A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfillment of the Degree of Master of Science

Integrated Modeling in support of Transboundary Water Cooperation in Central Asia: Ili-Balkhash watershed

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Aziza BAUBEKOVA

July, 2014

Budapest

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ABSTRACT OF THESIS submitted by:

Aziza BAUBEKOVA
for the degree of Master of Science and entitled: Integrated Modeling in support of Transboundary Water Cooperation in Central Asia: Ili-Balkhash watershed.

Month and Year of submission: July, 2014.

There is a concern that the Lake Balkhash can repeat the fate of the Aral Sea. In order to verify this assertion an integrated model of the transboundary Ili – Balkhash watershed was done. Climate change and socio-economical changes were assessedfor the level of influence on the lake system. The analysis is based on the use of GIS techniques and remote sensing as well as literature review. Nine main scenarios were developed including climatic, economic and combined sets. An initial scenario showed that the Lake Balkhash is actually drying and current system is unstable. The best or 4.5 scenario that provided favorable conditions for the water regime has showed the only positive result and increase of water level. But this scenario is not realistic as finding of this study indicated the rapid economic growth in the near future due to population increase. Therefore combined p4.5 scenario was found more feasible. Under this scenario lake volume gradually fell but did not exceed the minimum level. The worst scenario (r8.5) showed the complete loss of the lake in fifteen years. Despite the fact that this last scenario is based on the maximum values and implies dramatic changes in the climate conditions and economic activities it is still possible to happen. Therefore countries were recommended not only to examine current watershed management strategy and come to consensus on the Ili river water use limits but also to reconsider energy strategy and consumer behavior of the local population.

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Keywords: Transboundary watershed, Hydrological modeling, Integrated modeling, GIS, Climate change, Land use change, River basin management

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Acknowledgements

I would like to express my sincere gratitude to my advisor Prof. Victor Lagutov for the continuous support of my master study and thesis writing, for his patience and enthusiasm. His guidance helped me in all the time of the research.

Besides my advisors, I would like to thank my colleagues at Nazarbayev University Research and Innovation System for the help in data collection and analysis.

Finally, I thank my family for supporting me throughout all my studies at University.

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LIST OF ACRONYMS AND ABBREVIATIONS

CAREC - the Central Asia Regional Economic Cooperation

CEU - Central European University

GIS - Geographic Information System

Kazhydromet - Hydrometeorological Agency of Kazakhstan

IWRM - Integrated Water Resources Management

MNDWI - Modified Normalized Difference Water Index

NDWI - Normalized Difference Water Index

NURIS - Nazarbayev University Research and Innovation System

RCP - the Representative Concentration Pathways

STELLA – System Thinking for Education and Research

Syslab - Environmental Systems Laboratory

UN Convention - UN Convention on the Non-Navigational Uses of International Watercourses

UNDP - United Nations Development Programme

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1 Introduction

1.1 Background information and problem statement

The Balkhash Lake is among the biggest lakes on earth, but due to unsustainable water use, the lake is facing the same fate as the Aral Sea (Carec 2007). The lake belongs to the Ili Balkhash Basin that is shared by two countries Kazakhstan and China. Most of the water (around 80%), that feed the lake, comes with the Ili River that is born on the Chinese side(Dostay *et al.* 2012).

Sustainable use of water resources is one of the most challenging parts in the development of the sustainable strategies for the region. The issue of transboundary watershed is even more difficult. In order to avoid conflict there is need for the mutual agreement between states.

Recently the Chinese Government started to increase the irrigated area and develop more projects that require more water (UNDP 2012). The decrease in the transborder flow of Ili River may cause threat for environment with the loss of the lake ecosystem and degradation of land. Established ecological situation in Ile-Balkhash basin is characterized as critical, with progressive ecosystem vulnerability and instability of the level of Lake Balkhash, caused by problems of water allocation, the degradation of mountain ecosystems (deforestation, irreversible melting of glaciers, etc.) and other threats. According to the UN Environmental Program, Balkhash Lake may lose up to 86 percent of its water reserves by 2045 (UNDP 2007).

The loss of the Lake will lead to the deterioration of the climate change consequences in the region. An increase of the average air temperature by 1.3°C during the century that country is already facing is two times higher than the global warming value

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(Ibatullin 2009). This results in massive desertification and soil degradation, which will negatively impact on economy and living conditions in the region.

There were studies conducted on Ili-Balkhash basin development with statistical modeling and scenarios development that included climate change and land use change pattern (Kenshimov 2011; Propastin 2013; Propastin 2008). This work is a first attempt to connect geographic information system (GIS) techniques and computational modeling in the integrated model of Ili-Balkhash basin. This approach was well studied and successfully implemented in the water management of the Aral Sea basin thatprovided a good foundation for interstate negotiation dialog among decision makers.(Cai *et al.* 2002; McKinney and Cai 2002).

1.2 Research aim and objectives

The aim of this project is to analyze the current and prospective water consumption patterns in the Ili Balkhash Basin and to assess the implications of potential climate change on the Lake Balkhash.

Through developing the integrated model and model-based analysis of regional development scenarios the following research question will be answered:*How volume of the Lake Balkhash will change under different scenarios on land use and climate change?*

The research question will be addressed with the subsequent objectives:

- To study the pattern of environmental change in the Ili – Balkhash watershed.
- To analyze the recent trends of socio-economic change within the Ili Basin.
- To develop an integrated model of Ili-Balkhash system.

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- To formulate climate change and management scenarios and assess them using the developed model.

1.3 Outline

The thesis contains seven chapters with multiple subheadings. An Introduction chapter presents to the reader the background of the studied issue and the aim of the project. To improve the understanding of the case it is followed by literature review. Where the study area is described as well as the past research in the filed. From the available analysis techniques discussed in the chapter the suitable one was selected and described in the Methods chapter. The fourth chapter answers the first research question and assesses environmental and socio-economic changes in the basin. Model chapter consists of two parts: development and simulations. The results of model simulation are compared with historical data in the Discussion chapter. Also in the chapter six the recommendations were provided followed by the summary of the limitations. The final chapter sum-ups the findings and shows an opportunities for future research.

2 Literature review

The literature review chapter includes four subchapters that describethe study area, the transboundary water cooperation, and main GIS and modeling techniques. The study area subchapter is divided in two parts describing the lake and the river.

2.1 The study area

Ili-Balkhash watershed is transboundary basin as three countries Kazakhstan, China and Kirgizstan share it. Basin cover area is 501 000 km2 (Nomura 1999). The

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watershed has highly developed hydrological system with approximately 52 000 rivers and seasonal water flows and 24 000 of natural lakes and build reservoirs (Amanbayev 2011). The biggest lake in the system is Lake Balkhash that is the subject of interest of this paper along with biggest river in the system – Ili River.

2.1.1 The Lake Balkhash

Lake Balkhash is on the fifth position by size among isolated water reservoirs in the world. Main physical parameters are summarized in the Table 1. The lake is located in the Balkhash-Alakol depression. The uniqueness of Balkhash Lake is that it is divided into two different parts: western part is filled with freshwater with mineralization up to 1 g L^-1 and eastern part is filled with subsaline and salty water with mineralization between 2.5 and 3 g L^-1 (Petr 1992). The major quantity of inflow water dries up, which makes the lake's basin drained. The main rivers that contribute water to the Balkhash Lake are the Ili River carrying 10-13 km3 per year that is 78.2% of surface inflow, the Karatal River - 2.1 km3 per year (15.1%), the Aksu River - 0.3 km3 per year (0.13%) and the Lepsy River - 0.8 km3 per year (5.4%) (Petr 1992; Propastin 2008).

Table 1 Main physical parameters of the Lake Balkhash

Parameter	Value, units
Volume	112 km^3
Catchment area	501 000 km^2
Surface area	18 480 km^2
Water level	341.5 – 342.5 m
Mean depth	9 m

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Length	605 km
Width	4-74 km

2.1.2 Ili River

Ili River is the third largest river in Central Asia. The river mainly fed by glaciers and snow. It originates in China (Xinjiang province) from the merger of two rivers Kungesa and Tekes. Two rivers collect water from glaciers and eternal snows of the Tien Shan and Jungar Alatau. Tekes River is the bigger one, as its catchment area is 29,600 km2.

The Ili River with length of 1439 km originates in China and only 815 km flows in Kazakhstan (Amanbayev 2011). The actual length of Ili River counting from the confluence of two rivers is 950 km. The catchment area is 140 000 km2 (Kenshimov 2011). Most of the basin located in mountainous area more than 1000 m above sea level.

The main share of the Ili river flow occurs mainly in spring and summer (March-October). Seasonal snow storage, rainwater and groundwater, as well as the eternal snows and glaciers feed the river. According to the Schults' classification Ili basin refers to the glacial-snow fed rivers (Kazhydromet 2005).

River forms a vast delta before it flows into the lake. Irrigated agriculture was practiced in the basin before the revolution therefore there is no available data to model natural water regime of watershed without influence of human. The suitable data for Ili discharge is from 1953 to 1969 with mean value of 11.8 km3 per year as the population density in both countries was lower and industry was not developed

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(1990). Therefore human influenced data can be assumed from 1970 to present with mean number of 10.4 km3/year (Dostay *et al*. 2012).

2.2 Legal framework of the problem

Despite the fact that 60 percent of global freshwater flow is shared there are no international legally binding treaties in force (Clue 2012). The 1997 UN Convention on the Non-Navigational Uses of International Watercourses (UN Convention) and the 2004 Berlin Rules on Water Resources provide basis for the governance of international watercourses. Conventions oblige states to follow important rules: "1) equitable and reasonable utilization; 2) prevention of significant harm; and 3) prior notification of planned measure (McCaffrey 2006). The difference between last two Conventions is that the Berlin Rules emphasize the "obligation" and rule of doing no harm (Clue 2012). The 1992 UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convection) is a global legal framework for transboundary water cooperation and works as a basis for adoption of multilateral agreements. The Water Convention was ratified in Kazakhstan in 2001. Most of the transboundary issues on water are regulated by bilateral or multilateral agreement that include only directly affected countries.

There is number of bilateral water treaties between China and Kazakhstan: agreements on management and protection of transboundary rivers (Ili/Kunes He basin) in 2001, Agreement on water quality protection of transboundary waters in 2011(Clue 2012; UNDP 2012; UNECE 2011). In the compliance with those agreements the Kazakh – Chinese joint commission on use and protection of Transboundary Rivers was created (UNDP, 2012). Objectives of the commission are as follow: realization of existing agreements, the coordination of the monitoring and

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water quantity and quality works as well as conduction of joint research and experience sharing on integrated environmental studies (UNDP, 2012). However nether agreements or commission can not oblige China to take into consideration interests of Kazakhstan on use of the Ili River water.In 2007 Kazakh Government with the help of UNDP started the Program "Integrated Water Resources Management (IWRM) and Water Efficiency in the Republic of Kazakhstan up to 2025" for all basins in Kazakhstan and for Ili-Balkhash basin as well. According to UNDP definition IWRM is "a process that promotes coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in equitable manner without compromising the sustainability of vital eco-systems." (UNDP 2007).

2.3 Integrated Modeling

The role of integrated modeling in evaluation of the water crisis with its ecological and economical effects is crucial for management and monitoring of transboundary watersheds. Evidence that there are successful case studies of implementation of integrated assessment and modeling in catchment management confirms it reliability (Jakeman and Letcher 2003; Jansky *et al.* 2004; Jia *et al.* 2007; Lagutov 2009). One of the most appropriate tools for environmental modeling is System Dynamics (SD) that was developed in the 1950s by Jay Forrester and his associates in the 1950s (Lagutov 2009). There are available software packages that use the principle of System Dynamics among most popular are STELLA, VenSim and PowerSim. Environmental model can help in understanding of the crisis and choosing best practices and solutions by establishing the sustainable level of water withdrawal. Based on the results of the modeling the alternative practices and more sustainable

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economic potential of the area can be suggested. Also as models are aimed to visualize the process it can be used as consensus building tool for intergovernmental negotiations(van Daalen *et al.* 2002). Therefore it is important to look at historic trends and natural oscillations of water level in the Lake Balkhash and to produce the water balance model using the STELLA Software.

2.4 Geographic Information Systems (GIS)

Geographic Information Systems (GIS) uses a static model approach that is opposite to the dynamic model. This approach is used to systematize, visualize and analyze geo-referenced data. The developed maps are used as visual tool for decision makers and can be used as universal language among states. With the help of GIS techniques summary of the statistical data is easier and more understandable for interdisciplinary audience of managers.Using the remote sensing techniques there is possibility to fill the gaps in data and reconstruct historical pattern. It is possible to analyze a landscape change and trace a level of human impact in the ecosystem. Some satellite imagery is available free of charge on data portals. For example Landsat data is covering whole world from 1972 to current days. There are plenty of useful data portals that provide information on different subjects, for example, the Global River Discharge database, Goddard Earth Science Data and Information Services Centeror ILEC World Lake database.

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3 Methods

This chapter summarizes the methods used in the research. Firstly, the research design is presented, followed by data collection. Afterwards the main techniques used for the analysis are written.

3.1 Research design

In order to answer the research questionfour objectives were set. Table 2 shows the research design with institutions that helped on different steps of the study.

Table 2 Research design

Research question	Research objectives	Methods	Place	
			Institution	City
How volume of the Lake Balkhash will change under different scenarios on land use and climate change?	1. To study the environmental changes that affect Ili-Balkhash System	1. Literature Review 2. Data collection 3. GIS 4. Remote Sensing 5. Climate change analysis	CEU Syslab NURIS Kazhydromet	Budapest Budapest Astana Astana
	2. To analyze socio-economic development in the basin.	1. Literature Review 2. Data collection 3. Conceptual model in STELLA 4. GIS	CEU Syslab NURIS Kazhydromet Ministry of Environmental Protection and Water Resources	Budapest Budapest Astana Astana Astana
	3. To develop an integrated model of Ili-Balkhash watershed	1. Development of sub-models 2. Combination of them in STELLA	CEU Syslab	Budapest Budapest
	4. To formulate climate change and management scenarios and assess them using the developed model	1. Scenarios simulations using STELLA 2. Statistical analysis of results using Excel	CEU Syslab	Budapest Budapest

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3.2 Data collection

Data collection was done using different sources. Historical data was obtained from the reports provided by Kazhydromet, also from previous researches in the region conducted by different authors and from archival documents. Most of the numerical data used in the special and integrated modeling was obtained from the online resources such as data portals and data centers.Table 3 presents useful links of data sources available online and providing free data with authorization.

Table 3 Data or knowledge portals used in this work

Name	Link
The International Data Centre on Hydrology of Lakes and Reservoirs lake data center	http://www.legos.obs-mip.fr/fr/soa/hydrologie/hydroweb/Objets.html
ESGFEarth System Grid Federation	http://pcmdi9.llnl.gov/esgf-web-fe/
Landsat Landsat Missions USGS	http://landsat.usgs.gov/best_spectral_bands_to_use.php
GloVisGlobal Visualization online tool	http://glovis.usgs.gov
EarthExplorer USGS science for a changing world	http://earthexplorer.usgs.gov
Climate Change Knowledge Portal	http://sdwebx.worldbank.org/climateportal

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3.3 Environmental change analysis

The first part of this subchapter describes how the maps for ecosystem analysis were created using ArcGIS 9.3. In the second part the remote sensing tools used to produce the lake surface area maps for two years. In the part 3.3.3 the process of climate change analysis is presented.

3.3.1 Application of ArcGIS

Different ArcGIS techniques were used to analyze ecosystem development in the region. 90 m Digital Elevation Model (DEM) datasets from Shuttle Radar Topography Mission (SRTM) were used for the construction of topographic map of the area (Figure 1). Ili-Balkhash basin has dendritic morphology. Therefore 90 meters DEM is good enough for such large watershed. 8 tiles were downloaded from the CGIAR Consortium for Spatial Information (CGIAR-CSI) free of charge and process using the ArcGIS 9.3 Software (Figure 1).

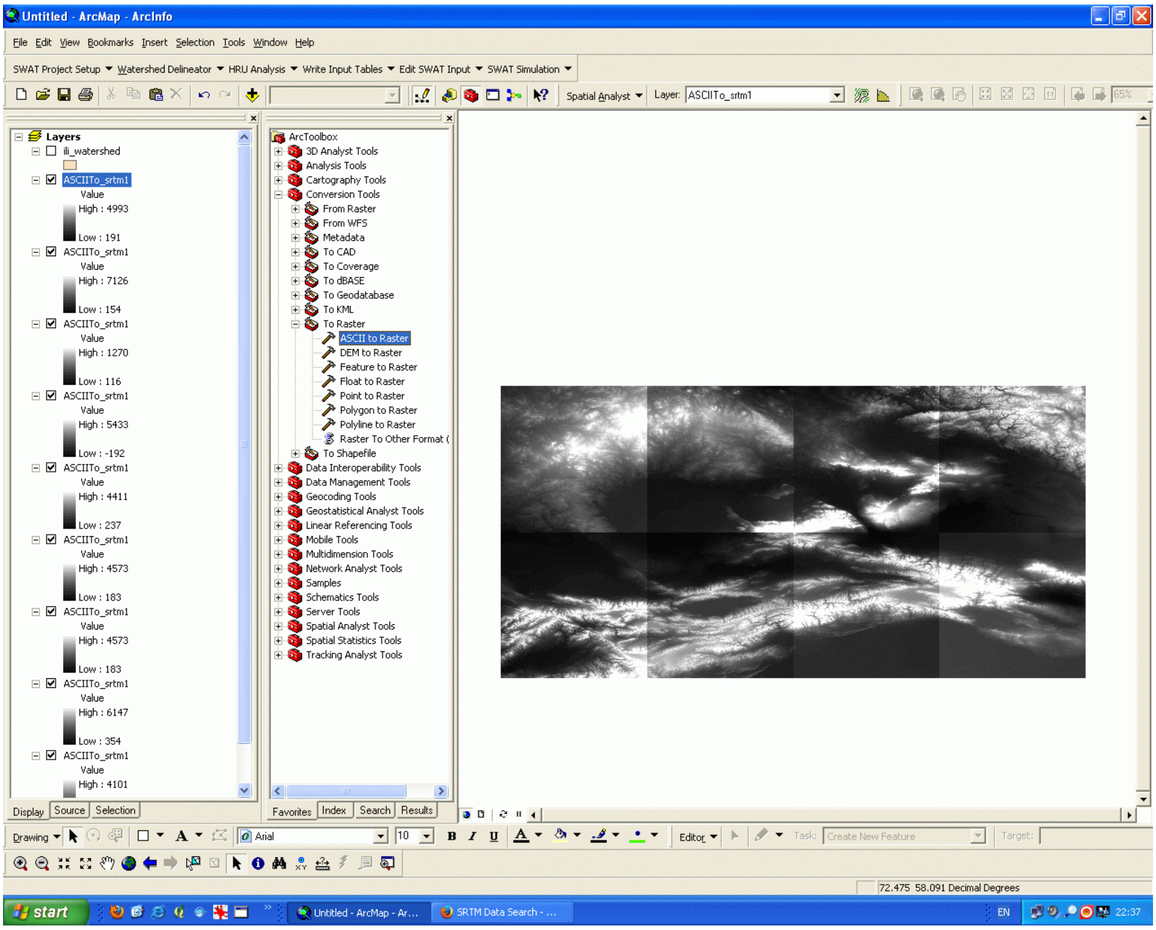

Figure 1 Processing of 90 meters DEMs using ArcGIS 9.3

As can be seen in the Figure 2 there was an attempt to process 89 tiles of 30m DEM however processing was time consuming and required extra operational memory of computer that was not available.

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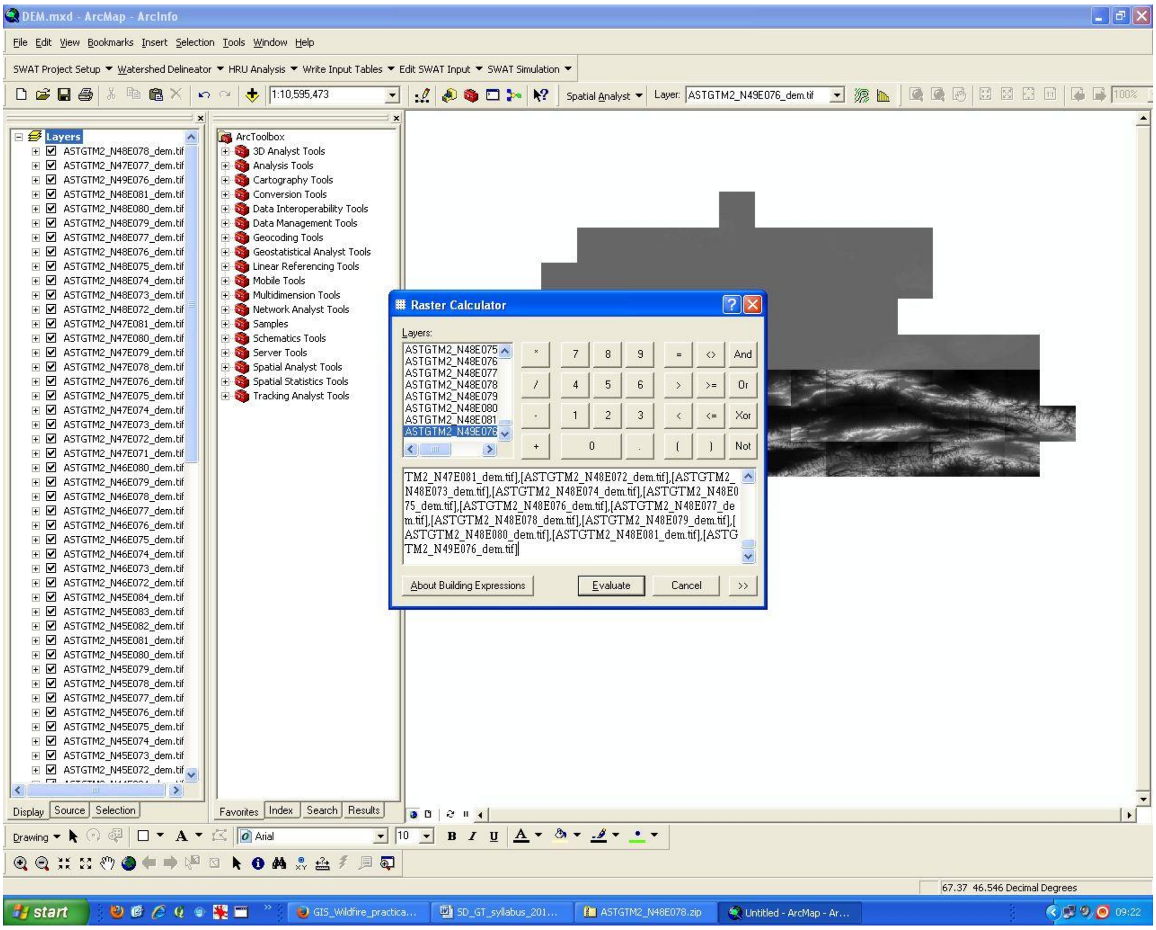

Figure 2 Processing of 30 meters DEM using ArcGIS 9.3

3.3.2 Remote Sensing

In order to analyze the change in Balkhash lake surface area. Remote sensing techniques were used. 9 Landsat 2 and 3 Landsat 3 scenes for May and June of 1978, and 6 Landsat 7 scenes with 5 Landsat 8 scenes for May and June 2014 were downloaded from the GloVis online tool. EarthExplorer were used for obtaining scenes from Landsat 4 and 5 but found less effective than GloVis. The resolution of Landsat MSS 2 and 3 is 60 meters and the 30 meters for Landsat 5, 7 and 8. Table 4 shows the summary of Landsat data. Satellite imagery was processed on ArcGIS desktop.

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Table 4 Specifications of Landsat MSS, TM, ETM+ and OLI data. Modified from (Rokni *et al.* 2014)

Satellite	Sensor	Year	Resolution (m)	Wavelength (µm)
Landsat – 2 - 3	MSS	1978	60	Band 4: 0.5-0.6 (Green) Band 5: 0.6-0.7 Band 6: 0.7-0.8 (NIR) Band 7: 0.8-0.11
Landsat - 5	TM	2011	30	Band 1: 0.45–0.52 Band 2: 0.52–0.60 (Green) Band 3: 0.63–0.69 Band 4: 0.76–0.90 (NIR) Band 5: 1.55–1.75 (MIR) Band 7: 2.08–2.35
Landsat - 7	ETM+	2014	30	Band 1: 0.45–0.515 Band 2: 0.525–0.605 (Green) Band 3: 0.63–0.69 Band 4: 0.75–0.90 (NIR) Band 5: 1.55–1.75 Band 7: 2.09–2.35
Landsat - 8	OLI	2014	30	Band 1: 0.435–0.451 Band 2: 0.452–0.512 Band 3: 0.533–0.590 (Green) Band 4: 0.636–0.673 Band 5: 0.851–0.879 (NIR) Band 6: 1.566–1.651 Band 7: 2.107–2.294 Band 9: 1.363–1.384

Land coveranalysis that is presented in the Table 11 was retrieved from the processed remote sensed data (the 1-kilometer (km) advanced very high resolution radiometer (AVHRR) data) for years 1992-1993 (Eidenshink and Faundeen 1994). Map of ecosystems for the studied region (Figure 5) was extracted from the global data. Ecosystems allocated according to the Udvardy classification.

