THE POTENTIAL OF OSMOTIC POWER FOR TURKEY

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

BY

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

FEBRUARY 2017

Approval of the thesis:

THE POTENTIAL OF OSMOTIC POWER FOR TURKEY

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ABSTRACT

THE POTENTIAL OF OSMOTIC POWER FOR TURKEY

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February 2017, 105 Pages

Osmotic energy is a renewable source of energy which is obtained from the physical movement of water molecules between semipermeable membrane due to salinity gradient difference. Pressure retarded osmosis (PRO) is a system which is derived from salinity gradient and uses that osmotic pressure forces to produce energy by the help of turbines at locations such as river mouths where river and sea provides the required salinity gradient. It is a rather new technology which is still in research and development stage. Fresh water from rivers flow into seas surrounding Turkey which have different salinity. The potential of osmotic power at these meeting points of the rivers have not been studied yet. This study assesses the potential of major rivers of Turkey and discusses the utility of the osmotic power. Study areas are selected according to data attainability of salinity gradient, flow rate, temperature of water bodies and membrane water relationships. The yearly change of the parameters needed for production of osmotic power is analysed and potential capacities for PRO facilities are calculated for Turkey. Land area required for membranes for the proposed PRO capacities are also determined and possible locations were selected at the study sites.

Keywords: osmotic power, pressure retarded osmosis, membrane, Turkey, renewable energy

ÖZ

TÜRKİYENİN OSMOTİK GÜÇ POTANSİYELİ

Korkmaz, Ahmet Berkan
Yüksek Lisans, İnşaat Mühendisliği Bölümü
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Şubat 2017, 105 Sayfa

Osmotik enerji, tuzluluk değişim farkına bağlı olarak yarı geçirgen zar arasındaki su moleküllerinin fiziksel hareketi sonucu elde edilen yenilenebilir bir enerji kaynağıdır. Basınç gecikmeli ozmos (BGO), tuzluluk gradyeninden türetilen ve nehir ve denizin gerekli tuzluluk farkını sağlayan nehir ağızları gibi yerlerde türbin yardımıyla osmotik basınç kuvvetlerini enerji üretmek için kullanıldığı bir sistemdir. Hala araştırma ve geliştirme aşamasında olan osmotik enerji oldukça yeni bir teknolojidir. Irmaktan gelen tatlı su, Türkiye'yi çevreleyen, farklı tuzluluk oranlarına sahip denizlere dökülmektedir. Nehirlerin bu buluşma noktalarında osmotik gücün potansiyeli henüz çalışılmamıştır. Bu tez Türkiye'nin büyük nehirlerinin potansiyelini değerlendirmekte ve osmotik enerjinin kullanılabilirliğini tartışmaktadır. Çalışma alanları, tuzluluk derecesi, akış hızı, su kütlelerinin sıcaklığı ve membran su ilişkileri verilerine göre seçilmektedir. Osmotik güç üretimi için gerekli parametrelerin yıllık olarak değişimi analiz edilmiş ve Türkiye için BGO tesislerinin potansiyel kapasiteleri hesaplanmıştır. Önerilen BGO kapasiteleri için membranlara gerekli arsa alanı da belirlenmiş ve çalışma sahalarında olası yerler seçilmiştir.

Anahtar Kelimeler: osmotik güç, basınç engelli osmoz, membran, Türkiye, yenilenebilir enerji

To The Lord, my Runades
and
my holy, precious country
survived from 15 of June;
Republic of Turkey

ACKNOWLEDGMENTS

Initially, I would like to thank The Lord for giving that chance to finish my thesis. He always sent someone who encouraged me to finish my thesis when I gave up. For that reason, I would like to express my appreciation for my main supporters, first Seda Nur ALKAN who really supported me when I stressed and got angry, my dear uncle Dr. Bülent KUTLUCA and my father who finished master degree before me; Sebahattin KORKMAZ.

I would like to give my special thanks to Assoc. Prof. Dr. Şahnaz TİĞREK, because when I asked her about "Please give me a topic which is innovative and unaccomplished thing" she came with this extraordinary subject. Even she left the METU, she wanted to support as co-advisor far away from there. She is a respectable woman.

I would like to thanks million times to my dear advisor Asst. Dr. Gülizar ÖZYURT TARAKCIOĞLU. She studied so much for me. She always showed me way to overcome issues that I faced. Even she was also new in these subjects, she learned and explained every detail of it. She believed me more than I to accomplish the thesis.

My most special thanks would be for Retired Colonel, my godfather, Deceased Hacı GEDİKLİ, who said "Military could not abandon me, because only I knew what others didn't know." He always showed the right way in any case of lifespan. I believe he sees me.

Moreover, my appreciation goes to great photographer Celal İLER, he is still assistant in Early Childhood Education. When something had to be done he always said "I can handle, go and write your thesis". My dear family, my mom Sema KORKMAZ, sister Zehra KORKMAZ, elder sister Büşra KORKMAZ, they also supported me by preparing coffee, tea, snack while studying.

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LIST OF ABBREVIATIONS

EPRSD	General Directorate of Electrical Power Resources Survey and Development Administration
ERD	Energy Recovery Device
GWh	Gigawatt-hours
HEPP	Hydroelectric Power Plant
HP	High Pressure
ICP	Internal Concentration Polarization
INDC	Intended National Determined Conditions
LP	Low Pressure
MW	Megawatt
NRE	Non-renewable Energy
PRO	Pressure Retarded Osmosis
PX	Pressure Exchanger
RE	Renewable Energy
RED	Reversed Electric Dialysis
RO	Reverse Osmosis
SHW	State Hydraulic Works
SWRO	Sea Water Reverse Osmosis
UNFCCC	United Nations Framework Convention on Climate Change
WWTP	Wastewater Treatment Plant

CHAPTER 1

INTRODUCTION

Turkey is a developing country where 75% of energy demand is imported (Çengel, 2015). As energy demand increases day by day dependency of Turkey on outside sources also become stronger. Solution for this problem is to develop energy potential of national resources. Therefore, all possible energy potential of the country must be critically assessed in detail.

Energy resources are generally divided into two main categories as renewable energy (RE) and non-renewable energy (NRE) according to depletion of the source while producing energy. The energy produced from the sources which are not depleted or can be replaced is accepted as renewable energy. These are solar, wind, geothermal, tidal, biomass and hydro. RE sources are accepted as clean energy, preserving their possible environmental impacts. When it comes to compare with NRE, RE sources have quite less impact (Rinkesh, n.d.).

NRE is produced from resources that are limited. Well-known NRE sources are fossil fuels (coal, oil and gas) and nuclear energy. NRE production is rather fast and easy, moreover, output power is often higher than RE sources. Besides its advantages, NRE production generally has significant impact on environment. One of the main contributors to global climate change is burning of fossil fuels in which carbon dioxide (CO_2) and other greenhouse gasses are exhausted to the atmosphere in enormous quantities (Rinkesh, n.d.).

RE trend is growing rapidly all over the world. RE sources were boosted by the new Paris Agreement and national intended determination contribution (INDC) under the United Nation Framework Convention on Climate Change (UNFCCC). In the report of Global Trends in Renewable Energy Investment 2016, Ban Ki-moon secretary general of United Nations, says in the year of 2015, RE set a new record in investment amount of $286 billion which is six times more than the amount invested in 2004. He added that to keep the increase in global temperature below 2^{o}C, main target 1.5^{o}C, fossil fuels must be avoided as soon as possible (Byrne et al., 2016).

In Turkey, Law on The Use of Renewable Energy Resources for Electrical Energy Production was come into operation in 2005. To support RE, Promotion on Renewable Energy Sources Law inured in 2010. Under the Renewable Energy Sources Act, the law on incentives also entered into force. It also envisages the implementation of additional support in the case of the use of domestic production equipment and equipment in the facilities used for energy production.

Renewable energy potential of Turkey is assessed by Renewable Energy General Directorate of Ministry of Energy and Natural Resources (Table 1).

Table 1: Renewable power potential of Turkey (A. Korkmaz, personal communication, October 15, 2016)[1]

Energy Resource	Potential	Unit
Solar Power	1500	KW/year-m^2
Wind Power	48000	MW
Geothermal (Electricity Production)	2000	MW
Biomass	8.6	Mtoe (oil-eq)
Hydraulic	34000	MW

Due to global demand on energy and together with renewable energy, osmotic power emerges as a new renewable energy source.

Osmotic power which is still under development, thus there is not any commercial osmotic energy plant built yet. The main idea behind this process is called osmosis, in which salt difference between two liquids separated by membrane cause an osmotic flow from fresh side to salty one. Due to this flow, osmotic pressure increases in salty side and energy is produced by depressurizing this energy by using turbines In fact, technology related to this process is known for more than a century but the weakest part of the process, the membrane, cannot provide sufficient power

[1] A.Korkmaz is an environmental engineer in Renewable Energy General Directorate of Ministry of Energy and Natural Resources, information have been taken by phone call.

density yet. On the other hand, membrane power density has been increased and cost of membranes has been reduced in recent years. So that the technology is now closer to accomplish economically feasible energy production.

The main purpose of thesis is to assess osmotic power potential of Turkey. The geography of Turkey being a peninsula with many rivers discharging to the seas is very advantageous to osmotic energy production, the potential is expected to be high. However, the flowrate of river does not show a regular regime which can limit this potential significantly. Therefore, this study assesses the osmotic power potential of the main rivers in Turkey considering seasonal changes in both river and sea water characteristics and proposes possible locations and capacities for osmotic power plants. As osmotic energy is a newly developing technology, this assessment is the first evaluation of osmotic power potential for Turkey to the best knowledge of the researchers.

Thesis consists of six main chapters which is shown in the Figure 1. After the current chapter, Introduction, second chapter reviews the available literature. In that chapter, osmosis theory and Pressure Retarded Osmosis (PRO) process are also explained in detail.

In Chapter 3, data and methodology is covered where parameters and related equations are evaluated. Some technical explanations are also included in that chapter related to the conditions of Turkey. Assessments of selected major rivers are presented in Chapter 4 to determine the national osmotic power potential. Chapter 5 provides further information on potential of osmotic energy in Turkey with area requirement for membrane stacks, more technical details and some other comments on osmotic power plant. In Chapter 6, environmental considerations, combination of PRO with other facilities such as sewage treatment systems, staged PRO studies and hybrid Reverse Osmosis PRO method have been worked through. At the end, conclusion chapter provides a short summary of all the study and future considerations of this new renewable energy source.

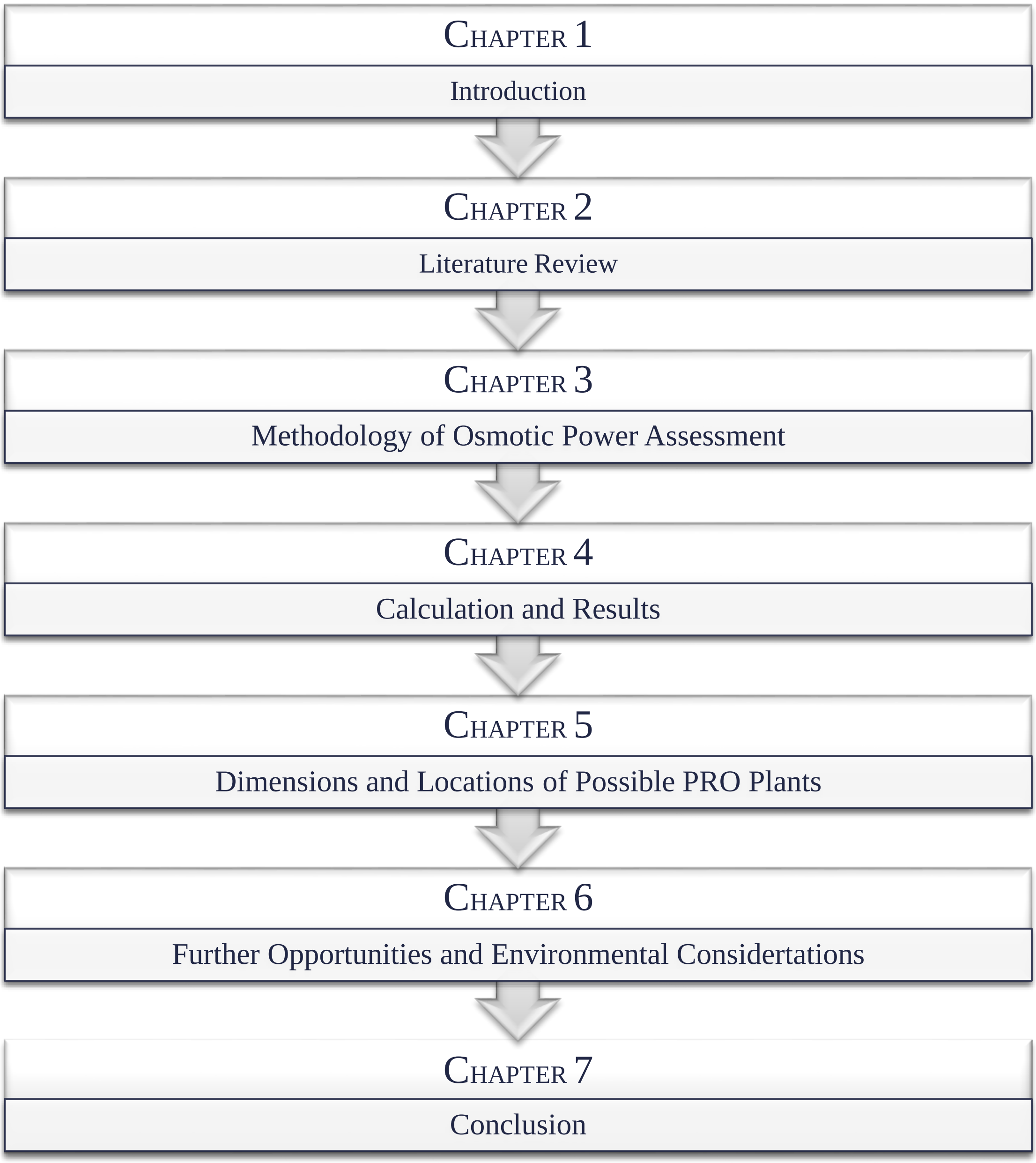

Figure 1: Chapters in thesis.

CHAPTER 2

LITERATURE REVIEW

In this chapter, osmosis, osmotic power plant, studies on osmotic energy in the literature are presented starting with general definition of osmosis process.

Osmosis is a natural process, which is the movement of water from concentrated solution to less concentrated one in a place where two solutions are separated by selectively permeable membranes. Semipermeable membrane allows water molecules to be transferred to other side, but prevents diffusion of solutes (Lankford and Friedrichsen, 2012).

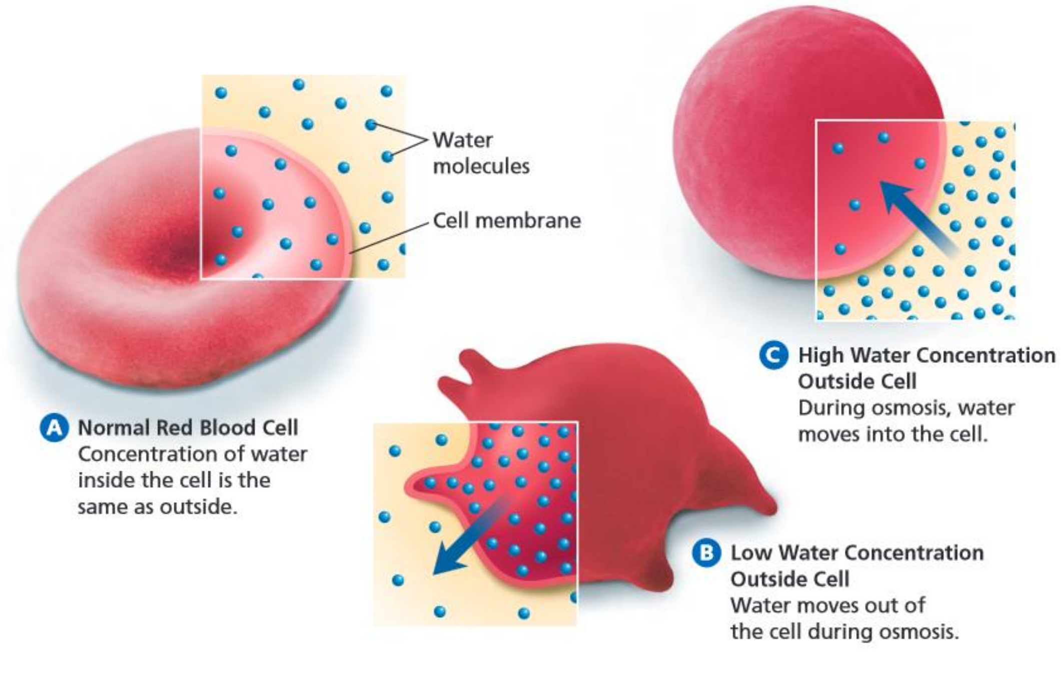

Figure 2: Effects of osmosis on red blood cells (“p33-34 Osmosis,” 2016)

In fact, osmosis takes place in every living cell to provide adequate water required for cell activities. Figure 2 illustrates cases in red blood cells, where osmotic process occurs. Depending on the concentration difference, water molecules move toward to the low water concentration zone creating osmotic pressure. Main idea of osmotic power plant is to convert this pressure difference between two sides of solution into electricity.

2.1 Brief History and Exploration of Osmosis

In 1748 Jean-Antione Nollet, a French priest and physicist, was the first person who discovered the osmosis. He put wine into bladder of a pig and then put that bladder in a barrel of water. He saw that water in the barrel went into the bladder, however, wine did not go into water at all. The bladder started to swell and burst at the end (Kleiterp, 2012). Later on, the bladder was replaced by membranes. Dutch scientist Jacobus H. Van't Hoff earned the Nobel Prize for Chemistry in 1902 by a formula used for calculating the osmotic pressure. R.E. Pattle (1954) is the first person showing osmosis as a potential energy source. He discovered that fresh river water meets with saline sea water by losing huge amount of free energy. He declared that free energy can be used to obtain power production by the help of semipermeable membrane (Kleiterp, 2012) .

In 1960s membrane technology was limited due to weak properties of membranes, therefore, they could not be used for widely in industry. In those years, Sidney Loeb developed a new technology for membranes which can be used in many areas. Today, membrane technology can provide better efficiency for specific conditions but it is still not a cheap product (Kleiterp, 2012).

2.2 Osmotic Power Production (Pressure Retarded Osmosis)

There are different approaches for producing energy from osmosis. One of the most well-known is Pressure Retarded Osmosis (PRO). PRO system requires two different solutions having different salinity that is molar free energy to work with. Other things for sustaining the system are flow rate and semipermeable membrane set. Lastly, turbine is needed to convert that free energy potential to electricity (Kleiterp, 2012). In this particular system, fresh water permeates through membrane to pressurized saline water and power is obtained by depressurizing on hydro turbine to obtain energy (Achilli and Childress, 2010). In nature, at river mouths and estuaries, fresh and saline water are located in favourable conditions satisfying the PRO system requirements. Greater the salt concentration difference larger the energy is obtained. Detailed technical information of PRO is given in Chapter 3. The main idea of PRO is shown in Figure 3.

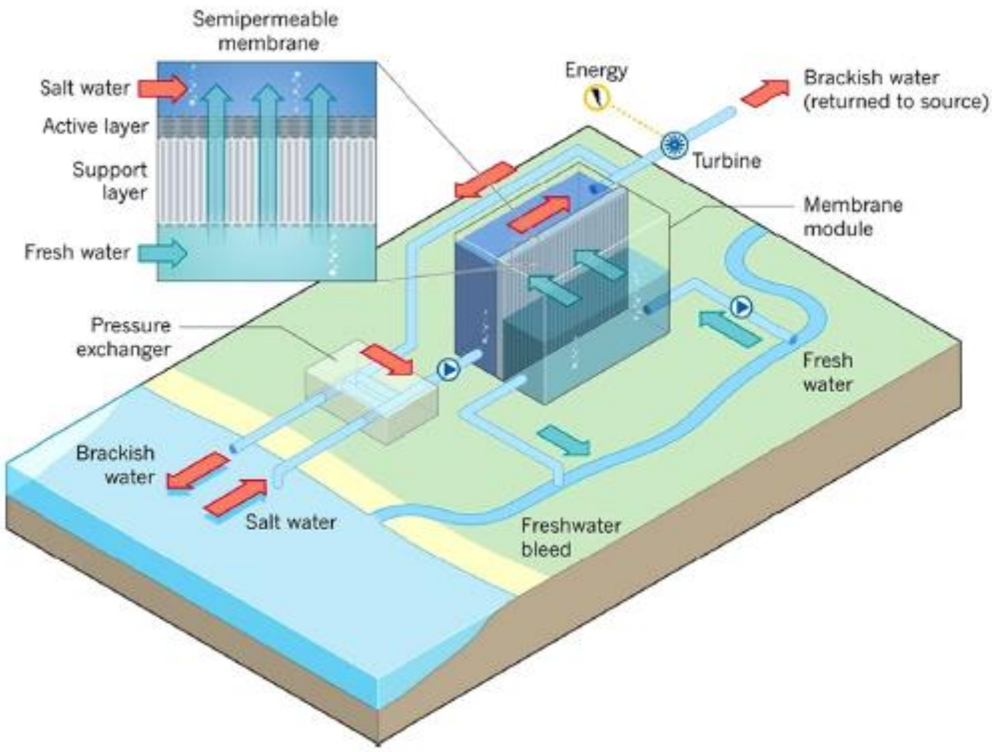

Figure 3:Representation of PRO plant sustained by river water and sea water (Helfer, Lemckert, and Anissimov, 2014).

2.3 Implementation Possibilities

When the nature of the water cycle is considered, river mouths will be favoured for osmotic energy production. Geological characteristics of Turkey should be suitable for that purpose because it is a peninsula surrounded with three important seas namely, the Black Sea, the Aegean Sea and the Mediterranean Sea.

2.4 Pressure Retarded Osmosis (PRO) in Literature

Osmotic power and PRO are new areas of study. For this reason, there are limited number of studies in the literature. Earliest articles have been written by Loeb (1975) , who is known as mastermind of energy production from osmotic power. Topic had not been studied for a while, the studies have been mostly conducted in recent years. Generally, studies have been made on membrane experiments and performance, feasibility calculations, energy efficiency, power production calculation and hybrid power plants.

In the article, *"Energy production at the Dead Sea by pressure-retarded osmosis: challenge or chimera?",* Loeb (1998) expressed the two kinds of approaches for PRO. Bringing seawater to "The Dead sea" which is a lake near Jerusalem elevated 400m below the sea level, is considered. It is claimed that elevation difference can be used either hydropower plant or PRO-RO combination for freshwater and energy production. Study shows 48 MW of energy production by the help of reject reverse osmosis (RO) water and $190 million cost for PRO construction. Hydropower potential is estimated as 130 MW. In case of a hybrid of Hydropower PRO is considered, there will be 70 MW power with a construction cost of US $230 million.

Loeb (2001) analysed the feasibility of hydroelectric power production by PRO in Great Salt Lake (GSL) with spiral module membranes. The question is focused on the possibility to apply an appropriate membrane to gain much power economically. The energy cost depends largely on the achievement of enough flux across the membrane. Herein, the main issue is the resistance to solute diffusion in the porous substructure of the membranes. If this resistance can be effectively reduced, it is possible to produce 66 MW at a capital cost of 9000$ per kW and an energy cost of 0.09 $ per kWh in PRO of the Jordan River discharging to the Jordan River. The outcomes could be the same in a twin plant using the Weber River discharging to the Great Salt Lake as the dilute solution, but giving a total power output of about 130 MW. Because of the higher salinity of the north end brine, a third plant using the Bear River could give better consequences. Payoff of the osmotic energy plant and cost of energy are the most important parameters.

In another study, Loeb (2002) indicates that there are two factors in PRO systems limited with spiral modules: the flow rate of the river being treated in PRO and porous substrate resistance to salt diffusion, k (d/m) the resistance to solute diffusivity in the porous substructure of the membrane. According to these variables, four different situations are calculated: moderate flow rate k=10; moderate flow rate, k=0; Mississippi flow rate, k=10; Mississippi flow rate, k=0. The results of these calculations show that compared to a small plant, a very large PRO plant is an economical way to produce energy and power considering economy-of-scale. The study points out that whether developing a convenient spiral module membrane for PRO will be difficult, this benign and renewable source of energy is justifiable for investigation on a large scale.

From Norwegian Statkraft company, which was the greatest investor on osmotic power plant, Skilhagen, Dugstad and Aaberg (2008) determined membrane efficiency as the key factor for osmotic power production in their article, *"Osmotic power — power production based on the osmotic pressure difference between waters with varying salt gradients".* Statkraft seeked collaboration with commercial membrane companies in order to develop sufficient membrane for osmotic power plants.

The work of Achilli, Cath and Childress (2009) is about experimental and theoretical investigation of PRO. It is the first article that compares model results and experimental results. According to the study, model predictions showed close results to experiments. At 970 kPa hydraulic pressure on the saline part, 2.8W/m^2 for the 35 g/L NaCl draw solution and up to 5.1 W/m^2 for the 60 g/L NaCl draw solution has been achieved. This new comparative approach leads to optimized studies for osmotic power production.

Achilli and Childress (2010) present the historical development of PRO from its first invention in the journal article *"Pressure retarded osmosis: From the vision of Sidney Loeb to the first prototype installation — Review"*. They concluded that more studies on power density of membranes are required. It is also mentioned that experimental studies conducted about power density were only made in 1970s and 2000s. It is emphasized that recent power density values are up to three times higher than earlier results, likely because of improvements in the membrane technology.

Stenzel and Wagner (2010) presented a report on potential analysis and site criteria of osmotic power plants. Their assessment determined the world potential for osmotic power approximately as 5.200 $TWh_{electricity}$/year. However, due to constraints of system, the technical potential was calculated as 520 $TWh_{electricity}$/year. Mediterranean part of Turkey was mentioned as having osmotic potential as also shown in the Figure 4.

Figure 4: Regions having appropriate properties to build osmotic power plants as river mouth type (Stenzel and Wagner, 2010)

Kleiterp (2012) prepared a thesis on the feasibility of commercial osmotic power plant. Two kind of osmotic power production techniques are investigated, which are PRO and reversed electric dialysis (RED). Rivers in the Netherlands are taken into consideration for feasibility calculations. Six case studies were evaluated; 1MW PRO plant, 25 MW PRO plant, 200 MW PRO plant, 0.55 MW RED plant, 25 MW RED plant and 200MW RED plant for each river. It is mentioned that a continuous flow of 1 m^3/s river water mixed with sea water produces a gross capacity of approximately 1 MW energy.

Hydrodynamic analysis at model and plant scale study was made by Zwana et al. (2012) for the feasibility of osmotic power. Numerical model was used for measuring technical feasibility of osmotic power plant. Model was compared to available experimental data and results were discussed.

Touatia and Schiestel (2013) evaluated osmotic power (PRO) in natural conditions. According to the study, when the warm water sources are used, significant amount of energy is produced. They also mentioned that further work is needed to understand the effect of temperature for osmotic power generation.

Sabah et al. (2013) also worked on optimisation of osmotic power production in PRO systems. They concluded that; "Total membrane area increases when increasing the applied hydraulic pressure for both feed and draw side flowrates. Net power production increases with increased applied hydraulic pressure. Specific energy consumption increases when increasing applied hydraulic pressure and decreasing the volumetric flow rate of feed."

The article of Helfer et al. (2014) provides a review of osmotic power with PRO in the context of theory, performance and trends. The article emphasizes the fact that even though the membrane prices are being reduced, cost effective boundary for membrane power per square meter should be over 5 W. They also declared that in order to make cost estimations, full scale power plant is required for accurate calculations. Additionally, they presented conclusions about capital cost of osmotic power plants.

Cui et al. (2014) analysed thin film composite (TFC) membranes to increase its osmotic power production. Chemical treatments like Sodium dodecyl sulphate (SDS), M-phenylenediamine (MPD), Trimesoyl chloride (TMC), Dimethylformamide (DMF) and combination of those chemicals resulted with 15.79 to 18.09 W/m^2 which is the best result for all flat-sheet membranes in the recent literature to the best knowledge of the researchers.

Altaee and Sharif (2015) studies *"Pressure retarded osmosis: advancement in the process applications for power generation and desalination"* where they showed the membrane performances for suitable hybrid PRO-RO (Reverse Osmosis), PRO-FO (Forward Osmosis) options. A similar article by Kim and Elimelech (2013) focuses on analysis and experiments related to potential of osmotic power generation by pressure retarded osmosis using seawater as feed solution. The most important remark of this article is that in the future, seawater can be used as fresh water solution while the brine from RO systems which has high-concentration of salt can be used as more salty solution. Article repeated the fact that membrane technology is the key factor of osmotic power plant systems.

Maisonneuve, Pillay, and Laflamme (2015) worked on non-ideal effects of PRO. This paper provides information about the effects of internal and external concentration polarization, mass transfer along the length of the membrane, and pressure losses along the membrane and throughout the system, which are the important dynamics of PRO. They also gave suggestion on rule of thumb flow rate ratios of system design such as permeate flowrate to feed flowrate as 0.8 and draw flowrate to feed flowrate as 2 for generating maximum power outputs. It is also emphasized that when water permeability increases, salt permeability decreases while the best operating cross-flow velocity increases as membrane length decreases. As the channel effective profile area increases, the best cross-flow velocity increases, and lastly, increment in efficiencies of equipment increases the pressure difference (Maisonneuve et al., 2015).

Another study done by Wan and Chung (2015) investigates osmotic power production from brine as sea water and retentate as wastewater. High power density 21 W/m^2 has been achieved by 0.81 molar NaCl and Deionized **Water (**DI) water as feeds. They achieved 4.55 W/m^2 by using the natural seawater and wastewater. If ultrafiltration and nanofiltration are used, power density goes up to 6.6 W/m^2 and 8.9 W/m^2, respectively. Important suggestions from the article are innovative cleaning for PRO, enhancement of the fouling resistance of the TFC membrane without losing its properties, development of antifoulant and anti-scalant and improvement of cheap pre-treatment mechanism.

Naghiloo, Abbaspour, Mohammadi-Ivatloo,and Bakhtari (2015) provided design conditions of a 25 MW osmotic power plant (PRO) on Bahmanshir River of Iran. The most significant outcome of the study is the analysis of intake and outfall systems costs, pre-treatment system costs and membrane system costs which are 61.5%, 28.4% and 4.4% of total capital costs of power plant respectively. They concluded that these costs should be decreased as much as possible to achieve an osmotic power plant feasible for Bashmanshir case. Like the study of Wan and Chung (2014), this paper also emphasizes the importance of fouling reduction.

Altaee and Hilal (2015) worked on dual stage power production from osmotic power. They designed a new combination of dual stage and achieved power density 17.4% higher than the old one. With that new design, smaller membrane area is required. Moreover, higher flowrate is achieved for this new design.

Another doctorate thesis was written by Tadeo (2015) about the modelling and experimental study on PRO. Water flux and power density, effect of the reverse salt flux, effects of temperature on hydromechanics and membrane parameters and integration of PRO in desalination process are discussed in detail. Author emphasized the importance on lack of studies about scaling and fouling and effect of pretreatment for the efficiency. Maisonneuve, Pillay and. Laflamme (2015) worked on osmotic power potential in remote regions in Quebec. Mathematical models have been used for PRO estimation and the effects of concentration polarization, spatial variation, pressure losses and system inefficiencies are reviewed. Model simulates ten rivers using temperature, concentration and flow rate parameters. Even lowest monthly electricity generation with PRO satisfies nearby peak electricity consumption. It is suggested that PRO plants can be used for base load and peak loads for Quebec's remote micro-grids.

CHAPTER 3

METHODOLOGY OF OSMOTIC POWER ASSESSMENT

Osmotic power production depends on several parameters, salinity, temperature, flow rate of river. In order to calculate potential of osmosis, data of these parameters needs to be collected from related sources or measured at the site.

Salinity is one of the main parameters for the calculation of osmotic power potential as it is the force that creates osmotic pressure. Even though freshwater have lower salinity and it is sometimes neglected in the calculations, salinity data of freshwater was collected and included in this study, whenever it is available. However, it is important to mention that the salt molecule that is considered is only Sodium Chloride (NaCl).

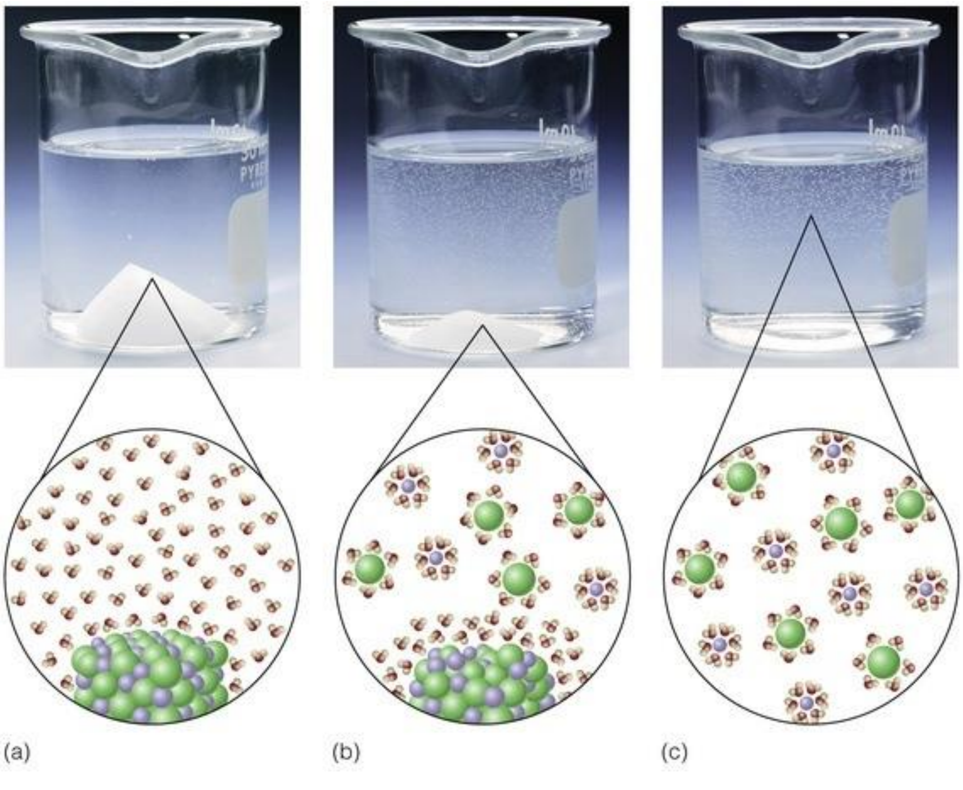

Figure 5: Dissolution of NaCl in water, Chlorine in green and Sodium in purple (Kee, 2016).

Dissolution of salt in water takes place by attraction of H_2O and NaCl molecules. Negative chlorine ion is attracted by positive hydrogen ion of water, on the other hand, positive sodium ion is attracted by negative oxygen ions and Na-H_2O and Cl-H_2O pairs are separated in aqueous solution (Figure 5). After certain amount of time solution becomes homogenous by diffusion. However, if two different solutions such as distilled water and salty water are separated by semipermeable membrane where only water molecules can pass, pair diffusion cannot entirely take place but water molecules diffuse to salty side, which constitutes osmotic flow (Figure 6).

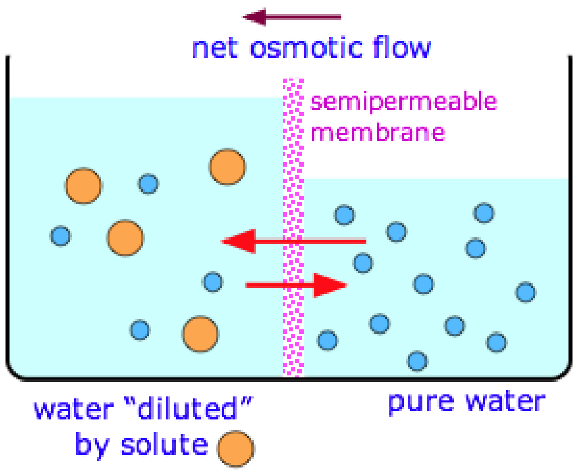

Figure 6: Representation of osmotic flow (Lower, 2010).

One of the other substantial parameter for osmotic power is temperature. Dissolution of salts increases when the temperature increases (Figure 7). Therefore, PRO system is expected to produce more energy in summer if flowrate does not change (Eq. 5).

The other parameter for osmotic power is the saltwater and fresh water availability. In this study, river flowrate becomes crucial for osmotic power potential as seawater is abundant to use. On the other hand, stream flowrate is very sensitive to seasons, upstream utilization and yearly meteorological events.

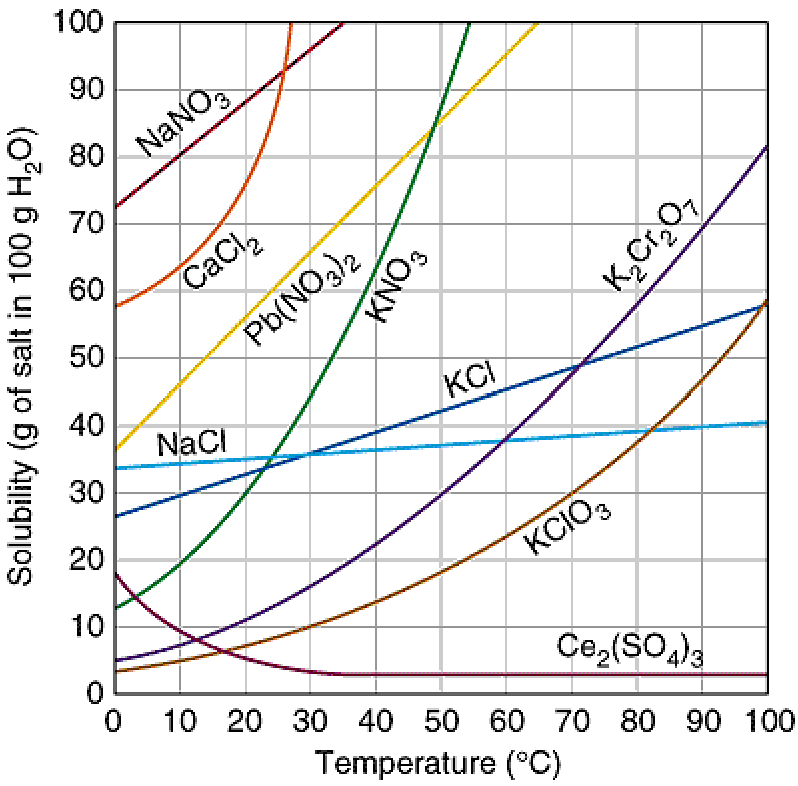

Figure 7: Solubility of different salts in 100g of water. NaCl (cyan) solubility increases linearly with increment of temperature (Volland, 2005).

Physical factors for building a PRO system is another factor that should be considered. For example, site availability, further construction requirements and flow management on rivers also are evaluated for selecting the appropriate osmotic power plant area.

3.1 Calculation Methodology

In order to understand the mechanism of osmotic energy production with PRO, the chemistry of the process and mathematical description, should be understood very well. