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

The implications of climate change on public health: Water resources in the Ural River Basin

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Budapest

Author's declaration

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

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ABSTRACT OF THESIS submitted by:

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Conceptual frameworks of public health assessment should address the needs of policymakers, government institutions and populations as well as account for potential climate change. Water is an important factor influencing public health in the Caspian region. The five Caspian states focus their water resource management programs on water availability and sanitation, but academics and international institutions emphasize the need to relate public health with ever-changing environmental gradients. The study analyzed how climate change affects water availability in the Ural River Basin and possible migration strategies for public health in the region.

There is insufficient data for the area, so extensive data collection was conducted including a GRID-Arendal research trip. The research project creates an integrated database of both climate and health variables for the Ural River Basin.

To assess the effects of climate change on public health, the study develops an Arc-GIS SWAT model, a STELLA conceptual diagram and analyzes the area's public health infrastructure. The developed SWAT model evaluates three climate change scenarios and concludes that water availability will decrease by 1.5-6.9% by 2049 depending on the scenario. For each of these scenarios the study evaluates the corresponding consequences for public health in the region, assesses available health infrastructure's readiness for changes and develops policy recommendations to help mitigate climate change's impact on public health. Russia and Kazakhstan need to drastically improve access to health care facilities and medical professionals.

The overall scheme and methodological framework developed by this research project can be applied to other watersheds.

Keywords: SWAT, Arc-GIS, spatial analysis, SWAT-CUP, STELLA, system dynamics, Ural River, Caspian Sea, water quality, vector borne diseases, climate change, public health, public health infrastructure, weather generator

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1 Introduction

1.1 Background

In the Ural River region, national governments lack sufficient funds for water quality and hydrological data collection. Financial restraints, along with strict or non-existent data sharing procedures, greatly limit the information available for the region. The project will create a unified database on the Ural River basin—an important step that can allow for future research.

The research project focuses on the Ural River basin because the body of water is mainly used for human consumption (Martino and Novikov 2008). Other areas in the Caspian region utilize different water sources like ground water, reservoirs or lakes for drinking water (Lagutov 2008;Martino and Novikov 2008). In the Ural River region, water availability and water quality are major ecosystem services that impact not only hydrological ecosystem services, but also local disease dynamics in the area. Climate change scenarios will alter the amount of available water, precipitation and temperature levels in the region. The Ural River basin's ecological changes will affect both environmental monitoring programs and infrastructure policies for public health in the region.

1.2 Research Aims and Objectives

Climate change affects not only the region's ecological structure, but also the available water ecosystem services. The project's aim is to assess the implications of climate change on public health in the Ural River Basin in relations to water resources using geographic information system (GIS) tools.

The following two research questions address the project's aim:

1) How will climate change influence water availability in the Ural River Basin and

2) Based on water availability forecasts, what are the consequences and possible mitigation measures for public health?

The first research question will be addressed with the subsequent objectives:

- Collection and development of environmental and hydrological database for the Ural River Basin;
- Development and calibration of a computer-based model using the created database;
- Formulation of different climate change and regional scenarios and their analysis utilizing the developed hydrological model.

The second research question will be addressed with the following objectives:

- Identify the connection between the effects of climate change (in particular changes in water and temperature regimes) on morbidity and mortality and develop a conceptual diagram;

- Integrate and visualize georeferenced public health and climate change information in order to identify (if any) patterns;
- Develop recommendations to link environmental data with health information to better characterize the impact of climate change.

1.3 Thesis Structure

The thesis contains five chapters with multiple subheadings. The first chapter provides background while establishing the project's aims and objectives. The second chapter describes the Caspian Sea, the Ural River, transboundary issues and Integrated Water Resource Management. This chapter also introduces the issue of climate change, public health and GIS modeling. The third chapter describes the methods employed by the project. The first section of this chapter reports the methodology for SWAT modeling and the second section describes studying climate change implications for public health.

The fourth chapter discusses the obtained results including the SWAT model, assessment of the developed climate change scenarios, .elaborated STELLA conceptual diagram as a study framework for public health implications and the gathered public health infrastructure data. The fifth and final chapter suggests policy and management implications while acknowledging the project's limitations. This section concludes with a summary of the research project.

2 Ural River Basin

2.1 Caspian Sea

Figure 1: Caspian Sea with transboundary borders (Martino and Novikov 2008)

The Caspian Sea region includes five nation states: Kazakhstan, Russia, Azerbaijan, Iran and Turkmenistan (O'Lear 2004) (see Figure 1). The Caspian Sea represents the world's largest "closed body of water on the surface of the Earth" with an approximate size of 371,000 square kilometers (Rucevska 2011). The Caspian Sea's landlocked feature allows rivers to drain collectively into the body of water and determines the sea level. Water security of the Caspian region reflects concerns about water quality, ecosystem services and the region's public health status (Bax *et al.* 2001, Chave 2001). Discharge from industrial processes or improper management of chemical waste byproducts eventually collects in the Caspian Sea (Kutenaee *et al.* 2011). However, access to basic public health data, water quality information and environmental health indicators are highly guarded and unsynchronized in the region (Rucevska 2011). A uniformed monitoring and regulation system would need to involve five different nation states which each have different degrees of access to resources and capital.

2.1.1 Overall climate

The environmental and climatic conditions of each country vary by region. The coastal areas of Kazakhstan and Turkmenistan in the northeast and eastern section of the Caspian region usually attain around 150-200mm of rain annually (Martino and Novikov 2008). The region is characterized by mostly low levels of vegetation, hot temperatures and a desert-like climate (Kosarev *et al.* 1994).The major centers of urban settlement remain along the Russian, Azerbaijan and Iranian coasts while lower population densities can be found in Kazakhstan and Turkmenistan's coastal zones (Martino and Novikov 2008).

The regional differences are highlighted by the economic importance of industry in the northwestern and western regions as opposed to a heavier reliance on agriculture and cattle farming in the northeastern and eastern areas. In general, higher levels of urbanization exist closer to the coastal regions while a smaller amount of individuals settle inland (Kosarev *et al.* 1994;Martino and Novikov 2008).

2.2 The Ural River: Overall

Figure 2: The Ural River with Russian and Kazakhstan administrative boundaries (Chilton and Faloutsos 2011)

The Ural River drains directly into the Caspian Sea (see Figure 2). Although not the largest river within the Caspian region, the Ural River still remains the third longest in Europe (Lagutov 2008). The Ural River's riparian countries include

Kazakhstan and Russia. The transboundary groundwater within the Ural River basin consist of the South-Pre-Ural, the Pre-Caspian and the Syrt within both countries (Chilton and Faloutsos 2011). The total length of the river ranges from 2,428 to 2,534 kilometers depending on the data source (Lagutov 2008). The river runs through the southeastern slopes of the Ural Mountains and eventually deposits into the Caspian Sea (Lagutov 2008). Russia attains about 36 percent of the total river's surface area while Kazakhstan receives a larger proportion of 64 percent (Chilton and Faloutsos 2011).

The Ural River is the largest free flowing river in the Caspian region (Lagutov 2008). The other large rivers that drain into the Caspian Sea include the Volga, Kura, Terek and Sulak rivers (Tehran Convention Secretariat 2013). However, all of these larger rivers have regulated hydrological flows through the use of dams and reservoirs. On the other hand, the Ural River's hydrological flow remains unrestricted in the middle and lower sections (Lagutov 2008).

2.3 Ural River's Geomorphology

The Ural River runs mostly through an ecosystem characterized by grassland plains and few trees. The majority of trees can be found near the river's boundaries for increased access to water (Lagutov 2008). The seasonal fluctuations in precipitation affect the river's annual flow. The river experiences 80 percent of the yearly hydrological flow after the spring floods and snow (Lagutov 2008). The river can be separated into three distinct parts: the upper, middle and lower streams (Tehran Convention Secretariat 2013). The upper region experiences a turbulent flow and runs through the eastern part of the Ural Mountains. Although the Iriklinskoe water reservoir exists in the upper region, the reservoir does not significantly affect the river's flow (Lagutov 2008). The middle section of the river flows from the east to the west with a large decrease in velocity. In this section, the Sakmara River is a tributary of the Ural River on the Russian side while the Ilek tributary crosses both Russia and Kazakhstan (Lagutov 2008). Finally, the lower stream of the Ural River is characterized by both deserted and non-deserted steppe areas (Lagutov 2008). Eventually, the lower stream flows into the Caspian Sea.

2.4 Hydrology

The precipitation and water levels for the Ural River fluctuate seasonally. The Ural River basin is located in an arid environment (Martino and Novikov 2008). The average precipitation fluctuates between 100 to 600 millimeters (see Figure 3) per year and the average evapotranspiration varies between 650 to 690 millimeters per year (Lagutov 2008).

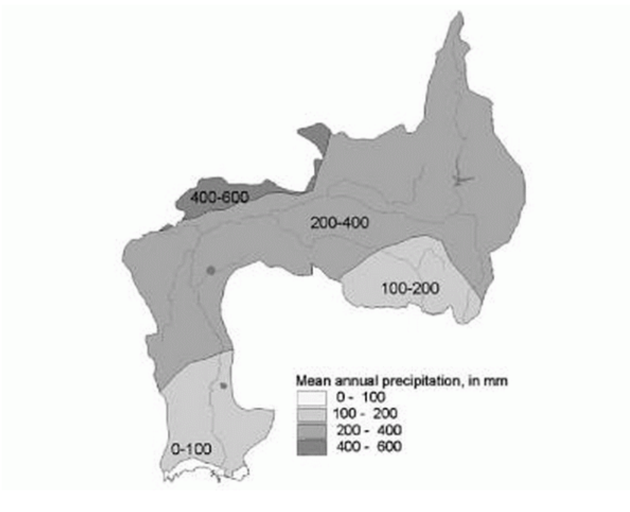


Figure 3: Mean annual precipitation (1970-2002) (Lagutov 2008)

Most of the water feeding the Ural River forms in the upper and middle regions through snowmelt (Lagutov 2008;Martino and Novikov 2008). The lowest water levels usually occur in July.

The seasonality of snowmelt creates an uneven distribution of flow and water levels for the river. The water levels vary differently in the southern versus northern sections of the river. Water levels in the upper regions increase during April and May due to flooding while the lower sections experience a surge in March and April (Lagutov 2008). The Ural River experiences the largest amount of precipitation through the accumulation of snow. In the spring, the river experiences 80 percent of its annual discharge when the snow melts. However, the annual floods can occur at different times each year causing fluctuations in the river's hydrological flow (Martino and Novikov 2008).

2.5 Transboundary Issues

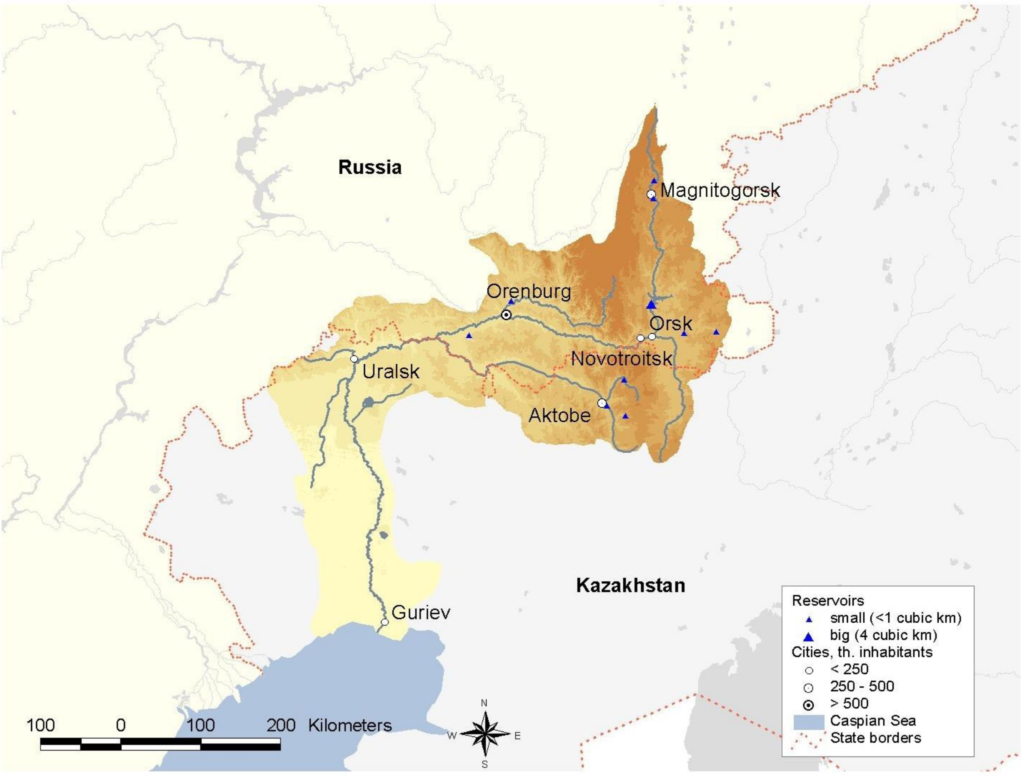


Figure 4: Transboundary map of the Ural River Basin (Lagutov 2008)

The Ural River crosses both the Russian Federation and Kazakhstan administrative boundaries (see Figure 4) (Rucevska 2011). As a result, water management strategies for the river must address possible transboundary issues. After the breakup of the Soviet Union in 1991, the area spilt into fifteen distinctive nation states (Dunlop 1993;Suny 1993). The infrastructure, economic stability and political integrity vary across all nations. The unequal distribution of wealth and resources through the allocation of hydropower and fossil fuels creates challenges for cooperation and research into the area (Chilton and Faloutsos 2011). Thus, a major challenge and limitation of the project is data collection and coordination between the two countries: Kazakhstan and Russia.

2.6 Integrated Water Resources Management (IWRM)

Integrated water resource management (IWRM) encourages a holistic approach to resource management that promotes the sustainable use of ecosystem services (Liu *et al.* 2008).

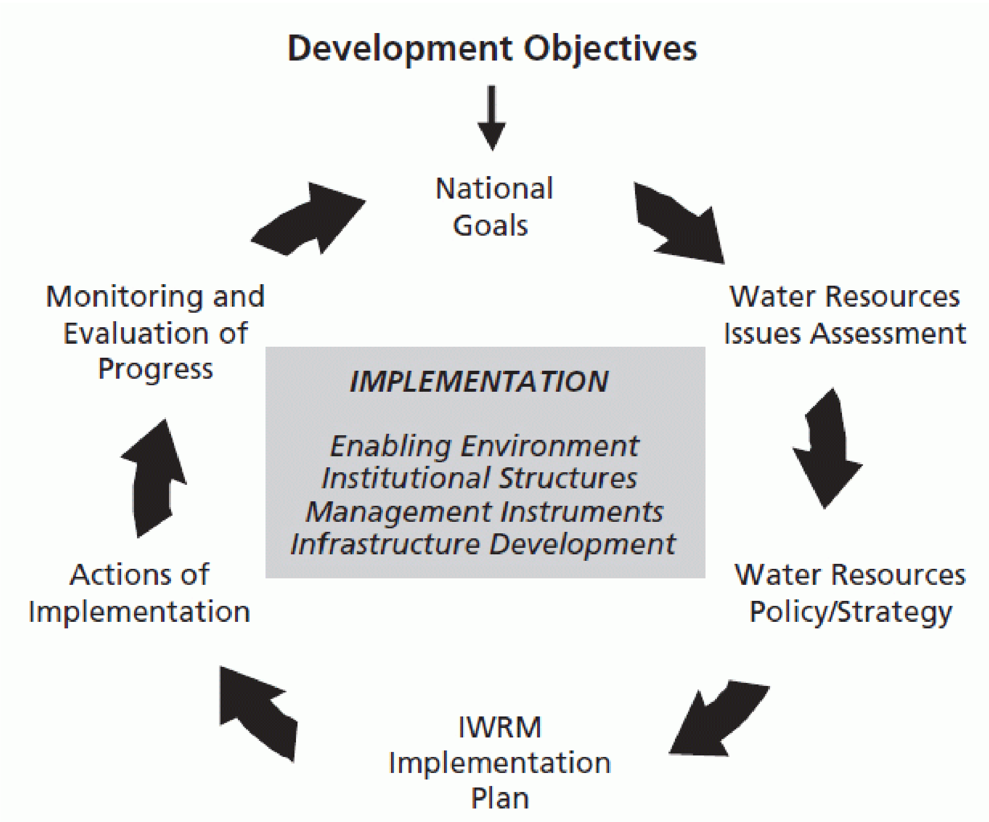


Figure 5: IWRM conceptual diagram with levels of planning and implementation (UN-Water Global Water Partnership 2007)

The IWRM framework emphasizes the significance of water for ecosystem services while highlighting the importance of institutional and governmental policies (see Figure 5).

Overall in the Caspian region, population growth rate continues to increase across all five nation states (Chilton and Faloutsos 2011). The increased number of individuals puts pressure on ecosystem services due to drinking water and agricultural needs (Vörösmarty *et al.* 2010). The general arid environment of both Kazakhstan and Russia make irrigation and water resources important factors for local agricultural economies and communities' wellbeing (Chilton and Faloutsos 2011). In general, the biggest user of water is the agricultural industry. The creation of reservoirs and dams reduces the hydrological flow, which could lead to desertification, salinization and land degradation. On the other hand, mismanaged water systems with inefficient drainage programs can cause both water and soil salinity (Arthington *et al.* 2006;Vörösmarty *et al.* 2010). IWRM is generally weak across all five Caspian states even though some legislation has been passed in all governments. The lack of capital support, transboundary cooperation and coordination are the greatest barriers to the successful implementation of IWRM (Chilton and Faloutsos 2011).

After the fall of the Soviet Union, the quality of hydrological data and monitoring has suffered (Dunlop 1993). Most countries cannot afford to invest money into IWRM programs. Kazakhstan and Russia both have some established water monitoring networks, but water quality data remains unavailable to the public (Martino and Novikov 2008). The Teheran Convention is a regional sea convention that helps maintain the quality of the Caspian Sea among all five nation states (Sands and Peel 2012).

2.6.1 Kazakhstan

In the Kazakhstan government, the Committee for Water Resources of the Ministry of Agriculture has the authority and responsibility over managing the country's water resources. The Committee works with eight River Basin Organizations to manage both the national water networks and basin level strategies. While the Committee approves and issues water permits, Kazhydromet monitors water levels and quality (Chilton and Faloutsos 2011). Kazhydromet is the national hydro-meteorological institute that does on the ground research and surveys. The Committee on Geology and Mineral Resources Use tracks groundwater while the Ministry of Health overseas drinking water (Chilton and Faloutsos 2011).

2.6.2 Russia

In the Russian Federation there are two separate legislative bodies for the approval of policies and implementation of water resource management. The Ministry of Natural Resources and the Environment develops federal policies while the Federal Water Resources Agency enforces these plans (Chilton and Faloutsos 2011). On a more local level, fifteen Basin Management Authorities help run the actual reservoir operations, issue permits and regulate water withdrawals. Roshydromet is the national hydrological institute that tracks surface water while Rosnedra controls the conditions of groundwater (Chilton and Faloutsos 2011).

2.7 Climate Change

2.7.1 Overview

Many researchers and academic organizations acknowledge that humans have increased the effect and rate of climate change (Hughes *et al.* 2003;McMichael *et al.*;Stott and Godlee 2006). The emission of greenhouse gases from fossil fuels collects in the atmosphere and traps excess heat on the earth's surface (Frolkis *et al.* 2002). Anthropogenic industrial activity accounts for an estimated 900 billion tones of released carbon dioxide (CO_2) of which 450 billion tones remain in the atmosphere (Costello *et al.* 2009). From the released CO_2, industrialization generates 80 percent while land use degradation produces the remaining 20 percent (Costello *et al.* 2009).

Within the next 100 years, the earth will experience an increase in surface temperature (Costello *et al.* 2009). The temperature will rise by at least 2°C beyond the safe pre-industrial surface temperatures. In higher altitude areas, surface temperatures are estimated to rise by 5°C (Costello *et al.* 2009). Rising global temperatures not only have a direct effect on climate and water, but also significant implications for human health (Frumkin *et al.* 2008;McMichael *et al.* 2006;McMichael *et al.* 2007). Climate change can affect human health by increasing the frequency of floods, droughts and heat waves (Costello *et al.* 2009). The shortage of water resources along with increased temperatures will affect the number of malnourished individuals and the distribution of vector-borne diseases (El-Fadel *et al.* 2012;Frumkin *et al.* 2008;Haines *et al.* 2006). Figure 6 shows the potential pathways through which climate change could influence human health.

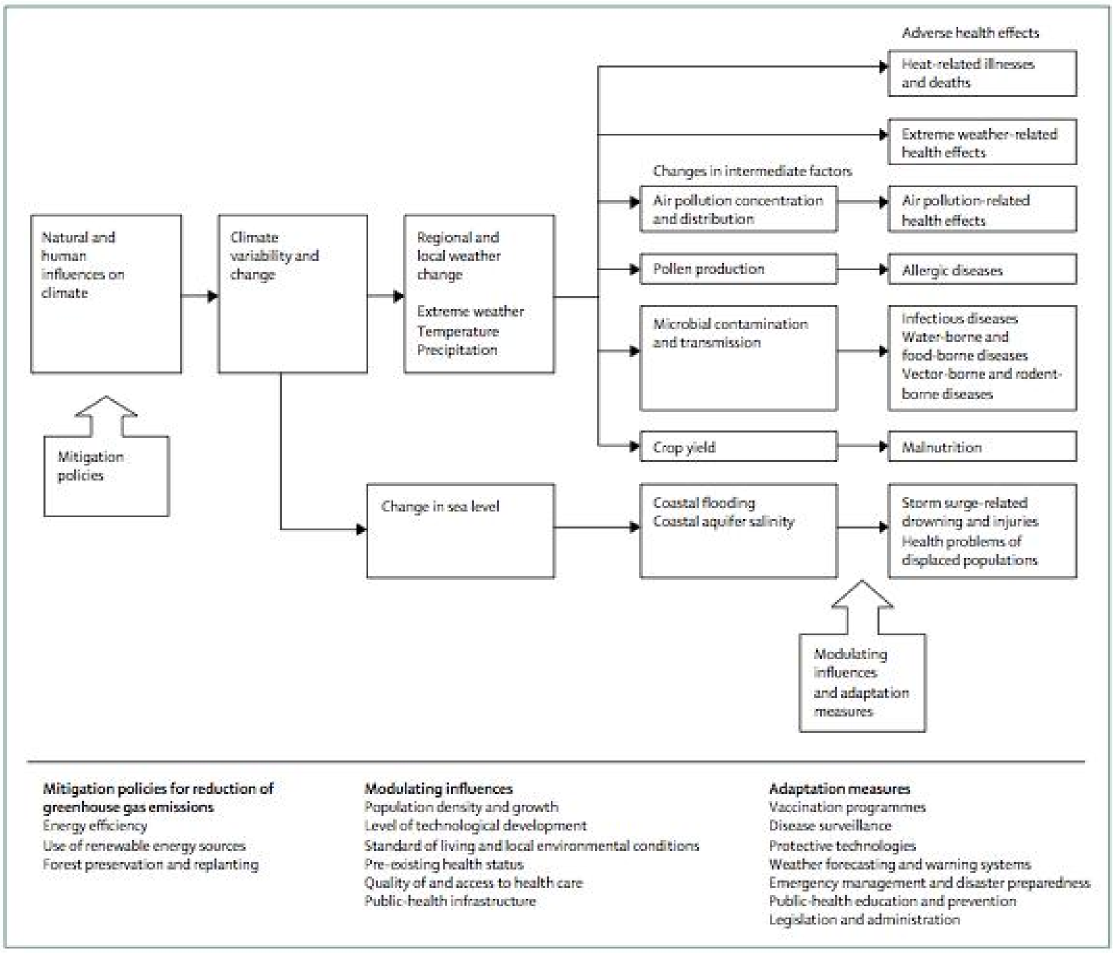


Figure 6: Potential pathways through which climate change can influence human health (Haines *et al.* 2006)

The overall academic consensus reports that climate change will have a general negative effect on human health for all nations with developing nations suffering disproportionately (Haines *et al.* 2006).

