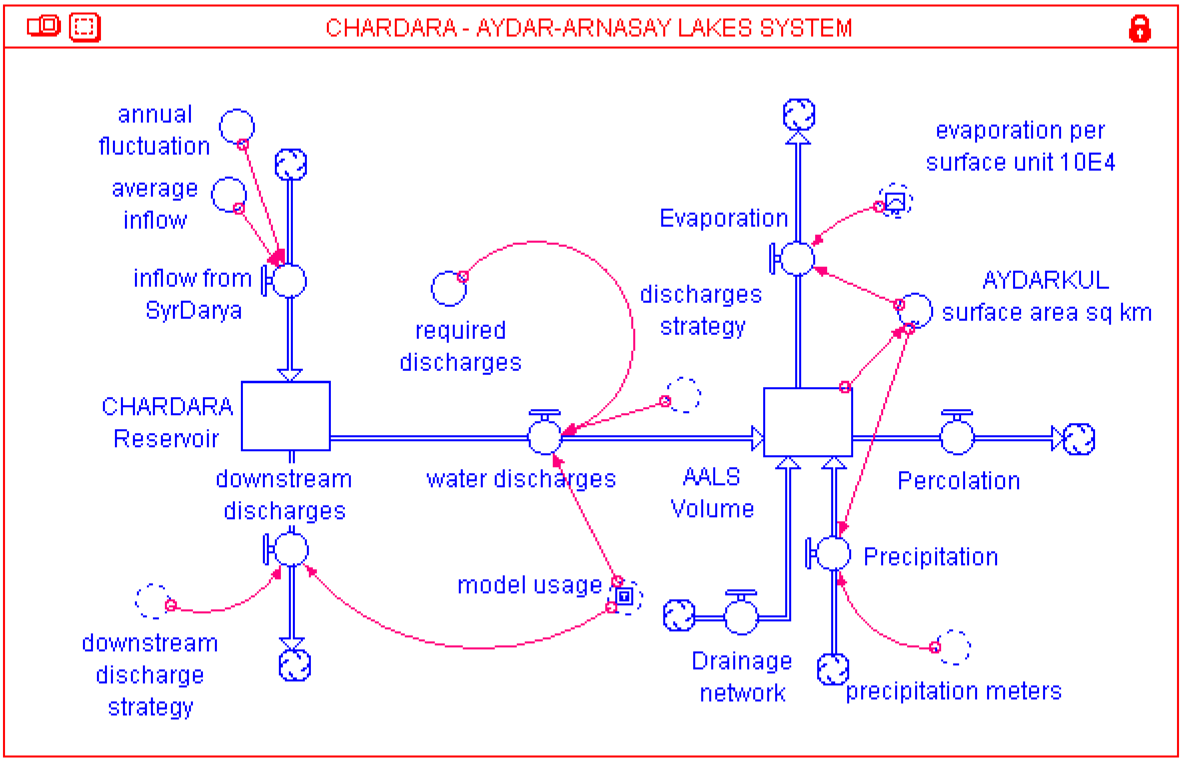


Figure 26. The model block “Chardara – Aydar-Arnasay lakes system”

**Environmental factors**

The second block of the model is focused on consideration of the important environmental parameters of the Aydar-Arnasay lakes, i.e. temperature, evaporation and precipitation. Figure 27 shows the model block simulating the respective environmental parameters.

It should be mentioned that this block is used for two regimes, model optimization and scenario analysis. In case of Mode I, *model optimization*, this block is used for temperature simulation in order to find out how much discharged water will be needed in future for the

AALS maintenance in the context of climate change. Temperature simulation incorporates two parameters, data about historical temperature and annual increase of temperature.

Also this block takes into consideration drought frequency which means the number of dry years a decade. By default it is assumed that nowadays the ratio between dry and wet years is 7 to 3. The model also assumes that due to future climatic changes this ratio will change. In case of Mode II, *scenario analysis*, this block is responsible for temperature simulation according to the climate change conditions considered in the water management scenarios.

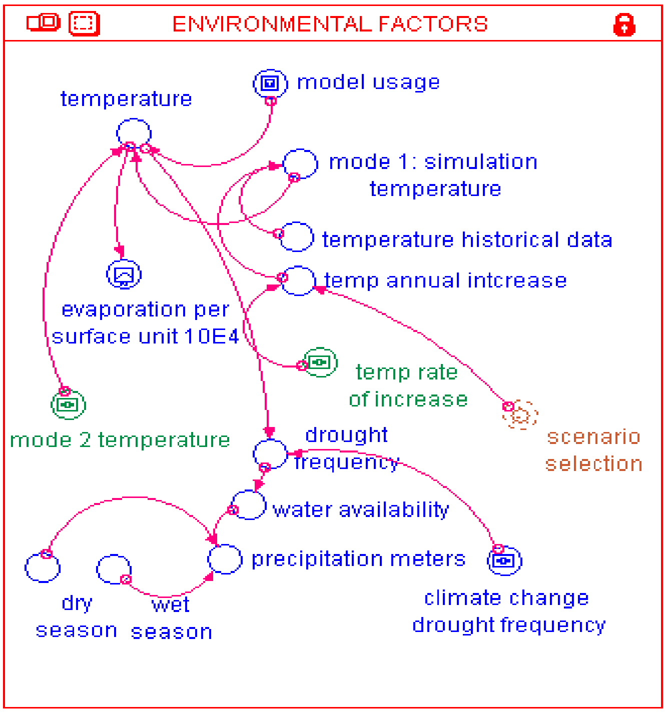


Figure 27. The model block "Environmental factors"

### Scenario analysis

The third block of the model consists of two subblocks, the Chardara downstream discharges and analysis of the scenario regarding water discharge strategy.

Figure 28 shows simulation of the water discharges according to the water management scenario selection. The left subblock demonstrated in Figure 28 mainly focused on downstream discharge strategy. As it was explained in the section about description of the AALS water management scenarios, downstream discharges play an important role in two elaborated water management scenarios. Downstream discharge strategy contains two management options:

- in case of high regional cooperation:

a) full cooperation between republics; it means that the Aydar-Arnasay lakes system takes the needed amount of the water discharges for the Chardara reservoir; the remaining amount of the Chardara water is released downstream ( sub-scenario Ia);

b) consulting interests; in this case water discharges from the Chardara are shared between the Aydar-Arnasay lakes and downstream areas of South Kazakhstan (sub-scenario Ib);

- in case of low level of regional cooperation all water from the Chardara reservoir is released to downstream areas; the AALS has no water discharges at all.

The right subblock shown in Figure 28 represents simulation of the four water management scenarios considered. Simulation of Scenario 1“Ready for Challenge” is set by default.