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3.3.3 Climate change analysis of Ili-Balkhash basin

Climate Change analysis was processed in Astana with the support of Laboratory of Energy, Ecology and Climate of Nazarbayev University Research and Innovation System. This is the first attempt of downscaling of Global Climate Models for Ili-

Balkhash region and make future projections. A Bayesian statistical model was used in order to make probabilistic forecast of climate change in the regional scale (Tebaldi *et al.* 2005). Long term variations in precipitations in the basin were studied in details previously but only for the past (Matsuyama and Kezer 2009).This chapter explains how temperature and precipitation projections for the period 2020-2050 years of studied region were produced. Nine Global Climate Models (GCMs) from CMIP5 ensemble(Table 5)with two CO2 scenarios emissions were analyzed: RCP4.5 and RCP8.5.Those scenarios were developed by collective work of different experts in the field of integrated assessment modeling, climate modeling, and environmental modeling (van Vuuren *et al.* 2011). There are four pathways that represents the level of radiative forcing that can be reached by the end of the century: 2.6, 4.5, 6, 8.5 W/m^2 (van Vuuren *et al.* 2011). Scenario RCP4.5 assumes stabilizing of CO2 emission without overshootingand RCP8.5a dramatic increase (Figure 3)(Moss *et al.* 2010).For each model Historical, RCP4.5, RCP8.5 simulations were downloaded.

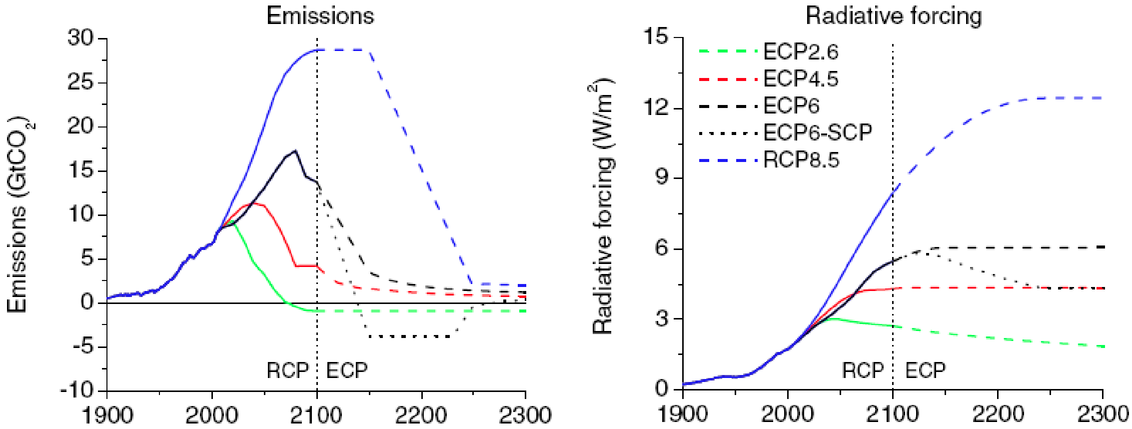

Figure 3 Extension of the RCPs (radiative forcing and associated CO2 emissions)(van Vuuren *et al.* 2011)

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Table 5 Nine models of CMIP5 used in projections

Model	Institute
BCC-CSM1.1	Beijing Climate Center, China Meteorological Administration
CCSM4	US National Center for Atmospheric Research (NCAR)
CESM1-CAM5	NCAR Community Earth System Model
IPSL-CM5A-LR	Institut Pierre Simon Laplace(IPSL) Jussieu
IPSL-CM5A-MR	Institut Pierre Simon Laplace(IPSL) Jussieu
MIROC_ESM-CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies and Japan Agency for Marine-Earth Science and Technology.
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies and Japan Agency for Marine-Earth Science and Technology.
MRI-CGSM3	Meteorological Research Institute (Tokyo)
GISS-E2-R	NASA Goddard Institute for Space Studies

Period from 1960 to 1990 has been chosen as the historical and 2020-2050 was taken as projection period. The observational data is gridded CRU3.21 for 1961-1990 was obtained from the European Centre for Medium-Range Weather Forecasts(ECMWF 2014). Matlab code was developed to extract information from netcdf file and to average climatic variable over selected region.

Rectangle around Ili-Balkhash basin was allocatedfor further analysis with following coordinates (latitude;longitude): 1(43.35; 73.23), 2(46.98; 72.23), 3(46.98; 82.35), 4(43.35; 82.35).

Observation data series of monthly air temperature in degrees Celsius and precipitation in mm per monthwere obtained from the British Atmospheric data center (Table 6, Table 7)

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Table 6 Observation data used: Air temperature, °C (BADC 2014)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
-12,01	-11,23	-2,37	8,47	14,9	19,66	22,02	20,18	14,72	6,67	-1,59	-8,25

Table 7 Observation data used: Precipitation, mm(BADC 2014)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
16,69	14,86	21,78	30,9	34,36	29,84	27,71	17,03	14,76	27,54	27,33	21,12

3.4 Integrated Modeling

Ili-Balkhash basin integrated model was developed using the STELLA7.0.3 software. Model consists of three sub-models: "starter" hydrological sub-model with natural flows only; climate change sub-model with evaporation and precipitation scenarios; and "development" sub-model with anthropogenic induced activities. Model was developed gradually from the simple water balance model to the integrated model. Climate change sub-model has three scenarios for precipitation rate and for evaporation rate. Scenarios based on the results of climate change analysis and data collected from the literature. "Development" sub-model introduced a reservoir that controls a discharge of Ili River and three scenarios of agricultural activity in China and Kazakhstan. "Business as usual" scenario in each sub-model presents a value that is true for the year 2000. This year was chosen as initial value because the lake water level was optimal and there is most complete data available.The second scenarios of development for both countries show what is planed and officially announced. The third scenarios show the worst scenarios of what is required or maximum value found in the literature. "Development" scenarios were simulated on the "business as usual"

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climate scenario. Finally, three combined scenarios of the system were developed with all scenarios to show current state of the system, planned and worst. Model was run for 20 times for each scenario and mean values were calculated. Graphs in results represent the mean of those runs.

For the discussion Ili-Balkhash model was modified in order to fit actors and decision-makers in the system. This model is conceptual. It is useful for understanding of complexity and imperfection of the management of the basin without IWRM. There are three parts in it: Kazakh, China and joint. In this model information connectors were introduced along with action connectors. It is important when an agency does not have power to force other governing body but provide some recommendations or data.

4 Ili –Balkhash watershed analysis

An analysis of current environmental and socio-economical changesis provided in this chapter. Therefore Chapter 4 has two subchapters describing past current and projected trends of natural and anthropogenic development of the basin. Those subchapters consist of smaller ones.

4.1 Environmental changes

This chapter includes three parts. First one describes an ecosystem of Ili-Balkhash basin and includes two maps produced in ArcGIS. The second part shows the process and results of the climate change downscaling for the studied area. And final one is assessment of water regime change using analysis of satellite imagery using remote sensing and comparison of results with historical data.

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4.1.1Ecosystem

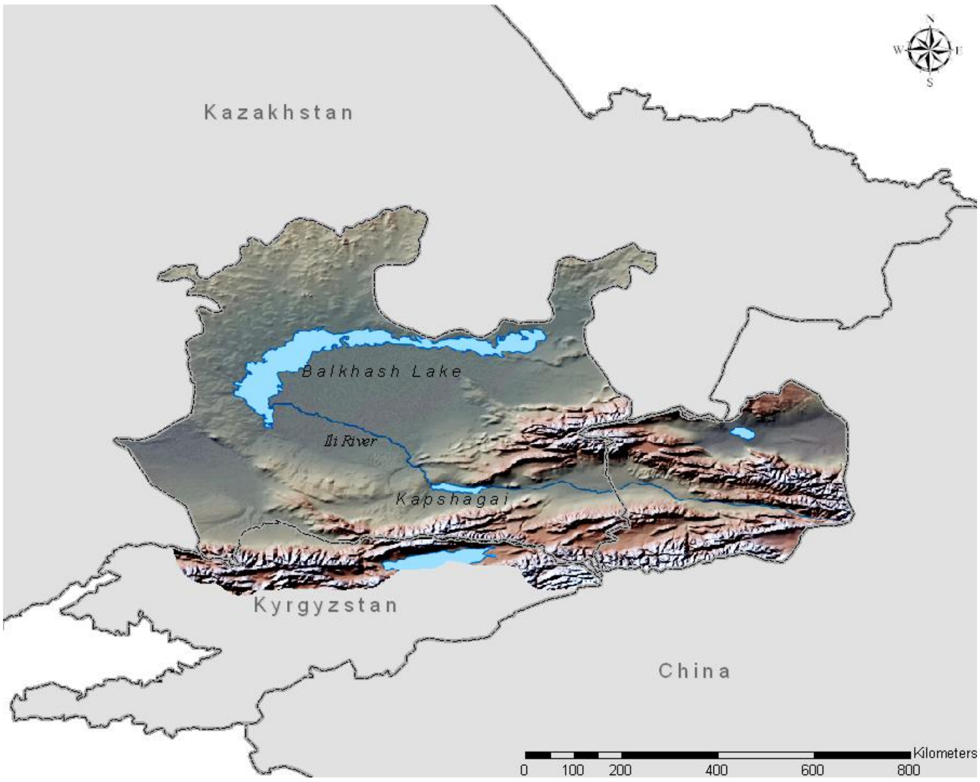

Figure 4 Physical map of Ili - Balkhash watershed

As can be clearly seen on the map, Ili - Balkhash basin is situated in southeastern Kazakhstan (60%) and northwestern China (34%) with a small part on Kyrgyz territory (Kenshimov 2011).

Ili River born in mountainous area of China (Figure 4). The river basin and its tributaries within Kazakhstan is restricted from the south by the Zailiysky and Kungei Tau mountains, from the west by the north-eastern spurs of Shu-Ili mountains (Aita), by the water area of the Balkhash lake from the north, Karatal river valley from northeast, by Dzungar-Alatau in the east, and south-east - Ketmen ridge and mountains Terskey Alatau(Kazhydromet 2005).

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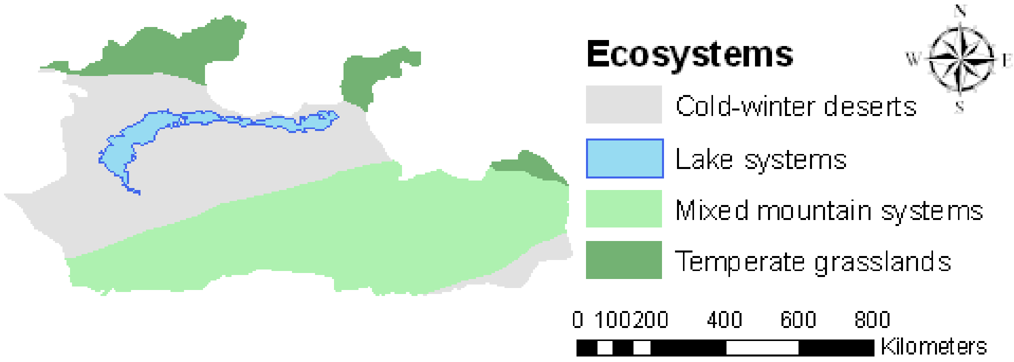

Figure 5 Ecosystem map based on Udvardy system

As can be seen in the Figure 5, according to Udvardy classification basin nearly equally divided between flat area of cold-winter deserts and heterogeneous mixed mountain systems.

4.1.2 Climate change

The Ili-Balkhash watershed is located in the eastern part of the Central Asian Arid Zone (CAAZ) that covers area from the Caspian Sea to the Altai Mountains (Feng *et al.* 2013). Ili-Balkhash watershed climate is sharply continental and heterogeneous. To characterize the climatic conditions of the studied area downscaling of nine GCMs were made using Bayesian statistics.Appendix Table 1, Appendix Table 2 and Appendix Table 3show the resultsof nine models projection under historical, RCP4.5 and RCP8.5 scenarios. Those results were further processed using the Bayesian approach that gives more weight to model with closest results to observational data (Tebaldi *et al.* 2005).This approach is found to be more reliable as it does not simply take mean value of all models but takes into consideration performance of each model.

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In general RCP8.5 scenario shows higher temperature raise than RCP4.5 (Table 8, Table 9).

Table 8 Projected seasonal summer temperature in K for Ili-Balkhash basin

Model	RCP85 (2020-2050)	RCP45(2020-2050)	Model historical(1960-1990)	Observations (1960-1990) T=293.77
BCC-CSM1.1	295.50	295.15	293.22	293.77
CCSM4	299.30	299.15	296.74	293.77
CESM1-CAM5	299.00	298.60	296.08	293.77
IPSL-CM5A-LR	296.56	296.52	293.33	293.77
IPSL-CM5A-MR	297.85	297.38	294.47	293.77
MIROC_ESM-CHEM	298.97	298.39	295.76	293.77
MIROC5	301.56	301.52	299.02	293.77
MRI-CGSM3	297.61	297.32	296.45	293.77
GISS-E2-R	292.37	291.97	291.28	293.77

Table 9 Projected seasonal winter temperature in K for Ili-Balkhash basin

Model	RCP85 (2020-2050)	RCP45(2020-2050)	Model historical(1960-1990)	Observations (1960-1990) T=262.62
BCC-CSM1.1	267.05	266.65	264.20	262.62
CCSM4	267.97	266.77	264.57	262.62
CESM1-CAM5	264.74	263.69	261.00	262.62
IPSL-CM5A-LR	266.12	265.31	263.25	262.62
IPSL-CM5A-MR	267.30	267.26	264.12	262.62
MIROC_ESM-CHEM	270.25	268.82	265.89	262.62
MIROC5	268.73	268.00	266.32	262.62
MRI-CGSM3	266.00	265.84	264.32	262.62
GISS-E2-R	270.52	270.13	268.13	262.62

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It can be seen from the Figure 6, Figure 7, Figure 8, Figure 9 that summer and winter will experience temperature rise in both scenarios. Winter temperature raise is stronger in RCP8.5 scenario, compare to summer RCP8.5. Reverse pattern in RCP4.5, where summer temperature raise is expected to be higher. In both RCP4.5 and RCP 8.5 scenarios temperature raise will be from about 2 to 3.5 degrees.

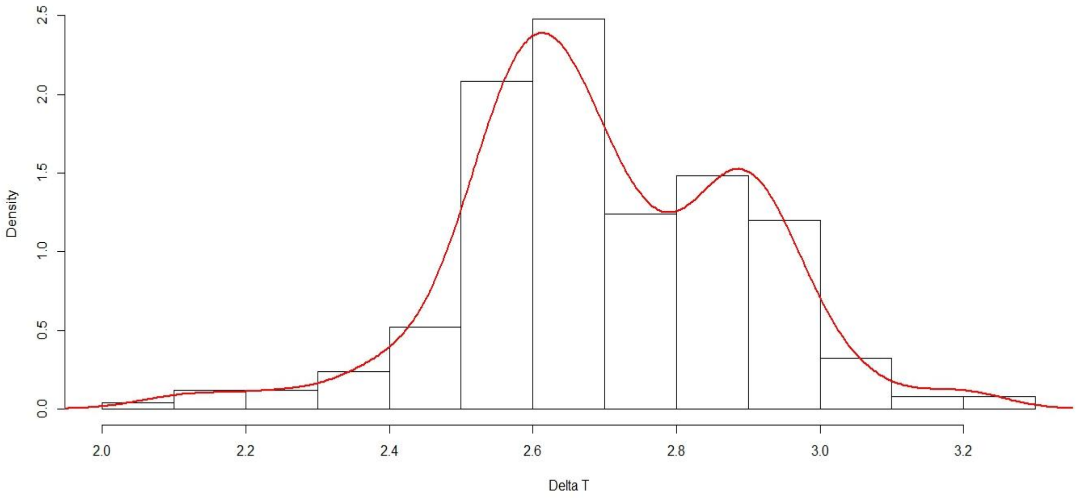

Figure 6 Temperature raise projection under RCP45 scenario for summer season 2020-2050

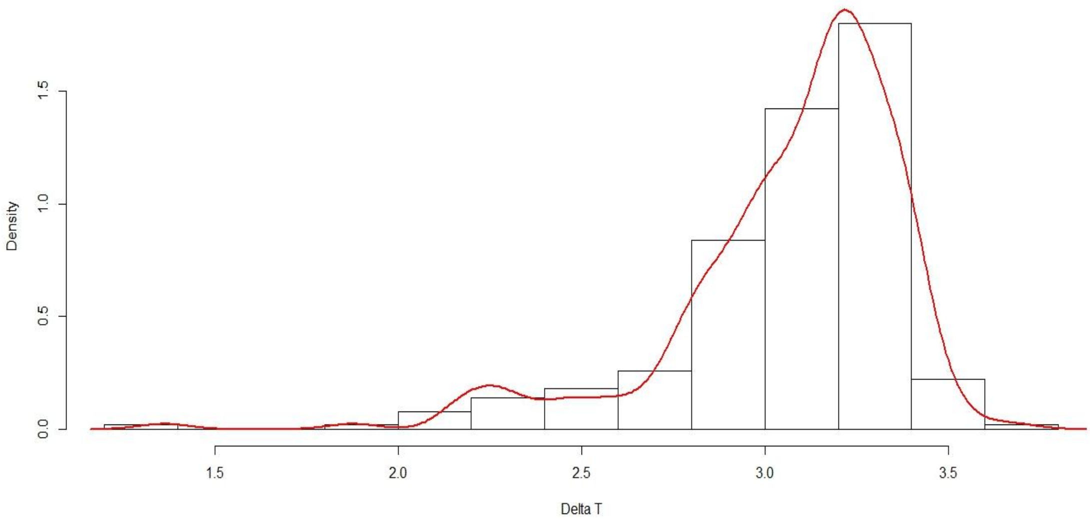

Figure 7 Temperature raise projection under RCP85 scenario for summer season 2020-2050

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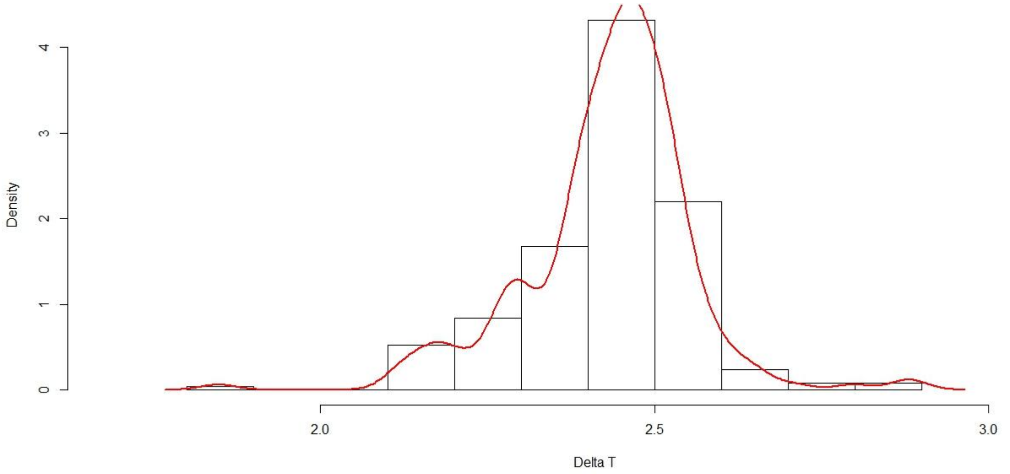

Figure 8 Temperature raise projection under RCP45 scenario for winter season 2020-2050

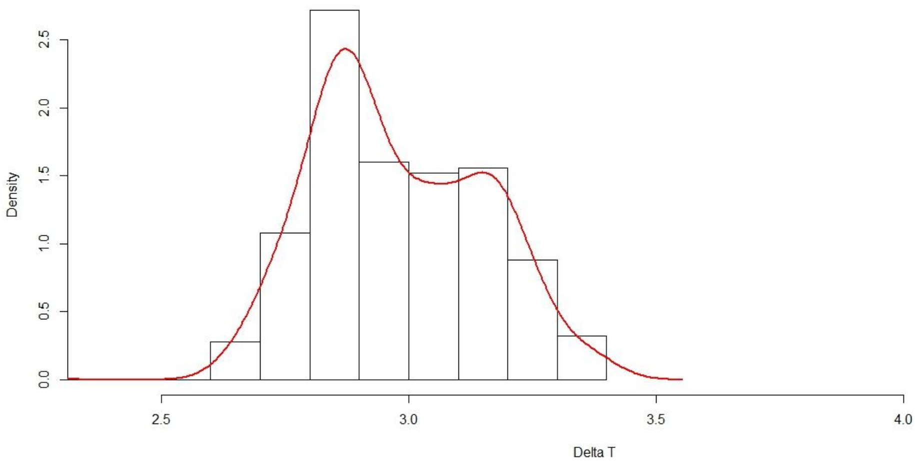

Figure 9 Temperature raise projection under RCP85 scenario for winter season 2020-2050

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Precipitation will increase under both scenarios in the basin in comparison to the historical and observational data (Table 10).

Table 10 Projected annualprecipitation in mm for Ili-Balkhash basin

Model	RCP85 (2020-2050)	RCP45(2020-2050)	Model historical(1960-	Observations (1960-1990)

			1990)	**Pr=283.92**
BCC-CSM1.1	348,42	342,39	321,57	283.92
CCSM4	299,88	289,76	306,4	283.92
CESM1-CAM5	238,87	246,13	235,69	283.92
IPSL-CM5A-LR	359,38	351,35	368,86	283.92
IPSL-CM5A-MR	276,46	303,49	296,16	283.92
MIROC_ESM-CHEM	582,62	564,46	499,03	283.92
MIROC5	256,88	239,56	218,33	283.92
MRI-CGSM3	277,61	273,27	227,26	283.92
GISS-E2-R	564,24	578,34	511,29	283.92

However RCP4.5 scenario shows average increase in annual precipitation that is equal to 9.799 with standard deviation (SD) 7.6336. Whereas RCP8.5 provides lower value of only 0.7625 (SD 12.6775). To be more precise with a probability of 95% annual precipitation can change from -5.4674 to 25.0673 in RCP4.5 (Figure 27) and from -24.5930 to 26.1182 in RCP8.5 (Figure 28). Therefore can be concluded that RCP45 would be favorable for semiarid climate of the region.

