T.C.
İSTANBUL UNIVERSITY-CERRAHPAŞA
INSTITUTE OF GRADUATE STUDIES

M.Sc. THESIS

SUSTAINABLE WATER RESOURCES MANAGEMENT IN ANKARA BASED ON SYSTEM DYNAMICS

Duygu ÇELİK MORKOÇ

SUPERVISOR
Asst. Prof. Dr. Ersin NAMLI

Department of Industrial Engineering

Industrial Engineering Programme

İSTANBUL - December, 2018

This study was accepted on 12/5/2018 as a M. Sc. Thesis in Department of Industrial Engineering, Industrial Engineering Programme by the follwing Committee.

EXAMINING COMMITTEE MEMBERS

Asst. Prof. Dr. Ersin NAMLI
İstanbul University-Cerrahpaşa
Faculty of Engineering

Prof. Dr. Ş.Alp BARAY
İstanbul University-Cerrahpaşa
Faculty of Engineering

Asoc. Prof. Dr. Tarık KÜÇÜKDENİZ
İstanbul University-Cerrahpaşa
Faculty of Engineering

Asst. Prof. Dr. Sinem BÜYÜKSAATÇİ KİRİŞ
İstanbul University-Cerrahpaşa
Faculty of Engineering

Asst. Prof. Dr. Zeynep GERGİN
İstanbul Kültür University
Faculty of Engineering

As required by the 9/2 and 22/2 articles of the Graduate Education Regulation which was published in the Official Gazette on 20.04.2016, this graduate thesis is reported as in accordance with criteria determined by the Institute of Graduate Sttudies by using the plagiarism software to which İstanbul University-Cerrahpaşa is a subscriber.

FOREWORD

I would like to express my sincere gratitude to my supervisor Asst. Prof. Dr. Ersin NAMLI, for his support, guidance and encouragement which facilitated the process of writing theses.

I appreciate the help and interest of my precious friend Mehmet ŞENGÜL. I think there's a lot to learn from him academically. I sincerely thank TÜBİTAK for their financal support during my graduation.

Finally, I am deeply grateful to my family who have been always with me and have supported me. I dedicate this work to them.

December 2018 Duygu ÇELİK MORKOÇ

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Page

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Explanation
t	: time
Xij	: the eigenvector value

Abbreviation	Explanation
AHP	: Analytic Hierarchy Process
ASKI	: Ankara Water and Sewerage Authority
BR	: Birth Rate
CLD	: Causal Loop Diagram
DR	: Death Rate
IFC	: International Freshwater Conference
MCDM	: Multi-Criteria Decision Making
SD	: System Dynamics
SFD	: Stock Flow Diagram
SWRM	: Sustainable Water Resources Management
TUIK	: Turkish Statistical Institute
WCED	: The World Commission on Environment and Development
WR	: Water Resources
WF	: Water Footprint
WRM	: Water Resources Management
WTP	: Water Treatment Plant
WWC	: The World Water Council
WWF	: The World Water Forum

ÖZET

YÜKSEK LİSANS TEZİ

SİSTEM DİNAMİĞİ İLE ANKARA'DA SÜRDÜRÜLEBİLİR SU KAYNAKLARI YÖNETİMİ

Duygu ÇELİK MORKOÇ

İstanbul Üniversitesi-Cerrahpaşa

Lisansüstü Eğitim Enstitüsü

Endüstri Mühendisliği Anabilim Dalı

Danışman : Dr. Öğr. Üyesi Ersin NAMLI

Yaşamımızın vazgeçilmez bir parçası olan su, içme suyu, ev kullanımı, tarım, sanayi ve rekreasyon gibi çeşitli amaçlarla kullanılmaktadır. Aynı zamanda insanlar için yaşam kalitesini doğrudan etkileyen sosyo-ekonomik faaliyetleri teşvik eden önemli bir moleküldür. Bütün bunlar göz önünde bulundurulduğunda su tüketiminin nüfusla doğrudan ilgili olduğu görülmektedir. Nüfusun artmasıyla birlikte suya olan talebin de her geçen gün arttığı ortadadır. Artan talebe karşın su arzını oluşturan su kaynakları ise sınırlıdır. Dolayısıyla su kaynaklarının, doğru ve sürdürülebilir bir şekilde yönetilmesi büyük önem arz etmektedir.

Bu çalışmada, Ankara'daki su kaynaklarının yönetimi Sistem Dinamikleri temel alınarak değerlendirilmiştir. SD, sistemin mekanizmasını çözümlemede ve uzun dönem tahminleme yapılmasında kullanılan bir metottur. SD Model ile Ankara'nın su durumu simüle edilmiş ve uzun vadede su yeterliliği incelenmiştir. TÜİK'in nüfus projeksiyonlarında kullandığı üç farklı nüfus senaryosu kullanılmış ve sonuçlar yorumlanmıştır. Özet olarak, mevcut parametrelerle Ankara'nın 50 yıllık su eğilimlerinin tahmin ve modellenmesi gerçekleştirilmiştir.

Aralık 2018, 84 sayfa.

Anahtar kelimeler: Sistem dinamikleri, sürdürülebilirlik, su kaynakları yönetimi

SUMMARY

M.Sc. THESIS

SUSTAINABLE WATER RESOURCES MANAGEMENT IN ANKARA BASED ON SYSTEM DYNAMICS

Duygu ÇELİK MORKOÇ

İstanbul University-Cerrahpaşa

Institute of Graduate Studies

Department of Industrial Engineering

Supervisor : Asst. Prof. Dr. Ersin NAMLI

Water, which is an indispensable part of our lives, is used for various purposes such as drinking water, home use, agriculture, industry and recreation. It is also an important molecule that promotes socio-economic activities that directly affect the quality of life for humans. Considering all this, water consumption is directly related to the population. With the increase in the population, the demand for water is increasing day by day. Despite the increasing demand, the water resources that make up the water supply are limited. Therefore, the management of water resources in a correct and sustainable way is of great importance.

In this study, the management of water resources in Ankara was evaluated on the basis of System Dynamics. SD is a method used to analyse the mechanism of the system and to make long-term prediction. With the SD Model, the water condition of Ankara was simulated and water adequacy was investigated in the long term. Three different population scenarios used by TUIK in population projections were used and the results were interpreted. In summary, 50-year water trends of Ankara were estimated and modelled with available parameters.

December 2018, 84 pages.

Keywords: System dynamics, sustainability, water resources management

1. INTRODUCTION

Water, as an indispensable part of our life that is used for various purposes such as drinking, home use, agriculture, industry and recreation, could be conceived as one of the most significant resources all over the world. Taking into account increasing population, urbanization, or similar reasons it could be seen as the scarcity of water. The scarcity problem of the water makes use of scarce resources in a proper way becomes increasingly crucial. In that point of view, building a comprehensive and extensive strategy about water management takes an important role with the consideration of the effects of the changing policies. On grounds that water is a critical resource for human due to its indispensable effects of lives, its sustainability must be provided using some approaches such as a water resources management (WRM).

"The water on earth is distributed in various places such as atmosphere, biosphere, lithosphere, and hydrosphere, and in various forms such as vapor, liquid and solid" (Çırpıcı, 2008). The conversion from one natural form of water to another natural form is called the hydrological cycle. The hydrological cycle simply can be described as vaporization and condensation processes. The groundwater, ocean water, and seawater are vaporized by the atmosphere. When the vaporized water reaches the proper temperature and concentration level, it is condensed as rain, snow back to the earth.

The water that falls on the surface of the condensate is confused with the ocean, the sea, and the groundwater. Surface water reaches the sea after it is used by people, animals or plants in the end. Groundwater spontaneously accumulates around the surface or are removed by people. Therefore, we can call this process a natural cycle that provides clean water for the soil. This cycle of water provided by the hydrological cycle for decades is a very important dynamic process for living things on earth. The hydrologic cycle is demonstrated in Figure 1.1.

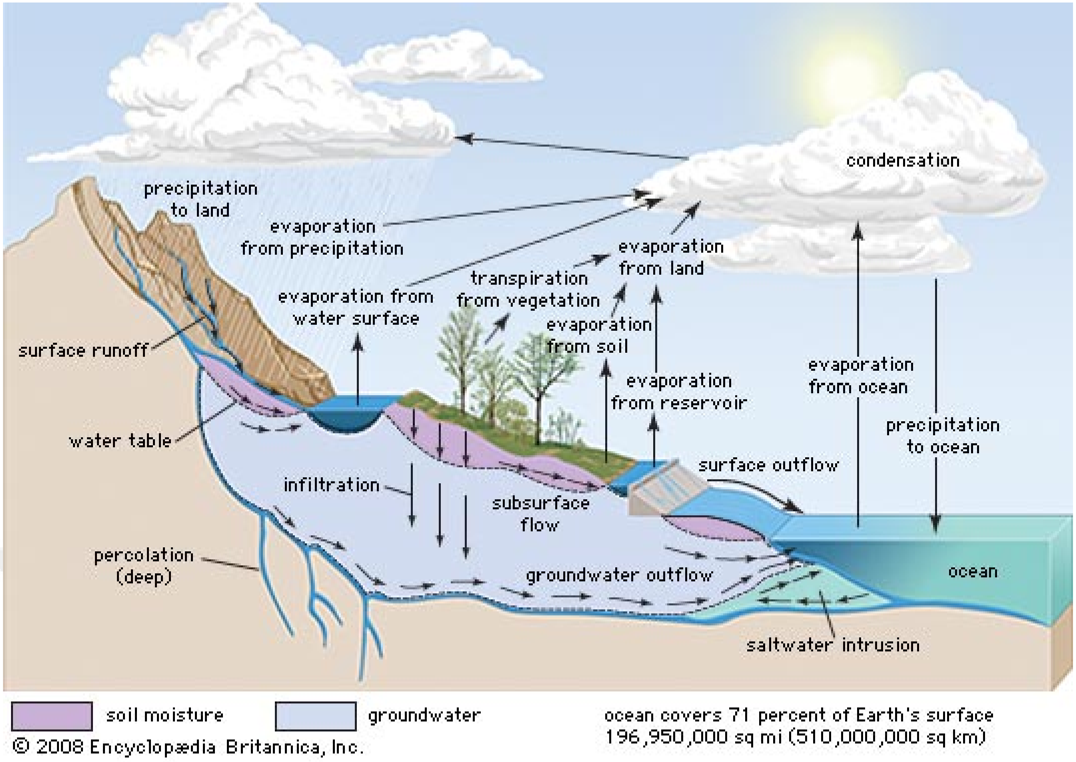


Figure 1.1: The Hydrological Cycle

Unfortunately, population growth and the efficient use of water by industry and industry are increasing at a great pace with freshwater (mostly rain, groundwater and surface waters) demands. In addition, the establishment of industrial dams, the change of course of rivers during the construction of industrial dams, causes changes in the distribution of water on the earth. Modern estimations show that the hydrosphere of the Earth consists of a great deal of water (approximately 1.386 million cubic kilometers), 97.5% of which is salt water and 2.5% as fresh water. It is also estimated that 68.7 percent of freshwater reserves are permanently covered with snow throughout Antarctic and mountainous regions. Besides, the 0.3 percent portion of these resources is economically available (Çırpıcı, 2008).

Water is an important molecule that promotes socio-economic activities that directly affect the quality of life for people. At the same time, it is the most important parameter in agricultural production and it is used effectively and very importantly in industrial processes such as energy production and energy production (Rehan et al., 2013). If we think about the socio-economic and socio-cultural situation of Turkey, we can say that Turkey is an agricultural country and the geographic situation of Turkey supports Turkey to be an agricultural country. In that perspective, the water resources, irrigation systems for agriculture are important parameters in the agricultural situation of Turkey.

It is known that the total area of Turkey is 779.452 km2 and 280.5 km2 of these are farmland areas. Within this farming area, irrigable area was reported as 258.5 km2. Turkey is a country whose geopolitical position is surrounded by sea on three sides. While the mountains in Turkey were settled parallel to the sea on the northern and southern coasts, the mountains in the west of Turkey settled perpendicular to the sea. This causes the temperate climate in the western part of Turkey to reach as much as it is inside. Because Turkey is a mountainous region, it contains altitude differences. Elevation differences cause the climate to change at short distances as they move away from the sea. Resulting from climate change, some differences also occur in the amount of rainfall and precipitation (TUIK).

Like almost all megacities in developing countries, great pressure has been faced in Ankara due to not only the growth in population but rapid urbanization, as well. Such a growth in urban areas places pressure on water resources in Ankara. In this sense, the water resources must be managed correctly and must be planned sustainability of water for future days. The dams of drinking water in Ankara are audited by Ankara Water and Sewerage Authority (ASKI).

This problem cannot be explained through static variables, or static equations. Therefore, system dynamics discipline reveals the causes of a dynamic problem, and thus search for policies that alleviate them is the most suitable method for this problem. This study aims to build a balance between water supply and water demand by using system dynamics model, to predict different scenarios according to increasing population, urbanization and limited water resources, and to create some policies for sustainability of water.

Water is an indispensable resource which responds to various human needs, such as drinking, domestic use, agricultural production, and industrial processes. As can be seen, water supports socio-economic activities apart from responding to those needs. When these factors are taken into consideration, water is directly related with the quality of life in human settlements (Rehan et al., 2013). In addition, water resources are getting inadequate in meeting increasing needs. It has been argued that the use of scarce resources in a proper way becomes exponentially important. Therefore, it is vital that an effective and optimum water resources management strategy be generated for life cycle of water resources (Çırpıcı, 2008).

This thesis aims at examining applied policies for sustainable water management system. We attempt to analyse the contemporary practices in supplying water and distributing water demand. In addition, this study is aimed to determine the significant aspects and components of the sustainable water resource policy apart from discussing new water scenarios for a long term. Finally, the study discusses how effective system dynamics are when enhancing a better evaluation of water management system in the long term. The continuation of Chapter 1 presents a general outline of the problem. Chapter 2 covers methodology, the scope of the study and implementation of the study using the system dynamics model while Chapter 3 mentions results of the implementation. Research discussions and conclusions follow the Chapter 3.

1.1 WATER

Water has many features except that to be a source of life. Water resources have a natural beauty which people feel a great interest. People want to live and vacation near lakes, coasts and rivers. Water is also likely to lead to erosion in rock while altering remaining landscapes and forming new ones. It shows that it is powerful. This power generates economic activities such as electricity, watermill and transportation. In addition, all of the food is grown, processed and eaten requires water. Consequently, the dependence of human on water, which is the basic requirement on every side of life, is indisputable (Loucks et al., 2005).

The water issue first appeared in an international policy document as one of 26 environmental principles related to the results of the United Nations Conference on the Human Environment (Handl, 2012). This principle is "protection of water, land air and natural ecosystems by planning or management for future generations".

The first global activity on water is the UN Water Conference in Mar del Plata in Argentina. In the conference text, it is stated that "whatever the socio-economic conditions and level of development, all peoples have the right to access the quality and quantity to meet their basic needs". Following the conference, UNESCO launched the World Water Program and in 1980, the UN General Assembly issued the "Declaration on International Decomposition of Drinking

Water Needs and Water Quality". The conference stressed the importance of drinking water so that it could be considered as one of the “human rights” (Biswas, 1977).

The World Commission on Environment and Development (WCED), established in 1983 under Norwegian Prime Minister “Gro Harlem Brundtland”, generated the concept of sustainable development, described in 1987 by our commission, "Our Common Future" as it was conceived as fulfilling the needs encountered today without endangering the potential capacity of future generations so that their needs could be satisfied on their own. According to the development model envisaged in this report, it is essential to ensure a balance between environment and development, to increase economic oppression on the environment and to achieve economic growth without consuming resources.

In 1992, the International Conference on Water and Environment organized in Dublin noted there remains limited water resource to keep sustainable life as well as environment and will save more on agriculture, industry and domestic water use and allow for more water use. As opposed to the previous one, it has been adopted that "water is an economic value". With this decision, water was opened to market conditions and the public service concept was out of the question (Anon., 1992a). The importance of water was highlighted in the Rio Summit, held in 1992, as an economic value in strengthening ties between water-related sectors, developing co-ordinated approaches among sectors, taking environmental impacts and development opportunities into account in improving water resources management (Anon., 1992b).

The World Water Forum (WWF), which is organized once in three years by the World Water Council (WWC), has been launched to address water issues in an international context. The Council is internationally a policy-setting organization, established in 1996, and projects pressures on freshwater resources at an international level. The Forum is a platform for the integration of all stakeholders, including all open, all-inclusive. The goal of the Forum is to increase the significance of water resources-related issues having remained on the political agenda, to promote further examination and solutions in order to resolve 21st-century international water issues, to produce sound recommendations and to achieve political results. WWC was assigned the task of generating a sustainable and lasting vision regarding Water, Life and Environment in the 21st century during the 1st WWF, held in Morocco in March 1997.

At the same time, the First World Water Forum has warned against considering water as a commodity with commercial value and has set some priorities. These priorities are Water and environmental health, common management of water, ecosystem protection, gender equality and efficient water use (5th World Water Summit Summary Report, 2009).

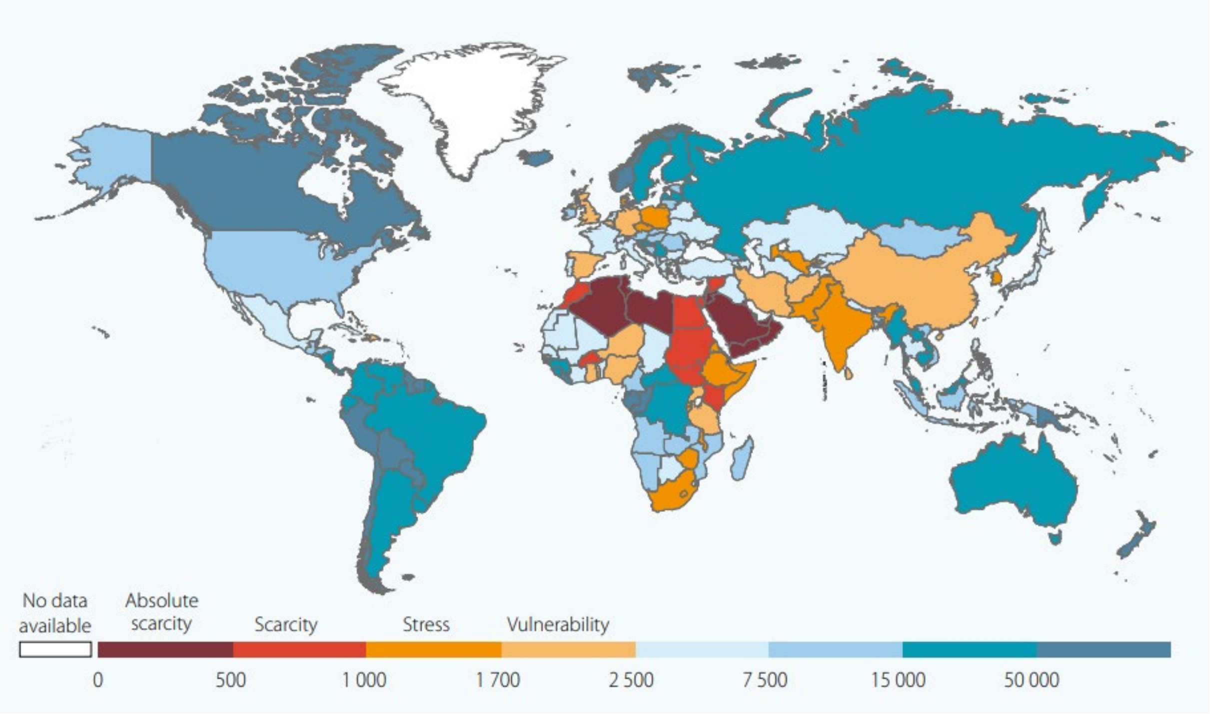


Figure 1.2: Total renewable water resources per capita in 2013 (m3) (WWAP, 2015)

The 2nd WWF, organized in Holland in 2000, highlighted the importance of water security for food and environmental safety. Increasing cooperation in transboundary basins has made it possible to use water consciously and effectively. The key message of the forum is "Everyone is interested in water". It has been stated that studies to resolve water-related problems should be regularly reviewed and that freshwater resources should be periodically reassessed. The most important decisions on global water resources were taken at the UN Millennium Council in 2000. The goal of the Millennium Development Goals is to decrease people’s proportion who live below poverty line in 2015 and who have no access to water resources. Integrated water management in this sense has been recognized as an important approach to achieving sustainable development (5th World Water Summit Summary Report, 2009).

The sub-title of the International Freshwater Conference (IFC), held in Germany in 2001, is "Key to Sustainable Development: Water". Until access to sanitary drinking water has been achieved, this conclusion has been reached that sustainable development cannot be achieved unless hygiene and water / wastewater infrastructure facilities are completed (Germany. Federal Ministry for Economic Cooperation and Development -DE, 2001). The World Summit on Sustainable Development, the first global conference of the 21st century, took place in South Africa, in 2002. It is also called "Rio + 10" because it aims to evaluate the applications of Agenda 21 in the world after the 1992 Rio Summit held 10 years ago. After summarizing the process from the conference Rio to Johannesburg, attention was drawn to the stresses and bottlenecks, and a global commitment to "sustainable development" was repeated, emphasizing partnership and emphasizing the strengthening of implementation. To this end, it has been stated natural resources management is required to be handled in a sustainable approach in addition to integrative approach so that a sustainable progress could be achieved. Parallel to "Millennium Declaration", the target of reducing the population by half by 2015, which does not have access to healthy water and water / wastewater infrastructure, has been reiterated (Anon., 2002).

The annual economic summit has been organized by the G8 countries since 1975. At the 29th meeting of the G8 International Governments Forum in June 2003 in France, "water" created the main agenda item. At this meeting, the G8 member countries came to an agreement to supply financial provision to achieve targets set for the 2015 year in Johannesburg and in the Millennium Council, and agreed to provide financial support for the projects to be carried out. The UN General Assembly decided in December 2003, at its 58th session, that it would be the "Water For Life" of the world's water day for 10 years from March 22, 2005 until 2015. It is stated that it is necessary to carry out water related programs and projects and to cooperate to facilitate the resolution of water related problems at all levels. The African continent, where water shortage is at stake, was chosen as a priority area to implement Decade Action Plan (United Nations, 2003).

The main sources of the law of the Republic of Turkey are the constitution, laws, decision in law, international treaties, statutes and regulations. Regarding water resources, laws and regulations are the most common legal regulations. The development and management of water resources in Turkey has been influenced by many legal regulations. More than 100 laws and regulations contain provisions on water use, management and insurance (Özel İhtisas Komisyonu, 2014).

It is aimed that the protection, use, improvement and development of water resources and aquatic life sustainably, collection and monitoring of water related information, basin-based studies and planning, based on the right of water access in an adequate amount beside appropriate quality of water in our country, The preparation of the Water Law Draft for the regulation of the procedures and principles for improving efficiency and participation in water management is carried out under guidance of "Ministry of Forestry and Water Affairs".

1.1.1. Water Supply

Water supply creates water sources. Conventional natural water sources can be expressed as surface (such as lake, river) and groundwater. Non-conventional sources include seawater, brackish and recycled water (Koleva et al., 2018).

Surface water sources are sources that can be used directly. By means of rainfall or by guiding the rivers, the dams which are established as storage areas and the natural storage lakes are included in this class. In order to use Groundwater sources, wells are constructed and water is drilled. In addition to the non-conventional sources, the sources of water reclamation are all water sources that have been re-used in wastewater treatment as well as desalinated brackish and seawater (Twort et al., 2000).

1.1.2. Water Footprint

Water supply, as we mentioned in Dublin principles, is one of the most important parts of sustainable water resources management. The impact of people on water supply can be seen in Hoekstra's water footprint (WF) developed in 2002 (Ding & Ghosh, 2017). WF is measured by the amount of water used or contaminated per unit time. The water footprint of an individual, society or branch is the amount of freshwater resources used by the individual or society to obtain goods and services, or that the producer applies for the production of goods and services (Chapagain, 2017).

Water footprint is actually a member of the footprint family. For this reason, the meaning of the footprint will be useful for better grip of WF. In general, the footprint is a method for calculating the burden of a particular population on nature. The carbon footprint calculates how many tons of greenhouse gases are produced, and the ecological footprint calculates how many hectares of bio-productive space is used. WF deals with how many cubic meters of water a year is used. Even if they are similar to each other, each one has its own characteristics (Chapagain, 2017).