2.7.2 Climate change and public health

"Climate change is the biggest global health threat of the 21st century" (Costello *et al.* 2009).

Climate change can indirectly alter individuals' health through changes in ecosystem services and biodiversity (Pascal *et al.* 2012;Patz *et al.* 2005). Changes in temperature will have a direct affect on water availability which in turn will alter water resources, food security and exacerbate extreme weather events (Costello *et al.* 2009). Current research focuses on three main public health topics: the relationship between climate and disease, the repercussions of current changes in climate and climate change's future role on health (see Figure 7) (Haines *et al.* 2006).

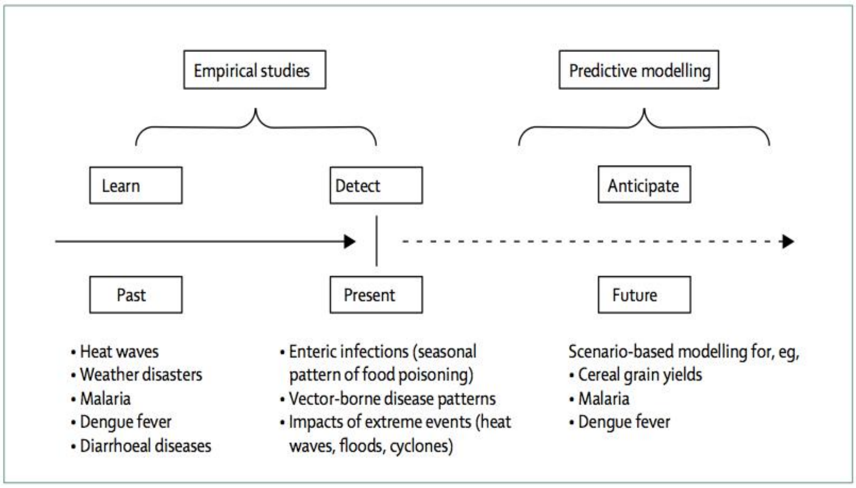


Figure 7: Three public health research topics related to climate change (Haines *et al.* 2006)

2.7.3 Extreme weather events

2.7.3.1 Increased temperature

Morbidity and mortality rates increase in climates with higher temperatures. The most vulnerable individuals in a population are people with weaker immune systems, such as the sick and the elderly (Haines *et al.* 2006;Oven *et al.* 2012). Climate change will most likely intensify the number and severity of heat waves (Kinney *et al.* 2008). These events will not only affect developing nations, but also industrialized countries. For example, the 2003 heat wave in Western Europe caused over 2000 deaths in the UK (Haines *et al.* 2006). France was the most affected country with 14,800 deaths reported above the mean for the month of August and the city of Paris experiencing a 140 percent increase in mortality (Haines *et al.* 2006). Europe 's 2003 heat wave was the hottest summer in 500 years with an average increase in temperature by 3.58°C. In total, approximately 20,000 to 45,000 deaths in Europe were related to the increase in temperature for the month of August (Patz *et al.* 2005). The summer of 2003 is the most recent example of temperature directly increasing health risks for individuals (Patz *et al.* 2005).

The above average mortality and morbidity rates are found mostly in the elderly population and correlated to cerebrovascular, cardiovascular and respiratory illnesses (Oven *et al.* 2012; Haines *et al.* 2006). Urban centers tend to trap heat through the urban heat island effect and air pollution rises with increases in temperature (White-Newsome *et al.* 2012). Individuals will over time acclimate to hotter weather, but populations will need years to fully compensate and cope with the physiological changes. Even with advance preparation, industrial changes will take longer than people's ability to physically cope with climate change (Haines *et al.* 2006).

2.7.3.2 Floods and Droughts

Long or short term variations in water levels can cause harm or deaths related to droughts or floods (Few 2007;Wetz and Yoskowitz 2013). Even slow rising floods can result in human fatalities. In Central Europe, the Rhine, Meuse and Danube rivers lately flooded. For example, the rivers in 1997 flooded and caused over 100 human deaths and left over 200,000 individuals and families without homes (Haines *et al.* 2006). In 2002, the Elbe River flooded Dresden, Germany, shutting down 4 out of 6 hospitals in the area. Thus, the increased frequency of flood related events not only causes direct harm to individuals, but also undercuts public health infrastructure in these areas (de Waroux 2011;Gupta and Barman 2010). Furthermore, floods can release toxic chemicals into the environment from industrial waste or agricultural byproducts (Haines *et al.* 2006). On the other hand, droughts can affect disease transmission and exacerbate malnutrition. Water shortages can disrupt local economics through crop failures and create shortages of drinking water (Jankowska *et al.* 2012).

2.7.3.3 Water and Sanitation

Public health infrastructure that ensures access to clean water is a basic prerequisite for an individual's wellbeing (Agénor 2008 ;Clark 2011). However, people all around the world lack access to safe drinking water and basic sanitation. In 2002, about 1/5 of people in developing nations did not have regular access to safe water; in 1995 approximately 1.5 billion individuals lived in water stressed regions (Costello *et al.* 2009). Without proper access to clean water, diarrheal and respiratory diseases increase due to biological and chemical pollutants (Clark 2011;Haines *et al.* 2006). Climate change will exacerbate the effect that water availability can have on health (see Figure 8) (Costello *et al.* 2009).

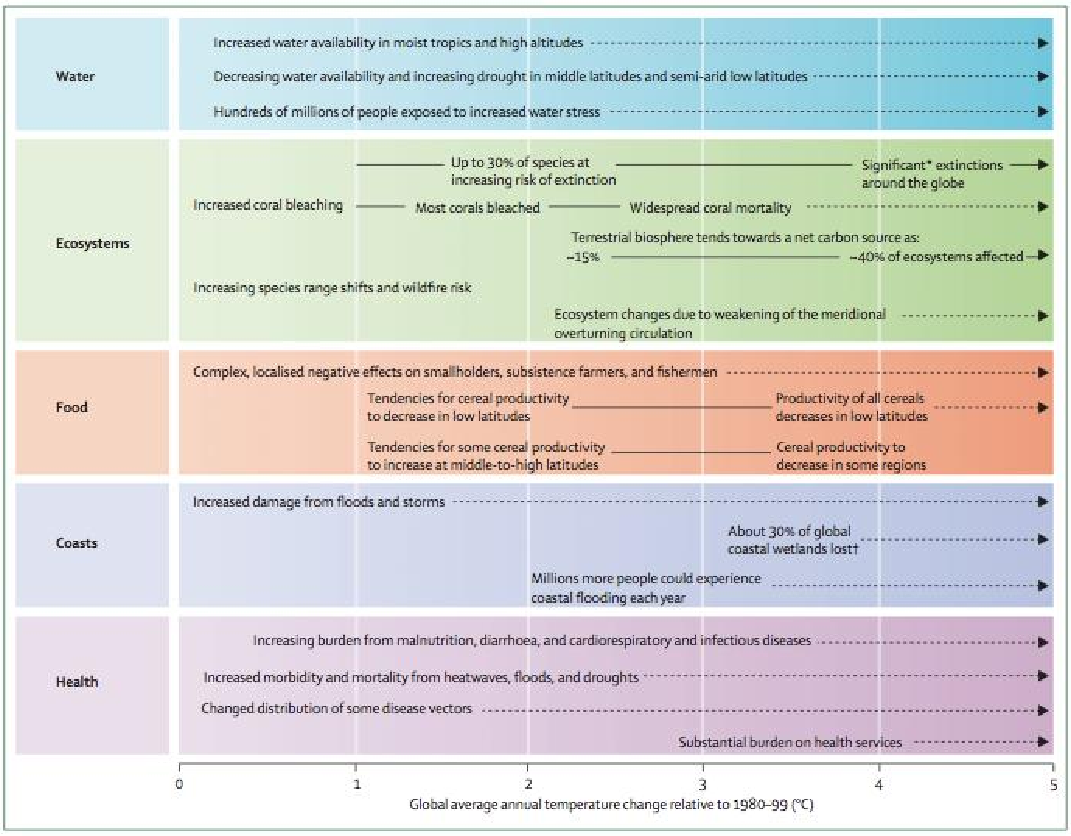


Figure 8: The effects of rising global temperatures on water availability and health (Costello *et al.* 2009)

As water temperatures rise and hydrological flows decrease, water quality will deteriorate. Less oxygen can lead to eutrophication and smaller bodies of water reduce their capacity to dilute pollutants (Haines *et al.* 2006). These negative effects increase the likelihood of morbidity among vulnerable populations and lead to general health problems in communities.

2.7.4 Disease Vectors

Vector-borne diseases are a group of illnesses transmitted to susceptible individuals through an infected microbe such as mosquitoes, ticks or fleas (Sutherst *et al.* 1998;Wei *et al.* 2008). The vectors become infected when they feed on sick organisms and in turn transmit the disease to the vulnerable individual (Sutherst *et al.* 1998). Vector-borne illnesses generally display seasonal patterns that correlate to climatic conditions (Ogden *et al.* 2005). Therefore, the infectious diseases are highly influenced by changes in climate and weather (El-Fadel *et al.* 2012). Climate change could increase transmission rates in areas where the prevalence of these diseases had previously been low. The new susceptible populations may lack immunity that others developed through continues exposure (Oven *et al.* 2012). Increases in transmission rates along with newly exposed geographic locations could result in severe public health repercussions (Patz *et al.* 2005; El-Fadel *et al.* 2012;Haines *et al.* 2006). The World Health Organization (WHO) estimates that developing countries will experience a 2 to 5 percent increase in diarrheal diseases by 2020 due to climate change (Haines *et al.* 2006). In more developed countries, especially in former Soviet Union economies, coastal floods will more than double fatalities and inland floods will increase the risk of death by 5 times (Haines *et al.* 2006).

Climate change in some cold climate areas will alleviate the population's disease burden, but these small gains are outweighed by the negative increases in global transmission rates (El-Fadel *et al.* 2012, Haines *et al.* 2006).

2.7.5 GIS and modeling overview in climate change studies

Many hydrological models that attempt to simulate and analyze environmental processes on different temporal and spatial scales (Arnold *et al.* 2010; Lowrance *et al.* 2000). The Water Erosion Prediction Project (WEPP) model simulates hydrological flow for small watersheds using hill slope sheet and rim erosion (Lane and Nearing 1989). The HYDRUS 2D model computes mathematical equations to track surface flows across different elevations (Simunek *et al.* 1999) while the Riparian Ecosystem Management Model (REMM) calculates riparian zones near water flows (Lowrance *et al.* 2000).

Various modeling software programs scale up to the watershed level following different methods (Arnold *et al.* 2010). Several models including TOPMODEL, AGNPS and MIKESHE delineate the watershed into cells. The advantage of cells is that they provide more detail, but in return the model loses accuracy while tracing water channels. Other models like WEPP and the Hydrological Simulation Program-Fortran (HSPF) (Bicknell *et al.* 1993) divide the watershed into subsections (Arnold *et al.* 2010;Hanganu *et al.* 2010). In this case, the models employ elevation data to attain the necessary topographical information to simulate the hydrological cycle (Arnold *et al.* 2010).

2.7.5.1 SWAT model background

The Soil Water Assessment Tool (SWAT) is a hydrological model that allows for large-scale simulations of watersheds (Douglas-Mankin *et al.* 2010;Hanganu *et al.* 2010). SWAT incorporates land-use, climate, soil erosion, chemical transfer and hydrological data to simulate watershed processes (Hanganu *et al.* 2010). SWAT first divides the watershed into sub-basins and then into hydrological response units (HRUs) (Arnold *et al.* 2010;Douglas-Mankin *et al.* 2010). The HRUs in each sub-area are added together to attain the sub-watershed's total water yield. The flow of water in and out of the watershed can be stored by 4 categories: shallow aquifers (usually 2-20 meters), deep aquifers (more than 20 meters), snow or soil profile (0-2 meters) (Arnold *et al.* 2010). SWAT can use daily to hourly time-series data and model the hydrological cycle for a period of 1 to 100 years (Hanganu *et al.* 2010). SWAT uses a geographic information system (GIS) interface, ArcGIS-SWAT, to build a geodatabase (Olivera *et al.* 2006). The GIS component integrates the series of numeric and text files generated by SWAT and graphically displaces and visualizes the information (Olivera *et al.* 2006).

2.7.5.2 Case studies

SWAT was developed and is still used today by the USDA Agricultural Research Service (Arnold *et al.* 1998;Douglas-Mankin *et al.* 2010). Gassman *et al.* (2007) reports the findings of over 250 academic articles that use SWAT software for hydrological modeling (Douglas-Mankin *et al.* 2010). The meta-analysis of the stream flow timelines show that SWAT is not only a useful hydrological model, but also provides reliable and accurate simulations (Gassman *et al.* 2007; Douglas-Mankin *et al.* 2010).

Several studies utilize SWAT to assess climate change scenarios for regions around the world. Rahman *et al.* (2010) modeled the Intergovernmental Panel on Climate Change's (IPCC) A2 scenario, high population growth and low advancement of technology, for a Canadian watershed. The researchers projected that between the years of 2041 and 2070 hydrological flow would increase in the spring and water, but decrease in the fall (Rahman *et al.* 2010; Douglas-Mankin *et al.* 2010). Hanganu *et al.* (2010) reports that approximately 50 journal articles discuss the use of SWAT in population loss for both small and large river basins. SWAT is officially acknowledged by the United States' Environmental Protection Agency (US EPA 2011). Recently, EnviroGRIDs (Building Capacity for a Black Sea Catchment Observation and Assessment System Supporting Sustainable Development) utilized ArcGIS-SWAT to make climate change adaptation policy recommendations for the Danube River catchment (Hanganu *et al.* 2010). These case studies justify the use of SWAT as a reliable hydrological modeling program for climate change scenarios in the Ural River Basin.

3 Methodology

In this chapter, the project utilizes both quantitative methods along with qualitative research methods for the study of the Ural River Basin and how water availability forecasts could influence the state of public health in the region.

The first section describes the research methods used to achieve the first research question's objectives while the second section illustrates the methodology for the second research question's objectives.

3.1 Research Design

The project creates a hydrological model of the Ural River Basin with ArcGIS-SWAT and uses the created geodatabase to help predict climate change scenarios in the region. SWAT will help visualize the georeferenced information for both climate change and public health to discover if any patterns exist. Furthermore, STELLA (System Thinking for Education and Research) will help create a conceptual diagram for the formulation of climate change scenarios in the Ural River Basin (STELLA 2013). In order to achieve these tasks, research will be conducted through 3 main stages including multiple parts and methods (see Table 1). Figure 9 shows a conceptual diagram of the research stages and steps associated with Table 1.

Table 1: Research Design

Stage	Stages of research	Steps	Methods
1	Analysis of Ural River Basins	- Understanding the existing climate and hydrology of the area - Watershed delineation	- Spatial analysis with GIS - Interviews
2	Development of the SWAT model for the Ural River watershed	-Develop and generate datasets needed ArcGIS-SWAT's input files - Create input files, reclassify information and run the SWAT model - Calibrate the SWAT model	-Collection of the GIS data - Spatial analysis with GIS - Statistical analysis - SWAT modeling - SWAT-CUP calibration
	Create climate change scenarios for hydrological analysis in SWAT	- Data collection for climate change scenarios - Preliminary analysis of climate change scenarios in ArcGIS	- GIS data collection -Weather generator - SWAT modeling
3	Identify connections between climate change and morbidity and mortality	- A comprehensive literature review of climate change's impact on public health - Develop a conceptual diagram with STELLA software -Develop recommendations based on STELLA and SWAT modeling	- Interviews - Literature Review - STELLA conceptual diagram

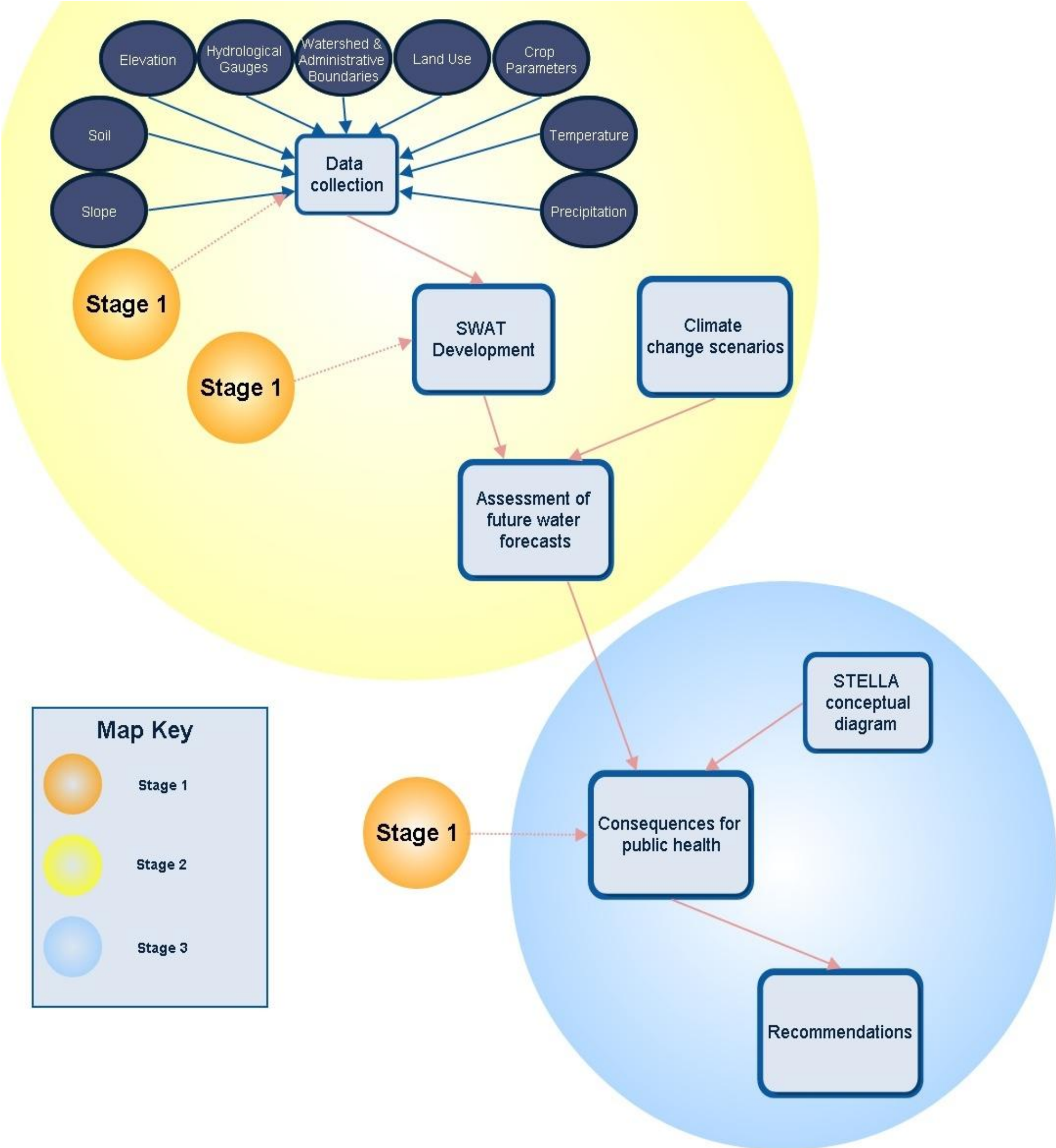


Figure 9: Conceptual diagram of research stages for this project

3.2 First section: SWAT modeling

3.2.1 SWAT Model Development

Several studies (as discussed in section 2.7.5) use a GIS approach to study the effect of climate change on different watersheds around the world. The SWAT modeling approach has been used successfully to model watersheds in Eastern Europe including the Azov Sea Basin for the Black Sea catchment (Gilfanova 2012). The University of Texas A&M created a SWAT extension, ArcSWAT, for the ArcGIS version 9.3 software (Winchell *et al.* 2010). The ArcSWAT extension allows for watershed delineation, HRU analysis and edits of input tables. Although the ArcSWAT extension is free to use, the ArcGIS platform software requires a paid license (Johnston *et al.* 2001).

After the research question focused on the Ural River Basin, the SWAT model was developed via the following:

- Data collection for the needed SWAT input files;
- Correctly formatting and creating input files for ArcSWAT
- Initiating the SWAT model;
- Calibrating the final model.

3.2.2 Data collection

The levels of accuracy for a SWAT model depends on both the quantity and quality of geographical, hydrological and land use data available (Moriasi *et al.* 2007). SWAT can effectively model the hydrological cycle of a watershed, but the ArcGIS extension requires multiple datasets (Bosch *et al.* 2004;Moriasi *et al.* 2007).

Region specific datasets for the Ural River Basin are generally not available for public use due to transboundary issues between Russia and Kazakhstan. Even if the governments of Russia or Kazakhstan have access to water quality or pollution data, distribution is highly guarded and restricted (Rucevska 2011). As a result, global or national datasets were utilized and the relevant information was extracted (see Table 2).

SWAT Model Data Collection

Table 2: Data collection

Data	Source	Relevant information
Elevation	United States Geological Survey (USGS) (Shuttle Radar Topography Mission (SRTM) 2003)	High resolution 90m
Hydrological Gauges	The Global River Discharge Database (RivDIS v1.1) (Gaylord Nelson Institute for Environmental Studies 2010)	Monthly data from 1970-1985
Watershed and Administrative Boundaries	GADM (GADM 2013)	
Land use	GlobCover 2009	Reclassification was required
Soil	ISRIC-WISE (Batjes 2012)	Derived soil properties on a 5 by 5 arc-minutes global grid (Version 1.2)
Slope	Based on elevation file	Extracted with ArcSWAT
Crop Parameters	Default SWAT crop parameters	
Temperature	European Climate Assessment and Dataset (ECA&D 2013)	Daily data from 1970-2005
Precipitation	ECA&D	Daily data from 1970-2005

3.2.3 Reclassification and organization of input files

All of the datasets in the Table 2 were reorganized or reclassified to fit the specifications of ArcSWAT. The elevation data needed to be reprojected into the correct geographic coordinate system of WGS_1984_UTM_Zone_39N with ArcMap. Any shapefile or DEM file's coordinate system in this model follows the UTM_Zone_39N based on the Ural River Basin's location (Morton 2013). Reclassification of the GlobCover2009's land use dataset was needed in order to match ArcSWAT's default land use classes (see Table 3).

