AGRICULTURAL REUSE OF WATER AND NUTRIENTS FROM WASTEWATER TREATMENT IN IZMIR REGION

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MAY 2012

AGRICULTURAL REUSE OF WATER AND NUTRIENTS FROM WASTEWATER TREATMENT IN IZMIR REGION

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

EBRU SARIKAYA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
ENVIRONMENTAL ENGINEERING

MAY 2012

Approval of the thesis:

AGRICULTURAL REUSE OF WATER AND NUTRIENTS FROM WASTEWATER TREATMENT IN IZMIR REGION

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

AGRICULTURAL REUSE OF WATER AND NUTRIENTS FROM WASTEWATER TREATMENT IN IZMIR REGION

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May 2012, 132 pages

Rapid urbanization and population growth have represented a great challenge to water resources management, since wastewater generated in urban areas forms a non-conventional source, wastewater reuse is being recognized as a sustainable water management approach.

This study focuses on with the potential and practibility of implementing wastewater reuse techniques in İzmir region, especially with the aim to use treated wastewater and nutrient for agriculture. To this end, qualititative and quantitative agricultural water demand were considered.

This thesis introduces a wastewater reuse planning model and optimization method with an emphasis on the wastewater treatment technology used as well as the agricultural demand in the area of the study. The model was developed with considerations over water quality, wastewater treatment and discharge. The objective of the model is to upgrade existing wastewater treatment plants or to design new treatment plants in regard to reuse wastewater in agriculture. The model is also capable of comparing treatment technologies from the point of design and cost. Three case studies were represented so as to demonstrate the modeling process and optimization studies for agricultural irrigation.

Key words: Reuse, treated wastewater, modular design approach, optimization

// ÖZ

İZMİR BÖLGESİNDEKİ ATIKSU ARITIMINDAN GELEN SUYUN VE BESİN MADDELERİNİN TARIMDA YENİDEN KULLANILMASI

Hızlı kentleşme ve nüfus artışı su kaynakları yönetiminde büyük bir tehlike oluşturmaktadır. Kentsel bölgelerden kaynaklanan atıksular konvansiyonel olmayan bir kaynak olduğundan, atıksuların yeniden kullanımı sürdürülebilir bir su yönetimi yaklaşımı olarak tanımlanmaktadır.

Bu araştırma İzmir bölgesinde atıksuların yeniden kullanımı için gerekli olan teknolojilerinin potansiyeli ve uygulanabilirliği; özellikle de tarımsal amaçla geri kullanımına odaklanılmıştır. Bu amaçla kalitatif ve kantitatif tarimsal su ihtiyaci dikkate alınmıştır.

Bu tez atıksuyun yeniden kullanılmasını planlayan bir model ve optimizasyon yöntemi sunmaktadır. Sunulan bu çalışmada atıksu arıtma teknolojileri ve bununla birlikte çalışılan bölgenin tarımsal su ihtiyaci dikkate alınmıştır. Model su kalitesi, atıksu arıtımı ve deşarjı göz önüne alarak geliştirilmiştir. Kullanım amacı tarımsal sulamaya yönelik olarak mevcut atıksu arıtma tesislerini geliştirmek veya yeni atıksu arıtma tesisleri tasarlamaktır. Model aynı zamanda arıtma teknolojilerini tasarım ve maliyet açısından da karşılaştırma olanağı sağlamaktadır. Modelin kullanımını ve tarımsal sulama için gerçekleştirilen optimizasyon sonuçlarını göstermek için üç adet örnek çalışma sunulmuştur.

Anahtar kelimeler: Yeniden kullanım, arıtılmış atıksu, moduler tasarım yaklaşımı, optimizasyon

To my beloved family and my husband

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to Prof. Dr. Göksel N. Demirer for his guidance, recommendations and support throughout this research and preparation of this thesis. I would like to acknowledge my other committee members, Prof. Dr. Celal F. Gökçay, Assist. Prof. Dr. Tuba H. Ergüder, Assist. Prof. Dr. Barış Kaymak and Assist. Prof. Dr. Selçuk Göçmez for their valuable suggestions contributed to this study.

I would also like to thank Scientific and Technological Research Council of Turkey (TÜBİTAK) (Project no. 108Y242) for its financial support and project partners, Timur Esemen, Prof. Dr. Thomas Dockhorn from Technische Universität Braunschweig, Institute of Sanitary and Environmental Engineering.

I would like to extend my gratitude to my friends, Selcen, Elif, and İlker for their endless support.

Finally, I am grateful to my parents and my husband for their endless patience, encouragement, support and confidence in me throughout my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION AND BACKGROUND TO THE STUDY

1.1 Introduction

In recent years, rapid population growth have resulted uneven population distribution. As urban population grows, consumption of water sources also increases in addition to energy use and waste generation (Asano, 2002). Human enhancement and utilization of natural resources affects ecosystems through the process of the water cycle in many ways such as deforestation, reduction of grass land for livestock and water discharges (Falkenmark, 1986; Rooda and Shiklomanov, 2003). The studies on availability of water resources throughout the world indicates that the greater part of the world's population is subject to water scarcity and approximately 30-35 percent of the world population will have low fresh water supply (less than 1000 m^3 per year per capita) by 2025 (Shiklomanov, 2009). In the light of potential water scarcity, countries have increasingly started the water resources management programs. Most of these management programs generally focus on water conservation; however this is not enough to meet the water demand. Therefore, alternative water supply methods should be considered (Stokes and Horvath, 2005).

Water reuse practices have rapidly increasing for two reasons; one is the quality requirements for discharge of sewage effluent into surface water is becoming increasingly difficult to protect environment. Secondly, it is an important water source option especially in water shortage areas (Bouwer, 1994). Other benefits of reuse include savings in operation and maintenance costs including pumping energy and treatment chemicals, savings in treatment and nutrient removal costs, reduced effects on aquatic life and agricultural benefits such as reduced diversion costs, increased yield and savings nutrients for irrigation (Angelakis et al., 2001; Anderson, 2003). Sources of water reuse include municipal and industrial wastewater effluent, brackish water, poor-quality groundwater, agriculture return flows, storm water and the oceans. Application of each system differentiates according to pollutants present, their concentrations and legal requirements (Miller, 2006). In this research, the source of reuse is selected as municipal wastewater generated from urban wastewater treatment plants.

Treated municipal wastewater reclamation is often preferred alternative to the disposal of effluents into natural water sources (Schmidt et al., 1975). In Turkey, approximately 73 percent of the population is served by wastewater collection networks and 46 percent of population is served by treatment facilities (TSI, 2008). This situation reveals that wastewater reuse is a good opportunity within many regions in Turkey. As city populations continue to expand, water supply, collection and treatment systems will continue to increase in numbers. Therefore, water reuse becomes one of the most feasible options for improving water resources and reducing the gap between water demand and supply (Cornel and Weber, 2006).

This thesis investigates an urban wastewater reuse planning and optimization for agricultural irrigation in İzmir, Turkey. In order to do this, three case studies have been investigated based on constructional and financial criteria and irrigational water demand.

1.2 Research Objective

The main objective of this research is to develop a water reuse model for agriculture in order to assess the feasibility of implementing wastewater reuse systems in selected circumstances. This model has been used in determining the best applicable treatment technology or operation condition for existing treatment plants and agricultural irrigation schedules has been planned based on the availability of wastewater to be reused.

1.3 Organization of the Thesis

This thesis contains five chapters. The first chapter introduces the background and objectives of this research. The second chapter provides a literature review on water reuse and reviews existing water reuse application studies. Chapter 3 describes the methodologies being used in this study. The water reuse model and the determination of crop water demand are introduced in this chapter. Chapter 4 demonstrates the model and optimization applications for case studies and discusses the results. Chapter 5 concludes the research and provides recommendations for future studies.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

This chapter outlines the concept of wastewater reclamation and the existing wastewater reuse applications from Turkey and the world. Last part of this section reviews legislative requirement for agricultural wastewater reuse in Turkey.

2.1 Background

2.1.1 Introduction to History of Water Reuse

Although indications for water reclamation for agricultural irrigation extend to ancient times, the first modern wastewater reuse practice was noted at the beginning of the last century (Urkiaga et al., 2006). Some of earliest wastewater reuse systems were developed during 1920's (Asano and Levine, 1996). On the other hand, engineering systems for water reuse have been developed in the 1970s (Jefferson et al., 2000).

During the last century, many cities in the world subject to problems in water supply. Therefore, reuse of water has gained importance as an alternative to disposal of untreated urban wastewater (Pedrero et al., 2010). Today's technology provides high quality treated wastewater by developed advanced treatment technologies (Levine et al., 1985). Thereby, treated wastewater has gained attention such that it has to be managed as a water resource.

2.1.2 Wastewater Reclamation, Recycle and Reuse

Recycle was defined as to recover useful materials from different types of wastes and to extract and reuse. While in many cases recycle term is generally applied for glass bottles and newspapers, water can also be recycled. The term water recycling is generally used same with water reclamation and reuse. In a regular day, water piped into homes is collected from water sources (rivers, reservoirs, etc.) and after using for a wide variety purposes, it is discharged to receiving environment. Therefore, necessary treatment of wastewater and its recycle is a key part of the water cycle (U.S. EPA, 2004; WaterUK, 2006).

2.1.3 Types of Water Reuse

Water reuse provides an important alternative to traditional water supplies and it can help to close the gap between the water supply and disposal (Asano, 2002). In general water reuse applications under one of six categories (U.S. EPA, 2004). These are urban, industrial, environmental and recreational, groundwater recharge, augmentation of potable supplies and agricultural.

2.1.3.1 Urban Reuse

The term urban water reuse is generally used for reclaimed water applied for the irrigation areas that are potential for human contact. Reclaimed water is generally domestic wastewater that provides effluent requirements such that reused water is suitable for public access (Aoki, and Memon, 2002). Since most areas where reclaimed water is to be used are open to public, treatment of this water is the primary interest for the implementation (Hartley, 2006). If necessary treatment requirements are satisfied, reused water has a major advantage such that it supplies a constant and reliable source; since water suitable for reuse is produced in large volumes, urban reuse can include distribution systems serving large users such as parks, playgrounds, golf courses, recreational and agricultural activities (U.S. EPA, 2004).

2.1.3.2 Industrial Reuse

Industrial reuse has gained importance due to increased water scarcity and population growth and legislation on water conservation (Yang and Abbaspour, 2007). In order to meet increased water demand, effluent is recovered after treatment and returned back into the process cycle in many industry facilities (Exall et al., 2004). Cooling water creates the largest industrial water demand. However, there are some industrial facilities benefiting from reused water not only for cooling but for processes need as well (U.S. EPA, 2004).

2.1.3.3 Environmental and Recreational Reuse

This category includes non-potable uses for wetland enhancement and restoration, development of recreational lakes and stream augmentation (Jimenez, 2008). There are many different application areas of reclaimed water for recreational purposes such as landscape impoundments, golf course storage ponds, incidental contact (i.e. fishing and boating) and body contact (i.e. swimming) (U.S. EPA, 2004).

2.1.3.4 Groundwater Recharge

In order to replenish groundwater, reclaimed water can be used for the purpose of groundwater recharge. This can be applied to provide salt water intrusion control and subsidence control, to provide storage of reclaimed water for future retrieval and reuse, or to provide further treatment for future reuse (Asano, 2002; Vries and Simmers, 2002).

2.1.3.5 Agricultural Reuse

Agricultural irrigation is estimated to represent 65 percent of the total water demand throughout the world (Abu-Zeid, 1998). The sources of wastewater used in irrigation could be different. It could be untreated domestic or industrial wastewater and biologically or mechanically treated wastewater (FAO, 2002). Water reuse for agricultural purposes provides an alternative water supply source that can conserve existing fresh water sources. Beside, water reuse reduce treatment costs for effluent discharge to surface waters by partially eliminating nutrients such as nitrogen and phosphorous. Therefore, agricultural water reuse is considered an important option for urban water management systems (Fabiani et al., 1996; Haruvy, 1998; Lopez et al., 2006; Bahri, 2009).

2.2 Benefits of Water Reuse

As mentioned above, reuse of wastewater has been used since ancient times and it is more preferable as an alternative water source all over the world. Therefore, the potential benefits for wastewater reuse instead of disposing it to receiving environment have been widely realized.

Water reuse provides an alternative resource displacing the need for other sources of water and it is reliable, secure and drought-proof (Asano, 2002). Instead of implementation a new freshwater supply, water reuse systems are easier to establish. When water reuse is evaluated in the framework of water cycle, it closes the water cycle and provides to save high quality freshwater for water supply (Lu et al., 2003). Agricultural irrigation is the most common practice of wastewater reuse. Compatibility with wastewater treatment regulations and controlled water reuse are important concerns to improve public health and enhance policy consciousness (Kamizoulis et al., 2003). Beside resource conservation and health advantages, economical value can be gained by avoiding costs for advanced wastewater treatment and discharge development (Miller, 2006).

Moreover, a considerable amount of revenue can be provided from sale of recycled water and agricultural products; during drought periods water reuse provides continuous supply for customers and industries (Asano, 1996). Moreover water reuse reduces pollutant discharge into receiving bodies, so recreational value of waterways can be enhanced (Lazarova and Bahri, 2005).

From the point of farmers, commercial fertilizer utilization can be reduced or completely eliminated by reusing wastewater (FAO, 2002). Effective use of nutrients including in wastewater for irrigation leads to higher crop yields and whether the benefits justify the cost depends not only on agricultural productivity, but also on the costs that would be incurred for wastewater disposal without irrigation (Khouri et al., 1994).

Thus, sustainable development of water management can be realized and yield can be increased by the help of water reuse (Haruvy, 1998; U.S. EPA, 2004).

2.3 Wastewater Treatment

Wastewater has to be treated before disposal or reuse and effluent quality should consider water quality requirements (Angelakis et al., 1999). The factors that affect the choice of treatment type and degree depends on raw wastewater quality and effluent quality, investment and operation cost, space requirements for treatment plant, type of irrigated crops, irrigation method, public access and potential hazards on soil and crops (Lazorava and Bahri, 2005). As compared to traditional wastewater treatment systems that produce an effluent usually of a single quality for disposal, the challenge for water reuse systems is further. Since the water quality aims will be more stringent, product water with different quality levels might be necessary to meet a variety of uses, and precautions are necessary to ensure public health protection (Asano, 1995).

Figure 1 illustrates the water quality parameters of concern for irrigational water reuse. In this figure pretreated wastewater enters from the center and the first parameter of concern in primary treatment is suspended solids which involves both suspended and colloidal matter and typically made up of silt and clay, microorganisms, and particulate organic matter. If suspended solids exist in the effluent, they might plug irrigation systems and decrease the efficiency of disinfection (Pescod, 1992). The second important parameter of wastewater treatment is the carbon removal. In some cases carbon removal might not be needed for irrigation, however to avoid regrowth residual microorganisms this process is important (Harremoes, 1997; Levine and Asano, 2004). The next parameter is the nutrients. The presence of nutrients is generally recommended for agriculture. If reuse application is different, such as groundwater recharge or industrial, it might be a problem. Further advanced treatment can be needed for removal of residual suspended solids, organic micropollutants, salts and heavy metals (Exall, 2004). Finally disinfection is the process used to achieve a given level of destruction or inactivation of pathogenic organisms (Oron et al., 1999).

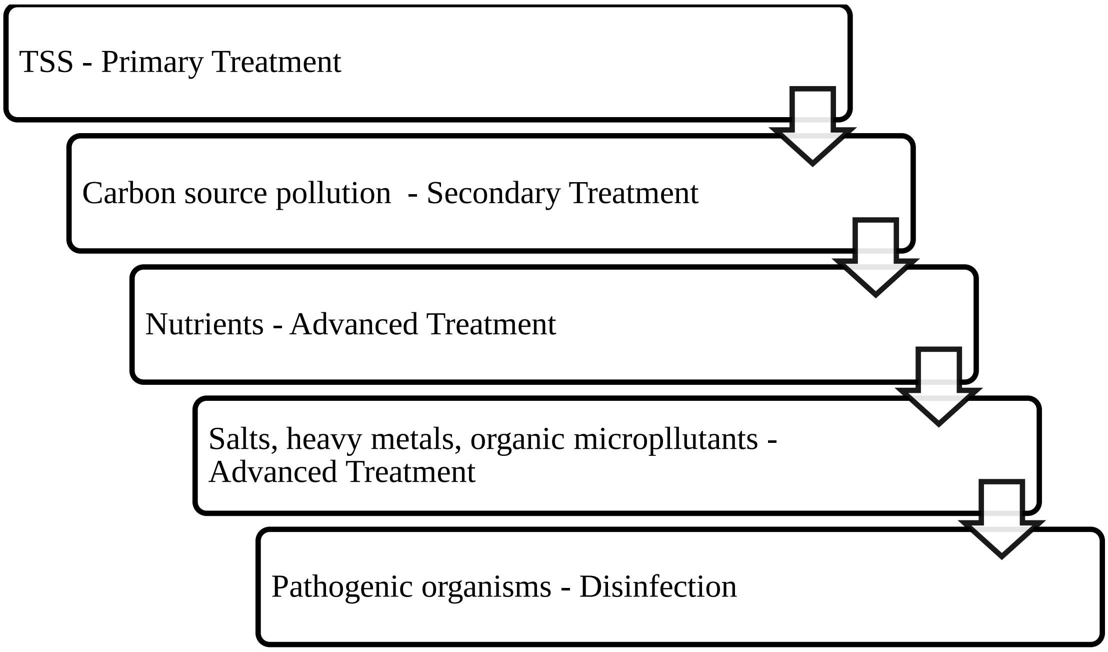

Figure 1 Treatment levels for pollutants that need to be removed for irrigational water reuse (adapted from Lazorava and Bahri, 2005)

Choice of appropriate wastewater reuse treatment flow contains five steps and it is summarized in Figure 1. The first step is the determination of treatment performance of the available technologies and processes to obtain the required effluent quality. Next step is evaluating the standards and restrictions. After that seasonal demands and need for storage should be identified. The choice of treatment flow should consider dimensioning of plant, climate conditions and social properties. The final step is technical and economical evaluation including the analysis of the existing plant constituents, optimization needs and financial sources for investment and operation (Helmer et al., 1997; Pescod, 1992).

Generally wastewater treatment technologies includes physical, chemical and biological components to remove suspended solids, organic matter, pathogens and in advanced cases nutrients, salt or organic micropollutants (Henze et al., 2002). There are three classifications of wastewater treatments depending on degree of treatment; primary, secondary and advanced treatment (Merritt et al., 1999). Technologies for wastewater treatment are mainly depends on the use of suspended growth, such as activated sludge, or attached growth, such as trickling filter, processes. According to desired effluent quality effluent filtration can be applied such as UV disinfection (Tchobanoglous and Angelakis, 1996).

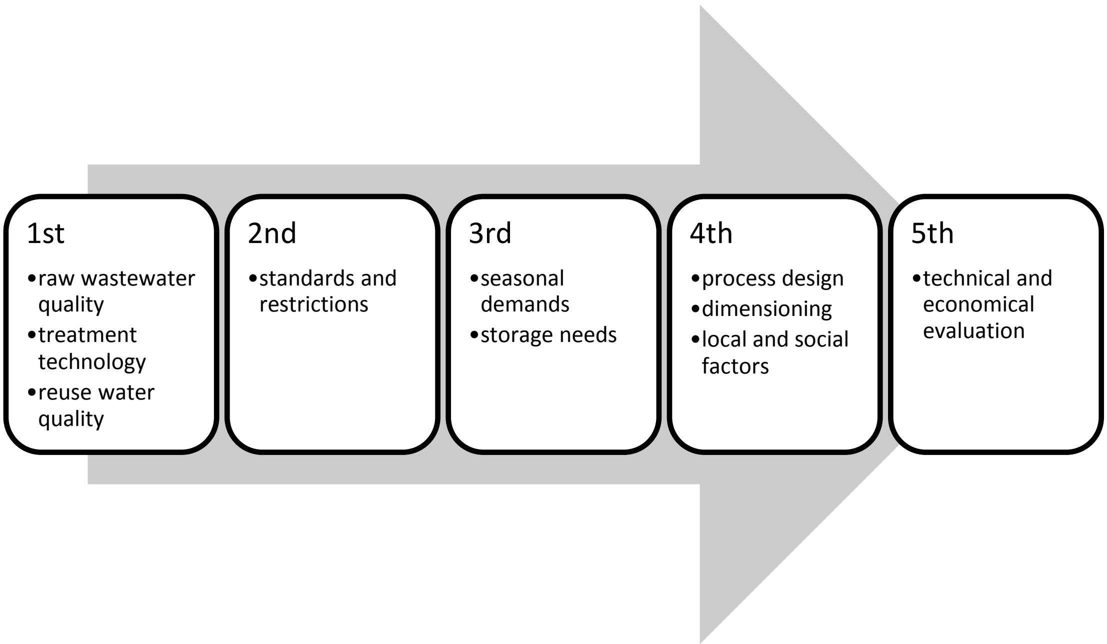

Figure 2 Main steps to select the most feasible wastewater treatment for reuse (adapted from Lazorava and Bahri, 2005)

2.4 Public Perspective on Wastewater Reuse

In addition to the water quality requirements for wastewater reuse, there are significant social aspects that should be focused for a wastewater reuse project. There are common misconceptions that wastewater reuse includes dirty or untreated wastewater that must be solved. Important issues that influence public acceptance of water reuse projects include (1) understanding of local water supply shortages and consciousness of reused water as having a place in the overall water supply allocation scheme; (2) understanding of the quality of reused water and (3) how it would be applied and used, and (4) confidence in the sufficiency of regulations and their implementation (Tchobanoglous and Burton, 1991). There are many studies assessing public perceptions of such reclamation schemes with a survey. As a response to a survey conducted in Greece, 60% reacted positively to the principle of wastewater reuse; however the perspective changes when applications were explained specifically (Kantanoleon, 2007). In California, a company has been irrigating broccoli, celery, and sweet corn with reclaimed water for several years. In 1983 individuals were interviewed regarding the use of reclaimed water for vegetable irrigation. One hundred and forty-four interviews were conducted with brokers, receivers, buyers and store managers. The primary focus of the interviews was the need or desire to label produce grown with reclaimed water. The responses indicated the product would be accepted (64%), and that labels would not be considered necessary (68%) (U.S. EPA, 2004). In the United States, a three phase research on public perception and participation in water reuse was made. It was determined that the public acceptance of wastewater reuse is higher when (1) the degree of human contact is minimal, (2) the quality of reclaimed water is high, (3) protection of public health and environment is clear, (4) the community is aware of water supply limitations and (5) the niche role of reclaimed water, and (6) when the public has confidence in the costs of treatment technologies, distribution systems and local management (Hartley, 2006). Beside brokers and receivers, farmers are also stakeholders in the reuse of treated reclaimed water for irrigation. In another study, Jordanian farmers were interviewed to explore how they perceive the quality of reclaimed water. Of the 11 farmers interviewed who irrigate with reclaimed water directly near treatment plants, responses of 10 indicates reclaimed water positively. In contrast, 27 of the 39 farmers who use reclaimed water indirectly (after it is diluted with fresh water) viewed the resource negatively, although 23 of the indirect reuse farmers also noticed the nutrient benefits for crops (Carr et al., 2011).

2.5 Economic Concerns of Wasrewater Reuse

The optimal wastewater reclamation is affected by costs, hazards and benefits. If the treatment level decreases, fertilization costs also decrease by increasing available nutrients in the wastewater. Additionally irrigation costs decrease depending upon the lower water prices. According to Haruvy's study (1998) wastewater reuse for irrigation saves 0.50-0.60 $\$/m^3$ compared to river disposal use. Another study shows that net benefit of wastewater reuse in morocco is at least 2.035 billion USD % of GDP (2008) (Kfouri, 2010). On the other hand agricultural yields or prices could increase/decrease according o nutrient balance between crop need and available in water (Haruvy et al., 1999).

Moreover wastewater reuse for irrigation provides more efficient water withdrawal rather than other freshwater withdrawal for agriculture. Thereby agricultural wastewater reuse has a big potential to bring out economic advantages (Khouri et. al, 1994).

2.6 Water Reuse Applications

2.6.1 Water Reuse Applications from World

Wastewater and agriculture are two sectors where the economic and environmental benefits have been represented through case studies around the world. It has been shown that the nutrients found in wastewater can increase productivity as much more than a combination of tap water and chemical fertilizer. (Mohammad and Ayadi, 2005; WHO 2006; Kiziloglu et. al., 2008).

There are many cases of modeling wastewater treatment systems for the reuse of treated wastewater around the world. The following cases are well documented in literature and represents important results for wastewater reuse.

A neural network model has been studied to predict nitrogen presenting in treated effluent to be used in aquifer recharge and/or agriculture rrigation. Nitrogen concentrations have been predicted by using a set of operational pa rameters which are ORP, pH, DO, NH_4-N, NO_3-N and BOD. Beside these parameters, the rainfall index has also been included to modeling and this has provided the flexibility in decision-making process. As a result neural networks model has been reported as a useful tool for water reuse practices to provide cost savings (Chen et al., 2003).

In a different study, a mixed integer linear program has been used in order to overcome ignored constraints and expensive piping systems. In this program only accessible data has been used (i.e. process location, current water demand, and information on reuse possibilities of wastewater sources). In this study model has been applied into an industrial case by generating various reuse scenarios and results are compared according to economical, ecological and technical aspects (Jödicke et al., 2001).

In another study, it has been stated that a decision support tool would be beneficial for both design and operation during the planning phase of a wastewater treatment plant and for the evaluation of new operational strategies. An integrated performance index for cost function has been developed in this study. It was emphasized that effluent quality, energy costs, costs for chemicals and investment cost should be the components of such models to minimize the cost (Vanrolleghem et al., 1996).

In a study carried out in Europe, wastewater reuse potential estimation has been investigated. A model based on analysis of water availability, water demand and treated effluent has been developed. Results depicted that there is an important potential for water reuse in Europe, specifically in Mediterranean region due to increased wastewater treatment capacity and increased demand for irrigation and groundwater recharge (Hochstrat et al., 2005).