In the calculation of WF, both direct and indirect water use are used. Direct water use refers to water used by the consumer or during the production of the product - service. Indirect water use indicates the water consumed in the entire supply chain of the product or service concerned (Ding & Ghosh, 2017). For example, a product manufactured in Turkey are exported to European countries. Thus, the WF of the production of this product is included in the WF of consumption in European countries. On the other hand, a portion of the WF in Turkey caused by imported goods. The WF of a product consumed in Turkey is included in WF of the country where it is imported from. WF consists of three components: the blue WF, the green WF, and the gray WF. The blue WF is used for the total volume of surface and underground freshwater resources needed to produce a good or service, or directly consumed by the individual or society. The green WF refers to rainwater consumption for the same reasons. Particularly related to agricultural production, horticultural crops and forest products, the green WF covers all the water contained in the evaporating rain water and harvested product or cut wood. The gray WF is an indicator of pollution. It is a conceptual figure that shows the degree of fresh water pollution caused by product production (Ding & Ghosh, 2017). Summary of these three components in hydrological cycle is seen in Figure 1.3.

Finally, we can make a little more concrete by referring to these components through the production of a product. the green WF measures the amount of rainwater consumed during the growth period, the blue WF measures the surface and groundwater used by the product during the same period. The gray WF refers to the amount of water used for the treatment of nutrients and pesticides involved in groundwater and / or filtration by groundwater, depending on the natural concentration and water quality standards in the environment.

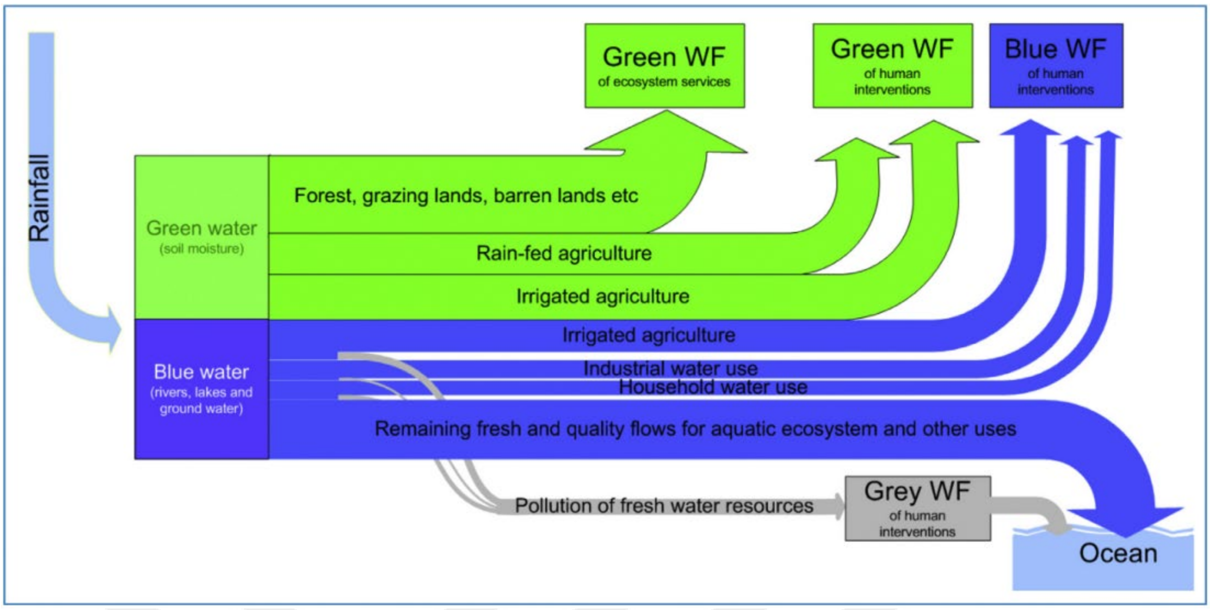


Figure 1.3: The three parts of the WF in hydrological cycle (Chapagain, 2017)

1.1.3. Water System

Generally speaking, a water system is a cycle of water from the natural environment where the water is obtained, the consumption of industrial and domestic water, and the process of wastewater treatment. Figure 1.4 shows the loop expressing the water system. As you can see from the elements in the loop, it is possible to examine the water system under four sub-systems (Kara, 1999).

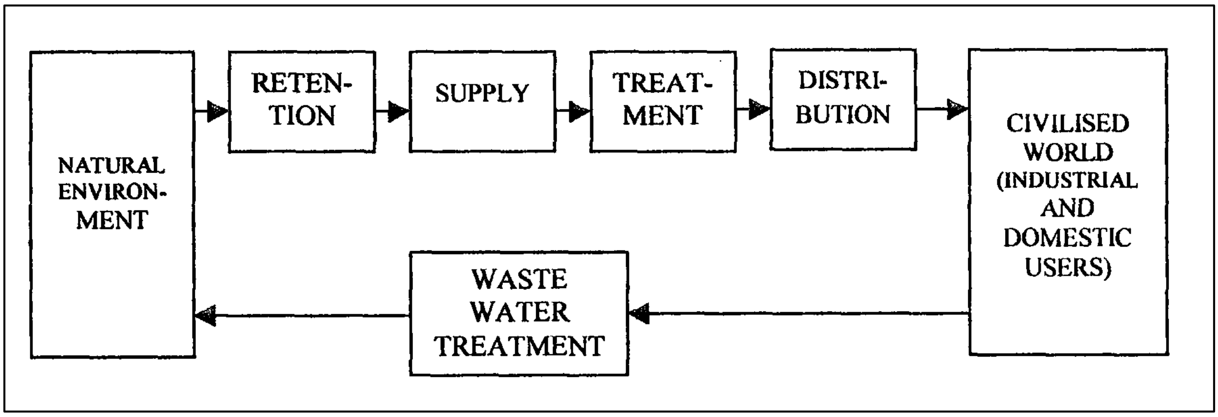


Figure 1.4: Diagram for the loop of water systems (Kara, 1999)

1.2. WATER RESOURCES MANAGEMENT

In the previous chapter, the importance of water has been mentioned. While water has a vital importance whole world, it also must be managed wisely. Water management must present logical solutions, because some problems increasingly have begun to emerge about water in recent years such as climatic change, pollution of water, population-growth, land-use shifts, urbanization and migration ranging from rural to urban districts. Growing population, quick developing agricultural and industrial activities, and increasing pollution indicate the importance for the proper management of water. Water management is the systematic and the efficient use of water. While planning was made only for economic purposes, in these times one must consider various problems, such as protection of environment, recreation and water pollution. In addition, the interaction between water systems are increasing and management becomes more complicated (Çırpıcı, 2008).

It has been argued that water resources management (WRM) could be clearly explained with an onion-analogy. Because of that, the activity of WRM is generally not very visible, although it collects and integrates the core of concentric levels and germination leaves, the root and the result are seen. This situation closely resembles the union (Bogardi & Nachtnebel, 1994). The onion of WRM is shown in the Figure 1.5.

WRM can be characterized a few aspects. Firstly, WRM has an integrative structure that has comprised science, nature, technics, economy, politics such as climatic changes, political and administrative structures, the state of the economy etc. In addition, WRM is a complex process in decision making, because results of the decisions appear, before the procedure itself. WRM can be summarized with two phase of water resources system which are preparatory phase contained in origin and planning, implementation phase has design and operation (Bogardi & Nachtnebel, 1994).

Moreover, Burak et. al. (1997) considers that the basic elements of water management may be stated under the follows:

- Short-run and long-run water demand
- River basin management
- Groundwater water use
- Interaction between water, land and forests
- Water quantity and quality management

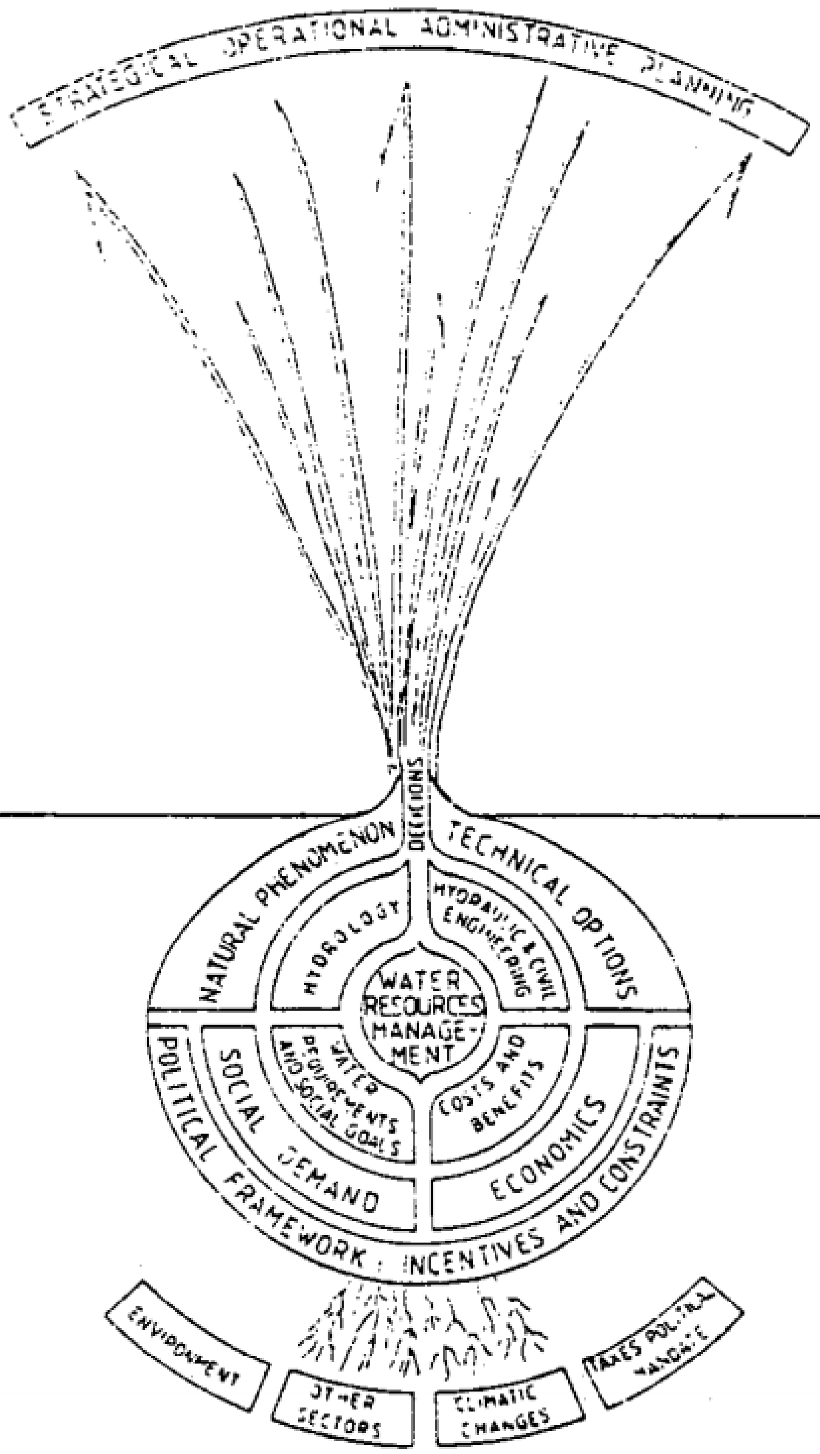


Figure 1.5: The onion-analogy of water resource management (Bogardi & Nachtnebel, 1994)

According to Berkoff (1994), water management could be analyzed in two perspectives: supply management and demand management. While supply management means to cover activities that necessitates managing, developing, and locating of new sources, demand management states to develop means, to ensure smarter degrees and forms of water use. Consideration of both together with environmental concerns is necessary for planning. In this study, the dynamic model is created combining these perspectives.

On the supply side, moreover, the water has to contend with some problems due to results of global climate change. In recent years, it has been stated that the most region of the world has unforeseen rainfall and unreliable water sources. On the demand side, the water also has to contend with some problems such as rapid population and urbanization growth. In addition, economic growth, agricultural activities and increasing industrial sector lead to not only rise water demand, but also more polluted water (Mavrommati et al., 2013).

Water Management is no longer just a subject of engineering as it is in the past. It has become an area where many scientific disciplines work together from the protection of the Natural Environment to international relations. This has led to the need to reorganize the legal and institutional structure of the administration (Yıldırım, 2013).

Efficiency is one of the basic elements to be taken into account in the management of water resources. For efficiency, planning at the basin level is quite critical. While water resources problems have been approached, it should be started a proper and detailed examination of the basin level is natural border of a hydrological system (Meriç, 2004). Loucks et al. (2005) argue that for comprehensive management of river basin system, a system view requires the modelling of multiple components is necessary. River basin planning, furthermore, is a precondition of integrated WRM that demands the integrating natural system components as well as the upstream and downstream water-related demands. In summary, Çırpıcı (2008) states about the basin as in the following: *"A basin is an area that is bounded by natural borders which controls the hydrological system. It is a region of land where water from rain or melting snow drains downhill into a body of water, such as a river, lake, sea or ocean. It includes both the streams and rivers that convey the water as well as the land surfaces from which water drains into those* *channels. Each drainage basin is separated topographically from adjacent basins by a ridge, hill or mountain, which is known as a water divide."*

1.2.1. Sustainable Water Resources Management

While current efficiency of the basin is provided, sustainability also should be taken into consideration. The other issue is sustainability has also a great importance in water resources management. While current efficiency of the basin is provided, sustainability also should be taken into consideration. The other issue is sustainability has also a great importance in water resources management. Sustainability has emerged in the definition of an economy that remains unchanged in the first 1070s and maintains its continuity. Presenting more natural resources today (Wood, 2003). With the general definition of sustainability, it is the principle that all elements which is covered by the ecosystem is transferred to future generations in the best conditions without creating unwanted changes in the system. It is an ideal approach which behaves parallel with the management. On the other hand, existent resources can be exposure to serious constraints such as not to meet current necessities, to ignore alternations of the system while it is planned to supply future generations' needs (Meriç, 2004). Briefly, it is expected that water resources management must determines a sustainable method will supply not only current requirements but also future needs without damaging resources and the hydrological system (Meriç, 2004). In other words, solutions balance between human-natural systems are found through sustainable water resources management (Mavrommati et al., 2013).

Furthermore, in terms of water resources management, top priority dwells on meeting the growing demand for water while having limited water resources. On the planet, the demand for water is gradually increasing, and the supply is gradually decreasing. The constant increase in demand for water, the ever-decreasing availability of available resources, has made water management mandatory so that water resources could be used efficiently. It is crucial that the quality, demand and supply of water be considered together for sustainable water management according to the Dublin principles – Dublin Statement on Water and Sustainable Development - declared in 1992 (Anon., 1992a). In general, the priority in the employment of water resources accepted by all countries is to meet the mandatory requirements for survival, and then to allocate water for other requirements. By effectively managing the water resources, it is possible that the demand for water can be met in accordance with the determined priorities. Water resources management means the provision of water to people at low cost, adequate quality, when and where they need, meeting social, economic and environmental needs. Water is directly linked to policies created in such many areas as industry, agriculture, forestry, energy, transportation, urban-regional development and environmental protection. In fact, the management of issues in the areas above-mentioned are involved in water resources management. Although the issues are multifaceted and interdependent, the institutions working on this issue are independent and fragmented. For this reason, existing administrative and legislative arrangements have not developed enough to ensure the necessary harmonization and cooperation between water management and other government policies (Özel İhtisas Komisyonu, 2014). Since the late 19th century, developed and developing countries in the world have adopted a number of water policies to ensure that water is used effectively and needs are met. In particular, with the industrial revolution, the use of water has widened and the use of energy production and industrial purposes has increased the value of the countries to the water beyond meeting basic needs. In this context, developed countries have adopted an understanding of water resources planning, which includes a large number of dams and irrigation canals with the aim of satisfying demands on energy, food, drinking water along with utility water.

After mentioning the importance of Sustainability, let's examine the relevant studies of SWRM. Several studies have been conducted on SWRM. For instance, sustainable water resources management has been based on some strategies in China. Firstly, water demand should be controlled and new strategies should be developed for water conservation. It can be listed different water users and it will be seen that water usage of them differ from each other. Furthermore, controlling pollution is another strategy. Notwithstanding it has been attached importance to wastewater treatment to control pollution, reducing discharge from sources has a vital importance. However, it is unforgotten that the wastewater can be thought of as a resource. Using this resource by the treatment, not only, we have a water resource and an energy resource, but also we are protected against unhealthy and damaging effects of the wastewater (Qian, 2016).

According to Distanont et al. (2018), collaboration of the communities is a very important way to achieve sustainabilty. In Thailand, they study three basic elements for SWRM: understanding water cycle, determining water quality and quantity, and developing water resource management. Collaboration between government agencies, universities and communities, as shown in Figure 1.6 is essential for working of community water resource management and sustainability. The government and universities should support the community as well as the exchange of information between them. Water resources management will not be fully realized when the community is not included.

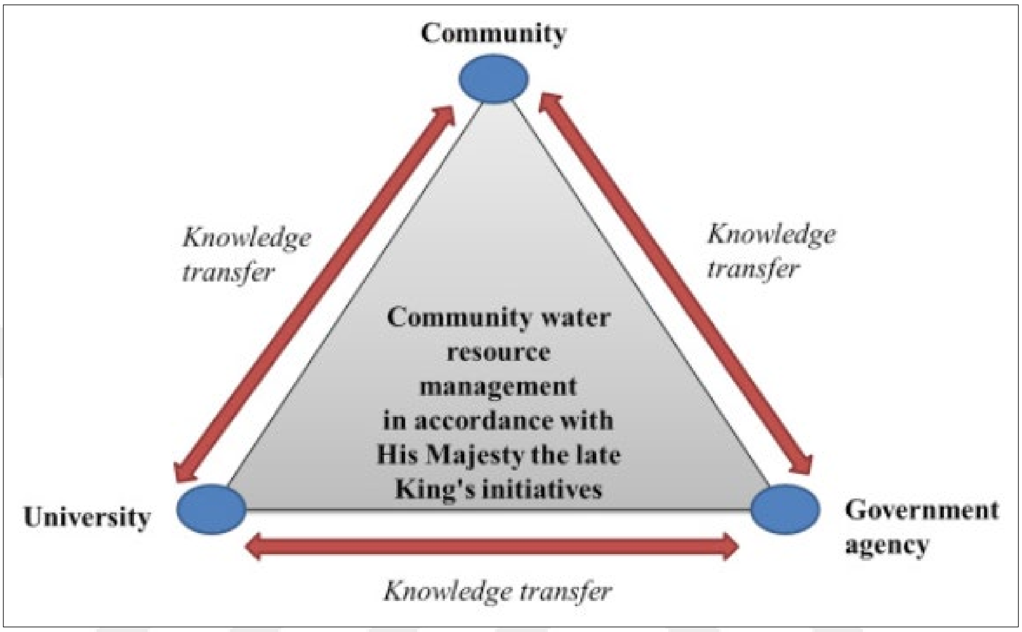


Figure 1.6: Triangle of community water resource management (Distanont et al., 2018)

In addition, water-sensitive urban design (WSUD) method and sustainable WRM applications are available. The Environmental Protection Authority developed the storm water management model (SWMM) to simulate rainfall runoff quantity and quality. With SWMM 5 WSUD method and SWRM samples are found in the literature (Ding & Ghosh, 2017).

SWOT (Strength, Weakness, Opportunity, Threat) analysis, which we mostly encounter in business management, has also been used in the evaluation of sustainable management (Sindhu et al., 2017). Stating that the letter T used in SWOT analysis stands for "Threat", a military term, SWOC (Strength, Weakness, Opportunity, Challenge or Constraint) analysis is used in sustainable solar power works. The terms "Challenge or Constraint" will play a more positive role and will play an active role in achieving more valuable results in strategic planning (Karatayev et al., 2017) SWOC factors were determined and the most effective ones were determined with AHP and SWRM model was determined in the regions applied according to the results.

1.3. WATER AND WATER MANAGEMENT IN TURKEY

Because Turkey is a developing country, water resources and to optimize the benefits of the water, at the same time minimize adverse environmental effects that an efficient method / strategy needs to improve. It is also clear that this requirement is essential in our consideration of the water availability graph shown in Figure 1.7. Approximately capita amount of water per capita in Turkey, the water is only about one-fifth of the rich countries. Therefore, it is of great importance that the amount of water per person is improved by increasing the quality of life of the people. Likewise, in Turkey in recent years, domestic use, irrigation, power generation, flood control and water resources development studies for other purposes is increasing (DSI, 2009).

Since the 1950s, extensive water planning activities have been accomplished in Turkey. With hydro-meteorological data of 1951-2000 period of Turkey, mean rainfall height is 643 mm / year, which corresponds to a mean of $501x10^9$ m^3 per year. Approximately 55% of the falling rain returns to the atmosphere through evaporation and sweating, $69x10^9$ m^3 (about 14%) feeds the surface and underground waters, $158x10^9$ m^3 (31%) passes through the streams and flows through the rivers and into the ponds in the seas and closed basins (Özel İhtisas Komisyonu, 2014).

The annual rainfall in Turkey is 642.8 mm, which corresponds to an average of 501 billion m3 per year. 274 billion m3 of this water is returned to the atmosphere by evaporation from the soil and water surface and plants. Average surface water run-off is 186 billion m3 and average of 7 billion m3 of water is coming from neighbouring countries per year. Totally, Turkey’s surface run-off is 193 billion m3 (DSI, 2009). In today's conditions, it has been determined that the amount of surface and groundwater that can be consumed technically and economically for various purposes is totally 112 billion m3. According to studies carried out to date, this reserve can only be utilized from 44 billion m3 (39%) (Özel İhtisas Komisyonu, 2014). Annual water potential of Turkey has been shown in Figure 1.8.

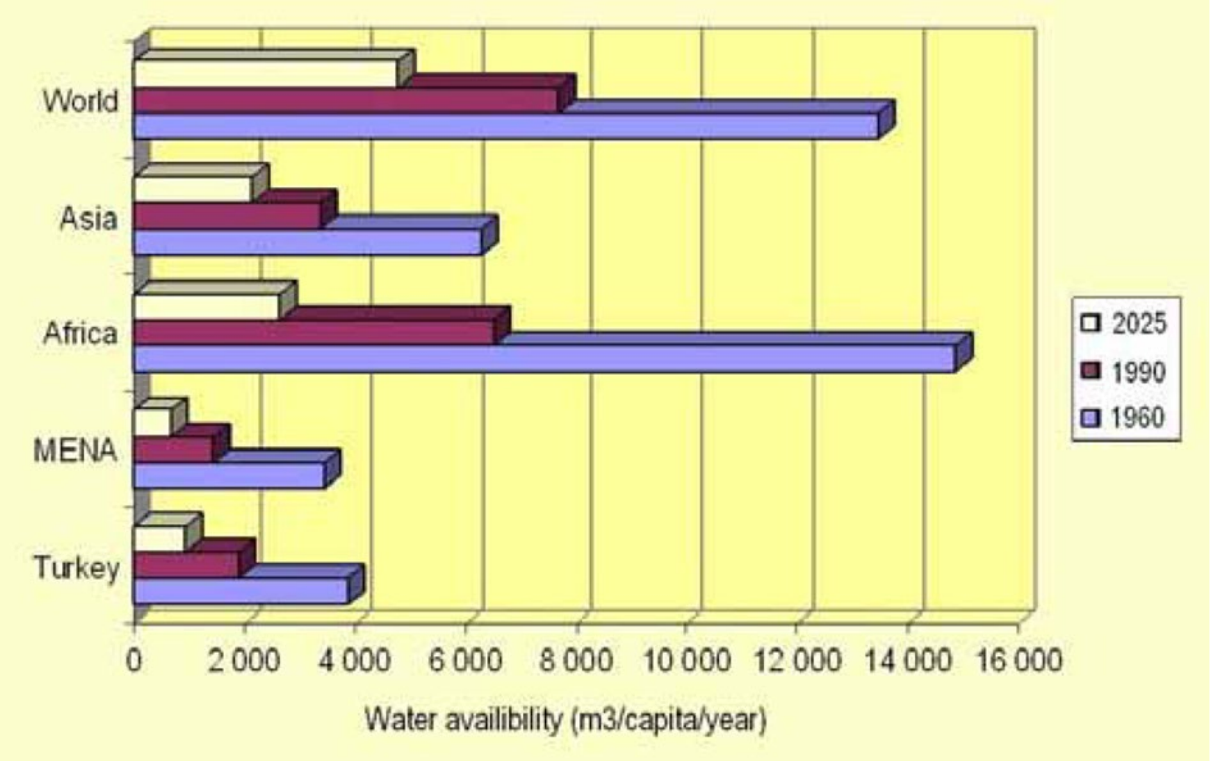


Figure 1.7: Water availability (DSI, 2009)

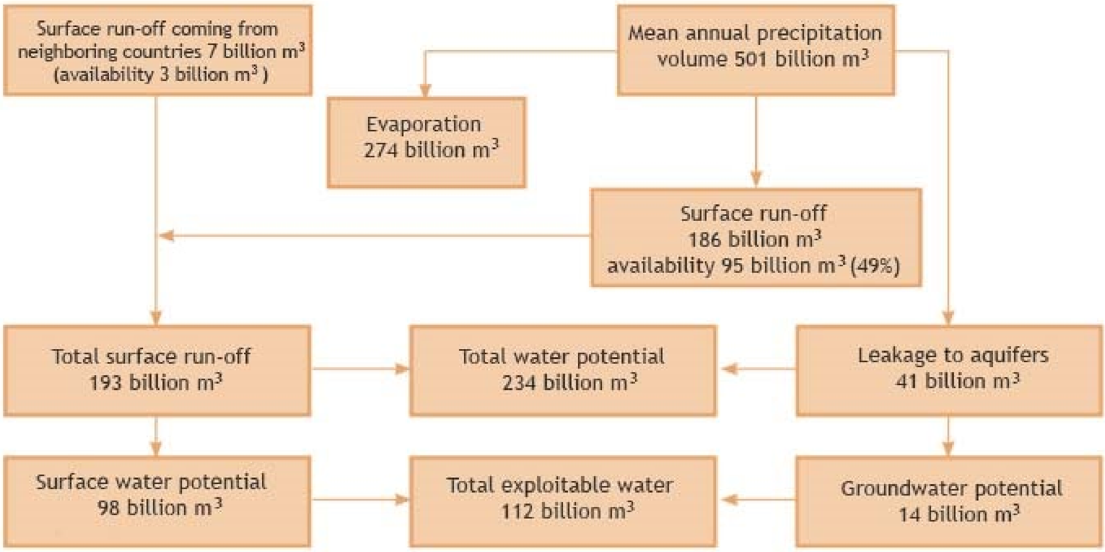


Figure 1.8: The annual water potential situation of Turkey (DSI, 2009)

Irrigation is the driving force of rural development. Every irrigation project is a rural development project at the same time. In dry conditions, the farmers who work with the cereal - fallow system are able to cultivate the field every year with the coming of irrigation facilities, the product variety increases, the yield increases 2-5 times and the agricultural - based industry is able to develop. 2/3 of the food production is covered by irrigated areas. Sustainable agriculture and sustainable rural development ensure sustainable management of land and water resources.