Table 3: Reclassification of Land use classes for ArcSWAT

Value	**SWAT**	Reclassified	ICNUM	Label
14	AGRL	14	1	Rainfed croplands
20	AGRL	14	1	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)
30	AGRL	14	1	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)
50	FRSD	50	7	Closed (>40%) broadleaved deciduous forest (>5m)
70	FRSE	70	8	Closed (>40%) needleleaved evergreen forest (>5m)
90	FRST	90	6	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)
100	FRST	90	6	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)
110	FRST	90	6	Mosaic forest or shrubland (50-70%) / grassland (20-50%)
120	RNGE	120	15	Mosaic grassland (50-70%) / forest or shrubland (20-50%)
140	RNGE	120	15	Closed to open (>15%) herbaceous vegetation (grassland or lichens/mosses)
150	RNGB	150	16	Sparse (<15%) vegetation
180	WETL	180	9	Closed to open (>15%) grassland or woody vegetation on regularly flooded soil
190	URBN	190	9	Artificial surfaces and associated areas (Urban areas >50%)
200	SWRN	200	17	Bare areas
210	WATR	210	18	Water bodies
230	SWRN	200	17	No data (burnt areas, clouds,…)

After all the datasets match SWAT's classifications and requirements, the model can be run and generate output files. Specifically, SWAT creates watershed, HRU analysis and simulation reports. The reports will be analyzed for key hydrological factors: stream flow, water yield and temperature.

3.2.4 Calibration

In order to access accuracy and reliability, the SWAT model needs to be calibrated. The project utilized the SWAT-CUP (SWAT Calibration and Uncertainty Procedure) software for the calibration process. SWAT-CUP runs multiple simulations where it compares historical hydrological gauge data with the model's output (Rouholahnejad *et al.* 2012). SWAT-CUP allows a user to compare the output files generated by a SWAT model with recorded weather data. SWAT-CUP uses five different algorithms to assess a model's calibration (see Figure 10).

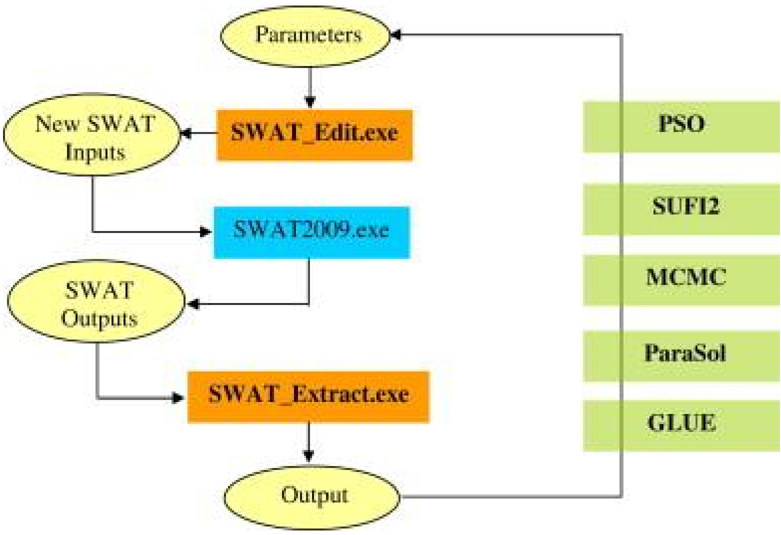


Figure 10: SWAT-CUP's design and the five integrated algorithms (Rouholahnejad *et al.* 2012)

The five algorithms help SWAT-CUP evaluate a model's accuracy:

- Particle Swarm Optimization (PSO) (Poli *et al.* 2007)
- Sequential Uncertainty Fitting (SUFI2) (Abbaspour *et al.* 2004)
- Markov chain Monte Carlo (MCMC) (Marshall *et al.* 2004)
- Parameter Solution (ParaSol) (Gupta *et al.* 1998)
- Generalized Likelihood Uncertainty Estimation (GLUE) (Beven and Binley 1992)

After submitting all of the input files for SWAT-CUP, the software program produces calibration results and sensitivity reports.

3.2.5 Climate change scenarios

The research project applies climate change scenarios produced by the LARS-WG weather generator which was developed by the Rothamsted Research Institute in coordination with the Biotechnology and Biological Sciences Research Council (BBSRC) (Mikhail *et al.* 1998). The weather generator uses information from 15 models assembled in the IPCC Fourth Assessment Report to create daily climate change data (Semenov and Stratonovitch 2010). Once LARS-WG creates the output scenario data, the information will be reclassified under the SWAT model classifications. The SWAT model will simulate each scenario and the results will be analyzed.

LARS-WG creates daily time series data for 50 years for the following hydrological parameters:

- Maximum temperature
- Minimum temperature
- Precipitation
- Solar radiation

The weather generator compares a specific site's historical data with one of the IPCC's models and generates scenarios based on the user's specifications (Semenov and Stratonovitch 2010). There exist four basic scenarios:

- *A1B*: High economic development, low population levels and rapid integration of new technology;
- *A2*: High population growth rates, less international cooperation and less economic stimulation
- *B1*: High emphasis on sustainable technology, improved economic equity among the classes and low population growth
- *B2*: High emphasis on local solutions with environmental and social equality attaining high priorities.

Each individual scenario assigns a different level of carbon dioxide (CO_2) concentration depending on the time period. The level of CO_2 continues to increase across time regardless of chosen scenario (Semenov and Stratonovitch 2010).

Various studies have successfully used the LARS-WG generator to create time series weather data for different regions around the world (Semenov and Stratonovitch 2010, Semenov and Barrow 1997, Semenov 2007).

3.3 Second Section: Climate change implications for public health

In order to identify the connection between the effects of climate change especially temperature and water on disease morbidity and mortality for the Ural River Basin an extensive overview of the current literature was conducted. To understand the current relationship, the project employed both quantitative and qualitative research methods.

The current relationship between weather fluctuations and disease dynamics were reviewed and analyzed through a comprehensive literature review, interviews and expert consultations. The necessary information was acquired through national reports from Russia and Kazakhstan, academic journals, international agreements, expert consultations and interviews.

3.3.1 Interviews

Interviews were conducted with representatives of Russian and Kazakhstan environmental agencies and GRID-Arendal UNEP researchers (Rucevska and Simonett 2013). GRID-Arendal is a research center that collaborates with the

United Nations Environment Program (UNEP) by establishing a network of collaboration between researchers, governmental agencies and other environmental organizations (Rucevska and Simonett 2013). The organization regularly publishes reports on the current environmental state for regions around the world while providing tools for communication and community outreach. In particular, the capacity building and assessments division within GRID-Arendal helped facilitate interviews and consultations with representatives from both Russia and Kazakhstan.

The public health infrastructure data was collected and synthesized from both the Ministry of Health of the Russian Federation's Department of Population and Healthcare Statistics (Chumarina *et al.* 2012) and the Agency of the Republic of Kazakhstan on statistics (The Agency of Statistics of the Republic of Kazakhstan 2013). Consultations with both agencies provided information regarding public health in the Ural River Basin.

3.3.2 Conceptual diagram with STELLA model

This section describes the development of a conceptual model of climate change's impact on public health by using the STELLA (Strongly Typed Lisp Like Language) software program (Ouyang 2008). STELLA is a modeling and mapping program created by IseeSystems which helps to visualize dynamic processes and designate mathematical functions to the model's individual parts (STELLA 2013). STELLA employs four main building blocks:

1) *Stocks* represent any variable of accumulation and can compile or accumulate anything that flows into or out of them;
2) *Flows* control the input and output of information to stocks which can influence a stock's size;
3) *Converters* are secondary variables that contain equations or constant values that modify each simulation;
4) *Connectors* help connect the other features together in order to help regulate the flow of information. Connectors can connect into convertors or flows, but not into stocks (Ouyang 2008).

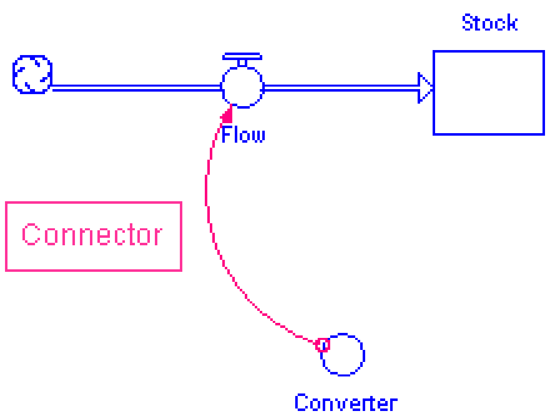


Figure 11: A diagram showing the four building blocks of STELLA: Stock, flow, converter and connector generated by STELLA®7.0.3

Another useful function of STELLA is the ghost tool, which allows a user to create a copy of a converter, flow or stock. The ghost tool allows for multiple copies of several building blocks of STELLA. Once a copy is made the user can avoid stretching connectors over long distances and create more visually clear representations. STELLA distinguishes the original by creating dash lines instead of solid lines for any copies (Costanza and Voinov 2001).

In this project, STELLA®7.0.3 version generated any of the figures or conceptual diagrams associated with this software package (STELLA 2013). The stock and flow diagrams help provide insight into how the changes in water or temperature could affect the morbidity and mortality rates in the Ural River Basin region.

4 Results

4.1 SWAT model

After all the datasets match SWAT's classifications and requirements, the model must run through several stages before attaining the watershed, HRU analysis and simulation reports. This chapter will show all of the individual steps in ArcGIS-SWAT to develop the final SWAT model for the Ural River Basin.

4.1.1 Watershed delineation

After starting a new SWAT project and setting up the appropriate working directories, the next step is the automatic watershed delineator (Gilfanova 2012). ArcSWAT utilizes the loaded elevation DEM file from USGS (see Table 2) to automatically calculate stream definition, flow direction and accumulation (Winchell *et al.* 2010). Since the elevation data was of fairly high resolution at 90 meters, one could disregard the predefined streams or watershed option. The program allows the user to input a specified area for steam delineation, in this case 900,000 hectare.

At this point, ArcSWAT starts the next section in the watershed delineation process. Once the program creates the stream network and marks outlets, the user can specify or modify the outlets or inlets. ArcSWAT allows for the manual entry of outlets by table or hand. An outlet was manually added to the watershed at the location of the hydrological gauge station on the Ural River. This step allows SWAT-CUP to compare the hydrological gauge data with the SWAT model's predictions, which contributes to a successful completion of the calibration process.

To outline the watershed's boundary, the user needs to specify the watershed's main outlet. The main outlet for the Ural River Basin is the point where the river drains into the Caspian Sea. Once the main watershed outlet is defined, ArcSWAT calculates the subbasin parameters and displays four new layers over the elevation file (see Figure 12):

- The *monitoring point layer* includes information about precipitation gages, temperature gages, and stream junction points;
- The *outlet layer* contains the automatic outlets generated by ArcSWAT and the manually added outlets;
- The *basin boundary layer* with marked watershed subbasins;
- The *stream reach definition layer* with the longest path.

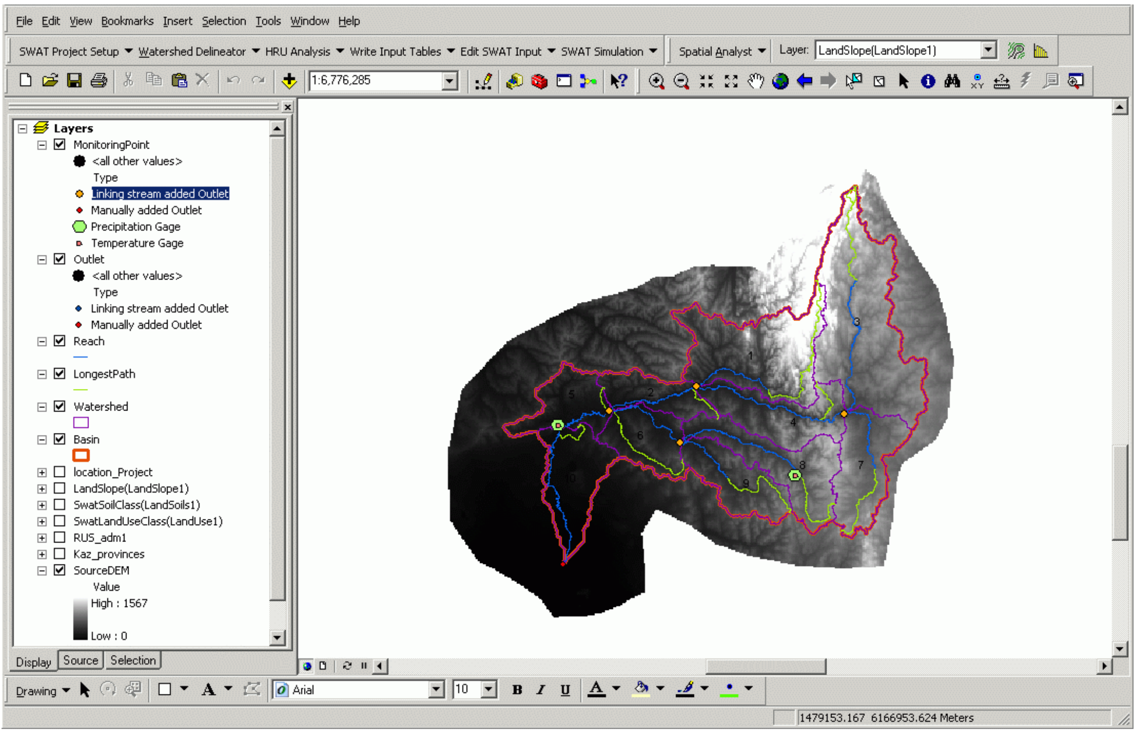


Figure 12: SWAT's automatic watershed delineation for the Ural River Basin

At the end of the automatic watershed delineation process, 10 subbasins with 10 outlets were identified for the Ural River Basin. The program also produced a topography report, which calculated statistics for the overall watershed and subbasins' elevation. The report states the average elevation, the percentage of area below elevation and the percentage of subbasin area.

4.1.2 HRU analysis

After the automatic watershed delineation, the next step calculates the hydrological response units (HRUs) for each subbasin. ArcSWAT uses external land use (GlobCover 2010) and soil (Batjes 2012) datasets and extracts slope information from the elevation file (see Table 2). The information for land use was reclassified to fit ArcSWAT categories (see Table 3). The soil layer was incorporated with a lookup table that related the ISRIC-WISE classifications with the default ArcSWAT categories (Gilfanova 2012). For the slope discretization, two slope classes were chosen with an upper limit of 3% based on the watershed slope statistics produced by ArcSWAT. After the program processed each layer, three new layers were added over the elevation file.

ArcSWAT requires land use, soil and slope definitions to better simulate hydrological variables like stream flow. Based on previous HRU studies for watersheds, the following multiple HRU thresholds were selected (Winchell *et al.* 2010):

- Land use percentage (%) over subbasin area: 20%
- Soil class percentage (%) over land use area: 10%
- Slope class percentage (%) over soil area: 20%

Once the program created HRUs for the 10 subbasins, the new layers were overlaid over with the output from the automatic watershed delineation stage (see Figure 13).

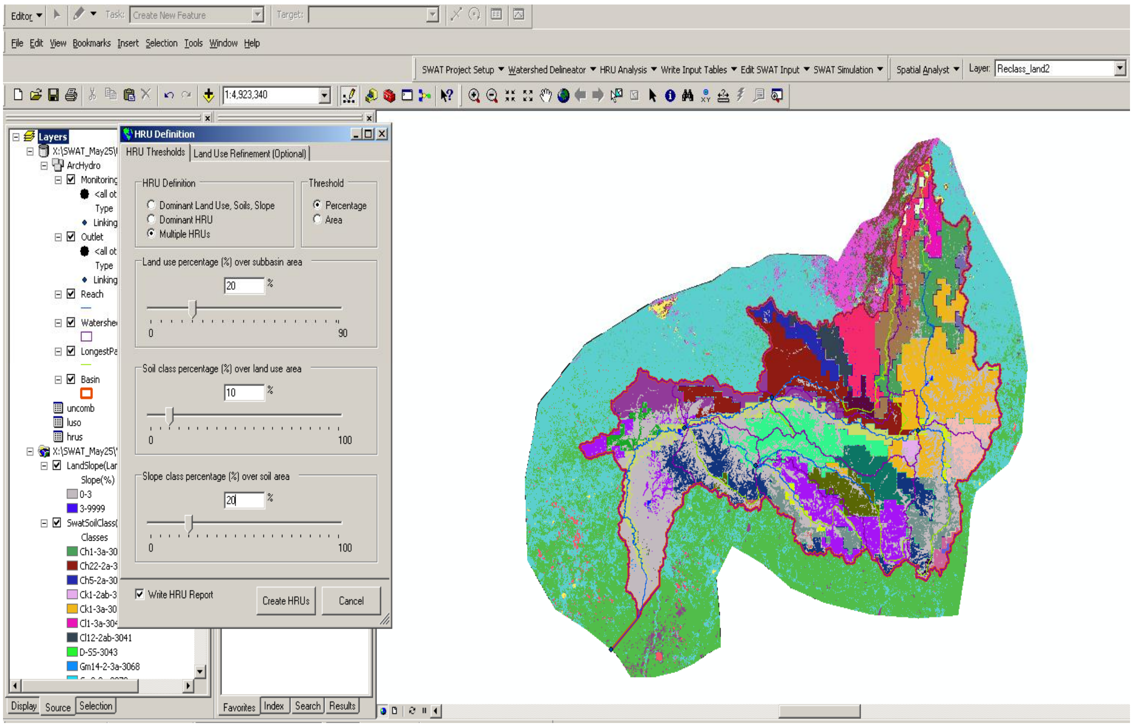


Figure 13: ArcSWAT's HRU definition output layers

The last step in the HRU analysis generates statistical reports for the watershed as a whole and individual data for each subbasin.

4.1.3 Write input tables

After the HRU analysis, the next step generates input tables and defines weather data for the region. The weather data definition allows the user to choose a preloaded US or custom database. In this case, two weather stations provided the weather data to increase the model's accuracy (see Table 4).

Table 4: Ural River Basin's metrological station for input tables

NAME	Latitude	Longitude	Elevation (m)
AKTOBE	50.28333	57.16667	219
URALSK	51.23333	51.36667	38

The two stations, Aktobe and Uralsk, provided minimum and maximum temperature along with daily precipitation data from the European Climate Assessment and Dataset (ECA&D) for the period of 1970 to 2005 (ECA&D 2013). Although four other stations could provide additional climate data using the ECA&D, these stations did not include one of the required parameters for temperature or precipitation. Once ArcSWAT successfully integrates the weather input tables, the precipitation and temperature stations are added to the monitoring stations layer (see Figure 14).

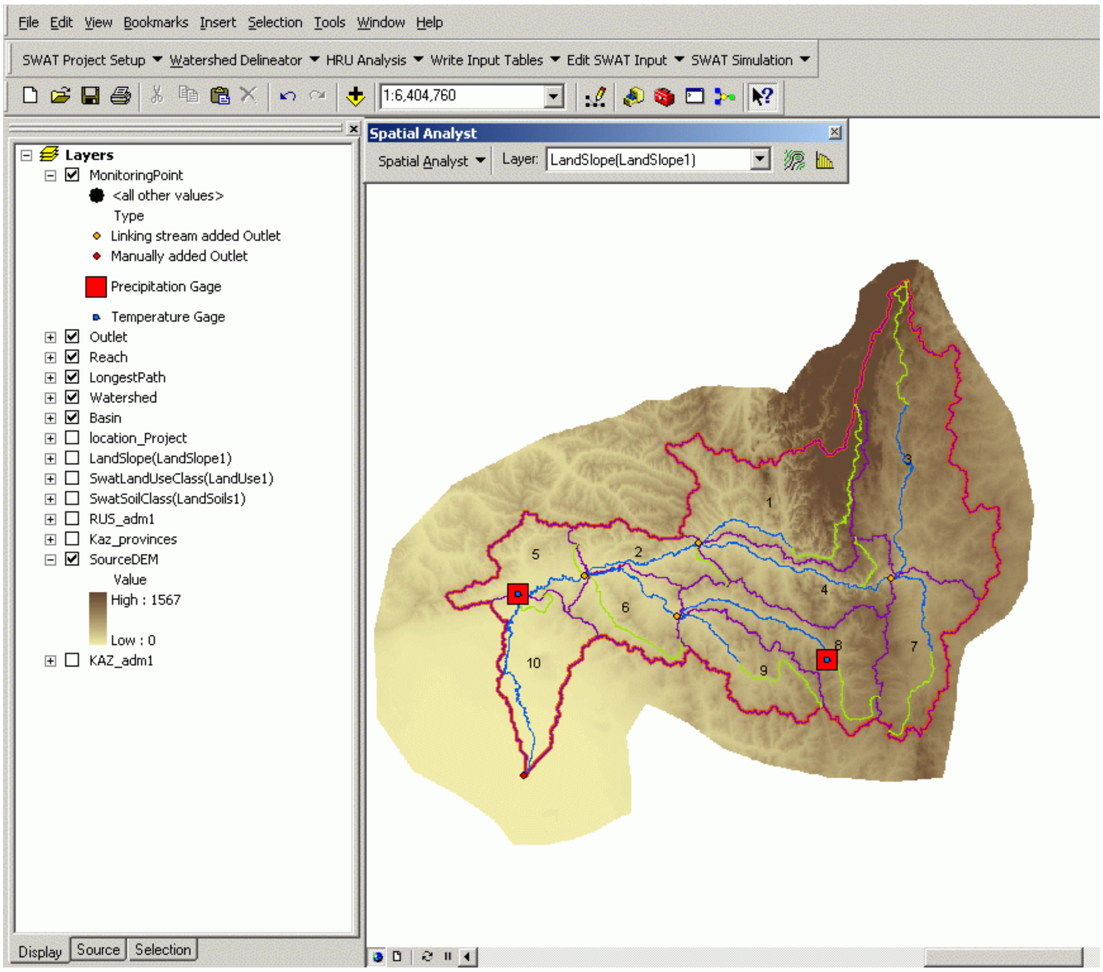


Figure 14: Precipitation and temperature gauges after weather data delineation

Figure 14 shows the monitoring point layer's inputted precipitation and temperature gauges. The bright red squares indicate the precipitation gauges while the light blue dots show the temperature gauges.

4.1.4 SWAT simulation

After writing the input tables and defining the weather data, the final stage is running the SWAT model. Before running the simulation, ArcSWAT requires the user to assign certain specifications (see Figure 15).