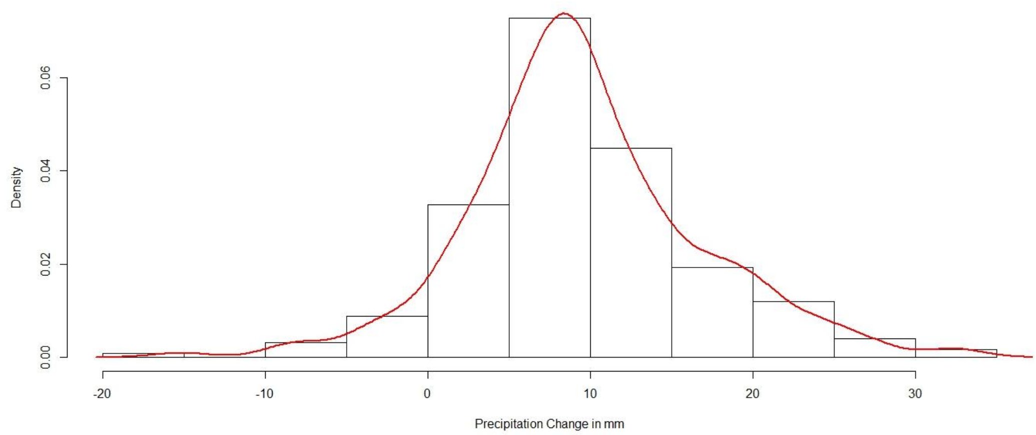

Figure 10 Annual precipitations change under RCP45 scenario for 2020-2050

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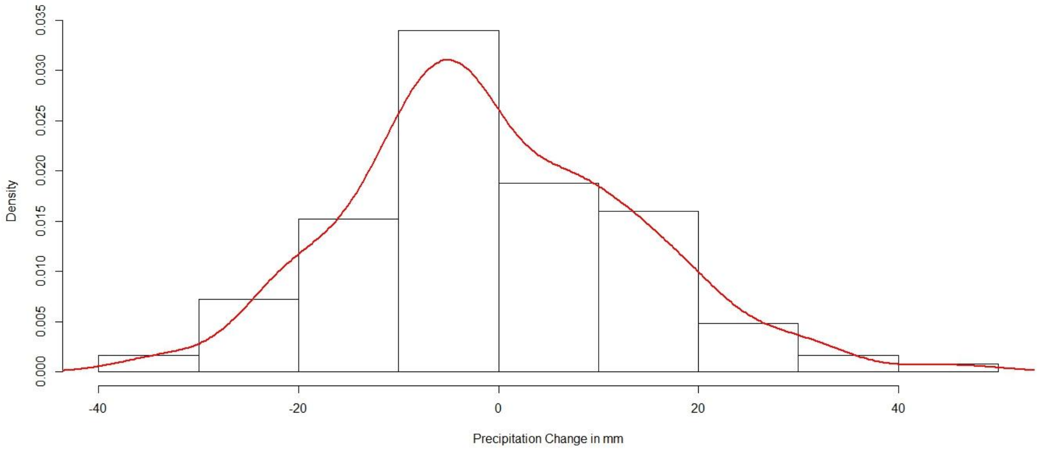

Figure 11 Annual precipitations change under RCP85 scenario for 2020-2050

4.1.3 Changes in the water regime

According to multiple studies there were significant drop in water level in Lake Balkhash after the construction of Kapchagay HES from 1970 to 1987 (Dostay *et al.* 2012; Petr 1992; Propastin 2012a; Propastin 2012b; Propastin 2013). Use of the river water for filling up the reservoir coincided with the natural oscillation of the Ili River. Therefore relatively stable in the past lake level decreased by 2.3m. That fact concerned the Soviet for that time Government and lead to the decision to reduce planed volume of the Kapchagay Reservoir and fill it for a half (Burlibayev 2011). From the other hand the reservoir improved management of the river water by controlling the river discharge.

Figure 12shows Balkhash Lake level variation provided by lake data center HYDROWEBfrom the satellite radar altimetry. Level variations and surface-volume variations for biggest lakes and reservoirs were retrieved from various satellite images (Modis, Asar, Landsat, Cbers) and radar altimetry (Topex–Poseidon, GFO, ERS-2, Jason-1, Jason-2 and Envisat) (Cretaux *et al.* 2011).

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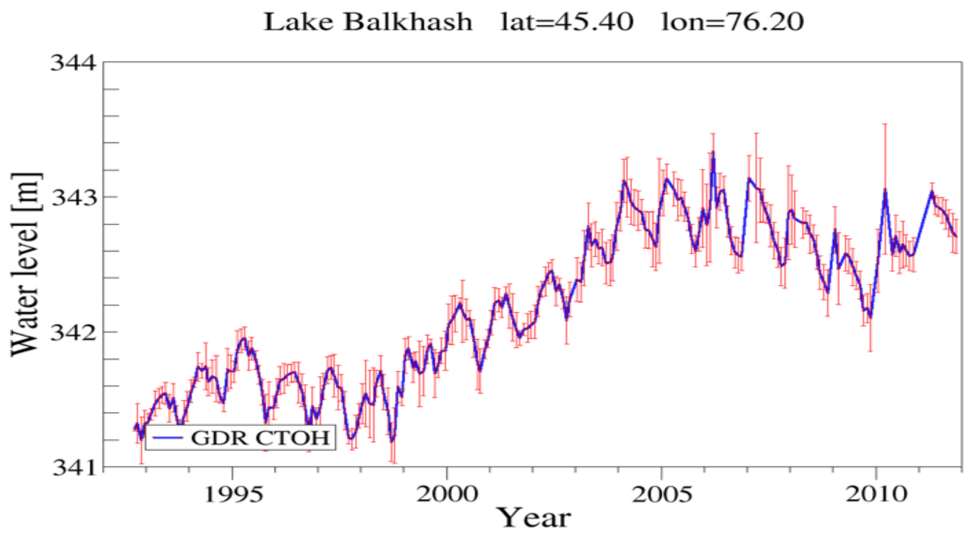

Figure 12 Water level graph of Lake Balkhash for the period from 1993 to 2012 (Cretaux *et al.* 2011)

Lake surface area change was determined using remote sensing technics from Landsat 2,3,5,7,8 missions' imagery. Balkhash Lake surface water was extracted using satellite-derived indexes such as Normalized Difference Water Index (NDWI) (McFeeters 1996) and Modified Normalized Difference Water Index (MNDW) (Xu 2006). According to the comparison analysis of indexes for water features extraction of Lake Urmia NDWI shows the most accurate results of 99.64% (Rokni *et al.* 2014). Therefore it was used for Lake Balkhash surface water change examination.

Two ways of processing of satellite imagery was used. The second one was found more efficient. Firstly on the example of year 1978 Green and NIR bands of the scene were uploaded in ArcGIS 9.3. Than NDWI was calculated using the formula: (Green – NIR)/(Green+NIR). And this was repeated for each scene (Figure 13).

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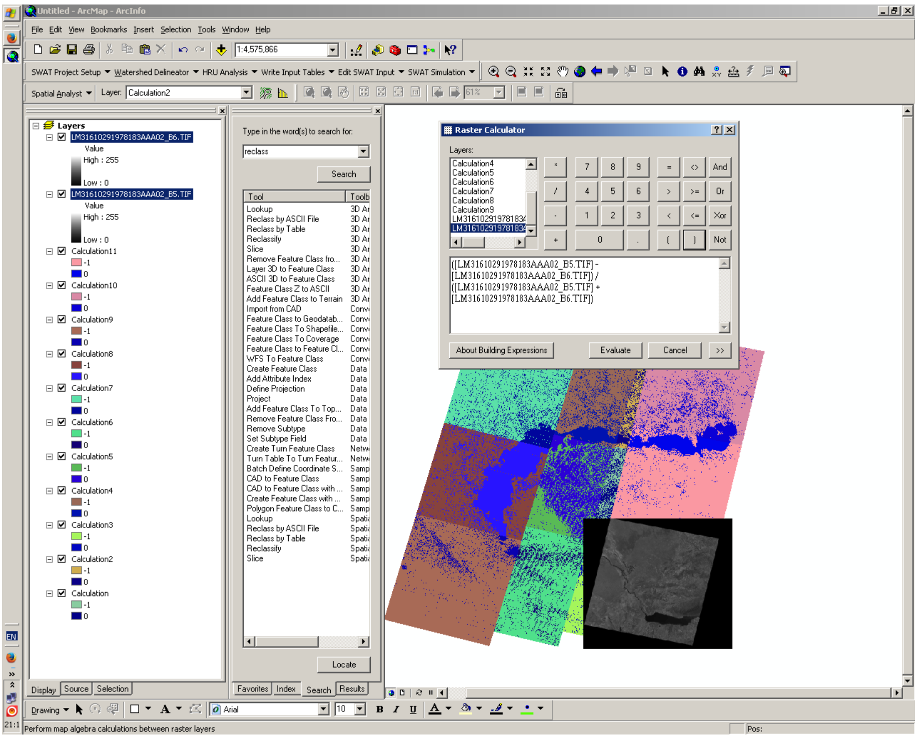

Figure 13 Calculation of NDWI, Raster calculator, 1978

When water is extracted all scenes were joined with the Data Management Tool – Mosaic to new raster (Figure 14). This raster file was converted in the shape file. From the shape file polygons of water was exported and joined using basic Analysis Tools such and Union and minor imperfections were removed with Dissolve function (Appendix figure 1, Appendix figure 2).

Secondly, on the example of year 2014 Green and NIR bands upload in ArcGIS 9.3 separately (Figure 15). NIR band of all scenes are joined by the Mosaic function and new raster was made (Figure 16). Than the same was done for the Green band. After NDWI was calculated ones for all scenes (Figure 17). This way was found more systematic and less time consuming.

When the final shape file with only lake water surface calculation of area was done. Spatial statistical Tools function Calculate Area is able to manage it (Figure 18).

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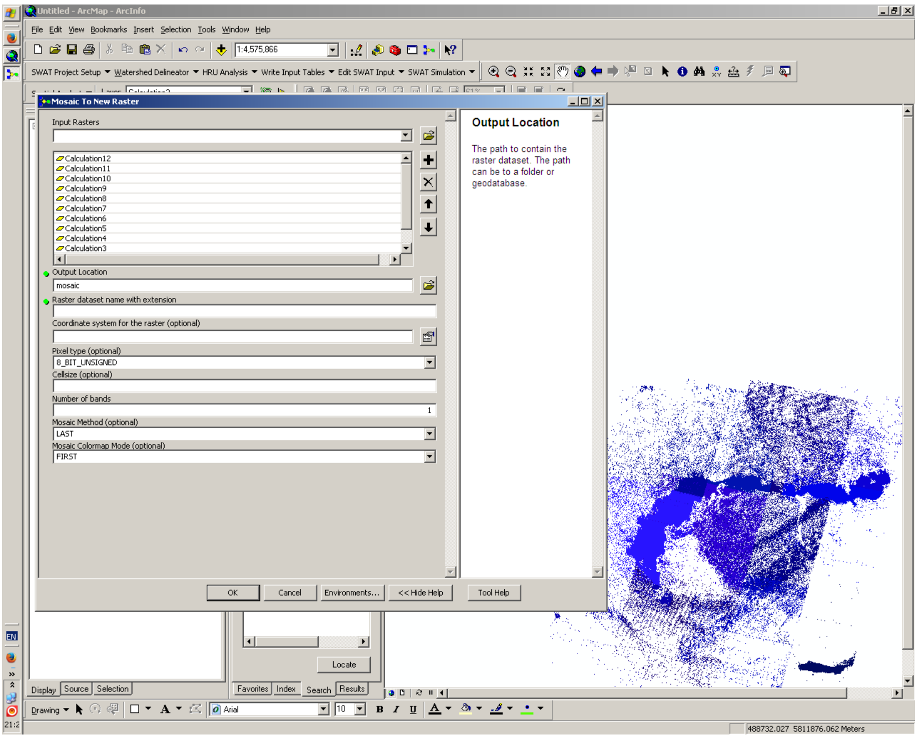

Figure 14 Connecting scenes, Mosaic to new raster, 1978

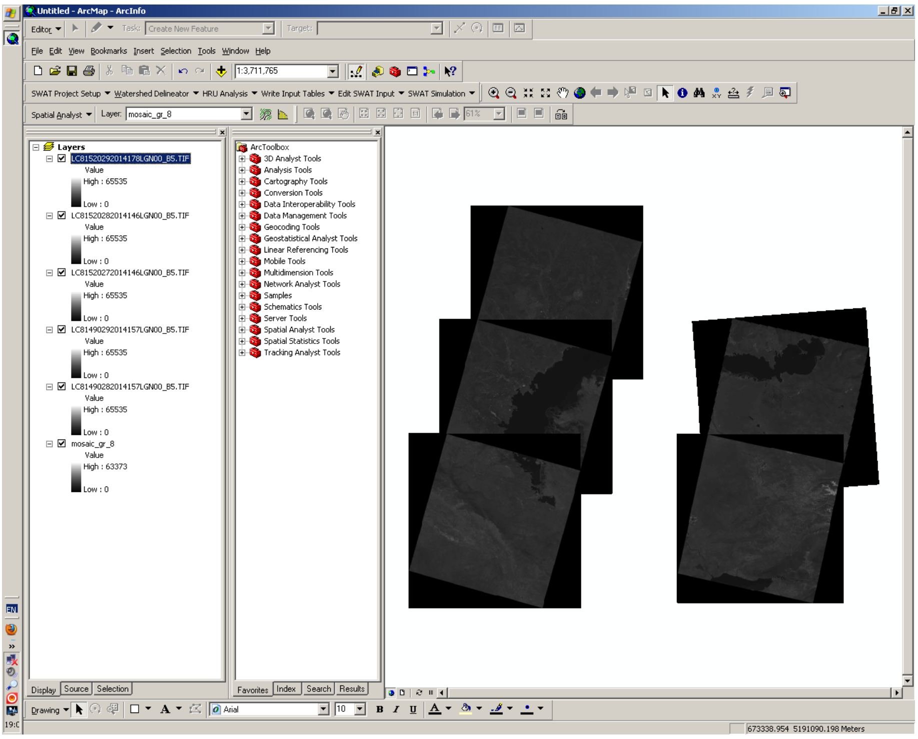

Figure 15 Band NIR upload of all scenes, 2014

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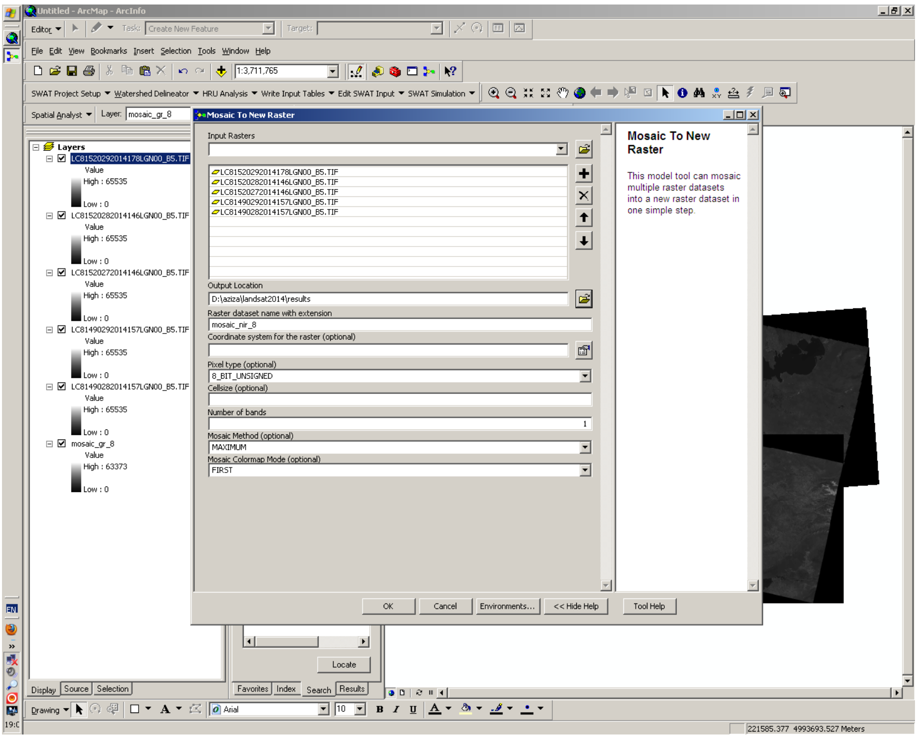

Figure 16 Mosaic to new raster of NIR bands, 2014

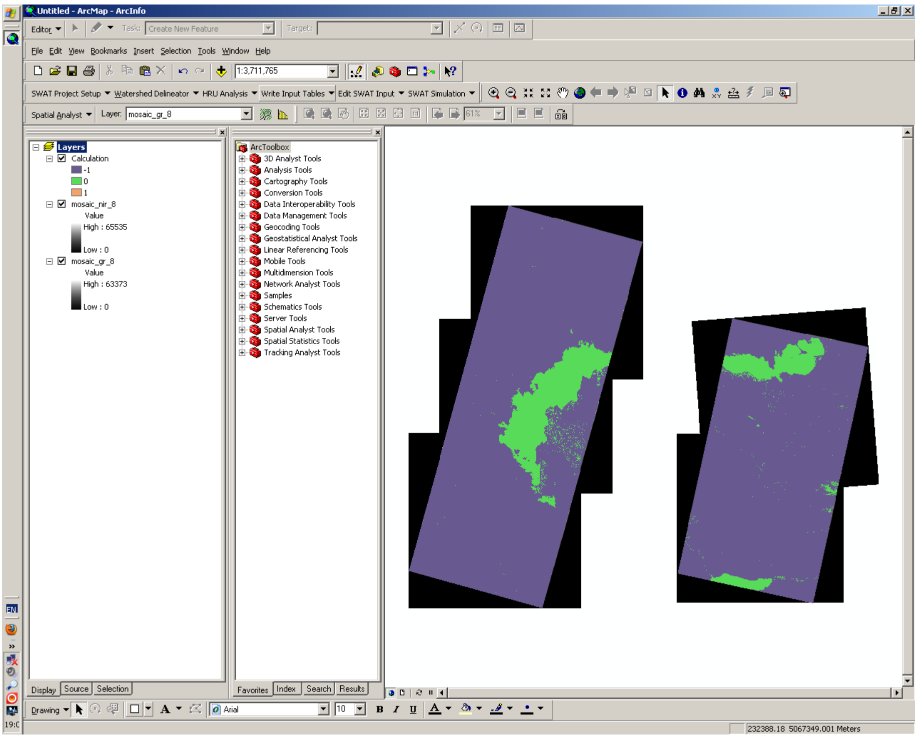

Figure 17 Calculation of NDWI, 2014

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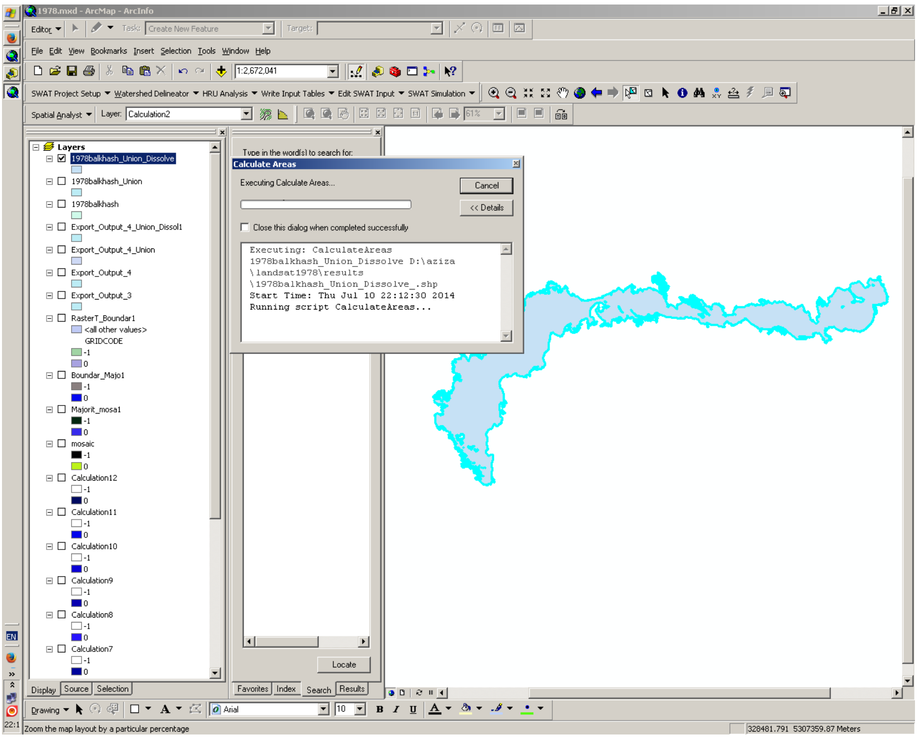

Figure 18 Final step, Calculate areas of the Lake

As a result two maps (Figure 19, Figure 20) was produced representing two different years 1978and 2014. Figure 19 shows a surface area of the Lake Balkhash in its critical condition when the filling of Kapchagay reservoir took place. Therefore the value of 17895 km^2 is smaller that average for the studied lake.The surface area of Balkhash is significantly higher in this year because of natural increase in Ili River runoff. Landsat 7 imagery was bad quality with some defects that could affect the result (Figure 20).

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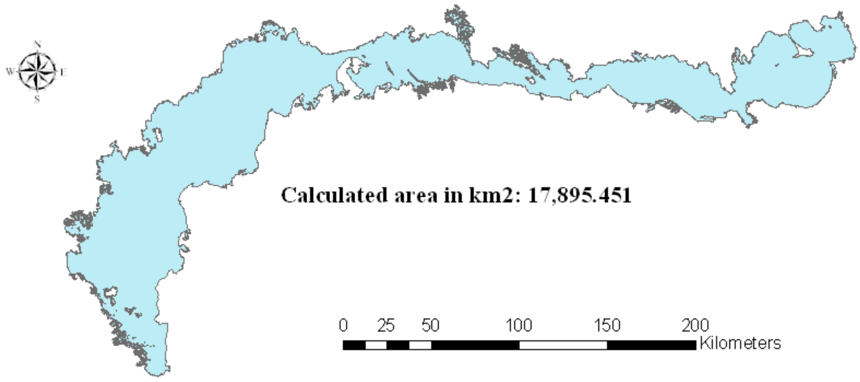

Figure 19 Surface area of Lake Balkhash in 1978

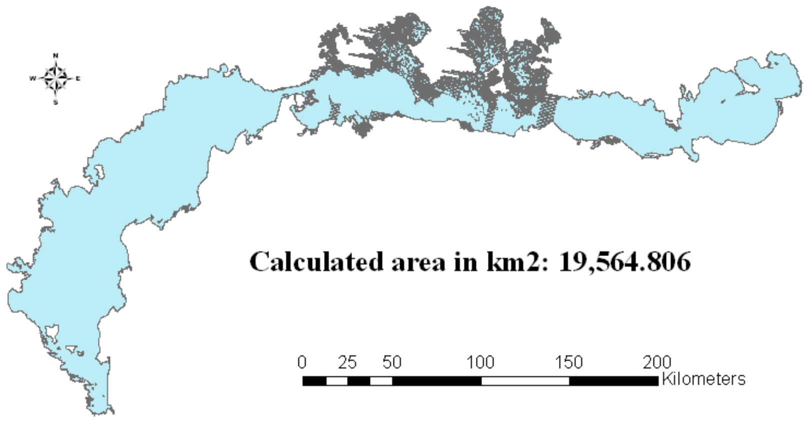

Figure 20 Surface area of Lake Balkhash in 2014

4.2 Social and economical development

This subchapter provides information on social and economical development and understanding of the problems with management. Firstly a conceptual model of decision – making system and management in the Ili-Balkhash watershed is analyzed. Land cover change in the basin is shown in the following part. The last two parts summarized past, current and projected land use patterns for Kazakhstan and China separately.

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4.2.1 Current management and decision-making system

Analyzing the managerial structure of the basin of two countries it is clearly seen that IWRM is not implemented yet(Figure 21). Too many actors are involved in the decision making process. There is limited exchange of information and data between different institutions. There is overlap in duties. The role of policy is to impose limits and fees on water use and encourage society to shift to less water consuming activities by introducing subsidies.

The Lake Balkhash is located on the territory of Kazakhstan however the basin is bigger and the agreement between Kazakhstan and China should be established (Figure 22). So the policy implementation of one country is not enough for solving the issue and even the help of third party - international organization without the cooperation with China will be unsuccessful (Giordano *et al.* 2002). The transboundary institutions can consider more facts using the scientific information from both countries. The Kazakh-Chinese joint commission has no legal power and can only conduct research (UNDP 2012).