Being an integral part of modern agriculture, "Water" is one of the most important strategic resources of our day and future. The savings to be provided in the transmission, distribution, system operation and application of the irrigation water are extremely vital. The planning and implementation of irrigation projects together with the consolidation projects are of great importance in order to improve the soil and water resources in our country and to provide the expected benefits from the irrigation more effectively. In the irrigation projects applied together with the consolidation, both the investment costs are reduced and the parcel structure is brought to provide the efficient use of soil and water.

Considering the whole WR used all around Turkey, more than 70% is employed in the irrigation. Most of the irrigation methods used are water irrigation (water loss is between 35% and 60%) and water loss is less (between 5% and 25%) in irrigation and drip irrigation (Yıldırım, 2013).

Considering the fact that water resources sustainability is an economic, ecological, physical and social concept, sustainable water resources management includes the services of water and ecosystem protection for drinking and using, irrigation, industrial and recreational purposes to enable the community to fulfil the following objectives without jeopardizing the future objectives belonging to WR system.

With the aim of ensuring sustainability, it is of necessity to bear in mind the following points:

- Protecting water by preventing water wastage
- Restriction of underground water shoots
- Increase the effectiveness of irrigation systems
- Limitation of the amount of surface water usage to the amount of soil and product type and irrigation method required
- Increase water quality

Since Turkey is surrounded by the sea, it is located in Eastern Mediterranean Basin, and Mediterranean climate features are seen in a wide area, high risk group is considered among the countries on the basis of negative impacts climate change leads to (Anon., 2008).

In the study entitled "Turkey's 2011-2012 Agricultural Drought Analysis" prepared by the Ministry of Forestry and Water Affairs, Meteorology General Directorate of Research Department; Turkey has an irregular precipitation regime and the variability in precipitation does not follow a meaningful course, which shows that Turkey is facing risk of drought from time to time with the change of violence (Şimşek et al., 2012). According to the report, "Turkey is on a semi-arid belt that is constantly threatened by drought throughout the world. In the past, drought has caused great damage to our country from time to time. Especially in agriculture, due to natural conditions drought in our vegetal production structure has been caused by large fluctuations, food deficit and high prices have emerged. There are still problems in agriculture and drinking water supply today and it is expected that the drought that will be caused by the climate change that can be experienced in the 21st century causes these troubles to increase even more. For this reason, it is of great importance that the drought is continuously monitored by a center composed of experts from different disciplines, and that the damage that may occur by taking necessary precautions and precautions without any dangerous growth is minimized." These findings are detailed in many of the studies conducted over the last 10 years (Şimşek et al., 2012).

Indeed, although it is not easy to arrive at concrete results on the effects of climate change, it can be argued that in certain regions where observations have been made up to now, the trends in the river flow will lead to a similar trend in future water resources. For this reason, this issue is a direct responsibility of the water management and will directly affect our Water and Food Safety.

In our country, which has gained important experience in the management of water resources, the most striking feature is the central plan. In the "5-year development plan", it is envisaged to provide the most appropriate distribution of all natural resources among various sectors. Looking at the relevant institutional structuring and activities within the framework of Turkey's administrative, social and economic structure, it can be seen that the management of water resources has been adapted to the requirements for water use to a large extent. Since the Republican era, there have been many irregular and unplanned additions to the central public administrative structure of water management over the past 30 years. The increase in the number of organizations that are competent in water management has caused a great deal of jurisdiction and coordination weakness. There are many legal regulations related to water management in Turkey. Some of them are adopted in the first years of the Republic and are legally conflicting with the new legal regulations adopted over the years (Özel İhtisas Komisyonu, 2014).

The most basic need for water management is to have a "water management strategy". On the basis of this strategy, water management should be restructured. Key points of this restructuring can be listed as Central Planning, Management at River Basin Scale, Public Effective Control, Fast and Scientific Solution Capability, and Natural Life Preservation Sensitivity. Water management should be dynamic, effective, fast decision-making, and audit function must be strong. In this structure, planning units should be established in the center for each basin in the river basin scale. The decisions of these units should be put into practice with the help of the provincial directorates of high effective intervention in the provinces (WWAP, 2015).

There is a clear need for all these regulations to experience the past experiences and accumulations. For this reason, the institutional structure of the General Directorate of State Hydraulic Works should be regarded as the cornerstones of this work without being violated and without the loss of competent personnel. The practice of central public building in water management and the dissemination of experience and accumulation to date is causing great gap and complexity in water management. In addition to other water projects, Turkey is still carrying out a very large regional development project based on three water types such as ‘GAP’, ‘KOP’ and ‘DAP’. These projects, which will change the face of Turkey when they are completed, also obligate the "management of the water" to be well managed.

1.4. SYSTEM DYNAMICS AND ITS APPLICATIONS

Being a methodology for examining dynamic systems via feedback mechanisms, system dynamics (SD) can also be said to stand as numerical modelling method aiming to understand behaviour of complex systems and to develop policies to change the desired direction. System can be described as anything that has parts and associations within the defined boundaries. Systems in which the relation of delay and feedback are not linear can be defined as complex systems. Things like the learning period of the recruited person, the time of the raw material conversion into the product, the period of realization of the investment, the period of taking the investment decision, the period of being realized of the investment necessity exemplify the delays in the systems. Undisturbed inventory fluctuations, chronic budget deficits, inflation-unemployment problems, economic growth/environment-ecology problems dilemma, irrational price-advertising wars, abnormal cost-price increases in the health care system, long waiting queues in the health system, disease / drug addiction dilemma can be examples of problems of system dynamics field. Stock-flow dynamics, feedback cycles, time delayed effects, non-linear effects, intuitive inadequacies, multiple of variables, complexity of human systems are the parameters that make the systems complex. The purpose in this modelling is to gain an in-depth understanding of the system behaviour using a simulation model and a valid representation of a real system (Eksin, 2009).

The system approach for the analysis of dynamic socio-economic management problems is based on principles and assumptions such as causality, causal cycles and feedback, internal structure of systems and behaviour of systems. It is essential to understand and model the direct causal relationships between variables. The causalities that form the basis of the model should not be confused with statistical correlation. Notwithstanding the fact that statistical relationship between/among variables is strong, this never proves the existence of a causal link. The assumption of causality must arise beyond statistical (with statistics), from the interpretation of theory or empirical facts (Saysel & Barlas, 2001).

We call the structure of that system the whole of the relations between the elements, variables that make up a system. According to system theory, the main factor determining the dynamic behaviour is the structure of that system (Forrester, 1961)

SD simulation modelling was designed by Jay W. Forrester in 1961 at the Massachusetts Institute of Technology. He intends that SD is modelling, analysis complex and dynamic socio-economic systems (Lee & Chung, 2012). It is observed that system dynamics, through which causal and feedback cycle are developed, have been used to contribute to policy-making in business sector and dealing with dynamic industrial management issues (Jafari et al., 2012).

The focal point of the dynamic system approach is not to predict where the events occur or to predict the instantaneous values of the variables. The aim is to comprehend the basic behavioural variable forms, to investigate the causes of this behaviour and to improve the system's long-running behaviour. Typical dynamic behaviours are exponential growth, balance reach behaviour, growth and decline, oscillation (fluctuation), and various combinations of these. A typical system operation is conducted to investigate the causes of a problematic dynamic behaviour. For this purpose, all factors considered to affect the problem are considered and the direct relationships between them are modelled. The incorporation of all these relationships leads to the structure of the model consisting of cause-and-effect cycles. The inner arrangement of the model creates a dynamic behaviour.

The dynamics of systems are too complex to be understood by simple heuristic estimation methods. The main reason for this complexity is its inadequacy in knowing the feedback cycles that are involved in the structure of our natural intuitions and common sense system and which are effective in system behaviour. Our intuition gives us the preconceived idea that the result relations are close to each other in time and space. In socio-economic systems involving many feedback cycles, consequences of the effects can occur both late (in the future) and at far-off points in the system. As a result, the decisions we make in the direction of our intentions to improve system behaviour can lead to undesirable, intuitive consequences. For example, J. W. Forrester's Urban Dynamic Model, has shown that insisting on residential building programs in cities that have been aging and economically stagnant in those years has aggravated the stagnation more than anticipated (Forrester, 1969). Forrester's experiments show that the area that will be the result of the demolition of a part of the old houses will create new opportunities for the operation of the economy and will stimulate the economy over time (Forrester, 1969). In addition, socio-economic models should include decision-making as well as mechanical relations in systems. The modelling of the human factor and decision processes increases both the internal complexity of the system (the number of feedback cycles that are dependent on each other) and creates some conceptual difficulties on the other hand. Dynamic system modelling provides a variety of instruments as well as various methods for the analysis and management of tangle combinations with numerous cyclic causalities (Saysel & Barlas, 2001).

As an area of system theory, SD is a method developed with the aim of understanding its dynamic behaviour. SD's basic principle is the system's behaviour is rooted in the structure and that the form of system (the relations between the components) is as important as the components themselves. Because all of the behaviours are often not explained by the singular handling of the components, the behaviour of the whole may be very different from the behaviour of the individual components. SD includes various perspectives and elements ensuring one to comprehend complex systems' form and dynamics. The system is based on dynamics, control theory and modern nonlinear dynamical theory. However, understanding of complex systems requires more than mathematical tools. Complex systems are also directly related to different social sciences ranging from system dynamics, cognitive and social psychology to economics, as physical and technical means include human and social systems instantly. Therefore, SD can be said to be an interdisciplinary method. For 'Radzicki', the approach of SD is a simulation methodology employed for analysing complex nonlinear, dynamic feedback systems and in designing policies to promote system's performance (Radzicki, 2011).

Conceptually, feedbacks are at the heart of the system dynamic approach. Complex systems are created by the interaction of feedback cycles. These feedback processes can be positive or negative (Zavr & Kljajić,2010).). Positive cycles produce self-feeding behaviours. Positive cyclic pathways in economic systems involve path dependent processes, one of the most important examples being speculative foams (Radzicki, 2011). On the other hand, neoclassical models with negative cycles tend to balance systems in general. This price effect, which is caused by an increase in household demand, is a negative feedback period, which has an effect in reducing the future demands of households. In this sense, it can be argued that negative feedback processes, which are at the core of neoclassical economic models, stabilize systems (Solow et al., 2010).

Feedback loops show circular causal relations between the variables. The variables could change in the process of time because they interact with each other. This shows that the problem is dynamic (Ulutaş, 2013). Figure 1.9 illustrates the complexity of nested response cycles. Each move and shift which are not easy to be predicted because of time delays between causes and effects are arranged in the feedback cycle system. As shown there is no beginning or end. The problem causes to action that produces a result that creates future problems and actions (Forrester, 2009).

Qualitative comparisons of the relationship between the model structure and the real world are crucial in conceptualizing a problem. For example, filling a cup with water may not be just a matter of flowing it into a glass ball. The important thing is to constantly control the amount of water in the cup. This control creates a feedback loop. This cycle is straightforward from the water level, from the eye to the hand, from the hand to the tap, and from it to the water flow. Such a closed loop controls the action everywhere.

The Causal Loop Diagrams (CLD) are the most significant means of showing response form of a system. CLD show all the associations and cycles in a system together. It is a simple diagram that facilitates the understanding of the problem by describing the cause-effect relations and information feedback in the system with variable names and directional arrows. In a system, the cause-effect diagram is used to show all relations and cycles together. Causal diagrams have causality at the root of causal diagrams. Causality is based on thinking about cause and effect relationships. When the same factors remain the same, only one factor is the change. Change has other effects on other factors, but in the case of direct causality it means that only one factor changes when the other items remain the same.

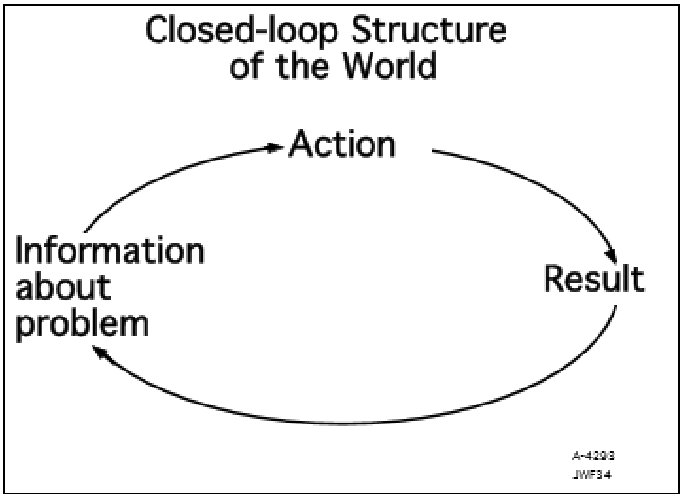


Figure 1.9: Closed-loop structure of the world. (Forrester, 2009)

The notion of non-linear dynamics and feedback control is mentioned to be regarding two essential kinds of SD: CLD and stock flow diagram (SFD). Jafari et al. (2012) have been expressed them as follows: "A CLD consists of variables connected by causal links shown by arrows with a polarity. A positive link (denoted by " + " on the arrow) implies that if the cause increases (decreases), the effect increases (decreases). A negative link (denoted by " - " on the arrow) implies that if the cause increases (decreases), the effect decreases (increases). Stocks and flows, along with feedback, are the central concepts of dynamic systems theory. All stock and flow structures are composed of stocks (represented by rectangles), inflows (represented by arrows pointing into the stock), outflows (represented by arrows pointing out from the stock), valves, and sources and sinks for flows (represented by clouds)."

A simple example is presented by Jafari et al. (2012). In Figure 1.10, how birth rate (BR) affects the population is illustrated besides depiction of death rate (DR). When there is an increase or decrease in BR, there appears increase or decrease in population correspondingly. Likewise, when there is a decrease in population, DR decreases. On the other hand, if the death rate increases, the population decreases. Two response cycles are observed in the example. Positive reinforcement cycle shows that growing BR leads to an increase in population. The positive feedback is expected to promote the increase of the population. Feedback cycle which exists on the right is negative reinforcement ("balancing"). The example indicates that once there is equality between BR-DR, population might not be different after a time. But, once BR exceeds DR, population would grow.

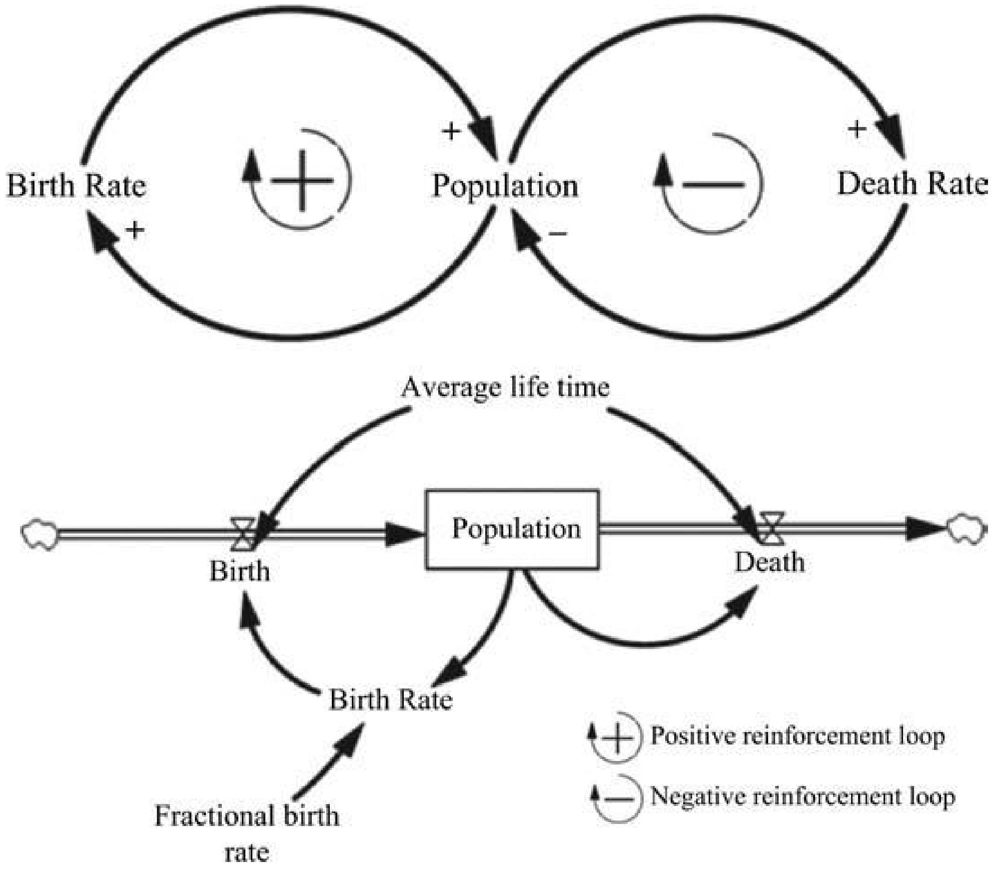


Figure 1.10: Causal loop and stock-flow representation (Jafari et al., 2012)

Briefly, the CLD is useful for making right decisions in a qualitative manner. In addition, the SFD is the initial process in building a SD model. Stocks and flows are basic terms of the SFD. Stocks also known as levels, accumulations, or state variables. They are used to represent the real-world processes. Whereas stock is defined as inactive division of a system, flow is defined as shifting rate of stock(s) – the way stocks' significance changes over time and thereby is defined as the system dynamics. Equation 2.3 illustrates the relation between them. It has been mentioned alteration of the stock during the time *d(t)* (Jafari et al., 2012).

$$Stock_t = Stock_{t-dt} + dt.(Inflow_{t-dt} - Outflow_{t-dt}) \tag{1.1}$$

$$\frac{d(Stock)}{d(t)} = Inflow_t - Outflow_t \tag{1.2}$$

Another essential part is simulation. Simulation express the complications introduced about by multiple interrelated subsystems and their complicated relationships. Since the SD includes dynamic factors, the policy-making for the system is easier with simulation. Simulation facilitate to see how the several entities in the system affect each other and all system (Ghazvini & Shukur, 2013).

Wu and Xu (2013) have assembled a SD model for empathizing with the dynamics of an urban coastal system by investigating long-term tendencies of systems' components. It has been analysing that different four scenarios about sustainability using the model. Like the study, Rehan et al. (2013) develop a SD model combining various disciplines (e.g. engineering, economics, and biology), and also two causal loop diagrams, about financial sustainability of water distribution networks.

There are some example using SD models for SWRM in literature, but a similar study has not been found in Turkey. It has been developed a SD model for simulate the water system and integrated other sub-systems such as the population system, and the agriculture system in Ghana. The SD model helps to examine the feedback processes and interaction between the sub-systems and to understand of the long-term dynamics of the Volta River Basin in Ghana (Kotir et al., 2016). In this study, therefore, it is preferred system dynamics.

SD methodology can be summarized as follows:

1. Being a perspective, System Dynamics includes a set of conceptual instruments which promotes the comprehension of structural causes as well as complex systems dynamics. Moreover, that formal computerized enactments belonging to complex systems are built is included in SD as they are used for designing more operative policy and organization (Sterman, 2000).
2. SD does not forecast for future like other methods. It assesses the coherence of our scenarios using the SD model. It enable us to develop effective and new policies in the long term using simulation (García, 2006).
3. Identifying the problem is the first step and all further steps depend on this. Therefore, it should be ensured that accuracy of the definition of the problem (García, 2006).
4. With the CLD relations between variables are defined. The CLD enable us to observe the relations obviously. After, under cover of the CLD and determining stocks and flows of the system the SFD is created.

5. Model validity has two components are structural and behavioural. While the former covers meaningful definition of the real relations existing in the problem of interest, the latter compares the real patterns with the patterns created by the model (Ulutaş, 2013).
6. Finally, scenarios and policy experiments are required to make useful recommendations at the end of the SD study. The realistic various different scenarios which may affect the simulation with creating a set of equations should be examined. On the other hand, the policy experiments include changing the values of some parameters and construction of some relations, which may be changed by decision maker in the real world (Ulutaş, 2013).

2. MATERIALS AND METHODS

Water, answers numerous needs of human, is a precious resource as it has been mentioned previous chapters. Water management, therefore, should be correctly arranged to prevent from some problems such as drought, floods, polluted water, degradation of aquatic and riparian ecosystem, bank erosion, dam related issues (Loucks et al., 2005). Briefly, water is managed to present solutions for the problems or to provide against emerging them.

The most important point about water management is to forecast long-term future impacts of decisions after planning. It has been mentioned that system dynamics is a suitable method to examine long-term impacts, and dynamics (Kotir et al., 2016). On the other hand, while the planners take decisions according to the immediate future, the impacts may depend on economic, demographic and physical conditions not only now, but also into distant future. Moreover, the decisions should be updatable and convertible to render sustainable management, because information, supplies, demands, objectives, cost and benefits change each passing day. Therefore, it could be provided that sustainability in water management, when planning is a continuing process.

Sustainability for water resources management is an essential issue when it is thought people needs which continue from one generation to the next. On the other hand, it is an inevitable reality that these needs will express some differences while alternating life conditions, developing high technology as it is highly necessary that its adverse or desired impacts on the people life be taken into consideration. Consequently, assessing management strategies for sustainable water resources considering change of the needs and new needs is concerned with economy, population increase, social issues, and maintenance of environment and protection of ecology (Loucks et al., 2005). Wu and Xu (2013) assume that these items also are interrelated with each other. For instance, economic developments encourage energy resources and environmental maintenance or vice versa. As it is assumed that this study is observed for long-term, and relations between these elements is non-linear. Therefore, they should be mentioned with differential equations, because they could be integrated with a system dynamics model it will be set. These equations has been expressed roughly as equations 2.1 and 2.2 in the previous chapter.(Jafari et al., 2012).

2.1. ASSUMPTIONS OF THE SD MODEL

Here need to focus on to state the stocks, inflows, outflows of our system. For that Ankara's water system has to be observed elaborately. To create a new system dynamic model according to the system is not only time consuming, it is also a complicated process. While this process have been continuing, data of past years such as annual precipitation, annual water consumption, capacity of dams, capacity of water treatment plants have been requested from ASKI. End of the study it will be argued the results of the operated model out, then some suggestions without will be made.

After creating the model, it has been run with three different population scenarios. The scenarios which are obtained from TUIK are used to create population projections. In the calculation of population projections, three main scenarios were designed and used. The scenarios were determined by consideration of variations in fertility and international migration (TUIK, 2018).

In the scenario 1, the birth rate is 17.8 per thousand. In the scenario 2, the birth rate is 21.1 per thousand. At last, the birth rate is 15.3 per thousand in the scenario 3. According to scenario 1 which is the main scenario of population projections, migrations data of Ankara has been obtained. However, the data couldn't been reached for the other scenarios. Therefore, the different birth rate of different scenarios have been used, while using the net migration rate of scenario 1 in all scenarios. (TUIK, 2018).