In Pakistan 26% of national vegetable production is irrigated with wastewater (Ensink et al., 2002). In Hanoi, Vietnam, 80% of vegetable production is from urban and peri-urban areas irrigated with diluted wastewater (Lai, 2002). In Ghana, informal irrigation involving diluted wastewater from rivers and streams occurs on an estimated 11.500 ha, an area larger than the reported extent of formal irrigation in the country (Keraita and Drechsel, 2002). In Mexico about 260.000 ha are irrigated with wastewater, mostly untreated (Mexico - Comision Nacional del Agua, 2004). Israel and Tunisia have adopted a national water reuse policy by which 25% of total water demand will be satisfied from reclaimed water. (Lazarova et al., 2001) In Jordan, treated domestic wastewater (reclaimed water) already provides a valuable contribution to the annual water budget and ensures the continuation of agriculture in parts of the country (Carr et al., 2010; Haddadin et al., 2006). In Spain, there are more than 100 reuse schemes in operation for irrigation on farms, golf courses and parkland (Lazarova et al., 2001). France is not a country where direct reuse of wastewater for irrigation is a primary solution for water source management, however spreading wastewater on areas, such as agricultural use, is a traditional practice within the bounds (Bontoux and Courtois, 1996). In Greece more than 83% of the treated wastewater generated in regions which has a deficient water balance, is reclaimed in these areas to satisfy the demand (Angelakis et al., 1999; Bakopulou et al., 2011).

2.6.2 Water Reuse in Turkey

The use of reclaimed water for irrigation in Turkey is mainly due to the scarcity of water resources and inefficient water resource management, both of which are increased by growing population, economic conditions and increasing urbanization (Çakmak and Aküzüm, 2006).

Domestic wastewater contains nutrients, which are essential for plant growth; it can be used after treatment as a water source in a more convenient way. Especially in arid summer times in which irrigation activities increase for agricultural production, wastewater can be reused for irrigation.

Most of the wastewater reclamation applications for agricultural irrigation are of small scale in Turkey. In most cases, treated wastewater is discharged to a receiving environment such as creek or stream. Farmers generally withdraw water from these water bodies to irrigate their lands; therefore, wastewater is reused indirectly for agricultural purposes (Medaware, 2003).

However, in recent years studies in water reuse has gained importance in Turkey. The following cases represent wastewater reuse studies from Turkey.

In a study, current situation of urban wastewater treatment plants were summarized and detailed information about influent and effluent quality of four selected wastewater treatment plants were given. According to legislation discharge qualities were assessed and it was concluded that effluent quality is suitable for conventional parameters and heavy metals. However bacteriological quality is not suitable in terms of fecal coliform content due to disinfection inadequacy. To overcome this problem operational changes have been offered as a recommendation for future studies (Arslan-Alaton et al., 2007).

In another study, Konya has been selected for agricultural water reuse due to its semi-arid land type. Firstly characteristic of wastewater has been determined and then treatment types have been assessed according to their efficiency for reuse of discharge as irrigation water for agriculture. As a result, salt has been determined above the limits. Therefore, it was recommended that plant type should be selected regarding salt if this water is used for irrigation. Beside this, importance of storage has been emphasized such that more than 33.000 ha can be irrigated if the effluent is stored for a year (Aydın and Özcan, 2009).

During design phase of a wastewater treatment plant for the purpose of reuse cost is one of the most important parameter for the decision makers. For this purpose a cost function based on population has been developed. Investment costs (constructional and mechanical/electricity) for three different technologies (i.e. activated sludge, extended aeration activated sludge and biological nutrient removal) can be determined by developed functions using population information (Erdoğan et al., 2006).

In another study, possible reuse for projected eight wastewater treatment plants has been identified in İstanbul. After that some of the plants have been eliminated from future assessments due to their location, treatment size or both. Specific reuse applications for remaining four plants (Tuzla, Küçükçekmece, Büyükçekmece and Ömerli) have been determined and it is concluded that possible reuse applications consider almost all types of reuse such as industrial, urban, groundwater recharge, recreational and augmentation with some additional treatment depending on the reuse purpose (Tanik et al., 2005).

The possibility of reuse option for Konya which has the most agricultural land in the Turkey has been conducted. The results indicated that effluent from the city meets the irrigational demand especially for grain and sugar beet crops. Since Konya has a semi-arid climate and subject to water scarcity in near future, such a reuse application for irrigation could be an economic and ecological solution to the wastewater disposal (Sarikaya et al., 1998).

The latest study conducted in Konya considers urban reuse such that effluent from Konya Wastewater Treatment Plant, which has been taken into operation in 2010 with a capacity of 200.000 m^3/day, is planned to be used for parks, landscaping area and refuge after tertiary treatment. For this study a pilot plant has been established with a 2 m^3/h. It was concluded that 3.600 m^3 water source could be provided daily for Konya city. As a first stage of the implementation project 22 km network will be built for irrigation of urban green areas (Nas et al., 2011).

2.7 Water Budget of Turkey

Turkey covering approximately 78 million ha with a coastline extending along the Black Sea, the Sea of Marmara, the Aegean Sea and the Mediterranean Sea, has a unique position connecting Europe and Asia, geographically as well as ecologically.

Approximately one third of the total area, 28 million ha, is used by agricultural activities. According to the field studies, area that can be irrigated technically and economically with existing water sources has been calculated as 8,5 million ha (State Hydraulic Works, 2011). The existing and projected situation of the irrigated area is summarized in Table 1.

Table 1 Land use in Turkey (State Hydraulic Works, 2011)

Agricultural area	28.05 million ha
Area than can be irrigated	25.75 million ha
Dry agriculture area	7.25 million ha
Projected area than can be irrigated	8.5 million ha
Irrigated area	5.42 million ha

Turkey's water budget is summarized in Table 2. In Turkey average annual rainfall is approximately 643 mm and this corresponds to 501 billion m^3 water. 274 billion m^3 of this water returns back to atmosphere through evaporation from soil and water surface and plants; 69 billion m^3 water feeds groundwater and 28 billion m3 of this water is added to surface water again through springs; 158 billion m^3 water discharges to sea and lakes in closed basin. Additionally there is 7 billion m^3 water coming from neighboring countries to our country. Therefore gross water budget of Turkey is 193 (158+28+7) billion m^3 (State Hydraulic Works, 2011).

Table 2 Water budget of Turkey (State Hydraulic Works, 2011)

Average annual rainfall	643 mm/year
The surface area of Turkey	783.577 km^2
Annual rainfall amount	501 billionm^3
Evaporation	274 billion m^3
Underground infiltration	41 billion m^3
Surface water	
Annual surface runoff	186 billion m^3
Available surface water	98 billion m^3
Groundwater	
Annual withdrawable water	14 billion m^3
Total available water (net)	112 billion m^3

Total renewable water resource potential of our country is calculated as 234 billion m^3 when the 41 billion m^3 water feeding groundwater is taken into consideration. However, there are some technical and economical concerns that have to be taken into consideration while computing water potential. When the technical and economical concerns are noticed, annual consumable surface water potential would be 98 billion m^3 with 95 billion m^3 water coming from rivers and 3 billion m^3 water coming from neighboring countries. Therefore sum of the surface water (98 billion m^3) and groundwater (14 billion m^3) potential is 112 billion m^3 (SHW, 2011).

Countries are classified according to their water budget; extreme water poor, water poor and water rich countries (Feitelson and Chenoweth, 2002; Lawrance et al., 2002).

- Extreme water poor: less than 1.000 m^3 / cap*year
- Water poor: less than 2.000 m^3/cap*year
- Water rich: between 8.000-10.000 m^3/cap*year

According to this classification, Turkey is not a water rich country. Turkey can be classified as country of water scarcity with a water budget of 1.652 m3/cap*year (State Hydraulic Works, 2011). According to Turkish Statistical Institute (TSI) the population of Turkey would be 100 million in 2030. Therefore available water per capita would be 1.020 m^3/year in 2030 (TSI, 2011). However this calculation has been carried out without taking into consideration the changes in population growth and the water consumption practices. When all of these are considered the stress on the water resources would increase. Therefore, water resources should be protected and managed properly to leave enough and healthy water for future generations.

2.8 Wastewater Production in İzmir

Izmir is one of the largest metropolitan cities of Turkey and its population reaches to 3.5 million with an annual growth rate of 22% (TSI, 2009). İzmir city is located on the Aegean coastline and it is entryway between the Aegean and Central Anatolia. When its climate is examined it would be seen that characteristics of Mediterranean climate is dominated such as hot, dry summers and warm, wet winters (Şimşek & Gündüz, 2006).

İzmir Metropolitan Municipality gives priority to environmental protection and the total number of wastewater treatment plants reached to 22 at the end of 2010. Amount of treated wastewater reaches to 256.7 million m^3 in 2009. When the treatment method is evaluated, it is seen that 12 plants are operated with advanced biological treatment level, 6 plants are operated with activated sludge system, 3 plants are operated with stabilization pond and remaining plant treats wastewater by biodisc (İZSU, 2011). All plants, their capacities, population served and treatment methods are summarized in Table-3.

İzmir Metropolitan Municipality gives importance to water reuse, therefore 5 of 22 plants were designed to be used for irrigation. These plants are Bayındır, Ayrancılar-Yazıbaşı, Torbalı, Menemen and Kemelpaşa wastewater treatment plants. When capacities of these plants are considered, it is seen that total treated wastewater that could be used for irrigation is more than 25 million m^3 per year. With rapid social and economical development, İzmir is a candidate city facing a shortage of water. Thereby, such amount of water is non-negligible as an alternative source for irrigation in İzmir.

2.9 Agriculture in Izmir

Approximately 19 percent of the population involved with agricultural production in Izmir. Izmir's total surface area is 1.201.200 hectares, 40.85 percent of forest area, 29.22% of agricultural area, the remaining 29.93% and other areas are the grassland. Farming area has the most portions (154.770 hectares) in agricultural areas.

In Izmir, there are 26 farming area, and 28 kind of fruits and 41 kind of vegetables are grown. When the irrigation water of Izmir is assessed, total agricultural area is 350.984 hectares, irrigated area is 183.252 hectares and uirrigated area is 167.732 hectares (Izmir Special Provincial Administration, 2009).

Table 3 İzmir-Wastewater treatment plants (İZSU, 2011)

No	WWTP	Location	Capacity m3/day	Population served capita	Operation year	Treatment method
1	Çiğli	Çiğli	605.000	3.000.000	2000	Advanced Biological
2	Güneybatı	Narlıdere	21.600	100.000	2001	Advanced Biological
3	Havza	Menderes	21.600	100.000	2004	Advanced Biological
4	Bağarası	Foça	2.100	10.500	2007	Activated sludge
5	Halilbeyli	Kemalpaşa	1.300	5.500	2007	Activated sludge
6	Kozbeyli	Foça	500	2.100	2007	Activated sludge
7	Balıklıova	Urla	1.000	5.000	2008	Stabilization pond
8	Foça	Foça	9.763	57.000	2008	Advanced Biological
9	Gümüldür	Menderes	960	4.000	2008	Activated sludge
10	Hacıömerli	Aliağa	250	1.250	2008	Biodisc
11	İYTE	Urla	2.250	22.500	2008	Activated sludge
12	Selçuk	Selçuk	10.200	50.000	2008	Stabilization pond
13	Ürkmez	Seferihisar	2.000	10.000	2008	Stabilziation pond
14	Urla	Urla	21.600	100.000	2009	Advanced Biological
15	Bayındır	Bayındır	6.912	40.000	2009	Advanced Biological
16	Ayrancılar Yazıbaşı	Torbalı	6.912	40.000	2009	Advanced Biological
17	Gödence	Seferihisar	250	1.250	2010	Activated sludge
18	Torbalı	Torbalı	21.600	100.000	2010	Advanced Biological
19	Menemen	Menemen	21.600	100.000	2010	Advanced Biological
20	Seferihisar	Seferihisar	10.800	50.000	2010	Advanced Biological
21	Kemalpaşa	Kemalpaşa	12.960	70.000	2010	Advanced Biological
22	Aliağa	Aliağa	21.600	100.000	2010	Advanced Biological
TOTAL		**-**	**802.757**	**3.969.100**	**-**	**-**

2.10 Water Reuse Quality Criteria- Regulatory Framework

There are many water and sanitation laws in Turkey, and many institutions are charged with developing policies for water supply and sanitation or for regulating the sector. Local governments play a substantial role in the sector as service provider, partially mobilizing resources for investment financing from their own revenues and being responsible for the detailing of location-specific Master Plans, feasibility studies and for the invention of the necessary works.

At the national level, a number of government entities form the institutional framework of the sector.

The major ministries related with water, wastewater and agricultural irrigation and their responsibilities could be summarized as follows. The Ministry of Health (MoH) has the responsibility of performing analysis related to water quality. The Ministry of Environment and Urbanization (MoES) is in charge of financing water and wastewater infrastructures and giving technical support. The Ministry of Energy and Natural Resources (MoENR) is in charge of investigating, planning and management of water resources for irrigation, community water supply and energy production. The Ministry of Forestry and Water Hydraulics (MoFWH) sets relevant standards for environmental pollution control, carries out inspection of pollution sources and routinely monitors the quality of water resources. The Ministry of Food, Agriculture and Livestock (MoFAL) has the responsibility of determining and implementing plans and policies on agriculture and agricultural irrigation.

The Turkish laws and regulations related with wastewater treatment, disposal and reuse are summarized in Table-4.

Table 4 Turkish laws and regulations related with wastewater treatment, disposal and reuse

Year	Establishment	Law/Regulation/Bulletin
1983	MoFWH	Environment Law
1988	MoFWH	Water Pollution Control Regulation (WPCR)
1989	MoFWH	WPCR Administration Aspects Bulletin
1989	MoFWH	WPCR Toxic and Hazardous Substances in Water Bulletin
1991	MoFWH	WPCR Technical Aspects Bulletin
1995	MoARA	Aquatic Products Regulation
2001	MoFWH	Environmental Inspection Regulation
2004	MoFWH	Water Pollution Control Regulation (WPCR)
2002	MoFWH	Environmental Impact Assessment Regulation
2010	MoFWH	Urban Wastewater Treatment Regulation
2010	MoFWH	UWTR Technical Aspects Bulletin

Rules on wastewater treatment and water pollution control are determined by the Water Pollution Control Regulation (WPCR), issued by MoFWH in 2004. According to this regulation surface waters are divided into four categories in terms of their inherent quality. Ambient quality standards are set for each category with reference to the quality and usage of a particular water body. The 1991 Water Pollution Control Regulation Technical Aspects Bulletin (WPCR-TAB) contains quality criteria to be used for categorizing agricultural irrigation waters and identifies important parameters and criteria to be followed in assessing wastewaters in irrigation. The criteria are indicated in table format, the maximum permissible heavy metal and toxic element concentrations and the maximum permissible levels for Boron; as well as suitability criteria for industrial effluents in irrigation. Moreover, the bulletin states the criteria for deciding whether domestic wastewaters may or may not be used for irrigation without disinfection in irrigation waters.

Tables and figures of WPCR and WPCR-TAB, which include standards and constraints related with wastewater, are summarized in Appendix A.

In addition to Water Pollution Control Regulation, a new regulation namely Urban Wastewater Treatment Regulation (UWTR) has been issued by MoFWH on March, 2010. According to this regulation reclamation of treated wastewater is subjected to "Article 28 of Water Pollution Control Regulation" at the moment. However it is stated that below requirements regarding wastewater treatment and reuse of treated wastewater will be valid after 2012. In this study, both WPCR and UWTR Technical Aspect Bulletin have been taken into consideration.

Tables of UWTR, which include standards and constraints related to wastewater reuse, are summarized in Tables 5-6.

Table 5 Requirements for discharges from urban wastewater treatment plants*
(UWTR, 2010)

Parameters	Concentration(mg/l)	Minimum percentage of reduction(%)	Reference method of measurement
Biochemical oxygen demand (BOD_5 at 20°C) without nitrification	25	70-90 8 (c) under Article 40	Homogenized, unfiltered, undecanted sample. Determination of dissolved oxygen before and after five-day incubation at 20°C ± 1°C, in complete darkness. Addition of a nitrification inhibator.
Chemical Oxygen Demand (COD)	125	75	Homogenized, unfiltered, undecanted sapmle Potassium dischromate
Total Suspended Solids (TSS)	35 8 (c) under Article 35 (more then 100.000 p.e.) 8 (c) under Article 60 (2000-10000 p.e.)	90[2] 8 (c) under Article 90 more then 100.000 p.e.) 8 (c) under Article 70 (2000-10000 p.e.)	-filtering of a representative sample through a 0,45 μm fitler membrane. Drying at 105 °C and weighing -centrifuging of a representative sample (for at least five minutes with mean acceleration of 2800 to 3200 g), drying at 105°C and weighing.

** the values for concentration or fort he percentage of reduction shall apply.*

[1] the parameter can be replaced by another parameter: total organic carbon (TOC) or total oxygen demand (TOD) if a relationship can be established between BOD_5 and the substitute parameter.

[2] this requirement is optional

Table 6 Requirements for advanced treatment discharges from urban wastewater treatment plants * (UWTR, 2010)

Parameters	Concentration	Minimum percentage of reduction(%)[1]	Reference method of measurement
Total phosphorous	2 mg/l P (10.000-100.000 p.e.) 1 mg/l P (more than 100.000 p.e.)	80	Molecular absorption spectro-photometry
Total nitrogen[2]	15 mg/l N (10.000-100.000 p.e.) 10 mg/l N (more than 100.000 p.e.)[3]	70-80	Molecular absorption spectro-photometry

[1] Reduction in relation to the load of the influent

[2] Total nitrogen means: the sum of total Kjeldahl-nitrogen (organic N+ NH_3), nitrate (NO_3)-nitrogen and nitrite (NO_2) –nitrogen

[3] Alternatively, the daily average must not exceed 20 mg/L N. This requirement refers to a water temperature of 12 ^oCor more during the operation of the biological reactor of the waste water treatment plant. As a substitute for the condition concerning the temperature, it is possible to apply a limited time of operation, which takes into account the regional climatic conditions.

CHAPTER 3

METHODOLOGY

This chapter presents the methodology used in this study. In the first part of this chapter, the general framework of the study and an overview for three case studies are presented. In the second part, the method of crop water and nutrient demand determinations are presented. Finally, in the third part of this chapter, the modular design approach for wastewater treatment plant and its application for three case studies are given.

3.1 General Framework of the Study

Figure 3 illustrates the general framework used in this study. Its objective is the determination of agricultural water demand for a certain location and to provide wastewater of certain quality by using modular design approach to satisfy this demand. The first part of this framework included developing modules to be used, selection of WWTPs and the data collection. In the second part, water and nutrient demands have been determined for several crops grown in the area of study (Menemen, Bayındır and Selçuk) and modules for wastewater treatment plant design has been used. In the third part an optimization study has been made for the wastewater treatment plant's operation to provide irrigational reuse at desired quality and according to this optimization a wastewater reuse scheme has been developed. This framework has been applied to three different wastewater treatment plants, namely Menemen, Bayındır and Selçuk.

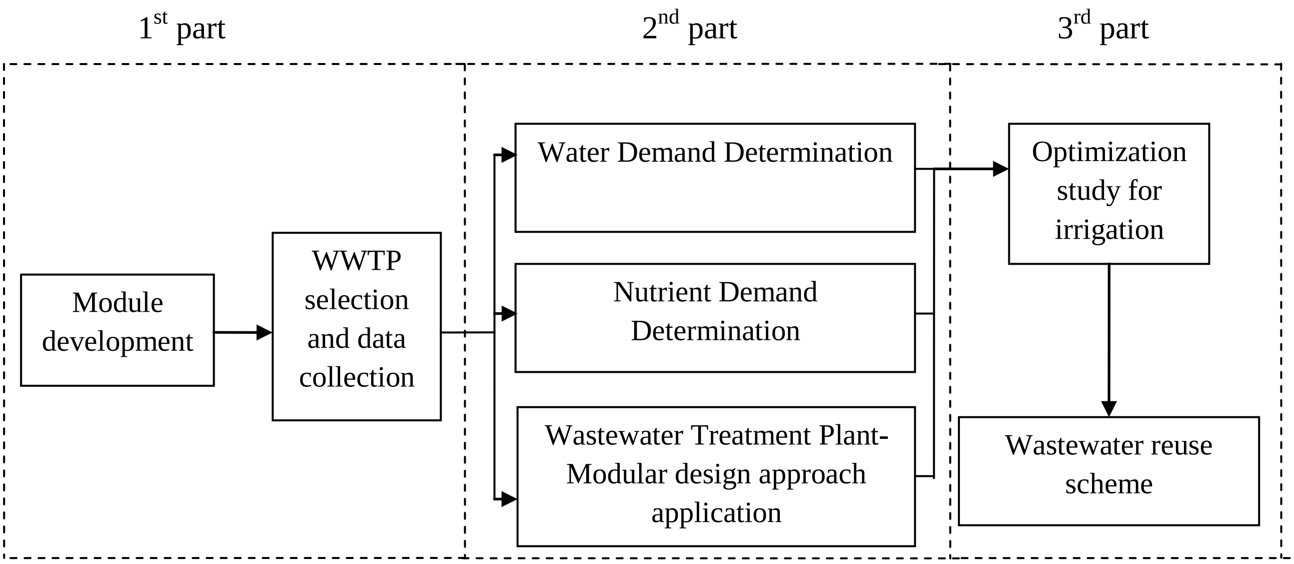

Figure 3 General framework of the study

An overview for three cases is presented as follows.

- *Menemen Wastewater Treatment Plant*: It is one of the largest municipal wastewater treatment plants in İzmir which is located nearby Günerli and serves to 100.000 population equivalent. Wastewater is planned to be used for reclamation in agricultural area after being treated and disinfected. During the site visit, it has been observed that farmers draw water from sanitary sewage directly or from the end of pipe of the treatment plant in order to use for agricultural purposes. For this reason, employees of the Menemen Wastewater Treatment Plant also stated that necessary precautions should be taken urgently and reclamation studies should be started. The details regarding optimization studies are given in section (Chapter 4). Location of the Menemen is shown in Figure 4.
- *Bayındır Wastewater Treatment Plant*: It serves to Bayındır town and neighborhood settlements with 40.000 population equivalent. The treated and disinfected wastewater is planned to be used for reclamation as is the case of Menemen Wastewater Treatment Plant. During the site visit, it has been learned that agriculture is the main branch of the agriculture and it needs irrigation water approximately for 12 months. For this reason, employees of

the Bayındır Wastewater Treatment Plant stated that reclamation of treated wastewater would be very important for the people who are interested in this sector. More details regarding optimization studies are in following sections (Chapter 4). Location of the Bayındır is shown in Figure 4.

- *Selçuk Wastewater Treatment Plant*: This wastewater treatment plant serves to Selçuk town with 50.000 population equivalent. The difference of this plant from other two plants is that its wastewater treatment is based on stabilization pond rather than activated sludge. Besides, its effluent wastewater quality does not meet the discharge standards for BOD_5 and COD (Table 5-6). That's why direct reclamation is impossible. Therefore, different wastewater treatment technologies (activated sludge and trickling filter) have been applied for this case during modular design approach phase. The details regarding optimization studies are given in fallowing sections (Chapter 4). Location of the Selçuk is shown in Figure 4.

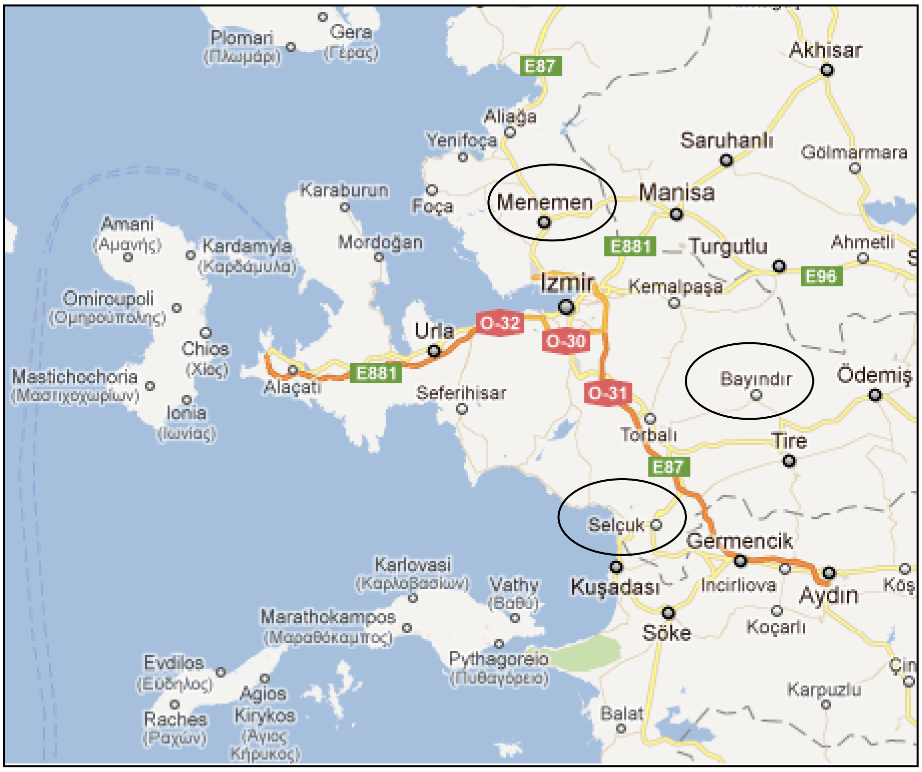

Figure 4 The location of three cases

3.2 Water Demand Determination-CROPWAT Model

CROPWAT is a software used for irrigation planning and management developed by several scientists (Doorenbos and Pruitt, 1976 and 1977; Smith et al., 1991; Smith, 1992, 1993). Its main use is to determine irrigation water demand for different crops on monthly basis. This model can be considered as a decision support tool for irrigation planning and management. Irrigation schedules for different management conditions and different water supply scheme for varying crop patterns can be developed by using this program.