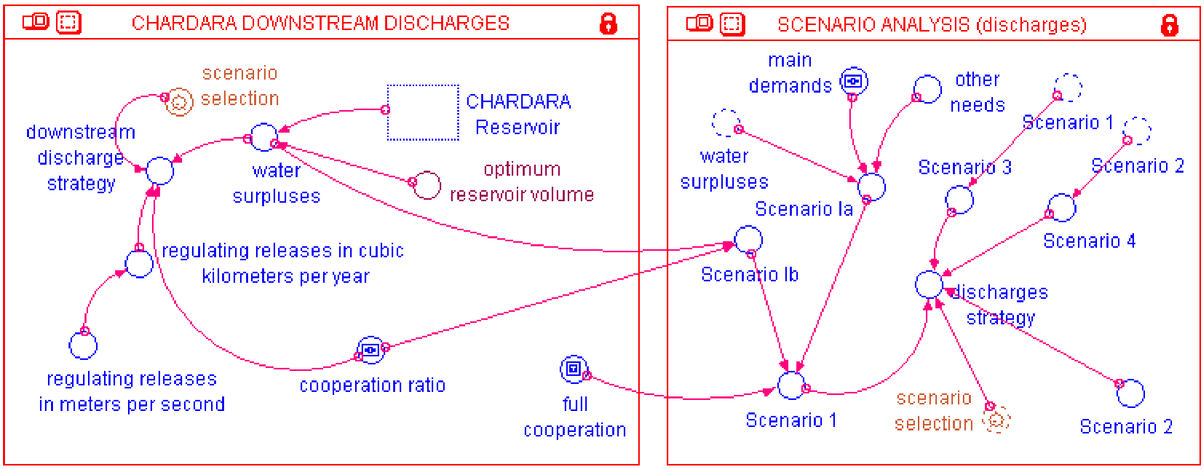


Figure 28. The model block “Scenario analysis”

### *6.2.1.5 Chardara - AALS model interface*

The Chardara – Aydar-Arnasay lakes model interface consists of:

- Main menu including the following control buttons: the AALS background, main goal and objectives of modeling, model description, scenario description, experiment and results interpretation and some illustrations (Figure 29);
- Model structure;
- Model modes including control panels with management options (Figure 30);
- Output tools (graphs, tables, etc.).

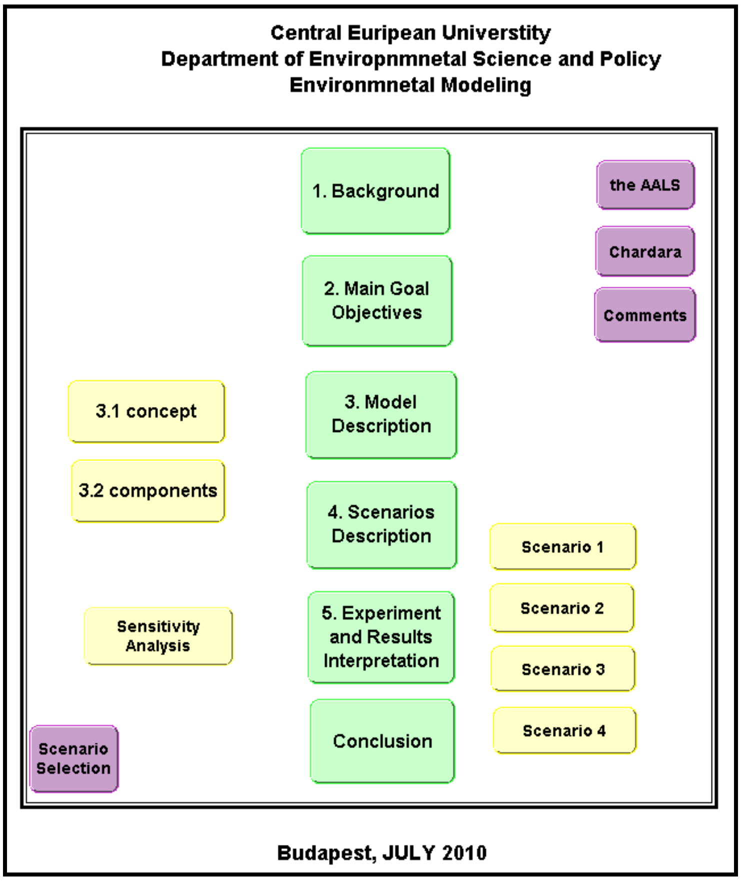


Figure 29. Fragment of the model interface presenting main menu

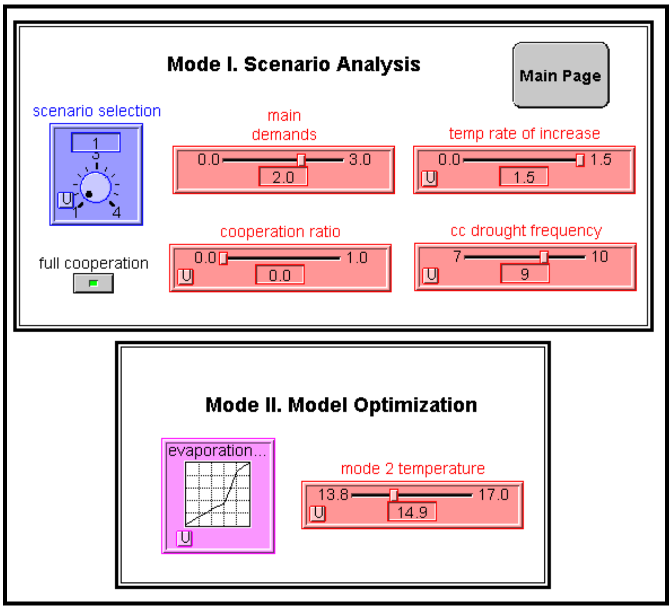


Figure 30. Fragment of the model interface presenting model modes including control parameters with management options

### 6.3 Chardara – AALS model simulation: experiments and results interpretation

The present section consists of three main parts:

- Model simulation: Mode I “Model optimization”;
- Description of the quantitative assumptions needed for the development of the water management scenarios; elaboration of the quantitative characteristics of the water management scenarios based on the model simulation in the Mode I;
- Model simulation: Mode II “Scenario analysis”.

#### 6.3.1 Model simulation: Mode I “Model optimization”

As discussed above[22], the main purpose of Mode I “Model optimization” is to examine how much water discharges will be needed for maintaining the AALS volume taking into account climate change in future. For this purpose, a set of experiments was developed and carried out.

According to IPCC estimates (IPCC 2001), annual average temperature will make up around 16,8 ºC during 2010-2040. The model interface with control parameter, called *Mode 2-temperature*, provides an opportunity to test our task taking into account different values of annual average temperature in future.

For the present experiment, it has been decided to use the following temperature values: a) 14,8ºC, b) 15,8ºC, and c) 16,8ºC. In order to determine how much water is required for the AALS maintaining under different temperature conditions, sensitivity analysis has been applied. Basically, sensitivity analysis is used to identify how “sensitive” a model is to changes in the value of the parameters. In our case, we executed the model ten times changing only the value of water discharges and attempted to analyze how much discharges is needed using the three temperature conditions listed above.

Figure 31, Figure 32, and Figure 33 demonstrate the results of the sensitivity analysis used for evaluation of the water discharges needed for the AALS maintaining over the next 30 years in the context of various values of annual average temperature.

[22] See in section 6.2.1

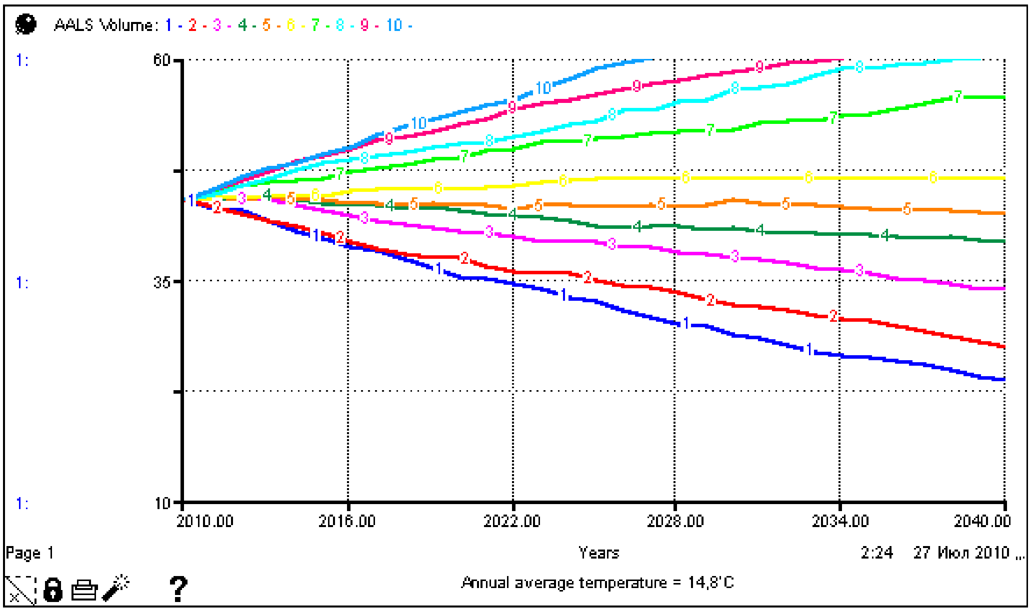


Figure 31. a) Amount of water discharges needed for the AALS maintaining at the temperature of 14,8ºC

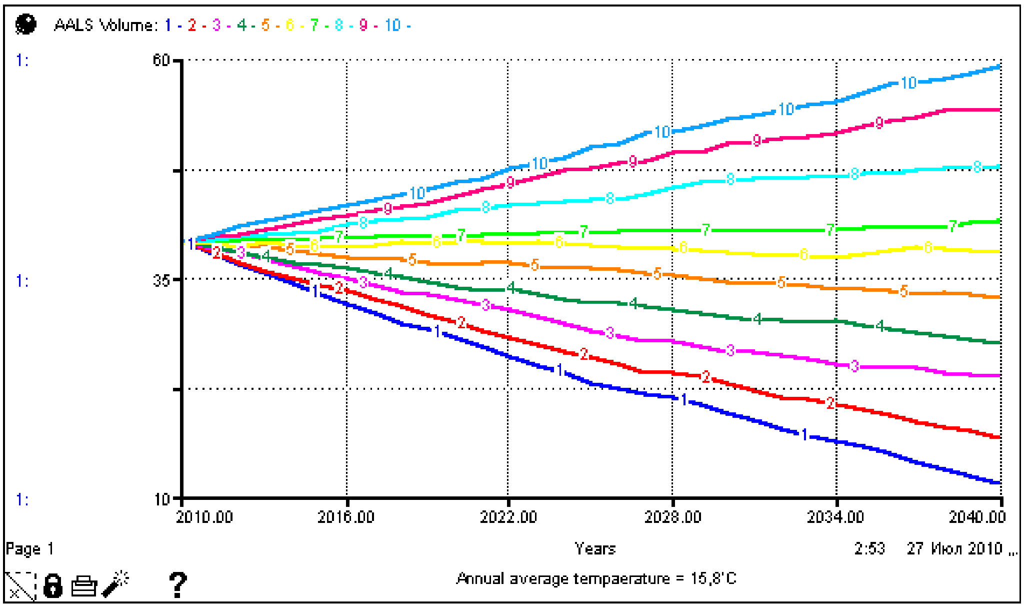


Figure 32. b) Amount of water discharges needed for the AALS maintaining at the temperature of 15,8ºC

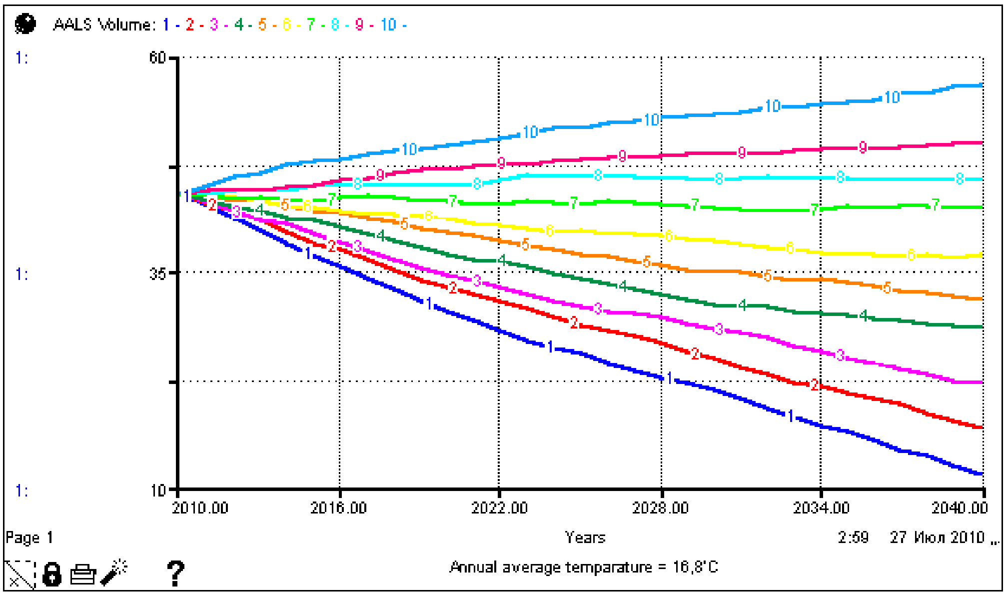


Figure 33. c) Amount of water discharges needed for the AALS maintaining at the temperature of 16,8ºC

Analyzing the graphs provided above, the following conclusions have been obtained:

- In order to maintain the Aydar-Arnasay lakes volume at the annual average temperature of 14,8ºC over the next 30 years, there is a need to discharge the amount of water corresponding to the value of yellow line 6 demonstrated in Figure 31. This value amounts to 2,11 km$^3$;
- In order to maintain the Aydar-Arnasay lakes volume at the annual average temperature of 15,8ºC over the next 30 years, there is a need to discharge the amount of water corresponding to the value of light-green line 7 demonstrated in Figure 32. This value amounts to 2,33 km$^3$;
- In order to maintain the Aydar-Arnasay lakes volume at the annual average temperature of 16,8ºC over the next 30 years, there is a need to discharge the amount of water corresponding to the value of light-blue line 8 demonstrated on Figure 32. This value amounts to 2,56 km$^3$;

To sum up, the results received will be used for the development of the quantitative description of the water management scenarios provided below and subsequently to put into the model.

### 6.3.2 Quantitative assumptions

In the previous section we considered some basic assumptions for the model. Based on the results of the model simulation in the Mode I we deem it wise to add a few important quantitative assumptions:

- In case of a substantial regional climate change, annual average temperature will be about 16,8 ºC during 2010-2040;
- In case of negligible climatic changes, annual average temperature will not change; the model assumes that it will be around 14,8 ºC during 2010-2040;
- A high level of cooperation in the Scenario I "Ready for challenge" assumes two alternative management strategies in terms of water discharges to the Aydar-Arnasay lakes:

a) full cooperation is estimated as 2,56 $km^3$ of water discharges which will be given to Uzbekistan for the AALS maintenance in case of substantial climatic changes;

b) consulting interests means that 2,56 $km^3$ of water discharges will be shared between Uzbekistan and Kazakhstan. For this, the model suggests introducing cooperation ratio and examining what will happen with the Aydar-Arnasay lakes in the context of prevailing water discharges either for Uzbekistan or Kazakhstan and if water discharges will be divided equally;

- A high level of cooperation in the Scenario III "Promising Future" assumes that 2,11 $km^3$ water discharges will be given to the AALS;
- A low level of cooperation implies the absence of water discharges to the Aydar-Arnasay lakes and their release to the South Kazakhstan downstream areas;
- In case of substantial climate changes, drought frequency, i.e. ratio between dry and wet years will increase; the model allows setting of the variable ratio.