2.2. MODEL SIMULATION

The aim of the research dwells on planning Ankara water management system using System Dynamics (SD). As shown Figure 2.1 the SD model that will be created first deals with real Ankara data. According to the results will be a discussion.

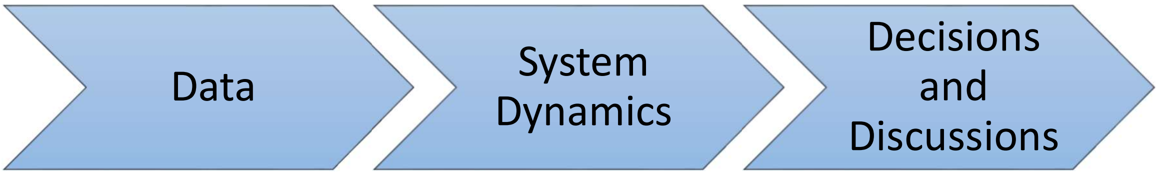


Figure 2.1: The system dynamics implementation

2.2.1. Scope of the Study

In this study, Ankara has been come up for review which is the capital of Turkey. Ankara is the strategic place for Turkey, when population growth, being capital city, centre of the economy and the policy are taken into consideration. In addition, because of seasons of drought in the past years, this study has great importance.

Ankara has twenty-five boroughs. Some of them have their own dams. For example, Şereflikoçhisar, which is one of the remote boroughs in the south of Ankara, has Peçenek Dam that feeds only on it. It also has its own a packaged water treatment plant which cleans water comes from Peçenek Dam. When all boroughs of Ankara are observed, it can be said that especially boroughs are far from the centre of Ankara are fed small dams and packaged treatment plants are also far from the centre of Ankara (Aski, 2014). There are eight central boroughs of Ankara as follows: Altındağ, Çankaya, Etimesgut, Gölbaşı, Keçiören, Mamak, Sincan and Yenimahalle. About 87% of Ankara's population has been living in these central boroughs. In this respect, centre of Ankara that means its central boroughs would be examined in this study.

Ivedik Water Treatment Plant distributes drinking water comes from Kurtboğazı, Çamlıdere, and Kesikköprü Dams to the central boroughs. These three dams are Ankara's the biggest ones which will be water resources of our model. Let's talk about all of them in general, respectively, starting from Ivedik Water Treatment Plant.

Ankara has 6 water treatment and 12 wastewater treatment plants. In addition, it has 56 packaged water treatment and 6 packaged wastewater treatment plants. They are shown below in Tables 2.1 and 2.2 without packaged ones.

Table 2.1: List of water treatment plants of Ankara (Aski, 2018)

Water Treatment Plants	
Name	**Capacity (m³/ day)**
Ivedik WTP*	1,692,000
Pursaklar WTP	75,000
Kazan WTP	30,000
Çubuk WTP	70,000
Polatlı WTP	30,000
Şereflikoçhisar WTP	26,935

* Water Treatment Plant

Table 2.2: List of wastewater treatment plants of Ankara (Aski, 2014)

Wastewater Treatment Plants	
Name	**Capacity (m³/ day)**
Tatlar Central Wastewater Treatment Plant	765,000
Karaköy Wastewater Treatment Plant	42,000
Çubuk Wastewater Treatment Plant	19,250
Kazan Wastewater Treatment Plant	10,289
Ayaş Wastewater Treatment Plant	6,500
Kalecik Wastewater Treatment Plant	2,500
Elmadağ Wastewater Treatment Plant	8,700
Lalahan Wastewater Treatment Plant	1,500
Hasanoğlan Wastewater Treatment Plant	3,000
Turkuaz Wastewater Treatment Plant	5,000
Yapracık Southwest Wastewater Treatment Plant	5,000
Yapracık Northeast Wastewater Treatment Plant	5,000

Ivedik Water Treatment Plant, the biggest one in Turkey, is constructed in order to meet industrial water need of Ankara. The plant has four units and water around 564.000 cubic meters is included in each unit per day. The plant is in the 10 biggest treatment plants in Europe, above the standards of Turkey, EU and World Health Organization. In addition, plant treats 1.692.000 cubic meters per day according to data of 2016. Providing water need until 2020 is planning. There are 3 main conveyance lines from Kurtboğazı Dam, 2 from Çamlıdere Dam, 3 from Kesikköprü Dam. Main objective of the plant is treatment of surface water on spring water quality by the help of highest technology. As a result, the plant services 7 million people (Aski, 2014).

Çamlıdere Dam is built between 1976 and 1985. It is the biggest dam in Ankara. Location is North-west of the city 59,6 km distant from Ivedik Water Treatment Plant. Total capacity of the dam is 1.220.150.000 cubic meters and its elevation is 995 m. Acun, Ilıca, Akpınar, Çay, Eşik, Avluçayır, Çayır and Değirmenözü are feeding the dam. It provides water with two units of 2200 mm diameter pipes to Ivedik Water Treatment Plant (Aski, 2014).
Kurtboğazı Dam is built between 1963 and 1967. Location is North of Ankara 47 km away from Ivedik Water Treatment Plant. Maximum water capacity is 92.000.000 cubic meters. The dam is fed by Pazar, Kınık, Uzunöz, Bahtılı, Kayıcık, Mera, Kirazlı, Bostan, İğmir, Batak, Karaboya and Eneğim creeks, in the meantime, the dam is in use as a recreation area. It provides water with two units of 2200 mm diameter pipes to Ivedik Treatment Plant. Length of pipeline is 47,2 km and diameters of pipes are 2200mm (two units). Capacity of Kesikköprü Dam is 95 million cubic meters. The dam is fed by Kızılırmak. There are 3 different pipelines between it and Ivedik Water Treatment Plant; each one of pipeline has 128 km length and totally 384 km. This Project is finished in a record time as one year. Long-term water need of Ankara is secured by providing water from another resource (Aski, 2014). The list of all dams are illustrated in the following table.

Table 2.3: List of Dams in Ankara (Aski, 2014)

Dams	Service Start Date	Water Supply Amount to Ankara (hm³ /year)	Maximum Temporary Water (m³)
Çubuk - 2	1936	20	22,445,000
Kurtboğazı	1973	60	92,053,000
Çamlıdere	1987	142	1,220,150,000
Eğrekkaya	1992	73	112,300,000
Kesikköprü	1996	45	95,000,000
Akyar	2000	45	56,000,000
Kavşakkaya	2007	58	80,835,000
Elmadağ–Kargalı Underground Dam	2014	-	2 ,500,000

According to ASKI data, comparison of precipitation from dams in Ankara over years (2001 – 2018) is given in Table 2.4 in m^3 representation.

Table 2.4: Comparison of the amount of water coming from precipitation to dams in Ankara between years 2001 – 2018

Years	January	February	March	April	May	June	July	August	September	October	November	December	Total
2001	4,042,000	6,202,700	34,095,300	10,904,400	59,138,700	4,022,300	1,454,200	3,936,700	1,348,700	3,830,600	5,300,500	135,235,500	269,511,600
2002	62,189,700	58,854,700	138,164,900	183,319,700	30,503,100	6,038,600	8,708,400	6,717,100	3,744,100	5,120,700	3,486,200	1,320,200	508,167,400
2003	16,264,300	49,909,200	39,240,400	110,260,800	21,051,300	7,581,600	4,329,300	6,132,000	4,632,600	3,066,400	5,520,500	9,181,400	277,169,800
2004	44,042,300	78,851,900	176,978,900	71,407,900	25,399,400	10,823,800	4,597,900	5,673,300	2,463,400	2,361,600	3,868,600	8,118,700	134,587,700
2005	8,272,800	16,647,100	130,214,900	131,680,300	38,142,400	15,488,000	7,019,200	7,061,366	2,481,691	6,305,466	8,357,800	6,593,100	378,264,123
2006	7,321,400	17,314,200	88,564,600	39,621,570	17,088,700	5,250,600	6,022,000	5,923,200	5,631,600	5,427,300	6,392,800	2,607,540	207,165,510
2007	6,795,700	13,981,600	40,551,700	23,258,000	13,169,890	6,738,300	4,403,300	4,104,785	1,823,700	1,794,500	1,994,500	40,165,000	158,780,975
2008	5,037,000	4,346,100	100,122,000	47,550,650	8,568,847	5,755,093	1,641,185	882,486	5,875,002	9,627,710	7,571,598	3,971,000	200,948,671
2009	49,013,500	108,581,500	130,719,000	174,982,500	70,587,600	6,112,300	2,736,150	2,173,600	1,174,900	1,980,000	6,913,850	71,481,200	627,056,100
2010	61,000,200	260,869,515	116,521,189	52,735,298	10,205,459	9,844,927	4,447,361	1,805,975	998,602	20,517,409	10,752,064	88,358,834	638,059,813
2011	40,953,500	21,847,511	71,552,488	95,846,316	39,296,842	29,381,309	4,149,205	2,147,980	1,045,532	5,314,642	6,173,052	6,502,817	324,211,194
2012	20,935,029	8,738,222	144,097,646	249,098,093	22,072,9218	7,403,517	2,291,081	2,013,400	2,363,149	4,046,656	6,065,353	16,889,641	486,014,705
2013	50,854,894	48,227,816	120,007,849	98,670,882	15,710,932	4,468,097	3,253,383	3,540,903	4,315,848	6,901,410	7,374,047	8,735,656	372,070,717
2014	8,962,115	8,955,115	36,998,913	10,177,000	51,460,235	52,650,688	11,856,056	10,125,428	8,775,215	11,311,596	9,742,572	49,322,093	270,337,026
2015	55,704,785	79,576,529	123,723,991	87,329,304	33,372,378	75,999,633	16,492,149	6,688,293	5,564,554	5,077,598	4,299,672	6,423,170	500,252,056
2016	57,674,967	124,340,672	85,044,940	29,568,730	27,929,137	10,785,605	3,695,697	4,295,736	3,349,761	2,688,231	5,369,698	14,352,031	369,095,205
2017	15,235,422	9,360,716	98,815,458	59,011,215	36,862,762	73,102,607	16,806,958	5,308,978	6,106,151	19,261,694	20,030,306	23,287,141	383,189,314
2018	40,481,595	60,173,654	145,433,997	27,480,409	29,706,200	20,541,812	5,696,182	6,403,330	3,152,609	6,509,941	675,034		346,254,763

According to ASKI data, the amount of water coming to the dams in Ankara by months and the comparison between the two years is given in Figures 2.2, 2.3, 2.4, 2.5, 2.6, 2.7 and 2.8.

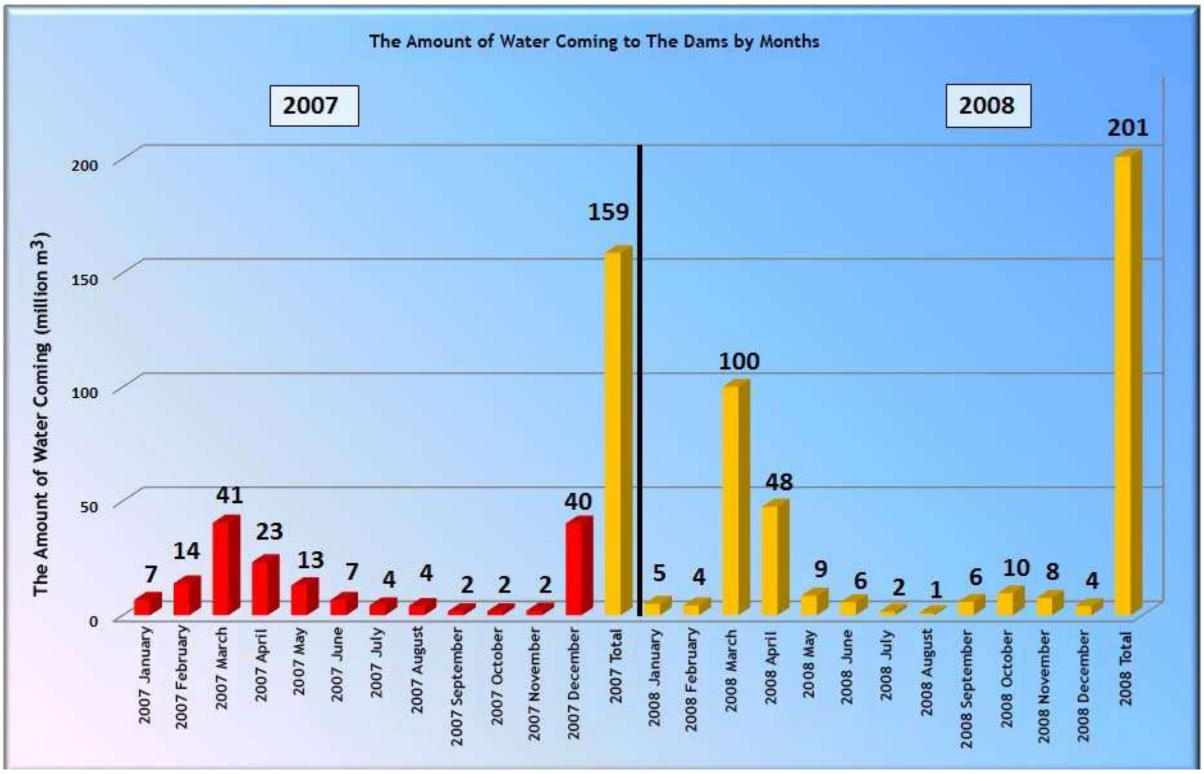


Figure 2.2: The amount of water coming to the dams in Ankara by months and in the comparison between 2007 and 2008

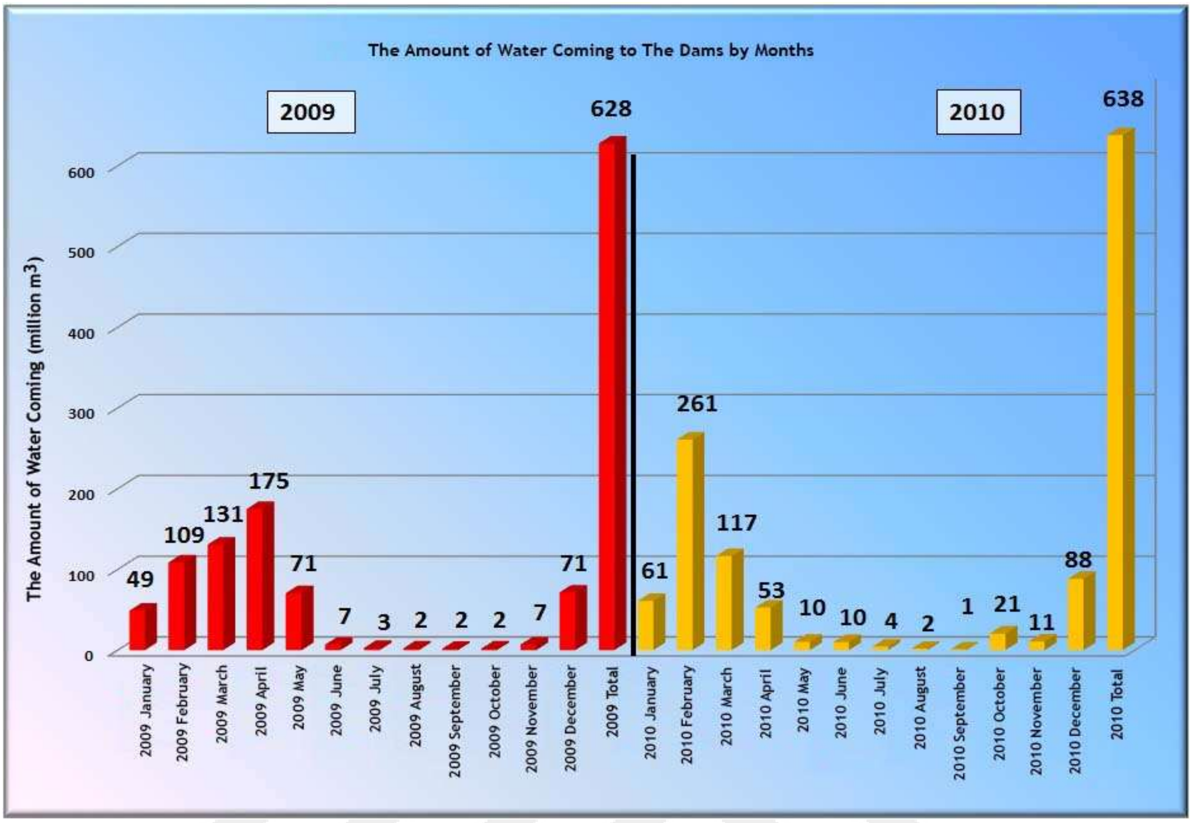


Figure 2.3: The amount of water coming to the dams in Ankara by months and in the comparison between 2009 and 2010

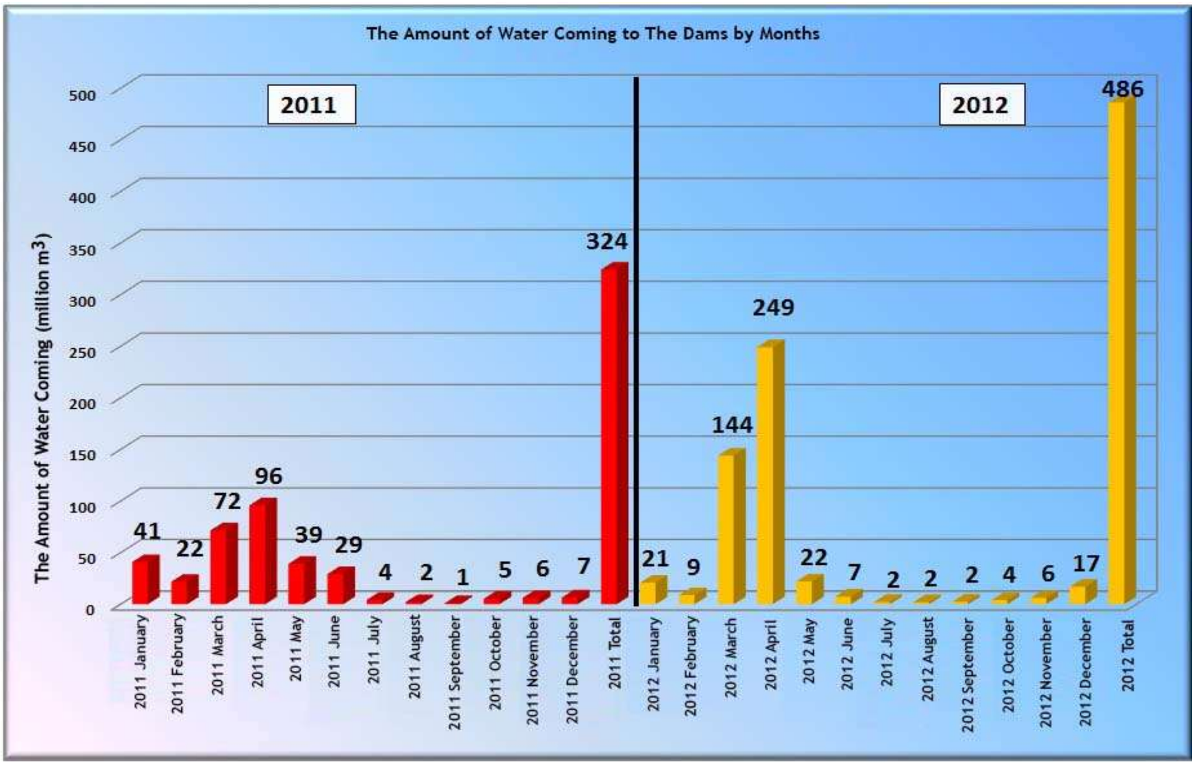


Figure 2.4: The amount of water coming to the dams in Ankara by months and in the comparison between 2011 and 2012

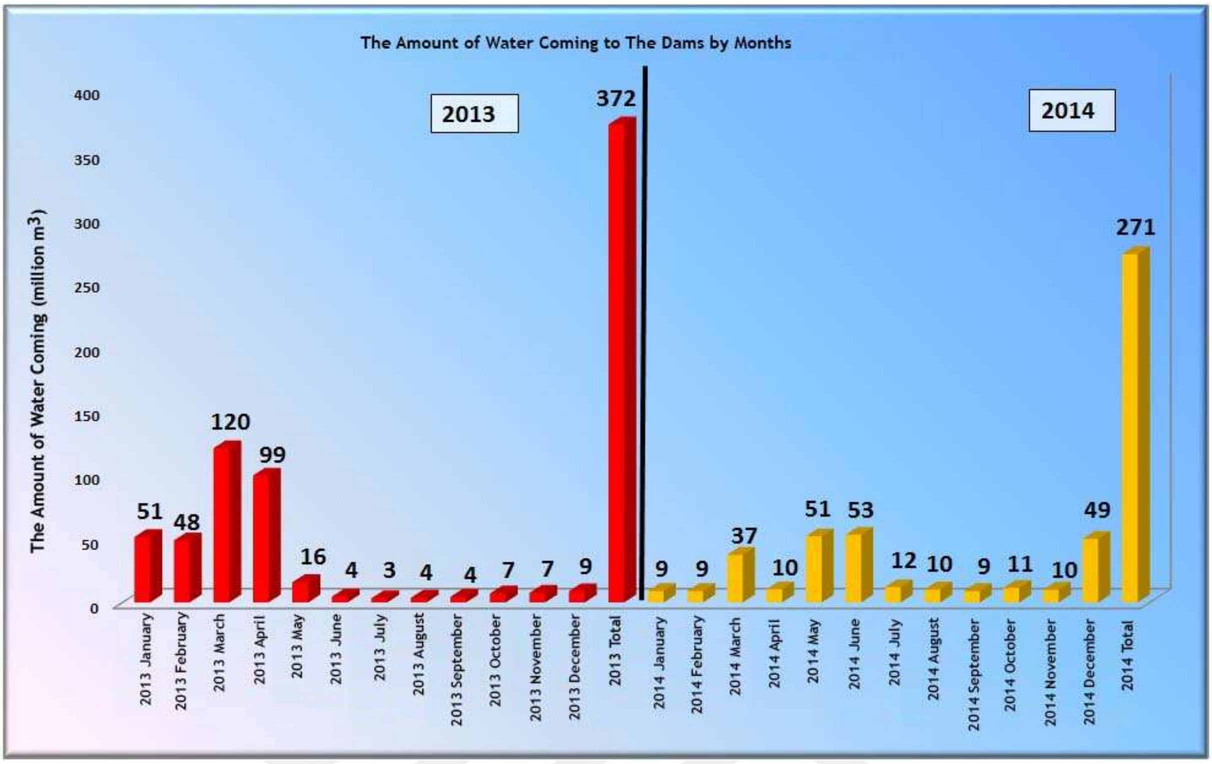


Figure 2.5: The amount of water coming to the dams in Ankara by months and in the comparison between 2013 and 2014

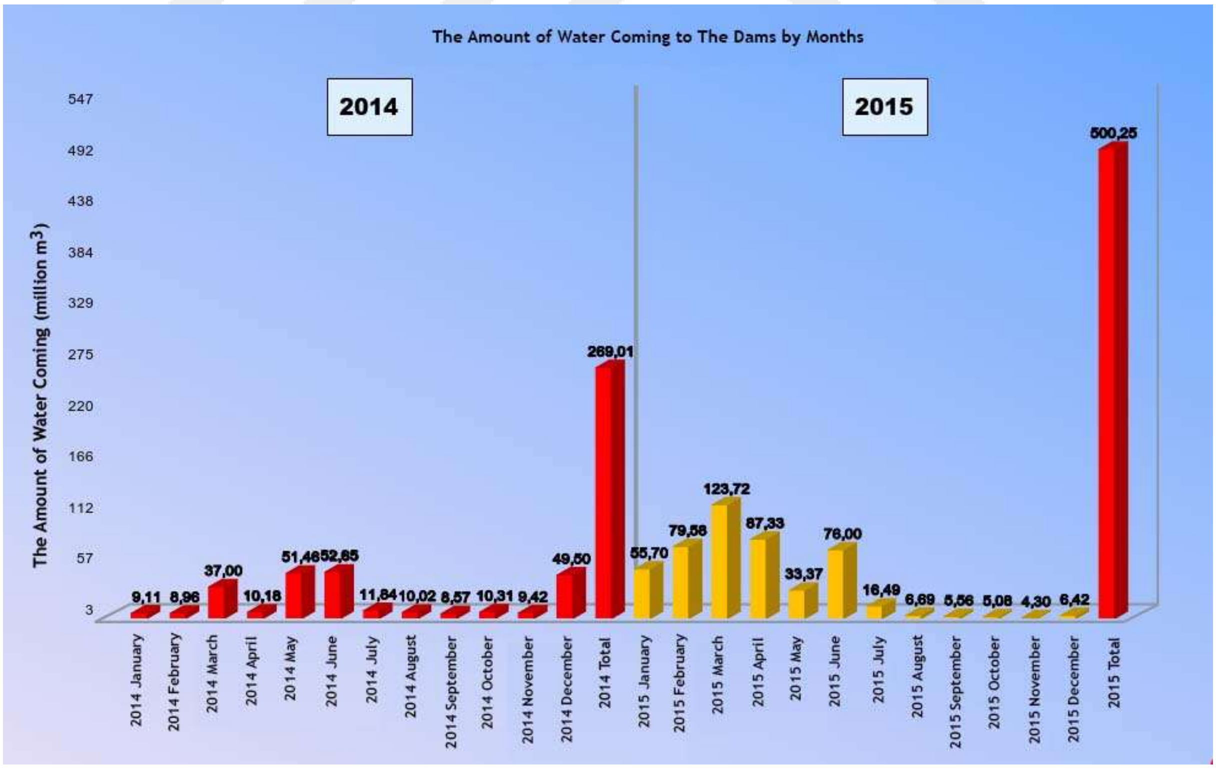


Figure 2.6: The amount of water coming to the dams in Ankara by months and in the comparison between 2014 and 2015