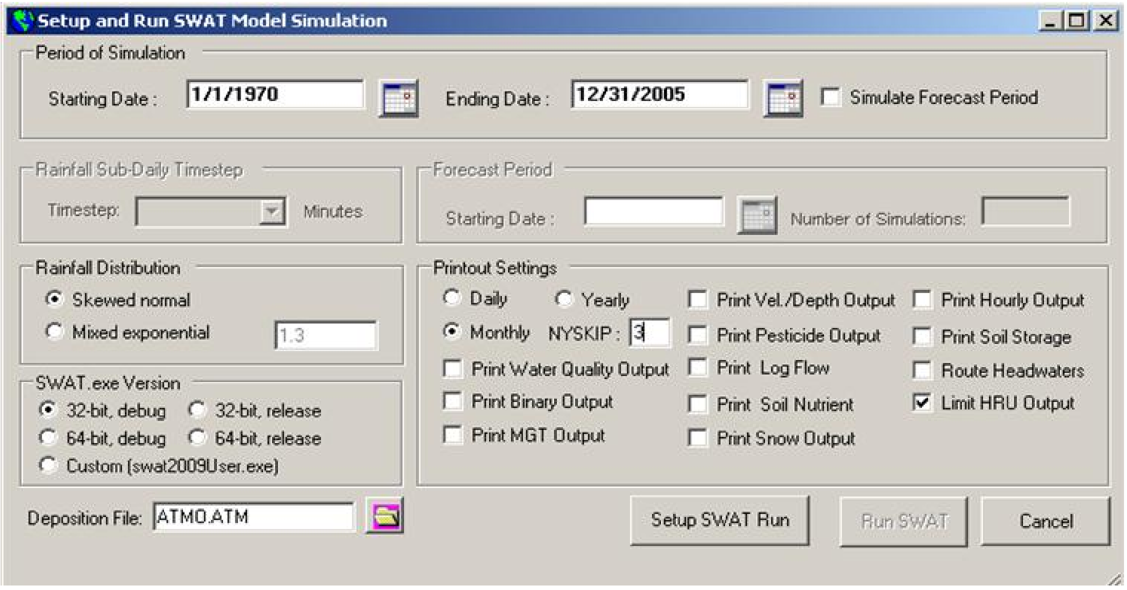


Figure 15: SWAT model simulation and setup specifications

The period of simulation for the Ural River Basin model runs from January 1, 1970 to December 31, 2005. The model retains the default settings for rainfall distribution and printout settings: skewed normal monthly data. Furthermore, a three-year warm-up period allows for better simulation results.

Once the user sets the parameters, ArcSWAT processes the information and generates output files in the form of text files and a Microsoft Access database. The database contains statistics for the HRU, subbasins and reaches for each of the 10 subbasins in the watershed (see Figures A 5 to A 8).

4.1.5 SWAT model calibration

The created SWAT-CUP project runs SUFI2 and allows for the input of monthly stream flow data from 1970 to 1985 collected from The Global River Discharge Database (RivDIS v1.1) (Gaylord Nelson Institute for Environmental Studies 2010). The software program ran the calibration process and generated the SWAT model's calibration results and sensitivity reports (see Figure 16).

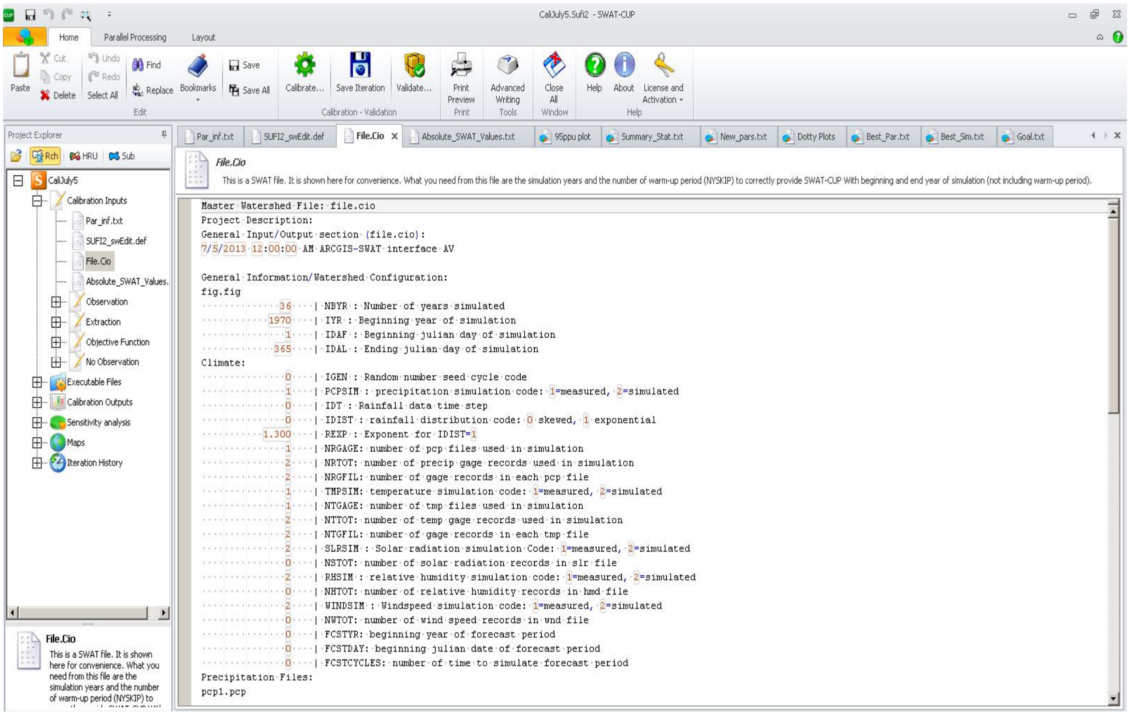


Figure 16: SWAT-CUP calibration input and output files

The SWAT model for the Ural River Basin was successfully calibrated with standalone software program SWAT-CUP.

4.2 Development of climate change scenarios

The LARS-WG produces the climate scenario data for each individual site in two stages: site analysis and generator. Two sites, Aktobe and Uralsk, were used to generate the climate change scenarios. These two stations are the same meteorological sites used to generate the input tables and define the SWAT model's weather data (see Table 4).

4.2.1 Site Analysis

The first step requires the user to arrange the site file and weather data according to LARS-WG specific format. The site file names and locates the individual station by providing the site's latitude, longitude and altitude. In addition, the site file informs the program about the location of each station's historical weather data and format (see Figure 17).

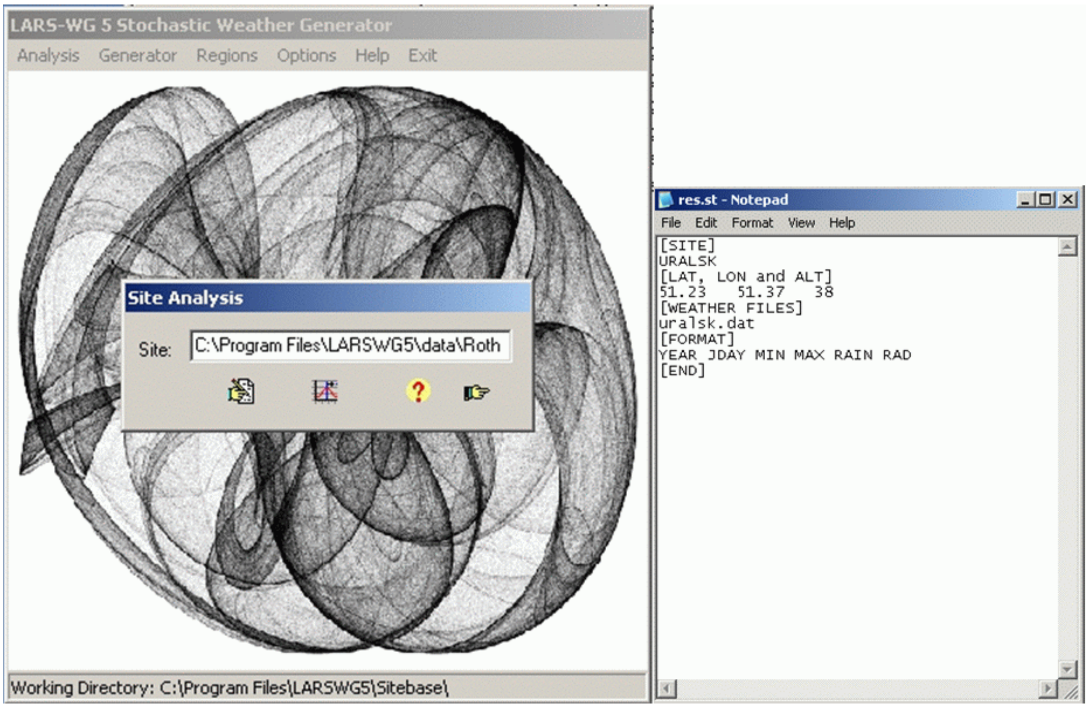
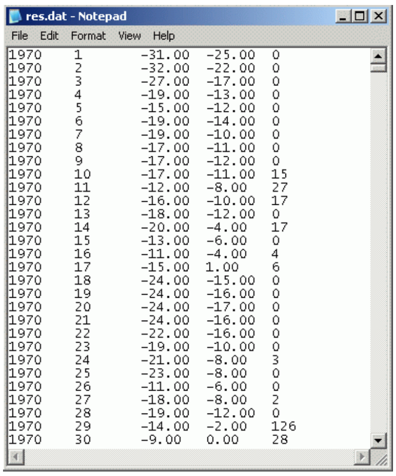


Figure 17: Site analysis for LARS-WG

Before running site analysis, the historical weather data for each station needed to be reformatted. The layout of the weather file needs to be in the following format: year, Julian day (Jday from 1-365 or 366), minimum temperature (°C), maximum temperature (°C), and precipitation (mm)(Semenov *et al.* 2002). Figure 18 shows the example weather file for the Aktobe station.


res.dat - Notepad

File Edit Format View Help

1970	1	-31.00	-25.00	0
1970	2	-32.00	-22.00	0
1970	3	-27.00	-17.00	0
1970	4	-19.00	-13.00	0
1970	5	-15.00	-12.00	0
1970	6	-19.00	-14.00	0
1970	7	-19.00	-10.00	0
1970	8	-17.00	-11.00	0
1970	9	-17.00	-12.00	0
1970	10	-17.00	-11.00	15
1970	11	-12.00	-8.00	27
1970	12	-16.00	-10.00	17
1970	13	-18.00	-12.00	0
1970	14	-20.00	-4.00	17
1970	15	-13.00	-6.00	0
1970	16	-11.00	-4.00	4
1970	17	-15.00	1.00	6
1970	18	-24.00	-15.00	0
1970	19	-24.00	-16.00	0
1970	20	-24.00	-17.00	0
1970	21	-24.00	-16.00	0
1970	22	-22.00	-16.00	0
1970	23	-19.00	-10.00	0
1970	24	-21.00	-8.00	3
1970	25	-23.00	-8.00	0
1970	26	-11.00	-6.00	0
1970	27	-18.00	-8.00	2
1970	28	-19.00	-12.00	0
1970	29	-14.00	-2.00	126
1970	30	-9.00	0.00	28

Figure 18: The historical weather data format for site analysis

Although LARS-WG gives the option for solar radiation, this field was disregarded because two sites did not provide solar radiation. Afterwards, the program produces two files, site.sta and site.wg, which provide the required statistics for the generator stage (Semenov *et al.* 2002).

4.2.2 Generator

The generator stage uses the two files produced by site analysis to produce the climate change scenario data. The generator uses the historical data to correspond to a specific scenario chosen by the user. In this case, the IPCC 4's GFCM21 model created by the Geophysical Fluid Dynamics Laboratory was utilized Jackson *et al.* 2011 (see Figure 19).

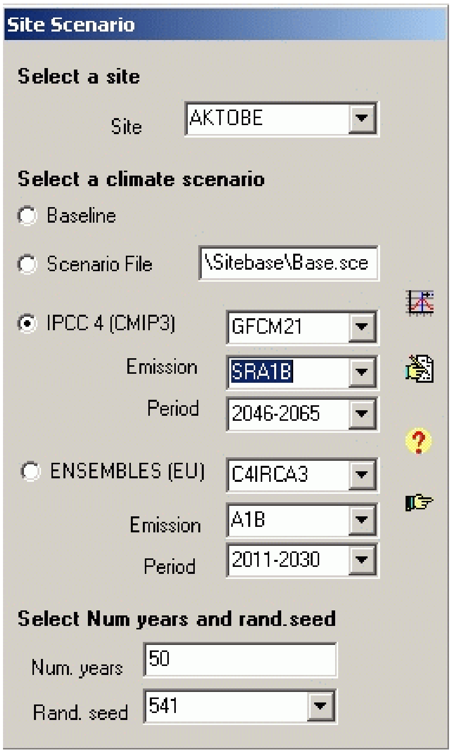


Figure 19: LARS-WG's generator criteria

Each individual site produces three different emission scenarios under the GFCM21 model. The GFCM21 model can produce information regarding the A1B, A2 and B1 scenario for the period of 2046-2065. The simulation was run for 50 years with a random seed number of 541. A total of six different data files were produced after running the weather generator for two sites. The climate change scenario data were integrated into the SWAT model for simulation.

4.2.3 SWAT model integration of climate change scenarios

The output data created by SWAT-CUP was reorganized into the required SWAT model's parameters. The SWAT model will take the climate change scenario data and repeat the process of generating input tables and defining weather data (see section 4.1.3). The two stations, Aktobe and Uralsk, will help compare hydrological parameters for the baseline years of (1970-2005) to the 2054 climate change scenarios.

The first step requires ArcSWAT to successfully integrate the weather input tables and define the precipitation and temperature stations for each scenario (see Figure 20). Since there are three climate change scenarios, the model requires this step to be repeated three times.

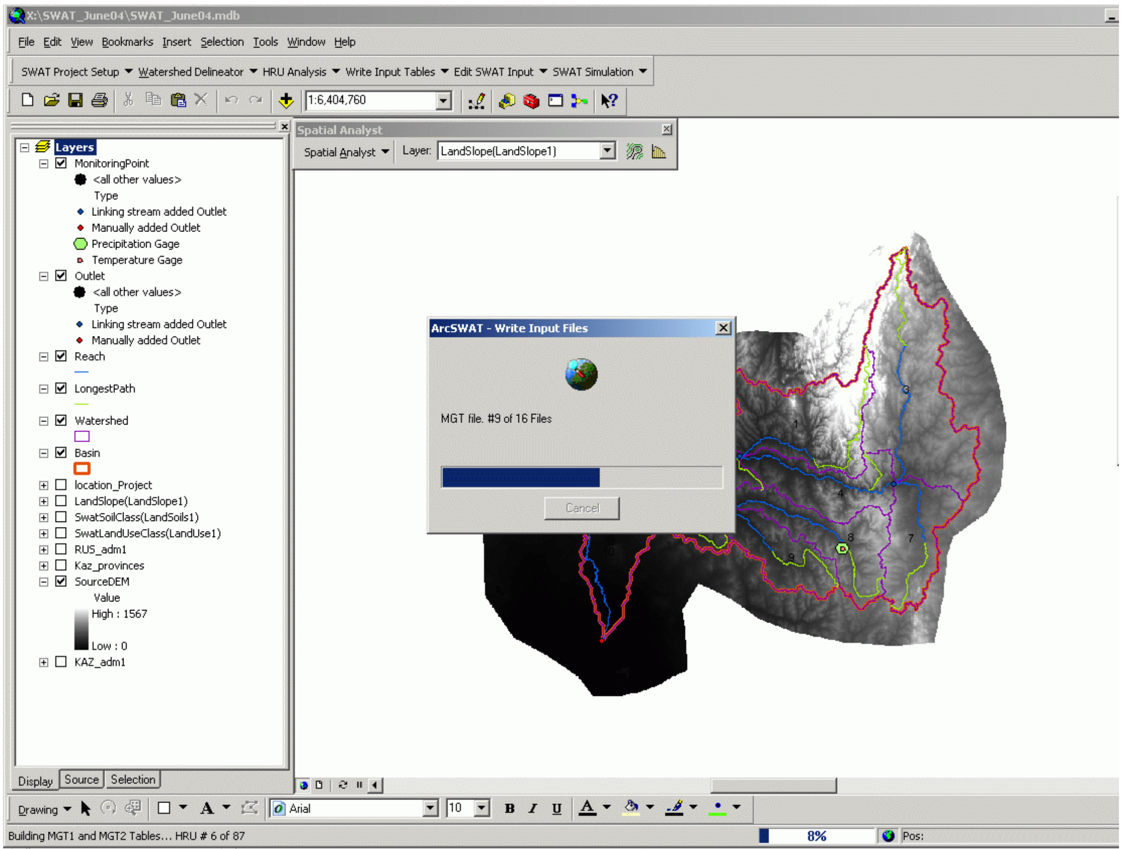


Figure 20: Writing input tables for climate change data in ArcSWAT

After writing the input tables and defining the weather data, the final stage is to run the SWAT model for the climate change scenario. Before running the simulation, ArcSWAT requires the user to assign certain specifications (see section 4.1.4 and Figure 21).

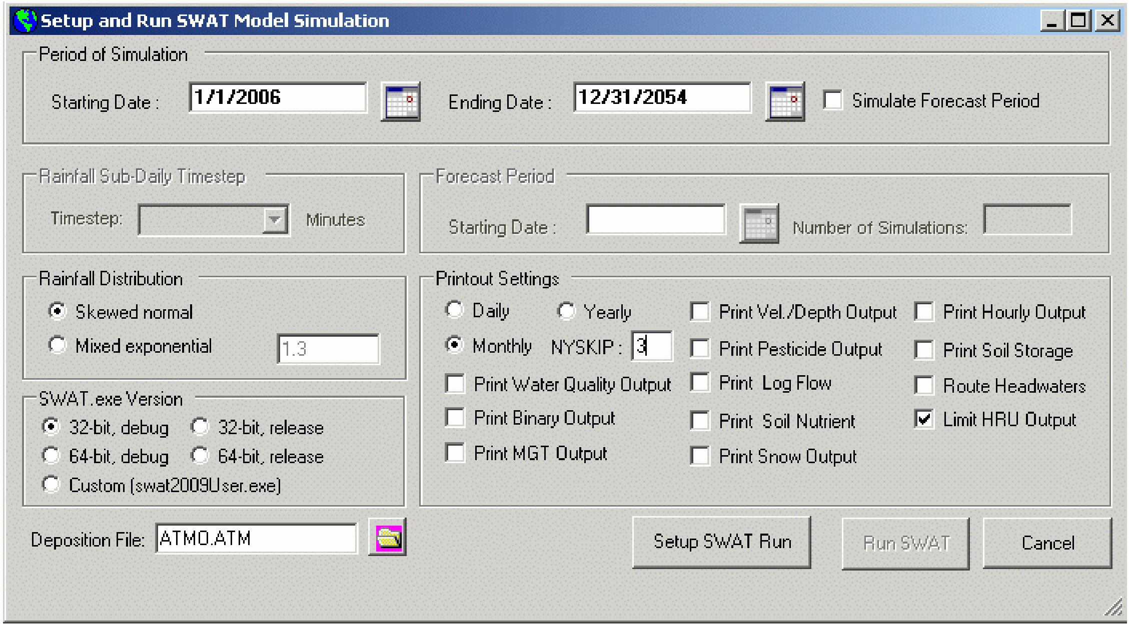


Figure 21: SWAT model simulation and setup specifications for climate change scenarios

The period of simulation for each scenario of the Ural River Basin model runs from January 1, 2006 to December 31, 2054. The model retains the default settings for rainfall distribution and printout settings: skewed normal monthly data. Furthermore, a three-year warm-up period allows for better simulation results.

Once the user sets the parameters, ArcSWAT processes the information and generates output files in the form of text files and a Microsoft Access database. The database contains statistics for the HRU, subbasins and reaches for each of the 10 subbasins in the watershed. The main results can be found within the output.std file under the TxtInOut folder for each climate change scenario simulation.

4.3 Climate change results

The developed SWAT model generated a set of hydrological parameters to assess three different climate change scenarios, A1B, A2 and B2, for the Ural River Basin until the year 2049. The climate change scenarios will analyze the hydrological changes for the main watershed outlet for the Ural River Basin flowing into the Caspian Sea.

Table 5: Baseline (1970-2005) and projected (2049) annual average of hydrological characteristics for the Ural River Basin

	Baseline	SRA1B	SRA2	SRB1
Rain (mm)	277.99	266.62	278.56	275.35
Snow Fall (mm)	90.56	78.11	83.79	86.49
Surface Runoff (mm)	187.04	177.09	188.07	185.69
LAT Q (mm)	0.20	0.19	0.19	0.19
Water Yield (mm)	244.93	228.74	241.19	238.31
Evapotranspiration (mm)	28.29	33.04	32.74	32.36
Sediment yield (T/HA)	8.99	8.55	9.10	9.10
Potential Evapotranspiration (mm)	60.36	69.65	67.85	66.28

Table 5 compares the main hydrological attributes for the baseline (2005) with the projected year of 2049. The baseline information for the Ural River Basin illustrates the average annual values for the period of 1970-2005 from the developed Arc-SWAT model (see section 3.2). In general, all three scenarios highlight the anticipated decrease in water availability and reduction of water flow for the Ural River Basin. In particular, the study will highlight in green (see Table 5) the reduction of water yield (mm) seen across all scenarios. The following highlights the individual differences found across the three climate change scenarios:

1) SRA1B

The SRA1B scenario will experience the greatest reduction in water yield across all projections by 6.9 %. With the exception of lat Q (mm), this scenario illustrates the largest percent change for all of the indicated hydrological variables. Rain and snow fall both experience a reduction by 4.1% and 13.7% respectively while evapotranspiration and potential evapotranspiration increase by 16.8% and 15.4%. Furthermore, sediment yield will decrease by 4.9%.

2) SRA2

With the following parameters SRA2 experiences the best-case scenario for climate change. Under this scenario, water yield only decreases from the baseline by 1.5%. This is the only scenario where rain will increase by 0.2% and experiences the highest sediment yield with a 1.2% increase. SRA2 produces the second highest reduction in snowfall by 7.5%. Even though SRA2 illustrates a marginal increase in rainfall, this scenario still projects the second highest increase in evaporation and potential evapotranspiration by 15.7% and 12.4% correspondingly.

3) SRB2

Under this scenario water yield undergoes the second highest reduction by 2.7%. Rainfall decreases by 1% while snow fall experiences the lowest reduction by 5.5%. The projection SRB2 indicates the lowest increase in evapotranspiration and potential evapotranspiration by 14.4% and 9.8% respectively. The sediment yield increases almost the same as the SRA2 scenario only slightly lower by 1.2%.

4.3.1 Water Yield Assessment

According to all scenarios, the water flow decreases through the main outlet for the Ural River Basin. The baseline annual flow for the baseline starts at 2939.14 mm while the climate change scenarios decrease in ascending order: SRA1B (2744.88 mm), SRB1 (2859.66 mm) and SRA2 (2894.29) (see Figure 22).