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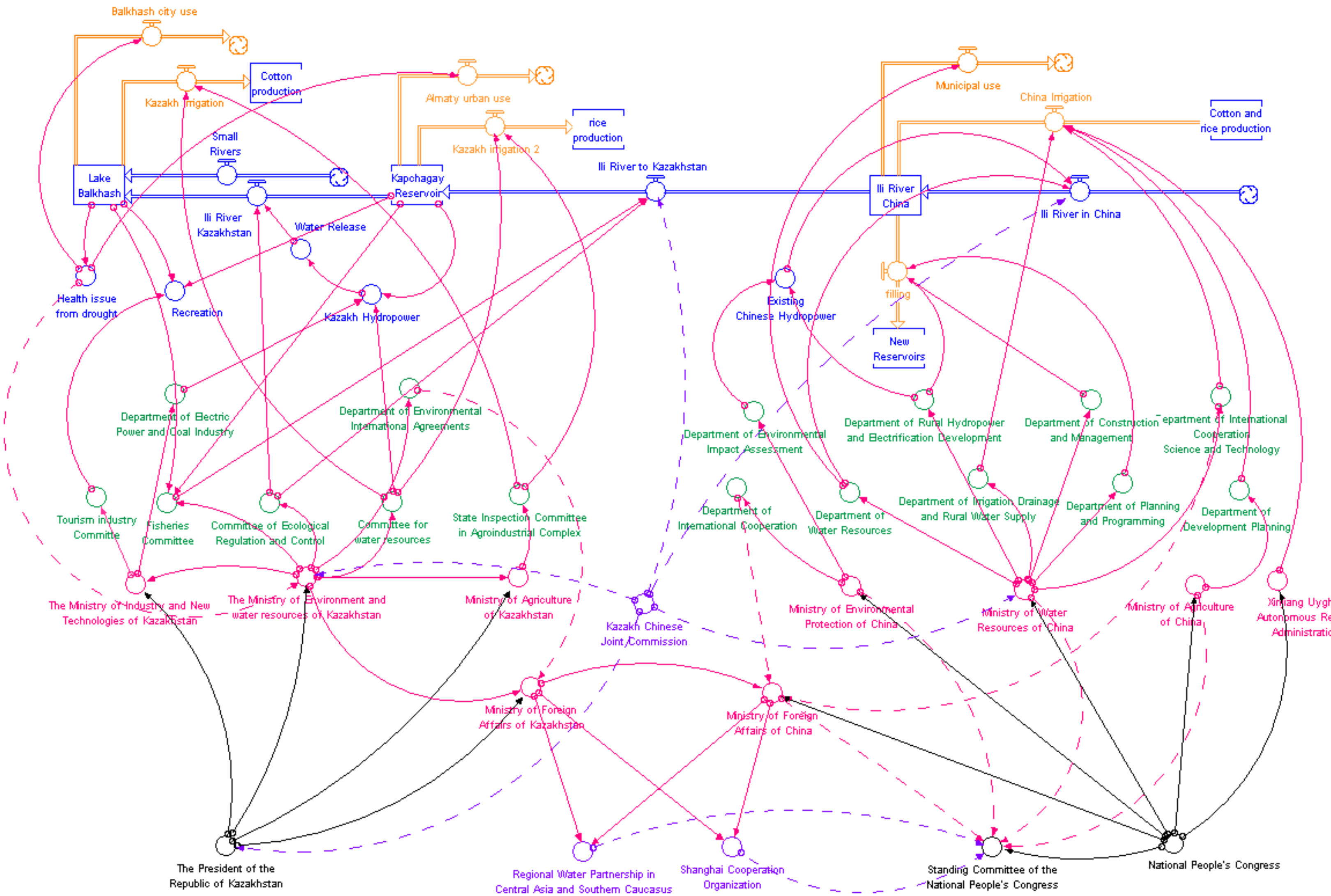

Figure 21 Conceptual model of actors involved in current management of the basin

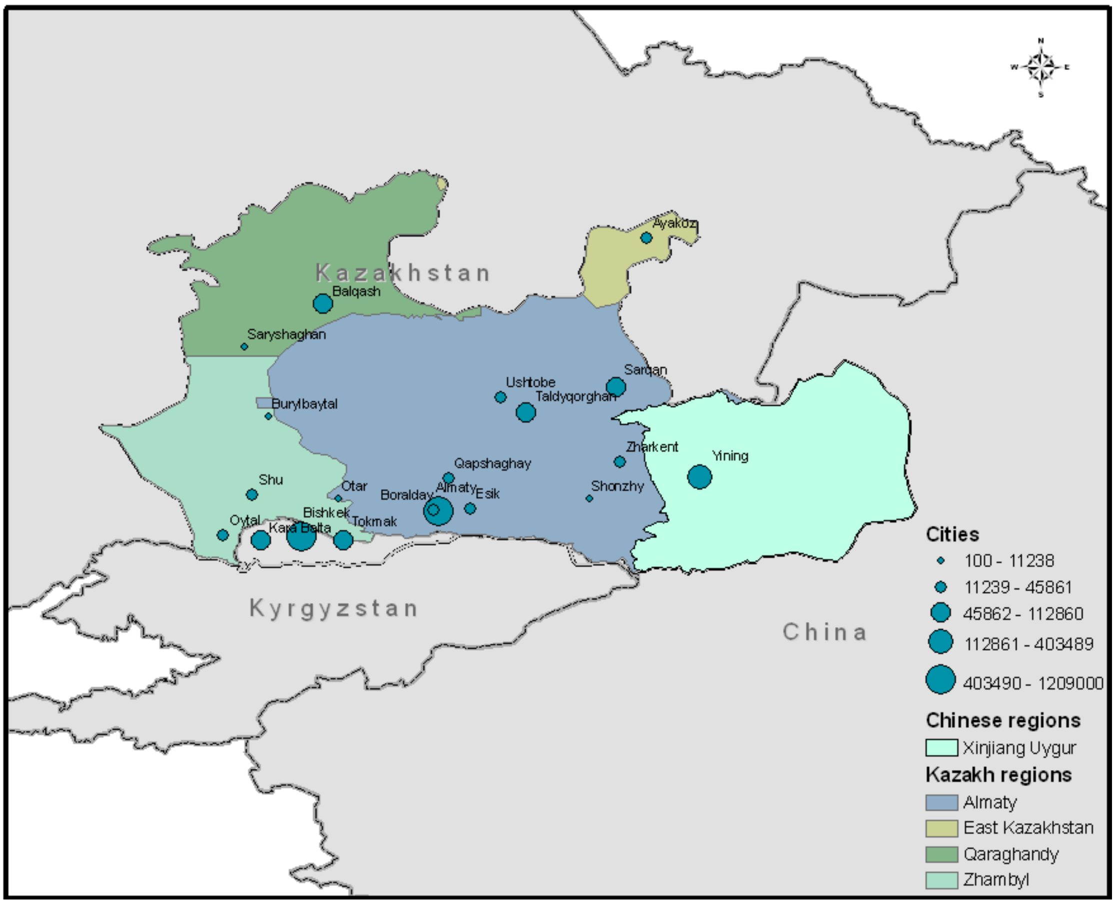

Figure 22 Population map with main cities and regional boundaries

Both countries are in the stage of fast economical development and rapid population growth. Direct importance of studied system for people in Kazakhstan and China is providing of ecosystem goods and services. However unstable system of the Ili river basin in case of drying of the lake will have effects not only on environment but also on economy and wellbeing of people. Chinese Government has started full-scale development of the Xinjiang-Uyghur Autonomous Region in the northwest China. That kind of fast economical growth required expansion of water use for industry and increased human needs. All of the development projects together with existing agricultural practices hamper the flow of Ili River into Kazakhstan and heavily polluting it (SIWI, 2010).

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4.2.2 Land cover change

Increased uptake from the river by Chinese Government creates many problems in the delta of the Ili River, which is a system of lakes and wetlands. Watershed interspersed with thickets of reeds and dry valleys. Ili River delta for centuries was a habitat for muskrats, birds and wild animals. However this area over the past 30 years has declined (UNDP, 2007). Only 5 lake systems from the former 16 have remained. As amount of water has decreased the quality of remain water has deteriorated. The main consequences of drying are increased water salinity, concentrations of pesticides and heavy metals in the water and in the sediment. Polluted water affected the biota high concentration of heavy metals was found in the phyto-and zooplankton as well as in fish tissues. Area of reeds serving forage for livestock farms and habitat for wildlife is considerably reduced. Constant winter floods from the discharges of water from Kapchagay reservoir for energy purposes destroyed habitats of muskrat. Reservoir also affected a soil in the delta. Accumulation of silt in the reservoir led to a reduction of organic particles in the delta and thus lowers fertility of floodplain soils. Because of it riparian forests are dying. Therefore loss of original forest for the period from 1980 to 1990 counts as 26%. As a result of reduced crop yields, farmers had to stop growing fruits and vegetables. This conditions forced people to grow rice and cotton. In 1992-1993 irrigated lands covered about 11% of the basin. Grasslands and shrub lands were prevailing in the basin covering 33.11 and 16.91 per cent respectively (Table 11). This picture has changed with the change in land use.

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Table 11 Land Cover characteristics data of Ili-Balkhash basin for 1992-1993 (USGS-EROS 1992)

Land cover Type	Area covered (km^2)	Percent
Urban and Built-Up Land	530	0.54
Dryland, Cropland & Pasture	8,215	8.35
Irrigated Cropland and Pasture	10,780	10.96
Cropland/Grassland Mosaic	9,525	9.68
Cropland/Woodland Mosaic	300	0.3
Grassland	32,570	33.11
Shrubland	16,635	16.91
Savanna	1,715	1.74
Deciduous Broadleaf Forest	495	0.5
Deciduous Needleleaf Forest	155	0.16
Evergreen Needleleaf Forest	200	0.2
Mixed Forest	3,205	3.26
Mixed Forest	3,205	3.26
Wooded Wetland	10	0.01
Barren or Sparsely Vegetated	8,985	9.13
Wooded Tundra	1,845	1.88
Wooded Wetland	10	0.01

4.2.3 Kazakhstan

Basin covers most part of Almaty region and small part of Zhambyl region. Area of the basin divided into two water districts, which consist of seven water use areas. The main consumer of water in all areas is a regular irrigation.

In recent years there was a reduction of irrigated agriculture on the Kazakh part of the basin and lower yields on them as well as degradation of pastures and desertification of areas of former flooded pastures (Table 12). Therefore the region has slowed the pace of economic development, industrial and agricultural production has declined. Pausing of agricultural production leads to a reduction in job places and migration of

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the rural population, especially young people, in the city. The biggest city of Kazakhstan Almaty is located in the Ili-Balkhash watershed and Kapchagay reservoir is providing drinking water for the city.Balkhash city uses water from the lake for household need and annually pumps up to 0.24 km^3. Also there are still some industries left which are responsible for 0.22 km3/year of water withdrawal from the lake. Currently, the area irrigated is about 350 thousand hectares. However in order to meet the needs of the population for food and industrial raw materials, the irrigated area in the basin should reach about 730 thousand hectares (Burlibayev 2011). Government of the Republic of Kazakhstan is planning to increase an irrigated area till the 583 thousand ha that will be considered as planned scenario in the "Development" sub-model.

Table 12Change of irrigated arable land area in the Ili – Balkhash basin, Kazakhstan (Modified from Burlibayev et al. 2011), see also Appendix Table 4

Year / Period	1945-46	1966-70	1976-80	1986-87	1992	1995	1996	2000
Thousands ha	322.00	405.30	499.60	583.20	617.60	359.60	508.90	346.30

4.2.4 China

For the last decade power China has been systematically working on maximizing of quite scarce water resources use. Therefore from the $585 billion Chinese economic stimulus package nearly 40% were invested in water infrastructure engineering and environmental projects. And two main direction of the water program are wastewater treatment and redistribution of water resources. It means that China is planning to build dams and channels that will reduce River flow to downstream countries. The government of China is planning the construction of channel transferring water from the Ili River to the Tarim River and replenishment of the salt lake Ebi-Nur(Feng and

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He 2009). This will cause misbalance in the ecosystem of Ili-Balkhash watershed. Current uptake of water from the Ili River by China is 3.5 km^3 per year that will rise at list up to 5 km^3/year (UNDP 2012). Therefore 5.5 km^3/year will be considered as a planed value in the "Development" sub-model in the scenarios of withdrawal change for irrigation purposes in China. The projected withdrawal will increase by 1.5 – 4.0 km^3/year that is 15 – 40 percent of average annual flow of Ili River on Chinese part of the river (Dostay 2011). That will increase water withdrawal by 7.5 km^3 per year in the worst scenario.Another value was stated as 7.4 km^3/year (Malkovskiy 2011). The reason is the intensive development of agricultural sector in Xingjian Uyghur Autonomous republic and corresponding expansion of arable land from 156 000 up to 570 000 ha in 2015 (Table 13). Average gross water consumption was estimated as 11 000 m^3/ha (Christiansen 2004; Quintas 2008).

Table 13 Dynamic of irrigated arable land area in the Ili – Balkhash basin, China (Modified from data from Institute of Geography)

Year /Period	1995	Planned
Thousands ha	156.00	569.40

This problem directly related to the overall situation in China that is dramatically "dehydrated". China is loosing at list thousands rivers annually. According to the results of the First National Census of Water (FNCW), published in April 2013 by the Ministry of Water Resources of China number of rivers reduced from 50000 counted in 1990 to 23000. Official governmental statement is that such big number can be explained by statistical mistakes as well as climate change and excessive water consumption by industries. Fast growth of cities and construction of industrial parks along with intensive agriculture often exhaust rivers. Most projects aimed to reserve

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water resources are carried out by interception and diversion of river flow. An intervention in natural flow of the river has drastic consequences for environment and leads to disappearing of rivers as can be summarized from the FNCW. Further more China is in the UN list of 13 countries with the greatest water scarcity with 300 million people cut form the water source.

5 Model

Model chapter has two subchapters and each of them divided in three more. Integrated model consist of parts representing the development of sub-models: hydrological or "starter"; climate change; and development or economical. In the Simulation subchapter scenarios are analyzed following the structure: climate change scenarios, development scenarios and combined scenarios.

5.1 Integrated model

The model has been developed in three steps. The river - lake water balance model has been used as base "starter" model. As the next step, the climate sub-model has been connected with hydrological sub-model. Finally, the "development" sub-model was developed including Kazakh and Chinese parts. All parts of the model are alternately connected, however the stages of sub-models development described separately.

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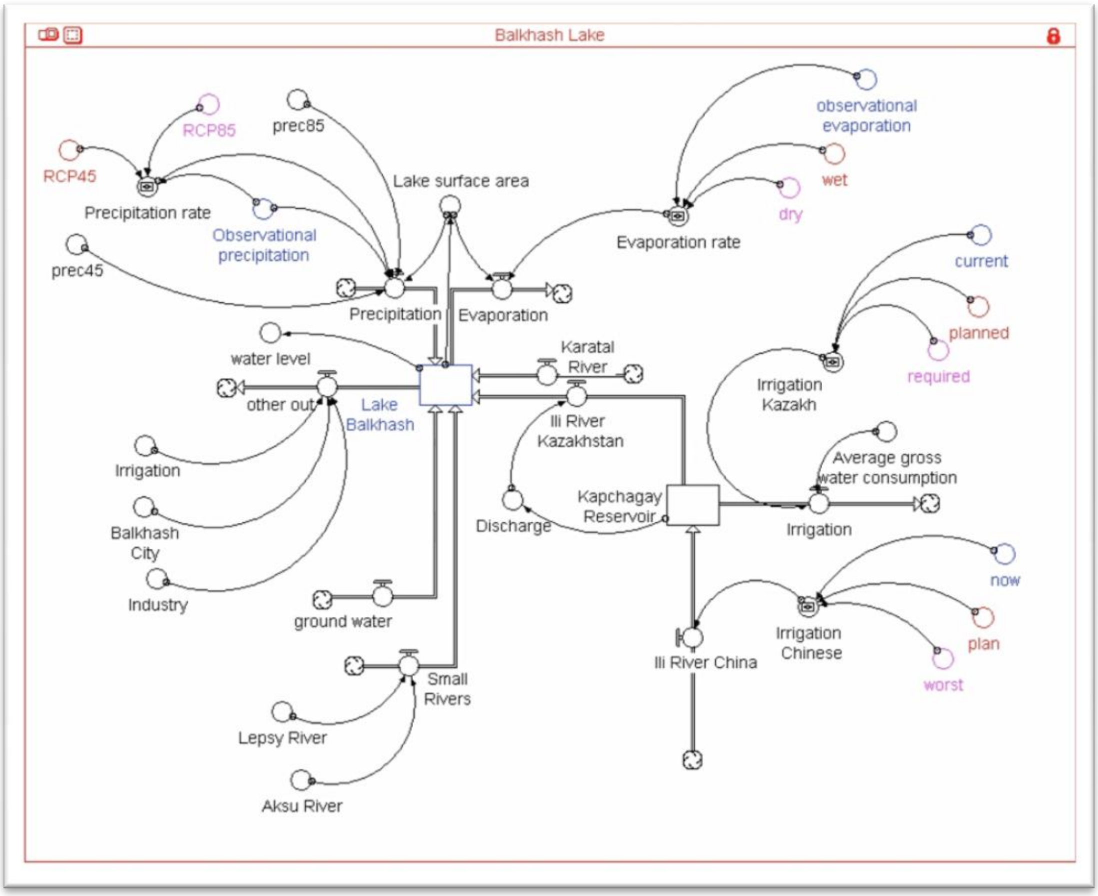

Figure 23 Integrated Ili-Balkhash basin model developed in STELLA 7.0.3

5.1.1 Hydrological "Starter" Sub-model

Firstly, in order to determine the amount of input water required for balanced conditions in the lake, the hydrological basis sub-model has been developed (Figure 24). It is important to understand a complex system dynamics of watershed hydrology. A total area of the basin is 512,010 km^2. The water in the Lake is the main stock where the accumulation takes place in the system. The stock was measured in km^3. The initial value of stock was set at 112 km^3 to represent the water stored in Lake Balkhash in 2000. The year was chosen as it shows average values for water level in the Lake. The principal flow into the Lake is the runoff from the Ili River with the smaller input from the Karatal (2.1 km^3/year), Lepsy (0.811

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km^3/year), Aksu (0.2935) as well as precipitation and ground water (0.08 km^3/year). The total of all rivers inflows is 17.5 km^3/year in the initial year in this case 2000. So there is a relatively constant inflow and naturally no outflow except evaporation.

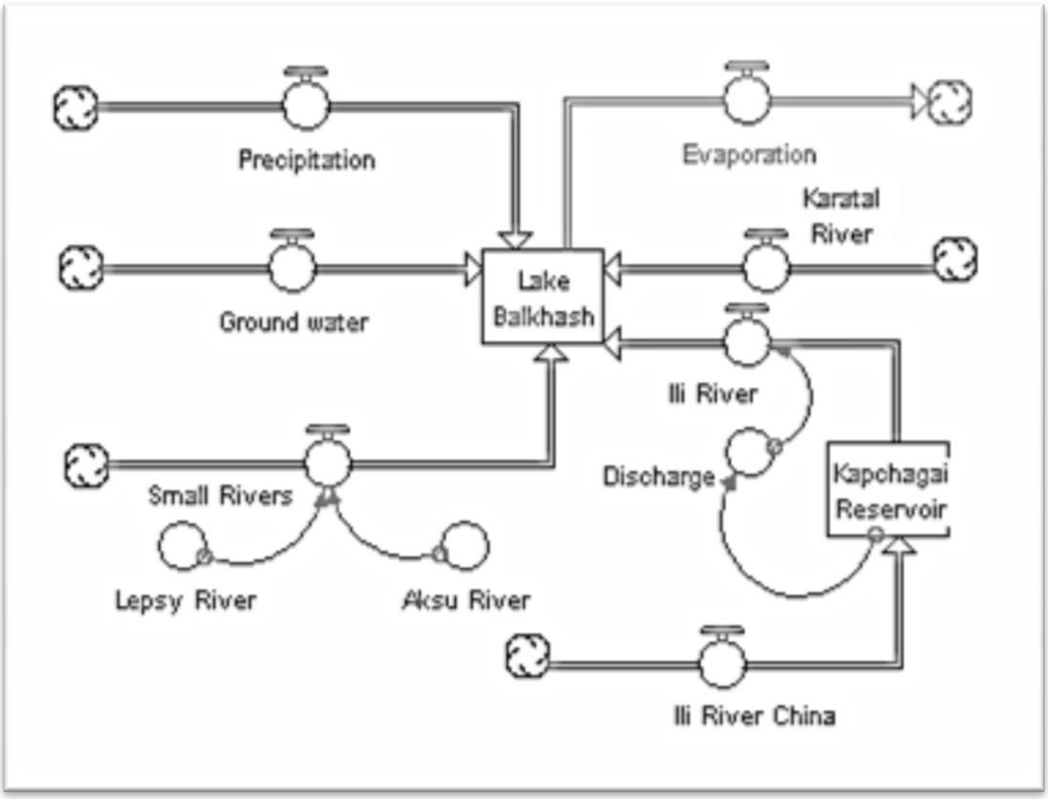

Figure 24 Hydrological sub-model with natural flows

Water level relation to the lake volume (Table 14) and dependence of surface area from the volume (Figure 25) was produced with the historical datafrom the different sources (Amanbayev 2011; Kazhydromet 2005; Malkovskiy 2011; Nomura 1999).

Table 14 Correlation between water level and water volume in the Lake Balkhash

Water level	340	340.5	341	341.5	342
Volume	<72	>72.1 and <85	>85.1 and <98	>98.1 and <110	>110.1

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The graph of lake level variation to lake volume was developed from the scenarios made by Malkovskiy and Toleubaeva (Malkovskiy 2011).

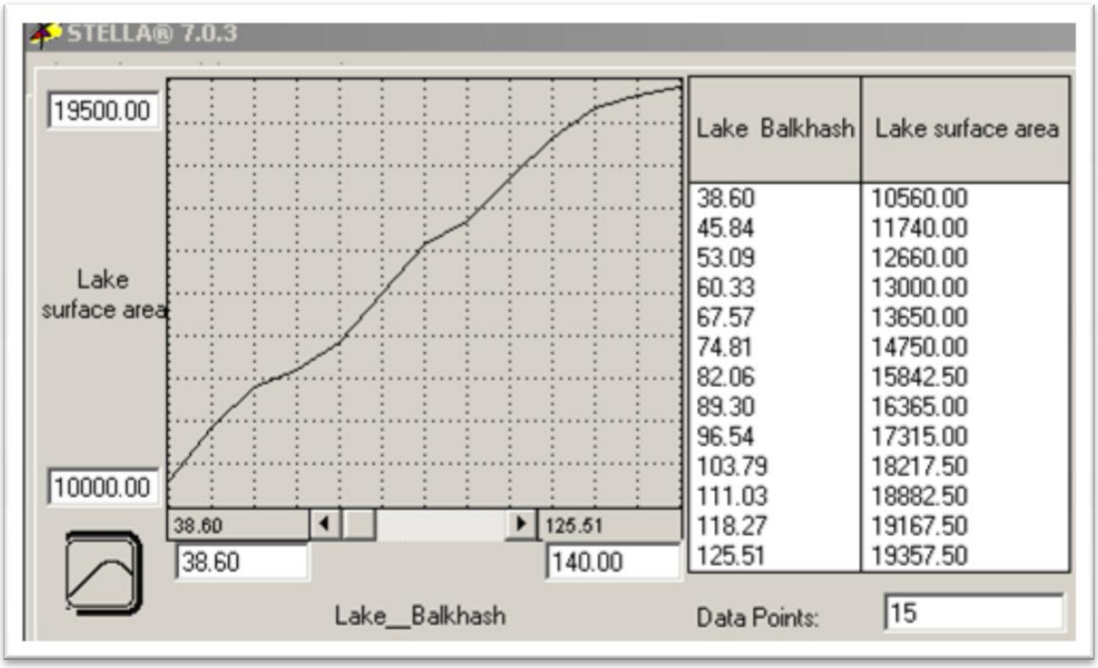

Figure 25 Correlation between water volume and surface area of the Lake Balkhash

Outflow has anthropogenic nature and will be added in the “Development” sub-model. The "Other Out" is a combination of water consumption for irrigations, industry, and household needs of the Balkhash City as can bee seen in Figure 23. Naturally a water loss from the system is due to evaporation.

5.1.2 Climate Change Sub-model and Scenarios

Therefore, secondly, evaporation has been set as conditional variable as an outflow that depends on climatic conditions and lake surface area. Climate sub-model based on meteorological data (Figure 26). The evaporation rate calculated using the values obtained from the literature.

It was assumed that volume of water correlates with lake surface area. The Climate Change Scenarios were considered in the calculation of the evaporation from the lake.