Based on these assumptions, a quantitative description of the water management scenarios has been elaborated (Figure 34).

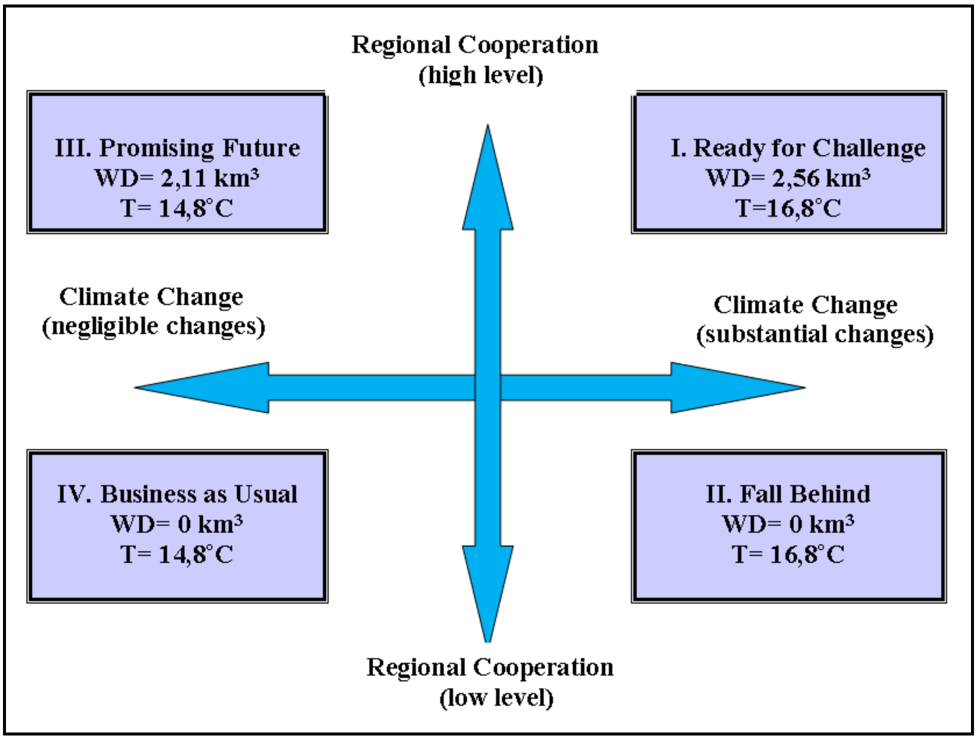


Figure 34. Quantitative description of the water management scenarios
(Notes: WD – water discharges, $km^3$; T – annual average temperature, ºC)

### 6.3.3 Model simulation: Mode II "Scenario analysis"

A series of experiments was developed and conducted in order to test alternative water management scenarios of the AALS future development. In total, four water management scenarios described in the previous chapters were tested using the Chardara – Aydar-Arnasay model. Model interface with numerous control parameters such as rate of temperature increase, drought frequency, and cooperation ration allowed testing 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. Results of the simulation for each water management scenario are presented below.

#### *6.3.3.1 Scenario I "Ready for challenge"*

In the simulation process, two alternative sub-scenarios in terms of regional cooperation have been identified. The sub-scenario Ia implies full cooperation between republics[23]. Figure 35 demonstrates the results of the model simulation for the first sub-scenario.

[23] See scenario analysis in section 6.2.1.4

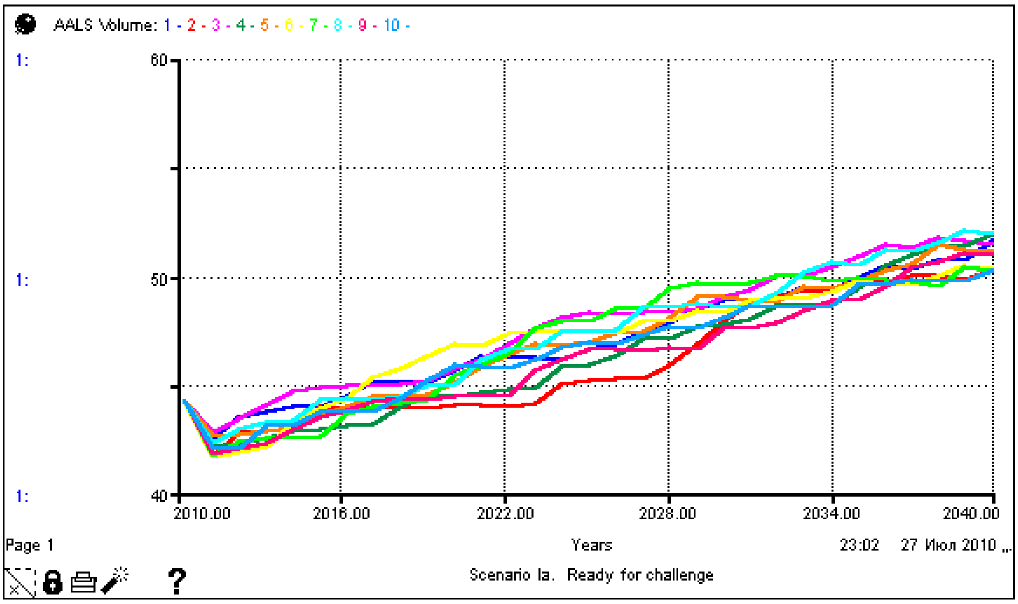


Figure 35. The AALS volume change in sub-scenario Ia (Scenario I "Ready for Challenge")

As it follows from the graph, the AALS volume will gradually increase within the next 30 years. According to the model simulation, the volume will change in the following ranges:

- from 44,2 to 48,3 $km^3$ in 2020;
- from 46,7 to 50,2 $km^3$ in 2030;
- from 48,7 to 52,7 $km^3$ in 2040.

The total AALS volume increase will amount to about 4-6 m over the next thirty years compared to the current volume.

The sub-scenario Ib[24] implies that water discharges will be shared between republics in accordance with republics' needs. Figure 36 shows the results of the model simulation for the sub-scenario Ib.