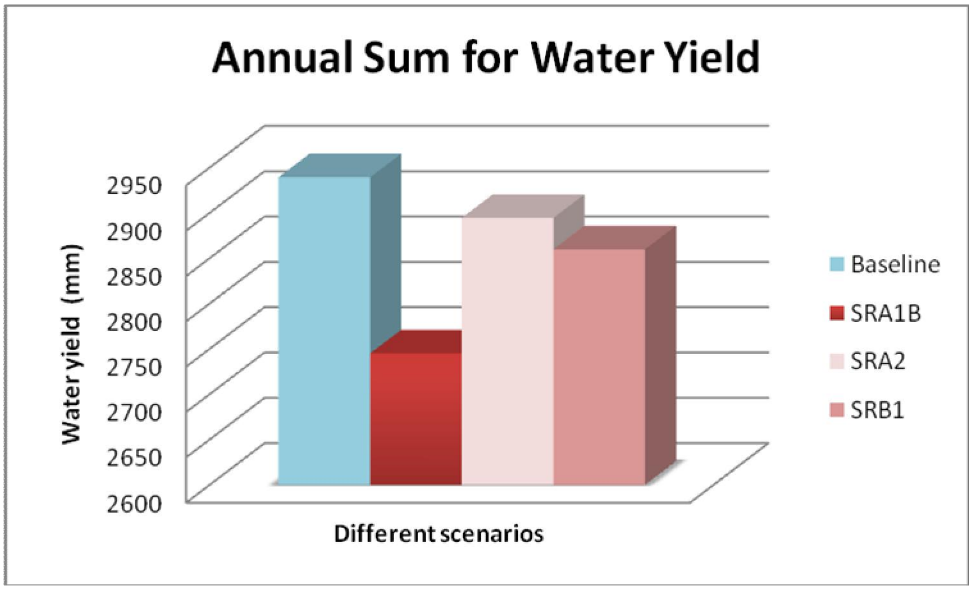


Figure 22: Annual sum for water yield comparing the baseline (1970-2005) with different climate change scenarios

From Figure 22, the graph displays the greatest decrease in water flow with the use of color. The reddest scenario, SRA1B, displays the greatest reduction in water flow while the lightest pink, SRA2, shows the smallest decrease. To further indicate the variation in water flow Figure 23 displays the percent change for each scenario when compared to the baseline information.

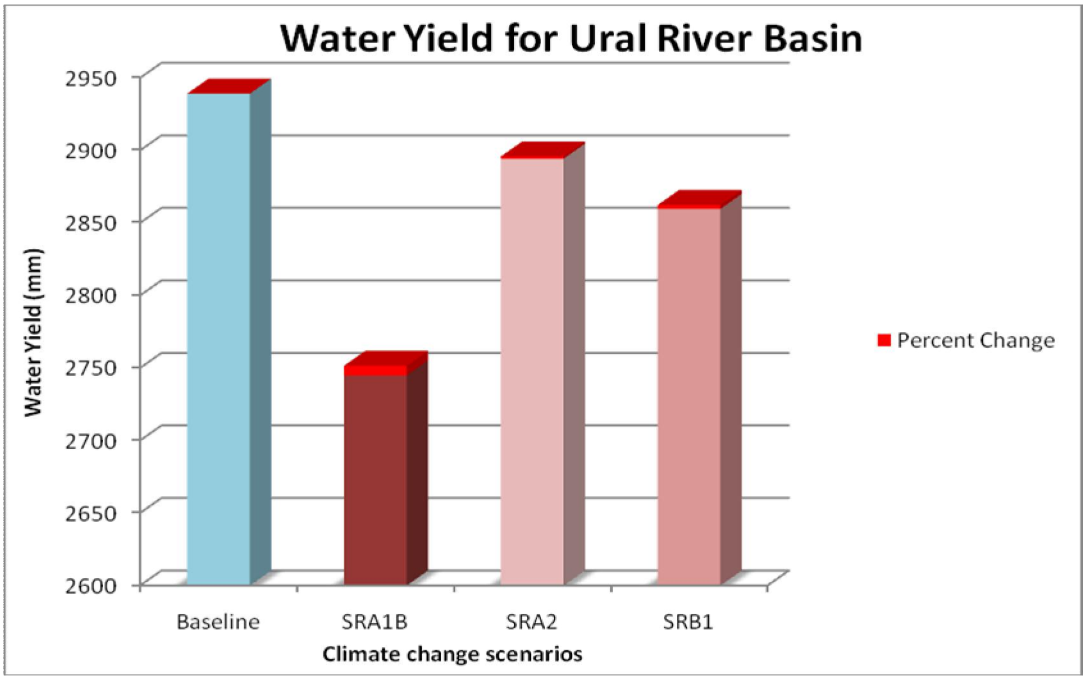


Figure 23: Annual sum of water yields comparing the percent change with the baseline for different climate change scenarios

SRA1B displays the greatest percent change with a 6.9% reduction while SRB1 follow with 2.70% and SRA2 with 1.53%. Although SRA2 only shows a 1.53% change reduction, the absolute value would decrease by 44.85 mm per year. This reduction in water flow could have a major impact on ecosystem services, agricultural practices and public health interventions for the region.

Climate change will not only affect annual water yields, but also the monthly distribution of water flow for the Ural River Basin. Figure 24 shows the average monthly water yields comparing the baseline (1970-2005) with projected (2049) values for the Ural River Basin.

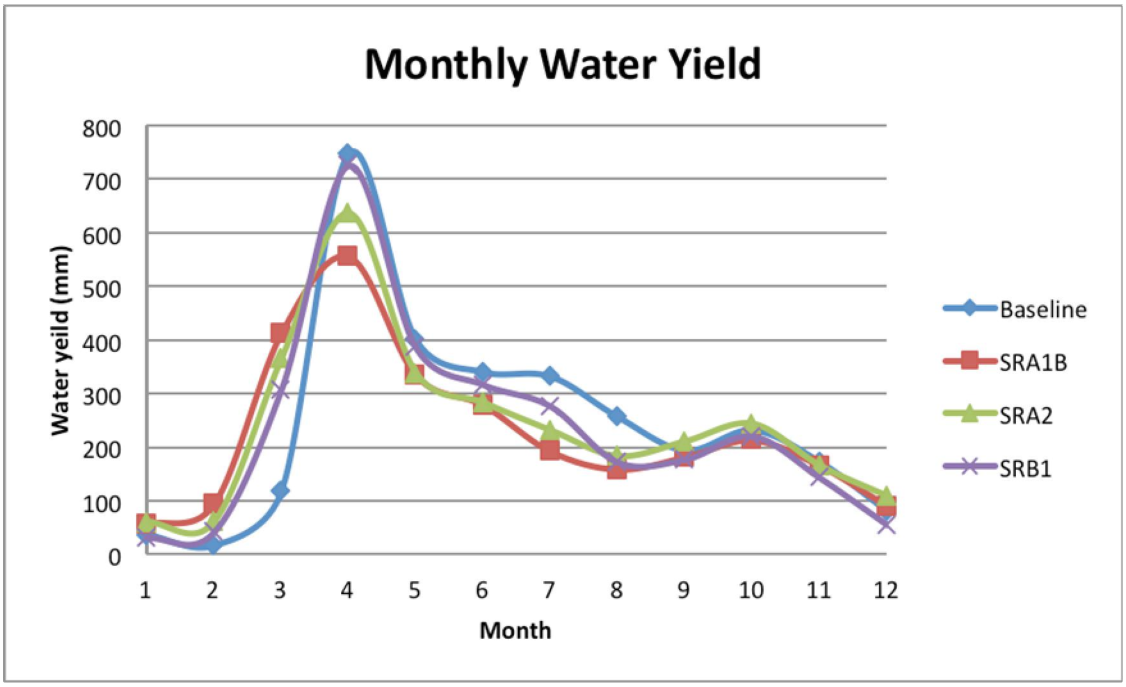


Figure 24: Baseline (1970-2005) and projected (2049) monthly average water yields for the Ural River Basin

According to the baseline, snowmelt that contributes to water yield occurs around March. The peak for all scenarios and the baseline takes place in April, but snowmelt for all three climate change scenarios occurs earlier late in February rather than March. As a result, there is less water at the peaks for all the scenarios. The reduction in water flow produces less flooding which could lead to some positive public health results like a reduction in water borne diseases. However, the change in water yields will likely have a larger negative impact by shifting the seasonality of vector borne diseases and limit ecosystem services for the region. Less water availability can lead to unsustainable agricultural practices and malnutrition for individuals living in the Ural River Basin.

4.4 System Dynamic Modeling: STELLA

The following chapter discusses the development of a STELLA conceptual diagram that identifies the connections between climate change and morbidity and mortality. The STELLA model contains four different parts: the hydrology of the Ural River Basin, water quality, public health implications of raising temperatures and vector borne diseases for each individual province. The model will help identify potential climate change mitigation strategies for public health infrastructure in each province within the Ural River Basin.

4.4.1 Hydrology of Ural River Basin

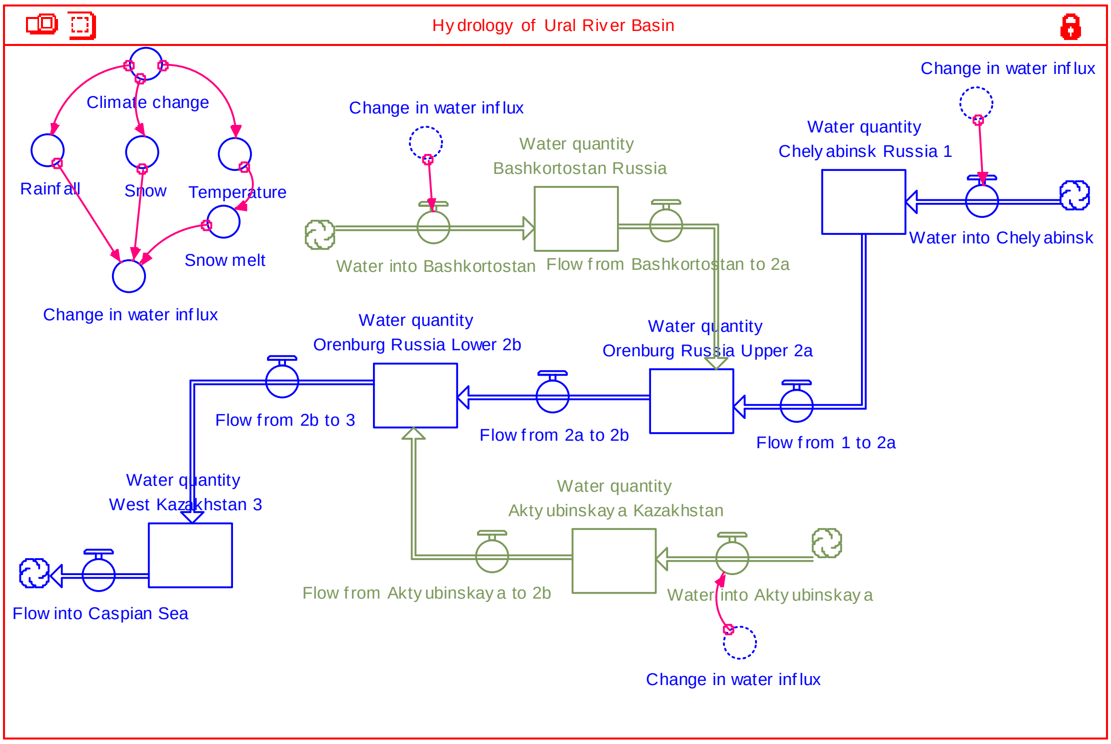


Figure 25: STELLA model of the hydrology of Ural River Basin

The Ural River Basin runs through five separate provinces within Russia and Kazakhstan. In Russia the river flows through the Orenburg, Bashkortostan and Chelyabinsk provinces and in Kazakhstan the river goes through the Aktyubinskaya and West Kazakhstan provinces (Lagutov 2008). The main stream (labeled in blue) goes through Chelyabinsk, Orenburg and West Kazakhstan before flowing into the Caspian Sea. In Figure 25 the direction of flow for the main stream is labeled by 1 (Chelyabinsk), 2a (Orenburg upper), 2b (Orenburg lower) and 3 (West Kazakhstan). Both Bashkortostan and Aktyubinskaya retain only tributaries that drain into the main stream and are labeled green.

The Orenburg water quantity is divided into two parts: Orenburg upper 2a and Orenburg lower 2b. Since a large percentage of the main stream river flows through Orenburg, the region was split into two sections to account for upstream and downstream factors. Furthermore, the water quantity for Orenburg upper 2a is influenced by the tributary flowing from Bashkortostan while the water quality for Orenburg lower 2b is affected by Aktyubinskaya's tributary. As a result, the upper and lower regions of Orenburg experience different amounts of water due to their different tributaries.

The hydrological model also includes the effect of climate change for the watershed. In the upper left part of Figure 25, the conceptual diagram highlights the possible changes for rainfall, snow and temperature. Also, fluctuations in temperature will influence the rate of snowmelt contributing to the overall change in water influx. The change in water influx caused by climate change will influence the water flowing into Chelyabinsk, Bashkortostan and Aktyubinskaya.

4.4.2 Water quality of the Ural River Basin

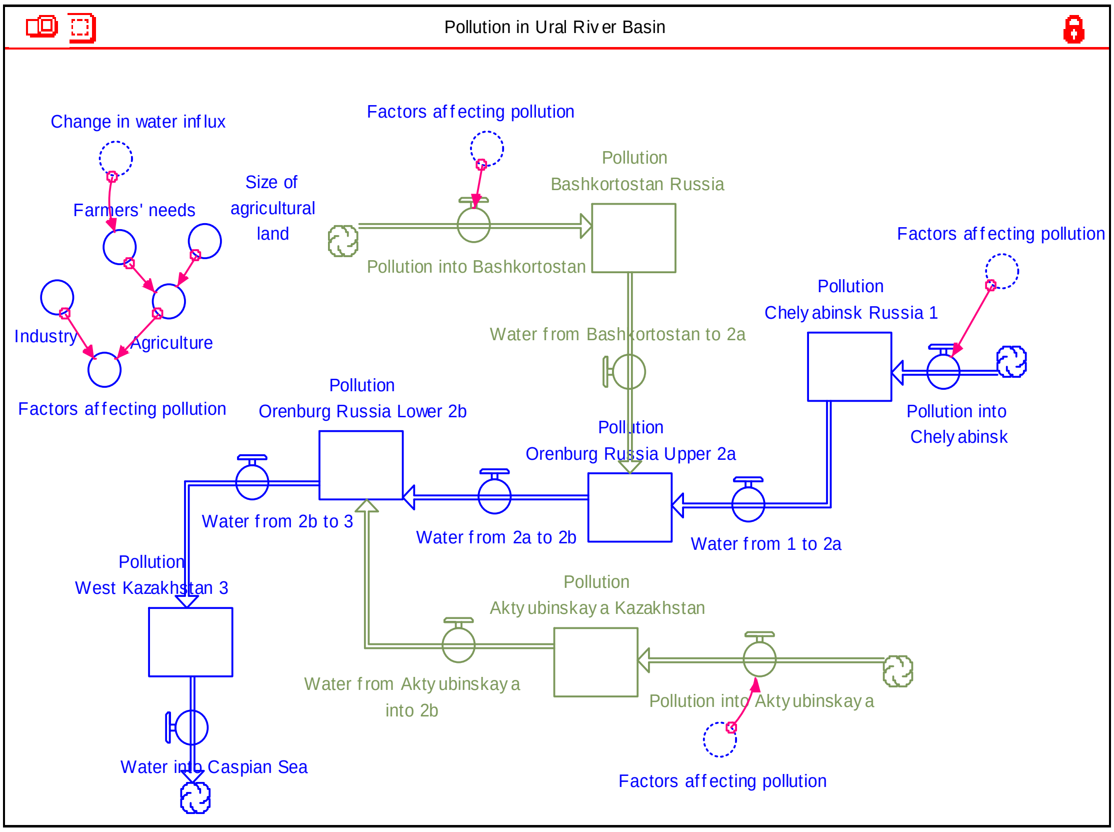


Figure 26: STELLA model of pollution in the Ural River Basin

The amount of pollutants in the Ural River Basin differs by province. The two major provinces that release the largest percentage of industrial waste and byproducts are Chelyabinsk in Russia and Aktyubinskaya in Kazakhstan (Rucevska 2011). In Figure 26 the main stream is labeled in blue and goes through the order of 1(Chelyabinsk), 2a (Orenburg upper), 2b (Orenburg lower) and 3 (West Kazakhstan). On the other hand, the two tributary provinces, Bashkortostan and Aktyubinskaya, are colored green.

The Orenburg pollution amount is divided into two parts: Orenburg upper 2a and Orenburg lower 2b. Since the tributary flowing from Aktyubinskaya influences the pollution level for Orenburg lower 2b, the level of industrial pollution flowing into Orenburg lower 2b remains higher. As a result, the upper and lower regions of Orenburg experience varying levels of pollution due to their different tributaries.

The STELLA model also includes various factors influencing pollution within the Ural River Basin. In the upper left corner of Figure 26, the figure illustrates how changes in water influx will affect the agricultural sector. Variable water levels impact a farmer's agricultural needs which in turn can influence the amount of pollution released into the river. On the other hand, industry can have an immediate impact on the amount of industrial waste and pollutants released directly into the Ural River.

4.4.3 Public health implications of raising temperatures

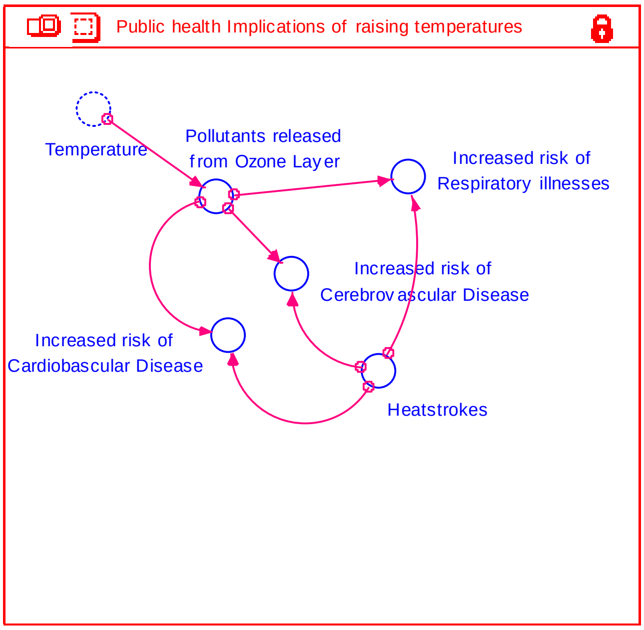


Figure 27: STELLA model of public health implications of raising temperatures

Climate change will most likely increase temperatures across many regions around the world (Haines *et al.* 2006). The most susceptible individuals in a population are the elderly and the immune compromised (Oven *et al.* 2012). Figure 27 shows that an increase in temperature will release pollutants from the ozone layer and decrease air quality. The reduction in air quality will lead to an increased risk of respiratory, cardiovascular and cerebrovascular morbidity (Haines *et al.* 2006). Increases in temperature will not only decrease air quality, but also increase the likelihood of heat waves (Kinney *et al.* 2008). Heat strokes will once again increase the risk for respiratory, cardiovascular and cerebrovascular illnesses within a population (see Figure 27).

4.4.4 Vector-borne diseases

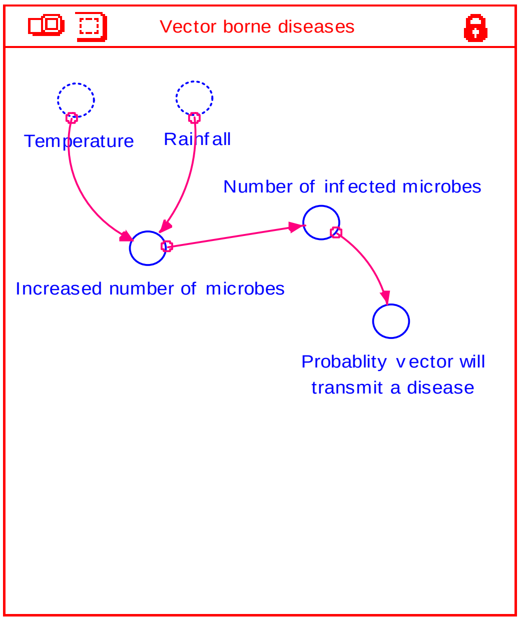


Figure 28: STELLA model of vector-borne diseases for the Ural River Basin

Vector-borne diseases are illnesses transmitted by infected microbes like mosquitoes, ticks or fleas to susceptible individuals (Sutherst *et al.* 1998). Changes in temperature and rainfall will influence the distribution and reproductive rates of insects (Ogden *et al.* 2005). While colder weather discourages population increases, warmer climates tend to promote an increase in the insect population (see Figure 28). As the insect population increases, the number of infected microbes increases. Therefore, the probability that a vector will transmit a disease rises with higher reproductive rates.

4.4.5 Public health implications for each province

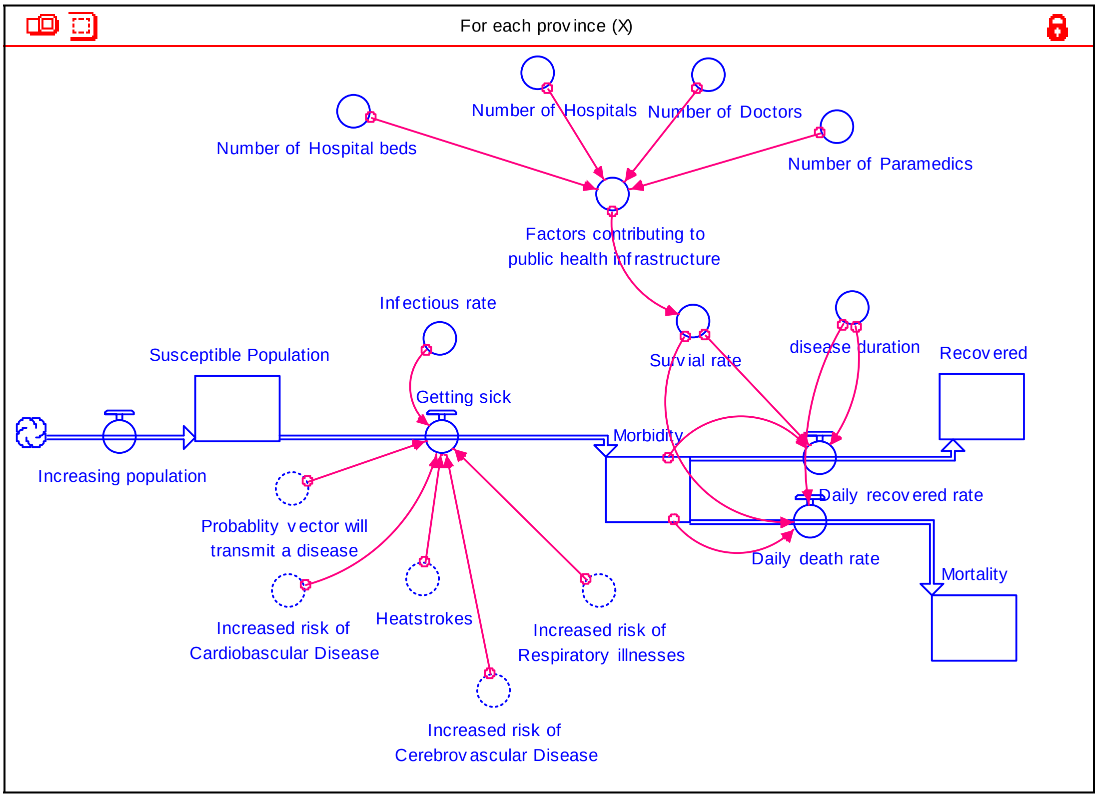


Figure 29: Public health dynamics for each province (X) excluding pollution

For each province, the varying hydrological will have different implications for a population's health. The model assumes that the infected individuals will either die or recover so they will not infect others. The disease duration, morbidity and survival rate influence both the recovery and death rate. A number of factors can increase the likelihood of survival for an infected individual. At the top of Figure 29 the factors contributing to public health infrastructure are shown: the number of hospital beds, hospitals, doctors and paramedics. Widespread distribution and access to healthcare services provides healthcare professionals with the necessary tools to treat and respond to a population's medical needs.

Stronger public health infrastructure increases a person's chance of survival and treatment.

Similarly, a wide range of factors influences a person's chance of getting sick. A disease's own infection rate can increase the likelihood of attaining an illness. If the illness is highly contagious then a person has a higher chance of getting sick. The conceptual diagram in Figure 29 accounts for the other aspects of the model: the hydrology of Ural River Basin, vector-borne diseases and public health implications of raising temperatures. A higher probability that a vector will transmit a disease, the increases in cardiovascular, cerebrovascular and respiratory risk and heat strokes will increase the likelihood that a person will get sick.

4.4.6 Complete conceptual diagram for province X

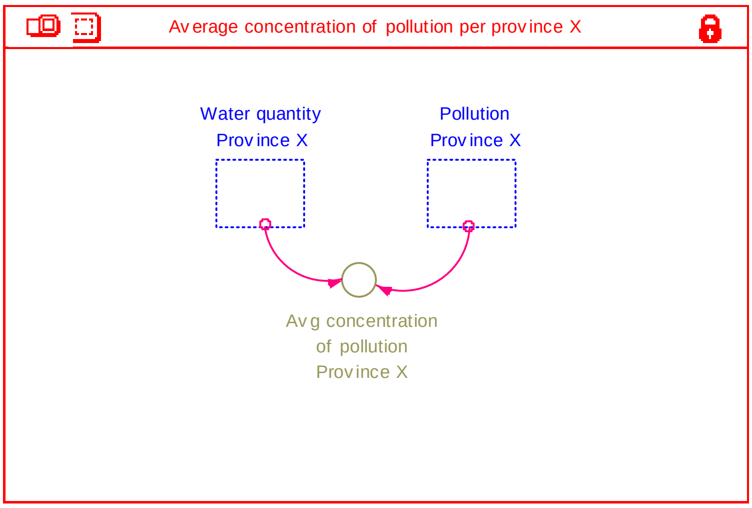


Figure 30: Average concentration of pollution per province X

The previous sections, Hydrology of Ural River Basin and Water quality of the Ural River Basin, only took into account the absolute amount of water or pollution flowing into or out of a region. Figure 30 takes into account the average concentration of pollution in a specific province. To account for all of the Ural River Basin, the complete conceptual diagram would include 6 components of the average concentration of pollution for Chelyabinsk, Orenburg upper, Orenburg lower, Bashkortostan and Aktyubinskaya.

The varying levels of water or pollution can influence the actual concentration of waste found in a region. The individual converter, average concentration of pollution per province X, was labeled dark yellow to help distinguish it in the complete conceptual diagram for the Ural River Basin.

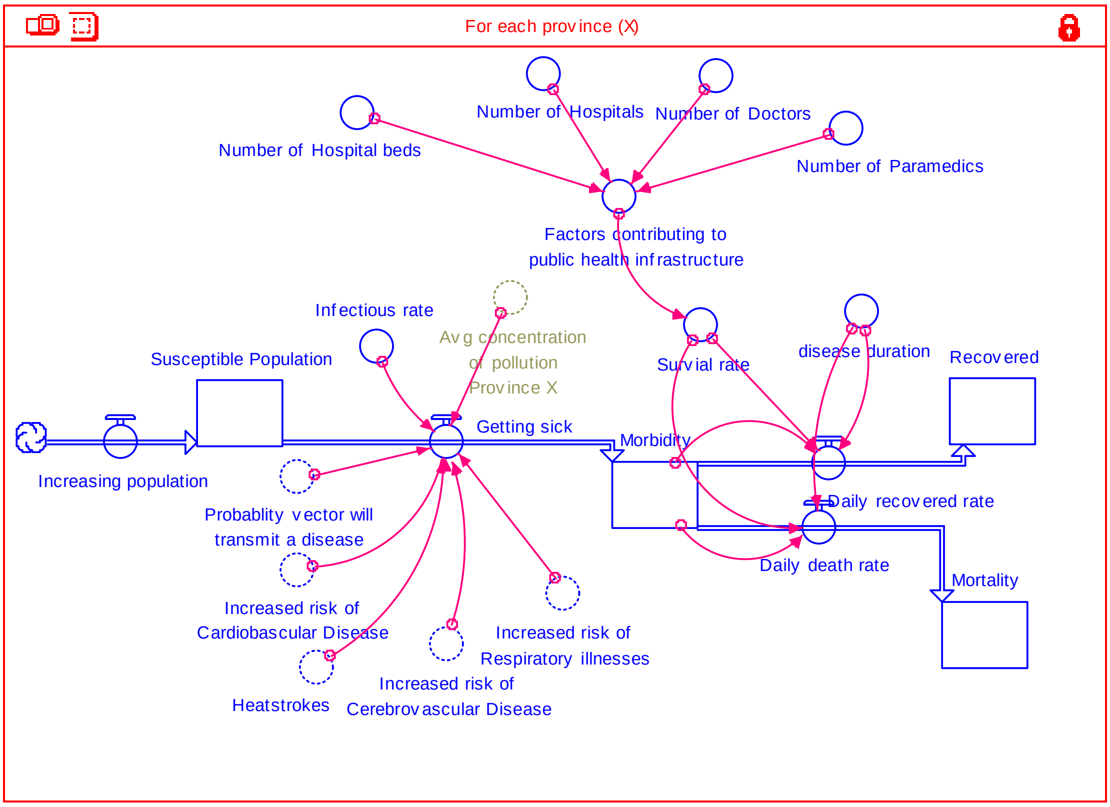


Figure 31: Public health dynamics for each province (X) including pollution

For each province, the combination of hydrological and pollution levels will influence each province's health. The system dynamics for the factors contributing to public health infrastructure, disease duration, morbidity, survival, recovery and death rate all remain the same as Figure 29. The major difference between Figure 31 and Figure 29 is that Figure 31 includes pollution as a possible factor contributing to a person's chance of getting sick. The conceptual diagram in Figure 31 integrates all aspects of the model: the hydrology of Ural River Basin, water quality, public health implications of raising temperatures and vector borne diseases for each individual province. For a complete overview of the whole STELLA conceptual diagram (see section 6, A 1 to A 4).

4.5 Public Health infrastructure data

In this study, three factors will help visualize public health infrastructure for the Ural River Basin: the number of hospital beds, the number of doctors of all specializations and the number of medical personnel. In total the Ural River flows through two countries and five provinces. In Russia the river flows through the Orenburg, Bashkortostan and Chelyabinsk provinces and in Kazakhstan the river goes through the Aktyubinskaya and West Kazakhstan provinces (Lagutov 2008). This chapter will help visualize public health information in order to identify if any patterns exist. The generated tables and graph in this section are based on data collected from The Agency of Statistics of the Republic of Kazakhstan 2013) and the Ministry of Health of the Russian Federation's

Department of Population and Healthcare Statistics unless listed otherwise (Chumarina *et al.* 2012).

4.5.1 Hospital Beds

The first factor looks at the absolute number of hospital beds available in each province. The general trend throughout all three indictors of public health infrastructure shows that all the provinces in Russia maintain a higher number of available facilities and personnel. Figure 32 illustrates the number of available hospital beds for each province for the period of 2003 to 2011.

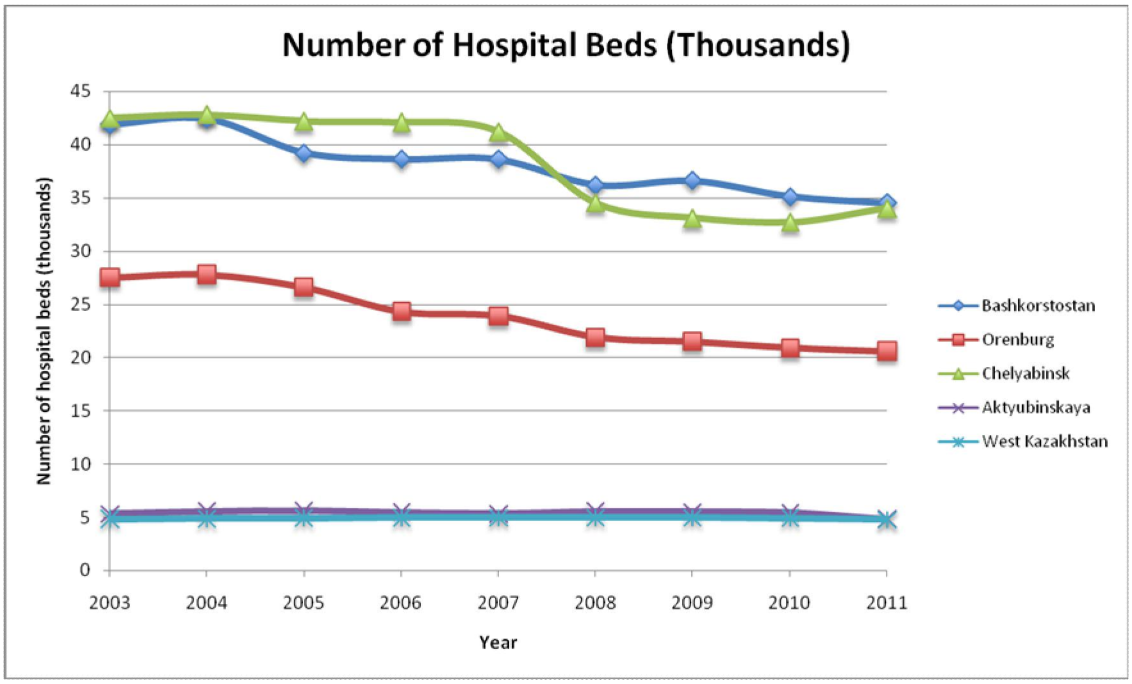


Figure 32: Number of hospital beds (thousands) in each province within the Ural River Basin from 2003 to 2011

Even though the Russian provinces maintain a higher absolute number of hospital beds in comparison to Kazakhstani provinces, the Russian provinces show a general decline in the number of available hospital beds from 2003 to 2011. On the other hand, the two Kazakhstani provinces maintain around the same number of hospital beds or slight decrease throughout the reported time frame.

Figure 33 illustrates the number of hospital beds in each province located in the Ural River Basin for 2011.

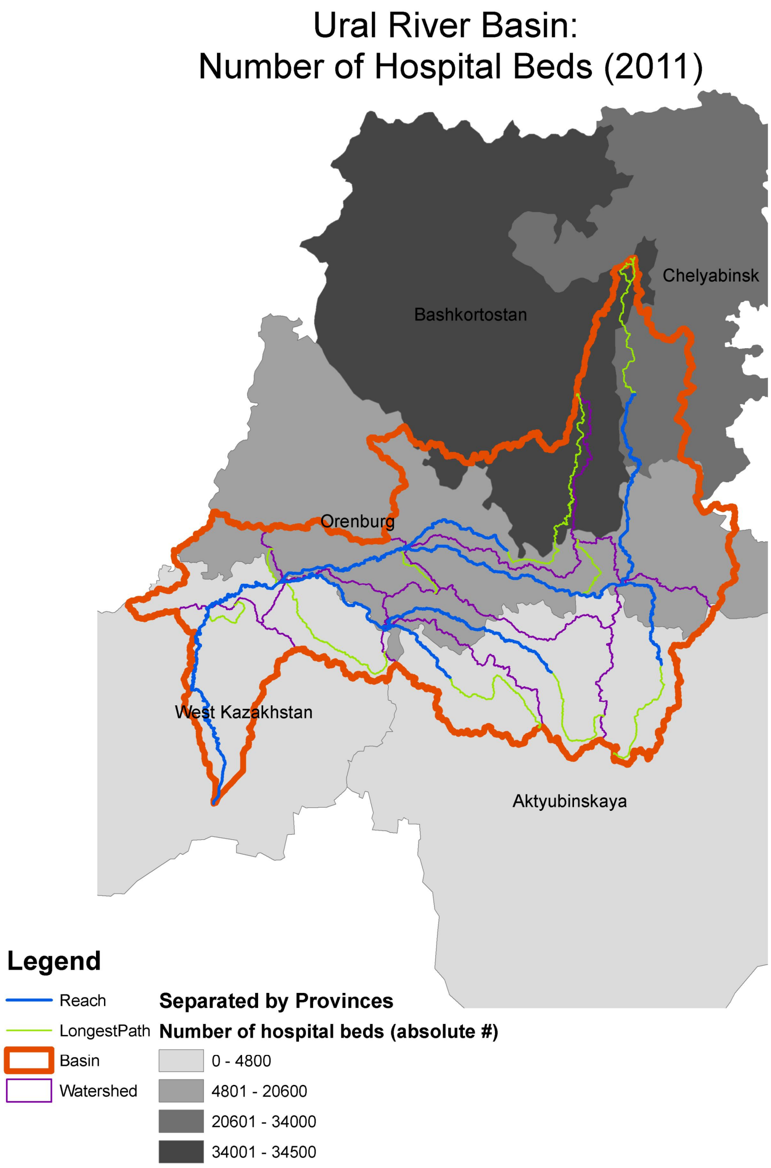


Figure 33: Number of hospital beds in the Ural River Basin by province in 2011

The Bashkortostan and Chelyabinsk retain the highest number of beds with 34,500 and 34,000 available. In contrast, Orenburg, which covers a significant part of the Ural River basin, only supports 20,600 beds. Section 4.4.1: Hydrology of Ural River Basin demonstrates the importance of water quality for the Orenburg province as a whole. The Orenburg province is divided into two parts, Orenburg upper 2a and Orenburg lower 2b, to account for different factors affecting water quality. However, Orenburg maintains the smallest number of available beds for the Russian provinces within the Ural River Basin.

The Aktyubinskaya and West Kazakhstan provinces report the smallest number of beds with 4,835 and 4,804 respectively. The number of hospital beds reported as one goes south in the Ural River Basin declines (see Figure 33). In general, the number of reported hospital beds for the Ural River Basin have either declined from 2003 to 2011 for Russian provinces or stayed at the same baseline levels for Kazakhstani provinces.

4.5.2 Number of doctors of all specializations

The second factor looks at the absolute number of doctors from all specializations that practice in each province. Once again, the Russian provinces maintain a higher absolute number of doctors than Kazakhstani provinces.

Figure 34 shows the number of licensed doctors of all specializations for each province in the period of 2003 to 2011.

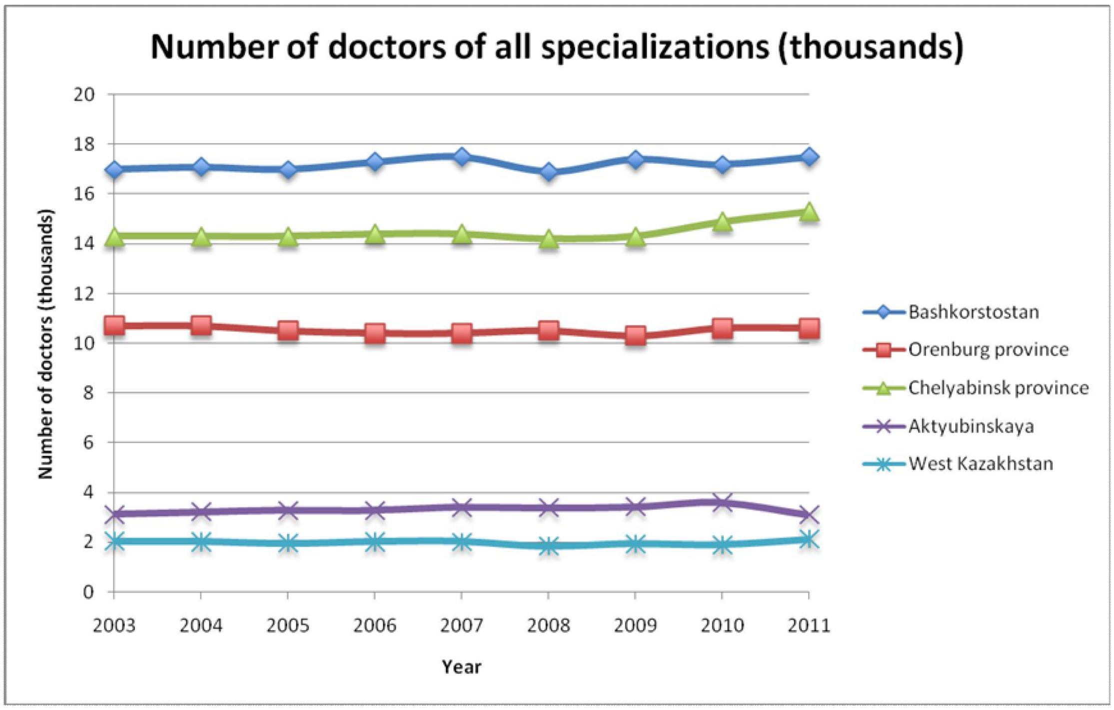


Figure 34: Number of doctors of all specializations (thousands) in each province within the Ural River Basin from 2003 to 2011

For the Russian provinces, Bashkortostan and Chelyabinsk report a higher number of doctors in 2011 than in 2003 by 2.9% and 7.0% respectively. On the other hand, Orenburg reveals a slight decline by 0.9%. Also, the two Kazakhstani provinces illustrate different trends. The number of doctors for the Aktyubinskaya province declines by 1.0% and increases for the West Kazakhstan province by 4.0%.

Figure 35 shows the number of doctors from all specializations in each province located in the Ural River Basin for 2011.

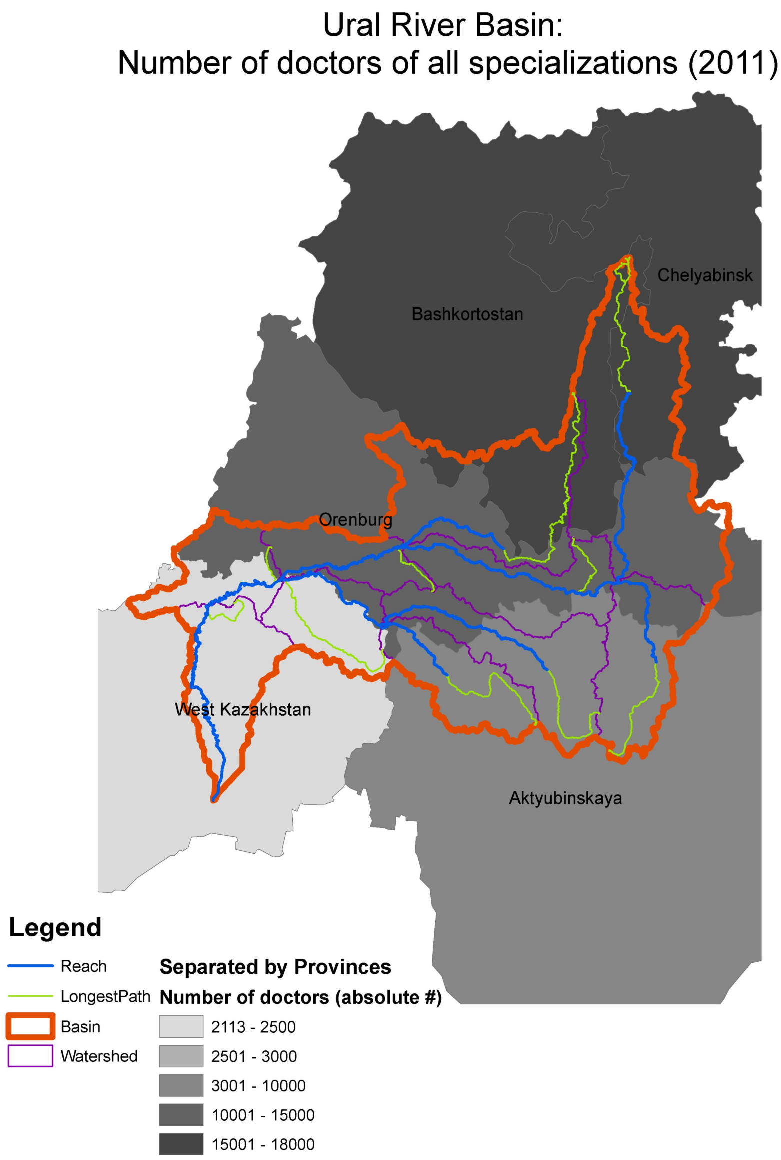


Figure 35: Number of doctors of all specializations in the Ural River Basin by province in 2011

The Bashkortostan and Chelyabinsk have the highest licensed doctors with 17,500 and 15,300 correspondingly. In comparison to the other Russian provinces, Orenburg reports a smaller number of available doctors with only 10,600 for the region. The Aktyubinskaya and West Kazakhstan provinces retain the smallest number of doctors with 3,091 and 2,113 respectively. Once again, the number of available doctors declines the further south one travels within the Ural River Basin (see Figure 35).

In general, the number of doctors from all specializations located in the Ural River Basin have either declined slightly from 2003 to 2011 for the Orenburg and Aktyubinskaya provinces or increased for the Bashkortostan, Chelyabinsk and West Kazakhstan provinces.

4.5.3 Number of medical personnel

The third and final factor looks at the absolute number of medical personnel reported in each province. The absolute number of reported medical personnel remains higher in Russia than in Kazakhstan. However, the number of medical personnel is the only indicator of public health infrastructure in which the percent change from 2003 to 2011 declines across all Russian provinces and increases for all the Kazakhstani provinces.

Figure 36 illustrates the number of medical personnel for each province in the period of 2003 to 2011.

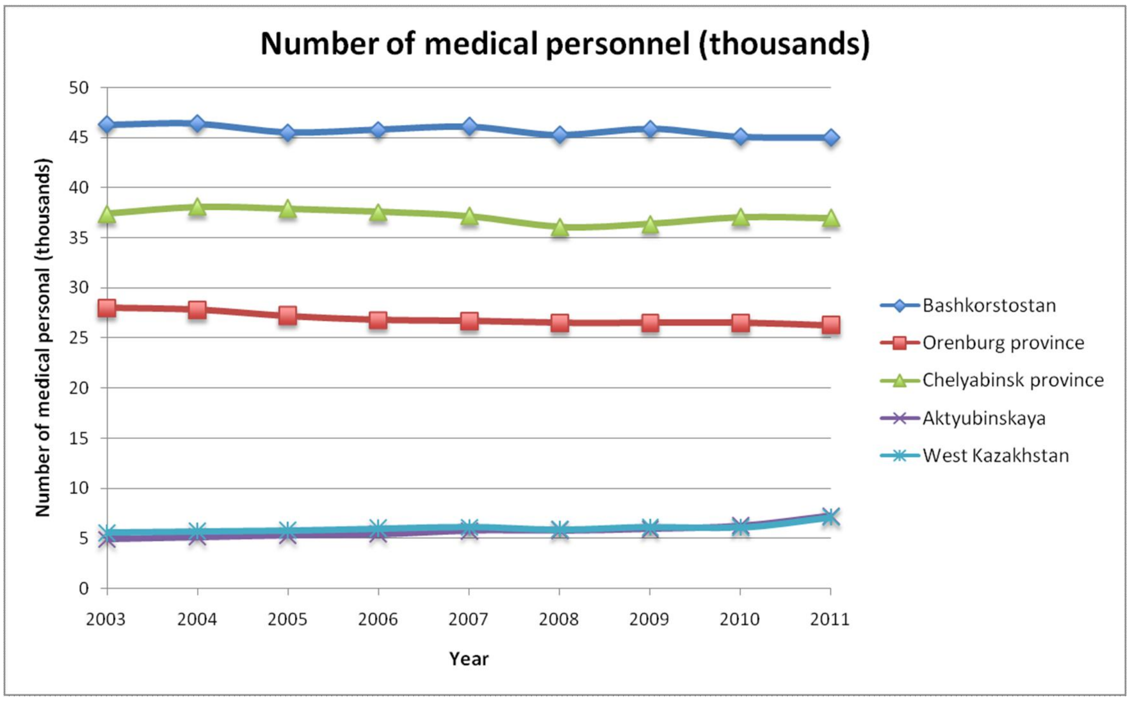


Figure 36: Number of medical personnel (thousands) in each province within the Ural River Basin from 2003 to 2011

For all of the Russian provinces, Bashkortostan, Orenburg and Chelyabinsk report a decline of medical personnel in 2011 than in 2003 by 2.8%, 6.1% and 1.1% respectively. Orenburg reports the largest decline in medical personnel from 2003 to 2011 for the Russian provinces. On the other hand, all of the Kazakhstani provinces demonstrate a significant increase in medical personnel by 2011. The Aktyubinskaya and West Kazakhstan provinces report a 47.1% and 28.4% increase in medical personnel in 2011 than in 2003.

Figure 37 illustrates the number of medical personnel in each province located in the Ural River Basin for 2011.

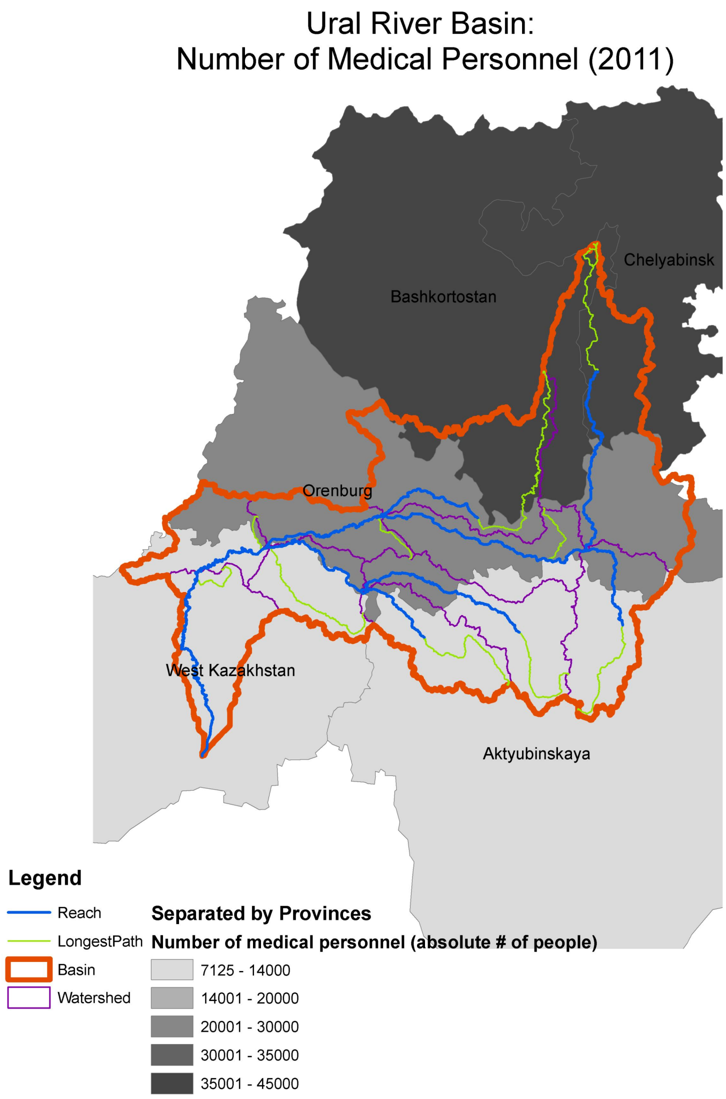


Figure 37: Number of medical personnel in 2011 and delineated watershed for the Ural River Basin

The Bashkortostan and Chelyabinsk have the highest absolute number of medical personnel in 2011 with 45,000 and 37,000 correspondingly. In comparison to the other Russian provinces, Orenburg reports a smaller number of medical personnel with only 26,300 for the region. The Aktyubinskaya and West Kazakhstan provinces retain the smallest absolute number of medical personnel with 7,241 and 7,125 respectively. Once again, the total number of medical personnel declines the further south one travels within the Ural River Basin (see Figure 37).

In general, the number of medical personnel located in the Ural River Basin have declined from 2003 to 2011 for the Russian provinces and increased significantly for the Kazakhstani provinces.

5 Discussion and Conclusion

Climate change will not only affect local weather conditions for the Ural River Basin, but also ecosystem services, agriculture, health and biodiversity for the region. The research project aims to study how climate change will influence water availability for the basin and the implications for public health for the region. The research project developed 2 separate sections: SWAT modeling and climate change implications for public health. The first section developed an Arc-GIS SWAT model and ran three different climate change scenarios. The second section developed a STELLA conceptual diagram and analyzed existing public health infrastructure data. The following chapter will discuss the results from each section while highlighting any potential limitations. Policy recommendations will help link environmental data with health information to better abate the impact of climate change.

5.1 Policy and Management Implications

5.1.1 Climate change scenarios

All three climate change scenarios simulated in the developed SWAT model for the Ural River Basin project a decrease in water availability by 2049. The three scenarios from the IPCC (description in section 3.2.5) produce varying levels of water stress for the region.

- *SRA1B,* which represents a world that values high economic development and low population levels, actually forecasts the worst-case scenario for the Ural River Basin. Water availability reduces by 6.9% and evapotranspiration increases by 16.8% in the year 2049.
- *SRB2* produces the second best climate change scenario for the region. Under this scenario, governments emphasize local solutions to social inequalities, but discourage global and international cooperation (Semenov and Stratonovitch 2010). The use of technology is undervalued and underutilized. In this case, water availability decreases by 2.7% and evapotranspiration increases by 14.4%.
- *SRA2* generates the best-case scenario for climate change in the Ural River Basin. Under this scenario, SRA2 emphasizes less economic or material growth while highlighting local solutions. Water availability decreases by 1.5% and evapotranspiration increases by 15.6% in the year 2049.

All three climate change simulations emphasize the point that changing temperatures will significantly affect water availability and ecosystem services in the Ural River Basin. The reduction in water flow will not only affect the region's hydrological cycle, but also communities' agricultural practices and health. The best-case scenario for climate change mitigation gives emphasis to policies that encourage local sustainable solutions, deemphasizes material wealth and empowers local communities. Furthermore, the use and integration of new technology will help reduce the negative effects of climate change in the region. A more effective IWRM strategy will help involve the local community while emphasizing environmental sustainability as a primary goal for the region.

5.1.2 STELLA conceptual diagram

The STELLA conceptual diagram helps visualize the connections between climate change and morbidity and mortality for the Ural River Basin. The water flow and pollution levels for the basin depend on the activities of the five provinces in two different countries. The conceptual diagram highlights the need for cooperation on transboundary hydrological, water quality and public health issues. In particular, the Ural River's hydrological flow calls attention to the Orenburg province. The Orenburg province is part of the main river system while two different tributaries, Bashkortostan and Aktyubinskaya, influence both the water quality and pollution for the Ural River Basin as a whole. As a result, the Orenburg province plays a major role in mitigating the effects of climate change and public health in the region.

The STELLA model shows the relationship that rising temperatures and decreases in precipitation can affect the mortality and morbidity of individuals in the area. Pollution is a result of both industrial activity and agricultural practices within each province. The effects of pollution can both be immediate and delayed. Industrial waste can rapidly decrease water quality and have a delayed effect on the population's general health. On the other hand, initially unsustainable agricultural practices can produce high crop yields, but later degrade water quality and availability, increase pollution and weaken the health of local communities.

All of the diagram's sections emphasize the biggest point that ecosystem services, resource management and climate change mitigation polices must be developed with each other in mind. The Ural River Basin's hydrology and public health interchangeably affect each other. Therefore, management and agricultural practices must consider environmental, economic and social implications for each individual province in the context of the basin as a whole.

5.1.3 Public health infrastructure

In general, the Russian provinces have a higher absolute number of public health infrastructure indictors than the Kazakhstani provinces. However, a large number of hospital beds, doctors and medical personnel do not necessarily indicate a strong public health system. In the particular case of hospital beds, all three Russian provinces show between a 17.7% and 25.1% decline of available beds from 2003 to 2011. The Kazakhstani provinces also report a lesser decline in hospital beds by 9.5% and 0.9%. While the Bashkortostan and Chelyabinsk Russian provinces retain a higher number of doctors from 2003 to 2011, the Orenburg province reports a decline. Even if all three Russian provinces indicate a decline (in hospital beds and medical personnel), the Orenburg province consistently emerges as the worst for Russia. The STELLA conceptual diagram highlighted the extreme importance of the Orenburg province for the Ural River Basin, but the public health infrastructure reports the conflicting priorities of the Russian government. The Orenburg province needs an influx of funds to improve their public health infrastructure in comparison to other regions. Furthermore, the general decline of beds and doctors across Russian provinces must be addressed against pressing climate change implications for public health.

The Kazakhstani provinces also report a low absolute number of hospital beds, doctors and medical personnel across their two provinces in the Ural River Basin. The Aktyubinskaya and West Kazakhstan provinces for the number of hospital beds report a slight decline while only the West Kazakhstan province retains an increase in doctors from the year 2003 to 2011. However, the Kazakhstani provinces show significant improvement in the number of medical personnel with a 47.1% and 28.4% percent increase from 2003 to 2011. Although the Kazakhstani provinces do not have a large absolute number of public health indicators, the country shows an exemplary effort in terms of the number of medical personnel. Kazakhstan may lag behind Russia due to a lack of funds and financial capital. Nevertheless, both countries need to reevaluate their public health systems to increase the number of available hospital beds, doctors and medical personnel across the Ural River Basin.

Several policy recommendations can help mitigate the effect of climate change on extreme weather events and disease vectors:

- Extreme weather events
    1. Increased temperatures (see section 2.7.3.1)
        - Increase public health education around local communities and among vulnerable populations like the elderly;
        - Develop and enhance heat wave surveillance systems (Haines *et al.* 2006).
    2. Floods and droughts (see section 2.7.3.2)
        - Advocate public health education coupled with community outreach programs;
        - Improve emergency preparedness on both the local and provincial level (Haines *et al.* 2006).
    3. Water and sanitation (see section 2.7.3.3)
        - Conduct risk assessments for rainfall and flood events (Alderman *et al.* 2012);
        - Enhance monitoring of drinking and agricultural water sources;
        - Promote education programs for proper sanitation procedures.
- Disease vectors (see section 2.7.4)

- Improve monitoring system of infectious diseases by both the watershed and provincial level;
- Increase the availability of databases for both disease dynamics and environmental monitoring in Russia and Kazakhstan;
- Develop outreach programs to increase awareness of health risks amount communities and individuals.

Climate change mitigation strategies for public health call for not only transboundary governmental cooperation, but also collaboration among researchers and local communities. The effects of climate change can already be seen, so policies should aim to assess and implement economical strategies to improve public health in the region. Early assessment coupled with the integration of renewable technologies will improve the Ural River Basin's hydrological system and the population's health.

5.2 Limitations

5.2.1 SWAT model

When reviewing the SWAT model the following limitations and assumptions should be considered:

- The lack of consistent data for meteorological stations limits the ability to calibrate and integrate all of the available weather information within the Ural River Basin.

- Although water quality data exists, those datasets remain inaccessible to the public. Therefore, water quality variables produced by SWAT were disregarded.
- Lack of hydrological gauge stations limited the calibration process.
- The integration of more historical weather data would increase the accuracy of the SWAT model.
- The large simulated area limits the model's ability to accurately represent extreme weather events due to the varying levels of precipitation in the basin (Gilfanova 2012).

In general, the model's calibration can be greatly improved with additional hydrological and climate data. Nevertheless, the SWAT model performs well enough to accurately describe climate change scenarios in the Ural River Basin region.

5.2.2 Climate change scenarios

The climate change scenarios produced the following list of limitations and assumptions:

- The SWAT model assumes that land use classes will not change very much with the climate change scenarios. Since most of the region utilizes the land for agriculture, the model assumes that it remains relatively consistent.
- A longer time series will help increase accuracy of the climate change scenario data produced by LARS-WG (Semenov *et al.* 1998).

5.2.3 STELLA model

The following limitations and assumptions should be considered for the developed STELLA model:

- STELLA's straightforward representation with stocks, flows and converters limits the model's ability to represent more complicated and non-linear relationships (Peirce 1998).
- STELLA's approach to system dynamics helps visualize the relationship between public health infrastructure and climate change, but the model does not produce statistical results.

5.2.4 Public health infrastructure

When reviewing the public health infrastructure data the following limitations and assumptions should be considered:

- No direct reports or databases from Russia or Kazakhstan are publicly available for disease mortality or morbidity.
- The non-existent data sharing procedures and non-standardized collection of data hindered the analysis of other indictors: the number of hospital beds for sick children, the number of accidents and the number of sick individuals reported for the first time.
- The non-standard practice of reporting public health infrastructure data without population numbers hindered the ability to integrate certain indictors between Russia and Kazakhstan

The research project provides the preliminary first steps for the analysis of the Ural River Basin and public health in the region. Further research could improved the SWAT model's calibration and integrate additional weather stations for increased accuracy. The appropriate data could be released from the Russian and Kazakhstani governments to provide water quality and disease dynamic information to further assess the region's public health status.

The project helped develop an overall scheme that can be applied to other regions. The combination of a SWAT model with the conceptual mapping of STELLA helps assess public health and climate change in other areas. Thus, the research project's methods can be applied to other watershed systems around the world.

5.3 Conclusion

The research project studies the spatial and temporal environmental features of the Ural River Basin through climate change scenarios, conceptual mapping and public health infrastructure data. The project creates an integrated database of climate and health variables for the Ural River Basin. The establishment of a more unified database will allow for further research.

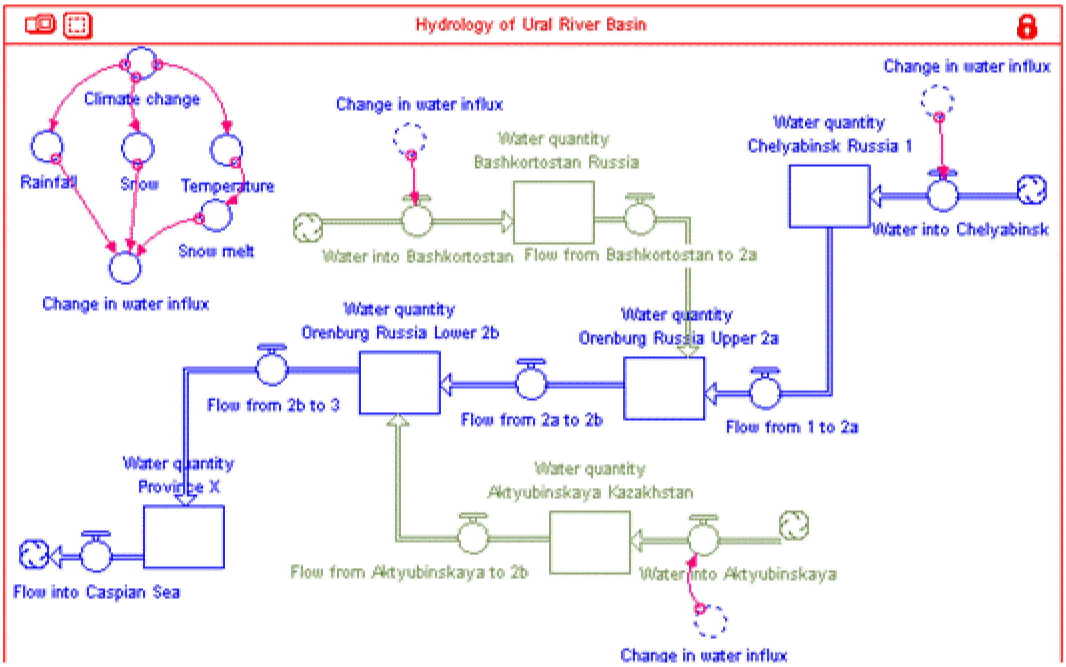
Analysis of the Ural River Basin required the collection of existing climate and hydrological variables, the development of the ArcGIS-SWAT model and calibration of the model with SWAT-CUP. The LARS-WG stochastic weather generator produced climate change scenarios for hydrological analysis in SWAT.

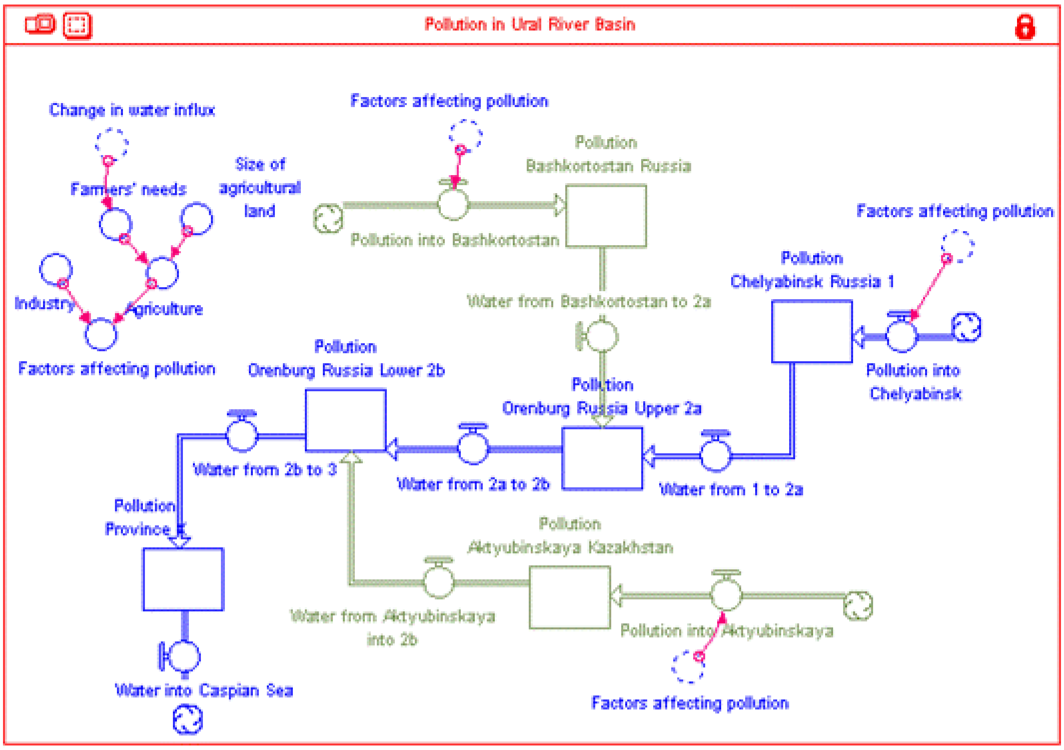
Afterwards, a comprehensive literature review, expert consultations and interviews of climate change's impact on public health helped develop a STELLA conceptual diagram. The final section acknowledges the limitations and develops recommendations based on the SWAT model, the STELLA diagram and the public health infrastructure data to help mitigate climate change's impact on public health.

The overall scheme developed by the research project can be applied to other watersheds to assess public health and climate change for regions around the world.

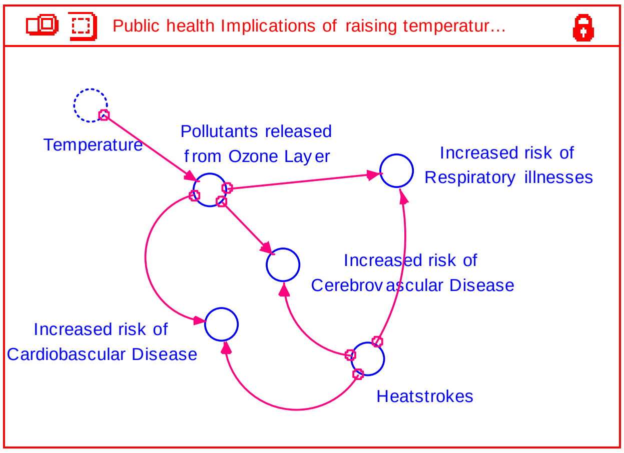
6 Appendix

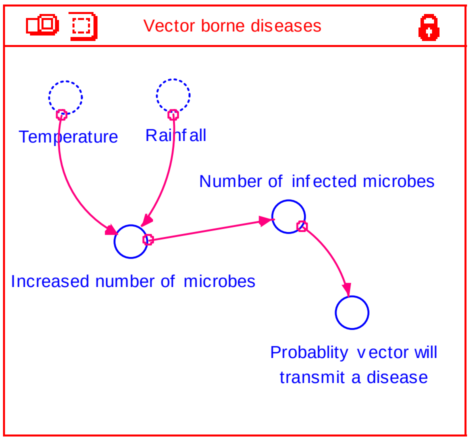
A 1: STELLA model of the hydrology and pollution of the Ural River Basin



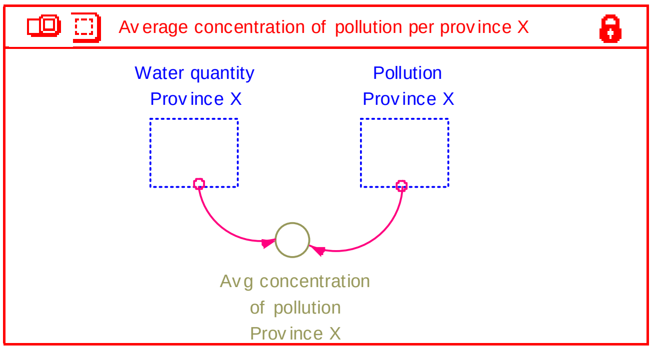


A 2: STELLA model of public health implications of raising temperatures and vector-borne diseases for the Ural River Basin

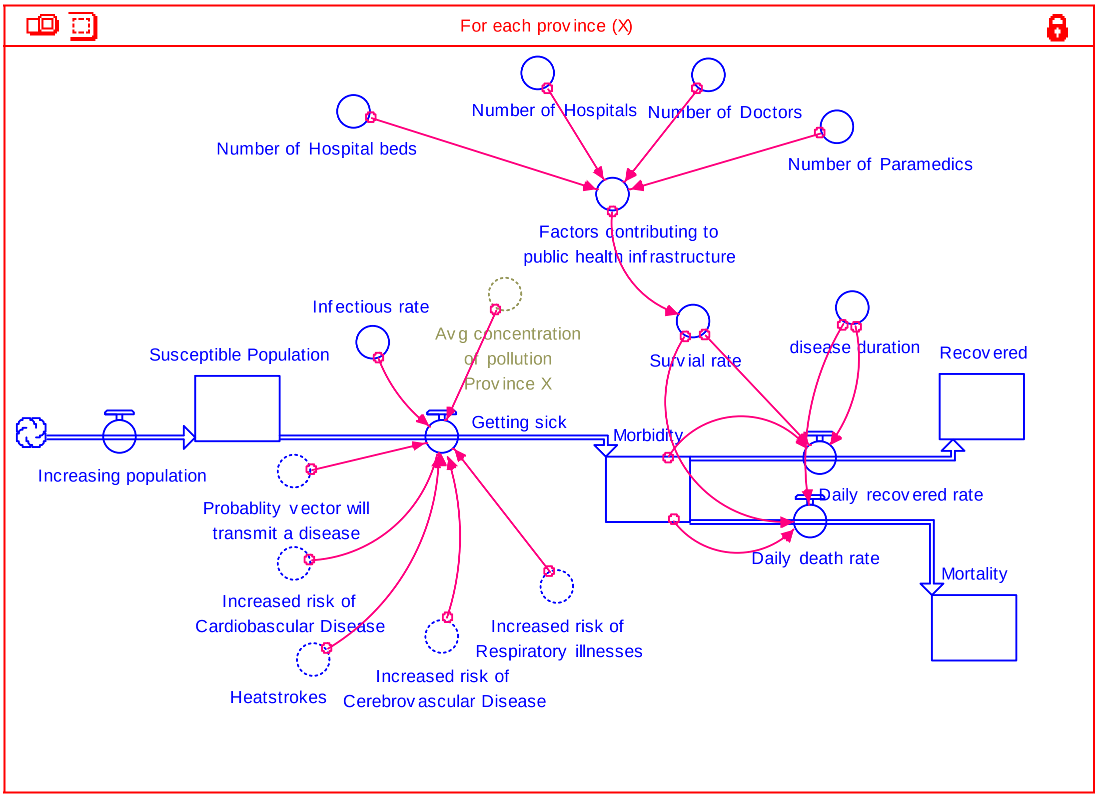




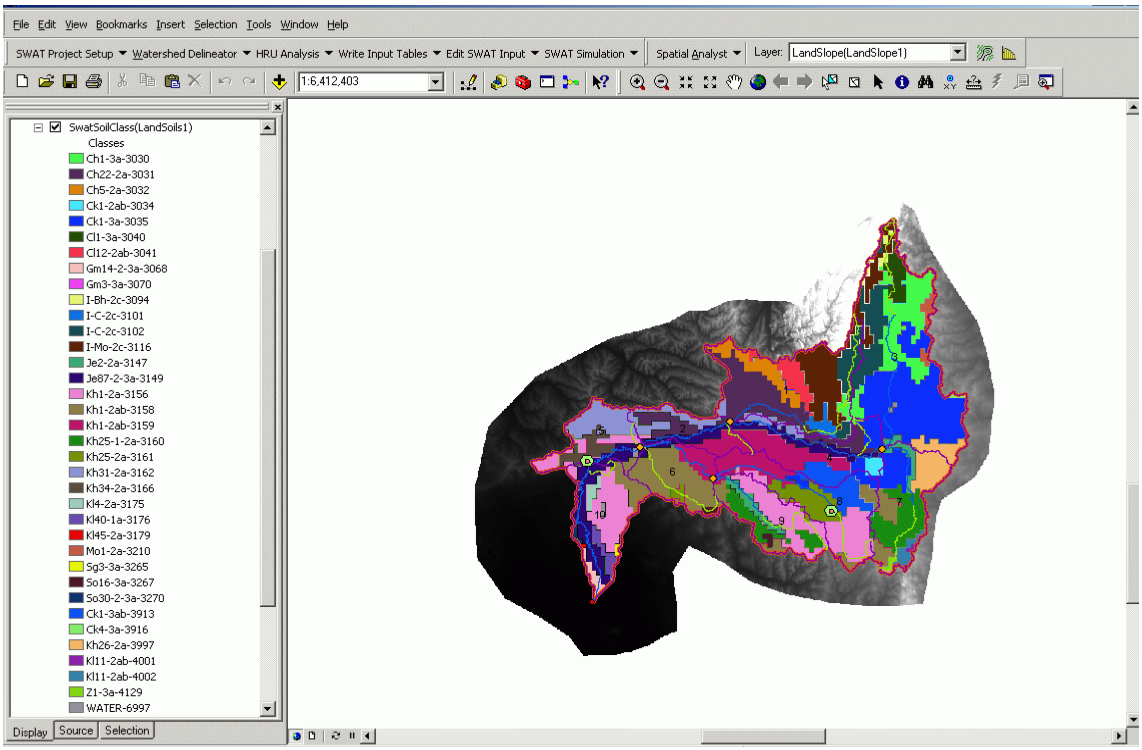
A 3: Average concentration of pollution per province X



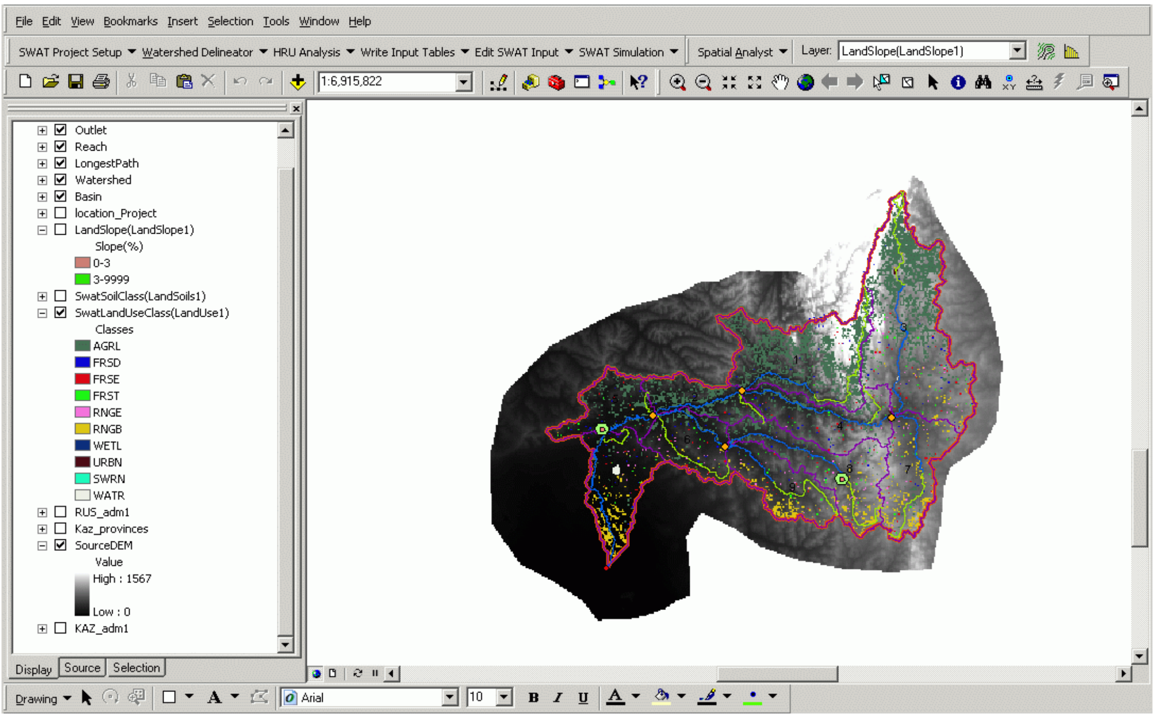
A 4: Public health dynamics for each province (X) including pollution



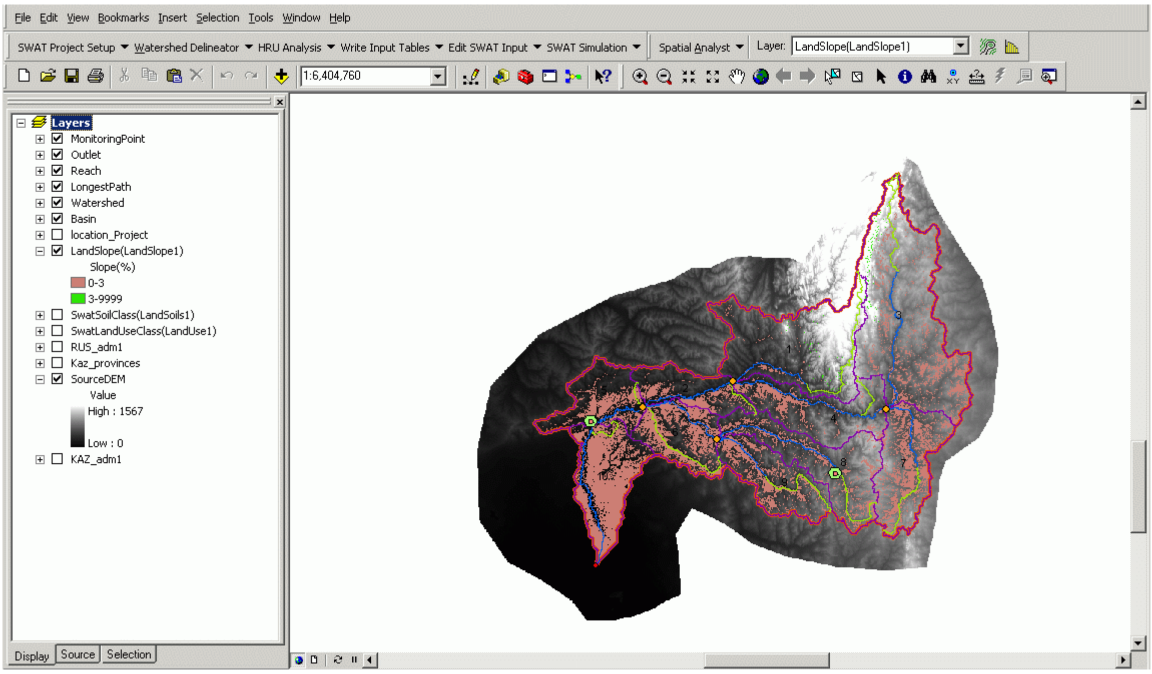
A 5: SWAT model classes for Soil type in the Ural River Basin



A 6: SWAT model classification of land use classes for the Ural River Basin



A 7: SWAT model classes for slope definition in the Ural River Basin



A 8: Example of HRU watershed report for the Ural River Basin (2005)

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HRU STATISTICS

AVE ANNUAL VALUES

HRU	SUB	CPMN SOIL AREAkm2	CN	AWCmm	USLE_LS	IRRmm	AUTONkh	AUTOPkh	MIXEF	PRECmm	SURQmm	GWQmm	ETmm	SEDth	NO3kgh	ORGNkgh	BIOMth	YLDth
1	1	AGRLCh22-2a-.683E+04	83.00	180.00	0.26	0.00	97.28	0.73	0.20	3298.79	2295.83	634.26	394.60	57.20	10.45	41.83	9.04	3.05
2	1	AGRLCh22-2a-.497E+04	83.00	180.00	0.91	0.00	99.52	0.76	0.20	3298.79	2295.72	641.48	395.12	236.15	10.63	46.34	8.70	2.94
3	1	AGRLCh5-2a-3.194E+04	83.00	180.00	0.26	0.00	99.88	0.16	0.20	3298.79	2311.69	624.41	395.17	89.54	10.40	45.95	8.93	3.01
4	1	AGRLCh5-2a-3.270E+04	83.00	180.00	0.98	0.00	101.72	0.49	0.20	3298.79	2311.46	642.45	395.12	319.23	10.49	49.31	8.78	2.96
5	1	AGRLCl12-2ab.260E+04	83.00	180.00	2.07	0.00	104.80	0.61	0.20	3298.79	2304.53	654.85	394.91	658.08	10.52	49.16	8.89	3.00
6	1	AGRLCl12-2ab.103E+04	83.00	180.00	0.26	0.00	101.05	0.21	0.20	3298.79	2305.10	631.09	394.93	97.72	10.15	45.12	9.09	3.06
7	1	AGRLI-C-2c-3.291E+04	83.00	100.00	1.61	0.00	102.94	2.31	0.20	3298.79	2343.21	665.05	348.69	494.38	11.00	40.22	6.64	2.23
8	1	AGRLI-C-2c-3.122E+04	83.00	100.00	0.26	0.00	99.80	1.67	0.20	3298.79	2343.77	632.57	350.03	96.14	11.14	37.18	6.52	2.18
9	1	AGRLI-Mo-2c-.706E+04	87.00	100.00	1.69	0.00	105.71	2.43	0.20	3298.79	2526.50	479.08	344.06	459.04	14.03	55.91	7.42	2.47
10	2	AGRLCh22-2a-.185E+04	83.00	180.00	0.23	0.00	104.72	0.06	0.20	3416.33	2408.96	613.60	410.43	75.95	11.58	45.88	8.04	2.63
11	2	AGRLCh22-2a-.117E+04	83.00	180.00	0.80	0.00	112.53	1.25	0.20	3416.33	2408.74	634.37	408.02	343.12	10.46	52.53	8.81	2.90
12	2	AGRLJe87-2-3.208E+04	83.00	10.00	0.17	0.00	100.04	0.16	0.20	3416.33	2292.58	898.44	210.72	54.76	13.02	35.81	7.47	2.25
13	2	AGRLKh1-2ab-.226E+04	83.00	180.00	0.20	0.00	104.38	0.14	0.20	3416.33	2419.72	604.32	408.90	56.31	11.10	46.61	8.73	2.86
14	2	AGRLKh31-2a-.149E+04	83.00	180.00	0.91	0.00	113.54	1.14	0.20	3416.33	2418.07	622.67	407.09	329.12	10.55	52.98	9.24	3.04
15	2	AGRLKh31-2a-.186E+04	83.00	180.00	0.23	0.00	105.84	0.16	0.20	3416.33	2419.10	605.21	409.07	70.82	11.34	46.48	8.62	2.82
16	3	AGRLCh1-3a-3.120E+05	83.00	180.00	0.24	0.00	79.43	0.63	0.20	3298.79	2635.47	482.57	391.58	55.52	13.92	54.35	9.01	3.03
17	3	AGRLCh1-3a-3.420E+04	83.00	180.00	0.90	0.00	82.01	0.00	0.20	3298.79	2633.94	469.17	393.29	319.57	13.64	59.56	8.35	2.80
18	3	AGRLCk1-3a-3.217E+05	83.00	180.00	0.21	0.00	100.07	0.23	0.20	3298.79	2272.27	784.66	396.06	33.48	10.06	25.57	8.68	2.93
19	3	AGRLI-C-2c-3.469E+04	83.00	100.00	0.23	0.00	101.34	1.69	0.20	3298.79	2343.78	730.65	349.79	66.54	11.42	36.07	6.61	2.21
20	3	AGRLI-C-2c-3.389E+04	83.00	100.00	1.92	0.00	103.25	2.52	0.20	3298.79	2343.18	788.79	348.43	600.32	11.05	40.21	6.68	2.24
21	4	AGRLCh22-2a-.122E+04	83.00	180.00	1.76	0.00	99.97	0.76	0.20	3298.79	2295.08	634.70	397.09	677.92	10.49	46.97	8.61	2.91
22	4	AGRLCh22-2a-.802E+03	83.00	180.00	0.23	0.00	98.28	0.75	0.20	3298.79	2295.54	616.02	396.21	89.08	10.50	43.70	8.93	3.01
23	4	AGRLCk1-3a-3.104E+04	83.00	180.00	0.23	0.00	104.13	0.67	0.20	3298.79	2272.05	635.27	397.53	91.00	10.00	29.83	8.52	2.87
24	4	AGRLCk1-3a-3.640E+03	83.00	180.00	1.15	0.00	104.81	0.50	0.20	3298.79	2271.29	647.36	398.49	523.88	9.56	32.22	8.16	2.75
25	4	AGRLCk1-3ab-.110E+04	83.00	40.00	0.24	0.00	108.12	1.52	0.20	3298.79	2298.42	750.54	256.55	110.22	12.97	25.98	3.23	0.93
26	4	AGRLCk1-3ab-.621E+03	83.00	40.00	0.80	0.00	125.31	3.46	0.20	3298.79	2297.11	759.34	254.46	398.83	12.03	30.10	4.61	1.40
27	4	AGRLJe87-2-3.841E+03	83.00	10.00	1.53	0.00	93.80	0.08	0.20	3298.79	2245.64	861.16	195.02	635.75	12.72	41.30	6.70	1.87
28	4	AGRLJe87-2-3.255E+04	83.00	10.00	0.18	0.00	90.95	0.00	0.20	3298.79	2247.56	852.33	195.70	55.38	12.85	36.44	7.00	1.96
29	4	AGRLKh1-2ab-.363E+04	83.00	180.00	0.21	0.00	96.19	0.06	0.20	3298.79	2308.72	604.16	396.09	52.78	10.71	42.76	8.92	3.00
30	4	AGRLKh1-2ab-.105E+04	83.00	180.00	0.84	0.00	98.32	0.13	0.20	3298.79	2308.57	622.88	397.09	311.21	10.86	47.89	8.47	2.85
31	4	RNGBCk1-3a-3.456E+03	74.00	180.00	0.27	0.00	0.00	0.00	0.20	3298.79	1910.72	1061.10	277.84	1.53	6.58	5.39	2.78	0.00
32	4	RNGBCk1-3a-3.443E+03	74.00	180.00	1.00	0.00	0.00	0.00	0.20	3298.79	1909.42	1060.79	279.18	6.00	6.54	13.87	2.68	0.00
33	4	RNGBCk1-3ab-.547E+03	74.00	40.00	0.27	0.00	0.00	0.00	0.20	3298.79	1934.89	1096.97	216.83	1.54	6.02	5.02	1.98	0.00
34	4	RNGBCk1-3ab-.375E+03	74.00	40.00	0.78	0.00	0.00	0.00	0.20	3298.79	1933.70	1096.53	216.82	4.75	5.99	11.12	1.94	0.00
35	4	RNGBJe87-2-3.531E+03	74.00	10.00	1.53	0.00	0.00	0.00	0.20	3298.79	1925.23	1173.97	166.98	8.48	6.93	21.85	2.58	0.00
36	4	RNGBJe87-2-3.466E+03	74.00	10.00	0.24	0.00	0.00	0.00	0.20	3298.79	1927.49	1148.82	167.87	1.28	7.04	6.61	2.67	0.00
37	4	RNGBKh1-2ab-.133E+04	74.00	180.00	0.24	0.00	0.00	0.00	0.20	3298.79	1941.41	1074.59	268.33	1.00	6.93	6.29	3.30	0.00
38	4	RNGBKh1-2ab-.689E+03	74.00	180.00	0.91	0.00	0.00	0.00	0.20	3298.79	1940.74	1080.10	269.19	4.46	6.85	19.36	3.20	0.00
39	5	AGRLJe87-2-3.131E+04	83.00	10.00	0.17	0.00	100.69	0.17	0.20	3416.33	2274.66	950.71	221.64	66.78	13.19	35.28	7.48	2.24
40	5	AGRLKh1-2a-3.198E+04	83.00	180.00	0.18	0.00	105.01	0.14	0.20	3416.33	2404.52	642.45	432.37	59.74	11.20	46.81	8.76	2.87
41	5	AGRLKh31-2a-.167E+04	83.00	180.00	0.76	0.00	113.67	1.18	0.20	3416.33	2403.68	684.86	430.28	263.36	10.58	52.67	9.35	3.08
42	5	AGRLKh31-2a-.311E+04	83.00	180.00	0.23	0.00	105.79	0.16	0.20	3416.33	2403.92	643.09	432.39	64.07	11.51	45.87	8.71	2.85
43	5	AGRLKh34-2a-.203E+04	83.00	180.00	0.17	0.00	104.22	0.12	0.20	3416.33	2404.51	641.53	432.31	52.99	11.03	46.05	8.80	2.88
44	5	RNGBJe87-2-3.318E+03	74.00	10.00	0.17	0.00	0.00	0.00	0.20	3416.33	1957.58	1236.73	175.32	0.94	6.67	5.05	2.64	0.00
45	5	RNGBKh1-2a-3.787E+03	74.00	180.00	0.21	0.00	0.00	0.00	0.20	3416.33	2017.56	1101.99	280.65	1.05	6.88	6.76	3.53	0.00
46	5	RNGBKh1-2a-3.223E+03	74.00	180.00	0.82	0.00	0.00	0.00	0.20	3416.33	2017.16	1083.03	281.34	4.50	6.80	19.64	3.44	0.00
47	5	RNGBKh31-2a-.190E+03	74.00	180.00	0.87	0.00	0.00	0.00	0.20	3416.33	2015.52	1063.70	281.64	4.84	6.78	19.70	3.42	0.00
48	5	RNGBKh31-2a-.337E+03	74.00	180.00	0.26	0.00	0.00	0.00	0.20	3416.33	2015.87	1083.36	280.92	1.36	6.85	8.04	3.51	0.00
49	5	RNGBKh34-2a-.726E+03	74.00	180.00	0.17	0.00	0.00	0.00	0.20	3416.33	2017.59	1102.27	280.60	0.82	6.88	5.46	3.54	0.00
50	6	AGRLKh1-2ab-.537E+04	83.00	40.00	0.17	0.00	111.02	1.74	0.20	3416.33	2365.95	780.95	296.29	46.26	13.87	37.26	3.49	1.07
51	6	AGRLKh1-2ab-.231E+04	83.00	180.00	0.15	0.00	102.46	0.04	0.20	3416.33	2399.92	652.81	431.91	47.96	11.16	45.05	8.73	2.86
52	6	RNGBKh1-2ab-.510E+04	74.00	40.00	0.18	0.00	0.00	0.00	0.20	3416.33	1993.69	1186.81	236.68	0.53	6.02	3.52	2.34	0.00
53	6	RNGBKh1-2ab-.662E+03	74.00	180.00	0.17	0.00	0.00	0.00	0.20	3416.33	2019.04	1136.19	278.58	0.96	6.89	6.25	3.50	0.00
54	7	AGRLCk1-3a-3.135E+04	83.00	180.00	0.16	0.00	102.43	0.25	0.20	3298.79	2271.13	648.72	400.05	62.24	9.82	28.34	8.50	2.87
55	7	AGRLJe2-2a-3.787E+03	77.00	10.00	0.16	0.00	91.50	0.76	0.20	3298.79	1770.52	1301.56	192.77	54.85	8.20	17.42	5.16	1.42
56	7	AGRLKh1-2ab-.824E+03	83.00	40.00	0.17	0.00	100.71	2.20	0.20	3298.79	2303.69	743.58	258.06	70.55	13.81	40.09	3.99	1.15

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