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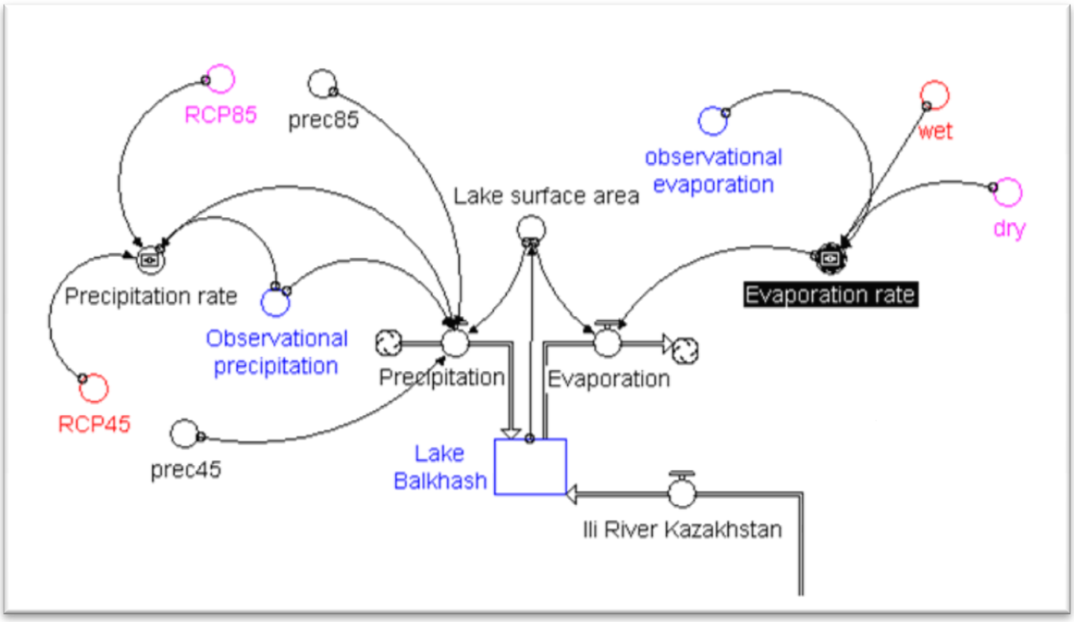

Figure 26 Climate change sub-model with scenarios

Climate change scenarios included two parts: precipitation and evaporation. Precipitation scenarios were based on the results of the downscaled climate change models. RCP4.5, RCP8.5 scenarios and observed precipitation make three scenarios for precipitation part. Observed precipitation is a fixed value calculated as a sum of monthly precipitation data from the Table 7. Annual rate of changein the RCP4.5 is -5.4673 to 25.0673 with 95% probability (Figure 10, Figure 27). In order to insert it in the model mean 9.799 and standard deviation 7.6336 was found. Annual rate of change in the RCP8.5 is -24.5930 to 26.0673 with 95% probability (Figure 11, Figure 28). For RCP8.5 mean is 0.7625 and standard deviation is 12.6775. NORMAL special purpose “built-in” function was used to generate a series of normally distributed random numbers with chosen mean and a standard deviation values. In the model those can be seen as two converters prec45 and prec84 (Figure 26). As flow in the model is in km^3/year all values was converted in km/year from the mm/year and than multiplied to the lake surface area (km^2). Slider input device was set on the

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precipitation rate converter. Switching between scenarios and observational data can be done on the Interface level of the model. That function simplifies process for decision makers.

Observed evaporation and scenariosbased on values mentioned in the several researches. It is assumed that equally to the RCP4.5 and RCP8.5 scenarios in Precipitation part there can be wet and dry scenarios for evaporation with 950 mm/year and 1200 mm/year respectively (Shnitnikov 2005). Observed or initial evaporation value is 1000 mm (Nomura 1999).

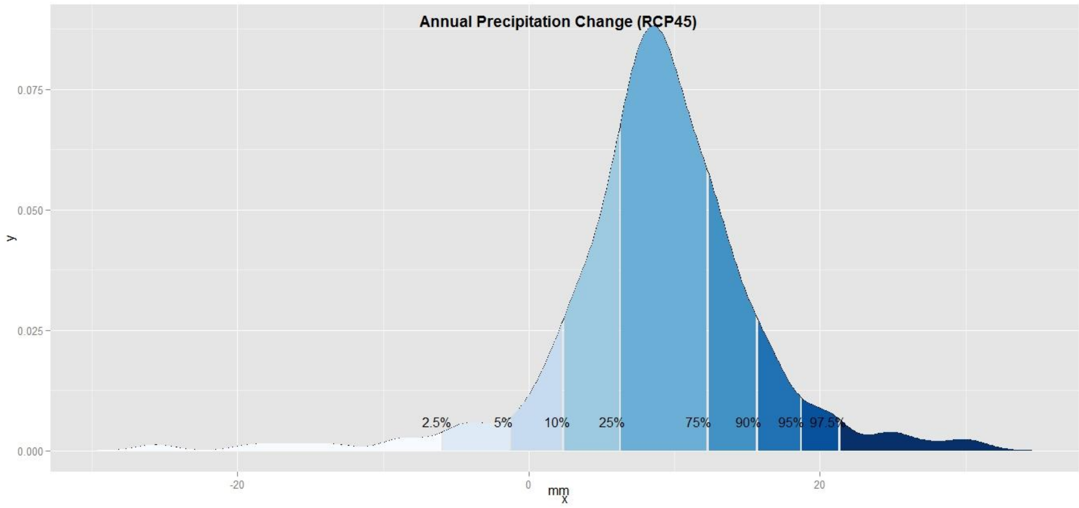

Figure 27 Annual changes in precipitation projection with confidence level under RCP45 scenario for 2020-2050

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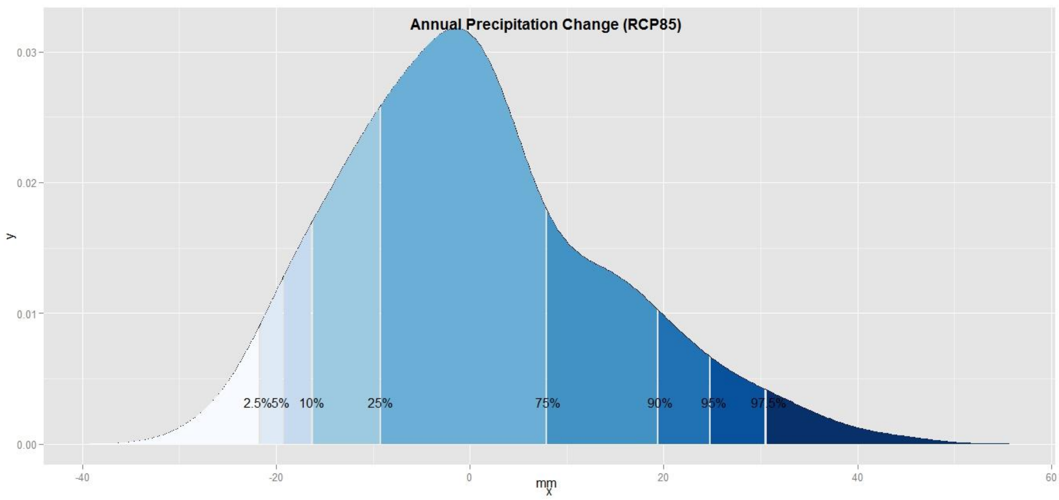

Figure 28 Annual changes in precipitation projection with confidence level under RCP45 scenario for 2020-2050

5.1.3 Economical "Development" Sub-model and Scenarios

Finally, development sub-model introduced the second stock in the system that is the Kapchagay reservoir that controls the Ili River discharge in the Kazakh part. The volume of water in the Lake is mainly depending on the volume of water discharged from the Reservoir. Also new outflow was added called "other out". It shows a sum of main water consuming practices around the Balkhash Lake such and irrigation, household in Balkhash City and water use by industry. The viewed inflow to the stock is the Ili River Discharge from the Chinese Xingjian region that is reduced by uptake for irrigation, which is different in several scenarios. The outflows from the reservoir are water loss due to evaporation and irrigation practices on the Kazakh part that is simulated in different scenarios according to the arable area size. Figure 29 shows main uptakes from the river with three scenarios of development for each country.

In 2000 water withdrawal from Ili River in China varied from 3.5 to 4.1 km^3/year, but for "Initial" (in the Figure 29 can be seen as "now") scenario 3.5 was taken as this number was confirmed by different studies (Christiansen 2004; Dostay *et al.* 2012; UNDP 2012). "Plan" scenario representsincreased uptake from the Ili River that

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Chinese government announced. The “Required” (in the Figure 29 can be seen as “worst”) scenario shows a concern of Kazakh researchers about the rise of water consumption in Xingjian and makes this value equal to 7.5 km^3/year.

According to analysis of development in Kazakh part of Ili-Balkhash basin, irrigated area was accounted for 346 300 ha in 2000. This is “Initial” (“current”) scenario.“Planned” scenario used 583 200 ha irrigated area in its calculation. “Required” scenario is one that consist projected area that could be sufficient in providing food for population in the basin and this value is as big as 730 000 ha. Average gross water consumption was converted in km^3/ha and was set as 1.1*10^-5. In order to calculate withdrawal from Ili River in Kazakhstan irrigated area and average gross water consumption were multiplied together.

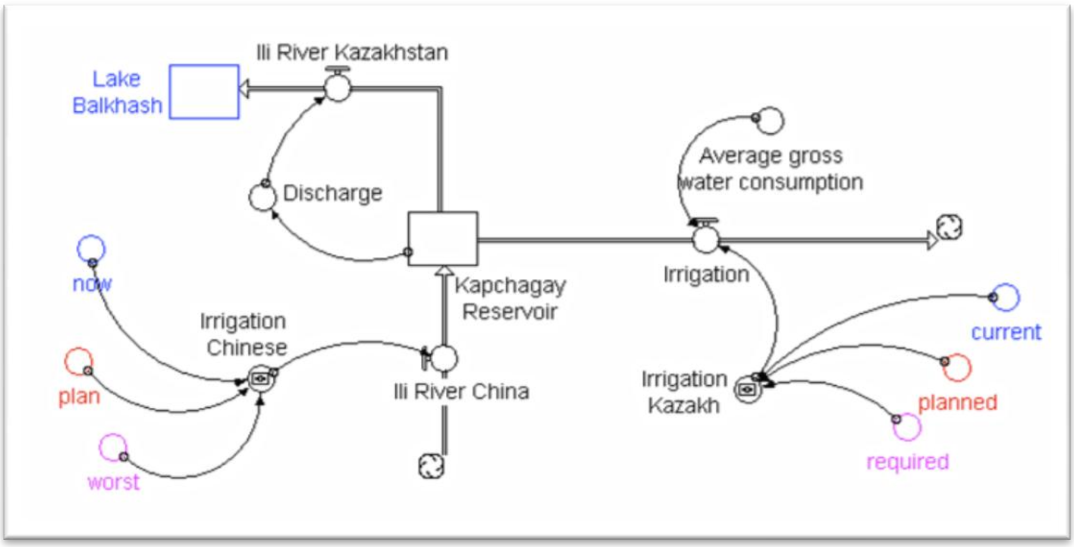

Figure 29 Sub-model of agricultural practices change in Kazakhstan and China

5.2 Scenarios Simulations

Nine main scenarios were allocated and simulated in the integrated model. Figure 30 shows codependence of scenarios and logic used in development process.Results of each set of scenarios is analyzed and discussed separately. First set shows an effect of

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natural change on ecosystem with initial data in “development” sub-model those were called “climate change scenarios”.

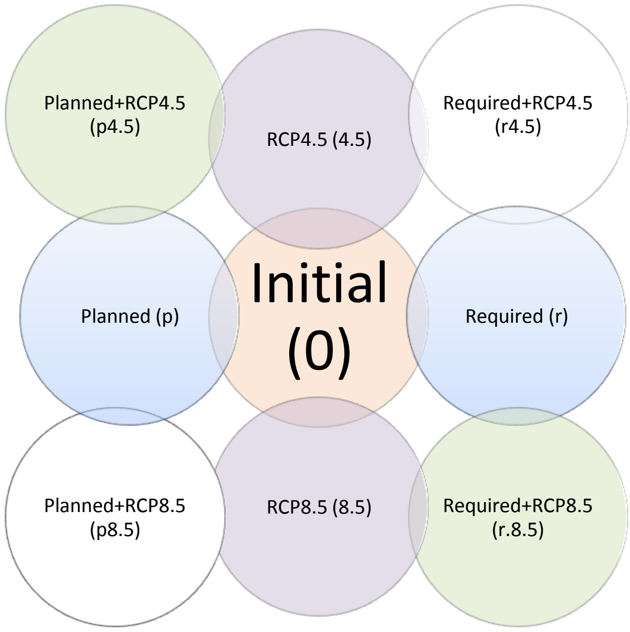

Figure 30 Scheme of scenarios

In the result table (Table 15)those can be seen as “4.5” and “8.5”. The “development” scenarios are simulated as coupled for two countries (“p” and “r”) and separately for each country. Four more scenarios present coupled simulations of natural and anthropogenic change (p4.5 and r.8.5) as well as p8.5 and r4.5 that was found to be less feasible. Table 15 and Figure 31 shows mean values of the volume of the Lake Balkhash from twenty simulations for each scenario.

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Table 15 Mean results of model simulation under different scenarios

Year/ Scenario	0	4.5	8.5	p	r	p4.5	p8.5	r4.5	r8.5
0	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00
1	111.05	113.44	107.86	110.39	109.89	112.77	106.56	112.84	106.32
2	109.17	114.12	102.51	108.06	105.66	113.38	100.59	111.34	99.15
3	107.42	114.83	98.09	103.48	97.41	111.57	92.86	105.40	88.63
4	105.77	115.33	94.22	99.24	89.88	109.08	87.29	99.26	78.31
5	104.23	116.06	90.17	95.36	82.89	106.69	82.30	93.66	70.00
6	103.78	117.33	88.28	89.89	76.41	103.37	75.16	88.66	62.83
7	102.38	118.03	85.06	87.10	72.80	102.26	71.00	86.44	58.31
8	101.11	119.07	82.11	82.25	65.43	98.83	65.64	79.76	49.33
9	99.94	120.30	79.59	77.75	58.59	95.75	60.09	73.64	41.21
10	98.87	121.01	77.47	73.65	52.38	92.54	54.91	68.44	34.49
11	98.87	122.53	76.02	72.22	47.22	92.25	52.37	64.38	28.36
12	97.89	123.29	73.65	68.74	42.54	89.69	47.81	60.68	22.38
13	97.00	124.11	72.11	65.59	38.35	87.24	43.58	56.99	16.71
14	96.18	125.12	71.11	62.60	34.37	84.36	40.12	53.35	11.17
15	95.44	125.68	69.70	62.07	30.40	84.19	38.71	50.11	6.05
16	95.09	127.09	69.23	59.32	26.42	81.87	35.47	47.03	2.57
17	94.45	127.87	68.25	56.69	22.44	79.60	31.80	44.02	0.51
18	94.83	130.05	68.69	54.12	21.47	77.21	28.28	43.91	1.17
19	94.21	131.16	67.61	53.97	16.49	77.56	27.29	40.15	0.44
20	93.64	132.01	66.81	51.58	11.51	75.58	24.24	36.67	0.13

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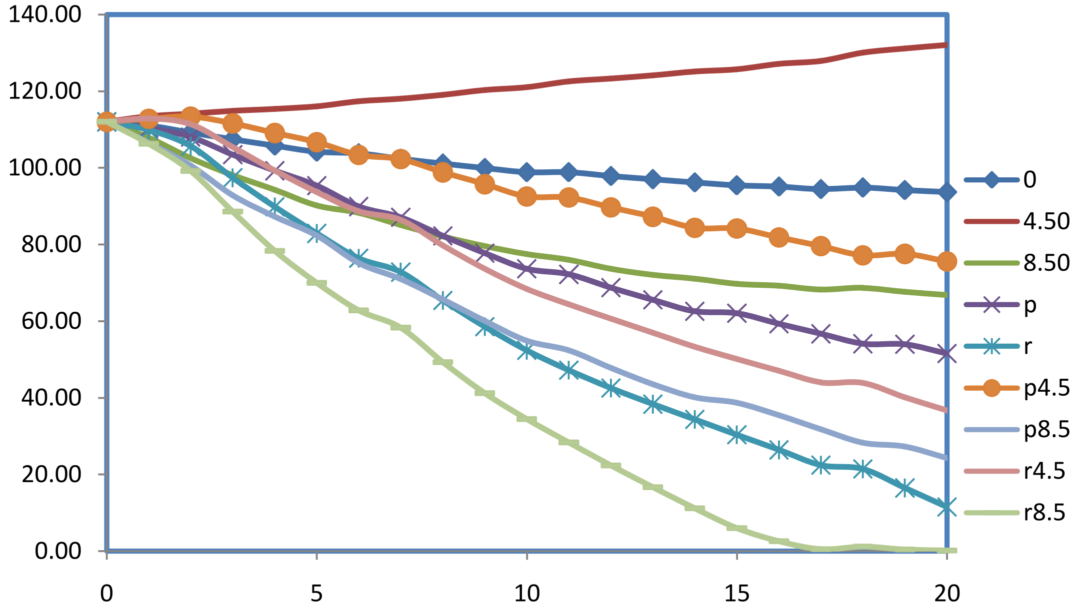

Figure 31 Comparison of the Balkhash Lake volume under nine scenarios

5.2.1 Climate change scenarios

Three Climate Change scenarios were simulated with initial "development " scenarios in order to analyze how natural changes can affect system (Table 16). "Observational" or initial scenario uses "current" values that were true for year 2000. The results are summarized in Table 16 and show 16.4% loss of the lake volume under current climate condition and management. Precipitation is 283.92 mm and evaporation is 1000 mm. Initial scenario in the Figure 32 can bee seen as blue line that shows gradual decline in lake volume.

Table 16 Summary of climate change scenarios

Scenario	Initial (0)	RCP4.5 (4.5)	RCP8.5 (8.5)
Precipitation	283.92 mm	Increase by 9.8 mm (SD 7.6336)	Increase by 0.8 mm (SD 12.6775)
Evaporation	1000 mm	950 mm (wet)	1200 mm (dry)

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The second scenario is combination of projected precipitation for RCP4.5 and “wet” year evaporation. Scenario 4.5 shows slight increase in lake volume in twenty years (Appendix Table 5). It is the only case with positive result. If land use in both countries will not change but climate will the lake starts to fill up. It is the second or red line in the Figure 32 that slightly rose. The line presenting considerable decline is the 8.5 scenario with higher rate of evaporation and dryer climate in general. This climate scenario leads to dramatic loss of water from the lake due to evaporation (Appendix Table 1). Lake declined nearly by 40.3% from its initial volume.

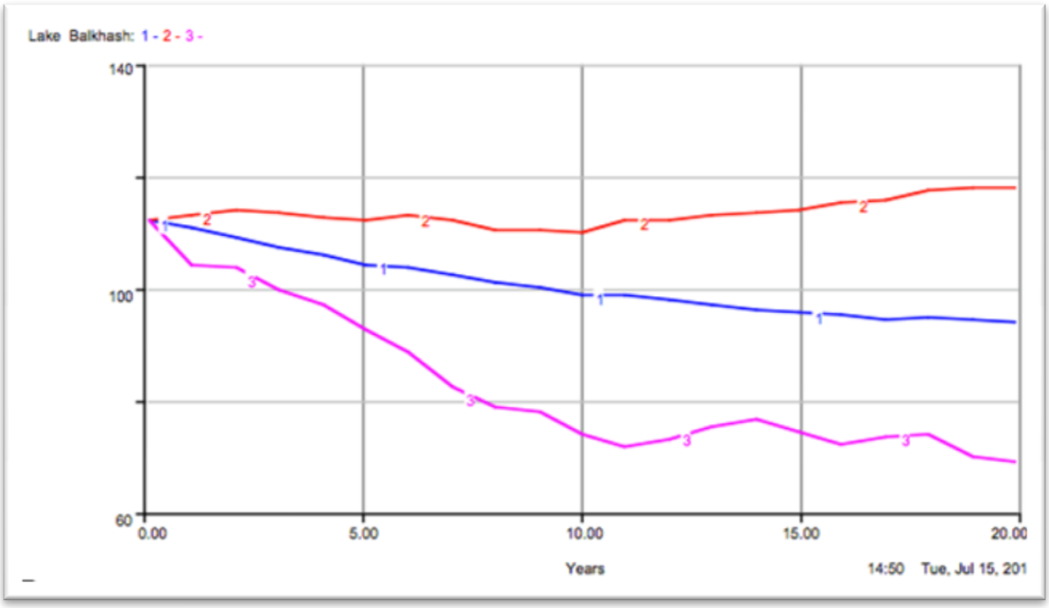

Figure 32 Results of climate change scenarios; change in the Balkhash Lake volume in twenty years

5.2.2 Economical development scenarios

Development scenarios were simulated and analyzed for China and Kazakhstan together (Figure 33) andseparately (Figure 34, Figure 35).

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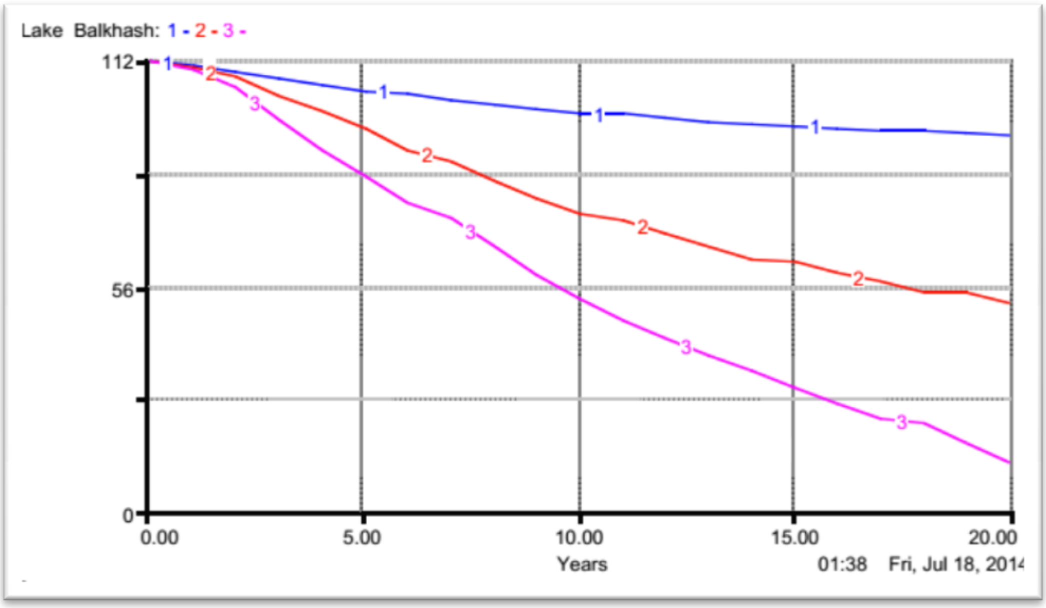

Figure 33 Change of the lake volume under three development scenarios: "current" (1), "planned" (2), "worst" (3)

The amount of water withdrawn by Chinese from Ili River for irrigation is increasing as the population in the region increase and so does consumption (Table 17).

Table 17 Summary of Chinese "development" scenarios

Scenario	Initial (0)	Planned (p)	Required (r)
Withdrawal for irrigation	3.5 km^3	5.5 km^3	7.5 km^3
Name in the model	“now”	“plan”	“worst”

Therefore Chinese has announced that the will uptake 5.5 km^3 that leads to decrease in lake volume as Figure 34 shows. However there are concerns that Chinese can required more water therefore will take 7.5 km^3 of River water annually. As the Ili River is counted as a main source of water for the Balkhash Lake change in water discharge from the upstream country plays considerable role in the water balance of the lake. We can see the dependence of the Lake volume from the amount of River water that Chinese discharge in the Figure 34.

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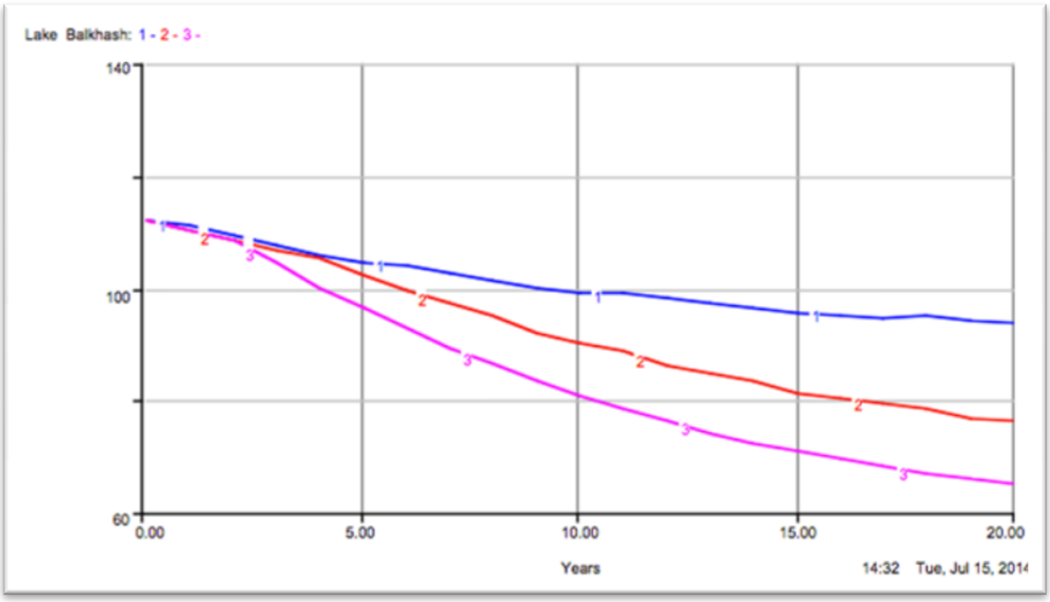

Figure 34 Results of scenarios of economical development in Chinese part

Currently in Kazakhstan agricultural lands are in decay in comparison with the soviet time. If irrigated area will stay in existing level the lake may face gradual decline as in the Figure 35 where Initial scenario marked with blue line. However Kazakh government is planning to increase arable land's territory that is "Planned" scenario whereas they need to increase it up to value that is fixed for "Required" scenario in the Table 18. "Required" means a required area to fulfill needs of population in food in the basin.