The CROPWAT 8.0 model calculates crop water requirement for a selected type crop or it can provide a total supply scheme, which is basically the combined crop water requirements of multiple crops (FAO, 2006). The CROPWAT 8.0 model interfaces for determining crop water demand are given in Appendix B.

3.2.1 Irrigation Water Demand Calculation

Irrigation water demand is calculated by the Penman-Monteith approach which is reported by the Paper No. 56 of the Food and Agriculture Organization of the United National (FAO, 1998). The equation is;

$$ET_0 = \frac{0.408\Delta(R_N - \mathrm{G}) + \gamma\frac{900}{T+273}U_2\,(e_a - e_d)}{\Delta + \gamma(1 + 0.34U_2)} \quad \text{(Eqn-1)}$$

where,

ET_0= reference crop evapotranspiration (mm d^{-1})

R_N= net radiation at crop surface (MJ^{-2} d^{-1})

G= soil heat flux (MJ^{-2} d^{-1})

T= average temperature (^{o}C)

U= wind speed measured at 2 height (m s^{-1})

(e_a-e_d)= vapor pressure deficit (kPa)

Δ = slope of the saturation vapour pressure temperature ($kPa^{o}C$)

γ = psychometric constant ($kPa^{o}C$)

Effective precipitation means useful rainfall for crops. Total precipitation is not utilizable at the amount in which it is received. Effective rainfall is evaluated by using rainfall, losses beyond the root zone, soil moisture uptake by crop for evapotranspiration. Effective rainfall in this thesis was determined by using “rain model” of the CROPWAT 8.0 model.

Irrigation requirements of each crop were estimated by subtracting effective precipitation from evapotranspiration;

$$Irr = \mathrm{A}\sum_{i=1}^{365}\left(ET_0 * K_c - P_{eff}\right) \qquad \text{(Eqn-2)}$$

where,

Irr = irrigation requirement (m^3/year)

A = cultivated area (percentage of 100% total area)

ET_0 = evapotranspiration (mm/day)

K_c = crop coefficient

P_{eff} = effective rainfall (mm/day)

3.2.2 Input and Output CROPWAT Data

Input and output data of the CROPWAT 8.0 model are shown in Table 7. The CROPWAT 8.0 model requires three type data, namely climatic, crop and soil data. The climatic data was gathered from İzmir Soil and Water Resources Research Institute (2008) and prepared as input data for CROPWAT 8.0 Model. In addition to climatic data, some other data such as latitude, longitude, and altitude were used in the CROPWAT 8.0 model (All needed data are in the Appendix C). Crop data including crop type, planting date and cultivated area was taken from Topraksu (2008) database. However, crop pattern including crop coefficient data including Kc values, stage days, root depth, depletion fraction, and Ky values were provided from the CROPWAT 8.0 model database since they were not available for the region studied. As soil data, total available soil moisture, maximum rain infiltration rate, maximum rooting depth, and initial soil moisture depletion were selected from FAO manual by using latitude and longitutude of the region studied (Allen et al., 1998).

Table 7 The input and output data of the CROPWAT model (FAO, 2006)

Data	Input	Output
Climatic	-Monthly rainfall data -Monthly means of minimum temperature, maximum temperature, air relative humidity, sunshine duration, wind speed -Potential evapotranspiration measured or calculated with Penman-Monteith	-Crop water requirement - Irrigation requirement
Crop	-Sowing date -Crop coefficient -Crop description: according to the observed crop phenology - Percent area covered by plant	Actual crop evapotranspiration
Soil	-Initial soil moisture condition -Maximum root infiltration rate - Maximum rooting depth	-

3.3 Nutrient Demand Determination

The assessment of the fertilizer demand should be based on the actual fertilization practice by evaluating the field record systems (Klein et al., 2010). Since the data was not available for the selected regions for this study, literature values for fertilizer demand were combined with recommendations concerning the application time(s) to create the nutrient demand on at least a monthly base (Klein et al., 2010). There are 5 main crops cultivated in İzmir, namely cotton, corn, fruit (mandarin orange, peach, citrud), vegetable (tomato) and vineyard. Phosphorous and nitrogenous requirement for these crops have been taken from Topraksu database (Table 8-9) (Topraksu, 1983). In general, phosphorous and nitrogen demand calculations are made with the unit of “kg/da”. In order to show nitrogen and phosphorous content coming from treated wastewater, “kg/L” is selected for this study. Phosphorous requirement has been calculated by using the molecular weight of P_2O_5 and percentage of P (43 %) existing in the P_2O_5. Nitrogenous requirement has been taken from Topraksu database directly. Application amounts and times have been determined by using field record system defined in Klein et al. (2010) (Table 10-11). Then phosphorous and nitrogenous amount coming from irrigation water (Table 13) has been calculated by using crop water demand (Table 12) (Eqn-3). Crop water demand has been calculated by taking average values of the crop water demand results of four year data (2007-2010).

Table 8 Yearly phosphorous (P) requirement for 5 main crops (Topraksu, 1983)

Crops	**P_2O_5 requirement (kg/L)**	**Pure P (kg/L) (43 % P_2O_5)**
Cotton	60	25.8
Corn	60	25.8
Fruit	80	34.4
Vegetable	60	25.8
Vineyard	70	30.1
Total	330	141.9

Table 9 Yearly nitrogenous (N) requirement for 5 main crops (Topraksu, 1983)

Crops	**N requirement (kg/L)**
Cotton	100
Corn	110
Fruit	80
Vegetable	110
Vineyard	120
Total	520

Table 10 Application amounts and times of the Phosphorous (all units are kg/L)

Crops	Jan	Feb.	Mar.	Apr.	May-Jun-Jul-Aug-Sept-Oct-Nov-Dec
Cotton	-	12.9	12.9	-	-
Corn	-	12.9	12.9	-	-
Fruit	-	17.2	17.2	-	-
Vegetable	-	-	12.9	12.9	-
Vineyard	-	-	15.1	15.1	-

Table 11 Application amounts and times of the Nitrogen (all units are kg/L)

Crops	Jan	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug-Sept-Oct-Nov-Dec
Cotton	-	25	50	25	-	-	-	-
Corn	-	55	55	-	-	-	-	-
Fruit	-	20	20	-	20	20	-	-
Vegetable	-	-	20	30	20	20	20	-
Vineyard	-	-	30	30	30	30	-	-

Table 12 Water demand of 5 crops (output of the CROPWAT Model)

Crops	**Crop Water Demand (m^3/year) (2007-2010 Avg.)**
Cotton	4382
Corn	1669
Fruit	481
Vegetable	668
Vineyard	733

$$D = (W * N)/1000 \quad \text{(Eqn-3)}$$

where,

D = Nutrient amount coming from irrigation water (ton/year)

W= Crop water demand (m^3/year)

N= Nutrient demand (kg/L)

Table 13 Nutrient demand of five main crops and application times (İzmir) (Topraksu, 1983)

Months	P (ton/year)	N (ton/year)
Jan	0.0	0.0
February	172.6	421.9
March	212.0	711.7
April	39.4	303.2
May	0.0	89.9
June	0.0	89.9
July	0.0	26.7
August	0.0	0.0
September	0.0	0.0
October	0.0	0.0
November	0.0	0.0
December	0.0	0.0
TOTAL	424.0	1643.4

Since the case study areas, Menemen, Selçuk and Bayındır, are all in the similar region, it has been assumed that crop water demand is similar for all regions and all calculations were made according to this assumption. During water demand determination, five main crops (cotton, corn, fruit, vegetable and vineyard) have been taken into consideration. Four years of climatic data (2007-2010) have been taken into consideration for climatic data calculations (MTSKAE, 2010) (Appendix C).

3.4 Modular Design Approach for Wastewater Treatment

Wastewater should be treated at desired quality and monitored for irrigational reuse. There are many wastewater treatment technologies that can be used; however selection of the technology should be considered in terms of applicability and feasibility for a given set of conditions. The selection of which technology to use for wastewater reuse depends on raw wastewater and effluent quality, land availability for treatment plant, and both investment and operation cost.

For the purpose of this study, a modular design approach estimating available wastewater treatment options for a given set of water reuse conditions has been used. This modular design approach has been developed by Braunschweig Technical University within the scope of a Project-108Y142 supported by International Bureau of the BMBF (German Ministry for Education, Research and Technology) and by the Scientific and Technological Research Council of Turkey (TUBITAK). METU was the Turkish partner in this Project.

There are two main characteristics of the "modular design approach:

(1) it can be used for planning the operation mode of an existing wastewater treatment plant, and

(2) it can be used to compare different wastewater treatment technologies to achieve a certain objective.

It provides options linked to wastewater treatment technologies and comparison strategy among wastewater treatment technologies to achieve a certain water reuse requirement for irrigation. Furthermore, the modular design approach for wastewater treatment enables an easy and fast modification of the existing plant configuration and operational conditions.

In order to reuse treated wastewater for irrigation, a simple flowchart (Figure 5) has been prepared in this study. The flowchart mainly depends on whether there is a wastewater treatment plant and an agricultural area which is planned to be irrigated with treated wastewater. The following section and Figure 5 describes this flowchart, which was applied in this study.

1. If there is a wastewater treatment plant in the area which is planned to be irrigated with treated wastewater:
    a. Make necessary analysis of wastewater treatment plant effluent according to requirements mentioned in relevant legislation whether it is appropriate or not for irrigation.
        i. (YES) Prepare an operation schedule according to crop water and nutrients demand.

ii. (NO) There are two choices;

- ✓ Using modular design approach for wastewater treatment, change operational parameters of the existing wastewater treatment plant to obtain treated wastewater at desired quality

  or

- ✓ Using modular design approach for wastewater treatment, design a different treatment units by using the wastewater treatment modules available.

After desired quality of treated water is obtained, prepare an operation schedule for irrigation by using CROPWAT.

2. If there is not a wastewater treatment plant:

   a. Using modular approach designed for wastewater treatment plant; design a treatment plant according to water quality requirements and nutrients demand for reuse by using the wastewater treatment modules.

After desired quality of treated water is obtained, prepare an operation schedule for irrigation by using CROPWAT 8.0 model.

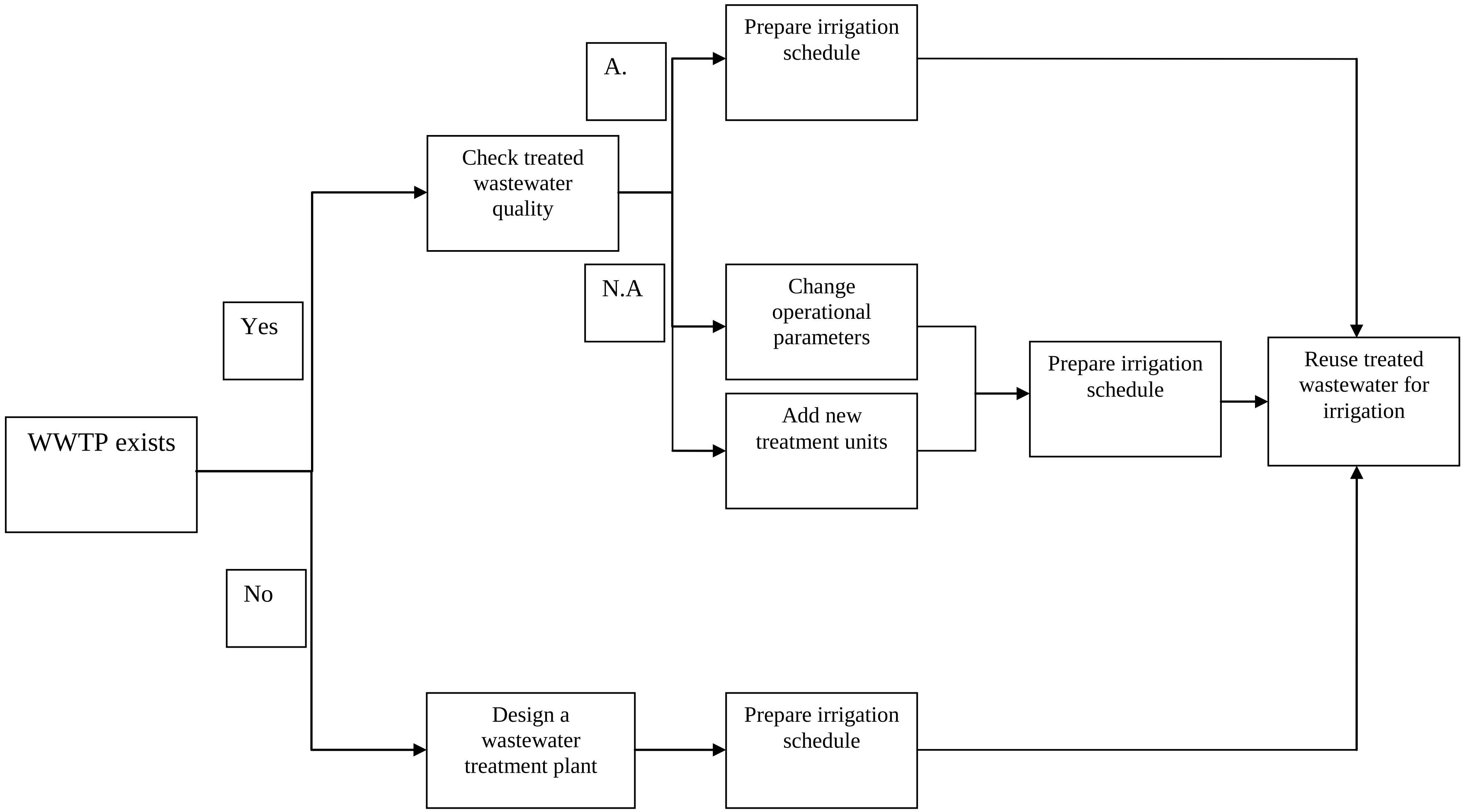

Figure 5 Flowchart of agricultural wastewater reuse (A: applicable, N.A: non-applicable)

The modular design approach developed for the wastewater treatment can be used to generate alternative scenarios for comparison (for design and cost). Different units of a wastewater treatment plant, such as primary sedimentation, activated sludge tank, anaerobic sludge stabilization or water disinfection unit can be designed separately by the help of the modular design approach. Moreover, the modular design approach can be used to design a complete treatment system by combining the modules to find the most effective method for a given set of conditions. As shown in Figure 6, modular design approach designed for wastewater treatment plants can be used for the optimization of an existing wastewater treatment plant as well as the design of new treatment plants.

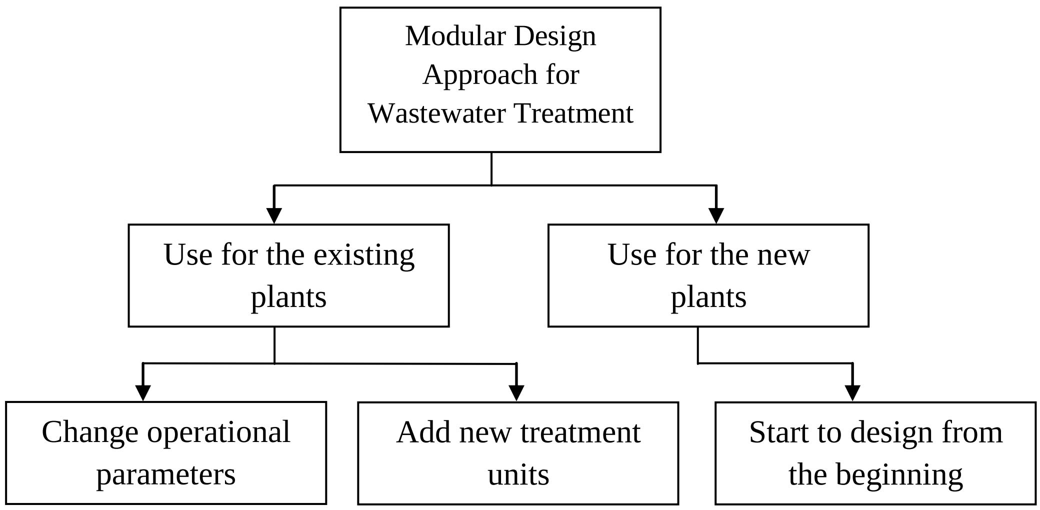

Figure 6 Modular design approach for wastewater treatment

By using modular design approach;

1) Wastewater treatment technologies can be compared in terms of their treatment performance and cost efficiency,
2) effects of operational changes on treatment performance and cost can be evaluated; changes of nitrogen and phosphorous amount among different configurations,

and,

3) operation conditions can be evaluated in terms of treatment efficiency. Moreover regional changes, such as temperature and unit costs, can be changed in the modular design approach for wastewater treatment and specific solutions can be generated for a set of conditions.

Actual data was used during the implementation phase (Figure 3- 2nd part) of the modular design approach for wastewater treatment plants. Therefore, related design calculations of the modular design approach, such as sizing, energy demand and cost analysis (Figure 3- 2nd part), could represent the reality as much as possible.

The modular approach of the wastewater treatment processes are based on Technical Procedures for Wastewater Treatment Plants (MoFWH, 2010), which is used as design standards in Turkey. Cost function (Eqn-4) has been taken from literature (Beckereit, 1988; Günthert, 1999) and investigations for different wastewater treatment facilities were updated according to actual construction cost indices, and used for all construction and machinery cost calculations (Arisu Co. Ltd., 2011).

$$C = 870 * V^{-0.173} \quad \text{(Eqn-4)}$$

where,

C: Volumetric investment for construction (€/m^3)

V: Volume of the treatment unit (m^3)

There are nine modules in the modular design approach for wastewater treatment plants. These modules can be collected under the wastewater treatment, sludge treatment, nutrient recycling and disinfection. Modules are given in Table 14 and an interface of modular design approach for wastewater treatment is shown in Figure 7. There are five modules for wastewater treatment; (1) Primary sedimentation, (2) Activated sludge process, (3) Trickling filter, (4) Stabilization Pond and (5) Anaerobic pretreatment. Modules (2) and (3) include secondary sedimentation and Module (2) includes anaerobic tank according to chosen elimination method of biological P-removal. There are two sludge stabilization method under the sludge treatment; Module (6) -Anaerobic sludge digestion and Module (7) - Aerobic sludge digestion. Nutrient recycling by recovery from liquids and solids is managed by Module (8). Lastly Module (9) UV Disinfection has been developed for disinfection. Modules can be used to combine different technologies for the selected set of conditions. The priorities in development of modules are set to instant result and easy-modification. Structure of the modular approach designed for wastewater treatment plants allows adaptations by changing parameters.

Table 14 Available modules for wastewater treatment plant

Wastewater treatment	**Sludge treatment**	**Nutrient recycling**	**Disinfection**
(1)- Primary Sedimentation	(6)- Anaerobic Sludge Digestion	(8)- Recovery from liquids and solids	(9)- UV Disinfection
(2)- Activated Sludge Process*	(7)- Aerobic Sludge Stabilization		
(3)- Trickling Filter Process*			
(4)- Stabilization Ponds			
(5)- Anaerobic Pretreatment			

*M2 and M3 includes secondary settling tanks, and M2 includes anaerobic tank according to chosen method of biological P-removal

Influent & Effluent Characterization

	Input load	Load after pretreatment	Effluent wastewater (Scenario1)	Effluent sludge (Scenario1)
BOD_5 [kg/d]	5,400	3,564	270	
COD [kg/d]	13,500	8,910	900	4,341
FiS/DS [kg/d]	9,000	3,213	96	
Ntot [kg/d]	3,600	2,376	234	160
Ptot [kg/d]	1,170	1,053	18	150
K [kg/d]	187	168	65	97
Mg [kg/d]	180	162	259	389
Ca [kg/d]	720	648	518	778
Sludge Amount [kg/d]				0

	Input load	Load after pretreatment	Effluent wastewater (Scenario1)	Effluent sludge (Scenario1)
BOD_5 [kg/d]	5,400	3,564	270	
COD [kg/d]	13,500	8,910	900	4,341
FiS/DS [kg/d]	9,000	3,213	96	
Ntot [kg/d]	3,600	2,376	234	160
Ptot [kg/d]	1,170	1,053	18	150
K [kg/d]	187	168	65	97
Mg [kg/d]	180	162	259	389
Ca [kg/d]	720	648	518	0
Sludge Amount [kg/d]				0

Model Outputs

Scenario2	
Investment costs [€]	1,411,219
Chemical costs [€/a]	70,368
Personal costs [€/a]	13,389
Operating costs [€/a]	1,171,101
Total costs [€/a]	1,447,073
Total area [m^2]	4,191
Energy demand [kWh/d]	29,168
Sludge disposal cost [€/a]	-
Total volume [m^3]	8,597
Energy Gain [€/a]	-

Scenario8	
Investment costs [€]	3,679,288
Chemical costs [€/a]	63,971
Personal costs [€/a]	57,367
Operating costs [€/a]	613,405
Total costs [€/a]	1,391,457
Total area [m^2]	13,206
Energy demand [kWh/d]	28,045
Sludge disposal cost [€/a]	560,334
Total volume [m^3]	56,275
Energy Gain [€/a]	64,381

Scenario List

Scenario 1	WASP+SST
Scenario 2	WASP+M
Scenario 3	EA
Scenario 4	TF
Scenario 5	SP
Scenario 6	EA+ Anaerobic Sludge treatment w/ Θc=25 days
Scenario 7	WASP+ Anaerobic Sludge treatment w/ Θc=10 days
Scenario 8	TF+ Anaerobic Sludge Treatment
Scenario 9	WASP+SST+Disinfection
Scenario 10	WASP+M+Disinfection
Scenario 11	EA+Disinfection
Scenario 12	TF+Disinfection
Scenario 13	SP+Disinfection
Scenario 14	EA+ Anaerobic Sludge treatment w/ Θc=25 days+Disinfection
Scenario 15	WASP+ Anaerobic Sludge treatment w/ Θc=10 days+Disinfection
Scenario 16	TF+ Anaerobic Sludge Treatment+Disinfection

Figure 7 Modules for Wastewater Treatment Plant

According to the given inflow data, the nine modules presented in Table 14 calculate the required size of the treatment units as well as the resulting output streams (liquid, solid and gas phase) and the energy demand. In addition to operational parameters, these nine modules provide the investment and operational costs of the wastewater treatment units or the cost of entire treatment system. The list of parameters needed to run the modules are given in Table 15.

Table 15 List of parameters needed to run the modules

Parameters	**Units**
Population equivalent	P.E
Daily water consumption	L/P.E*days
Biochemical Oxygen Demand (BOD_5)	mg/L
Chemical Oxygen Demand (COD)	mg/L
Total Suspended Solids (TSS)	mg/L
Total Organic Carbon (TOC)	mg/L
Total Kjeldahl Nitrogen (TKN)	mg/L
Total Phosphorous (TP)	mg/L
Potassium (K)	mg/L
Magnesium (Mg)	mg/L
Calcium (Ca)	mg/L
Nitrate (NO_3)	mg/L
Acid capacity	mmol/L

Modular design approach for wastewater treatment covers almost all parameters stated in the Technical Procedures for Wastewater Treatment Plants (MoFWH, 2010). Some parameters such as salinity has not been included, however such parameters can be added to the modules. This flexibility offered by modular design approach can be used when the modification of the existing tool is necessary.

There are many parameters which can be varied according to desired water quality. Treated wastewater quality as well as mass of the nutrients in liquid and solid phases can be set to desired levels by changing the operational parameters given in Table 16.

Table 16 List of parameters that can be changed in the modules

Parameters	**Units/Status**
Sludge age	days
Sludge volume index (SVI)	mL/g
Temperature	^{o}C
Thickening time	hour
Denitrification	Simultaneous/ without/ preanoxic
Chemical phosphorous removal	Yes /no
Biological phosphorous removal	Yes /no
Design parameters (outflow quality)	-
Population equivalent	P.E
Daily water consumption	L/P.E*days

When the modules are run with the parameters given in Table 15 and 16, they provide outputs for the wastewater treatment units. For example, when an activated sludge system is investigated, related results are taken from four modules; aerated grit chamber (if any), primary sedimentation tank, aeration tank and secondary sedimentation tank. The results taken from the modules are effluent phases (gas-liquid-sludge), dimensioning and cost (Table 17). Effluent phase results are output gas, liquid and solid phase. Dimensioning results include area and volume requirement of the treatment units and cost outputs include investment cost of construction and machinery, chemical, personal and operating (energy) cost. Outputs of the modular approach designed for wastewater treatment plants are given in Table 17.

Table 17 Output data of the modules

Effluent phases (Gas-Liquid-Sludge) [1]

Output gas phase	Output liquid phase	Output sludge phase
-N_2 -CO_2	-BOD_5 -TP -COD -K -TSS -Mg -TN -Ca	-COD -K -TN -Mg -TP -Ca -Total sludge amount

Dimensioning

Primary Sedimentation	Activated sludge process	Trickling filter
• Volume (m^3) • Area of primary sedimentation tank (m^2)	• Aeration tank volume (m^3) • Area of aeration tank (m^2) • Area of secondary sedimentation tank (m^2) • Anaerobic tank volume[2] (m^3) • Area of anaerobic tank[2] (m^2)	• Trickling filter tank volume (m^3) • Area of secondary sedimentation tank (m^2)

Dimensioning

Extended aeration	Stabilization pond	Sludge treatment	UV disinfection
• Aeration tank volume (m^3) • Area of aeration tank (m^2) • Area of secondary sedimentation tank (m^2) • Anaerobic tank volume [2](m^3) • Area of anaerobic tank[2] (m^2)	• Stabilization pond required area (m^2) • Volume of stabilization pond (m^3)	• Volume of digestion tank[3] (m^3)	-

Cost (all units are euro/€)

- Investment of machinery
- Investment of construction
- Chemical
- Personnel
- Operating (energy)

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[1] all units are kg/day
[2] if Phosphorous elimination exists
[3] it could be selected as aerobic or anaerobic

3.4.1 Validation of the Modular Approach Designed for Wastewater Treatment Plants

Evaluation of a model is an important step which includes a test assessing the results with a data set (Table 24). If the deviations are not significant between the model calculations and the measurements, the model assumptions are compatible with the selected system (Reichert, 1994).