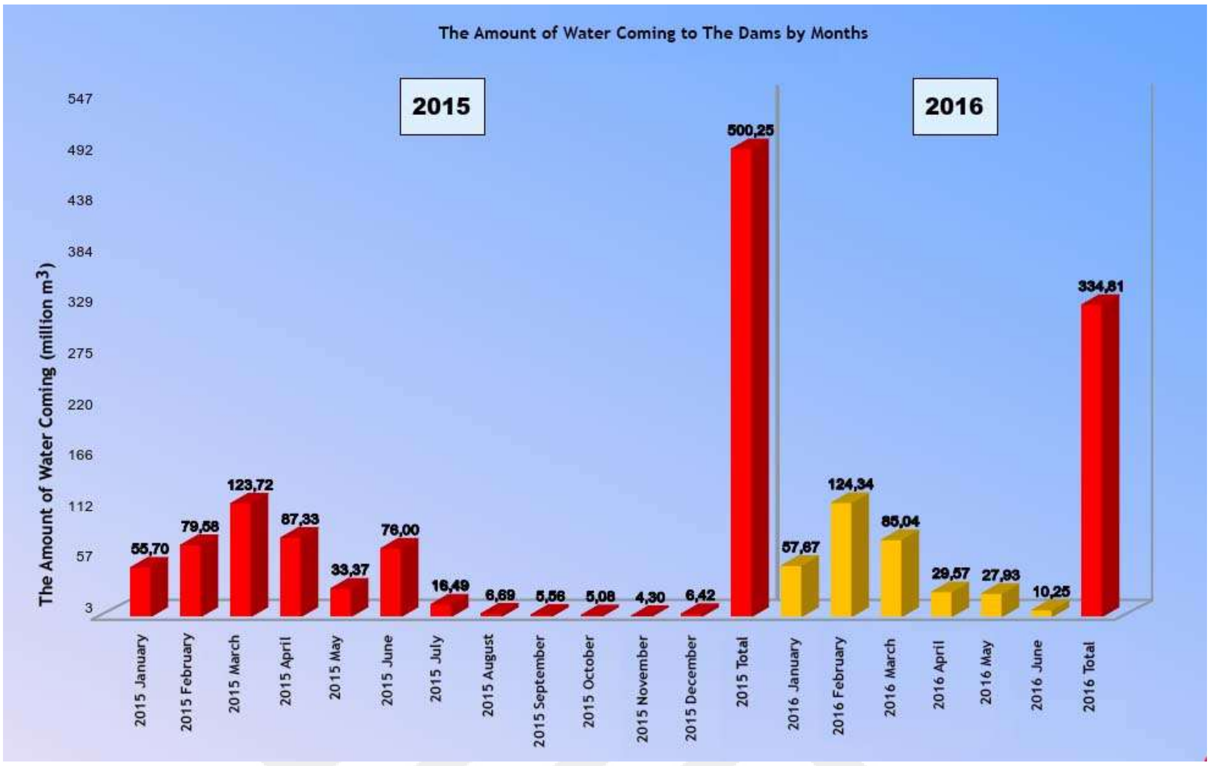


Figure 2.7: The amount of water coming to the dams in Ankara by months and in the comparison between 2015 and 2016

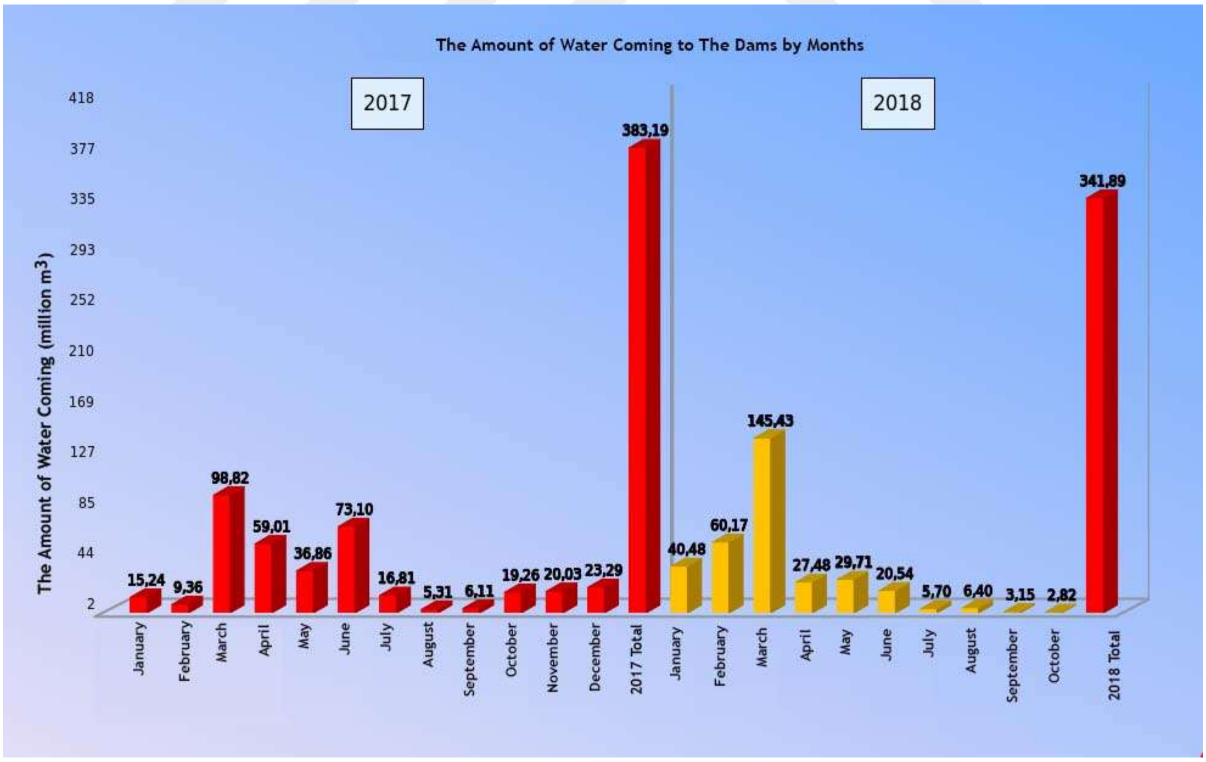


Figure 2.8: The amount of water coming to the dams in Ankara by months and in the comparison between 2017 and 2018

In this study, we will use data of Ivedik Water Treatment Plant provide water for approximately 90% of Ankara and data of dams supply to the plants which are Çamlıdere, Kurtboğazı and Kesikköprü at the model that will be generated according to centre of Ankara.

2.2.2. Model Formulation and Model Development

With the aim of capturing the core of Ankara's water sector, a system dynamics model has been built. System Dynamics approach remains really proper considering any progressive organization identified by interdependence, interactions that are reciprocal, info feedback along with circular causality. SD is a distinguished element for studying issues which emanates within closed-loop systems. On grounds that Ankara's water resources system can be seen as highly integrated, using SD to obtain interdependence and feedback between different sub-systems is fitting around a good place. Likewise, most applicable data sources necessary for model developing exist readily available and are received from ASKI. Such rational data have fundamentally increased model's validity. Therefore, we can say that SD is a powerful technique to analyse the water resource system of Ankara. The System Dynamics approach is an approach that can be used very efficiently to analyse problems and processes that occur in closed loop systems. SD approach is suitable for any dynamic system characterized by interdependence, mutual interaction, information feedback, and circular causality (Mavrommati et al., 2013). Since Ankara's water resources system is quite dispersed and combined, the power of System Dynamics to analyse interdependencies and feedback among the various subsystems can be used effectively. In addition, the data required to create the model is provided by ASKI. In this way, we can say that the data came from a secure source. The reliability of the data also ensures the validity and accuracy of the model. For this reason, we can say that the System Dynamics approach is an important approach in analysing Ankara's water resources system.

The model is sourced from a demand and supply framework according to demand for water and water supply from water resources. On the demand part, population level and the economic and industrial situation are milestones that determines demand level for water. When we think about the strategical and geographic situation of Ankara as the capital city of Turkey, we can easily say that the population level is high and because of the industrial needs, the water demand is in the tremendous level. On the supply side, water treatment plants such as Ivedik, Pursaklar, Kazan, Çubuk, Polatlı, Şereflikoçhisar and refinements of wastewater treatment plants of

Ankara are diversified. The casual loop diagram in the figure demonstrates the key elements of the system such as capacity of refinement plants, precipitation processes, water in dams, and capacity of dams, water supply and water demand in total, adequacy index.

We identified adequacy indicates total water supply should be balanced or higher than total water demand. The exact and main aim pursues that capacity indicator needs to be greater than one. The model we have created using System Dynamics approach illustrates basically the relationship between supply and demand. In the demand section, the level of population is determined as total demand-setting parameters. On the supply side, the waters accumulated from the dams and Ankara provide water for the consumption of Ankara. These key factors are schematized in Figure 2.10 by a Casual Loop Diagram (CLD). In a modern and developed capital city like Ankara, the quality of water supply must be carefully monitored and very careful work on sustainable water management should be undertaken.

Adequacy index: water sufficiency in sustainable water management in Ankara, sufficiency of water obtained for Ankara and sustainability of the model's economic model. In the case of adequate water, the total amount of water already squeezed out should be equal to or greater than total water demand. To capture demand and supply factors, the Casual Loop Diagram (CLD) data must be equal or greater for Ankara to be able to claim its self-sufficiency in water.

Adequacy is calculated by dividing ‘Total Water Supply’ at a specific time expressed with ‘t’ to ‘Total Water Demand’ at a specific time expressed with ‘t’. Adequacy is calculated by using the formula of:

$$Adequacy = \frac{Total\ Water\ Supply_{(t)}}{Total\ Water\ Demand_{(t)}} \tag{3.1}$$

From the casual loop diagram of Ankara in Figure 2.9, a Stock and Flow Diagram was created regarding Ankara water system. The figure demonstrates essential stocks and flows. After comparing the full stocks and flow diagrams with ASKI's system descriptions and data, it is concluded System Dynamics model in fact catches the essential tools of Ankara's integrated water system.

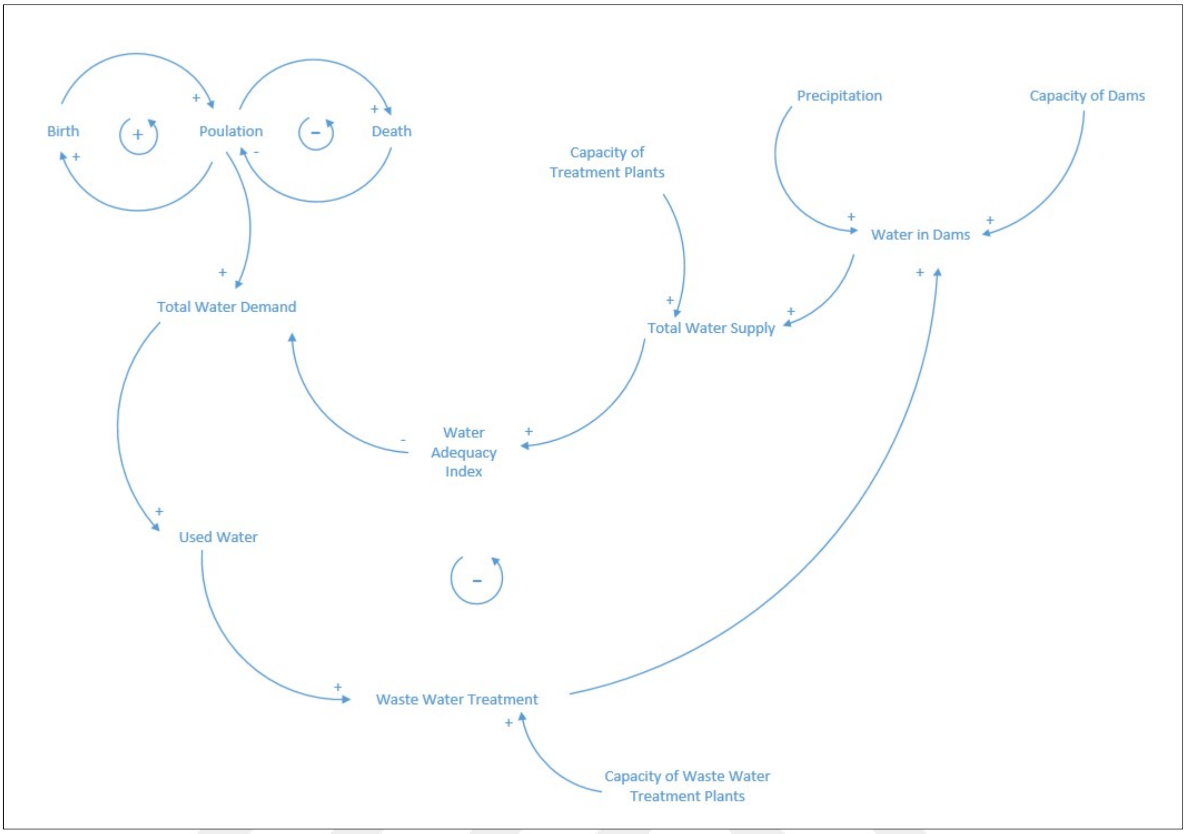


Figure 2.9: Casual loop diagram of Ankara Water System

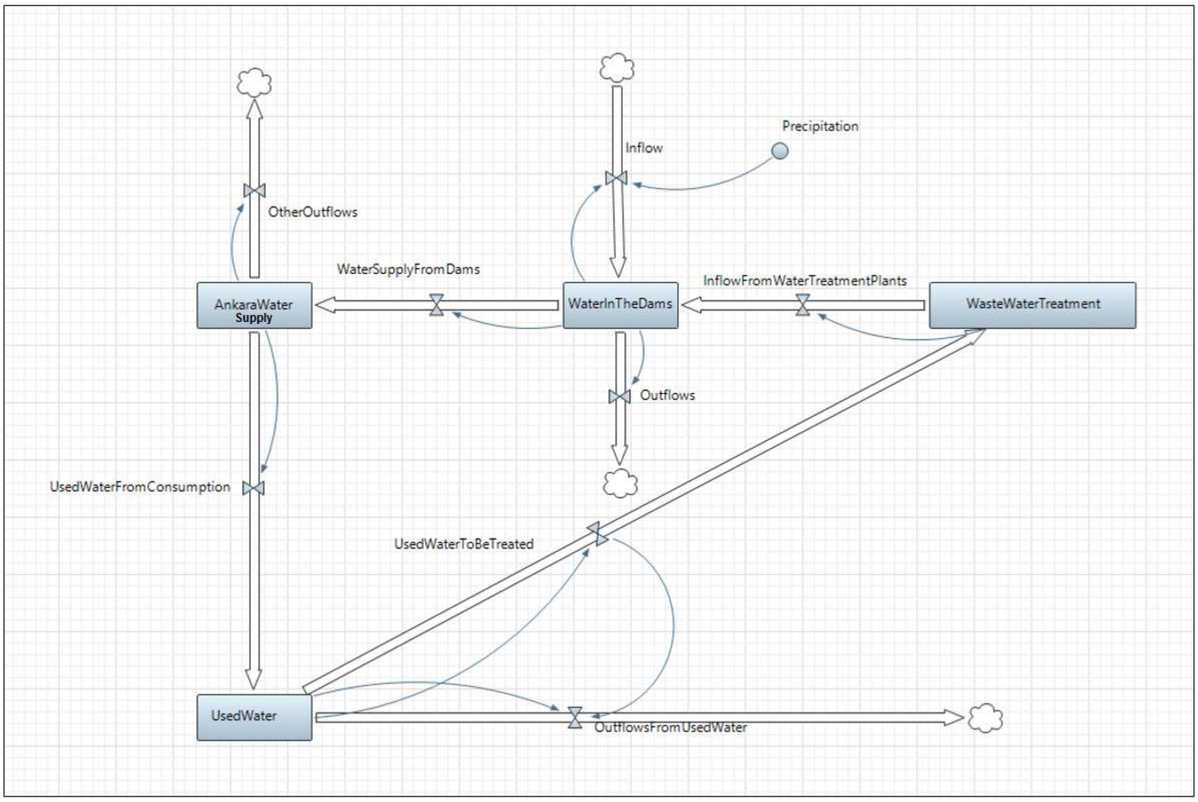


Figure 2.10: Key stocks and flows in Ankara Water System

Due to limited information and system uncertainties in the water system, assumptions should be made using the system dynamics approach during the modelling process. The first assumption is if water is inadequate, then not only private sector but also public sector will begin investing in water sector only, and that they will not struggle to make the water available. This is logical, because it is clear that a small amount of investment in major sectors and resources will be required to obtain a higher qualification index.

While producing the System Dynamics model for Ankara, it is also necessary to discuss the change in Ankara population and its population. We assessed the similarities and differences between model calibration, observation, and simulated behaviours in terms of population. Population growth and decline are significant variables which fundamentally influence future population level, hence future water demand, as well. From 2000 to 2017, periodic Ankara population data is given in Table 2.5 and periodic migration data is given Table 2.6.

Table 2.5: Population of provinces by years, 2000-2017 (TUIK)

Population of provinces by years, 2000-2017

Year	Population
2000	3,890,000
2001	3,970,000
2002	4,050,000
2003	4,130,000
2004	4,210,000
2005	4,290,000
2006	4,380,000
2007	4,470,000
2008	4,550,000
2009	4,650,000
2010	4,770,000
2011	4,890,000
2012	4,970,000
2013	5,050,000
2014	5,150,000
2015	5,270,000
2016	5,350,000
2017	5,450,000

Table 2.6: Provincial in-migration, out-migration, net migration, rate of net migration, 1980-2017 (TUIK)

Provincial in-migration, out-migration, net migration, rate of net migration, 1980-2017

Period	Province	Total population	In-migration	Out-migration	Net migration	Rate of net migration **(‰)**
		Address Based Population Registration System				
2016-2017	Ankara	5,445,026	188,100	156,058	32,042	5.9
2015-2016	Ankara	5,346,518	177,166	159,915	17,251	3.2
2014-2015	Ankara	5,270,575	204,048	153,001	51,047	9.7
2013-2014	Ankara	5,150,072	203,621	163,612	40,009	7.8
2012-2013	Ankara	5,045,083	186,642	153,791	32,851	6.5
2011-2012	Ankara	4,965,542	160,235	137,834	22,401	4.5
2010-2011	Ankara	4,890,893	191,864	137,385	54,479	11.2
2009-2010	Ankara	4,771,716	182,845	133,440	49,405	10.4
2008-2009	Ankara	4,650,802	168,193	131,114	37,079	8.0
2007-2008	Ankara	4,548,939	156,760	126,198	30,562	6.7
1995-2000	Ankara	3,597,662	377,108	286,224	90,884	25.6
1985-1990	Ankara	2,825,967	326,301	256,790	69,511	24.9
1980-1985	Ankara	2,843,732	257,516	220,885	36,631	13.0
1975-1980	Ankara	2,423,789	253,407	203,908	49,499	20.6

Most of the data were obtained from ASKI and TUIK. On the basis of these data, some parameters were mentioned with distribution, when the data sets have been examined. Parameters of “Precipitation”, “Consumption Per Capita Per Year”, “Net Immigration Rate” fit into normal distribution as shown in Appendix 3. Using the data from ASKI and the data of population and migration, the SD model has been run with AnyLogic 8.3.2 University Edition. All the SD model input data, formulae, parameters, and detailed explanations are mentioned in Appendix 2.

The model also has been run with three different population scenarios as mentioned in Chapter 2.1. Firstly, the model has been run considering the scenario 1. In the scenario 1, the birth rate is 17.8 per thousand. Secondly, the scenario 2 which has the birth rate is 21.1 per thousand was used to run the model. At last, the model has been run according to the scenario 3. The birth rate is 15.3 per thousand in the scenario 3. The same migration data were used in every three scenarios as stated in Chapter 2.1.(TUIK, 2018).

3. RESULTS

In this study, we aimed to model the water of Ankara and forecast the water sustainability of Ankara for 50 years. The model started from 01.01.2017 and finished in 01.01.2067. The system dynamics model is given in the Figure 3.1 below.

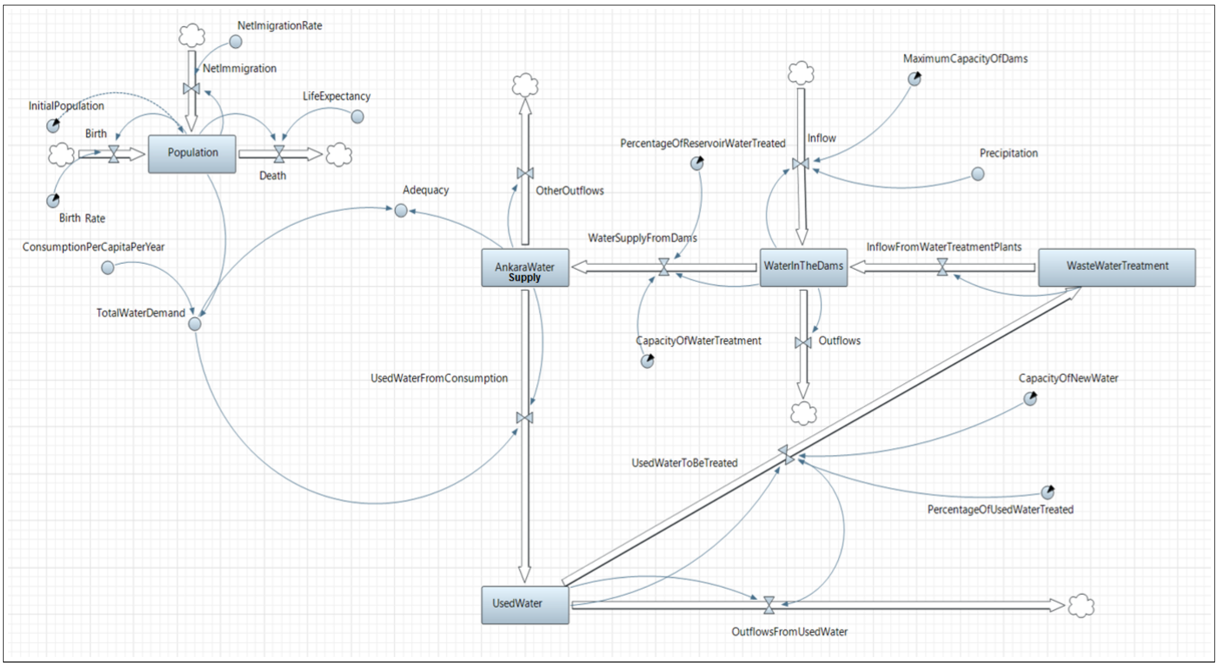


Figure 3.1: The system dynamics model for the Ankara Water System

3.1. SD MODEL RESULTS UNDER THE SCENARIO 1

In this scenario, the birth rate is 17.8 per thousand. The population graphic for 50 years is given in Figure 3.2. After 50 years, the population will reach about 13 million people. The comparison graphic for Total Water Demand and Ankara Water Supply is given in Figure 3.3. Water Adequacy Index also has been shown in Figure 3.4. At last, simulation output after the model has been run is given Appendix 1.

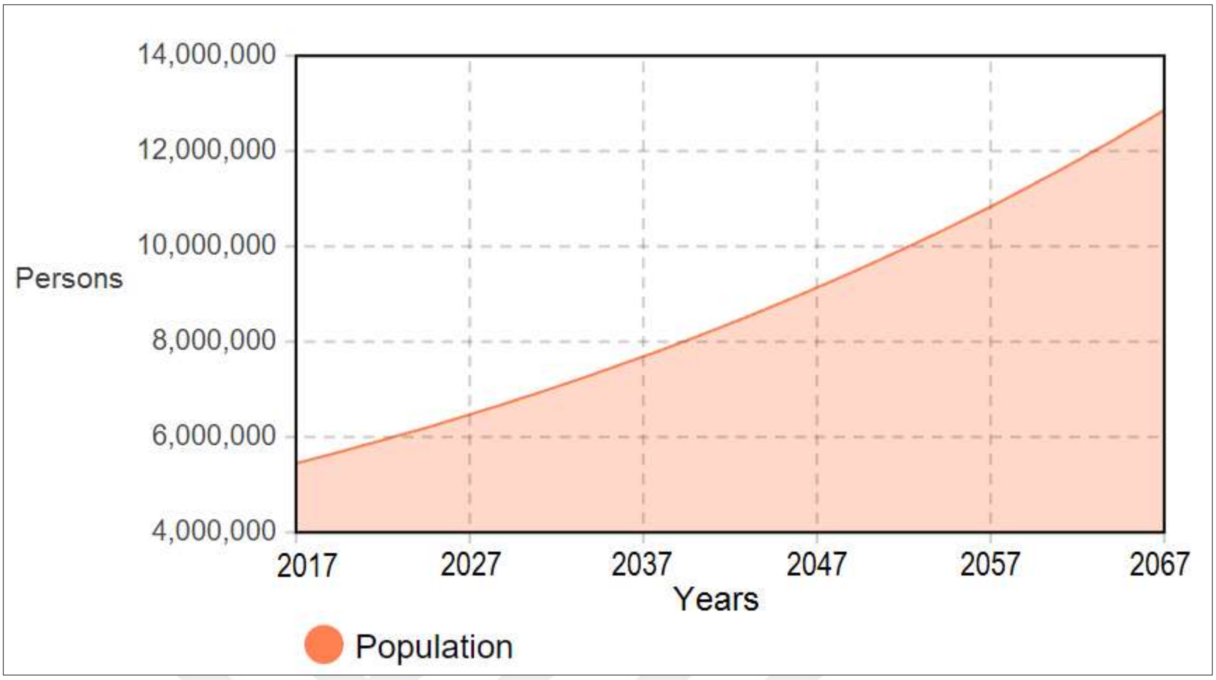


Figure 3.2: The population graphic for results of the scenario 1 (AnyLogic)

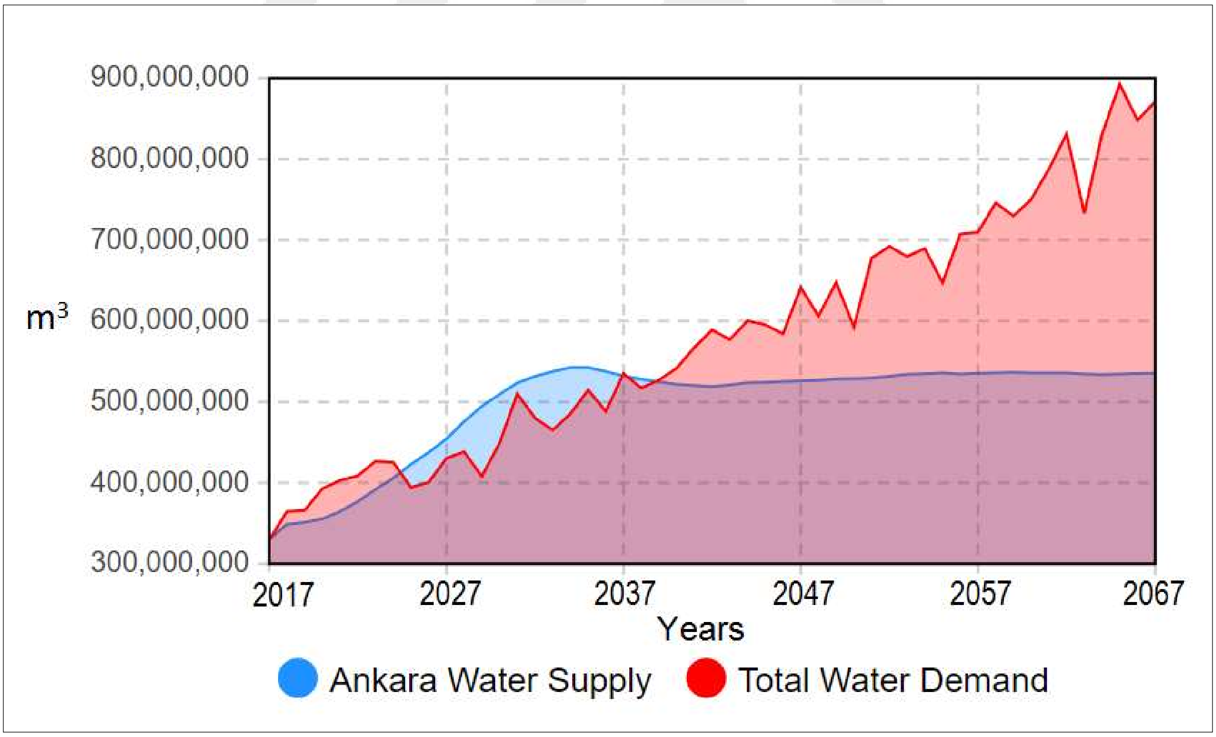


Figure 3.3: The comparison graphic for Total Water Demand and Ankara Water Supply for results of the scenario 1 (AnyLogic)

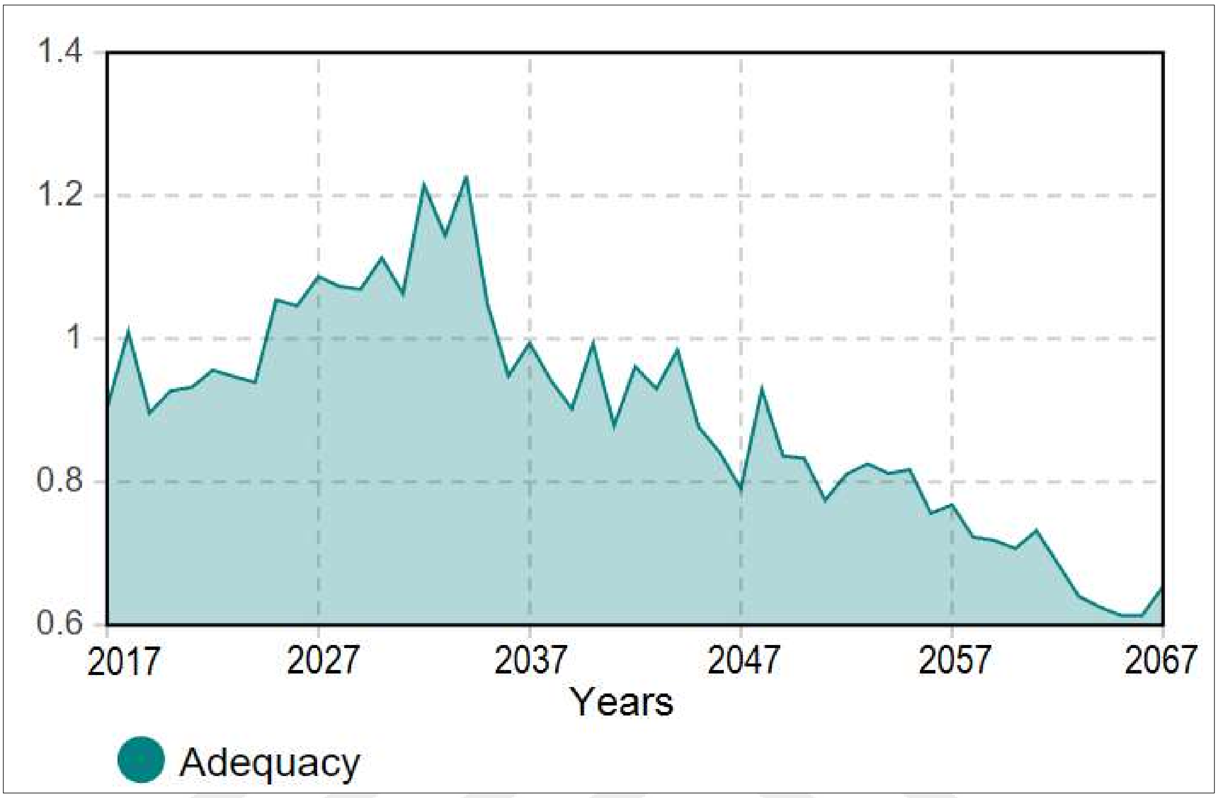


Figure 3.4: The Adequacy index graphic for results of the scenario 1 (AnyLogic)

According to the simulation result of the scenario 1, the expected population of Ankara, the amount of Ankara water supply, the adequacy index of Ankara, the amount of total water demand, the amount of used water at the end of the process of 50 years are given in the Table 3.1 below and in the Figure 3.5.

Table 3.1: The resulting table of the scenario 1

Years	**The Expected Population Of Ankara**	**Total Water Demand In Ankara (m3)**	**The Adequacy Index**	**Ankara Water Supply (m3)**	**The Amount Of Used Water (m3)**
2017	$5.45x10^6$	$3.90x10^8$	0.926	$3,61x10^8$	$2,17x10^8$
2027	$6.47x10^6$	$4.25x10^8$	1.120	$4,76x10^8$	$4,20x10^8$
2037	$7.69x10^6$	$5.39x10^8$	0.987	$5,32x10^8$	$5,02x10^8$
2047	$9.13x10^6$	$6.21x10^8$	0.847	$5,26x10^8$	$5,25x10^8$
2057	$1.08x10^7$	$6.97x10^8$	0.769	$5,35x10^8$	$5,35x10^8$
2067	$1.29x10^7$	$8.85x10^8$	0.605	$5,35x10^8$	$5,35x10^8$

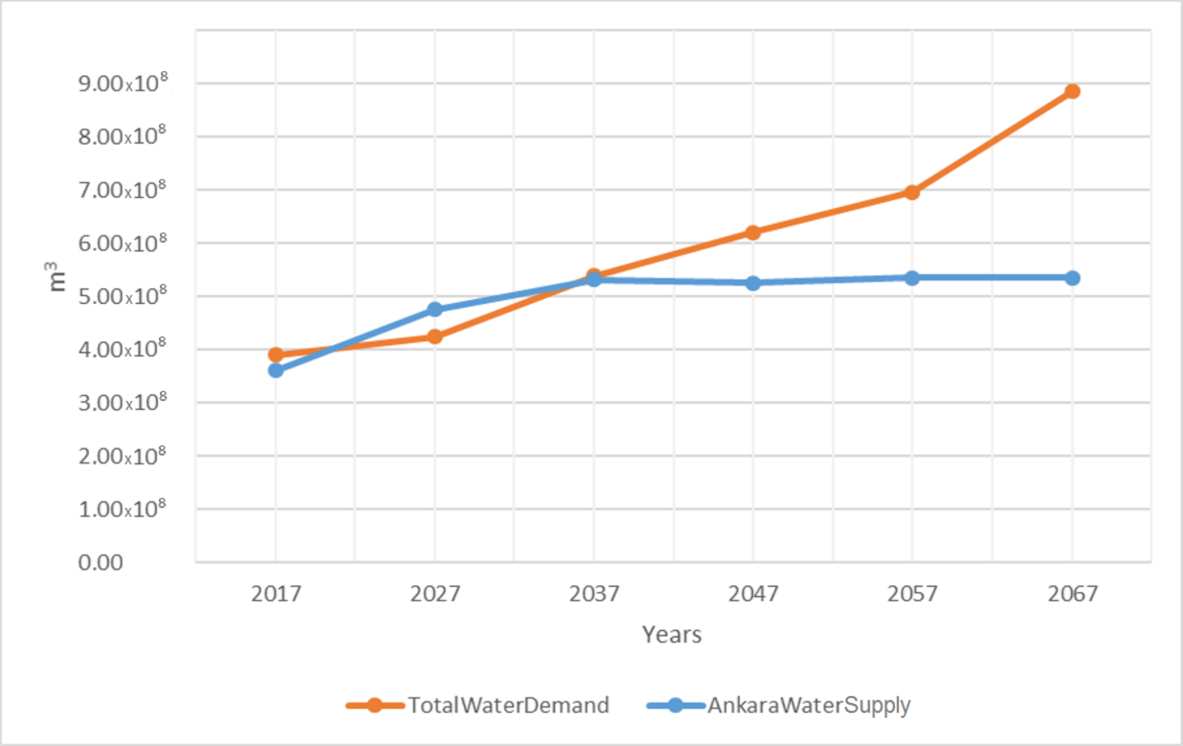


Figure 3.5: The comparison graphic for Total Water Demand and Ankara Water Supply for results of the scenario 1

3.2. SD MODEL RESULTS UNDER THE SCENARIO 2

In the scenario 2, the birth rate is 21.1 per thousand. The population graphic for 50 years is given in Figure 3.6. After 50 years, the population will reach about 15 million people. The comparison graphic Total Water Demand and the Ankara Water Supply is given in Figure 3.7. Water Adequacy Index also has been shown in Figure 3.8.

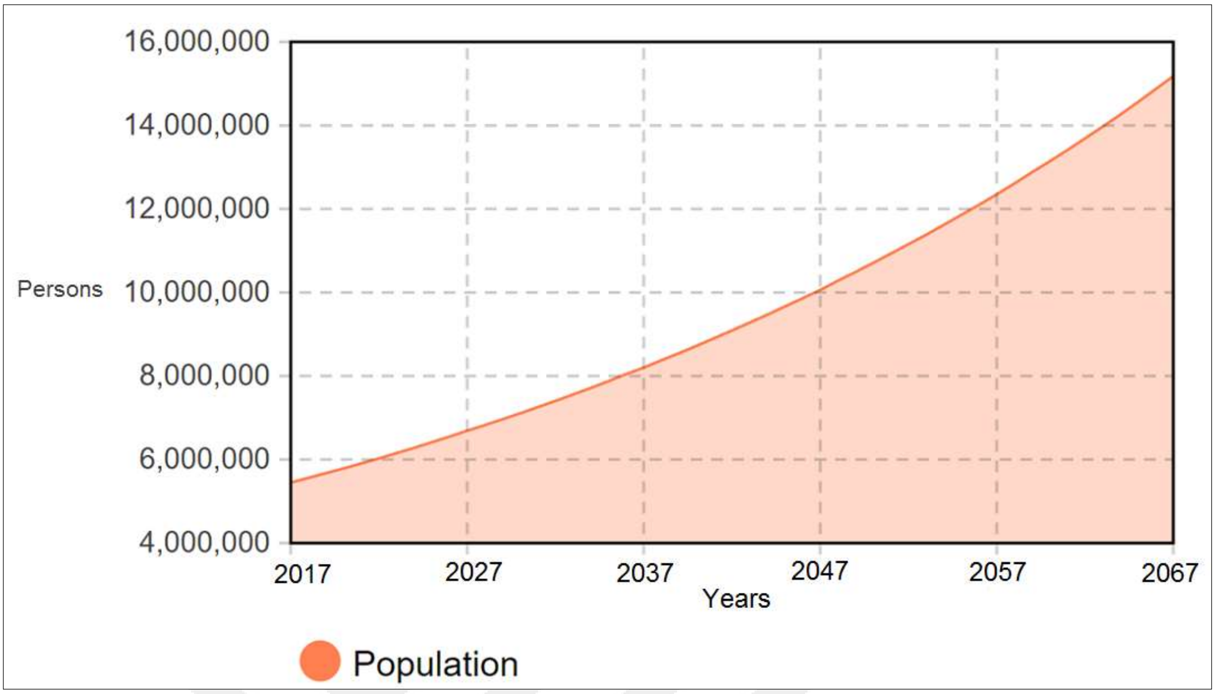


Figure 3.6: The population graphic for results of the scenario 2 (AnyLogic)

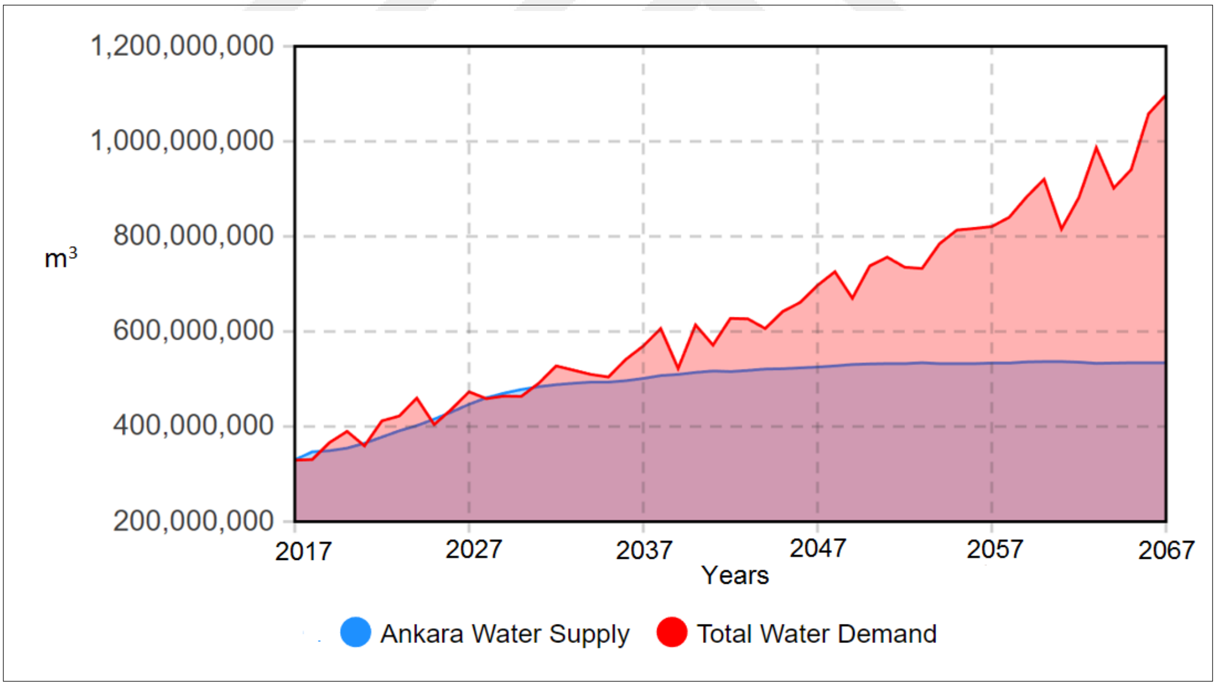


Figure 3.7: The comparison graphic for Total Water Demand and Ankara Water Supply for results of the scenario 2 (AnyLogic)

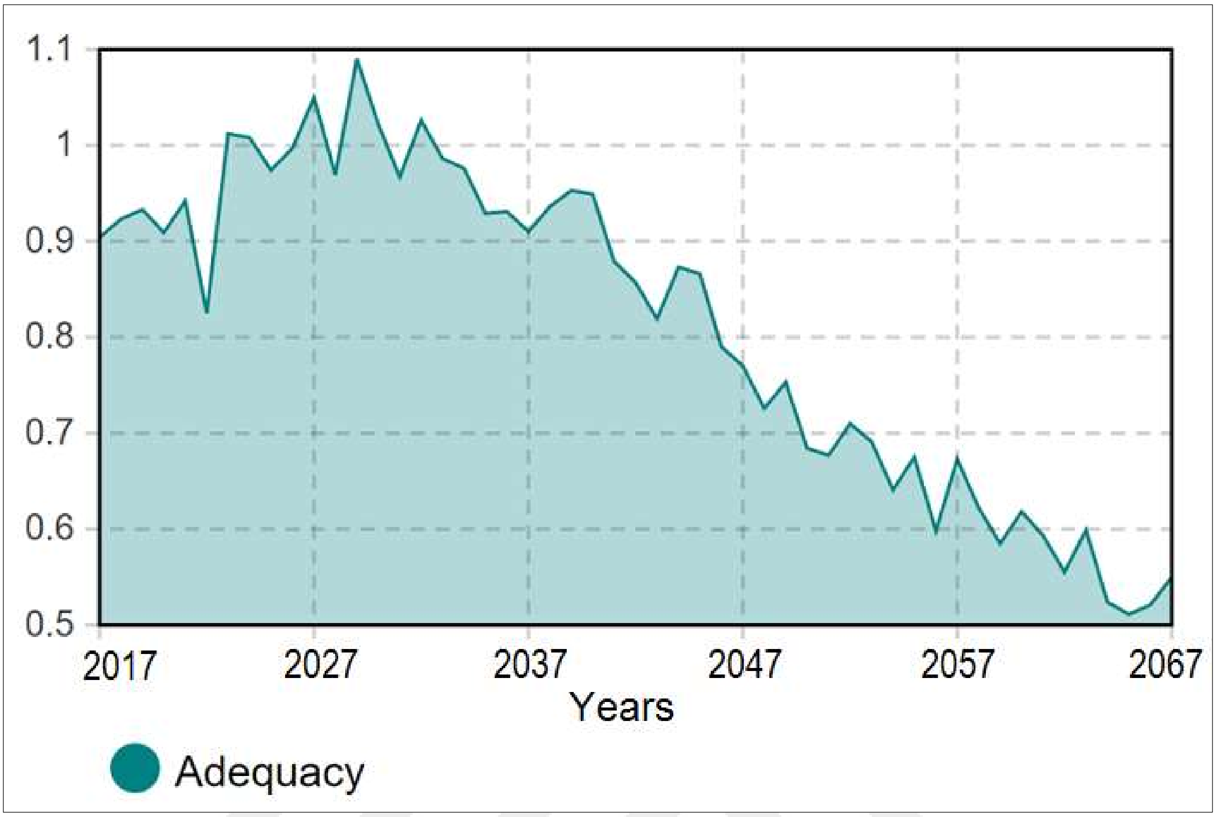


Figure 3.8: The Adequacy index graphic for results of the scenario 2 (AnyLogic)

According to the simulation result of the scenario 2, the expected population of Ankara, the amount of Ankara water supply, the adequacy index of Ankara, the amount of total water demand, the amount of used water at the end of the process of 50 years are given in the Table 3.2 below and in the Figure 3.9.

Table 3.2: The resulting table of the scenario 2

Years	The Expected Population Of Ankara	Total Water Demand In Ankara (m3)	The Adequacy Index	Ankara Water Supply (m3)	The Amount Of Used Water (m3)
2017	$5.45x10^6$	$3.90x10^8$	0.923	$3.60x10^8$	$2.17x10^8$
2027	$6.69x10^6$	$4.44x10^8$	1.042	$4.51x10^8$	$4.32x10^8$
2037	$8.20x10^6$	$5.43x10^8$	0.918	$5.03x10^8$	$4.96x10^8$
2047	$1.01x10^7$	$6.64x10^8$	0.79	$5.25x10^8$	$5.24x10^8$
2057	$1.24x10^7$	$8.40x10^8$	0.636	$5.34x10^8$	$5.33x10^8$
2067	$1.52x10^7$	$1.02x10^9$	0.521	$5.34x10^8$	$5.35x10^8$

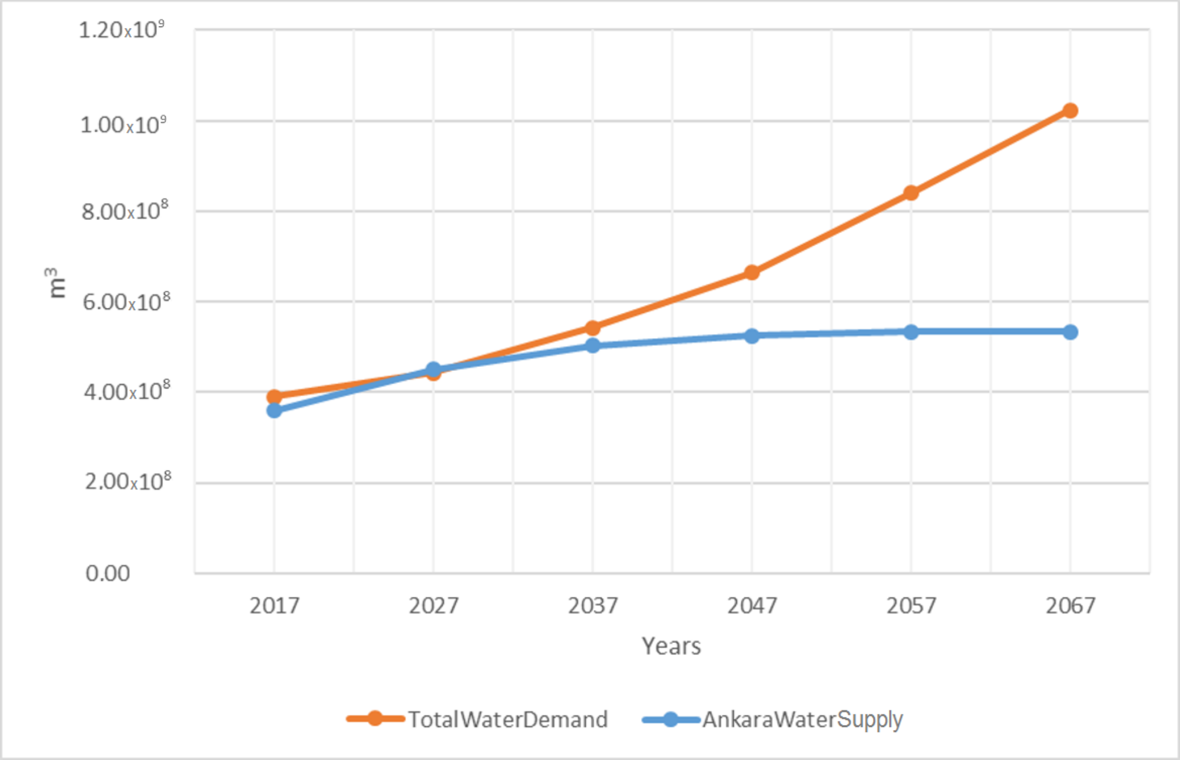


Figure 3.9: The comparison graphic for Total Water Demand and Ankara Water Supply for results of the scenario 2

3.3. SD MODEL RESULTS UNDER THE SCENARIO 3

In the scenario 3, the birth rate is 15.2 per thousand. The population graphic for 50 years is given in Figure 3.10. After 50 years, the population will reach about 11 million people. The comparison graphic Total Water Demand and the Ankara Water Supply is given in Figure 3.11. Water Adequacy Index also has been shown in Figure 3.12.