[24] See the description of the Scenario Ib in section 6.4.2.1

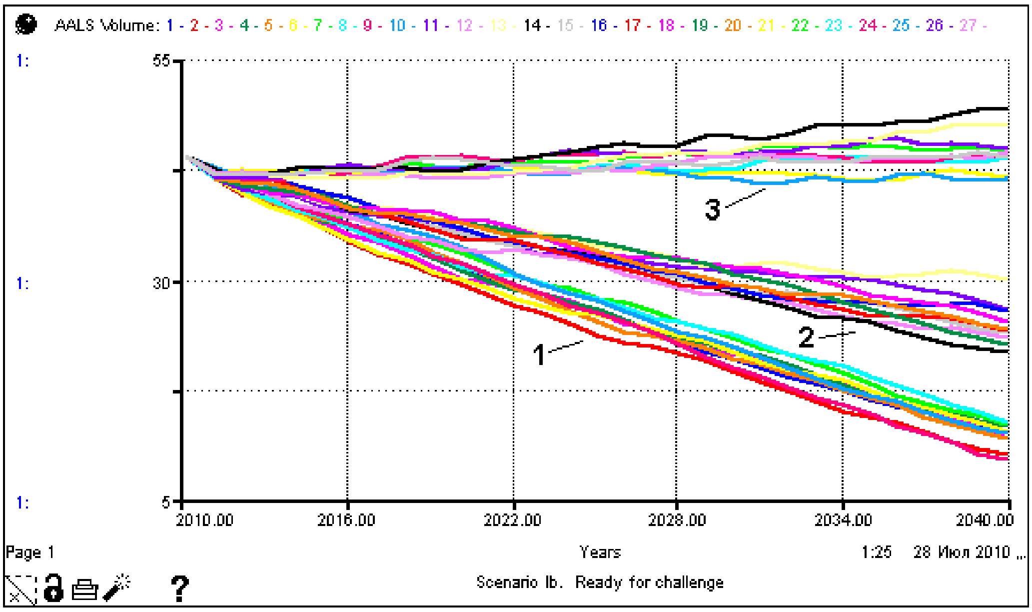


Figure 36. The AALS volume change in sub-scenario Ib (Scenario I “Ready for Challenge”)

As can be seen from the graph, there are three main trends of the AALS volume change.

- Trend 1 demonstrates the change of the AALS volume in future on the assumption that only 20% of water will be discharged to the Aydar-Arnasay lakes and the remaining 80% to the downstream of the Syrdarya river. According to the model simulation, in case of trend 1 the AALS volume will decrease during next thirty years. In particular, the volume will range from 29,0 to 32,6 km$^3$ in 2020, 18,9-22,4 km$^3$ in 2030, and 9,3-14,3 km$^3$ in 2040. The total volume will decrease by 27-30 km$^3$ compared to the current volume;
- Trend 2 demonstrates the change of the AALS volume in future on the assumption that only 30% of water will be discharged to the Aydar-Arnasay lakes and the remaining 70% to the downstream of the Syrdarya river. According to the model simulation, in case of trend 2 the AALS volume will also decrease during next thirty years. However, the decrease will be slower in comparison with the trend 1. Specifically, the volume will range from 34,1 to 36,4 km$^3$ in 2020, 27,5-30,5 km$^3$ in 2030, and 23,2-27,06 km$^3$ in 2040. The total volume will decrease by 21-25 km$^3$ regarding the current volume;
- Trend 3 demonstrates the change of the AALS volume in future on the assumption that water discharges will be divided between the Aydar-Arnasay lakes the downstream areas of the Syrdarya river equally. According to the model simulation,

the AALS volume will remain at the same level during 2010-2040 compared to the present volume. The total volume will range from 42,01to 45,67 km$^3$.

#### *6.3.3.2 Scenario II "Fall Behind"*

The results of the model simulation for the following scenario are presented in Figure 37.

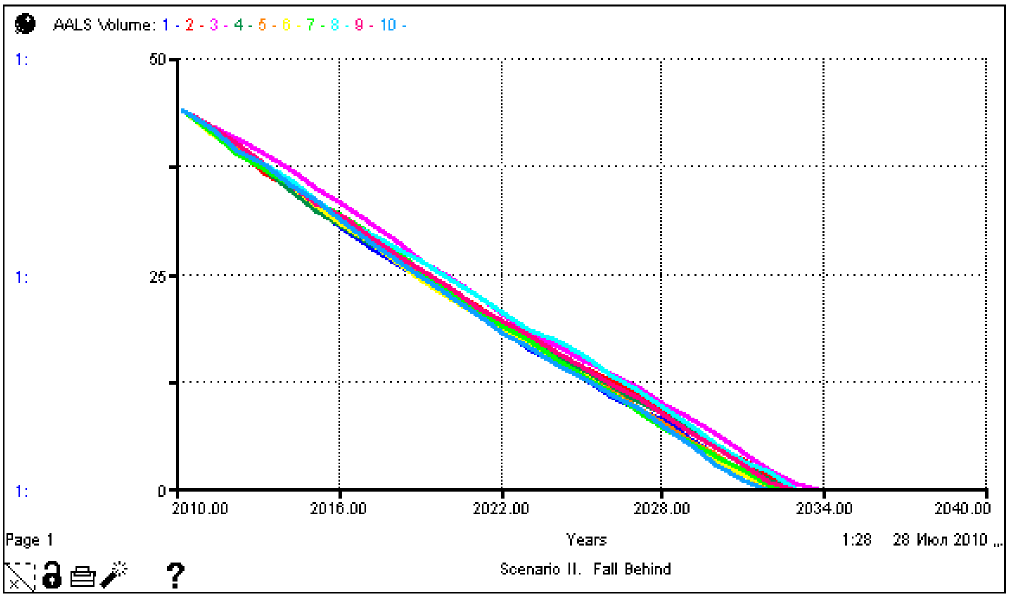


Figure 37. The AALS volume change in Scenario II "Fall Behind"

From the graph it can be observed that model simulation for Scenario II indicates the sharp shrinking of the Aydar-Arnasay lakes in future which can be explained by absence of the water discharges to the AALS and severe climatic changes. In particular, 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 2032-2034 the Aydar-Arnasay system will dry out entirely.

In the course of the model simulation it has been found that drought frequency will not influence significantly the volume change. The volume will reduce equally in case of drought frequency amounting to eight dry years a decade or nine dry years a decade.

#### *6.3.3.3 Scenario III "Promising Future"*

Figure 38 illustrates the results obtained from the model simulation for Scenario III "Promising Future".

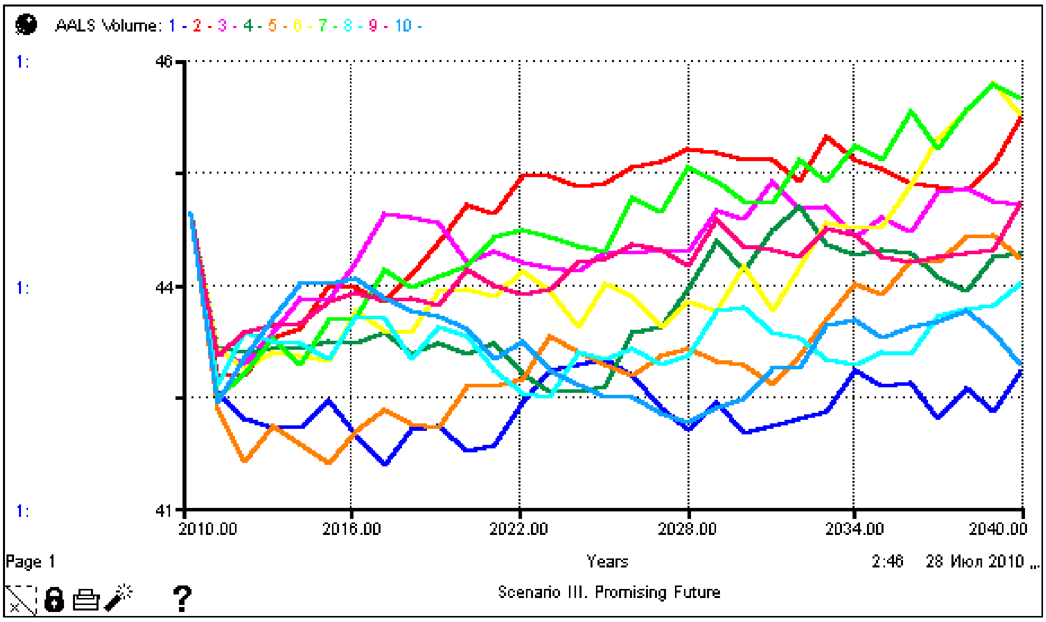


Figure 38. The AALS volume change in Scenario III “Promising Future”

The experiments with Scenario III have identified a stable AALS volume over the next thirty years. This result is well justified by a high level of regional cooperation between countries and minor climatic changes in future.

It should be noted that the model is sensitive to fluctuations of the stochastic environmental parameters such as annual average temperature and precipitation. Therefore, a wide range of the volume values can be observed in the graph.

As it can be seen from the graph, 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, the AALS volume will be around 43,4 – 44,5 $km^3$ in 2010-2040 that corresponds to the current value.

In general, the results obtained from the model simulation show that the Aydar-Arnasay lakes will get the necessary amount of the water discharges for maintenance. As it was found, the water discharges needed for the AALS maintenance at a temperature of 14,8ºC are supposed to total 2,11 $km^3$.



#### *6.3.3.4 Scenario IV “Business as Usual”*

Figure 39 illustrates the results obtained form the model simulation for Scenario IV “Business as Usual”.

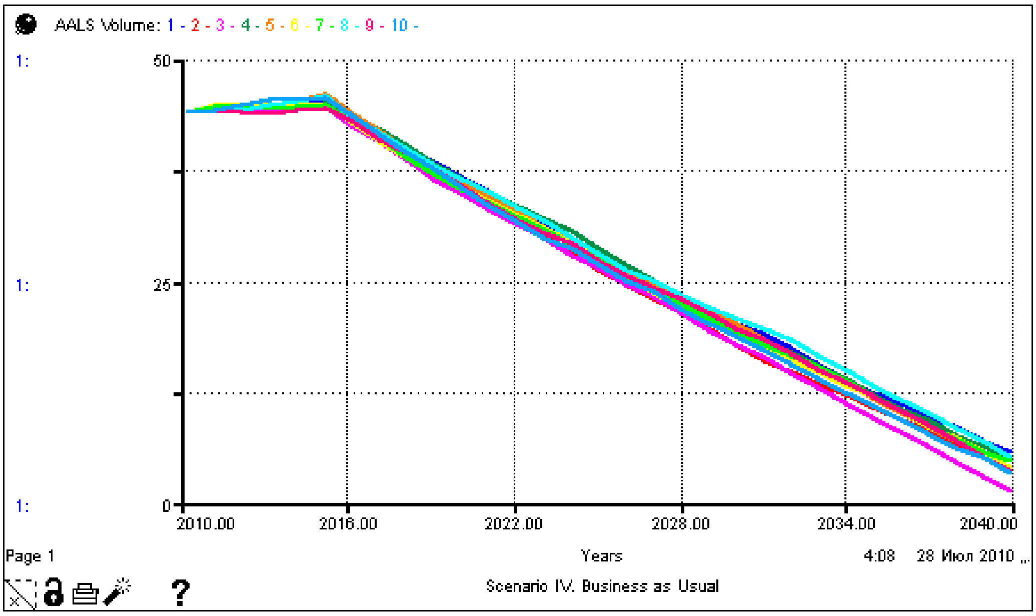


Figure 39. The AALS volume change in Scenario IV "Business as Usual"

Analyzing the graph, it can be clearly observed that two stages of the AALS future development in the context of volume are possible in future.

The first stage implies that the AALS volume will remain at the same level during 2010-2015. According to the results achieved the volume will range from 43,3 to 44,7 km$^3$ in 2010-2015 and the system will be characterized by abalanced development.

According to the second stage, starting from 2015, the AALS volume will start to decrease gradually. 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 2039-2040, the volume will be about 1,3-3,4 km$^3$. After 2040 the Aydar-Arnasay lakes will ultimately dry out.

The main reasons of these trends in Scenario IV "Business as Usual" will be explained in the discussion chapter presented below.

## 7. DISCUSSION

In order to achieve the established goal of the present thesis the following steps have been undertaken:

- The water management scenarios demonstrating the alternative of the Aydar-Arnasay lakes future development have been elaborated;
- The Chardara – Aydar-Arnasay model using STELLA software has been created;
- The Chardara – Aydar-Arnasay model has been simulated for the respective scenarios;
- The results obtained from the model simulation have been obtained.

The following chapter is aimed to analyze the results and discuss the main implications from the model simulation for each water management scenario. The discussion will be based on the analysis of the various aspects of the AALS future development. Discussion is built on the vision and reality of each water management scenario.

**Scenario I "Ready for challenge"**

As it was found above, the present scenario contains the two alternative management strategies in terms of the water discharges to the Aydar-Arnasay lakes system (AALS). Let us start the discussion about the AALS future development according to the sub-scenario Ia assuming full cooperation between republics[25].

***Scenario Ia.***

***Vision.*** A high level of cooperation between republics, i.e. between Uzbekistan, Kazakhstan and Kyrgyzstan will promote the balanced development of the Aydar-Arnasay lakes followed by the gradual increase of the AALS volume in 2010-2040. Furthermore, Kazakhstan will completely consider Uzbek' interests in terms of providing the necessary amount of Chardara water[26] for maintaining the lakes. For its own needs, mainly for irrigation purposes, Kazakhstan will use the water surpluses from the Chardara reservoir.

Kyrgyzstan, in turn, will take into consideration the downstream interests by regulating the Toktogul Reservoir operation. Close regional cooperation between Kyrgyzstan and Kazakhstan will probably give rise to renewal of the barter relationships with regard to gas provision of Kyrgyzstan for energy purposes. Consequently, Kyrgyzstan will diminish using

[25] See scenario analysis model block in section 6.2.1.4
[26] See results in section 6.3.1

the Toktogul Reservoir in the power-focused regime that will bring about the decrease of the water released during the winter time. Besides, Uzbekistan will stop suffering from unexpected and severe flooding during the winter time. Thus, it will make maintaining the AALS, including fisheries development, recreational activity and biodiversity conservation, more coordinated and efficient.

It should be pointed out that assumed severe climatic changes in the scenario concerned will have no negative consequences for the environmental characteristics of the Aydar-Arnasay lakes. Probable increase of the annual average temperature over the next thirty years will have an adverse effect neither on change of the AALS water level nor on volume. On the contrary, a high level of the regional cooperation, which is the driving force in this scenario, will compensate the substantial climatic changes and result in the increase of the AALS volume[27] .

However, in our opinion, it is quite unclear how the growth of the AALS volume will impact on fisheries development, maintenance of biodiversity, in particular, wetlands designated as a Ramsar site and endangered bird species living there and recreational activity. According to the results achieved from the model simulation, the volume will increase by 4-6 m during 2010-2040. It is quite possible that the volume's increase will cause a negative development of the future situation for the aspects mentioned above.