Formulations of modular design approach for wastewater treatment plants depends on ATV-DVWK, 2000 method as stated in Wastewater Treatment Technical Aspect Bulletin which is effectuated on 20 March, 2010 by the Ministry of Forestry and Water Hydraulics of Turkey.

The modular design approach for wastewater treatment provides results under two main categories: sizing and cost.

Sizing

Construction results of the modular design approach for wastewater treatment plants have been compared with the results obtained with an internationally accepted method's results. "Design of Municipal Wastewater Treatment Plants" (WEF, 2010) has been selected for the purpose of dimensioning validation. The input parameters, which are used to run the modules of the modular design approach, have been selected from a study prepared especially for Turkey. This study represents daily produced wastewater amount and pollutant loads depending on population in Turkey (Erdoğan et al., 2006). The input parameters used for the modules of the modular design approach in the validation are given in Table 18, while comparison of the results is given in Table 19. As it could be seen from Table 19 the difference is not more than 11% for six wastewater treatment units, while the average difference is 7.9 % and standard deviation of the difference is 3.6 %.

Table 18 The input parameters used for validation (Erdoğan et al., 2006)

Parameter	Input parameters
Population equivalent	100.000
Consumption (L/cap*day)	200
Wastewater amount (m^3/day)	20.000
BOD (mg/L)	299
COD (mg/L)	650
TSS (mg/L)	390
TOC (mg/L)	149
TKN (mg/L)	65
P_{tot} (mg/L)	10.4
Temperature (^oC)	15

Table 19 Validation of dimensioning the wastewater treatment units

(input parameters were given in Table-31)

	Selected parameter	Modules developed for this study	WEF	% Difference
Primary sedimentation	Volume	1.250 m^3	1.333 m^3	6.3
Waste Activated Sludge-Aeration Tank	Volume	7.423 m^3	6.651 m^3	10.4
Waste Activated Sludge-Secondary Sedimentation	Area	1.200 m^2	1.309 m^2	9.1
Extended Aeration Tank	Volume	31.962 m^3	29.046 m^3	9.2
Trickling filter	Volume	11.213 m^3	9.968 m^3	11.1
Stabilization Pond	Area	106.786 m^2	108.174	1.3
			Average	7.9
			Standard deviation	3.6

Cost

Validation of cost analysis has been prepared in a similar manner to the sizing validation. Since there is no detailed information for the cost estimation of a wastewater treatment plant in the market in Turkey, literature based results have been used during cost validation. A study including cost based optimal design of wastewater treatment plant has been used for the cost validation results (Erdoğan et al., 2006). Since the most important two processes for this research are waste activated sludge and extended aeration, validation of cost analysis have been evaluated for these processes.

The investment cost functions for different populations has been determined in mentioned study and they are given in Table 20 (Erdoğan et al., 2006). Cost functions, given separately in this study, have been sum up and then used for the validation since modules of the modular approach designed for wastewater treatment plants calculate the investment cost and electricity/mechanical cost together. Population has been taken 100.000 as same as in constructional validation. Comparison of the results is given in Table 21. As it can be seen from the Table 21, average percent difference is not more than 22. Since unit costs are changeable parameters for the investment, 22.1 percent difference is thought to be acceptable.

Table 20 The investment cost functions for different populations

Selected process and cost	Estimated cost function	R^2
Waste activated sludge (investment cost)	Population*7.2263	0.9917
Waste activated sludge (electricity/mechanical cost)	Population*8.2427	0.9938
Extended aeration (investment cost)	Population*8.9157	0.9971
Extended aeration (electricity/mechanical cost)	Population*9.5948	0.9440

Table 21 Validation of cost

Process	Module	Cost estimating function (Erdoğan et al., 2006)	% Difference
Waste activated sludge	1.881.818	1.546.900	17.8
Extended aeration	2.517.735	1.851.050	26.4
		Average	22.1
		Standard deviation	4.3

Modular Design Approach of Wastewater Treatment- Cost Figures

During investment cost calculations, the components of the investment cost functions have been selected as population, the amount of treated wastewater and pollution load. The investment costs of the activated sludge, extended aeration and biological nutrient removal systems are presented in Figure 8 and 9. Input parameters were taken from Table 18 during cost calculations. Electrical and mechanical equipment costs for various process options show substantial differences. Therefore significant differences are observed in the investment costs. Electrical and mechanical equipment investment costs of the biological nutrient removal system are similar to the activated sludge system, while extended aeration system is less costly than other two systems, since sludge stabilization process takes place in biological process (a separate system is not required). Therefore the investment cost of the extended aeration system has a similar linearity but is lower than biological nutrient removal.

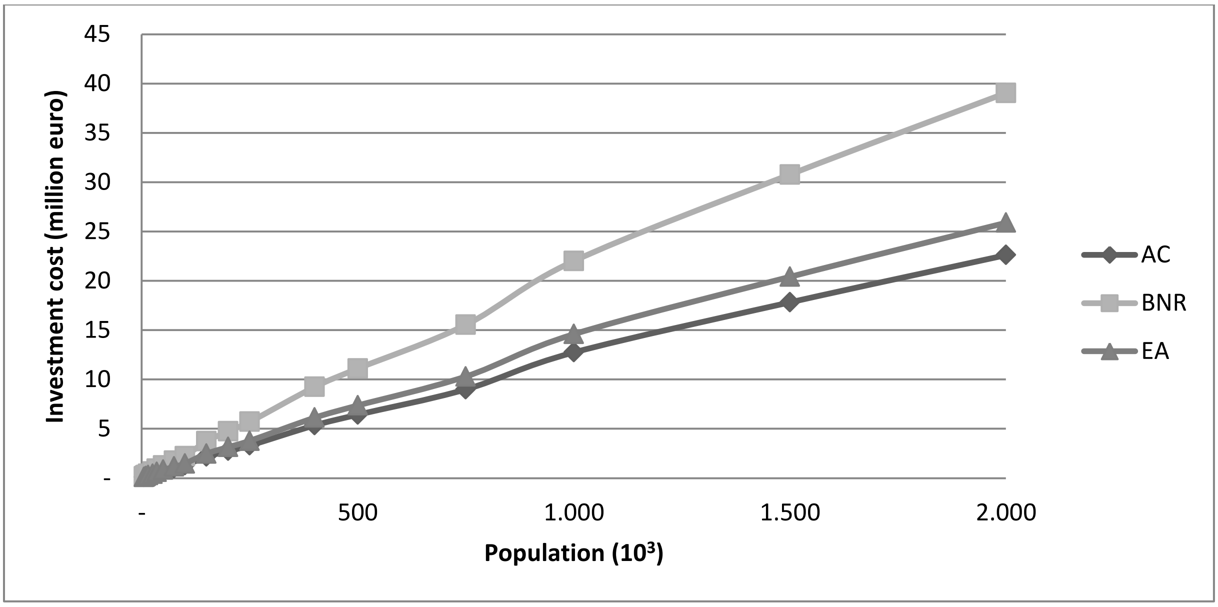

Figure 8. Investment cost of Activated Sludge (AS), Extended Aeration (EA) and Biological Nutrient Removal (BNR)

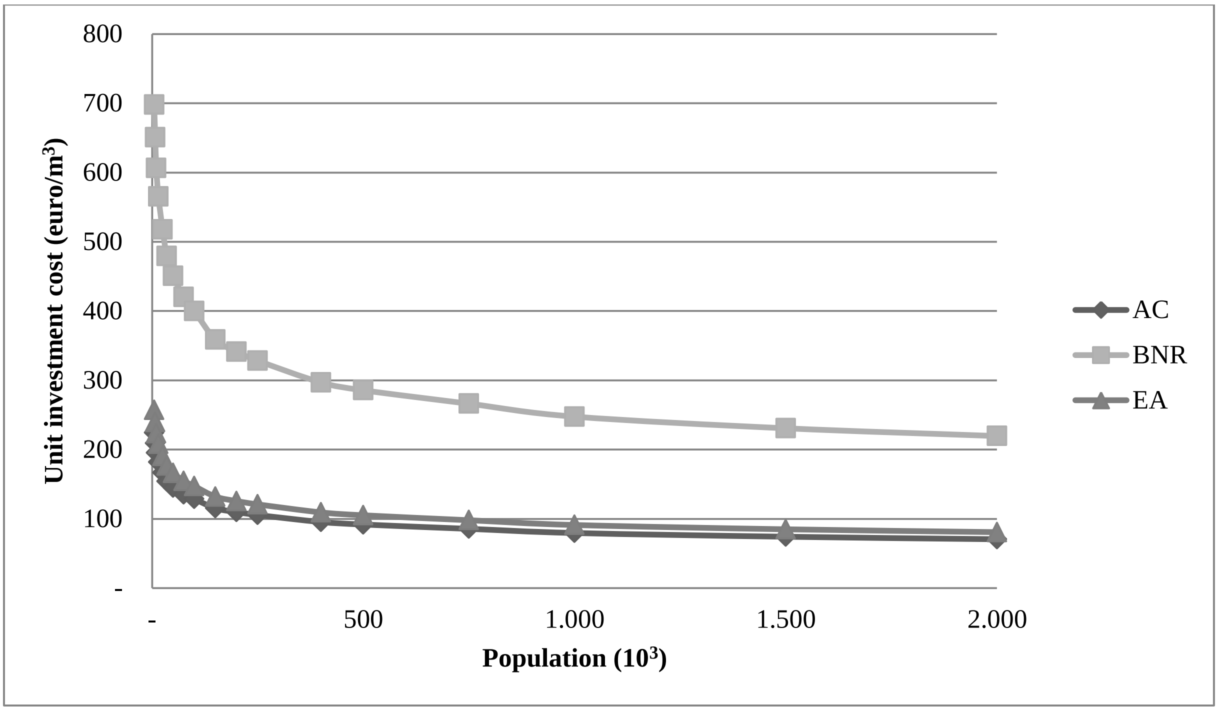

Figure 9. Unit investment cost of Activated Sludge (AS), Extended Aeration (EA) and Biological Nutrient Removal (BNR)

Operational Cost

The major operational costs for a wastewater treatment plant are employment of adequate number of staff, supply of chemical substances, and energy requirements. The variation of operation costs of activated sludge, extended aeration and biological nutrient removal systems with respect to served population are evaluated. The results for activated sludge system show that with the increasing population personnel cost decrease linearly whereas energy cost increases. However, as expected, the electricity cost of extended aeration system is approximately two times the requirement for activated sludge system. When the distribution of operation cost of biological nutrient removal system is evaluated, it is similar to activated sludge system and less than the cost of extended aeration system.

The unit cost of wastewater treatment

Both investment and operational costs could be obtained by modular design of wastewater treatment plants. The minimum tariff of wastewater treatment could be calculated using data obtained from investment and operation cost; and this tariff is calculated regardless of profit. The minimum tariff representing treatment of 1m^3 of wastewater could be calculated[4] as below;

$$C_{min} = \frac{(c/a)}{q} + \frac{o}{q}$$

C_{min} = Minimum tariff (TL/m^3)

a = Amortization time of wastewater treatment plant (year)

c = Annual investment cost (TL/year)

q = Annual amount of treated wastewater (m^3/year)

o = Annual operation cost of wastewater treatment plant (TL/year)

Amortization period has been taken as 30 years for financing of investment and operation expenses to be paid back. The minimum tariffs for 1 m^3 wastewater treatment with respect to population are given in Table 22.

[4] Official Journal, (2010). Regulation on the Procedures and Principles for Determination of the Tariffs for Waste Water, Infrastructure and Domestic Solid Waste Disposal Plants under the heading of urban-based housing as stated in the manual, Issue No: 27742, Issue Date: 27.10.2010.

Table 22 The minimum tariffs for 1 m^3 wastewater treatment

Population	**Activated sludge**	**Extended aeration**	**Biological nutirent removal**
P.E	euro/m^3	euro/m^3	euro/m^3
5.000	0.1138	0.1293	0.2099
7.500	0.1067	0.1217	0.1945
10.000	0.1011	0.1155	0.1819
15.000	0.0966	0.1106	0.1715
25.000	0.0921	0.1057	0.1608
35.000	0.0890	0.1023	0.1532
50.000	0.0869	0.1000	0.1479
75.000	0.0849	0.0978	0.1427
100.000	0.0837	0.0965	0.1394
150.000	0.0814	0.0939	0.1332
200.000	0.0806	0.0930	0.1308
250.000	0.0799	0.0923	0.1290
400.000	0.0785	0.0906	0.1249
500.000	0.0780	0.0901	0.1234
750.000	0.0772	0.0892	0.1210
1.000.000	0.0765	0.0883	0.1188
1.500.000	0.0758	0.0876	0.1168
2.000.000	0.0754	0.0871	0.1156

One of the most important factors for initial investment and operational cost is treatment process selection. The effect of this factor could be seen in Figure 10 for activated sludge system. Percentage contribution of operational cost is higher than investment for the places which has small population. This case is similar for both extended aeration and biological nutrient removal systems; Percentage contribution of operation cost decrease with increasing population.

Calibration curves (Figure 10-11) of "Modular Design of Wastewater Treatment Plant" were prepared. The results coincide with the results of Erdoğan et al. (2006). All related figures are given in Appendix-D.

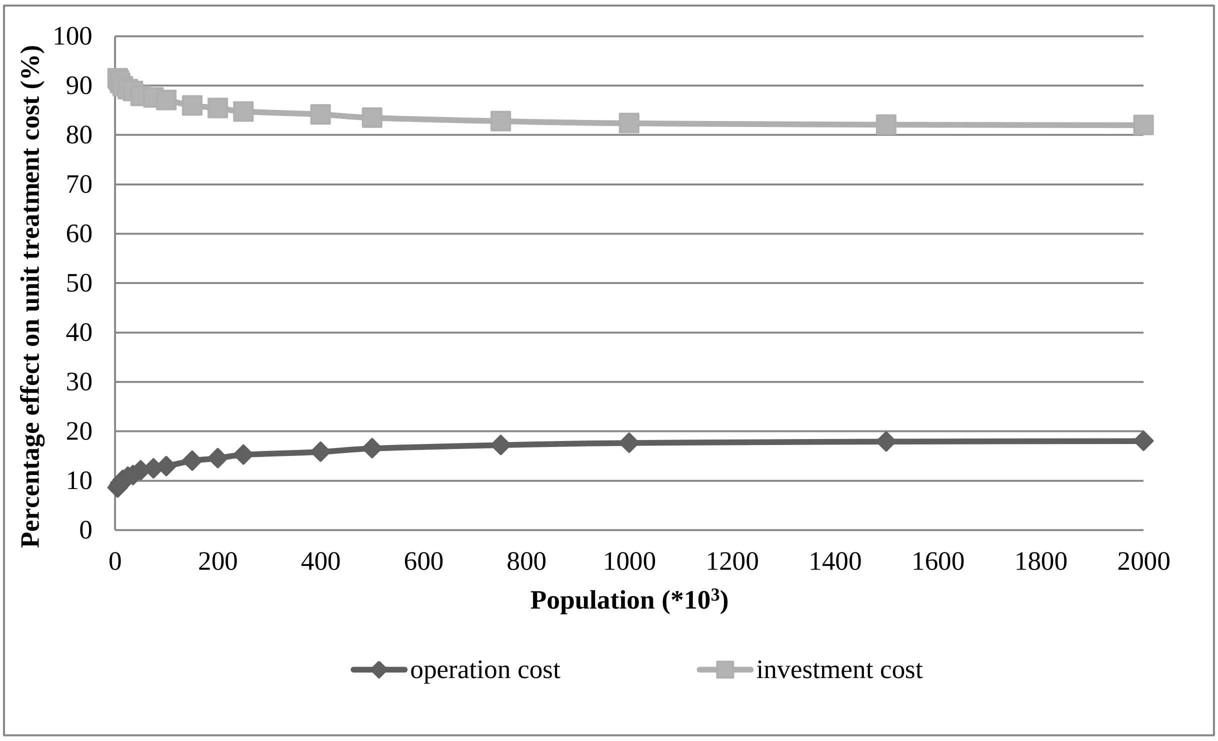

Figure 10 Effect of investment and operation cost on unit wastewater treatment cost

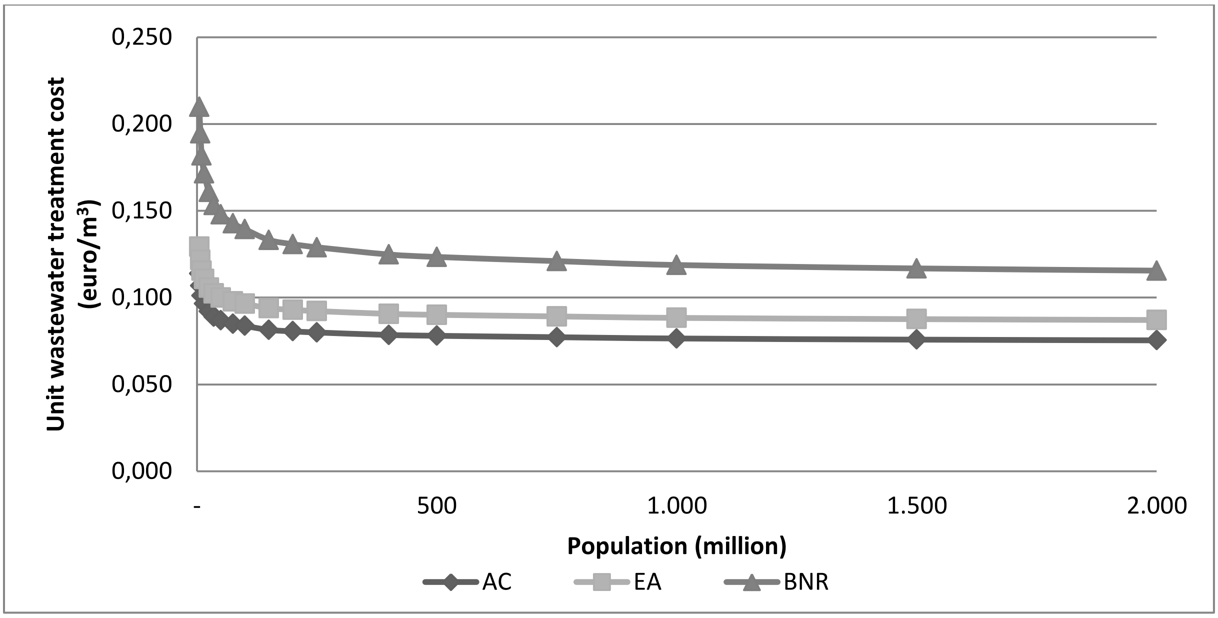

Figure 11 Unit wastewater treatment cost for AC, EA and BNR

3.4.2 Case studies

Three existing wastewater treatment plants in İzmir were selected for this study: (a) Menemen WWTP, (b) Bayındır WWTP, (c) Selçuk WWTP. During selection phase of these regions, availability of data has been taken into consideration. In addition to these wastewater treatment systems are compatible with the modular design approach used in this study.

İzmir Region is divided into two with respect to wastewater treatment plant distribution, north and south. Menemen Wastewater Treatment Plant has been selected from the North Region. Bayındır and Selçuk Wastewater Treatment Plants have been selected from the South Region. Information regarding these three plants is summarized in Table 23, while notations using for case studies through this study are summarized in Table 24.

Table 23 General information of three wastewater treatment plants studied (İzmir Municaipality, 2011)

Treatment plants/Properties	**Design Flow (m^3/day)**	**Population served**	**Treatment Type**	**Start-up**
Menemen	21.600	100.000	Advanced biological	2010
Bayındır	6.912	40.000	Advanced biological	2009
Selçuk	10.200	50.000	Natural treatment	2008

Table 24 Notations using for the case studies

WWTP/Notations and definitions	Existing situation	Run-1	Run-2	Run-3	Run-4
Menemen	M-2a (extended aeration, SRT=25 days, biological phosphorous elimination)	M-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal)	M-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination)	M-3 (trickling filter)	M-4 (stabilization)
Bayındır	B-2a (extended aeration, SRT=25 days, biological phosphorous elimination)	B-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal)	B-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination)	B-3 (trickling filter)	B-4 (stabilization)
Selçuk	S-4 (stabilization, SRT =360 days, no nutrient removal)	S-2a (primary sedimentation+activated sludge, SRT =25 days, preanoxic denitrification, biological phosphorous elimination)	S-2b (primary sedimentation+activated sludge, SRT =15 days, preanoxic denitrification, biological and chemical phosphorous elimination)	S-3 (trickling filter)	-

3.4.2.1 Case 1-Menemen Wastewater Treatment Plant

A case study on treated water reuse in Menemen is presented to shed some lights on its role in sustainable water management for agriculture. Wastewater is viewed as an economic good that should be valued and managed in a rational manner. The case study shows that if the current operational conditions change reuse of treated wastewater could be realized within agricultural applications.

Menemen Wastewater Treatment Plant 1st stage has a design capacity of 21.600 m^3/day with 100.000 population equivalent and it has taken into operation on April 2, 2010. It serves to Menemen town center, Asarlık, Koyundere, Seyrek and Günerli. It was built on farmland belonging to Ege University Agriculture Faculty which is near the village of Günerli.

Menemen Wastewater Treatment Plant's treatment type is advanced biological treatment including extended aeration with nitrogen and phosphorous removal. Treatment units are coarse and fine screens, aerated grit and grease chamber, anaerobic P-removal tanks, aeration tanks, sedimentation tanks, mechanical sludge thickening and sludge dewatering units.

Dewatered sludge is carried by a conveyer to Çiğli Wastewater Treatment Plant storage areas. Municipality is planning to use the treated wastewater as irrigation water for the surrounding agricultural land.

Treated wastewater quality satisfies discharge criteria (MoFWH, 2010). However current situation of the wastewater treatment plant treat nutrients with high sludge retention time. Therefore valuable nutrients are discharged. Although there is a plan to reuse treated wastewater for irrigation, an application associated with reuse has not practiced yet.

M-2a, 2b, 2c and M-3, 4

M-2a (extended aeration, SRT=25 days, biological phosphorous elimination), M-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal), M-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination)and M-3 (trickling filter), M-4 (stabilization) have been run for the Menemen WWTP. Module M-2a represents the existing situation of the Menemen Wastewater Treatment Plant. WWTP has extended aeration with 25 days sludge retention time. There are five parameters (pH, TSS, COD, TP and TN) which are periodically analyzed and recorded. Therefore, these parameters have been taken for input parameters and remaining parameters (BOD_5, TOC, K, Mg, Ca, NO_3 and acid capacity) have been taken from literature since there were no available information with regard to these parameters (Metcalf and Eddy, 2002; Erdoğan et al., 2006). The inflow and outflow values (pH, TSS, COD, TP and TN) of wastewater are summarized in Table 13 (İZSU, 2011). When the inflow (raw wastewater) TSS, COD, TP and TN concentrations are evaluated, it can be seen that they are so low for a typical domestic wastewater. During the site visit, the reason of low concentration of raw wastewater was investigated and the main reason of the low concentrations was stated to be groundwater leakage by the İZSU staff. Infiltration of groundwater to sewage system decreases the pollution strength along with the concentrations. Therefore, both inflow and outflow wastewater concentrations of the Menemen WWTP are less than a typical domestic wastewater composition (Table 25).

Since the inflow concentrations are so low, the average inflow concentrations of the North Region WWTPs of İzmir (Aliağa, Kemelpaşa, Kozbeyli, Halilbeyli, Hacıömerli, Foça, Menemen and Çiğli) have been calculated and taken into consideration to run the modules for this wastewater treatment plant. The inflow parameters used to run modules are summarized in Table 26.

Table 25 Characterization of wastewater from Menemen WWTP [5]

Parameter	pH	TSS	COD	TP	TN
		mg/L	mg/L	mg/L	mg/L
Typical domestic wastewater composition for 100.000 P.E (Erdoğan et al., 2006)	-	390	650	10,40	65
Inflow	7,8	149	153	19,6	3,0
Outflow	7,78	25	34	11,7	2,8

Table 26 Input parameters used to run the M-2a, M-2b, M-2c, M-3, M-4

Parameter	Influent WWTP	Unit
PE	100.000	-
Daily water consumption	216	L/PE*d
Wastewater amount	21.600	m^3/d
BOD_5	251.3	mg/L
COD	550.36	mg/L
TSS	864.52	mg/L
TOC	149	mg/L
TKN	35.35	mg/L
TP	11.2	mg/L
K	10	mg/L
Mg	40	mg/L
Ca	80	mg/L
NO_3	0	mg/L
acid capacity	7	mmol/L

Beside inflow values, there are also parameters being specific to M-2a, M-2b, M-2c to obtain case specific outputs. They are basically sludge age, existence of denitrification, chemical and biological phosphorous elimination, acid capacity, sludge volume index, thickening time and temperature. If the first three parameters are changed and primary sedimentation (M-1) is added to the system, nutrient

[5] İZSU-Department of Wastewater Treatment- Average values of 2010

distribution is changed through liquid and solid output phases. In this context, M-2b and M-2c have been run. Defined parameters for M-2a, M-2b and M-2c are summarized in Table 27.