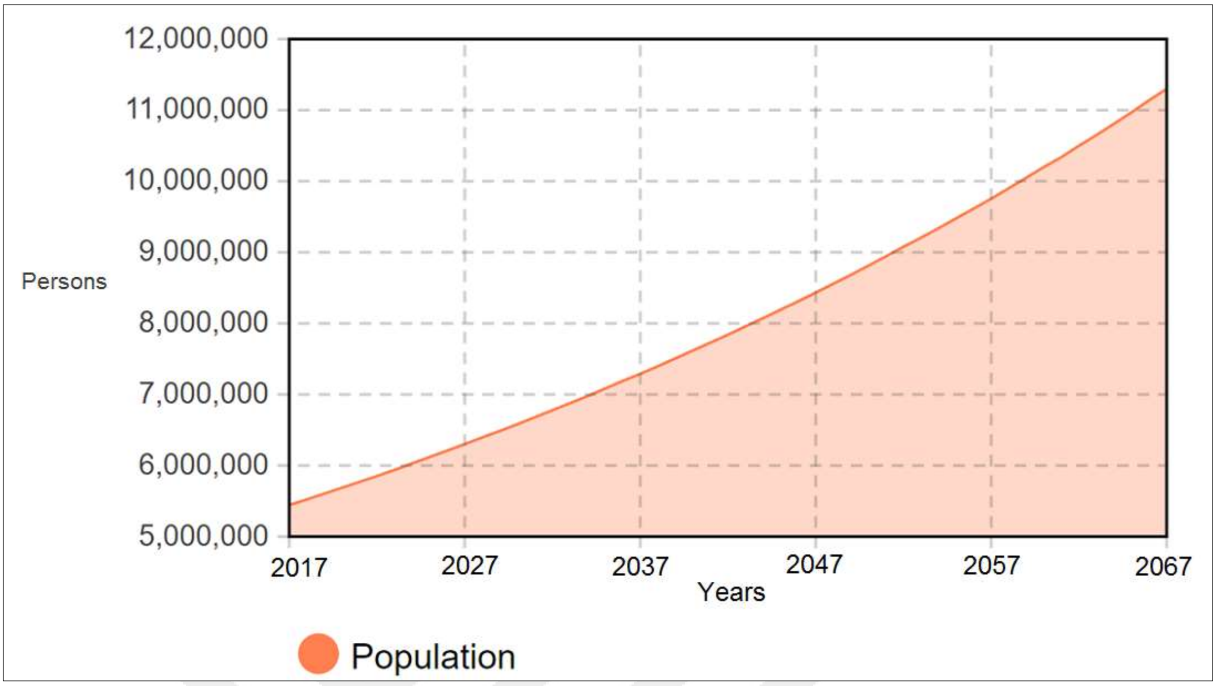


Figure 3.10: The population graphic for results of the scenario 3 (AnyLogic)

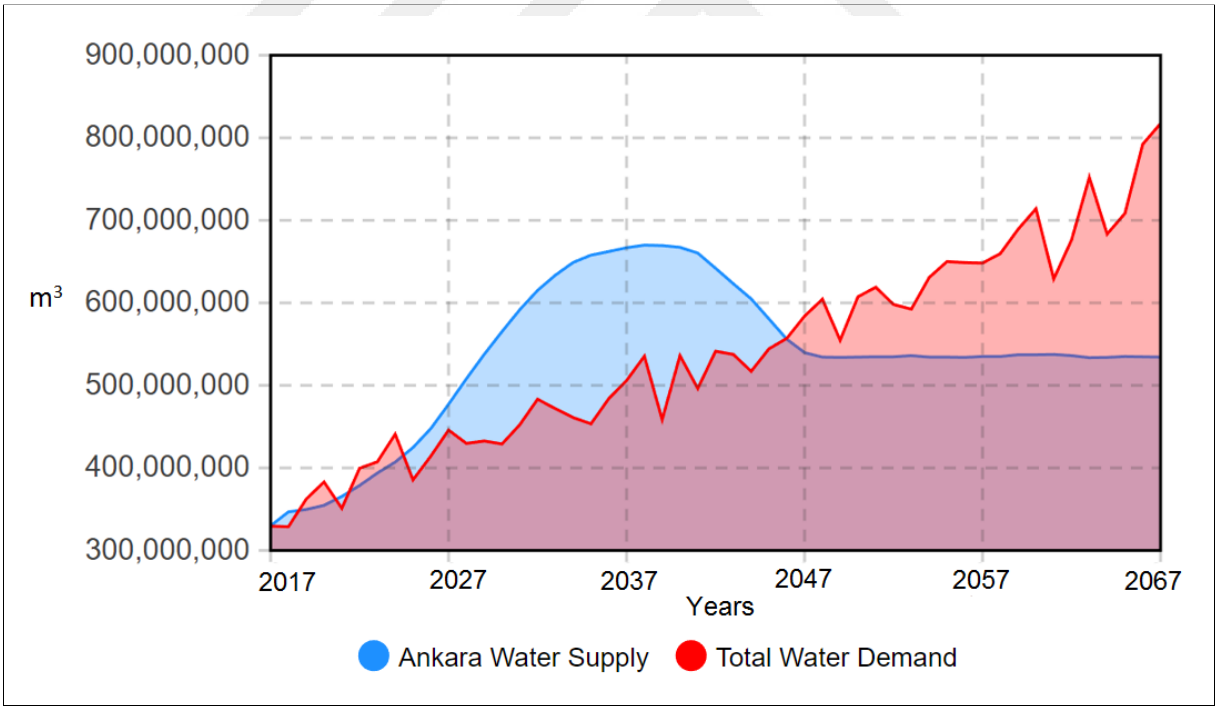


Figure 3.11: The comparison graphic for Total Water Demand and Ankara Water Supply for results of the scenario 3 (AnyLogic)

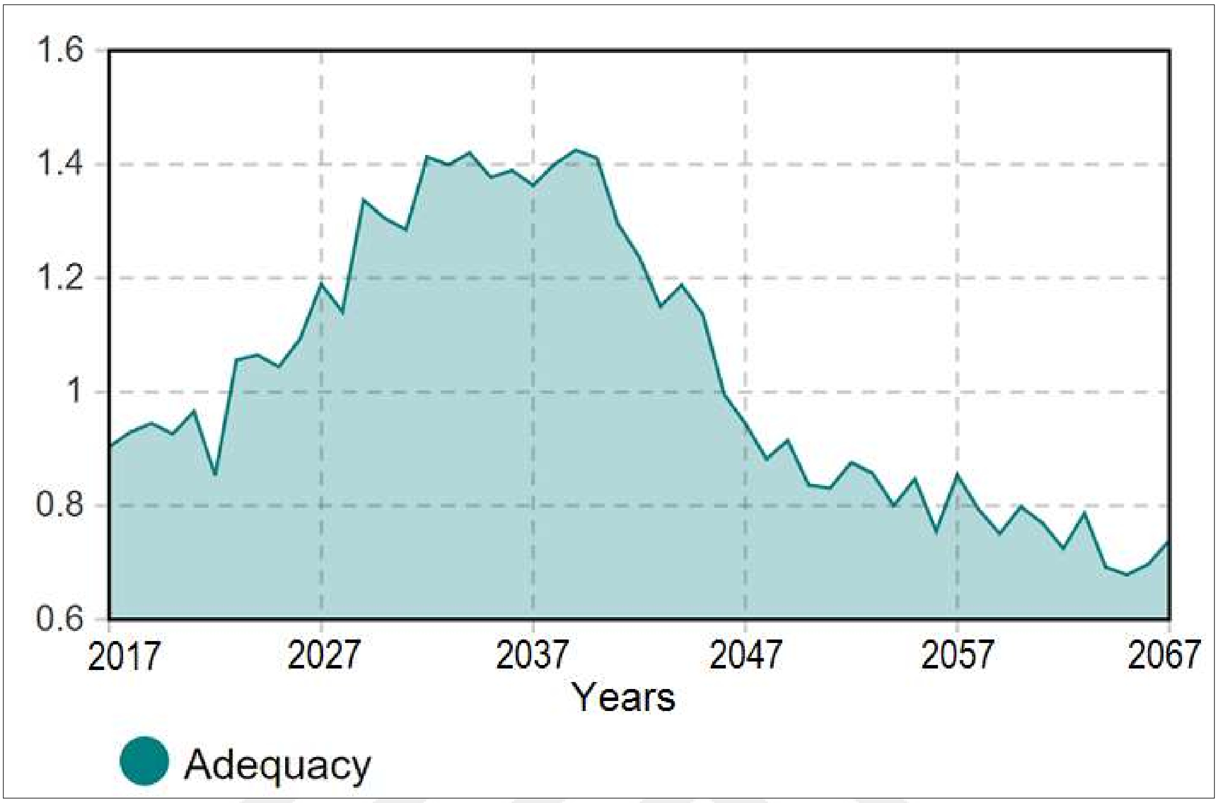


Figure 3.12: The Adequacy index graphic for results of the scenario 3 (AnyLogic)

According to the simulation result of the scenario 3, the expected population of Ankara, the amount of Ankara water supply, the adequacy index of Ankara, the amount of total water demand, the amount of used water at the end of the process of 50 years are given in the Table 3.3 below and in the Figure 3.13.

Table 3.3: The resulting table of the scenario 3

Years	The Expected Population Of Ankara	Total Water Demand In Ankara (m3)	The Adequacy Index	Ankara Water Supply (m3)	The Amount Of Used Water (m3)
2017	$5.45x10^6$	$3.90x10^8$	0.929	$3.62x10^8$	$2.16x10^8$
2027	$6.40x10^6$	$4.10x10^8$	1.237	$5.07x10^8$	$4.19x10^8$
2037	$7.29x10^6$	$4.87x10^8$	1.374	$6.70x10^8$	$4.87x10^8$
2047	$8.43x10^6$	$5.40x10^8$	0.999	$5.40x10^8$	$5.40x10^8$
2057	$9.75x10^6$	$6.42x10^8$	0.833	$5.35x10^8$	$5.34x10^8$
2067	$1.13x10^7$	$7.56x10^8$	0.707	$5.34x10^8$	$5.34x10^8$

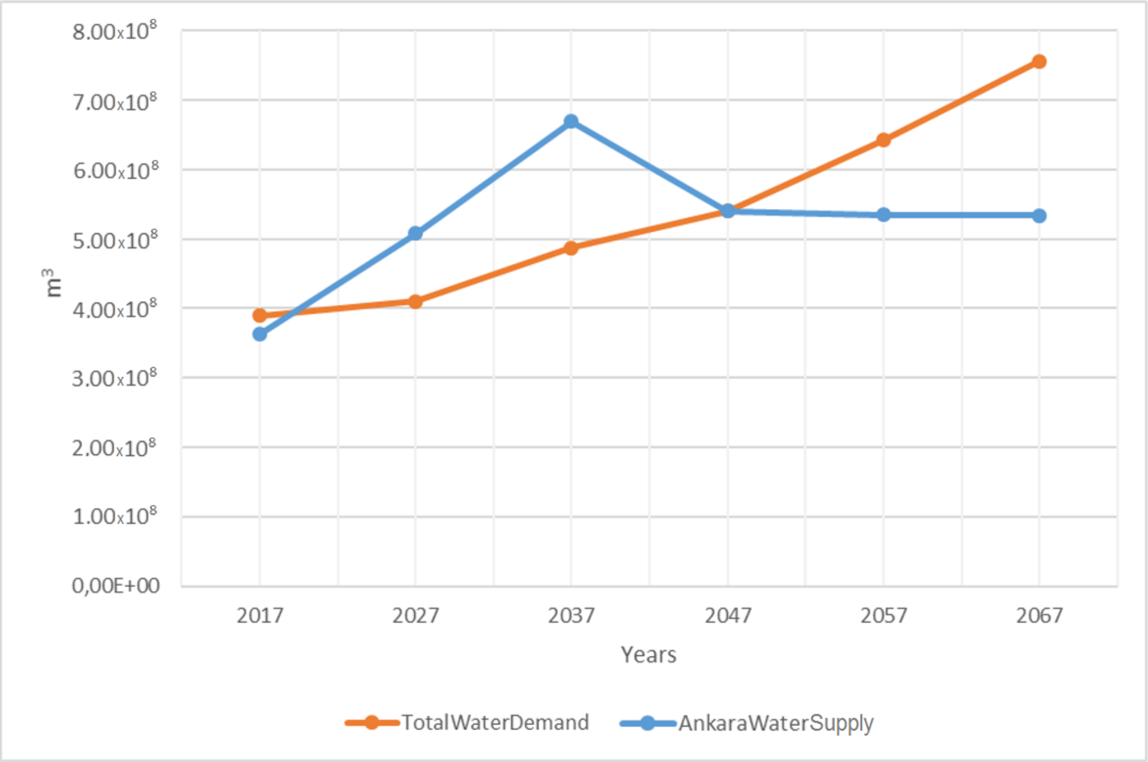


Figure 3.13: The comparison graphic for Total Water Demand and Ankara Water Supply for results of the scenario 3

4. DISCUSSION

According to the population of the scenario 1 which is Figure 3.2, we can say that the population of Ankara annually increases. It starts from around 5 million people to increases to around 13 million people within 50 years. It also explains to us that there is an increase in the total water demand annually while the population increases in Ankara within 50 years. Also, in the scenario 2, and in the scenario 3, an increase in the population is observed. However, there is a difference in the rate of increase. While the population reaches from 5 million people to 15 million people in the scenario 2, it reaches from 5 million people to 11 million people in the scenario 3.

According to the total water demand graphics which are Figure 3.3, Figure 3.7, and Figure 3.11, we can see mini fluctuations due to small changes in water consumption per capita per year. In this model, it has been mentioned normal distribution which is shown in Appendix 2. However, we can obviously see that the total demand for water in Ankara within the 50 years is increasing in the total view. If we combine those graphics with the population graphics, we can see the increase in both.

In the scenario 1, according to Figure 3.3, we can say that the amount of Ankara Water Supply gets higher value every passing year. After about 20 years process, the increase has almost stopped and the value remains steady. Looking at the greatest value, we can see that the level of Ankara Water Supply has not reached 543 million cubic meters. (The highest value of Ankara Water Supply is 542 million cubic meters after 18 years from the initial year as shown in Figure 3.3.). In the scenario 2, Ankara Water Supply also increases within 20 years, but water adequacy falls below the critical level after about 15 years as total demand more increases due to the more increase in population (Figure 3.7, Figure 3.8, and Figure 3.9). In the scenario 3, Ankara Water Supply more increases, because total demand fewer increases due to the less increase in population. However, the amount of water will be below the critical limit after about 30 years (Figure 3.11, Figure 3.12, and Figure 3.13).

Adequacy index has fallen below 1 shown in Figure 3.4 which indicates Ankara Water Supply has come down critical value after about 20 years in the scenario 1. In the scenario 2, it falls critical value about 15 years later, while it falls critical value after about 30 years in the scenario 3. Also, Table 3.1, which shows the changes in the parameters within 50 years at 10-year intervals, summarizes the scenario 1. Briefly, 20 years later, in 2037, Ankara Water Supply would not be able to meet the Total Water Demand (Figure 3.5). This situation is inevitable due to limited water resources against increasing population.

Finally, we can summarize the study by comparing the Adequacy values in different scenarios. Although the first years more water is drawn from the dams to meet the increasing demand, Ankara Water Supply is inadequate to meet the demand after a few years. As shown in Figure 3.14 and Table 3.4, in the scenario 1, Adequacy index falls below the critical value after 20 years (the year of 2037). In the scenario 2, the index falls below 1 before reaching the 15th year (the year of 2032). In the scenario 3, the water demand is met for the first 30 years and the index remains above the value of 1. Also, this scenario demonstrates that Ankara Water Supply will fall below the critical level 30 years later (the year of 2047). As a result of the three different scenarios, the water will not able to enough for the Ankara in the following years.

Table 3.4: The comparison table of Adequacy values in different scenarios

Adequacy Index in Different Scenarios

Years	Scenario 1	Scenario 2	Scenario 3
2017	0.926	0.923	0.929
2027	1.120	1.042	1.237
2037	0.987	0.918	1.374
2047	0.847	0.79	0.999
2057	0.769	0.636	0.833
2067	0.605	0.521	0.707

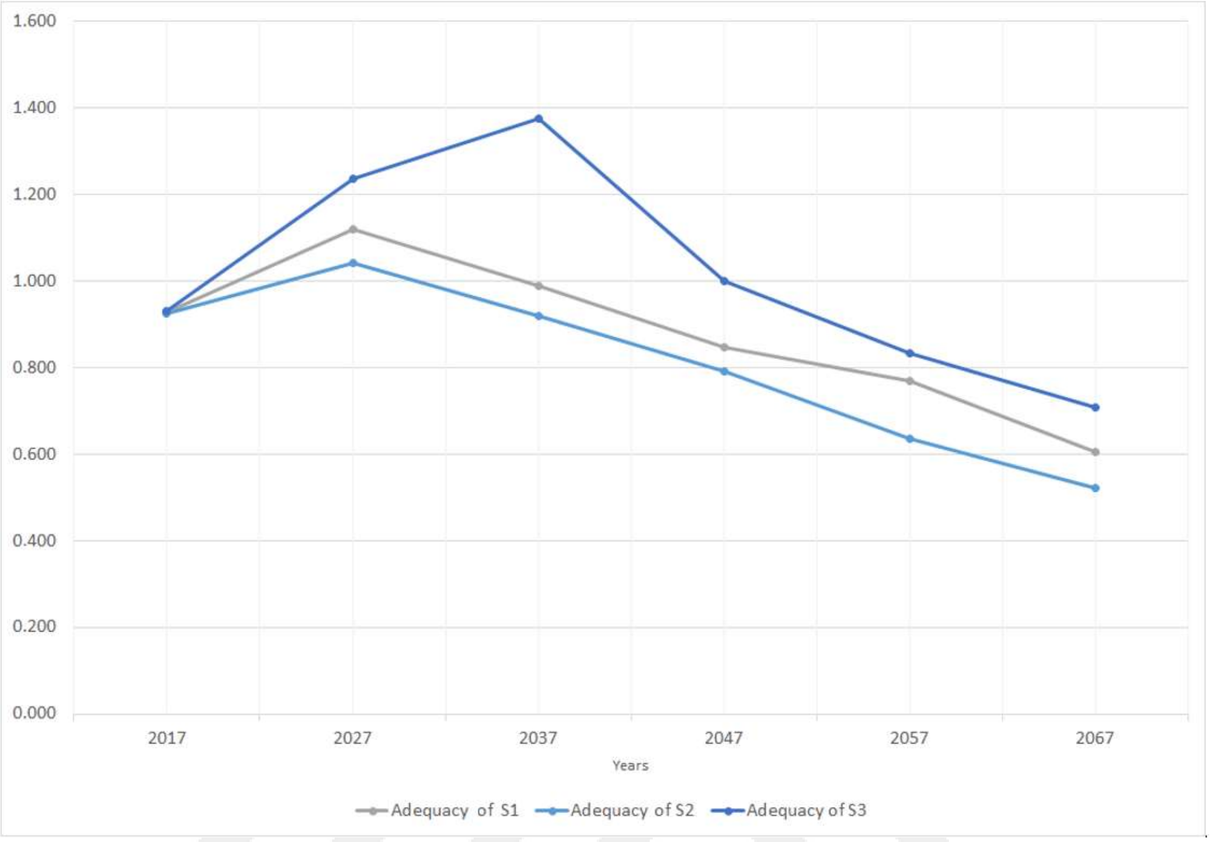


Figure 3.14: The comparison graphic of Adequacy values in different scenarios

5. CONCLUSION AND RECOMMENDATIONS

One of the most important problems of the century in the world is the reduction of usable water resources and the resulting water scarcity. The main objective of water resources management is to use water, which is a natural resource without any alternative, to be more planned and economical, to identify and prevent water threatening problems, to protect water and water-dependent ecosystems, and to provide a sustainable water resources management (SWRM).

In this study, an SWRM model has been formed based on system dynamics to view the progress of the water resources in the long term (for 50 years). The SD model has been run using three different population scenarios obtained from TUIK. In the scenario 1, the population of Ankara is increasing with a significant acceleration (Figure 3.2). Total water demand also increases due to population growth (Figure 3.3). Unless serious measures are taken, the water demand of Ankara will gradually increase and after about 2037 the amount of water will be below the critical limit as shown in Figure 3.3 and Figure 3.4. Also, according to other scenarios, the amount of water will be below the critical limit (Table 3.4, Figure 3.14). In the scenario 3 it will be about 30 years later (Figure 3.10 – 3.13), but in the scenario 2, it will be about 15 years later (Figure 3.6 – 3.9).

Therefore, Ankara's own water policy needs to be determined in Ankara for the effective and sustainable management of water resources as soon as possible. In this context, underground-water resources of Ankara can be evaluated and put into them operating efficiently. In order to increase the rainwater coming from the dams, systems where rainwater can be collected more effectively and efficiently can be developed. Also in very difficult cases, water resources can be imported from the neighbouring provinces rich in water. In fact, the cost-benefit analysis of importing water will be very good for preparation for the future. On the other hand, it should be informed to people about public conscious water consumption, especially industrial consumers should be monitored at certain intervals about wastes to water resources. Ankara Metropolitan Municipality and ASKI have great responsibilities in these matters.

In future studies, demand side and also supply side of sub-models can be mentioned. For instance, the demand can be modelling with domestic and industrial demand sub-models. Also, new supply methods can be entrained to the model to be a solution to water scarcity such as underground water, and import water from other city’s water resources. When adding new methods, the cost side of the water supply can be added to the model and this will bring the work to a more realistic level. In addition to all these, the establishment of Turkey's SD model of great significance in terms of the expression of Turkey's big picture of SWRM.

REFERENCES

5th World Water Summit Summary Report, 2009. *International Institute for Sustainable Development Repoting Services.* [Online] Available at: http://enb.iisd.org/crs/water/worldwater5/html/ymbvol82num23e.html [Accessed 2017].

Anon., 1992a. *The Dublin Statement on Water and Sustainable Development.* Dublin, s.n.

Anon., 1992b. *Rio Declaration on Environment and Development,* Rio de Janeiro: s.n.

Anon., 2002. *Report of the World Summit on Sustainable Development Johannesburg, South Africa, 26 August - 4 September 2002.* New York, United Nations.

Anon., 2008. *İklim Değişikliği ve Yapılan Çalışmalar,* Ankara: T.C. Çevre ve Orman Bakanlığı.

Aski, 2018. *Aski.* [Online] Available at: http://www.aski.gov.tr/TR/ICERIK/Icme-Suyu-Aritma/31 [Accessed November 2018].

Aski, S. P. E., 2014. *ASKİ Genel Müdürlüğü 2015-2019 Sratejik Plan,* Ankara: s.n.

Berkoff, J., 1994. *A Strategy for Managing Water in the Middle East and North Africa.* Washington, D.C..

Biswas, M. R., 1977. *Water Supply and Management.* s.l., United Nations Water Conference: A perspective, pp. 72-255.

Bogardi, J. J. & Nachtnebel, H.-P., 1994. *Multicriteria Decision Analysis in Water Resources Management.* Paris: UNESCO.

Burak, S., Duranyıldız, İ. & Yetiş, Ü., 1997. *Ulusal Çevre Eylem Planı: Su Kaynaklarının Yönetimi,* Ankara: State Planning Office.

Chapagain, A. K., 2017. Water Footprint: State of the Art: What, Why, and How. *Encyclopedia of Sustainable Technologies,* Volume 3, pp. 153-163.

Çırpıcı, Y. A., 2008. *Economy-wide Analysis of Water Resources Management: A CGE Model for Turkey.* Thesis (MS): Middle East Technical University.

Ding, G. K. C. & Ghosh, S., 2017. Sustainable Water Managementd - A Strategy for Maintaining Future Water. In: M. A. Abraham, ed. *Encyclopedia of Sustainable Technologies.* Ohio: Elsevier Inc., pp. 91-103.

Distanont, A., Khongmalai, O., Rassameethes, R. & Distanont, S., 2018. Collaborative triangle for effective community water resource management in Thailand. *Kasetsart Journal of Social Sciences,* 39(3), pp. 374-380.

DSI, 2009. *State Hydraulic Works,* Turkey: Turkey Water Report.

Eksin, C., 2009. *Application of Genetic Algorithms to Analysis and Policy Design in System Dynamics.* Thesis (MS): Boğaziçi University.

Forrester, J. W., 1961. *Indutrial Dynamics,* Cambridge MA: MIT Press.

Forrester, J. W., 1969. *Urban Dynamics,* Waltham MA: Pegasus Communications.

Forrester, J. W., 2009. *Some Basic Concepts in System Dynamics.* s.l.:Sloan School of Management Massachusetts Institute of Technology.

García, J. M., 2006. *Theory and Practical Exercises of System Dynamics.* Barcelona: Registro Propiedad Intelectual.

Germany. Federal Ministry for Economic Cooperation and Development -DE, G. -E. D. G. F. M. f. t. E. N. C. a. N. S. -D., 2001. *Water - a key to sustainable development : international conference on freshwater, Bonn 2001 : conference report,* Eschborn, Germany: Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ).

Ghazvini, A. & Shukur, Z., 2013. System Dynamics in E-Health Policy Making and the "Glocal" Concept. *Procedia Technology,* Issue 11, pp. 155-160.

Handl, G., 2012. *Declaration of the United Nations Conference on the Human Environment (Stockholm Declaration), 1972 and the Rio Declaration on Environment and Development, 1992.,* s.l.: United Nations.

Jafari, M., Hesamamiri, R., Sadjadi, J. & Bourouni, A., 2012. Assessing the dynamic behavior of online Q&A knowledge markets: A system dynamics approach. *Program,* Issue 46, pp. 341-360.

Kara, T., 1999. *Mathematical Modelling of Water Supply Systems.* Thesis (MS): University of Gaziantep.

Karatayev, M., Kapsalyamova, Z., Spankulova, L., Skakova, A., Movkebayeva, G. & Kongyrbay, A., 2017. Priorities and challenges for a sustainable management of water resources in Kazakhstan. *Sustainability of Water Quality and Ecology,* Volume 9-10, pp. 115-135.

Koleva, M. N., Calderón, A. J., Zhang, D., Styan, C.A. & Papageorgiou, L. G., 2018. Integration of environmental aspects in modelling and optimisation ofwater supply chains. *Science of the Total Environment,* Volume 636, pp. 314-338.

Kotir, J. H., Smith, C., Brown, G., Nadine M. & Johnstone, R., 2016. A system dynamics simulation model for sustainable water resources management and agricultural development in the Volta River Basin, Ghana. *Science of the Total Environment,* Issue 573, pp. 444-457.

Lee, C.-F. & Chung, C.-P., 2012. An Inventory Model for Deteriorating Items in a Supply Chain with System Dynamics Analysis. *Procedia - Social and Behavioral Sciences,* Issue 40, pp. 41-54.

Loucks, D. P., Beek, E. van, with contributions from Stedinger, J. R.; Dijkman, J. P. M., & Villars, M. T., 2005. *Water Resources Systems Planning and Management An Introduction to Methods, Models and Applications.* s.l.:UNESCO Publishing / WL - Delft Hydraulics.

Mavrommati, G., Bithas, K. & Panayiotidis, P., 2013. Operationalizing sustainability in urban coastal systems: A system dynamics analysis. *Water Research,* Issue 47, pp. 7235-7250.

Meriç, B. T., 2004. Water Resources Management and Turkey. *Geological Engineering ,* Issue 1, pp. 27-38.

Özel İhtisas Komisyonu, 2014. *Su Kaynakları Yönetimi ve Güvenliği,* Ankara: Türkiye Cumhuriyeti Kalkınma Bakanlığı.

Qian, Y., 2016. Sustainable Management of Water Resources. *Engineering,* 2(1), pp. 23-25.

Radzicki, M. J., 2011. System Dynamics and Its Contribution to Economics and Economic Modeling. *Complex Systems in Finance and Econometrics*, pp. 727-737.

Rehan, R., Knight, M., Unger, A. & Haas, C., 2013. Development of a system dynamics model for financially sustainable management of municipal watermain networks. *Water Research,* Issue 47, pp. 7184-7205.

Saysel, A. K. & Barlas, Y., 2001. Güneydoğu Anadolu Projesi ve Sürdürülebilir Kalkınma: Dinamik Sistem Modellemesi Yaklaşımı. Eylül.

Sindhu, S., Nehra, V. & Luthra, S., 2017. Solar energy deployment for sustainable future of India: Hybrid SWOC-AHP analysis. *Renewable and Sustainable Energy Reviews,* Volume 72, pp. 1138-1151.

Solow, R. M., Winter, S. G., Page, S. E.; Colander, D. C. & Chari, V.V., 2010. Building a Science of Economics for Real World. *Authenticated U.S. Government Information (GPO)*, 20 July.

Sterman, J. D., 2000. *Business Dynamics Systems Thinking and Modeling for a Complex World.* s.l.:McGraw-Hill Higher Education.

Şimşek, O., Yıldırım, M. & Gördebil, N., 2012. *2011-2012 Tarım Yılının Kuraklık Analizi,* Ankara: Metoroloji Genel Müdürlüğü.

TUIK, 2018. *Turkish Statistical Institute.* [Online]
Available at: http://tuik.gov.tr
[Accessed November 2018].

Twort, A. C., Ratnayaka, D. D. & Brandt, M. J., 2000. Hydrology and surface supplies. In: *Water Supply.* s.l.:Butterworth-Heinemann, pp. 63-113.

Ulutaş, S., 2013. *Modeling and Analysis of Employee Performance Management Based on System Dynamics Approach.* M.S. Thesis: s.n.

United Nations, 2003. *UN General Assembly 58th Session.* [Online]
Available at: http://www.un.org/ga/58/
[Accessed 20017].

Wood, W. W., 2003. Water Sustainability: Science or Science Fiction? Perspective from One Scientist. *Developments in Water Science,* Issue 50, pp. 45-51.

Wu, Z. & Xu, J., 2013. Predicting and optimization of energy consumption using system dynamics-fuzzy multiple objective programming in world heritage areas. *Energy,* Issue 49, pp. 19-31.

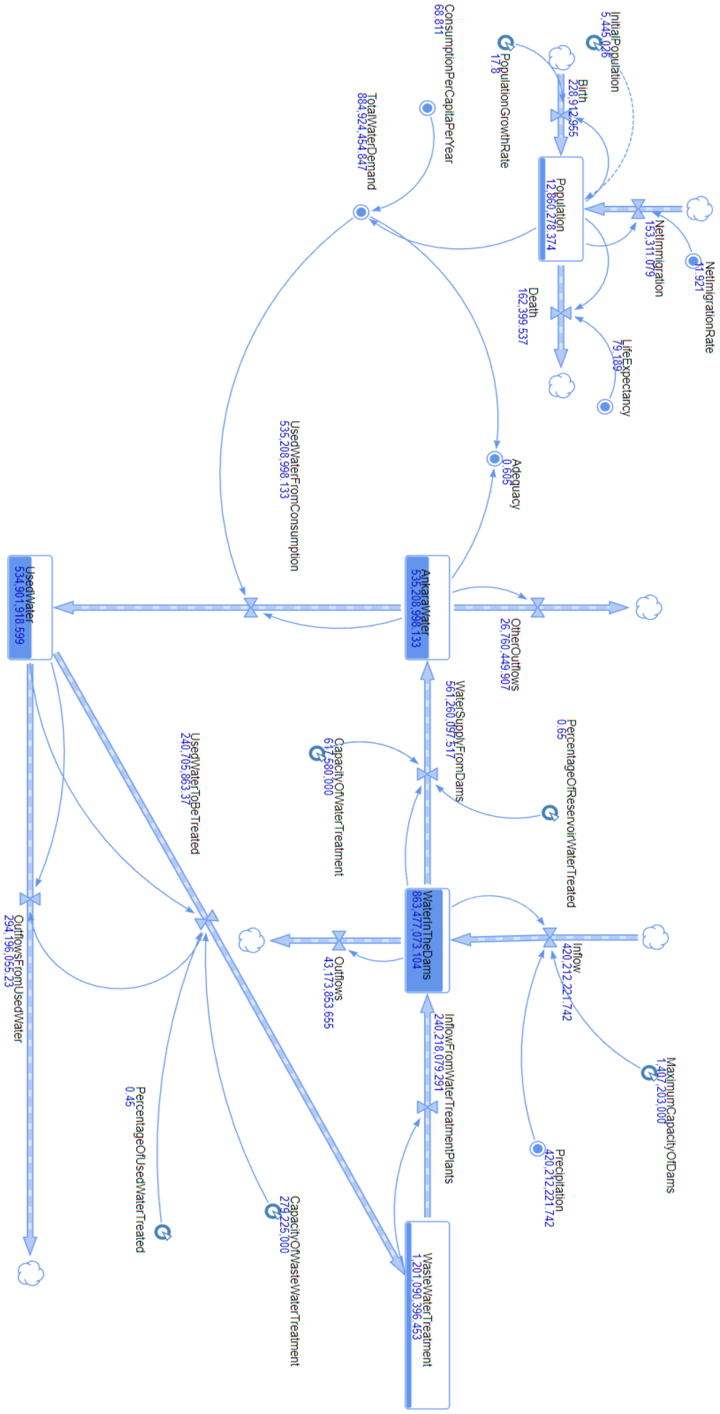
WWAP, 2015. *The United Nations World Water Development Report 2015: Water for a Sustainable World,* Paris: UNESCO.

Yıldırım, Y. E., 2013. *Su Kaynaklarının Yönetimi Politikalar ve Sorunlar: Küreselden Yerele.* Nevsehir, Nevsehir University.

Zavr, D. & Kljajić, M., 2010. *An Institutional Dynamics Model of the Euro zone crisis:Greece as an Illustrative Example.* Seoul, Korea, proceedings of The 28th International System Dynamics Conference, pp. 1-18.

APPENDICES

APENDIX 1: Simulation output after The SD model for the Ankara has been run.



APENDIX 2: Model input data and formulae.

Adequacy = AnkaraWaterSupply/TotalWater Demand

Units: Dmnl [0,10]

The goal is to have sufficient water supply to meet the water demand in any particular year. This means that supply/demand should be larger or equal to 1.

Birth = Population/1000*BirthRate

Units: persons per year

BirthRate = 17.8

Units: Dmnl

This estimate is obtained from Turkish Statistical Institute.

(The report of population and annual average population growth rate by provinces, 2017, 2023 from http://www.tuik.gov.tr/UstMenu.do?metod=temelist)

CapacityOfWasteWaterTreatment = 765,000 * 365

Units: cubic meters per year

As shown in Table 2.2

CapacityOfWaterTreatment = 1,692,000 * 365

Units: cubic meters per year

As shown in Table 2.1

ConsumptionPerCapitaPerYear = normal(3.232, 66.56)

Units: cubic meters per person per year

Estimated based on data from ASKI.

As shown in Apendix 3.

Death = Population/Life expectancy

Units: persons per year

d(AnkaraWaterSupply)/dt = WaterPumpedUp + WaterSupplyFromNewDams + WaterSupplyFrom NewWater - UsedWaterFrom Consumption - OtherOtflows - WaterSurplus
Units: cubic meters per year

d(Population)/dt = NetImmigration + Birth - Death
Initial value: Initial Population (in 2017)
Units: persons per year

d(UsedWater)/dt = UsedWaterFromConsumption -Outflow
Units: cubic meters per year

d(WasteWaterTreatment)/dt = UsedWaterToBeTreated - InflowFromWaterTreatmentPlants
Units: cubic meters per year

d(WaterInTheDams)/dt = Inflow - WaterEvaporation - Outflow -WaterSupplyFromDams
Units: cubic meters per year

Inflow = min (Precipitation, MaximumCapacityOfDams - WaterInTheDams)
Units: cubic meters per year

InflowFromWaterTreatmentPlants = WasteWaterTreatment * 0.2
Units: cubic meters per year
(According to ASKI, 20 percent of the amount of treated waste water comes back to dams.)

Initial population in 2017 = 5,445,026
Units: persons
Population in year 2017. Data is obtained from Turkish Statistical Institute.

INITIAL TIME = 2017
Units: Year
The initial time for the simulation.

Life expectancy = uniform(76.7, 81.9)

Units: year

This estimate is obtained from Turkish Statistical Institute.

(The report of life expectancy at birth by provinces and sex, 2015 – 2017 from http://www.tuik.gov.tr/UstMenu.do?metod=temelist)

MaximumCapacityOfDams = 1,407E+09

Units: cubic meters per year

The total of maximum capacity of the Dams which are Kurtbogazi, Camlidere, and Kesikkopru feed the center of Ankara. (As shown Table 2.3)

NetImmigrationRate = normal(7.675, 12)

Units: ‰

This estimate is obtained from Turkish Statistical Institute.(For Minitab outputs see Apendix 3)

(The report of provincial in-migration, out-migration, net migration, rate of net migration, 1980-2017 from http://www.tuik.gov.tr/UstMenu.do?metod=temelist)

NetImmigration = Population * NetImigrationRate / 1000

Units: persons per year

OtherOutflows = AnkaraWaterSupply * 0.05

Units: cubic meters per year

Outflows = WaterInTheDams * 0.05

Units: cubic meters per year

OutflowsFromUsedWater = UsedWater - UsedWaterToBeTreated

Units: cubic meters per year

PercentageOfReservoirWaterTreated = 0.65

Units: Dmnl [0,1]

(This information is obtained from ASKI)

PercentageOfUsedWaterTreated = 0.45
Units: Dmnl [0,1]
(This information is obtained from ASKI)

Precipitation = normal(146391030, 377058885)
Units: cubic meters per year
(For minitab outputs see Apendix 3)

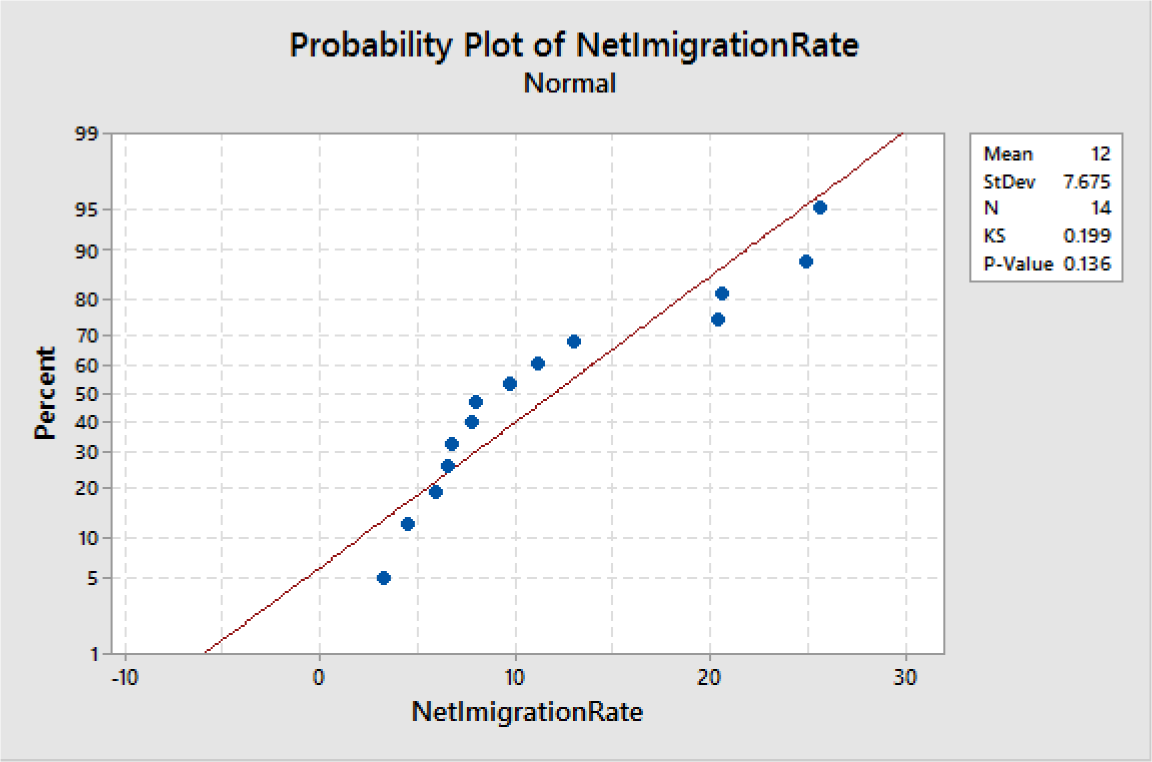
TotalWaterDemand = Population * ConsumptionPerCapitaPerYear
Units: cubic meters per year

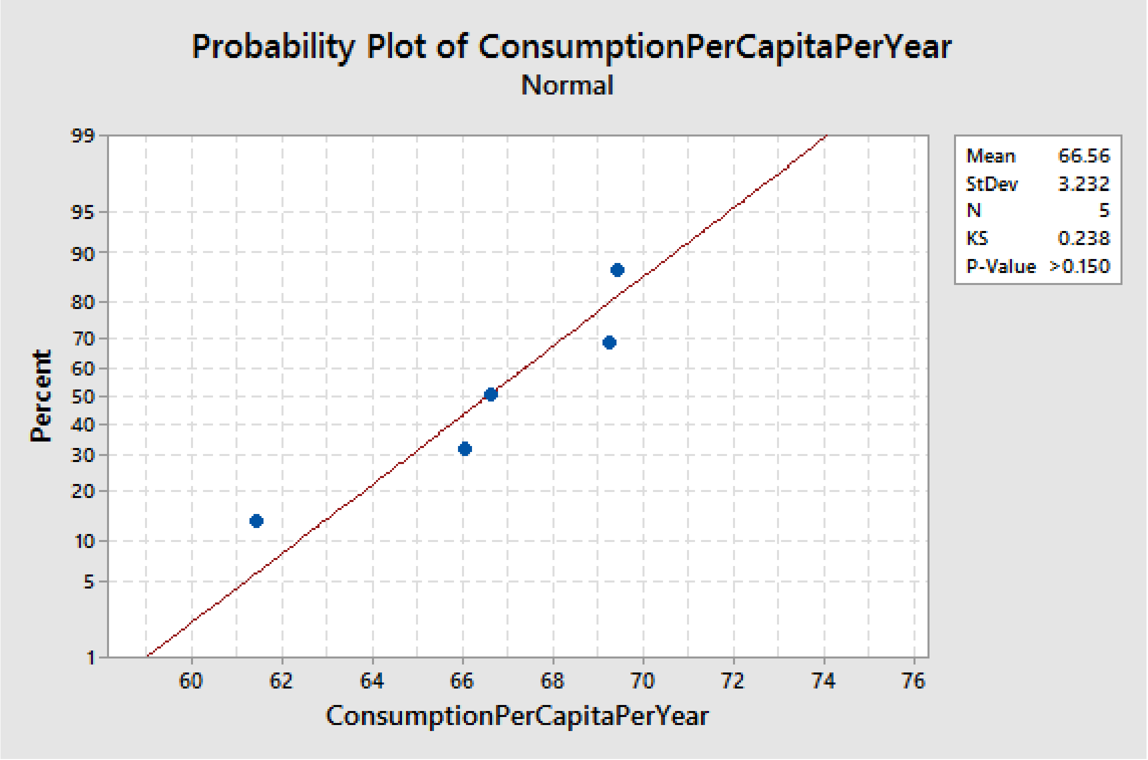
UsedWaterFromConsumption = AnkaraWaterSupply > TotalWaterDemand ? TotalWaterDemand : AnkaraWaterSupply
Units: cubic meters per year

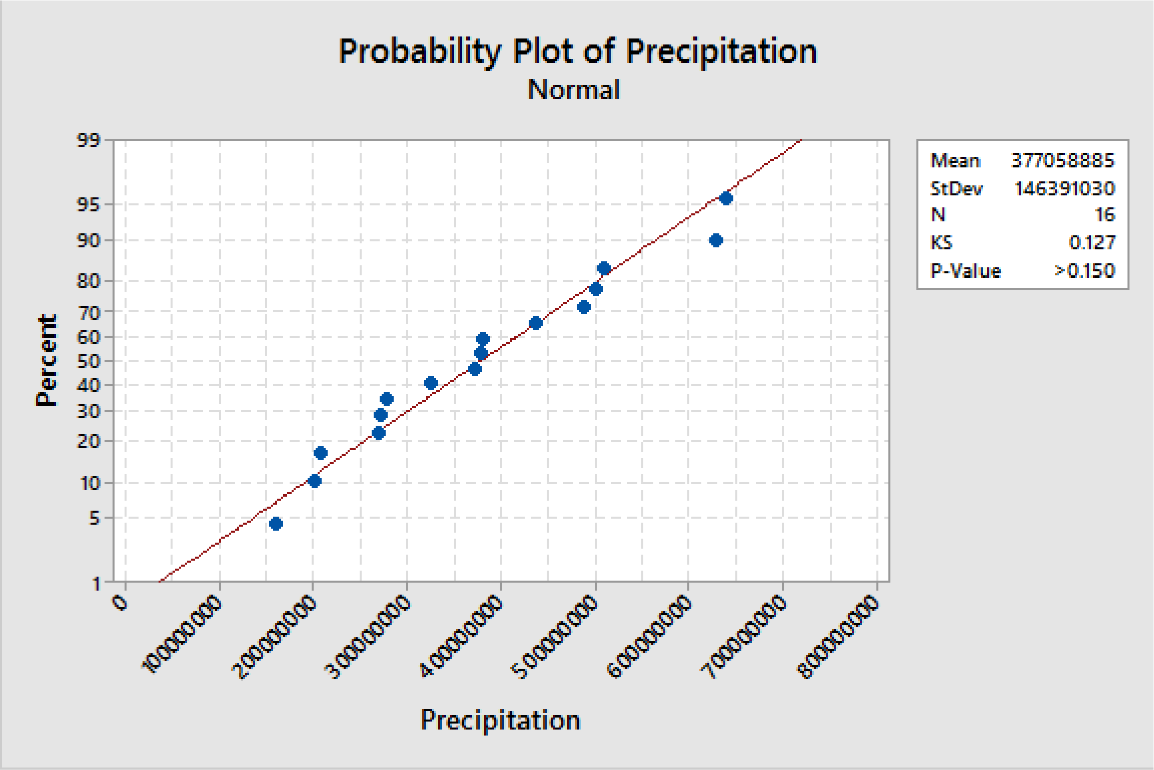
UsedWaterToBeTreated = min (UsedWater * PercentageOfUsedWaterTreated, CapacityOfWasteWaterTreatment)
Units: cubic meters per year

WaterSupplyFromDams = min (WaterInTheDams * PercentageOfReservoirWaterTreated, CapacityOfWaterTreatment)
Units: cubic meters per year

APENDIX 3: Minitab outputs.






Probability Plot of Precipitation
Normal
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
0
100000000
200000000
300000000
400000000
500000000
600000000
700000000
800000000
Precipitation
Mean 377058885
StDev 146391030
N 16
KS 0.127
P-Value >0.150

CURRICULUM VITAE

Personal Information	
Name Surname	Duygu ÇELİK MORKOÇ
Place of Birth	İskilip
Date of Birth	26.10 1989
Nationality	☑ T.C. ☐ Other:
Email	dcmrkc@gmail.com

Educational Information	
B. Sc.	
University	Fatih University
Faculty	Faculty of Engineering
Department	Industrial Engineering (Full Scholarship)
Graduation Year	2011

Educational Information	
M. Sc.	
University	İstanbul University-Cerrahpaşa
Institute	Institute of Graduate Studies
Department	Department of Industrial Engineering
Programme	Industrial Engineering Programme
Graduation Year	2018