The first probable downside of this is that fisheries situated along the lakes could be flooded and fish production benefiting the republic's economy will be impeded. The second probable downside relates to the unknown future of the Aydar-Arnasay wetlands and their wildlife inhabitants. In order to evaluate how the AALS volume change will influence the wetland conditions, the detailed research using modern GIS techniques and modeling are highly recommended. Therefore, considering this scenario we may assume quite undetermined state of the AALS wetlands. The last uncertain issue focuses on the future development of recreation and tourism on these lakes in case of the volume increase. On the one hand, future change of the AALS hydrological conditions will be probably considered in the construction of recreational facilities. On the other hand, existing recreational facilities situated along the lakes' shoreline could be vulnerable to volume increase.



[27] See graph in section 6.3.3.1

***Reality.*** In our point of view, the present sub-scenario is slightly idealistic concerning a high level of regional cooperation. Analyzing the current relationships between Uzbekistan, Kazakhstan and Kyrgyzstan, we should highlight the following features:

- Current political situation in Kyrgyzstan and Uzbekistan is very tense and stressful; it is unclear how the Toktogul Reservoir will function in future;
- Prevailing self-interests and self-security is a high priority for the republics in question;
- Nonperformance of obligations in terms of agreed and coordinated water discharges to the Aydar-Arnasay lakes is a common occurrence for the parties concerned;

Summing it all up, realistically we think that this scenario has low-probability mainly because of the impossibility to have such high cooperation between countries. In order to turn this scenario into reality, plenty of time will be needed for the countries to come closer in their cooperation. Anticipated climatic changes are highly probable according to numerous scientific forecasts; however, the present scenario excludes their impact on the lakes system.

***Sub-scenario Ib.***

***Vision.*** This sub-scenario seems to be more plausible for the future development of the Aydar-Arnasay lakes in comparison the previous one.

The main reason is that the republics will take into account mutual interests in water discharges in future. As was concluded in the model simulation section, various situations[28] of the AALS volume fluctuations are possible within this scenario. There is a high probability that Uzbekistan and Kazakhstan will share water coming from the upstream Syrdarya equally. In this situation, Aydar-Arnasay lakes will be in the equilibrium condition, i.e. the AALS volume will remain at the same level as the model simulation showed[29]. Fish farming, tourism and recreation will gradually prosper and benefit the national economy. Conservation activity, in particular, protection of the AALS wetlands and their inhabitants will be effectively carried out.

On the other hand, there is a high likelihood that Kazakhstan will take more water for its own needs, i.e. assumed 70-80% of water discharges. Therefore, the remaining 20-30% will be given for the AALS maintenance. As the model simulation demonstrated it will not be enough for keeping the volume at the particular level.  In case of releasing such an amount of

[28] See in section 6.3.3.1

[29] See results of the model simulation in section 6.3.3.1

water discharges, the volume and water level will slowly decrease, causing disturbance to the whole lakes system.

***Reality***. As we assumed above, taking into consideration their own interests rather than interests of neighbors is much more probable for the republics concerned. Thus we consider this sub-scenario more plausible over the next thirty years than the sub-scenario Ia.

Besides, we think that forecasting change of the regional climate will influence the ecological conditions of the Aydar-Arnasay lakes to a larger extent since the regional cooperation will not be at such a high level as in the sub-scenario Ia and will not compensate the climatic changes. Increase of the annual average temperature will be responsible for the increased evaporation and growth of mineralization. Growth of mineralization in turn will have negative impact on fisheries development altering the rate of fish reproduction and total fish yield.

Summarizing our viewpoint, sub-scenario Ib focusing on consulting interests is more realistic in terms of the future the AALS. A level of regional cooperation will definitely indicate willingness of the republics for future challenges.

***Scenario II "Fall Behind"***

***Vision.*** The following scenario assumes a completely different future for the Aydar-Arnasay lakes. The countries will take into consideration only their own interests disregarding the neighbors' needs. There will be no regional cooperation at all. For instance, Kazakhstan will block the water access from the Chardara reservoir for the AALS by closing the dam located near the border with Uzbekistan. The water surpluses will be accumulated in the new launched Koksaray dam located in the downstream Syrdarya instead of the Aydar-Arnasay lakes (map).

Hence, the Aydar-Arnasay lakes will lose the sole feed source and start to dry out. As the results of the model simulation demonstrated[30], the AALS volume will be gradually decreasing and by 2032-2034 the whole system will disappear. Disappearance of such an important human-made lakes system will disrupt the other systems related with the lakes, i.e. fisheries will be completely ruined and Uzbekistan will lose a significant item of national



[30] See in section 6.3.3.2

income; wetlands situated around the AALS[31] will be entirely destroyed and their dwellers will have to find a new suitable habitat; recreational activity and tourism will cease to exist.

Along with that, the change of the regional climate will considerably impact on the AALS hydrological features, i.e. increase of the annual average temperature will trigger the increase of evaporation from the AALS water surface and growth of mineralization. Similar to sub-scenario Ib within Scenario "Ready for Challenge", future climatic changes will probably one of the determinant factors of the AALS disturbance.

***Reality.*** We deem this scenario one of the most plausible and realistic for the future development. The main reason of our assumptions is based on a high probability of low regional cooperation between countries nowadays. The main features of the contemporary relationships between republics were considered above.

We think that accumulation of the Chardara water in the Koksaray dam will be one of the top future priorities because it will make Kazakhstan more secure in terms of water resources for irrigation purposes. Besides, accumulation of the Chardara water will not result in flooding of the South Kazakhstan areas. In this case, the Aydar-Arnasay lakes will disappear and functioning of other related systems will be disrupted.

On the other hand, we assume that Kyrgyzstan will probably continue operating the Toktogul reservoir in the power-focused regime that will bring about a huge amount of water discharges during the winter time and flooding of the downstream countries. It will entirely concentrate on its own interests and neglect the interests of its neighbors.

The presumed change of the regional climate will not be the definite factor of the scenario development, but at the same time, its influence of the lakes system could not be excluded from this scenario.

***Scenario III "Promising Future"***

***Vision.*** Having analyzed the results[32] of the model simulation for the present scenario, we should highlight that the respective scenario draws the AALS future development from the positive perspective. According to this scenario, a level of the regional cooperation between countries is as high as in Scenario I "Ready for Challenge". Namely, the countries will be concerned in the mutual interests in terms of distribution of the water discharges.



[31] See map in section 5.2.2
[32] See results in section 6.3.3.3

As the model simulation demonstrated[33], around 2,11 $km^3$ water discharges will be needed for the AALS maintaining in future. Taking into account this fact, Kazakhstan will probably give this amount of Chardara water to the Uzbek lakes and will use only the remaining water surpluses for its own needs. Kyrgyzstan will probably renew the barter relationships with Kazakhstan and this will result in the consequences which are representative for sub-scenario Ia.

Generally speaking the future development of the Aydar-Arnasay lakes will corresponds to development in sub-scenario Ia based on the full cooperation between republics. A minor change of the regional climate is the only factor which distinguishes this scenario from the first one. Climate will have a certain influence on the evolvement of the lakes' hydrological processes. The graph indicating the results of the model simulation for this scenario accurately depicts that volume fluctuation in 2010-2040 will relate to stochastic environmental factors such as temperature and precipitation.

The AALS future existence will be characterized by balanced development, i.e. volume and water-level will remain at the same level in comparison with contemporary values.

Fisheries and recreational activity will probably gradually thrive, making financial contributions to the national economy. Conservation measures, especially, protection of the AALS wetlands and their inhabitants will be effectively accomplished.

***Reality.*** In our view this scenario is the most idealized for the future development of the Aydar-Arnasay lakes.

The main reason of our viewpoint is that Uzbekistan, Kazakhstan and Kyrgyzstan will hardly achieve such high level of cooperation due to the features of the current relationships described in the discussion for sub-scenario Ia. Undoubtedly, Kazakhstan and Kyrgyzstan will primarily meet their own water needs, i.e. a) Kyrgyzstan will use the Toktogul Reservoir in the power-focused regime and release a huge amount of water during the winter time; b) Kazakhstan will accumulate some water surpluses from the Chardara in the Koksaray dam.

Summing it all up, we suppose that this scenario is not very probable and is unrealistic for the Aydar-Arnasay future development. In order to bring into reality a promising future for the Aydar-Arnasay lakes much time will be needed.



[33] See results in section 6.3.3.3

*Scenario IV "Business as Usual"*

**Vision.** Future development of the Aydar-Arnasay lakes will have the well-defined current trends. According to the modeling results[34], two AALS development stages have been identified in 2010-2040.

The first stage will be characterized by stable volume and water-level of these lakes. We think it could be explained by the fact that Kazakhstan will still continue releasing water for the Chardara reservoir to the AALS, thereby keeping the balanced condition of the lakes. For its own needs, Kazakhstan will use only the Chardara water surpluses. It is probable that use of water surpluses will be needed for testing new operated Koksaray dam located in the downstream Syrdarya. With the present course of development, the AALS functioning will keep during 2010-2015.

The second stage will begin after 2015 when the general concerning the lakes development situation will probably completely change. The graph provided in the simulation section[35] shows that the gradual decline of the Aydar-Arnasay lakes volume will take place. We suppose that the main reason of a such course is based on the change of emphasis from the Kazakh part. Namely, starting from 2015, there is a high probability that Kazakhstan will start using the Koksaray dam in full operating mode. Consequently, it will use Chardara water needed for maintaining the Aydar-Arnasay lakes for its own needs, i.e. mainly for irrigation of the southern Kazakh areas. In this situation, the AALS volume will steadily decrease amounting to 1,3 to 3,4 $km^3$ in 2039-2040. After 2040, these lakes will disappear, disrupting of all surrounding natural as well as human-induced systems, such as fish farms, wetland ecosystems, and recreational facilities.

Continuing with cooperation between countries it should be pointed out that consulting only its own interests, Kyrgyzstan will carry on use of the Toktogul in the power-generated regime, releasing a huge amount of water downstream and flooding areas located there.

According to Scenario "Business as Usual", the future climatic changes will be negligible and will have no impact on the hydrological characteristics of the lakes. Therefore, we can conclude that climate changeforecast will have a minor effect in terms of change of AALS activity.



[34] See results in section 6.3.3.4
[35] See graph in section 6.3.3.4

**Reality.** Based on the detailed review and analysis of the contemporary AALS conditions[36], we consider this scenario is highly probable in future. There are two main reasons why we believe in that.

The first reason is related to the issue of water self-sufficiency from the Kazakh side. Meeting of their own needs will be top priority for Kazakhstan.

The second reason is that a low cooperation between Kazakhstan and Kyrgyzstan will not give rise to the renewal of the barter relationships. Consequently, the Toktogul operation in the power-focused regime will be kept.

The political tensions and disagreements between these three countries, which are currently specific features of the Central Asian region, will probably hinder interaction between republics in terms of implementation of the coordinated water policy, and especially, distribution of the water discharges even more.

Summarizing, we deem this scenario quite plausible due to the three reasons explained above. This scenario stands a big chance of being illustrative for the future Aydar-Arnasay lakes development.

The author has drawn the following conclusions:

- Scenario “Ready for challenge” has two alternative water management sub-scenarios that focus on:

  a) full cooperation strategy which is quite idealistic for the AALS future development;

  b) consulting interests which is more probable for the AALS future development;

- The “Fall behind” scenario is one of most plausible and realistic for the future development because of a high probability of low regional cooperation between countries in future;
- The “Promising Future” scenario is the most idealized for the AALS future development and could not be put into life because of the impossibility to achieve such high regional cooperation;
- The “Business as Usual” scenario has a high probability to be realistic in AALS future.



[36] See chapter 5

# 8. CONCLUSION

In the course of the present research the established objectives have been accomplished. The detailed review of the Aydar-Arnasay lakes system (AALS) has been conducted in the second chapter. Apart from that, modern methods such as application of scenario approach, GIS technologies, remote sensing, and modeling, assisting for environmental research have been also analyzed in the second chapter.

The main methods for data analysis applied by the author in the present research are scenario approach, fostering the finding of alternative AALS water management strategies; application of GIS technologies, contributing to the analysis of the AALS change dynamics in past; and environmental modeling assisting for simulation of the alternative ways of the AALS future development.

Based on the analysis of the archival materials and national scientific books and reports historical stages of the Aydar-Arnasay lakes formation have been identified by the author in the fourth chapter. Besides, a set of maps illustrating the lakes' evolution has been made by the author and presented in the same chapter. Practical exercise aimed to analyze the change dynamics of the AALS water-surface area in 1969-2009 has been accomplished by the author using GIS technologies.

Examination of the present state of the Aydar-Arnasay lakes, including analysis of the fisheries situated in these lakes, wetlands designated as a Ramsar site and recreational activity has been carried out and described in the fifth chapter.

The most important objectives established for the main goal achievement have been executed by the author in the sixth chapter. Namely, a set of various water management scenarios based on level of regional cooperation and level of climatic changes have been elaborated. They are "Ready for Challenge", "Fall Behind", "Promising Future", and "Business as Usual". Then, the Chardara – Aydar-Arnasay lakes model aimed to test these scenarios has been created using the STELLA software. Finally, the model created has been simulated for each water management scenario and results illustrating the change of the AALS volume in 2010-2040 have been obtained.

In the process of the interpreting results and their discussion the following conclusions have been found:

- Scenario I "Ready for challenge" has two alternative water management sub-scenarios, which are:

a) Sub-scenario Ia which is focused on the *full cooperation* between Uzbekistan, Kazakhstan, and Kyrgyzstan; it has been concluded that this sub-scenario is quite idealistic for the future development of the Aydar-Arnasay lakes; the main reason of that is impossibility to have such high cooperation between countries as it is assumed in the scenario; besides, consulting interests which is more probable for the AALS future development;

b) Sub-scenario Ib which is based on consulting interests; it has been found that this scenario is more probable for the AALS future development comparing with the previous one. Meeting the water needs of the neighbors will be taken into account and the AALS maintenance will be included into the national water policies of Uzbekistan's neighbors. Moreover, it is highly probably that climate changes will have some impact on the hydrological conditions of the lakes;

- Scenario II "Fall behind" is one of most plausible and realistic for the future development because of a high probability of low regional cooperation between countries in future and assumed change the regional climate which will lead to aggravation of the balanced development of the whole lakes system;
- Scenario III "Promising Future" is the most idealized for the AALS future development and could not be brought into real life because of the impossibility to achieve such high regional cooperation between countries.
- Scenario IV "Business as Usual" is the most realistic and feasible for the future development of these lakes; the prime features of this scenario are illustrative for the current state of the Aydar-Arnasay lakes condition; it is possible that these same AALS development trends will be observed over the next thirty years.

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