Table 27 Defined parameters for M-2a, M-2b and M-2c

Defined parameters	**M-2a** (extended aeration, SRT=25 days, biological phosphorous elimination)	**M -2b** (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal)	**M-2c** (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination)
Primary sedimentation	No	Yes	Yes
Chosen sludge age	25	15	10
Temperature	15	15	15
Denitrification	Preanoxic	No	Preanoxic
Chemical phosphorus elimination	No	No	Yes
Biological phosphorus elimination	Yes	No	Yes

In M-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal) and M-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination) only operational parameters have been changed and primary sedimentation tank has been added. In addition to this biological treatment process can also be changed. Trickling filter and stabilization pond – M-3 (trickling filter) and M-4 (stabilization) - have been used for this purpose. Selection criteria of these systems mainly depend on operational stability, treatment performance and cost efficiency (Fitzgerald and Rohlich, 1958; Boller and Gujer, 1986; Brissaud et al., 1991; Diks and Ottengraf, 1991). In addition to technology change, primary sedimentation tank has been added to the M-3 (trickling filter) and M-4(stabilization). Therefore pollutant load can be decreased for these modules different from the existing situation, M-2a (extended aeration, SRT=25 days, biological phosphorous elimination). Defined parameters for M-3 (trickling filter) and M-4(stabilization) are summarized in Table 28.

Table 28 Defined parameters for existing situation M-2a, M-3 and M-4

Defined parameters	**M-2a** (extended aeration, SRT=25 days, biological phosphorous elimination)	**M-3** (trickling filter)	**M-4** (stabilization)
Primary sedimentation	No	Yes	Yes
Chosen sludge age	25	30	360
Temperature	15	15	15
Denitrification	Preanoxic	No	No
Chemical phosphorus elimination	No	No	No
Biological phosphorus elimination	Yes	No	No

3.4.2.2 Case 2 - Bayındır Wastewater Treatment Plant

A case study on treated water reuse in Bayındır is presented to shed some lights on its role in sustainable water management for agriculture. Wastewater is viewed as an economic good that should be valued and managed in a rational manner. The case study shows that if the current operational conditions change reuse of treated wastewater could be realized within agricultural applications.

Bayındır Wastewater Treatment Plant has a design capacity of 6.912 m^3/day with 40.000 population equivalent. It serves to Bayındır town center, Canlı, Yakapınar, Çıplak, Elifli, Fırınlı and neighborhood settlements.

Bayındır Wastewater Treatment Plant's system is also same with Menemen WWTP and it is advanced biological treatment including extended aeration with nitrogen and phosphorous removal. Treatment steps are coarse and fine screens, aerated grit and grease chamber, anaerobic P-removal tanks, aeration tanks, sedimentation tanks, mechanical sludge thickening and sludge dewatering units.

Dewatered sludge is carried by a conveyer to Çiğli Waste Water Treatment Plant storage areas. Municipality is planning to use the treated wastewater as irrigation water for the surrounding agricultural land as well as Menemen WWTP.

Treated wastewater quality provides discharge criteria (MoFWH, 2010). Although there is a plan to reuse treated wastewater for irrigation, an application associated with reuse has not practiced yet.

B-2a, 2b, 2c and B-3, 4

B-2a (extended aeration, SRT=25 days, biological phosphorous elimination), B-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal), B-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination) and B-3 (trickling filter), B-4 (stabilization) have been run for Bayındır WWTP. B-2a represents the existing situation of the Bayındır Wastewater Treatment Plant. It has extended aeration with 20 days sludge retention time. There are five parameters (pH, TSS, COD, TP and TN) which are periodically analyzed and recorded. Therefore, these parameters have been used as module input parameters and remaining parameters (BOD_5, TOC, K, Mg, Ca, NO_3 and acid capacity) have been taken from literature since there were no available information with regard to these parameters (Metcalf and Eddy, 2002; Erdoğan et al., 2006). The inflow and outflow characterization of wastewater are given in Table 29 (İZSU, 2011) and input parameters used to run modules are given in Table 30.

Table 29 Characterization of wastewater from Bayındır WWTP[6]

Parameter	pH	TSS	COD	TP	TN
		mg/L	mg/L	mg/L	mg/L
Inflow	7.62	183	416	6.0	30.48
Outflow	7.97	8	14	3.8	17.4

Table 30 Input parameters used to run the B-2a, B-2b, B-2c, B-3, B-4

Parameter	Influent WWTP	Unit
PE	40.000	-
Daily water consumption	172.8	L/PE*d
Wastewater amount	6.912	m^3/d
BOD_5	190	mg/L
COD	416	mg/L
TSS	183	mg/L
TOC	149	mg/L
TKN	30.48	mg/L
TP	6	mg/L
K	10	mg/L
Mg	40	mg/L
Ca	80	mg/L
NO_3	0	mg/L
acid capacity	7	mmol/L

Beside inflow values (Table 29) there are also operational parameters being specific to B-2a, B-2b, B-2c. They are basically sludge age, existence of denitrification, chemical and biological phosphorous elimination, acid capacity, sludge volume index, thickening time and temperature. When first three parameters are changed and primary sedimentation is added, nutrient distribution is changed through liquid and solid output phases. In this content, B-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal) and B-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological

[6] İZSU-Department of Wastewater Treatment- Average values of 2010

phosphorous elimination) have been run. Parameters used to run B-2a (extended aeration, SRT=25 days, biological phosphorous elimination), B-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal) and B-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination) are given in Table 31.

Table 31 Defined parameters for Module B-2a, B-2b and B-2c

Defined parameters	**B-2a** (extended aeration, SRT=25 days, biological phosphorous elimination)	**B-2b** (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal)	**B-2c** (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination)
Primary sedimentation	No	Yes	Yes
Chosen sludge age	20	15	10
Temperature	15	15	15
Denitrification	Preanoxic	No	Preanoxic
Chemical phosphorus elimination	No	No	Yes
Biological phosphorus elimination	Yes	No	Yes

In B-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal) and B-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination) only operational parameters have been changed and primary sedimentation tank has been added. In addition to this biological treatment process can also be changed. B-3 (trickling filter) and B-4 (stabilization) have been run in this context by using trickling filter and stabilization pond respectively. Selection criteria of these systems mainly depend on operational stability, treatment performance and cost efficiency

(Fitzgerald and Rohlich, 1958; Boller and Gujer, 1986; Brissaud et al., 1991; Diks and Ottengraf, 1991). In addition to process change, primary sedimentation tank has been also added to the B-3 (trickling filter) and B-4 (stabilization). Therefore pollutant load can be decreased for these modules different from the existing situation, B-2a. Defined parameters for B-3 (trickling filter) and B-4 (stabilization) are given in Table 32.

Table 32 Defined parameters for existing situation Module B-2a, Module B-3 and B4

Defined parameters	**B-2a** (extended aeration, SRT=25 days, biological phosphorous elimination)	**B-3** (trickling filter)	**B-4** (stabilization)
Primary sedimentation	No	Yes	Yes
Chosen sludge age	20	30	360
Temperature	15	15	15
Denitrification	Preanoxic	No	No
Chemical phosphorus elimination	No	No	No
Biological phosphorus elimination	Yes	No	No

3.4.2.3 Case 3- Selçuk Wastewater Treatment Plant

A case study on treated water reuse in Selçuk is presented to shed some lights on its role in sustainable water management for agriculture. Wastewater is viewed as an economic good that should be valued and managed in a rational manner. The case study shows that if the current process changes discharge standars could be obtained and reuse of treated wastewater could be reailized within agricultural applications.

Selçuk Wastewater Treatment Plant has a design capacity of 10.200 m^3/day with 50.000 population equivalent. It serves to Selçuk town and its treatment system has a stabilization pond as a type of natural treatment. However treated wastewater quality does not satisfy discharge criteria for two parameters (BOD_5 and COD) as shown in Table 33.

S-2a, 2b, S-3 and S-4

S-2a (primary sedimentation+activated sludge, SRT =25 days, preanoxic denitrification, biological phosphorous elimination), S-2b (primary sedimentation+activated sludge, SRT =15 days, preanoxic denitrification, biological and chemical phosphorous elimination) and S-3 (trickling filter), S-4 (stabilization, SRT =360 days, no nutrient removal) have been run for Selçuk Wastewater Treatment Plant. Module S-4 represents the existing situation of the Selçuk WWTP. It has a stabilization pond with 360 days sludge retention time. There are five parameters (pH, TSS, COD, TP and TN) which are periodically analyzed and recorded. Therefore, these parameters have been taken for input parameters and remaining parameters (BOD_5, TOC, K, Mg, Ca, NO_3 and acid capacity) have been taken from literature (Metcalf and Eddy, 2002; Erdoğan et al., 2006). The inflow and outflow characterization of wastewater are summarized in Table 33 (İZSU, 2011) and input parameters used to run modules are summarized in Table 34.

Table 33 Characterization of wastewater from Selçuk WWTP[7]

Parameter	**pH**	**TSS**	**COD**	**TP**	**TN**
		mg/L	**mg/L**	**mg/L**	**mg/L**
Inflow	7.93	359	765	12.4	79.5
Outflow	8.38	160	283	7.5	45.7
Requirements (UWTR. 2010)	-	35	125	2	15

[7] İZSU-Department of Wastewater Treatment- Average values of 2010

Table 34 Input parameters used to run the Module S-2a, S-2b, S-3 and S-4

Parameter	Influent WWTP	Unit
PE	50.000	-
Daily water consumption	204	L/PE*d
Wastewater amount	10.200	m^3/d
BOD_5	349	mg/L
COD	765	mg/L
TSS	359	mg/L
TOC	149	mg/L
TKN	79.5	mg/L
TP	12.4	mg/L
K	10	mg/L
Mg	40	mg/L
Ca	80	mg/L
NO_3	0	mg/L
acid capacity	7	mmol/L

Beside inflow values, there are also some defined parameters being specific to modules. They are basically sludge age, existence of denitrification, chemical and biological phosphorous elimination, acid capacity, sludge volume index, thickening time and temperature. S-2a (primary sedimentation+activated sludge, SRT =25 days, preanoxic denitrification, biological phosphorous elimination), S-2b (primary sedimentation+activated sludge, SRT =15 days, preanoxic denitrification, biological and chemical phosphorous elimination) and S-3 (trickling filter) have been run in this context. Selection criteria of the trickling filter system mainly depend on operational stability, treatment performance and cost efficiency (Boller and Gujer, 1986; Brissaud et al., 1991; Diks and Ottengraf, 1991). Defined parameters for Module S-2a, S-2b, S-3 and S-4 are given in Table 35.

Table 35 Defined parameters for S-2a, 2b, 3 and 4

Defined parameters	**S-4 Existing situation**	**S-2a**	**S-2b**	**S-3**
Primary sedimentation	No	Yes	Yes	Yes
Chosen sludge age	360	25	15	30
Temperature	15	15	15	15
Denitrification	No	Preanoxic	Preanoxic	No
Chemical phosphorus elimination	No	No	Yes	No
Biological phosphorus elimination	No	Yes	Yes	No

CHAPTER 4

RESULTS AND DISCUSSION

This section discusses the results generated by the modular design approach as well as irrigation and nutrient demand calculations. The results of optimization studies towards meeting the agricultural irrigation and nutrient demand with wastewater reuse are also given.

4.1 Modular Design Approach - Case 1- Menemen Wastewater Treatment Plant

The agricultural water demand could be partially supplied by treated municipal wastewater from wastewater treatment plant. The conditions of this plant can be optimized toward wastewater and nutrient reuse by changing sludge retention time and addition of treatment units for primary treatment or nutrient removal. Table 36 gives the scenarios developed for Menemen Wastewater Tretment Plant. These modules were developed according to irrigation and nutrient demand of the study area.

- Module M-2a: extended aeration, SRT=25 days, biological phosphorous elimination
- Module M-2b: primary sedimentation+activated sludge, SRT =15 days, no nutrient removal
- Module M-2c: primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination

Table 37 gives the model results using the input data given in Table 25. Raw wastewater, treated wastewater, excess sludge, gas phase, energy demand, investment cost and annual operation cost results are given in Table-37.

Table 36 Defined parameters for M-2a, M-2b and M-2c

Defined parameters	**M-2a** (extended aeration, SRT=25 days, biological phosphorous elimination)	**M -2b** (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal)	**M-2c** (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination)
Primary sedimentation	No	Yes	Yes
Chosen sludge age	25	15	10
Temperature	15	15	15
Denitrification	Preanoxic	No	Preanoxic
Chemical phosphorus elimination	No	No	Yes
Biological phosphorus elimination	Yes	No	Yes

All calculations are made for 100.000 population equivalent (PE). Since current wastewater treatment plant serves to 100.000 PE. The influent wastewater characterization values for the Menemen Wastewater Treatment Plant are given in Table 26. They were obtained from İZSU-Department of Wastewater Treatment. They are average inflow values of North Region wastewater treatment plants of İzmir (Aliağa, Kemelpaşa, Kozbeyli, Halilbeyli, Hacıömerli, Foça, Menemen and Çiğli) and they are used for representing typical domestic wastewater pollutant loads for the Menemen WWTP. Other input data (PE, daily water consumption, wastewater amount, BOD_5, COD, TSS, TOC, TKN, TP, K, Mg, Ca, NO_3, acid capacity) are given in Table 26 and they are the same for all studied modules (M-2a, M-2b, M-2c, M-3 and M-4).

Table 37 M-2a, 2b and 2c results

Parameters/Modules	M-2a (extended aeration, SRT=25 days, biological phosphorous elimination)	M-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal)	M-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination)
Wastewater **(inlet point of aeration tank)**	ton/year	ton/year	ton/year
COD	4339	3254	3254
tN	279	251	251
tP	88	79	79
Treated wastewater	ton/year	ton/year	ton/year
COD	986	499	499
tN	87	184	80
tP	49	72	32
Excess sludge	ton/year	ton/year	ton/year
COD	1108	1064	1098
tN	89	67	70
tP	40	7	48
Gas Phase	ton/year	ton/year	ton/year
N_2	103	0	107
CO_2	2245	1692	1657
Required Energy	MWh/year	MWh/year	MWh/year
Total energy demand	4493	3411	3533
Total investment cost	€ 11.957.880	€ 6.353.510	€ 7.318.621
Annual operation cost	€/year 1.687.193	€/year 1.046.499	€/year 1.054.763

4.1.1 Wastewater

Three water parameters were considered in Table 37, namely Chemical Oxygen Demand (COD), Total Nitrogen (tN) and Total Phosphorous (tP). Effluent wastewater quality changes according to existence of primary treatment before the aeration tank. Effect of the primary treatment on pollution load to the aearation tank could be seen from Table-37 There is a significant reduction (25%-COD, 10%-tN, 10%-tP) on pollution load in the case of M-2b and M-2c compared to current situation (M-2a). There is no primary treatment in M-2a while M-2b and M-2c include primary treatment. So the existence of primary treatment has a significant impact on the pollution load to the aearation tank.

4.1.2 Treated wastewater

Three water parameters were considered in Table 37, namely Chemical Oxygen Demand (COD), Total Nitrogen (tN) and Total Phosphorous (tP). The effluent quality requirements in terms of these parameters for irrigation reuse were discussed in 2.9. Effluent quality of three modules (M-2a, M-2b and M-2c) were pre-set in modules to comply with the releavant legislation. The results represent that carbon removal can also be achieved in M-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal) and M-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination); and even better than the performance (M-2b COD= 499 ton/year, M-2c= 499 ton/year) of current extended aeration system (M-2a COD = 986 ton/year). M-2c (activated sludge with 10 days SRT) has both nitrogen and phosphorous removal units. Therefore yearly discharge amounts of both nitrogen and phosphorous are less than other two modules. On the other hand, nutrients could be reused in agriculture for the case of M-2b (activated sludge with 15 days SRT) by cancelling nutrient removal. 184 ton nitrogen and 72 ton phosphorous could be gained yearly by operating M-2b. Therefore these nutrients could be valued for irrigation.

4.1.3 Excess sludge

Three parameters were evaluated in Table 37, namely Chemical Oxygen Demand (COD), Total Nitrogen (tN) and Total Phosphorous (tP). Increase in carbon removal performance was observed in M-2b and M-2c. 25% COD is removed by primary treatment in M-2b and M-2c. Therefore the amount of carbon loads removed through excess sludge decrease in M-2b (1064 ton/year) and M-2c (1098 ton/year) compared to M-2a (1108 ton/year). For the existing system, M-2a, the significant amount of nitrogen and phosphorous is accumulated in the excess sludge. Since nutrients are subject to only biological treatment within an extended aeration system and they are discharged mostly with sludge at the end of the treatment system. The second module (M-2b) has a primary treatment and does not have nutrient removal. Therefore significant amount of nutrient is discharged with wastewater and a small quantity of nutrient is discharged through sludge phase. On the other hand, both nitrogen and phosphorous dominate in sludge form in the third module, namely M-2c, which has primary sedimentation and nutrient remova. For M-2c, denitrification and biological phosphorous removal make it possible to eliminate 28% of the incoming total nitrogen (70 ton/year) and 60% of the incoming total phosphorous (47 ton/year) (Table 37).

4.1.4 Gas Phase

After carbon removal and denitrification unit, the main gas phase products are nitrogen (N_2) and carbon dioxide (CO_2). Since denitrification takes place in M-2a and M-2c, more than 100 ton/year N_2 released to atmosphere and almost half of the incoming total nitrogen is eliminated by off-gas. On the other side, carbon dioxide emissions have significant contribution to global warming as being a greenhouse gas. Results show that primary treatment has an important role on reduction of carbon source. It makes it possible to reduce 25% of carbon dioxide emission (M-2b and M-2c) compared to the current situation of the wastewater treatment plant (M-2a).

4.1.5 Energy Demand

In terms of energy demand, M-2a (extended aeration, SRT=25 days, biological phosphorous elimination) requires more energy (4493 MWh/year) rather than M-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal-3411 MWh/year) and M-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination-3533 MWh/year). Its required aeration rate, thus the main component of the energy demand increase to provide recommended effluent quality. When M-2b and M-2c are compared in terms of their energy demand, there is 3% difference. M-2b requires 3411 MWh/year and M-2c requires 3533 MWh/year. Energy demand of M-2c is higher than M-2b. Since M-2c's sludge retention time (10 days) is smaller than M-2b (15 days). Therefore M-2c's aeration rate demand increase to provide recommended effluent quality.

4.1.6 Investment and operational cost

The investment costs and operational costs are presented in Table-37. They provide cost comparison of the modules used. The cost analysis results could be used at the stage of decision making before treatment technology selection. Since their influent and effluent quality values are same. When the investment and operational costs are evaluated, results show that extended aeration system (M-2a) requires higher annual operation costs and also higher investment costs. Alternatively, the activated sludge plant can be operated at a reduced sludge age, with a primary settling tank. Table-37 shows the resulting investment cost and operational cost in case of M-2b (with 15 days SRT) and M-2c (with 10 days SRT). Both investment and operation cost could be reduced in spite of an additional treatment unit.

In addition to the extended aeration and activated sludge systems, Table 38 shows the results of the modular runs for trickling filter and stabilization ponds. The effluent stream qualities were set as same as M-2a, M-2b and M-2c. They are designed for carbon removal without nutrient removal. Module results show that both systems need significantly lower energy demand and investment cost compared to extended aeration and activated sludge processes. Additionally, the effluent streams of these treatment systems contain high loads of nutrients that can be valued for agricultural applications. Since they do not have nutrient removal units.

Table 38 M-3 and M-4 results

Parameters/Modules	**M-3** (trickling filter)	**M-4** (stabilization)
Wastewater	ton/year	ton/year
COD	3254	3254
tN	251	251
tP	79	79
Treated wastewater	ton/year	ton/year
COD	499	499
tN	184	184
tP	65	65
Excess sludge	ton/year	ton/year
COD	950	818
tN	67	67
tP	14	14
Gas Phase	ton/year	ton/year
N_2	0	0
CO_2	1805	1937
Required Energy	MWh/year	MWh/year
Total energy demand	552	79
Total investment cost	€ 4.023.450	€ 1.158.314
Annual operation cost	€/year 437.769	€/year 99.352

4.2 Modular Applications - Case 2- Bayındır Wastewater Treatment Plant

The agricultural water demand could be partially supplied by treated municipal wastewater from wastewater treatment plant. The conditions of this plant can be optimized toward wastewater and nutrient reuse by changing sludge retention time and addition of treatment units for primary treatment or nutrient removal. Table 37 gives the scenarios developed for Bayındır Wastewater Tretment Plant. These modules were developed according to irrigation and nutrient demand of the study area.

- Module B-2a: extended aeration, SRT=25 days, biological phosphorous elimination
- Module B-2b: primary sedimentation+activated sludge, SRT =15 days, no nutrient removal
- Module B-2c: primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination

Table 39 gives the model results using the input data given in Table 29. Raw wastewater, treated wastewater, excess sludge, gas phase, energy demand, investment cost and annual operation cost results are qualitatively given in Table 40.

Table 39 Defined parameters for Module B-2a, B-2b and B-2c

Defined parameters	**B-2a** (extended aeration, SRT=25 days, biological phosphorous elimination)	**B-2b** (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal)	**B-2c** (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination)
Primary sedimentation	No	Yes	Yes
Chosen sludge age	20	15	10
Temperature	15	15	15
Denitrification	Preanoxic	No	Preanoxic
Chemical phosphorus elimination	No	No	Yes
Biological phosphorus elimination	Yes	No	Yes

All calculations are made for 40.000 population equivalent (PE). Since current wastewater treatment plant serves to 40.000 PE. The influent wastewater characterization values for the Bayındır Wastewater Treatment Plant are given in previous chapter (Table 29). They were obtained from İZSU-Department of Wastewater Treatment. They are used for representing typical domestic wastewater pollution loads especially for Bayındır WWTP. Other input data (PE, daily water consumption, wastewater amount, BOD_5, COD, TSS, TOC, TKN, TP, K, Mg, Ca, NO_3, acid capacity) are given in Table 30 and they are the same for all studied modules (B-2a, B-2b, B-2c, B-3 and B-4).

Table 40 B-2a, 2b and 2c reuslts

Parameters/Modules	**B-2a** (extended aeration, SRT=25 days, biological phosphorous elimination)	**B-2b** (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal)	**B-2c** (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination)
Wastewater **(inlet point of aeration tank)**	ton/year	ton/year	ton/year
COD	1050	787	787
tN	77	69	69
tP	15	14	14
Treated wastewater	ton/year	ton/year	ton/year
COD	315	160	160
tN	28	53	28
tP	6	12	3
Excess sludge	ton/year	ton/year	ton/year
COD	260	231	253
tN	22	16	18
tP	10	2	11
Gas Phase	ton/year	ton/year	ton/year
N_2	28	0	23
CO_2	556	396	375
Required Energy	MWh/year	MWh/year	MWh/year
Total energy demand	1147	878	907
Total investment cost	€ 1.561.329	€ 599.525	€ 1.433.621
Annual operation cost	€/year 273.872	€/year 165.091	€/year 224.654

4.2.1 Wastewater

Three water parameters were considered in Table 40, namely Chemical Oxygen Demand (COD), Total Nitrogen (tN) and Total Phosphorous (tP). Effluent wastewater quality changes according to existence of primary treatment before the aeration tank. Effect of the primary treatment on pollution load could be seen from Table-40. There is a significant reduction (25%-COD, 10%-tN, 10%-tP) on pollution load in the case of B-2b and B-2c compared to current situation (B-2a). There is no primary treatment in B-2a while B-2b and B-2c include primary treatment. Therefore the existence of primary treatment has a significant impact on the pollution load.

4.2.2 Treated wastewater

Three water parameters were considered in Table 40, namely Chemical Oxygen Demand (COD), Total Nitrogen (tN) and Total Phosphorous (tP). The effluent quality requirements in terms of these parameters for irrigation reuse were discussed in 2.9. Effluent quality of three modules (B-2a, B-2b and B-2c) was pre-set in modules to comply with the releavant legislation. The results represent that carbon removal can also be achieved in B-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal) and B-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination); and even better than the performance (B-2b COD= 160 ton/year, B-2c= 160 ton/year) of current extended aeration system (B-2a COD = 365 ton/year). B-2c (activated sludge with 10 days SRT) has both nitrogen and phosphorous removal units. Therefore yearly discharge amounts of both nitrogen and phosphorous are less than other two modules. On the other hand, nutrients could be reused in agriculture for the case of B-2b (activated sludge with 15 days SRT) by cancelling nutrient removal. 53 ton nitrogen and 12 ton phosphorous could be gained yearly by operating M-2b. Therefore these nutrients could be valued for irrigation.

4.2.3 Excess sludge

Three parameters were evaluated in Table 40, namely Chemical Oxygen Demand (COD), Total Nitrogen (tN) and Total Phosphorous (tP). Increase in carbon removal performance was observed in B-2b and B-2c. 25% COD is removed by primary treatment in B-2b and B-2c Therefore the amount of carbon loads removing through excess sludge decrease in B-2b (231 ton/year) and B-2c (253 ton/year) compared to B-2a (260 ton/year). For the existing system, B-2a, the significant amount of nitrogen and phosphorous is accumulated in the excess sludge. Since nutrients are subject to only biological treatment within extended aeration system and they are discharged mostly with sludge at the end of the treatment system. The second module (B-2b) has a primary treatment and does not have nutrient removal. Therefore significant amount of nutrient is discharged with wastewater and a small quantity of nutrient is discharged through sludge phase. On the other hand, both nitrogen and phosphorous dominate in sludge phase in the third module, namely B-2c, which has primary sedimentation and nutrient removal system. For B-2c denitrification and biological phosphorous removal make it possible to eliminate 28% of the incoming total nitrogen (18 ton/year) and 60% of the incoming total phosphorous (11 ton/year).

4.2.4 Gas Phase

After carbon removal and denitrification unit, the main gas phase products are nitrogen (N_2) and carbon dioxide (CO_2). Since denitrification takes place in B-2a and B-2c, more than 20 ton/year N_2 released to atmosphere and almost half of the incoming total nitrogen is eliminated by off-gas. On the other side, carbon dioxide emissions have significant contribution to global warming as being a greenhouse gas. Results show that primary treatment has an important role on reduction of carbon source. It makes it possible to reduce almost 28% of carbon dioxide emission (B-2b and B-2c) compared to current situation of the wastewater treatment plant (B-2a).

4.2.5 Energy Demand

In terms of energy demand, B-2a (extended aeration, SRT=25 days, biological phosphorous elimination) requires more energy (1147 MWh/year) rather than B-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal-878 MWh/year) and B-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination-907 MWh/year). Its required aeration rate, thus the main component of the energy demand increase to provide recommended effluent quality. When B-2b and B-2c are compared in terms of energy demand, there is 3% difference. M-2b requires 878 MWh/year and M-2c requires 907 MWh/year Energy demand of B-2c is higher than B-2b. Since B-2c's sludge retention time (10 days) is smaller than B-2b (15 days). Therefore B-2c's aeration rate demand increase to provide recommended effluent quality.

4.2.6 Investment cost and annual cost

The investment and operational costs are presented in Table 40. They provide cost comparison of the modules used. The cost analysis results could be used at the stage of decision making before treatment technology selection since their influent and effluent quality values are same. When the investment and operational costs are evaluated, results show that extended aeration system (B-2a) requires higher annual operation costs and also higher investment costs. Alternatively, the activated sludge plant can be operated at a reduced sludge age, with a primary settling tank. Table 40 shows the resulting investment cost and annual operation cost in case of B-2b (SRT of 15 days) and B-2c (SRT of 10 days). Both investment and operation cost for B-2b and B-2c has been reduced in spite of adding a new treatment unit (primary sedimentation).

In addition to the extended aeration and activated sludge systems, Table 41 shows the results of the modular runs for trickling filter and stabilization ponds. The effluent stream qualities were set as same as above modules. They are designed for carbon removal without nutrient removal. Module results show that both systems need significantly lower energy demand and investment cost compared to extended aeration and activated sludge processes. Additionally, the effluent streams of these treatment systems contain high loads of nutrients that can be valued for agricultural applications. Since they do not have nutrient removal units.

Table 41 B-3 and B-4 results

Parameters/Modules	**B-3** (trickling filter)	**B-4** (stabilization pond)
Wastewater	ton/year	ton/year
COD	787	787
tN	69	69
tP	14	14
Treated wastewater	ton/year	ton/year
COD	160	160
tN	53	53
tP	10	10
Excess sludge	ton/year	ton/year
COD	205	174
tN	16	16
tP	4	4
Gas Phase	ton/year	ton/year
N_2	0	0
CO_2	422	453
Required Energy	MWh/year	MWh/year
Total energy demand	177	25
Total investment cost	€ 1.348.390	€ 280.245
Annual operation cost	€/year 150.957	€/year 26.017

4.3 Modular Applications – Case 3- Selçuk Wastewater Treatment Plant

The agricultural water demand could be partially supplied by treated municipal wastewater from wastewater treatment plant. The conditions of this plant can be optimized toward wastewater and nutrient reuse by changing sludge retention time and addition of treatment units for primary treatment or nutrient removal. Table 42 gives the scenarios developed for Selçuk Wastewater Tretment Plant. These modules were developed according to irrigation and nutrient demand of the study area.

- Module S-4: stabilization, SRT =360 days, no nutrient removal
- Module S-2a: primary sedimentation + activated sludge, SRT =25 days, preanoxic denitrification, biological phosphorous elimination
- Module S-2b: primary sedimentation+activated sludge, SRT =15 days, preanoxic denitrification, biological and chemical phosphorous elimination
- Module S-3: trickling filter

As it is shown in Table 33, Selçuk Wastewater Treatment Plant effluent stream cannot provide discharge quality (MoFWH, 2010). Consequently, scenario representing current situation, S-4, has an essential role for the Selçuk WWTP.

Table 42 Defined parameters for S-2a, 2b, 3 and 4

Defined parameters	**S-4** (stabilization, SRT =360 days, no nutrient removal)	**S-2a** (primary sedimentation + activated sludge, SRT =25 days, preanoxic denitrification, biological phosphorous elimination)	**S-2b** (primary sedimentation+activated sludge, SRT =15 days, preanoxic denitrification, biological and chemical phosphorous elimination)	**S-3** (trickling filter)
Primary sedimentation	No	Yes	Yes	Yes
Chosen sludge age	360	25	15	30
Temperature	15	15	15	15
Denitrification	No	Preanoxic	Preanoxic	No
Chemical phosphorus elimination	No	No	Yes	No
Biological phosphorus elimination	No	Yes	Yes	No

Table 43 gives the model results using the input data given in Table 34. Raw wastewater, treated wastewater, excess sludge, gas phase, energy demand, investment cost and operational cost results are given in Table 43. All calculations are made for a load of 50.000 population equivalents (PE). Since current wastewater treatment plant serves to 50.000 PE. The influent wastewater characterization values for the Selçuk Wastewater Treatment Plant are given in previous chapter (Table 33). They are used for representing typical domestic wastewater loads especially for Selçuk WWTP. Other input data (PE, daily water consumption, wastewater amount, BOD_5, COD, TSS, TOC, TKN, TP, K, Mg, Ca, NO_3, acid capacity) are given in the Table 30 and they are the same for all studied modules (S-4, S-2a, S-2b, and S-3).

Table 43 S-4, S-2a, 2b and S-3 results

Parameters/Modules	**S-4** (stabilization, SRT =360 days, no nutrient removal)	**S-2a** (primary sedimentation + activated sludge, SRT =25 days, preanoxic denitrification, biological phosphorous elimination)	**S-2b** (primary sedimentation+activated sludge, SRT =15 days, preanoxic denitrification, biological and chemical phosphorous elimination)	**S-3** (trickling filter)
Wastewater	ton/year	ton/year	ton/year	ton/year
COD	2848	2136	2136	2136
tN	296	266	266	266
tP	46	42	42	42
Treated wastewater	ton/year	ton/year	ton/year	ton/year
COD	235	235	235	235
tN	238	41	41	223
tP	33	27	4	32
Excess sludge	ton/year	ton/year	ton/year	ton/year
COD	842	701	761	684
tN	58	50	44	44
tP	13	15	38	10
Gas Phase	ton/year	ton/year	ton/year	ton/year
N_2	0	176	182	0
CO_2	1771	1200	1140	1217
Required Energy	MWh/year	MWh/year	MWh/year	MWh/year
Total energy demand	37	3232	3154	261
Total investment cost	€ 1.012.848	€ 3.926.857	€ 3.342.351	€ 1.071.555
Operational cost	€/year 82.359	€/year 714.122	€/year 696.773	€/year 133.672

4.3.1 Wastewater

Three water parameters were considered in Table 43, namely Chemical Oxygen Demand (COD), Total Nitrogen (tN) and Total Phosphorous (tP). Effect of the primary treatment on pollution load is shown in Table 43. There is a significant reduction (25%-COD, 10%-tN, 7%-tP) on pollution load in the case of S-2a, S-2b and S-3 compared to current situation (S-4). There is no primary treatment in S-4 while S-2a, S-2b and S-3 include primary treatment. Therefore the existence of primary treatment has a significant impact on the pollution load.

4.3.2 Treated wastewater

Three water parameters were considered in Table 43, namely Chemical Oxygen Demand (COD), Total Nitrogen (tN) and Total Phosphorous (tP). The effluent quality requirements in terms of these parameters for irrigation reuse were discussed in 2.9. As it mentioned in methodology section, current technology and operation conditions of Selçuk WWTP does not satisfy discharge requirements (MoFWH, 2010). According to the legal requirements, effluent quality of four modules (S-4, S-2a, S-2b and S-3) was pre-set in modules to comply with the releavant legislation. Calculated loads for effluent wastewater are presented in Table 43. The results indicate that re-dimensioning of current situation with modular design approach achieves the discharge standards. S-2a (activated sludge with 25 days SRT) has preanoxic nitrogen removal unit and biological phosphorous removal unit. Therefore yearly discharge amounts of both nitrogen and phosphorous are lower than current situation (S-4). On the other hand, in S-2b phosphorous are eliminated by chemical methods in addition to biological methods. Therefore phosphorous removal is higher than S-4 (stabilization, SRT =360 days, no nutrient removal) and S-2a (primary sedimentation + activated sludge, SRT =25 days, preanoxic denitrification, biological phosphorous elimination). In contrast to stabilization pond (S-4) and activated sludge (S-2a and S-2b), trickling filter (S-3) has a different biological treatment technology. Nitrogen and phosphorous are not treated in trickling filter, therefore valuable nutrients can be valued for agricultural applications.

4.3.3 Excess sludge

Three parameters were evaluated in Table 43, namely Chemical Oxygen Demand (COD), Total Nitrogen (tN) and Total Phosphorous (tP). Increase in carbon removal performance was observed in S-2a (701 ton/year), S-2b (761 ton/year) and S-3 (684 ton/year). 25% COD is removed by primary treatment. For the existing system, S-4, the significant amount of nitrogen and phosphorous is accumulated in the excess sludge. Since nutrients are subject to only stabilization and they are discharged mostly with sludge at the end of the treatment system. The second module (S-2a) has primary treatment and does have pre-anoxic nitrogen removal. Therefore significant amount of nitrogen is discharged with sludge while phosphorous content of sludge is low. On the other hand, both nitrogen and phosphorous dominate in sludge phase in the third module, namely S-2b which has primary sedimentation and nutrient removal. For the case of S-3, namely trickling filter, does not treat the nutrient, therefore nitrogen and phosphorous content shows the distribution within liquid and solid phase. S-3 makes it possible to eliminate 17% of the incoming total nitrogen (44 ton/year) and 24% (10 ton/year) of the incoming total phosphorous.

4.3.4 Gas Phase

After carbon removal and denitrification unit, the main gas phase products are nitrogen (N_2) and carbon dioxide (CO_2). Since denitrification take place in S-2a and S-2b, more than 170 ton/year N_2 released to atmosphere and almost half of the incoming total nitrogen is eliminated by off-gas. On the other side, carbon dioxide emissions have significant contribution to global warming as being a greenhouse gas. Results show that primary treatment has an important role on reduction of carbon source. It makes it possible to reduce almost 36% of carbon dioxide emission compared to current situation of the wastewater treatment plant (S-4).

4.3.5 Energy Demand

In terms of energy demand, S-2a (primary sedimentation + activated sludge, SRT =25 days, preanoxic denitrification, biological phosphorous and S-2b (primary sedimentation+activated sludge, SRT =15 days, preanoxic denitrification, biological and chemical phosphorous elimination) requires more energy rather than S-4 (stabilization, SRT =360 days, no nutrient removal) and S-3 (trickling filter). Since activated sludge aeration rate requirement, thus the main component of the energy demand increase to provide recommended effluent quality. Stabilization pond and trickling filters have a low energy demand (S-4= 37 MWh/year and S-3= 261 MWh/year) when compared to activated sludge system (S-2a=3232 MWh/year and S-2b= 3154 MWh/year.

4.3.6 Investment and operational cost

The investment costs and operational costs are presented in Table 43. They provide cost comparison of the modules used. The cost analysis results could be used at the stage of decision making before treatment technology selection since their influent and effluent quality values are same. The consideration of the calculated costs shows that if true operation conditions and sizing would be provided for the current treatment technology (stabilization pond), the investment cost is almost half of an activated sludge. Alternatively, the trickling filter plant can be operated and it could be invested at almost same cost with stabilization pond. Modules for Selçuk WWTP have also been compared in terms of their annual operation cost. The results show that current technology has the lowest operational cost compared to activated sludge and trickling filter. This result shows that such a tool designed for wastewater treatment plant design could be useful for decision making to choose correct sizing.

4.4 Water Demand Determination

The agricultural area and the percentage of the different field crops of the respective region have been evaluated to determine the potential of agricultural wastewater reuse with CROPWAT model. Menemen, Selçuk and Bayındır, are all in the same region, İzmir. Therefore, it has been assumed that crop water demand is same for all regions to provide simplicity.

Based on the methodology described in 3.2.1, analysis of meteorological data were resulted in graphs in Figure 12a and 12b. Uneven temporal rainfall distribution was observed from time series of reference evapotranspiration and effective precipitation. In addition to this, significant water shortage occurs during summer months, specifically in July and August, effective rainfall ranged from 2.6 to 3.0 mm.

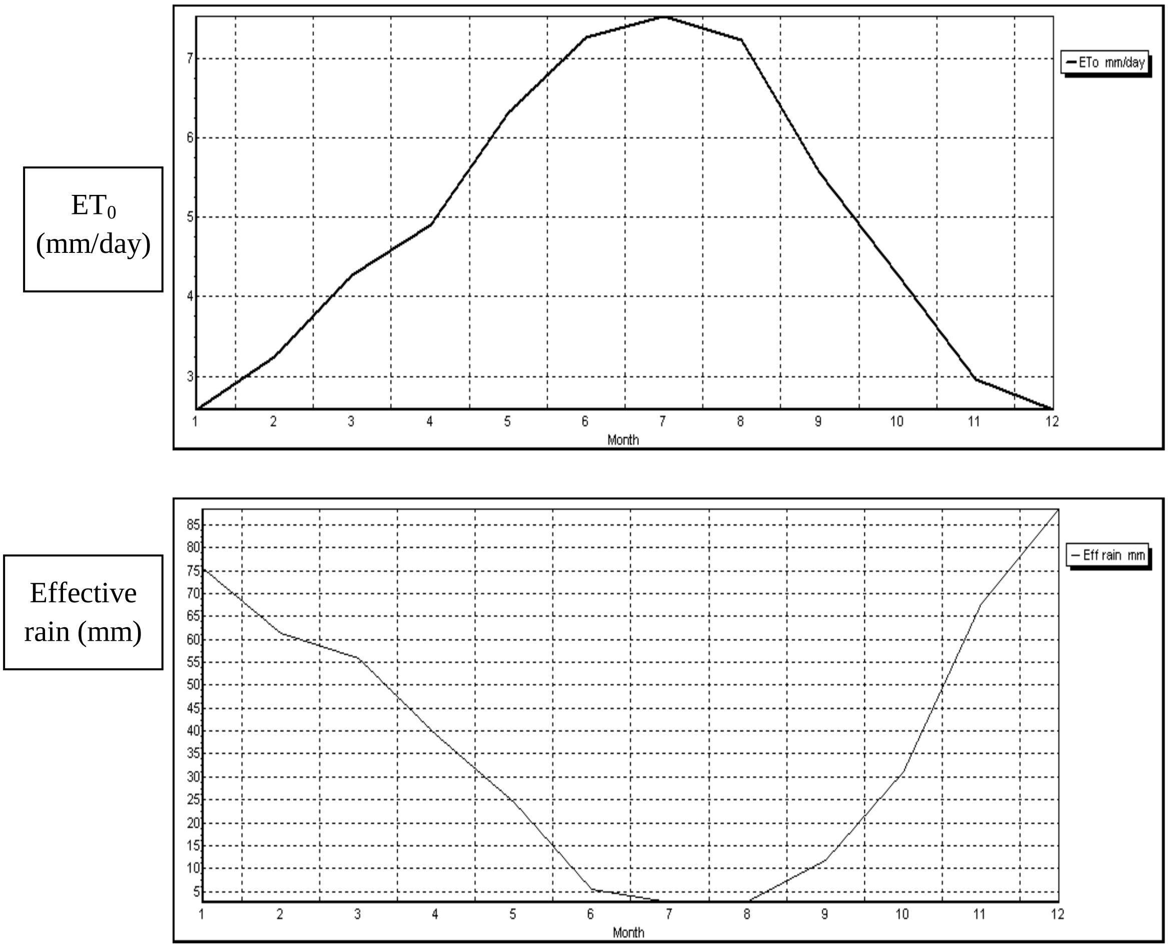

Figure 12 Monthly distribution of (a) reference evapotranspiration and (b) effective precipitation for four years meteorological data (x axes: month, y axes: mm/month)

During crop water demand determination five main crops have been taken into consideration, namely cotton, corn, fruit, vegetable and vineyard; and for climatic calculations four years have been taken into consideration respectively 2007, 2008, 2009 and 2010. Crop water demand of the regions on monthly basis is given in the Table 44. According to Table 44, total crop water demand is 76.02 million m^3 and July is the month that the most irrigation water required (24.47 million m^3).

Table 44 Calculated water demand for the areas studied

Months	**Total water demand of five crops (million m^3)**
January	-
February	-
March	-
April	-
May	3.84
June	17.49
July	24.47
August	22.42
September	7.67
October	0.13
November	-
December	-
TOTAL	76.02

When the water demand distribution is evaluated (Figure 13), the results indicate that the most water consuming products are respectively cotton, corn, fruit, vegetable and vineyard. The water demand of crops are; 43.82 million m^3 for cotton, 17.9 million m^3 for corn, 6.6 million m^3 for fruit, 4.9 million m^3 for vegetable, 2.8 million m^3 for vineyard. Water demand reaches to its highest value in July. In summer times water demand of crops increase, therefore supplying agricultural water becomes an important subject for the study area studied. Based on the estimated crop water requirements and results of modular design of wastewater treatment plant, a large agricultural area could be irrigated with wastewater.

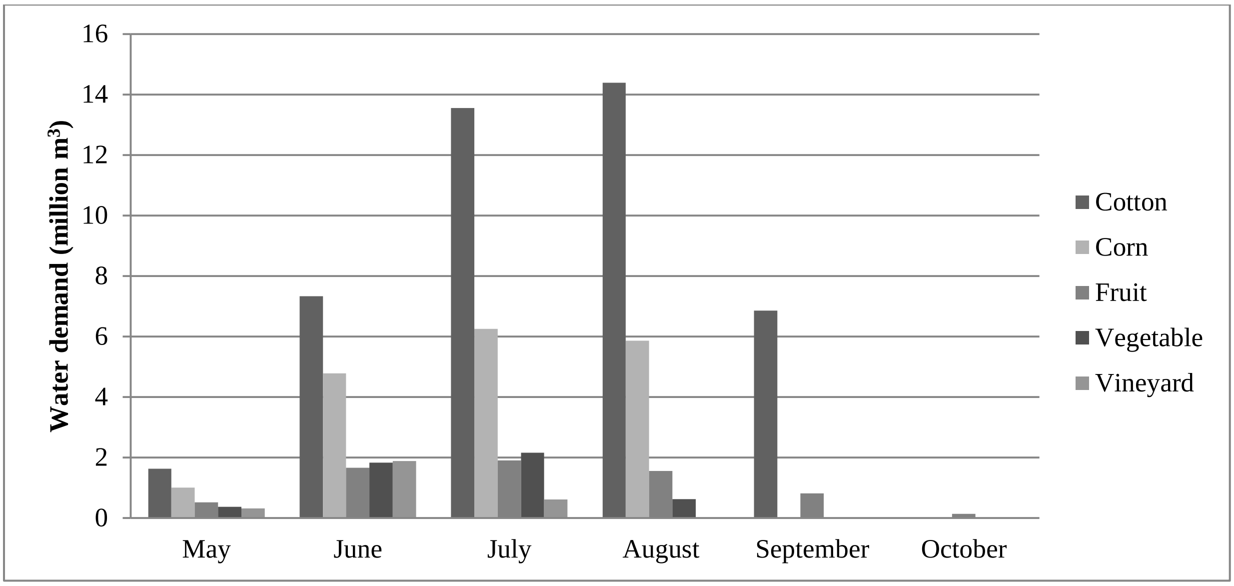

Figure 13 Water demand of five main crops for İzmir region

4.5 Nutrient Demand

Determination of the fertilizer demand is based on the actual fertilization practice, e.g. by evaluating the field record systems (Klein et al., 2010). Since actual fertilization data was not available for the regions studied, literature values for fertilizer demand were combined with recommendations concerning the application time(s) to create the nutrient demand on at least a monthly base. Table 45 summarizes N and P demand of selected five crops on monthly basis. Four years database have been taken into consideration during nutrient demand calculations. Figures 14-15 show the distribution of nutrient demand among the crops while Figure 16 represents nutrient and water demand distribution together.

Table 45 P and N demand of selected five crops

Months	Phosphorous (ton)	Nitrogen (ton)
January	0	0
February	173	422
March	212	712
April	39	303
May	-	89,9
June	-	89,9
July	-	26,7
August	-	-
September	-	-
October	-	-
November	-	-
December	-	-

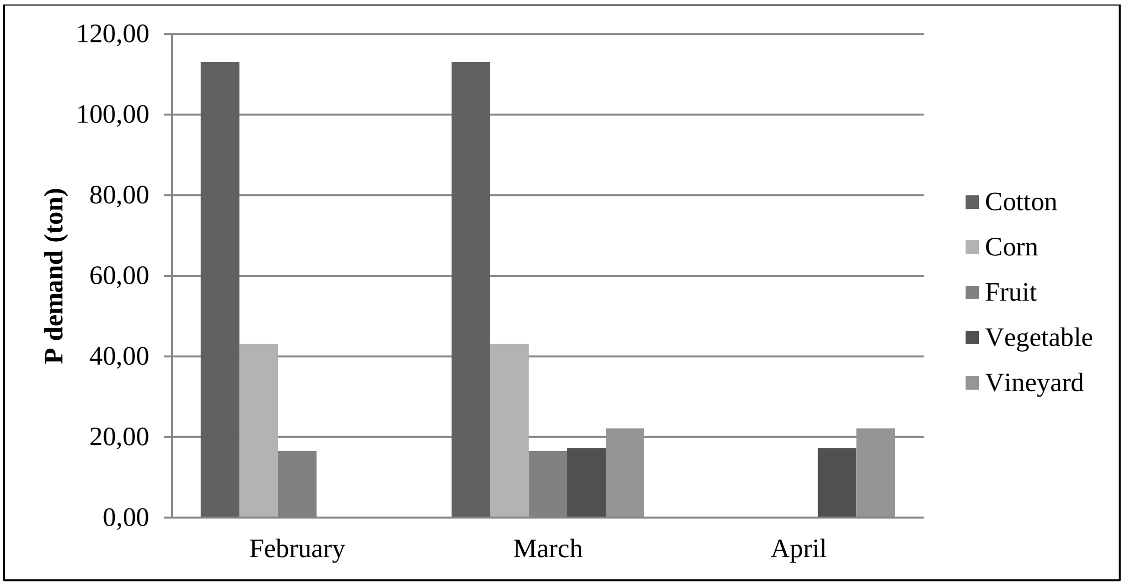

Figure 14 Phosphorous demand of the crops

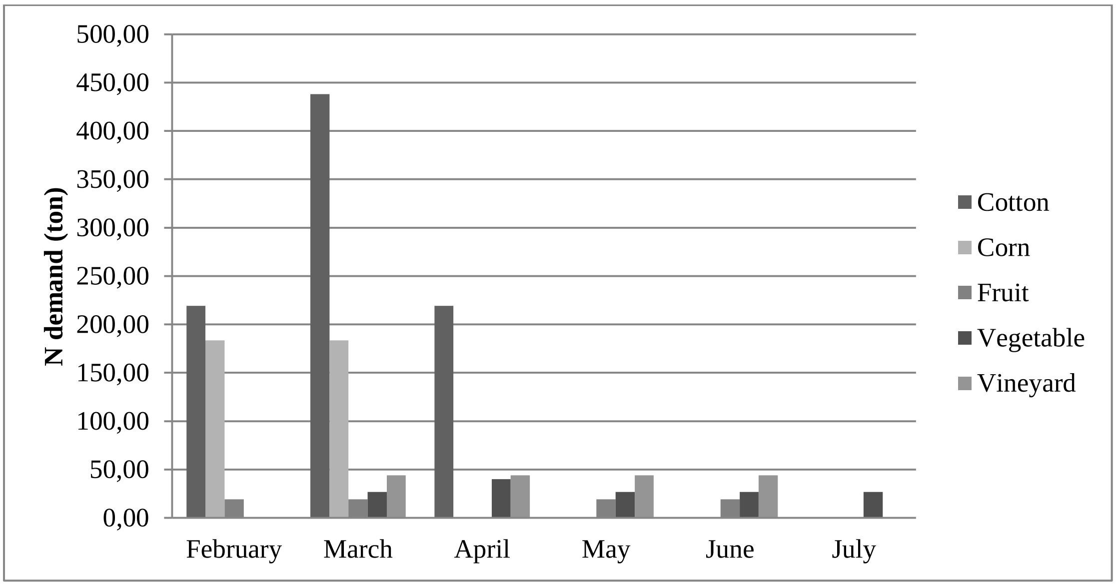

Figure 15 Nitrogen demand of the crops

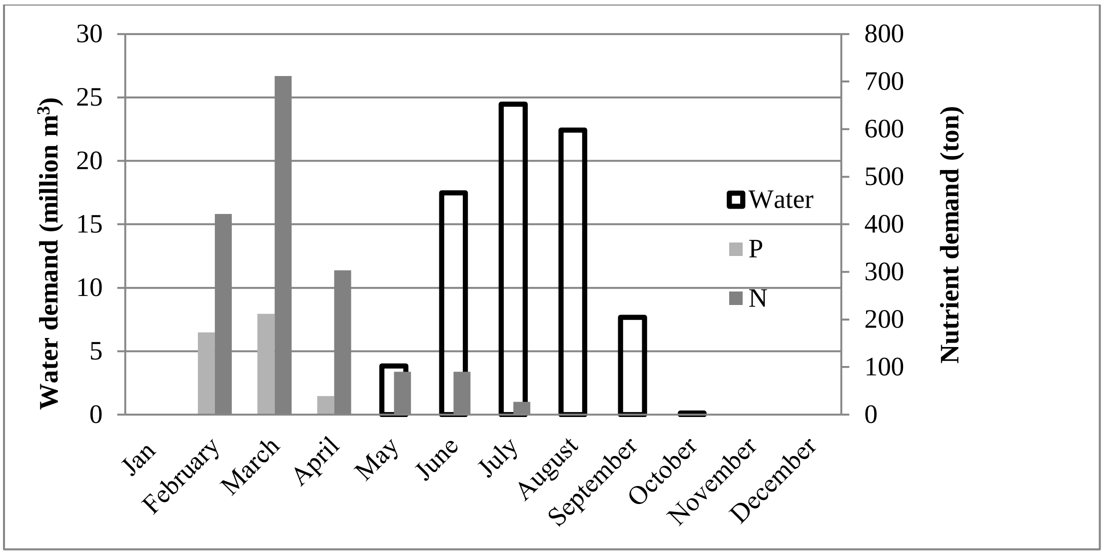

Figure 16 Nutrient (N&P) and water demand distribution of the crops

When water demand and nutrient demand combined in one figure it has been noticed that nutrient demand and water demand does not coincide. That's why the combination of nutrient and water demand of the crops has been taken into consideration during optimization studies. In another words irrigation schedules with treated wastewater based on both nutrient and water demand of crops.