Table 18 Summary of Kazakh development scenarios

Scenario	Initial (0)	Planned (p)	Required (r)
Irrigated area	346 300 ha	583 200 ha	730 000 ha
Average gross water consumption		11000 m^3/ha	1.1*10^-5 km^3/ha

Those actions may affect the lake dramatically. The Figure 35 shows how actions of Kazakhstan itself can lead to the disasterand loss of nearly half of the Lake.

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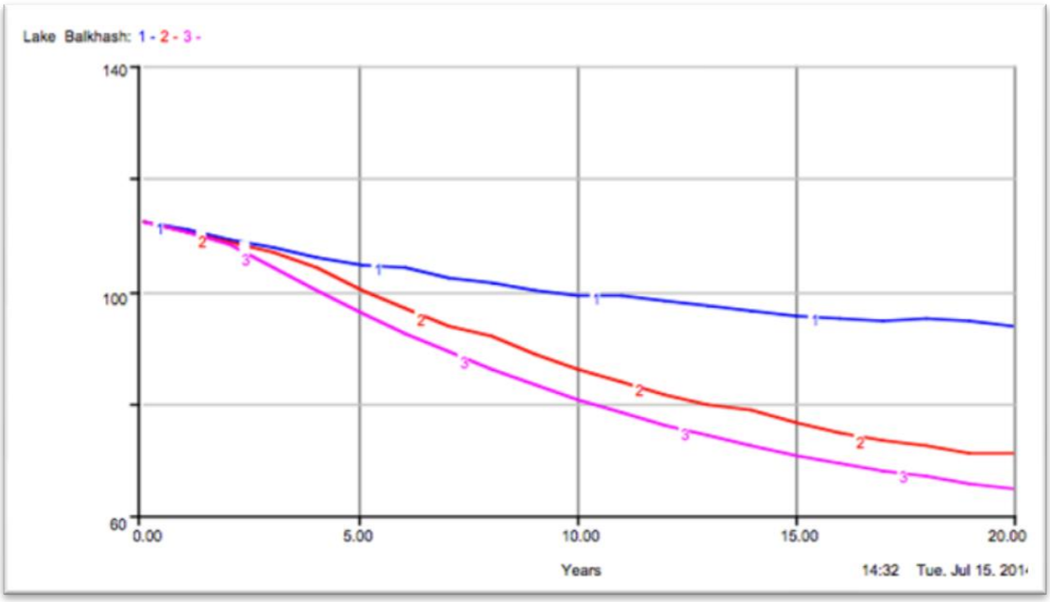

Figure 35 Results of scenarios of development of economy in Kazakh part

5.2.3 Combined scenarios

Two more simulations were done for combined scenarios of planned and required actions of Kazakhstan and China (Figure 38). In order to make it on the basis of initial climate conditions development sub-model was manipulated to show the reaction of Lake system on announced management scenarios (p) and one that was assumed from the literature (r) (Table 20).

If countries follow announced development plans and will increase water withdrawal from Ili River than the water level will drop until 340.0 m that is limiting state of the lake or minimum level when the basic functions of the lake can be kept. 340.5 m level is the lowest observed in the century. Lake will lose 30% of its area by decreasing from 19 000 km^2 to 13 300 km^2 (Figure 37).

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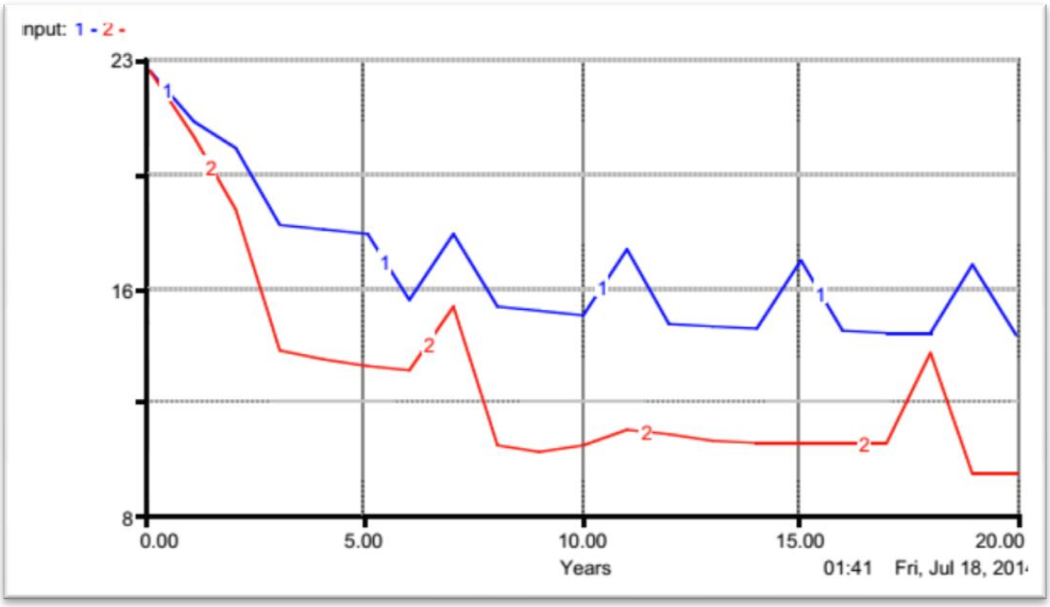

Figure 36 Comparison of input under "planned" (1) and "worst" (2) scenarios

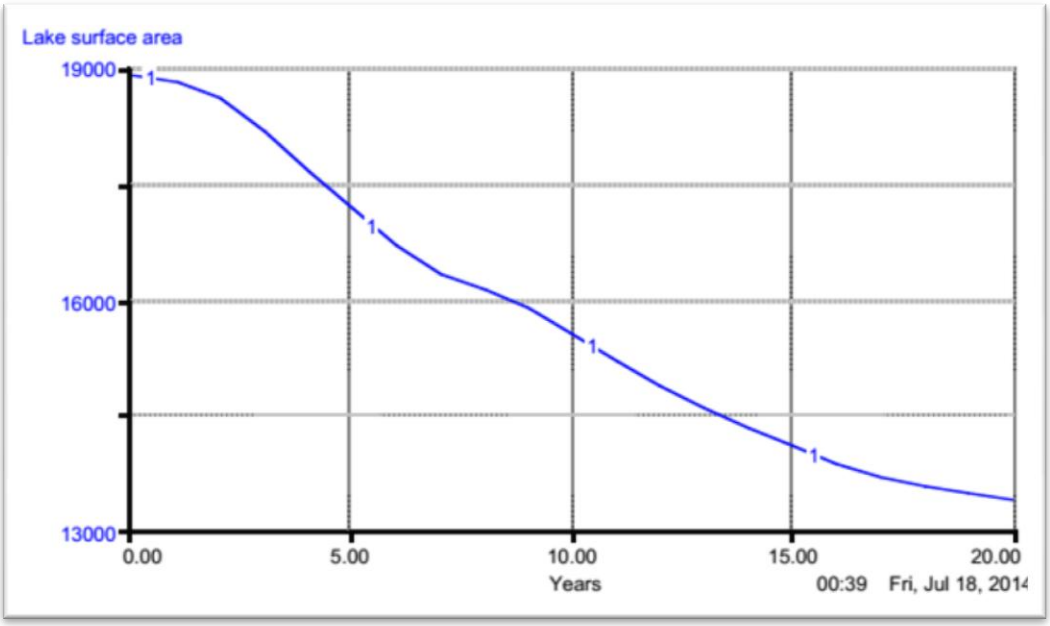

Figure 37 "Planned" development scenarios in the current climate condition, lake surface area change

If countries will suddenly decide to use maximum of the River water an amount of water in the lake becomes ten times smaller. However planned scenario does not show optimistic results. More than a half of the lake will be lost.

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Table 19 Results of combined planned and required scenarios for two countries

Year	Planned (p)	Required (r)
0	112	112
1	110.39	109.89
2	108.06	105.66
3	103.48	97.41
4	99.24	89.88
5	95.36	82.89
6	89.89	76.41
7	87.1	72.8
8	82.25	65.43
9	77.75	58.59
10	73.65	52.38
11	72.22	47.22
12	68.74	42.54
13	65.59	38.35
14	62.6	34.37
15	62.07	30.4
16	59.32	26.42
17	56.69	22.44
18	54.12	21.47
19	53.97	16.49
20	51.58	11.51

It is more likely that the climate will change in the future, as we are already facing a global warming and its consequences. Therefore climate scenarios should not be ignored. Four more sets of simulations were processed in order to get the results for

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joined climate and development scenarios (Appendix Table 7, Appendix Table 8, Appendix Table 9, Appendix Table 10). Mean values of simulations are presented in the Figure 38. Obviously, that scenario r8.5 is the worst one as the lake may dry out completely in sixteen years. In this scenario the worst conditions of the climate are coupled with the extreme predictions of land use change in Kazakhstan and China.

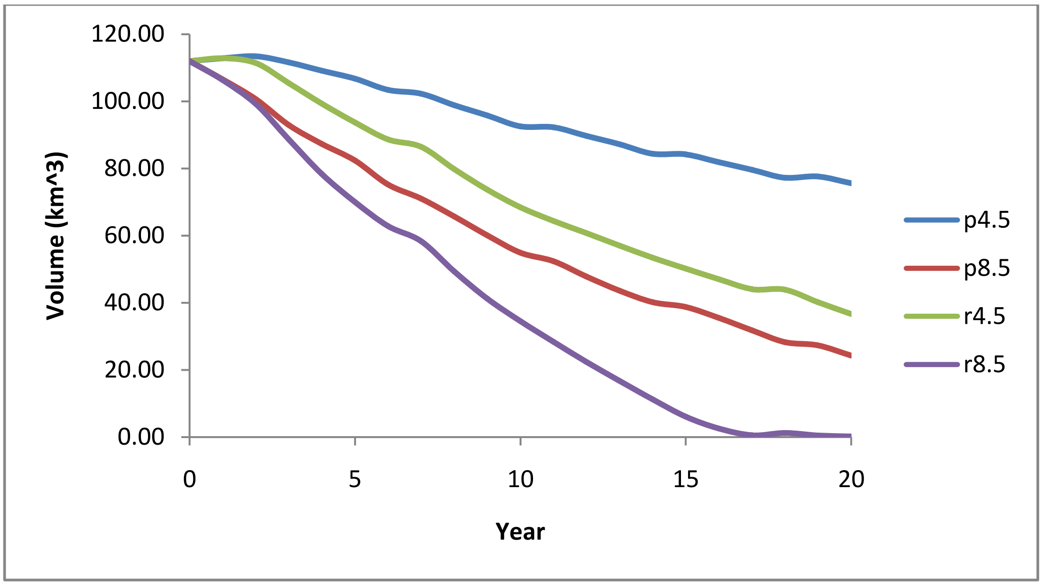

Figure 38 Mean results of the lake volume change under combined scenarios

It can be concluded from the obtained results that the climate changes are equally important as an anthropogenic interfere in the system of the rivers and the Lake.

6 Discussion

Discussion chapter includes three subchapters. Firstly outstanding results are discussed in the context of existing research and historical data. That allowed coming up with the recommendation on further development of the transboundary system. Finally limitations are described.

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6.1 Effect of environmental and economical change on the Lake Balkhash

Four combined scenarios were highlighted and discussed in this chapter (Figure 39). Firstly, an "Initial" (0) scenario was presented followed by three combined scenarios of climate and land usechange (4.5, p4.5 and r8.5).

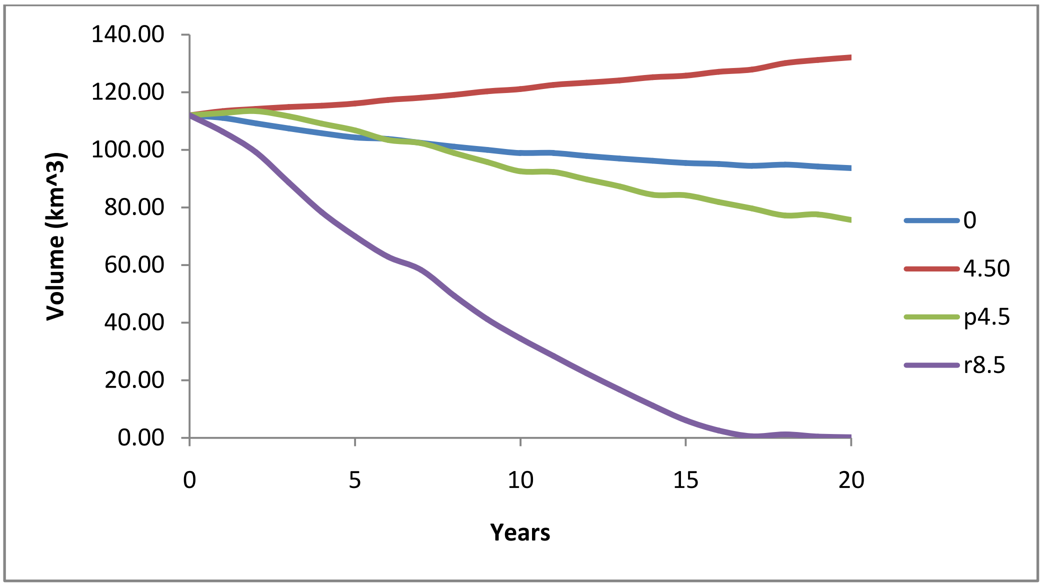

Figure 39 Mean results of the lake volume under four scenarios: 0, 4.5, p4.5, r8.5

The first is "initial" or "business as usual". It presents the projection of the system change for next twenty years without any changes in the management and climate.

This study showed that in case of "business as usual" scenarios when level of development for countries as well as climate projections will stay on the "current" level the lake will shrink. Sum of all outflows showed gradual fall in next twenty years whereas inflow dropped more dramatically with conspicuous fluctuations (Figure 40).

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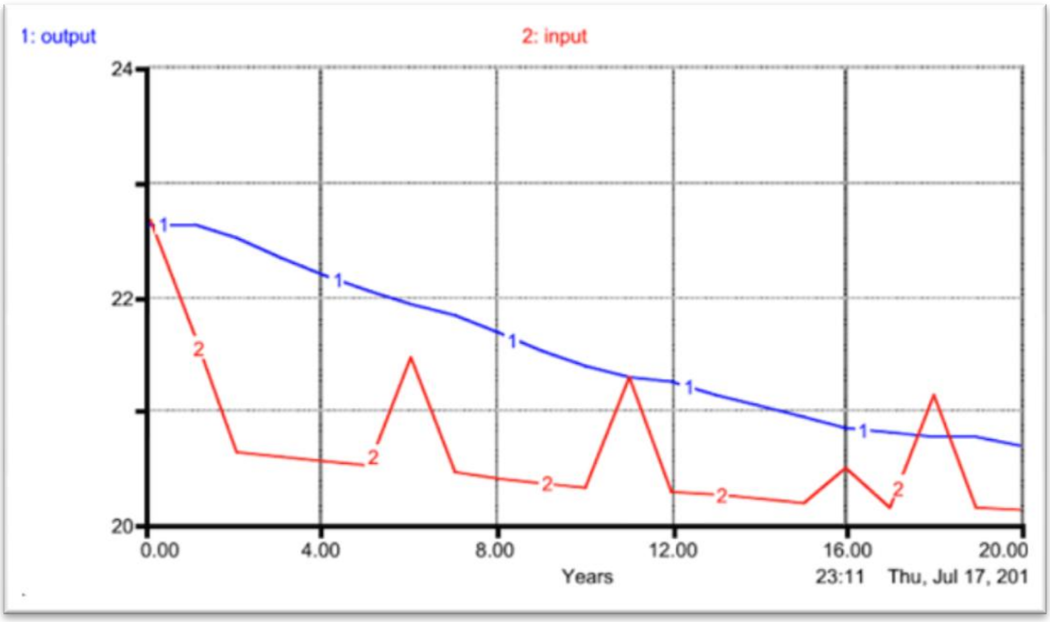

Figure 40 "Business as usual" for climate and development scenarios, output and input in the lake

Unbalanced water flows in the system can lead to the reduction of lake surface area (Figure 41). Therefore can be concluded that system is not sustainable in its current state. If there will be no change in the management of the basin the lake become smaller than it was in its critical years in the 1970s when Kapchagay Reservoir was filled. Visually this drop can be seen on the example of 2014 and 1978 conditions of Balkhash (Figure 20, Figure 19). This trend is supported by number of researches and raises concerns of Kazakh authorities and international agencies such as The Central Asia Regional Economic Cooperation (CAREC) and UNDP – United Nations Development (Amanbayev 2011; Carec 2007; Dostay *et al.* 2012; Kazhydromet 2005; Quintas 2008). In twenty years the lake will reach its ecological optimal or water level of 341 m. According to previous researches this levels allow to preserve the lake under it natural conditions (Malkovskiy 2011).

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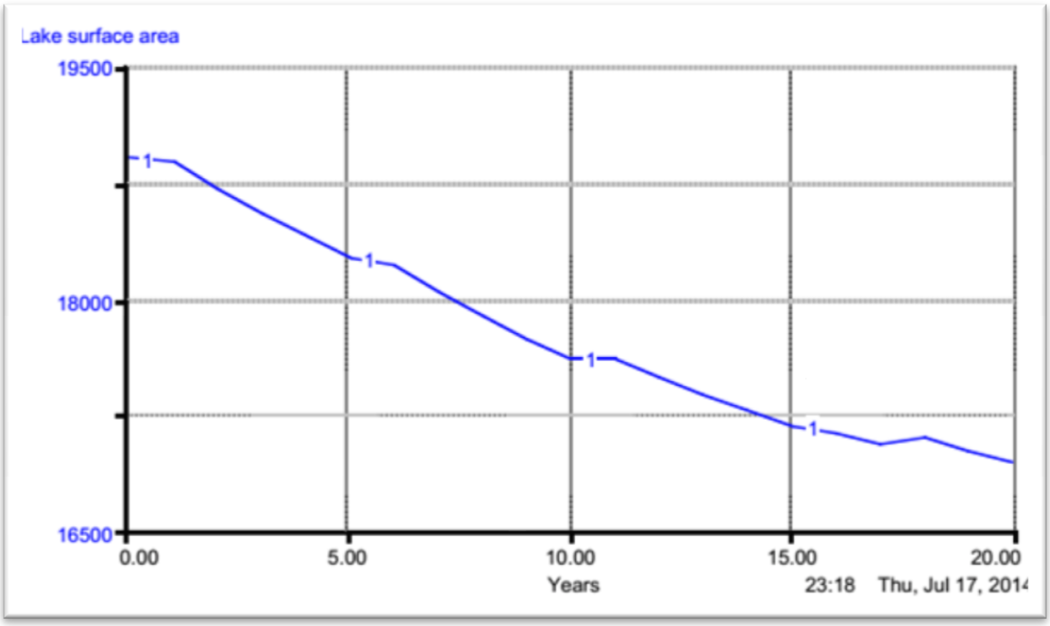

Figure 41 "Business as usual" for climate and development scenarios, lake surface area change

Land use and land cover interrelatedwith the CO2 emissions and climate change (Wise *et al.* 2009). Therefore if there will be changes in land use and rapid growth in industry the climate will respond respectively. In the Figure 42 an overall input of water in the Lake is presented and under same climate condition in the scenarios 4.5 (blue line) and p4.5 (red line) volume can vary a lot under an effect of economic activity. The water volume of the Lake starts to rise with an increase in evaporation and decrease in evaporation but only if irrigated area is still untouched as in the “4.5” scenario (blue line in the Figure 43). The most dramatic change will face the Lake if system will develop in the r8.5 scenario. The Lake Balkhash may dry out completely in fifteen years and country will have to deal with the disaster worse that the Aral Sea case. However it is not a sudden degradation of the system as it was under stress in the end of the last century.A desertification of rich with biota deltas has started during the Soviet time because of inappropriate agricultural development and mining of copper ore (Mnatsakanian 1992).

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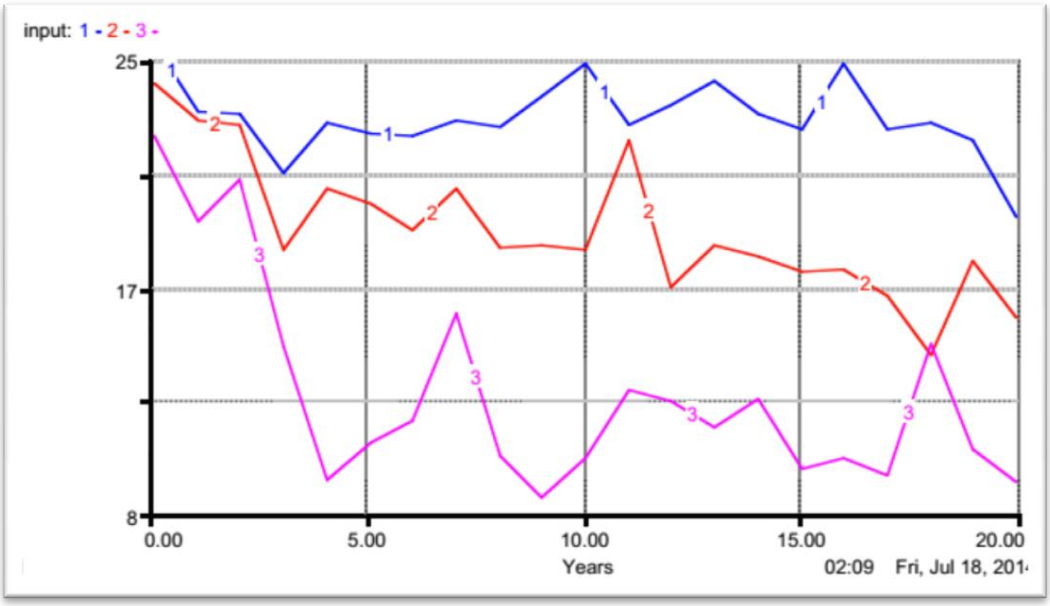

Figure 42 Combination of climate change scenarios and development scenarios effecting input into the lake: "4.5" (1), "p4.5" (2), "r8.5" (3)

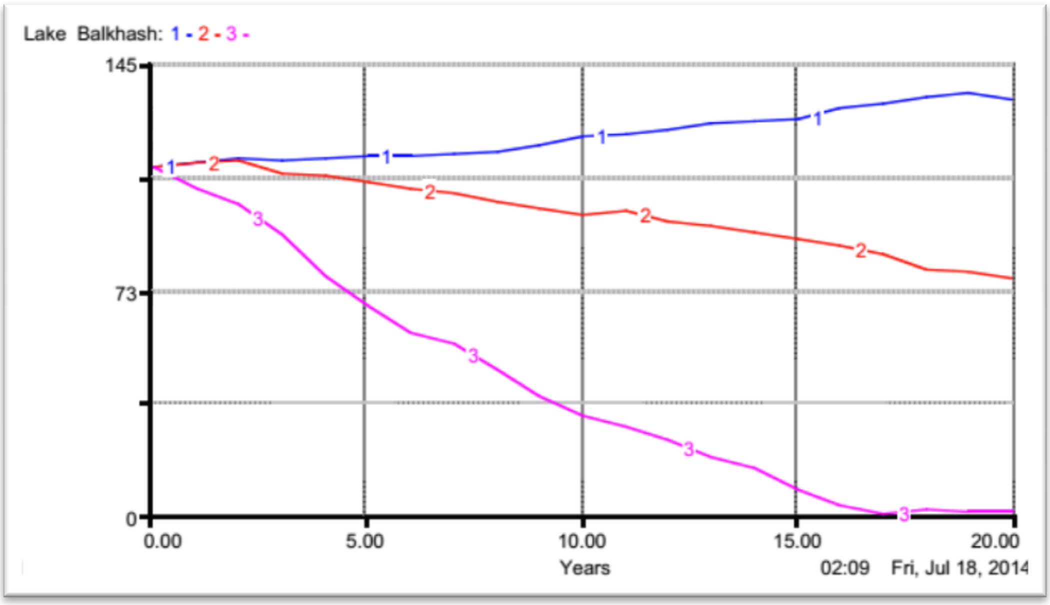

Figure 43 Combination of climate change scenarios and development scenarios effecting volume of the lake: "4.5" (1), "p4.5" (2), "r8.5" (3)

The most probable scenario p4.5 presents the combination of preferable scenarios of climate (RCP4.5) and planned development. RCP 4.5 is a stabilization scenario as CO2 concentration, CH4 emissions and total radiative forcing are on the almost stable

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medium level without dramatic changes(van Vuuren *et al.* 2011; Wise *et al.* 2009). This effect reached by underlined socio-economical models that included low emissions and climate policy scenarios(van Vuuren *et al.* 2011). However there are some inconsistences in the scenarios used during the development of RCP4.5 and the "Development" scenarios used in this work. An RCP4.5 assumes the reduction of agricultural lands and change in land use in the direction of reforestation and recovery of natural ecosystems. This should be achieved by change of dietary and innovations in the field of productivity of agriculture (van Vuuren *et al.* 2011). Whereas "planned" development scenarios implies an increase of arable lands in the future. Therefore those development scenarios for Xingjian and Kazakhstan and climate change scenario are joined as the most plausible.