4.6 Optimization Studies

The traditional approach for process design is to consider the discharge standars with respect to some legal requirements. However, this approach ignores existence of valuable nutrients in the wastewater which could be used for agricultutal purposes. The usual practice of considering operation control issues ignores the interaction of process control and wastewater reuse. The optimization problems arising from process control and wastewater reuse are very challenging. In this study, the main objective is to show how the process control and wastewater reuse can be handled by changing operational conditions with respect to satisfying the water and nutrient demand.

4.6.1 Menemen Region

Optimization scenario offers further options for agricultural reuse. The sludge retention time of the current wastewater treatment plant is 25 days. SRT of the optimization scenario can be adapted with respect to agricultural demand. Between August and January water demand of the crops dominates over nutrients. Therefore M-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination) is run for six months. On the other hand between February and July nutrient demand dominates over crop water demand. Therefore M-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal) is run for the rest six months. The percantage contribution of treated wastewater reuse to total demand is given in Figure 17. As a result, 45 t of N and 3 t of P could be additionally used in agriculture, compared to the current situation with a SRT of 25 days (M-2a) (Figure 18). In addition to that, annual electricity of 1.021 MWh can be saved at Menemen WWTP.

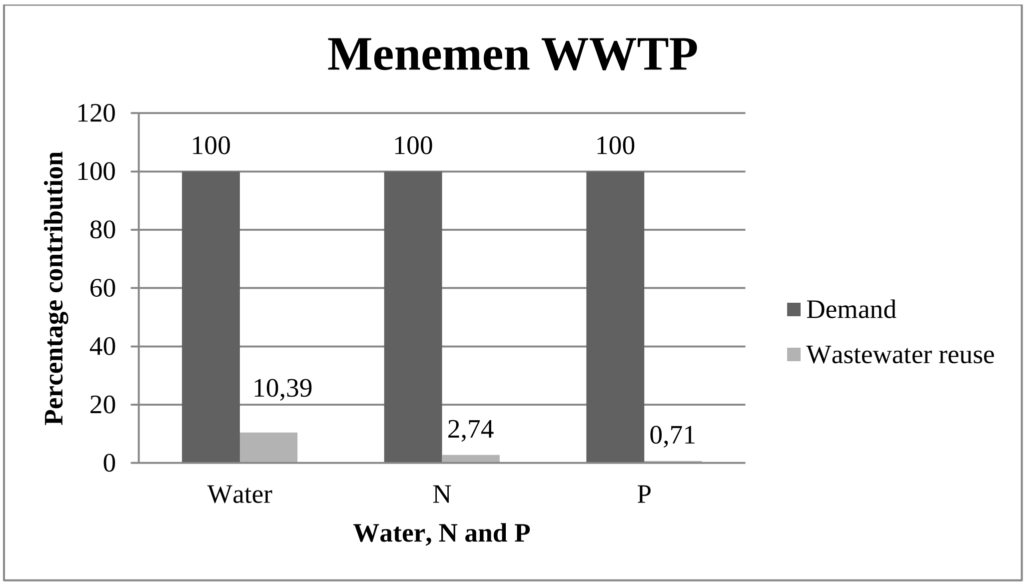

Figure 17. Percentage contribution of treated wastewater to total demand

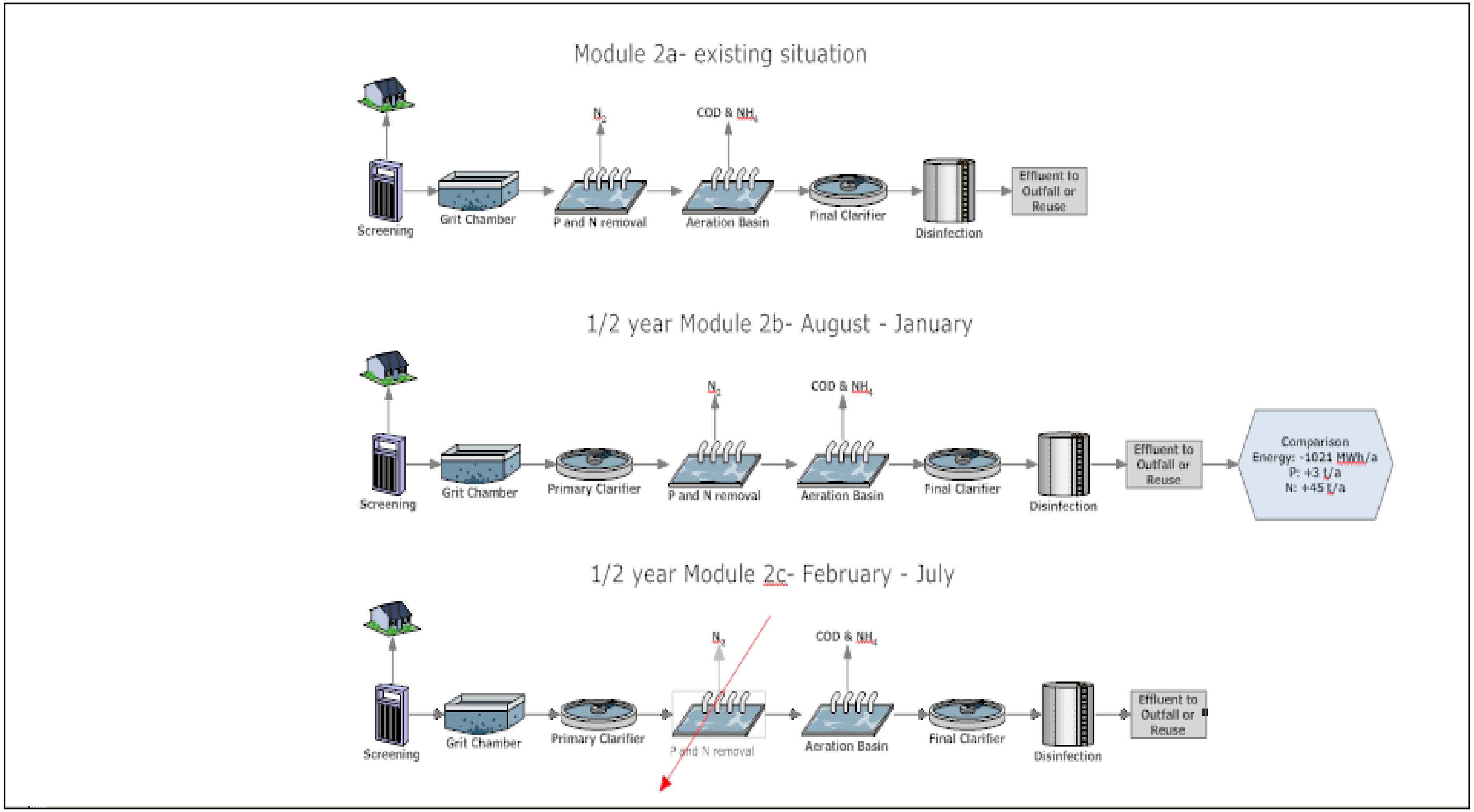

Figure 18 Proposed system for Menemen WWTP

So irrigation with treated wastewater containing such kind nutrients increase soil microelements, namely nitrogen and phosphorous. Reuse of treated wastewater could also take place of fertilizers applied to the lands and thereby production cost could be reduced significantly.

4.6.2 Bayındır Region

Optimization of wastewater treatment plant's operation conditions offers further options to find new irigation sources. The sludge retention time of the current wastewater treatment plant is 25 days. SRT of the optimization scenario can be adapted with respect to agricultural demand. Between August and January water demand of the crops dominates over nutrients. Therefore B-2c is run for six months. On the other hand nutrient demand dominates over crop water demand between February and July. Therefore B-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal) is run for the rest six months. The percantage contribution of treated wastewater reuse to total demand is given in Figure 19. As a result, approximately 13 t of N and 2 t of P could be additionally used in agriculture, compared to the current scenario with a SRT of 25 days (B-2a) (Figure 20). In addition to that, annual electricity of 225 MWh can be saved at Bayındır WWTP.

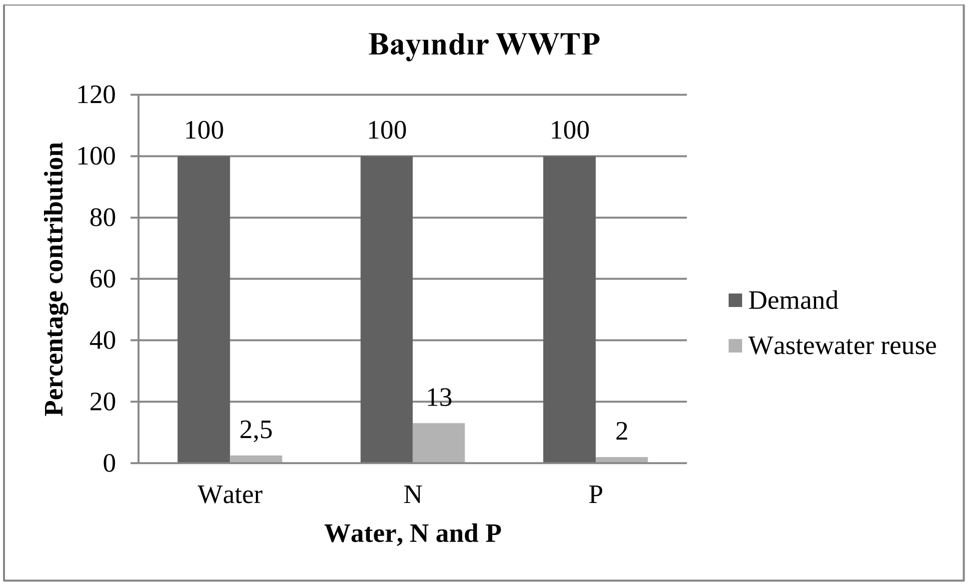

Figure 19 Percentage contribution of treated wastewater to total demand

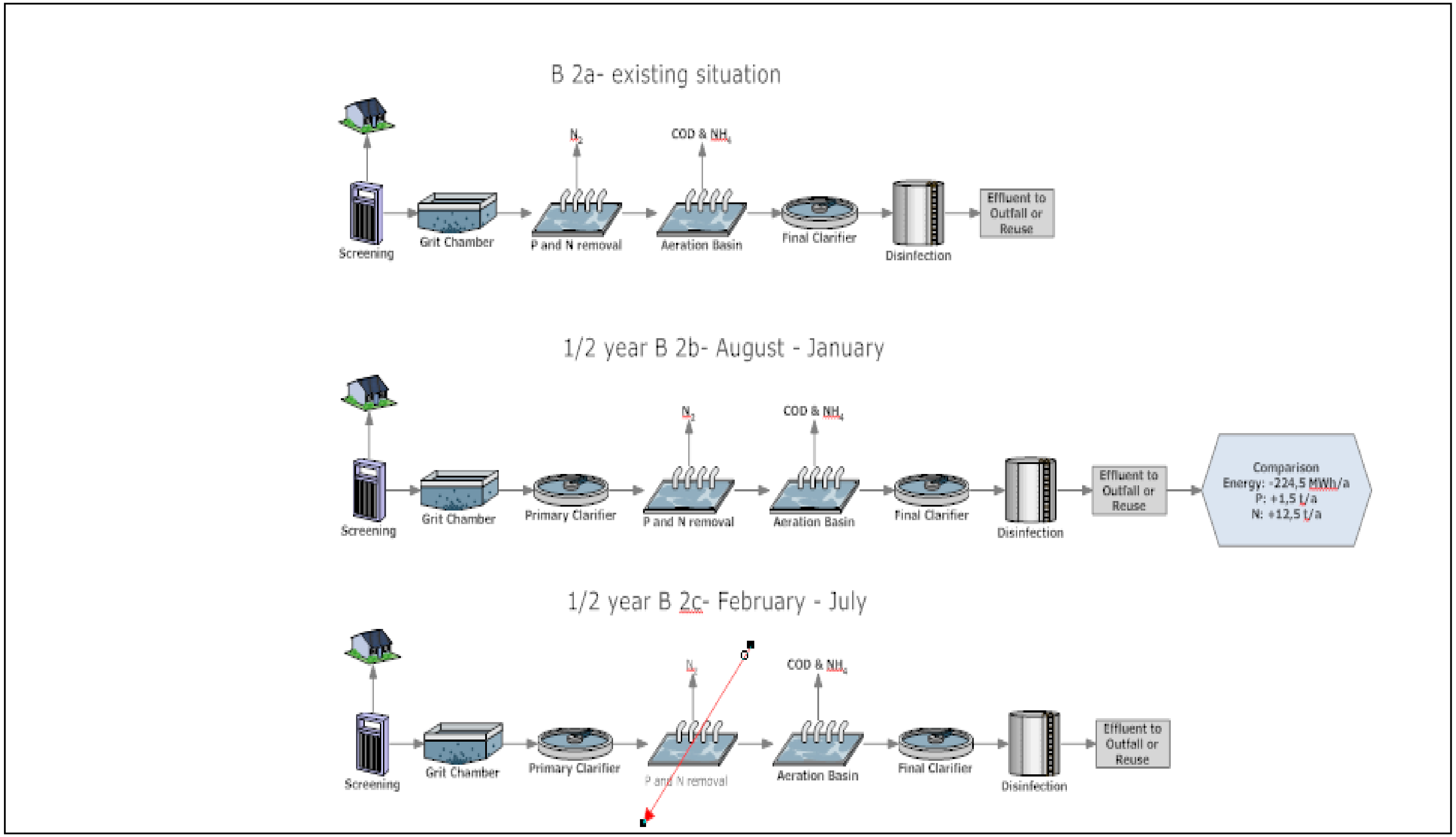

Figure 20 Proposed system for Bayındır WWTP

Therefore, wastewater could offer adequate amount of crop requirements from nitrogen and phosphorous. Reuse of treated wastewater could also take place of fertilizers applied to the lands. Thus fertilizer demand could be reduced and crop production cost could be minimized.

4.6.3 Selçuk Region

Selçuk Wastewater Treatment Plant has a natural treatment system with a stabilization pond. The effluent stream characterization shows (Table 28) that its quality does not provide recommended effluent quality criteria. During optimization, the investment cost and operation cost criteria have to be compared among different scenarios. As presented in Table 43 the minimum investment and operation cost estimate was observed for the case of stabilization pond (S-4). Therefore optimization studies have been carried out in this respect. To improve the effluent quality of this wastewater treatment plant, re-construction of stabilization tank is a must. Since the effluent quality values of module were pre-set according to relevant legislation, treated wastewater could be reuse for the purpose of irrigation after re-construction of the stabilization pond. If necessary volume of stabilization pond is provided, the effluent stream would contain high amount of valuable nutrients for irrigation (Table 43). The percantage contribution of treated wastewater reuse to total demand is given in Figure 21. As a result, effluent stream could be used for irrigational purposes for whole year, and approximately 238 t of N and 33 t of P could be valued for irrigation.

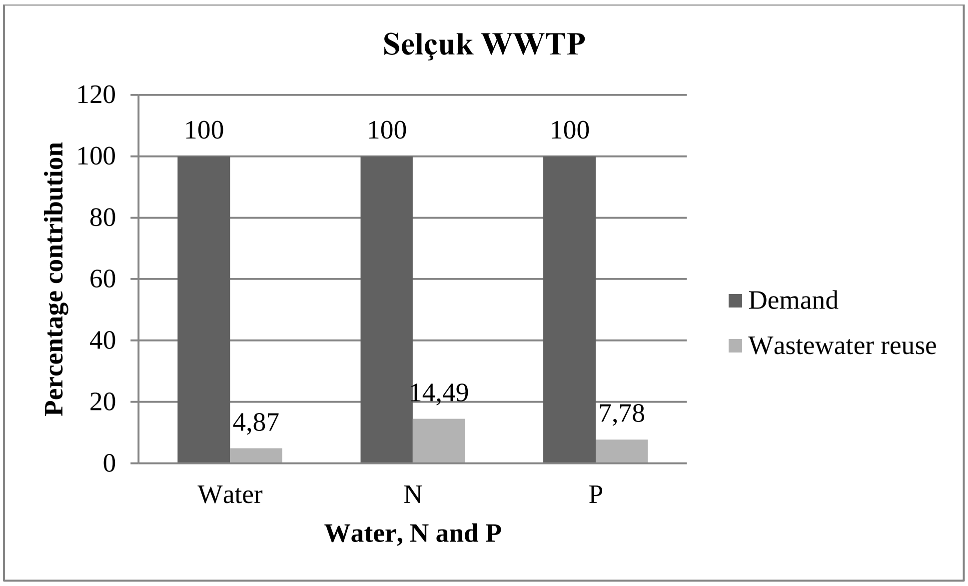

Figure 21 Percentage contribution of treated wastewater to total demand

CHAPTER 5

CONCLUSION

In this study, as a part of modular design of wastewater treatment plant for reuse, an approach for the design of wastewater treatment plant and reuse of treated wastewater for irrigational purpose is demonstrated. In this regard, three wastewater treatment plants are re-designed by modules and optimization studies are conducted for each plant.

In case Menemen, five modules were run; M-2a (extended aeration, SRT=25 days, biological phosphorous elimination), M-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal), M-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination), M-3 (trickling filter) and M-4 (stabilization pond). Module results show that primary treatment has a significant impact on the pollution load to the aearation tank. 1085 ton COD/year, 28 ton N/year and 9 ton P/year could be removed before the aeration tank by using primary treatment. M-2b and M-2c could achieve carbon removal with better performance than M-2a. While M-2a discharges 986 ton COD/year, M-2b and M-2c discharges 499 ton COD/year. Additionally, 184 ton nitrogen and 72 ton phosphorous could be gained for irrigation by operating M-2b. In terms of energy demand M-2a requires more energy (4493 MWh/year) rather than M-2b (3411 MWh/year) and M-2c (3533 MWh/year). When the investment and operational costs are evaluated, M-2a requires higher operational costs (1.687.193 €/year) and also higher investment costs (11.957.880 €). In addition to the extended aeration and activated sludge systems, trickling filter and stabilization ponds were run. Both systems need significantly lower energy demand (M-3= 552 MWh/year, M-4= 79 MWh/year) and investment cost (M-3= 4.023.450 €, M-4= 1.158.314 €) compared to extended aeration and activated sludge processes (M-2a=11.957.880 €, M-2b= 6.353.510 €, and M-2c= 7.318.621 €). Optimization studies show that 50 ton of N and 3 ton of P could be additionally used in agriculture, compared to the current situation with a SRT of 25 days (M-2a) if M-2b is run between August and January, and M-2c is run between February and July. Additionally, annual electricity of 1.021 MWh can be saved at Menemen WWTP.

In case Bayındır, five modules were run; B-2a (extended aeration, SRT=25 days, biological phosphorous elimination), B-2b (primary sedimentation+activated sludge, SRT =15 days, no nutrient removal), B-2c (primary sedimentation+activated sludge, SRT=10 days, preanoxic denitrification, chemical and biological phosphorous elimination), B-3 (trickling filter) and B-4 (stabilization pond). Significant impact of primary treatment on the pollution load to the aearation tank has been resulted. 263 ton COD/year, 8 ton N/year and 1 ton P/year could be removed before the aeration tank by using primary treatment. B-2b and B-2c could achieve carbon removal with better performance than B-2a. While B-2a discharges 315 ton COD/year, M-2b and M-2c discharges 160 ton COD/year. Additionally, 53 ton nitrogen and 12 ton phosphorous could be gained for irrigation by operating B-2b. In terms of energy demand B-2a requires more energy (1147 MWh/year) rather than B-2b (878 MWh/year) and B-2c (907 MWh/year). When the investment and operational costs are evaluated, B-2a requires higher operational costs (273.872 €/year) and also higher investment costs (1.561.329 €). In addition to the extended aeration and activated sludge systems, trickling filter and stabilization ponds were run. Both systems need significantly lower energy demand (B-3= 177 MWh/year, B-4= 25 MWh/year) and investment cost (B-3= 1.348.390 €, B-4= 280.245 €) compared to extended aeration and activated sludge processes (B-2a= 1.561.329 €, B-2b= 599.525 €, and B-2c= 1.433.621 €). Optimization studies indicate that 13 ton of N and 2 ton of P could be additionally used in agriculture, compared to the current situation with a SRT of 25 days (B-2a) if B-2b is run between August and January, and B-2c is run between February and July. Additionally, annual electricity of 225 MWh can be saved at Bayındır WWTP.

In case Selçuk, four modules were run; S-4 (stabilization, SRT =360 days, no nutrient removal), S-2a (primary sedimentation + activated sludge, SRT =25 days, preanoxic denitrification, biological phosphorous elimination), S-2b (primary sedimentation+activated sludge, SRT =15 days, preanoxic denitrification, biological and chemical phosphorous elimination), and S-3 (trickling filter). There is a significant reduction (712 ton COD/year, 3 ton N/year, 4 ton P/year) on pollution load in the case of S-2a, S-2b and S-3 compared to current situation (S-4). The module results show that resizing of stabilization pond (current system, S-4) achieves the discharge standards and valuable nutrients discharged with wastewater (238 ton N/year and 33 ton P/year) could be reused for irrigation. In terms of energy demand, S-2a (3232 MWh/year) and S-2b (3154 MWh/year) requires more energy rather than S-4 (37 MWh/year) and S-3 (261 MWh/year). . The consideration of the calculated costs shows that if true operation conditions and sizing would be provided for the current treatment technology, the investment cost (S-4 - 1.012.848 €) is almost half of an activated sludge (S-2a - 3.926.857 €, S-2b - 3.342.351 €). For the case of Selçuk, optimization studies show that if necessary volume of stabilization pond is provided, the effluent stream would contain high amount of valuable nutrients (238 ton N and 33 ton P) for irrigation.

CHAPTER 6

RECOMMENDATIONS

In case studies, the modular design scenarios show that treated wastewater could be use for agricultural purposes; since the treated wastewater has high nutrient potential. Therefore there is a high potential to optimize the agricultural water and nutrient reuse. Nutrient concentrations in the effluent can be adjusted with respect to the demand of the irrigated plants by changing the sludge age and/or the nutrient removal efficiency of a wastewater treatment plant. So, crop yield could be improved and fertilizer could be saved.

The current work investigates the potential of treated wastewater for irrigational reuse by using modular design approach. The development studies could be focused for the modular design to improve the compliance with the criteria depicted in the related regulation such as boron, heavy metals and conductivity. In addition to that, for further work, concrete case studies and practical development of the potentials may be focused. If the feasibility of reuse concept is projected in full scale, results could support the decision makers to change the operation parameters of the existing systems or design new wastewater treatment plants. Therefore more attention should be paid to full scale projects and the general public could be invited to visit urban water reuse facilities. The responsibilities of the construction companies and design companies should be made clearer so that each stakeholder could know its duty and the cooperation between different stakeholders would become better in future.