However there was the only one scenario that showed a positive result. Called the "best" or "4.5" and assumes the RCP4.5 climate change scenario and continuation of existing pattern of agricultural activity. The lake should to start to expand and its volume rise. It is almost the right combination if the RCP scenarios were developed taking into consideration an average land cover pattern in the world. Whereas developed countries are more effected by human than Kazakhstan and China that still in transition. Also the territories of these countries exceed countries in Europe several times. It can be argued that China is developing fast and its population density is really high but in case of North-West of China it is not quite true. As the most of the population of the Xingjian is represented by Chinese ethnic minority and less densely populated. Uighurs continuously fight for independence of East Turkestan (Xingjian) from the nineteenth century (Hastings 2005). East Turkestan has similar problems as Karakalpakstan living on the South to the Aral Sea in Uzbekistan that has no support from the central governments and facing poverty and devastation.

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However unlike Uzbek Government, which was passive in their punitive actions and just waited when the ecological disaster with the Aral Sea will force unfavorable population to migrate China has the enforced Chinese from central part of the country to the problematic province. Therefore it is quite likely that China will actively develop industry and agriculture in this region. Thereat r8.5 scenario can happen as well. The high energy–intensive climate scenario RCP8.5 differs from the previous ones by rapidly increasing CH_4, N_2O as well as CO_2because of dramatic growth of low-income population(van Vuuren *et al.* 2011). This will increase an area of irrigated agricultural lands to fulfill the needs of those people. This fact does not contradict the “Development” scenario called “Required”. Where an increase of water consumption for agricultural purposes were projected.

6.2 Recommendation

The management before IWRM failed as it was focused only on one narrow goal and for new management it can be suggested to pause and try to look at the problem outside the economical benefit and see broader picture into win-win relationship with environment or with more appropriate economic projects. That is the point when integrated model become handy. It is important to reflect the past experience to avoid the same mistakes(Gosling and Mintzberg 2003). The issue cannot be managed without the proper analysis of the situation, continues monitoring and independent auditing that should help to understand the local conditions. Not only agricultural management requires a correction but also energy sector place an importantpart in the future of the system. As all climate scenarios assumes an improvement of policies and reduction of green house gas emissions. An identification of appropriate for this region alternative energy sources and agricultural technologies and practices is

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required. For instances the high water consuming monocultures can be replaced by more suitable for arid area cultures. More money can be allocated for projects studying the efficiency of agriculture. Also state governments should promote water saving behavior through the education and environmental awareness with the help of NGOs. Effective water management action "requires the collective effort of women and men" on local and national level and should be "linked with country's overall sustainable development strategy and public administration framework" (Kattelus 2009).

6.3 Limitation

Data collection was limited by information that could be found online or in the official reports. Kazakh authorities provided data of land use change in China therefore it can be argued. Chinese authorities do not publish such data. Also unstable situation in Uyghur autonomy makes a field trip to the area difficult. Limited funding does not allow to travel to the study side as it is remote are from the university.

Limitation of remote sensing in this work was in the limited time for repetitive experiments or comparison of different technics. For instance, water surface from the Landsat 5 mission was extracted using MNDWI and showed quite good results however cannot be used as should not be compared with the results of NDWI.

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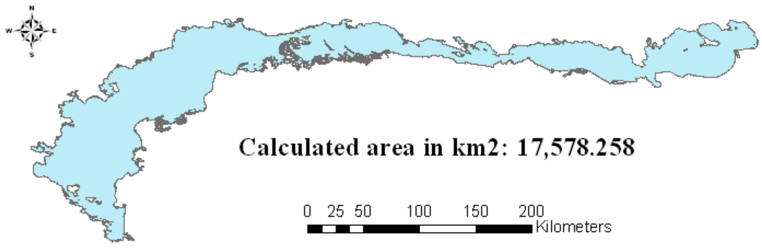

Figure 44 Extracted surface area of the Balkhash Lake from Landsat 5 images using MNDWI

Modeling itself cannot represent a complex system existing in the real life. Therefore it is the main limitation of the model that it consist of what the author decides is important or makes significant change. Model can be easily expended if other researchers will be interested in it. It also can be completed by some specific information that is required for decision makers.

7 Conclusion

An analysis of current state of the Ili-Balkhash system showed that the system is unstable. An Initial scenario showed a decrease of water volume. Therefore there was a need to find how the consumption patterns in China and Kazakhstan can affect the water balance of the lake. It was found that there are natural oscillations in the water level of the Balkhash Lake due to climate change. However, the development of countries' economy controls an extentof the natural change. RCP4.5 and RCP8.5 scenarios used in the model assume that lands use pattern will change in the future as well as energy consumption behavior. Change in agricultural practices of Xingjian and Kazakhstan in the basin will directly affect the lake. As in the "planned" and "required" development scenarios withdrawal of water from the River Ili has increased and lake started to shallow. The best scenario (4.5) assumes that the climate become wetter in the future and the area of irrigated land will not grow. However this

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is unlikely taking in the account the rapid population growth in China. In order to follow the RCP4.5 countries would need to revise the legislation and support clean technologies and alternative energy. More probable is the result of simulation of scenario p4.5. The irrigated area will increase as planned. That will reduce the flow to the Balkhash Lake but will be partially compensated by precipitation. Therefore lake could be saved on the optimal level for ecosystem to survive. But taking into consideration the failure of negotiation between countries and the consumption behavior of developing countries the worst scenario (r8.5) can be possible. If Chinese will continue their strategy of relocation of Chinese population from the center of the country to the Xingjian they will use more water than they announced. As Uighur is minority in the China the possibility that China will invest a lot of money in the region is small. This fact leads to the increase of low-income population with an employment in the agricultural sector.

An integrated model shows the complexity of the system and a need in the multi-faced way of solving the issue. A model can be handy for decision-makers in the process of development of bilateral agreements and setting the limits of withdrawalfrom the transboundary river Ili. The developed model is easy to use and results are visual and understandable for specialists from the different fields.

The problem of the Balkhash Lake requires more attention from the international community, as it should not repeat the fate of Aral Sea. There is need in the research of water quality and more projects involving international specialist in the field of watershed modeling. Future studies should include work with local population in order to develop the management strategy and keep the tradition way of life of people.

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Appendix

Appendix tables

Appendix Table 1 Results of temperature projections for 9 models: historical, RCP45, RCP85

Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BCC-CSM1-1_Hist	-10,16	-7,42	-3,15	5,73	12,95	19,32	22,57	18,34	12	3,3	-3,14	-9,27
RCP45	-7,83	-6,12	-1,3	6,63	15,12	21,19	24,08	20,74	13,88	4,98	-1,06	-5,53
RCP85	-6,62	-6,34	-0,59	7,56	15,18	21	24,66	21,41	14,51	5,27	-1,52	-5,34
CCSM4_Hist	-9,78	-9,11	-2,22	8,34	17,08	22,43	25,18	23,16	15,58	6,27	-0,31	-6,83
RCP45	-8,74	-5	1,19	10,32	19,06	25,1	27,55	25,37	17,59	8,36	1,94	-5,38
RCP85	-6,77	-4,81	1,81	10,82	19,08	25,02	27,75	25,7	18,43	8,9	0,18	-3,96
CESM1-CAM5_Hist	-14,56	-12,66	-4,16	8,2	17,25	22,51	24,13	22,17	15,21	6,82	-1,24	-9,22
RCP45	-11,32	-10,03	-0,21	11,16	18,84	24,62	26,99	24,75	17,02	7,87	0,54	-7,01
RCP85	-10,22	-8,6	-0,4	11,4	19,31	25,14	27,19	25,24	17,65	8,69	0,66	-6,39

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IPSL_CM5A-LR_Hist	-10,76	-9,94	-4,02	3,94	12,88	18,76	21,7	20,08	12,57	3,75	-4,77	-8,98
RCP45	-8,38	-8,29	-1,81	6,68	15,37	21,5	24,89	23,73	16,04	6,56	-2,61	-6,84
RCP85	-8,87	-5,48	-1,13	6,8	15,5	21,57	25,12	23,56	16,51	7,51	-1,42	-6,73
IPSL-CM5A-MR_HIst	-10,13	-7,63	-1,67	6,17	13,96	19,67	23,01	21,29	14	4,45	-2,84	-9,32
RCP45	-7,41	-4,7	0,34	8,1	16,29	22,37	26,02	24,32	16,45	6,72	-0,78	-5,55
RCP85	-7,55	-5,18	1,26	9,01	16,35	22,66	26,38	25,07	17,51	6,89	-1,07	-4,8
MIROC-ESM-CHEM_Hist	-8,09	-7,8	-2,11	6,51	15,06	21,6	24,54	21,71	14,14	5,99	-1,5	-5,88
RCP45	-5,55	-4,29	1,47	8,81	17,43	23,48	27,16	25,1	17,03	8,71	1,87	-3,14
RCP85	-3,61	-3,04	2,21	10,51	17,79	24,48	27,78	25,21	17,18	8,77	1,77	-2,03
MIROC5	-8,24	-6,09	0,34	9,72	17,41	25,1	27,77	24,74	16,29	6,55	-0,23	-6,15
RCP45	-6,82	-3,77	3,64	12,13	19,76	27,2	30,28	27,63	19,23	9,2	1,78	-4,85
RCP85	-6,13	-3,42	3,34	12,34	20,42	27,22	30,32	27,71	19,98	8,99	1,57	-3,7
MRI-CGCM3_Hist	-10,4	-7,28	-1,55	8,22	16,17	23,36	24,8	21,75	14,08	5,18	-3,46	-8,81
RCP45	-9,05	-6,39	0,51	8,36	16,55	23,93	26,11	22,47	15,2	6,82	-1,66	-6,47
RCP85	-9,13	-5,56	0,96	8,68	16,35	24,3	26,68	22,42	15,2	6,96	-0,94	-6,53
GISS-E2-R_Hist	-6,15	-5,53	-1,59	4,37	11,44	16,58	19,54	18,29	13,24	6,47	0,95	-3,38

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RCP45	-3,93	-3,59	0,08	6,16	12,48	17,57	19,76	19,15	14,36	8,4	2,67	-1,53
RCP85	-3,06	-3,07	0,17	6,67	12,43	18,01	20,13	19,53	14,89	8,79	3,31	-1,75

Appendix Table 2 Results of precipitation projections for 9 models: historical, RCP45, RCP85

Model	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
BCC-CSM1-1_Hist	32,26	32,18	31,88	29,08	29,97	26,84	17,49	9,2	14,04	30,72	37,59	30,32
RCP45	34,81	33,25	36,19	34,77	31,04	28,29	18,8	9,78	15,02	27,94	35,28	37,22
RCP85	39,05	35,45	33,17	34,29	32,1	29,3	16,55	11,18	15,05	29,3	34,25	38,73
CCSM4_Hist	26,24	24,19	23,54	26,7	27,39	31,84	28,28	17,31	11,6	31,09	27,59	30,63
RCP45	26,06	27,09	25,78	30,28	29,52	29,22	22,35	14,1	11,87	16,61	26,25	30,63
RCP85	28,09	29,59	26,53	27,5	29,39	30,79	28,79	13,57	12,14	19,29	25,97	28,23
CESM1-CAM5_Hist	16,71	15,39	13,56	21,62	19,94	26,84	32,15	18,19	10,27	19,17	21,74	20,11
RCP45	18,38	14,44	15,73	25,47	22,24	28,33	33,03	21,3	11,21	13,53	21,7	20,77
RCP85	16,45	15,99	20,26	22,38	20,65	24,57	29,62	22,2	10,47	14,86	21,01	20,41
IPSL_CM5A-LR_Hist	34,64	28,36	33,15	27,2	26,5	33,49	37,69	14,02	20,26	36,31	41,25	35,99

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RCP45	41,6	32,53	30,64	26,51	25,83	30,36	27,13	13,13	14,12	27,5	39,99	42,01
RCP85	42,47	38,54	26,99	24,43	29,07	34,26	25,4	15,58	15,34	28,41	41,81	37,08
IPSL-CM5A-MR_HIst	31,71	28,04	28,29	21,6	19,94	23,95	23,89	11,13	9,96	31,8	34,01	31,84
RCP45	37,87	32,84	23,52	19,9	19,59	28,45	20,24	12,44	11,2	23,68	32,75	41,01
RCP85	33,37	28,14	27,13	18,81	19,98	22,34	20,75	11,01	10,73	21,87	28,99	33,34
MIROC-ESM-CHEM_Hist	38,85	31,06	30,87	39,35	53,19	58,36	62,81	39,88	28,95	39,62	35,56	40,53
RCP45	37,42	34,78	35,26	47,35	59,55	80,11	60,28	43,22	36,42	36,91	48,78	44,38
RCP85	45,19	39,27	36,58	48,93	65,28	70,38	63,17	50,69	35,15	38,54	45,04	44,4
MIROC5	16,63	18,54	21,25	22,79	19,69	20,12	22,75	14,35	14,84	13,57	20,29	13,51
RCP45	16,36	19,63	21,65	24,45	23,55	21,86	22,98	15,6	13,9	21,24	20,57	17,77
RCP85	20,75	21,44	23,11	24,36	23,63	23,68	21,77	14,21	15,17	22,55	24,55	21,66
MRI-CGCM3_Hist	23,42	19,13	19,89	24,57	19,87	12,73	18,8	11,17	10,93	23,18	20,09	23,48
RCP45	25,99	23,05	27,9	29,97	27,01	19,5	18,37	11,91	10,07	24,96	28,31	26,23
RCP85	24,26	26,58	26,33	30,69	29,36	18,1	17,3	14,46	10,78	19,59	31,94	28,22
GISS-E2-R_Hist	44,99	40,46	37,75	37,44	38,65	40,96	38,75	36,43	41,75	51,85	52,57	49,69
RCP45	53,32	46,13	41,14	41,63	44,3	44,69	40,05	38,74	51,72	60,87	60,12	55,63

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RCP85	49,13	47,87	43,21	40,35	42,68	43,8	45,02	33,55	45,23	59,39	63,59	50,42

Appendix Table 3 Results of evaporation projections for 9 models: historical, RCP45, RCP85

Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BCC-CSM1-1_Hist	8,60	13,32	24,56	32,41	36,91	32,44	19,41	10,71	12,69	17,05	13,67	8,54
RCP45	10,32	14,84	27,12	39,02	41,18	37,89	21,26	11,47	13,50	19,27	15,08	9,65
RCP85	9,81	15,41	26,92	38,80	40,94	38,12	19,19	12,49	13,44	20,09	14,64	10,47
CCSM4_Hist	3,15	6,95	19,85	45,62	50,31	54,12	49,38	34,46	20,58	19,20	11,63	5,46
RCP45	4,68	10,06	25,78	46,63	51,72	53,12	44,80	30,54	20,53	17,58	12,91	6,95
RCP85	6,14	10,64	27,80	45,06	51,48	53,95	48,84	31,18	20,64	18,34	12,82	7,29
CESM1-CAM5_Hist	1,58	3,86	13,93	33,88	38,79	45,33	47,85	32,41	18,33	14,17	9,26	3,39
RCP45	2,85	5,97	18,62	35,58	41,25	46,67	48,53	35,16	19,77	14,16	9,96	4,78
RCP85	3,17	6,84	19,33	34,82	38,53	44,39	45,57	34,52	19,21	14,47	10,63	5,05
IPSL_CM5A-LR_Hist	8,70	12,93	19,76	23,91	39,02	59,17	58,88	31,29	18,48	13,95	11,66	8,05
RCP45	10,48	13,88	19,69	23,78	41,15	57,04	51,11	29,83	15,71	13,27	12,65	9,44

RCP85	9,97	14,55	18,96	22,72	41,46	58,92	50,23	31,25	16,16	13,15	12,64	9,30
IPSL-CM5A-MR_HIst	9,99	14,79	21,95	26,68	42,57	54,22	49,93	30,03	16,74	13,81	12,95	9,15
RCP45	12,38	16,88	22,03	27,67	44,62	57,40	49,37	31,25	18,14	11,91	13,81	12,03
RCP85	11,30	15,49	21,36	26,74	41,73	51,33	45,14	29,66	17,52	14,16	12,29	10,92
MIROC-ESM-CHEM_Hist	1,33	3,76	11,52	35,36	75,57	83,96	76,59	49,90	29,27	15,21	6,19	2,00
RCP45	2,92	5,92	16,61	44,41	86,11	102,46	84,31	55,35	38,47	20,46	8,67	3,56
RCP85	3,52	7,06	18,19	52,09	92,00	97,55	84,53	60,52	36,11	21,30	9,43	3,88
MIROC5	3,62	6,91	15,64	29,52	34,47	33,92	35,10	28,38	22,28	16,59	9,64	4,48
RCP45	4,72	8,03	18,23	31,55	36,97	36,77	37,01	29,67	22,96	18,60	10,73	5,66
RCP85	4,99	8,88	19,24	33,33	39,71	39,77	37,73	29,49	23,51	18,98	11,18	5,83
MRI-CGCM3_Hist	1,98	3,21	15,36	37,51	37,13	21,54	22,59	13,33	10,97	13,67	6,02	2,35
RCP45	2,27	4,64	21,88	45,30	47,44	34,20	26,33	17,12	11,85	14,00	8,42	3,14
RCP85	2,21	5,40	22,71	46,25	49,51	34,85	26,02	20,35	13,22	13,55	8,75	3,33
GISS-E2-R_Hist	17,23	16,72	21,10	30,98	46,75	61,89	61,18	56,06	55,02	46,50	31,89	23,45
RCP45	22,26	19,27	23,69	34,83	53,57	70,83	71,37	64,32	62,98	53,42	38,53	28,11
RCP85	21,09	20,12	25,08	34,95	54,41	70,98	71,23	63,88	60,18	52,89	39,20	28,10

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Appendix Table 4 Dynamic of irrigated arable land area in the Ili – Balkhash basin, Kazakhstan (Modified from Burlibayev et al. 2011)

Year/ Period	1900	1925	1938	1945-46	1961-65	1966-70	1971-75	1976-80	1981-85	1986-87	1992	1993	1994	1995	1996	1997	1999	2000
Irrigated area (thousands ha)	437.02	125.64	385.00	322.00	358.60	405.30	455.50	499.60	526.10	583.20	617.60	587.70	589.00	359.60	508.90	462.20	375.40	346.30

Appendix Table 5 Twenty simulations and mean of the lake volume under 4.5 scenario

Run/ Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mean
0	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112
1	113.89	112.85	114.02	114.10	113.26	115.16	112.86	111.72	113.84	111.66	113.27	114.53	113.13	114.05	110.90	113.50	115.07	114.53	113.75	113.27	113.47
2	115.67	114.33	115.09	114.26	111.82	115.10	111.85	112.97	113.00	113.47	114.05	113.36	115.22	114.46	110.83	115.09	117.48	114.19	114.08	116.31	114.13
3	116.21	114.47	118.34	114.30	112.14	116.39	112.73	113.21	113.76	114.45	115.07	112.90	117.91	114.86	112.05	115.17	118.29	114.37	115.00	116.35	114.90
4	116.60	113.77	118.91	115.68	114.35	116.98	114.18	112.39	115.66	113.18	115.71	114.94	118.32	114.56	112.35	113.92	119.25	114.67	116.53	117.69	115.48
5	118.55	115.31	119.50	116.20	116.30	116.88	115.59	112.91	116.34	114.22	114.41	115.58	117.35	116.16	113.45	114.40	120.51	112.81	117.92	115.95	116.02

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6	120.38	117.75	120.18	117.07	116.39	117.18	117.66	115.92	115.58	115.89	115.52	116.64	120.47	117.82	115.35	115.86	121.19	113.61	120.53	116.27	117.36
7	119.97	116.49	121.29	117.63	114.30	118.64	119.89	117.36	114.21	116.20	117.10	120.07	121.92	118.51	115.71	117.71	123.24	114.27	122.61	118.49	118.28
8	120.13	117.89	122.29	118.96	116.04	119.78	120.67	117.38	116.72	118.25	116.90	122.17	120.80	120.14	116.70	118.78	124.37	116.37	122.06	117.73	119.21
9	122.80	119.75	123.35	121.41	117.22	120.41	121.44	117.53	117.52	118.42	116.05	120.60	121.58	121.28	118.49	121.16	124.27	116.70	122.62	120.75	120.17
10	124.77	119.20	124.53	123.54	118.40	122.14	121.02	119.28	118.34	118.94	115.40	120.40	123.66	120.61	118.71	123.32	123.50	116.54	123.80	120.60	120.84
11	124.34	120.06	127.59	124.17	119.36	123.19	124.43	121.60	119.94	121.18	117.18	122.38	127.32	121.54	117.89	124.81	125.48	117.47	126.28	123.75	122.50
12	123.23	121.80	129.23	124.37	119.01	123.43	124.06	123.38	120.82	121.27	117.24	123.84	126.24	123.17	118.59	124.81	125.59	118.86	127.30	127.05	123.16
13	122.95	124.89	129.84	125.24	118.94	126.05	124.43	124.90	119.94	120.75	119.34	124.78	128.79	125.46	119.95	124.43	126.04	119.68	128.61	127.74	124.14
14	123.40	126.99	130.43	126.59	121.18	125.36	124.67	125.93	121.08	121.79	121.07	124.07	131.07	125.95	121.47	125.56	126.04	121.21	131.50	127.94	125.17
15	124.26	126.40	130.49	130.44	121.52	124.51	124.89	129.03	119.27	122.44	120.78	123.86	132.24	126.94	122.14	127.90	123.46	122.49	132.66	127.68	125.67
16	124.80	129.04	132.43	131.62	124.01	126.05	124.10	130.27	121.68	123.70	121.71	126.83	133.99	126.17	123.90	128.12	123.54	125.05	136.81	129.26	127.15
17	124.45	131.36	133.49	132.61	126.11	129.42	124.04	131.92	121.72	125.09	123.05	129.57	136.98	125.58	124.53	127.87	124.26	125.51	136.73	129.13	128.17
18	124.79	134.00	135.22	136.07	127.05	131.39	125.17	134.46	124.37	129.14	127.91	131.05	139.26	127.04	128.22	130.34	126.09	128.12	139.23	130.16	130.45
19	123.80	136.64	137.66	136.37	127.83	132.22	125.30	136.93	126.09	129.84	128.88	131.44	140.09	129.04	129.07	131.19	125.48	128.77	142.04	131.40	131.50
20	123.62	137.83	139.97	136.74	127.93	133.78	123.04	138.67	128.08	130.86	130.93	132.07	142.82	129.71	129.52	131.87	125.64	127.45	145.33	134.21	132.50

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Appendix Table 6 Twenty simulations and mean of the lake volume under 8.5 scenario

Run/	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mean

Year																					
0	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00
1	107.34	109.39	110.37	106.94	104.72	109.37	107.53	111.99	105.91	106.07	110.35	105.22	108.79	109.25	106.55	107.66	105.72	104.26	108.66	111.13	107.86
2	102.30	102.72	104.84	99.84	100.76	104.35	98.26	108.86	100.02	97.60	104.36	101.50	102.25	106.19	102.61	101.56	104.93	99.26	99.89	108.07	102.51
3	97.43	97.58	100.71	95.87	95.80	99.58	94.29	103.31	94.81	95.61	100.41	99.93	96.70	100.78	98.07	99.08	98.93	93.29	96.98	102.72	98.09
4	90.54	93.27	100.24	94.12	93.58	95.59	91.36	97.67	89.21	90.12	96.87	96.47	94.42	96.22	93.59	96.52	95.40	88.35	93.22	97.72	94.22
5	85.17	88.08	98.20	91.78	87.15	90.54	89.31	95.26	86.90	86.34	91.66	95.01	89.37	90.85	88.73	90.68	89.92	82.38	92.35	93.67	90.17
6	84.39	85.98	97.81	90.88	85.17	86.52	87.19	95.82	84.96	84.02	88.43	88.86	87.27	91.12	86.71	87.99	86.83	82.31	91.61	91.73	88.28
7	84.82	84.75	91.06	87.61	81.11	83.04	84.91	93.33	81.28	80.16	84.03	82.79	85.29	85.48	84.25	85.87	82.37	79.28	90.40	89.32	85.06
8	79.72	85.72	84.88	83.99	77.37	80.90	81.57	91.57	82.13	79.14	80.15	77.48	80.98	82.93	80.69	81.33	79.49	77.32	88.80	85.95	82.11
9	75.07	81.56	83.28	80.63	74.95	80.03	78.03	87.52	78.46	77.32	78.53	75.33	79.27	78.16	80.91	80.04	77.59	77.00	87.36	80.70	79.59
10	73.02	77.56	81.29	81.34	74.15	78.51	76.74	84.78	77.63	74.82	76.45	73.77	76.49	72.49	77.81	76.34	76.83	76.77	84.23	78.43	77.47
11	71.79	77.80	80.37	79.80	73.72	78.18	75.48	83.41	76.37	70.68	73.38	72.37	76.64	71.27	75.35	73.61	74.99	73.55	83.32	78.41	76.02
12	70.65	74.91	79.65	77.23	72.47	72.78	70.88	80.16	74.39	68.80	72.62	69.79	73.29	68.70	71.39	70.66	72.15	70.91	84.50	77.05	73.65
13	69.23	73.47	76.62	75.91	70.90	68.80	69.92	77.85	73.81	68.81	71.20	69.64	72.02	66.61	67.92	70.47	69.05	69.96	84.86	75.17	72.11
14	66.52	71.45	74.60	74.55	71.00	68.14	69.05	76.80	74.55	69.79	69.91	70.66	71.90	66.29	67.06	68.20	68.79	67.04	82.46	73.39	71.11
15	64.17	71.38	70.83	72.90	71.25	66.97	67.61	72.07	73.34	69.25	67.10	68.49	72.01	65.55	67.96	68.41	67.05	67.52	77.85	72.35	69.70
16	68.14	71.95	70.27	73.05	69.80	66.38	68.24	71.76	72.26	70.19	66.81	67.79	69.69	66.67	68.04	67.66	65.29	66.60	73.99	70.04	69.23
17	67.89	73.51	70.19	70.59	68.59	66.66	66.62	70.10	73.14	68.10	67.23	65.55	67.13	63.07	67.89	66.09	65.41	66.79	72.00	68.52	68.25

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18	70.08	73.09	71.19	68.87	67.83	67.06	68.28	70.09	73.02	69.41	68.87	66.95	68.48	64.10	69.33	64.35	65.39	66.79	72.74	67.94	68.69
19	69.98	72.06	72.19	66.23	65.87	66.14	66.23	68.90	74.36	70.28	65.97	63.75	66.93	63.80	68.28	64.90	63.89	65.92	70.44	66.14	67.61
20	70.62	72.33	72.13	65.46	66.95	65.04	63.59	67.09	72.75	68.00	65.09	61.38	67.05	64.54	65.02	65.10	63.61	65.64	68.99	65.77	66.81

Appendix Table 7 Twenty simulations and mean of the lake volume under p4.5 scenario

Run/ Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mean
0	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00
1	110.67	113.59	113.70	114.90	112.22	112.30	111.75	111.20	114.45	112.55	113.60	112.48	112.67	112.82	111.89	112.63	114.47	114.59	110.44	112.46	112.77
2	110.50	112.92	116.50	117.52	112.95	113.06	112.71	110.45	115.04	115.96	114.32	114.81	112.23	111.15	111.71	111.74	115.09	112.23	112.07	114.73	113.38
3	109.38	112.14	115.24	116.22	110.78	109.85	109.86	109.74	112.43	116.14	112.91	114.20	110.51	109.44	110.16	108.49	113.37	110.14	108.24	112.25	111.57
4	106.67	110.69	113.09	114.58	105.21	108.21	106.50	108.06	108.29	113.24	110.32	112.24	108.21	104.94	108.32	107.19	112.86	107.60	107.15	108.32	109.08
5	102.54	108.45	110.70	110.85	104.45	105.47	103.60	106.44	107.33	109.67	109.22	109.61	105.69	101.92	106.24	105.11	110.56	106.17	104.71	105.12	106.69
6	100.06	102.88	108.19	105.77	99.69	101.62	102.60	103.63	103.84	107.26	104.51	104.82	102.35	99.24	103.19	101.44	107.38	105.29	102.17	101.44	103.37
7	98.61	103.07	106.24	104.68	96.78	101.64	102.17	102.38	100.96	105.31	102.70	102.08	101.95	100.38	103.65	102.28	105.70	103.77	102.39	98.43	102.26
8	95.41	98.26	101.65	101.07	94.59	97.20	98.24	99.08	97.90	100.20	98.26	100.36	98.64	97.50	101.43	101.02	101.49	99.39	99.87	95.06	98.83
9	91.27	94.99	98.00	98.03	91.75	93.35	95.95	96.67	96.30	95.53	95.47	97.18	95.41	93.69	99.23	99.34	97.76	96.97	96.76	91.36	95.75
10	87.63	92.29	93.65	94.04	89.17	89.85	92.25	94.80	91.62	92.61	92.30	93.32	92.87	89.69	95.52	96.42	94.39	94.49	93.81	90.10	92.54

11	87.55	90.33	90.20	92.83	89.06	90.16	92.11	96.29	92.19	92.70	90.77	93.11	92.25	92.10	95.41	95.75	92.38	94.30	94.42	91.16	92.25
12	83.25	87.10	86.12	92.27	85.52	87.49	89.94	96.17	88.64	89.96	87.51	90.83	93.00	89.65	93.22	92.20	89.80	91.48	90.28	89.40	89.69
13	82.70	82.84	82.73	90.38	83.71	84.74	87.33	93.10	85.47	87.02	85.92	88.90	90.12	86.89	90.20	91.17	87.60	89.96	87.44	86.61	87.24
14	81.75	80.10	80.00	87.05	82.67	81.96	83.38	89.47	81.77	84.83	82.39	87.39	87.66	83.56	86.27	86.74	85.01	87.82	85.27	82.10	84.36
15	81.86	78.84	81.14	87.24	81.62	81.03	82.92	88.68	81.36	84.32	81.62	88.66	87.99	82.41	85.46	86.92	85.44	88.30	86.83	81.24	84.19
16	80.90	77.39	80.00	84.34	79.30	77.80	81.66	86.13	79.55	81.05	79.64	85.70	84.86	81.30	82.71	83.74	83.64	84.83	83.58	79.28	81.87
17	79.58	73.48	78.02	81.49	77.29	77.31	80.65	82.91	77.15	79.73	76.02	83.91	83.70	79.33	80.14	80.65	79.35	82.96	80.70	77.59	79.60
18	76.94	70.20	76.51	79.14	74.43	73.95	78.47	79.90	75.29	78.38	73.14	80.62	81.31	77.83	77.75	78.86	77.30	79.34	79.08	75.66	77.21
19	76.16	71.16	77.60	81.39	74.23	75.12	78.50	79.51	76.15	78.58	73.30	80.45	81.06	79.63	77.44	79.65	76.33	80.20	79.37	75.33	77.56
20	75.03	69.31	76.42	78.55	71.77	74.61	76.99	76.59	72.99	76.89	71.60	78.60	79.93	77.37	74.29	77.08	73.45	78.40	76.83	74.94	75.58

Appendix Table 8 Twenty simulations and mean of the lake volume under p8.5 scenario

Run/ Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Mean**
0	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00
1	105.55	106.14	107.52	107.84	105.99	105.69	105.95	104.53	105.00	109.42	106.17	106.07	105.85	108.61	108.06	105.01	107.37	106.34	109.05	105.11	106.56
2	98.74	103.34	103.67	101.65	101.30	98.07	101.05	99.99	99.00	100.22	96.46	99.69	99.63	102.27	104.39	97.28	100.17	100.13	103.04	101.64	100.59
3	91.46	96.80	96.57	92.21	93.50	89.67	94.97	93.83	94.09	94.76	86.19	90.49	90.88	93.03	97.13	88.53	92.97	91.41	95.83	92.92	92.86

4	85.42	91.91	90.00	85.62	87.37	85.81	89.85	90.89	89.45	89.08	80.12	86.35	83.67	87.09	90.07	84.24	86.76	84.65	89.84	87.63	87.29
5	80.30	82.72	80.20	80.37	81.75	80.55	84.09	88.96	85.53	82.42	77.09	80.67	80.18	82.43	85.90	82.25	80.82	79.02	86.84	83.93	82.30
6	73.56	76.01	69.67	76.78	75.67	70.59	76.03	81.72	77.92	76.40	69.64	72.79	75.34	76.07	79.47	74.75	73.17	71.74	78.60	77.21	75.16
7	71.64	70.35	65.46	72.76	70.37	65.64	72.02	75.56	74.58	72.78	68.04	69.93	70.10	72.09	73.45	71.17	69.86	68.41	72.36	73.40	71.00
8	66.74	64.23	59.79	67.88	65.20	60.55	66.21	69.80	70.68	66.93	62.48	64.60	65.11	64.52	68.18	63.67	66.62	62.73	68.35	68.55	65.64
9	58.25	57.18	55.25	62.56	60.63	55.78	59.02	64.20	66.13	62.22	56.98	58.38	57.70	57.70	62.23	57.28	61.86	59.75	62.21	66.47	60.09
10	55.06	52.66	50.52	56.07	56.61	49.91	54.48	58.07	63.73	56.21	51.15	54.72	52.97	51.02	55.77	50.44	56.29	54.96	57.62	59.85	54.91
11	52.89	51.00	47.56	54.15	53.83	48.09	51.70	52.91	62.45	52.82	50.38	53.60	51.23	47.93	51.73	46.18	51.64	52.23	56.17	58.92	52.37
12	47.90	46.91	42.07	51.11	48.45	45.17	47.80	46.90	57.98	47.36	46.81	48.23	45.29	44.53	46.46	41.71	47.35	45.58	52.99	55.57	47.81
13	44.15	44.31	38.34	46.94	44.81	41.46	46.27	41.23	52.67	42.40	42.22	43.22	39.61	39.63	42.67	37.34	43.84	41.36	48.79	50.37	43.58
14	40.00	41.76	35.60	44.26	40.95	38.57	43.64	35.20	50.57	37.78	39.04	38.06	34.97	35.44	38.30	35.79	41.81	39.97	45.86	44.88	40.12
15	38.47	40.59	34.84	43.54	38.91	37.94	41.97	33.39	46.13	36.24	40.02	36.13	31.76	33.74	37.63	36.04	41.30	37.36	44.40	43.82	38.71
16	34.07	36.31	30.16	40.57	35.43	34.97	38.42	31.01	41.02	32.03	38.34	31.33	28.42	32.67	35.56	36.03	38.30	33.88	42.04	38.76	35.47
17	29.54	33.01	25.55	37.28	32.10	30.69	33.39	28.85	40.10	28.05	34.73	27.12	22.87	28.32	32.98	32.23	36.07	31.01	37.88	34.22	31.80
18	26.36	28.69	20.88	33.59	27.68	27.95	31.46	25.99	37.13	24.85	30.67	23.46	17.64	25.45	29.96	26.38	32.06	28.50	34.90	31.93	28.28
19	26.23	28.11	18.41	33.08	26.75	27.28	31.50	25.93	36.49	23.83	28.30	22.88	15.77	25.36	28.20	24.38	31.58	28.66	33.60	29.44	27.29
Final	23.59	24.53	16.24	31.12	24.18	24.81	26.13	21.84	34.99	21.24	25.49	20.68	11.48	21.67	24.52	20.87	27.94	26.62	31.18	25.73	24.24

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Appendix Table 9 Twenty simulations and mean of the lake volume under r4.5 scenario

Run/ Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mean
0	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00
1	112.52	113.38	112.30	114.96	113.53	113.49	110.48	111.82	111.44	113.88	114.13	113.67	113.50	112.20	113.70	112.66	113.17	111.18	111.06	113.77	112.84
2	109.38	114.29	112.70	112.37	113.43	111.72	106.96	111.65	110.35	109.98	112.48	113.81	112.78	110.53	108.64	113.34	111.49	110.24	109.77	110.93	111.34
3	102.74	107.83	106.83	106.61	106.28	106.97	100.43	106.05	106.05	104.39	107.88	107.49	107.18	103.85	102.28	108.08	105.02	103.55	104.11	104.37	105.40
4	97.30	100.57	101.30	99.99	100.19	99.60	96.15	97.86	102.14	98.92	100.72	102.35	100.27	98.28	96.15	100.68	99.34	97.85	96.94	98.66	99.26
5	93.04	94.17	97.78	95.24	93.87	93.19	92.08	93.51	96.78	91.74	94.82	95.08	93.45	93.13	91.18	94.47	93.47	92.78	90.95	92.54	93.66
6	87.03	90.31	94.20	91.62	89.80	86.99	87.74	87.77	92.34	85.03	89.85	90.97	88.74	88.81	86.67	88.17	87.75	87.56	85.63	86.27	88.66
7	84.27	89.50	91.10	88.28	87.94	84.95	85.54	86.63	89.27	82.46	89.53	89.67	86.67	85.80	84.76	85.32	84.56	86.52	81.77	84.34	86.44
8	76.93	81.89	81.96	83.20	81.02	78.93	77.99	81.24	81.86	77.73	82.24	82.57	79.43	80.20	78.43	79.53	76.71	79.19	76.64	77.56	79.76
9	70.63	75.06	75.19	77.68	74.70	73.36	72.38	75.45	77.76	71.19	74.80	75.17	72.39	74.66	72.44	73.16	70.60	73.24	70.94	72.02	73.64
10	65.63	70.34	70.90	72.26	69.40	68.20	66.81	69.84	73.16	65.19	69.28	68.76	66.41	69.59	67.69	67.71	66.03	68.98	66.66	66.02	68.44
11	61.87	65.60	67.20	67.76	66.68	64.09	62.69	64.94	67.96	61.27	65.80	63.85	61.74	65.68	63.40	63.81	62.07	65.85	62.46	62.93	64.38
12	58.03	62.13	64.35	63.27	64.01	60.32	59.01	60.47	64.13	56.72	62.57	59.65	57.67	61.33	59.34	61.25	58.58	62.48	59.63	58.70	60.68
13	54.51	57.50	61.32	58.90	60.90	56.12	55.66	56.12	60.23	54.94	57.94	56.00	54.01	56.73	54.24	58.01	56.25	58.19	57.18	55.08	56.99
14	50.72	54.49	58.13	54.72	57.09	52.45	51.38	52.96	55.70	52.56	54.66	52.90	50.49	51.80	50.01	54.61	54.31	55.28	51.79	50.91	53.35
15	47.48	51.95	54.40	52.18	53.81	48.85	48.38	49.01	51.82	50.85	51.52	49.00	48.35	49.02	47.17	50.86	51.37	51.35	47.86	46.96	50.11

16	45.01	47.83	51.41	49.64	51.67	46.82	46.03	45.90	48.52	46.47	48.50	47.24	45.08	45.26	42.43	48.52	48.53	47.53	45.17	42.94	47.03
17	42.03	44.46	47.19	46.78	48.49	45.38	42.40	41.04	45.43	43.70	45.75	44.52	42.84	42.47	39.88	45.55	45.26	45.58	42.79	38.76	44.02
18	42.27	45.89	46.24	45.84	47.83	45.99	42.68	40.16	44.62	43.05	44.69	45.19	43.39	41.44	40.21	45.35	44.72	45.10	43.66	39.88	43.91
19	37.26	42.48	42.08	41.75	41.73	42.55	39.42	36.47	41.51	39.89	39.82	41.67	39.65	38.99	37.43	40.98	41.35	42.02	39.74	36.27	40.15
Final	33.14	38.93	37.56	37.63	38.20	39.49	36.81	33.27	38.24	36.80	35.11	37.75	36.00	36.06	35.98	36.69	36.48	38.75	36.89	33.61	36.67

Appendix Table 10 Twenty simulations and mean of the lake volume under r8.5 scenario

Run/ Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Mean**
0	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00	112.00
1	105.51	101.52	106.09	106.70	110.71	105.85	105.41	110.22	103.91	107.43	103.51	109.86	103.02	109.01	105.01	105.76	109.50	105.58	105.03	106.69	106.32
2	96.62	92.98	101.27	99.69	99.91	97.28	97.69	104.10	101.45	99.27	98.50	103.46	97.45	101.05	99.41	96.63	104.78	97.51	93.86	100.15	99.15
3	85.94	81.84	90.38	88.95	86.63	86.85	85.97	94.77	91.78	87.00	90.95	90.43	85.73	91.50	86.08	91.31	92.69	87.01	84.48	92.25	88.63
4	73.44	71.11	78.23	78.69	75.33	75.83	76.53	83.29	84.26	77.60	80.57	76.66	76.21	83.23	74.30	85.20	82.95	76.33	73.53	82.93	78.31
5	68.69	60.40	66.85	71.55	66.98	66.91	69.33	71.98	75.39	72.41	71.80	66.85	66.50	75.72	66.41	76.99	73.45	68.24	67.58	76.00	70.00
6	63.47	52.47	58.60	62.83	63.78	57.70	62.71	61.80	67.98	66.40	63.08	57.01	60.38	68.88	60.77	66.45	65.81	61.01	64.72	70.70	62.83
7	56.71	48.55	56.10	55.44	57.01	52.07	58.74	54.65	62.19	63.31	57.03	52.63	55.55	64.97	56.43	63.57	61.51	58.72	63.79	67.29	58.31
8	45.35	40.65	47.60	46.43	50.27	43.62	50.17	44.83	52.28	55.88	48.15	42.21	46.92	54.91	48.04	57.25	50.79	50.73	54.58	55.97	49.33

9	35.71	35.18	41.23	40.36	43.94	35.23	42.05	36.07	45.19	45.85	37.75	33.42	36.71	44.88	41.12	48.16	43.25	44.49	45.92	47.60	41.21
10	30.32	29.83	34.13	35.14	36.90	30.21	35.76	29.96	39.45	39.18	29.08	26.27	29.26	38.18	34.59	38.67	36.78	39.53	36.54	40.10	34.49
11	24.31	24.18	27.67	30.43	31.79	25.59	30.83	23.63	34.34	32.81	21.66	19.27	23.67	31.77	28.20	32.90	28.25	33.41	29.14	33.26	28.36
12	17.96	18.81	21.61	23.60	24.51	19.96	26.07	16.16	28.37	28.87	14.41	11.68	17.62	26.09	21.10	28.99	20.84	27.49	24.16	29.29	22.38
13	12.37	13.87	16.01	15.29	19.64	14.03	21.25	10.22	21.79	27.10	6.86	5.01	12.03	18.84	14.78	24.11	15.35	22.02	19.11	24.61	16.71
14	7.61	9.51	8.50	8.20	13.85	9.20	15.97	4.29	17.63	19.77	2.57	0.00	5.52	13.65	8.88	19.22	9.39	16.86	14.58	18.11	11.17
15	3.07	3.74	3.03	3.09	8.31	3.60	10.22	0.00	12.41	12.65	0.96	0.00	0.00	6.71	3.41	14.75	3.67	11.58	7.60	12.27	6.05
16	1.15	0.00	0.00	0.00	3.20	1.09	4.13	0.00	6.18	8.02	0.36	0.00	0.00	2.28	1.28	9.74	0.00	5.90	2.85	5.18	2.57
17	0.43	0.00	0.00	0.00	0.00	0.41	0.00	0.00	1.95	3.31	0.14	0.00	0.00	0.00	0.00	3.91	0.00	0.00	0.00	0.00	0.51
18	1.54	0.43	1.11	0.77	0.61	1.03	0.58	0.59	1.83	3.31	1.22	0.96	0.69	1.13	0.61	2.69	0.61	1.11	1.16	1.47	1.17
19	0.58	0.16	0.42	0.29	0.23	0.39	0.22	0.22	0.69	1.24	0.46	0.36	0.26	0.42	0.23	1.01	0.23	0.42	0.43	0.55	0.44
Final	0.22	0.06	0.00	0.11	0.09	0.15	0.08	0.08	0.26	0.47	0.17	0.14	0.10	0.00	0.09	0.00	0.09	0.16	0.16	0.21	0.13

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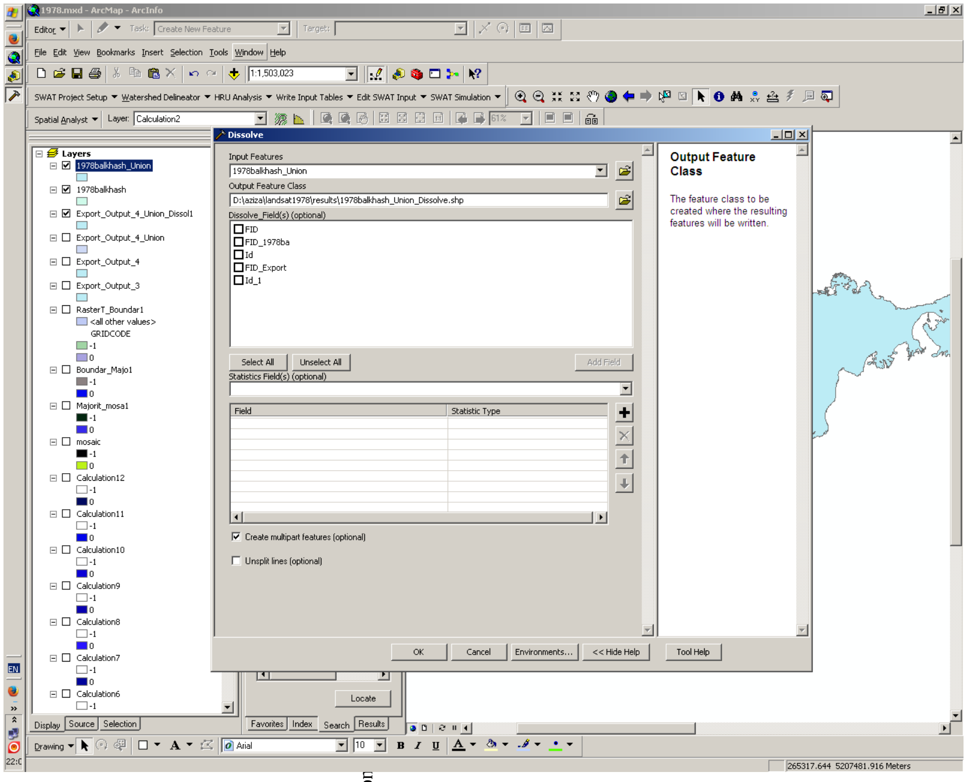
Appendix figures



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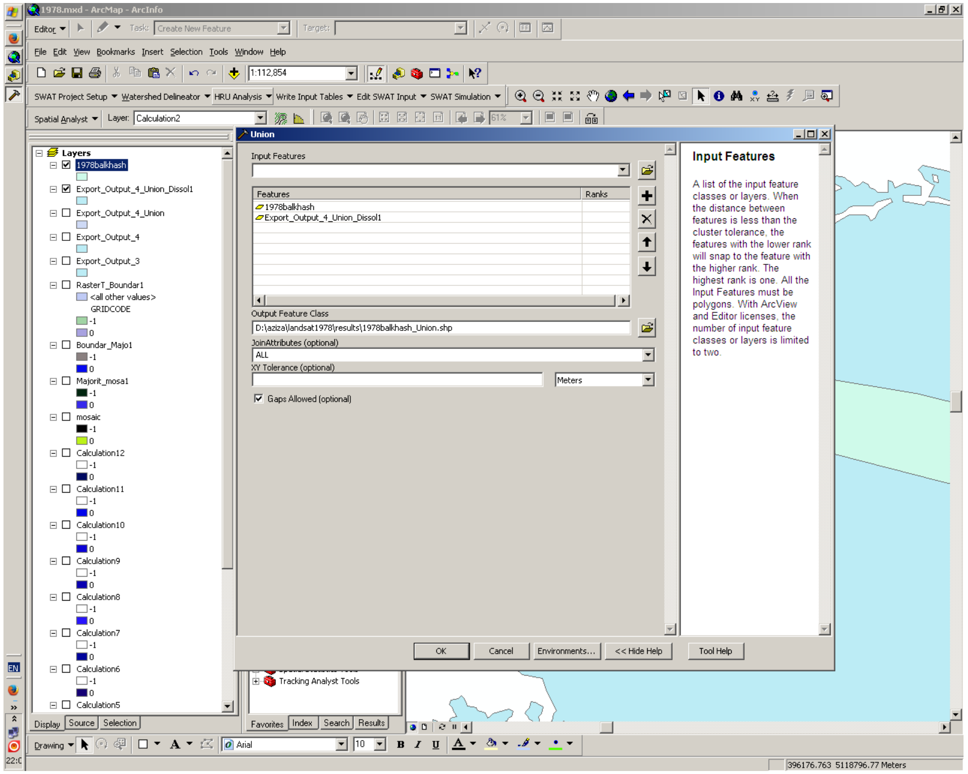
Appendix figure 1 Removing line in the shape file, Dissolve function



Appendix figure 2 Removing voids in the shape file

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