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APPENDICES

APPENDIX A: Legislative Information

Table A 1 Criteria for inland water quality classes

	Water Quality Class			
Water Quality Parameter	I	II	III	IV
A) Physical and inorganic-chemical parameters				
1. Temperature (^{o}C)	25	25	30	> 30
2. pH	6.5-8.5	6.5-8.5	6.0-9.0	outside 6.0-9.0
3. Dissolved oxygen (mg O_2/l)[a]	8	6	3	< 3
4. Oxygen saturation (%)[a]	90	70	40	< 40
5. Chlorine ions (mg Cl^{-}/l)	25	200	400[b]	> 400
6. Sulfate ions (mg $SO_4^{=}$/l)	200	200	400	> 400
7. Ammonia nitrogen (mg NH_4^{+}-N/l)	0.2[c]	1[c]	2[c]	> 2
8. Nitrite nitrogen (mg NO_2^{-}-N/l)	0.002	0.01	0.05	> 0.05
9. Nitrate nitrogen (mg NO_3^{-}-N/l)	5	10	20	> 20
10. Total phosphorus (mg PO_4^{-3}-P/l)	0.02	0.16	0.65	> 0.65
11. Total dissolved matter (mg/l)	500	1500	5000	> 5000
12. Color (Pt-Co units)	5	50	300	> 300
13. Sodium (mg Na^{+}/l)	125	125	250	> 250
B) Organic parameters				
1. COD (mg/l)	25	50	70	> 70
2. BOD (mg/l)	4	8	20	> 20
3. Organic carbon (mg/l)	5	8	12	> 12
4. Total Kjeldahl-nitrogen (mg/l)	0.5	1.5	5	> 5
5. Emülsified oil and grease (mg/l)	0.02	0.3	0.5	> 0.5
6. Methylene blue active substances	0.05	0.2	1	> 1.5

	Water Quality Class			
Water Quality Parameter	I	II	III	IV
(MBAS) (mg/l)				
7. Phenolic substances (volatile) (mg/l)	0.002	0.01	0.1	> 0.1
8. Mineral oils and derivatives (mg/l)	0.02	0.1	0.5	> 0.5
9. Total pesticides (mg/l)	0.001	0.01	0.1	> 0.1
C) Inorganic pollution parameters[d]				
1. Mercury (µg Hg/l)	0.1	0.5	2	> 2
2. Cadmium (µg Cd/l)	3	5	10	> 10
3. Lead (µg Pb/l)	10	20	50	> 50
4. Arsenic (µg As/l)	20	50	100	> 100
5. Copper (µg Cu/l)	20	50	200	> 200
6. Chromium (total) (µg Cr/l)	20	50	200	> 200
7. Chromium (µg Cr^{+6}/l)	indeterminable	20	50	> 50
8. Cobalt (µg Co/l)	10	20	200	> 200
9. Nickel (µg Ni/l)	20	50	200	> 200
10. Zinc (µg Zn/l)	200	500	2000	> 2000
11. Cyanide (total) (µg CN/l)	10	50	100	> 100
12. Florine (µg F^{-}/l)	1000	1500	2000	> 2000
13. Free chlorine (µg Cl_2/l)	10	10	50	> 50
14. Sulfur (µg $S^{=}$/l)	2	2	10	> 10
15. Iron (µg Fe/l)	300	1000	5000	> 5000
16. Manganese (µg Mn/l)	100	500	3000	> 3000
17. Boron (µg B/l)	1000[e]	1000[e]	1000[e]	> 1000
18. Selenium (µg Se/l)	10	10	20	> 20
19. Barium (µg Ba/l)	1000	2000	2000	> 2000
20. Aluminum (mg Al/l)	0.3	0.3	1	> 1
21. Radioactivity (pCi/l)				

	Water Quality Class			
Water Quality Parameter	I	II	III	IV
alfa-activity	1	10	10	> 10
beta-activity	10	100	100	> 100
D) Bacteriological parameters				
1. Fecal coliform (MPN/100 ml)	10	200	2000	> 2000
2. Total coliform (MPN/100 ml)	100	20000	100000	> 100000

(a) It is sufficient to ensure concentration and percentage saturation of only one of the parameters

(b) It may be necessary to lower the limit of this concentration for irrigation of chlorine-sensitive plants

(c) The concentration of free ammonia may not exceed 0.02 mg NH_3-N/l depending on pH

(d) Criteria in this group give total concentrations of chemical derivatives constituting the parameters

(e) These criteria may have to be lowered to 300 µg/l for irrigation of boron-sensitive plants

Table A 2 Discharge standards of domestic wastewaters to receiving bodies

Class 1 – Pollution load: 5-60 kg/day BOD, Population < 1000

Parameter	Unit	Composite sample (2 hrs)	Composite sample (24 hrs)
BOD_5	mg/l	50	45
COD	mg/l	180	120
SS	mg/l	70	45
pH		6-9	6-9

Class 2 – Pollution load: 60-600 kg/day BOD, Population: 1000-10000

Parameter	Unit	Composite sample (2 hrs)	Composite sample (24 hrs)
BOD_5	mg/l	50	45
COD	mg/l	160	110
SS	mg/l	60	30
pH		6-9	6-9

Class 3 – Pollution load > 600 kg/day BOD, Population > 10000

Parameter	Unit	Composite sample (2 hrs)	Composite sample (24 hrs)
BOD_5	mg/l	50	45
COD	mg/l	140	100
SS	mg/l	45	30
pH		6-9	6-9

Class 4 – For domestic wastewater treatment plants treating with stabilization ponds (independent of population)

Parameter	Unit	Composite sample (2 hrs)	Composite sample (24 hrs)
BOD_5	mg/l	75	50
COD	mg/l	150	100
SS	mg/l	200	150
pH		6-9	6-9

Table A 3 Irrigation water quality parameters as basis to irrigation water classification

Quality Criteria	Irrigation Water Class				
	I. Class (very good)	II. Class (good)	III. Class (usable)	IV. Class (usable with caution)	V. Class (detrimental, unusable)
EC25 x 106	0 – 250	250 – 750	750–2000	2000-3000	> 3000
Variable Sodium Percentage (%Na)	< 20	20 – 40	40 – 60	60 – 80	> 80
Sodium Adsorption Ratio (SAR)	< 10	10 – 18	18 – 26	> 26	
Sodium Carbonate Residue (RSC), meq/l mg/l	> 1.25 < 66	1.25 – 2.5 66 – 133	> 2.5 > 133		
Chloride (Cl-), meq/l mg/l	0 – 4 0 – 142	4 – 7 142 – 249	7 – 12 249 – 426	12 – 20 426 – 710	> 20 > 710
Sulphate (SO4-), meq/l mg/l	0 – 4 0 – 192	4 – 7 192 – 336	7 – 12 336 – 575	12 – 20 575 – 960	> 20 > 960
Total salt concentration (mg/l)	0 – 175	175 – 525	525–1400	1400-2100	> 2100
Boron concentration (mg/l)	0 – 0.5	0.5 – 1.12	1.12 – 2	> 2	
Irrigation water class*	C_1S_1	C_1S_2, C_2S_2, C_2S_1	C_1S_3,C_2S_3, C_3S_3,C_3S_2, C_3S_1	C_1S_4,C_2S_4, C_3S_4,C_4S_4, C_4S_3,C_4S_2, C_4S_1	
NO3- or NH4+, mg/l	0 – 5	5 – 10	10 – 30	30 – 50	> 50
Fecal Coliforms** (per 100ml)	0 – 2	2 – 20	20 – 100	100 – 1000	> 1000
BOD5 (mg/l)	0 – 25	25 – 50	50 – 100	100 – 200	> 200
Suspended Solid Matter (mg/l)	20	30	45	60	> 100
pH	6.6 – 8.5	6.5 – 8.5	6.5 – 8.5	6.5 – 9	< 6 or >9
Temperature	30	30	35	40	> 40

Table A 4 Permissible maximum heavy metal and toxic element concentration in irrigation water

Elements	Maximum total amounts per unit area, kg/ha	Permissible maximum concentrations	
		Limits for continuous irrigation under all soil conditions, mg/1	Limits for irrigation for less than 24 years on clayey soils with pH value 6.0-8.5, mg/1
Aluminium (Al)	4600	5.0	20.0
Arsenic (As)	90	0.1	2.0
Berlyllium (Be)	90	0.1	0.5
Boron (B)	680	-	2.0
Cadmium (Cd)	9	0.01	0.05
Chrome (Cr)	90	0.1	1.0
Cobalt (Co)	45	0.05	5.0
Copper (Cu)	190	0.2	5.0
Fluorine (F)	920	1.0	15.0
Iron (Fe)	4600	5.0	20.0
Lead (Pb)	4600	5.0	10.0
Lithium (Li)[1]	-	2.5	2.5
Manganese (Mn)	920	0.2	10.0
Molybdenum (Mo)	9	0.01	0.05[2]
Nickel (Ni)	920	0.2	2.0
Selenium (Se)	16	0.02	0.02
Vanadium (V)	-	0.1	1.0
Zinc (Zn)	1840	2.0	10.0

[1] 0.075 mg/1 for citrus

[2] Concentration allowed only for acidic-clayey soils with high iron content

Table A 5 Principles and Technical Constraints for Reuse of Wastewater in Agriculture

Agricultural Production	Technical Constraints
Orchards and Vineyards	- Sprinkler irrigation is prohibited
	- Fruits falling from the trees should not be eaten
	- Number of fecal coliform 1000/l00 ml
Fibrous Plants and Seed Crop Plants	- Surface or sprinkler irrigation is permitted
	- Biologically treated and chlorinated wastewater can be used in sprinkler irrigation
	- Number of fecal coliform 1000/100 ml
Forage crops, oil crops, after cooked eaten plants, floriculture	- Surface irrigation with mechanically treated wastewater

Table A 6 Industrial Effluents Reusable in Irrigation

I	II	III
Effluent from the following can be used in irrigation of nearby lands	**Effluent from the following can be used in irrigation under certain conditions**	**Effluent from the following is unsuitable for use in irrigation**
Beer, malt, wine, potato, vegetable, canning, marmalade, fruit canning, milk, potato starch processing plants and factories	Yeast, sugar, rice and cereal starch, bone glue factories, slaughterhouse, meat plants, tanneries, margarine factories, paper factories, textile industry (bleaching, mercerizing, dye house, print house, etc.), wool washing, fish flour, fish canning, mining facilities	Polish and paint factories, soap factories, inorganic heavy chemicals industry, pharmaceutical plants, metal processing plants, sulphide cellulose plants, viscous artificial silk factories, pyrolysis plants, gas plants, generator gas turbines, metallic oil industry, coal washing plants, dynamite industry, coking plants

Table A 7 Whether the domestic treated wastewater can be reused without prior disinfection

reusable (+) not reuseable (-)	Crop Field		Pasture Meadow		Vegetable		Forage Crops		Orchards		Woodland and forests
	B.N.E	B.E	B.N.E	B.E	B.N.E	B.E	B.N.E	B.E	B.N.E	B.E	
Effluent from biological treatment plant, or from min. 2-hr clarification ponds (preliminary treatment)	+	+	+	+	-	-	+	-	-	-	+
Effluent from aerobic stabilization ponds or lagoons	+	-	+	-	-	-	+	-	-	-	+

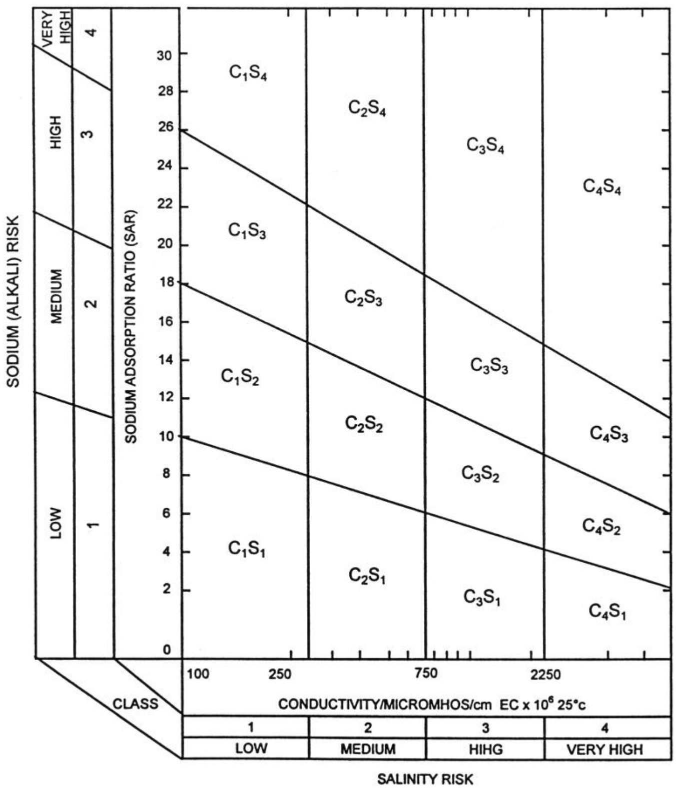
Table A 8 Irrigation water classification according to resistance of crops to boron

	Boron concentration in irrigation water (mg/1)		
Irrigation water class	Sensitive crops [1] (mg/1)	Fairly sensitive crops [2] (mg/l)	Resistant crops [3] (mg/l)
I	less than 0.33	less than 0.67	less than 1.0
II	0.33-0.67	0.67-1.33	1.00-2.00
III	0.67-1.00	1.33-2.00	2.00-3.00
IV	1.00-1.25	2.00-2.50	3.00-3.75
V	more than 1.25	more than 2.50	more than 3.75

[1] : Example: walnut, lemon, fig, apple, grape and green beans

[2] : Example: wheat, barley, maize, oat, olive, cotton

[3] : Example: sugar beet, clover, broad beans, onion, cos lettuce, carrot



Figıre A 1 Irrigation water classification diagram

APPENDIX B: CROPWAT Interfaces

Monthly ETo Penman-Monteith - C:\Documents and Settings\All Users\Application Data\CROPWA...

Country: Turkey | Station: Menemen-Right Coast

Altitude: 10 m. | Latitude: 38.00 °N | Longitude: 36.00 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m?/day	mm/day
January	-7.6	22.8	65	214	4.0	7.5	2.58
February	-5.6	26.5	63	209	5.1	10.5	3.24
March	-4.4	31.9	61	180	6.1	14.4	4.27
April	-1.4	33.8	58	152	7.5	18.9	4.90
May	2.8	40.2	55	141	9.6	23.6	6.31
June	6.7	43.0	48	141	11.0	26.1	7.26
July	10.7	42.3	46	158	11.8	26.9	7.52
August	10.8	44.3	48	147	11.6	25.1	7.23
September	6.0	41.4	54	130	9.6	19.6	5.56
October	1.2	39.4	60	130	7.5	13.8	4.27
November	-2.0	31.3	64	146	5.6	9.3	2.97
December	-4.5	25.4	67	197	3.9	6.8	2.59
Average	**1.1**	**35.2**	**57**	**162**	**7.8**	**16.9**	**4.89**

Figure B1 Climate data- CROPWAT interface determining crop water demand for citrus species

Monthly rain - C:\Documents and Settings\All Users\Application Data\CROPWAT\data\r...

Station: Menemen | Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	87.6	75.3
February	68.8	61.2
March	62.1	55.9
April	41.9	39.1
May	25.4	24.4
June	5.5	5.5
July	2.6	2.6
August	3.0	3.0
September	11.9	11.7
October	32.7	31.0
November	77.2	67.7
December	106.6	88.4
Total	**525.3**	**465.7**

Figure B2 Effective Rain- CROPWAT interface determining crop water demand for citrus species

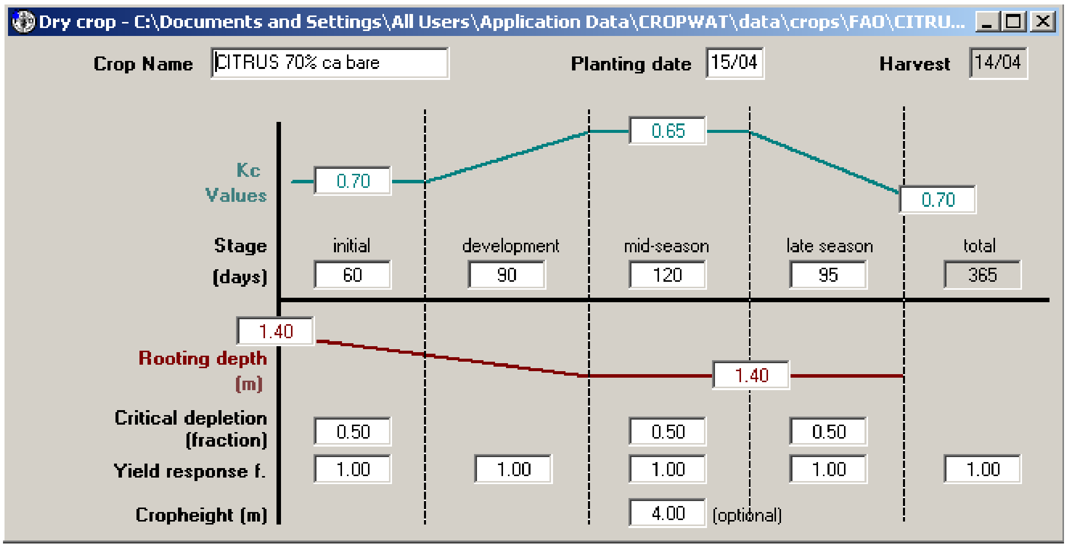


Figure B3 CROPWAT interface determining crop water demand for citrus species

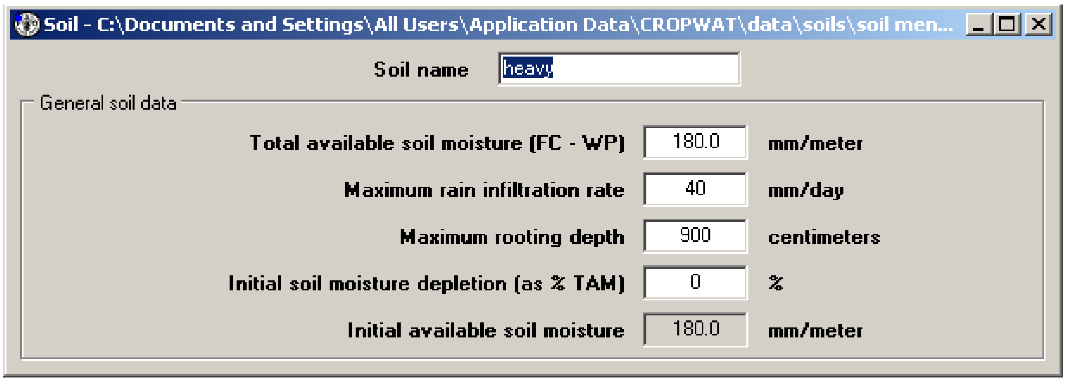
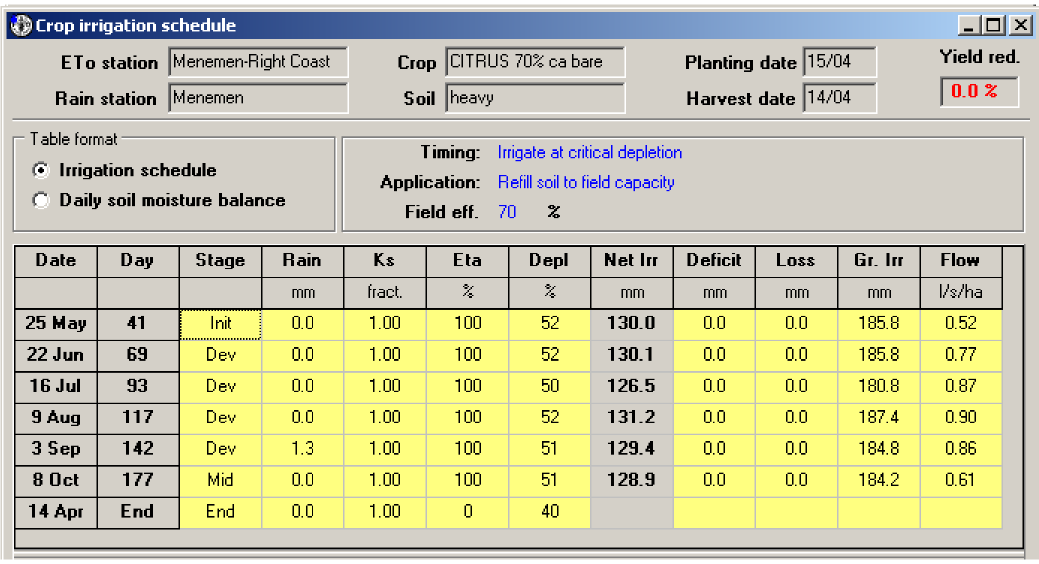


Figure B4 Soil - CROPWAT interface determining crop water demand for citrus species



Crop irrigation schedule

ETo station Menemen-Right Coast | Crop CITRUS 70% ca bare | Planting date 15/04 | Yield red.
Rain station Menemen | Soil heavy | Harvest date 14/04 | 0.0 %

Table format
Irrigation schedule
Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
25 May	41	Init	0.0	1.00	100	52	130.0	0.0	0.0	185.8	0.52
22 Jun	69	Dev	0.0	1.00	100	52	130.1	0.0	0.0	185.8	0.77
16 Jul	93	Dev	0.0	1.00	100	50	126.5	0.0	0.0	180.8	0.87
9 Aug	117	Dev	0.0	1.00	100	52	131.2	0.0	0.0	187.4	0.90
3 Sep	142	Dev	1.3	1.00	100	51	129.4	0.0	0.0	184.8	0.86
8 Oct	177	Mid	0.0	1.00	100	51	128.9	0.0	0.0	184.2	0.61
14 Apr	End	End	0.0	1.00	0	40					

Figure B5 Crop irrigation schedules - CROPWAT interface determining crop water demand for citrus species

APPENDIX C: CLIMATIC DATA

Table C1. 2007-2010 climate data of Menemen (MTSKAE, 2010)

MONTHS			**X**	**XI**	**XII**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**Yıllık**
PRECIPITATION **(mm)**		**TOTAL**	**32,7**	**77,2**	**106,6**	**87,6**	**68,8**	**62,1**	**41,9**	**25,4**	**5,5**	**2,6**	**3,0**	**11,9**	**525,3**
		DAILY MAX	69,2	119,8	75,8	79,0	64,0	83,9	42,0	44,6	32,3	21,6	33,9	72,9	119,8
TEMPERATURE **(ºC)**	AIR	**AVERAGE**	**17,3**	**12,9**	**9,6**	**7,8**	**8,7**	**11,0**	**15,0**	**20,0**	**24,7**	**27,0**	**26,3**	**22,2**	**16,9**
		EXT, MAX	39,4	31,3	25,4	22,8	26,5	31,9	33,8	40,2	43,0	42,3	44,3	41,4	44,3
		EXT, MIN	1,2	-2,0	-4,5	-7,6	-5,6	-4,4	-1,4	2,8	6,7	10,7	10,8	6,0	-7,6
	SOIL	**5 cm AVG,**	**17,7**	**12,2**	**8,4**	**7,0**	**8,4**	**11,4**	**16,5**	**22,2**	**27,0**	**30,0**	**29,7**	**25,1**	**18,0**
		5 cm EXT, MIN,	3,2	-0,7	-2,3	-4,0	-4,8	-1,8	3,4	9,0	12,0	15,1	16,5	9,0	-4,8
EVAPORATION **(mm)**		**TOTAL**	**101,0**	**57,5**	**44,2**	**44,5**	**49,5**	**77,9**	**110,5**	**169,5**	**222,1**	**263,1**	**230,2**	**162,1**	**1532,1**
		DAILY MAX	9,4	8,9	7,2	7,4	8,0	7,4	9,9	13,7	15,5	14,8	15,5	11,2	15,5
RELATIVE HUMİDİTY **(%)**		**AVERAGE**	**59,9**	**63,9**	**66,9**	**65,2**	**62,5**	**61,1**	**58,2**	**54,8**	**48,0**	**46,3**	**48,4**	**54,2**	**57,5**
WIND **(m/sec)**		**AVERAGE VELOCITY**	**2,3**	**2,6**	**3,5**	**3,8**	**3,7**	**3,2**	**2,7**	**2,5**	**2,5**	**2,8**	**2,6**	**2,3**	**2,9**
		THE MOST WIND DIRECTION	E	E	E	ENE	E	SSE	E	E	E	ENE	ENE	NE	E
		THE FAST	19,9	18,9	17,7	23,6	27,1	23,5	20,7	17,1	14,4	16,8	18,3	14,2	23,6
		DIRECTION	SSE	S	S	N	NNE	SSE	S	NE	NNE	NE	E	SSW	N

APPENDIX D

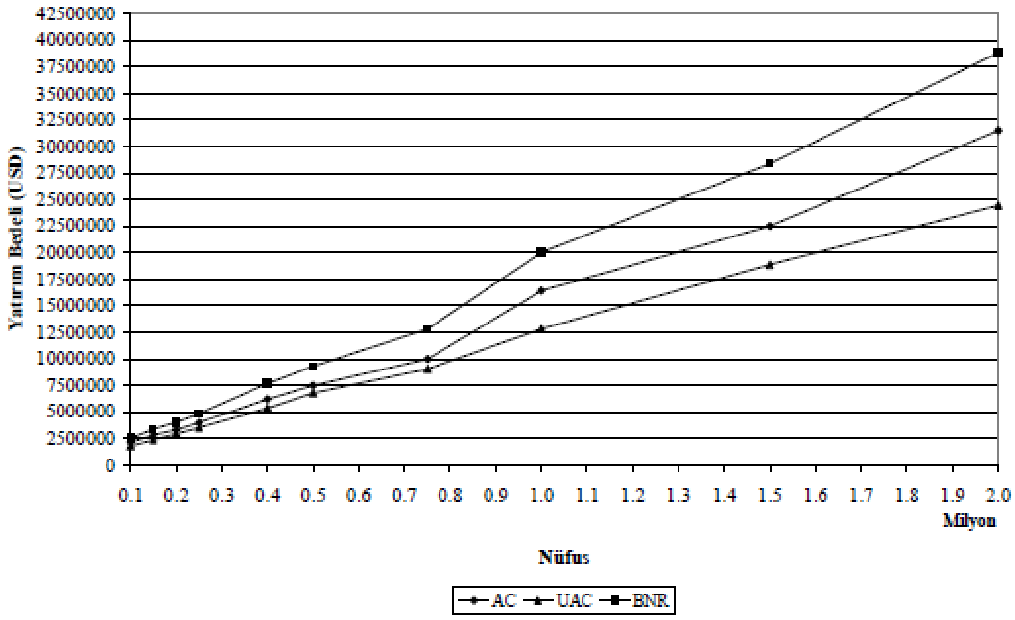


Figure D 1 Investment cost of Activated Sludge (AS), Extended Aeration (EA) and Biological Nutrient Removal (BNR)

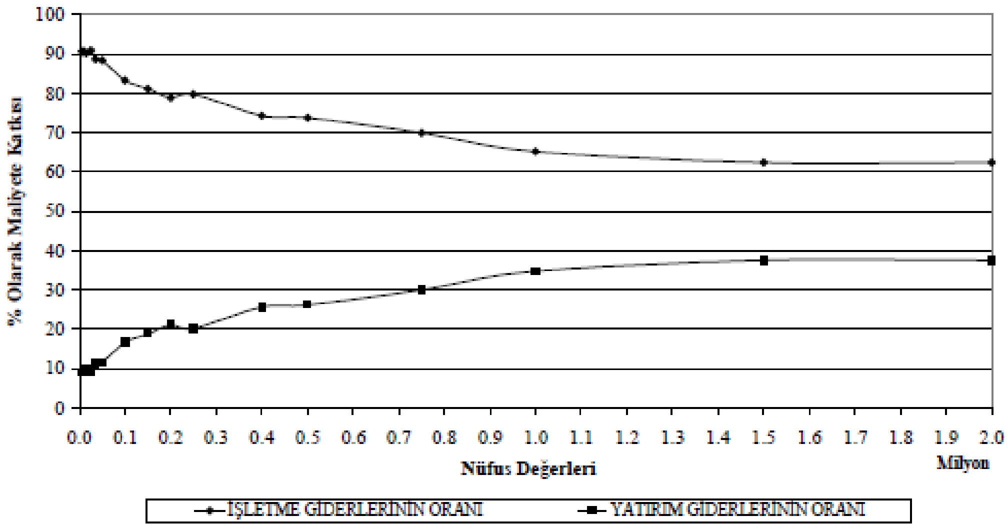


Figure D 2 Effect of investment and operation cost on unit wastewater treatment cost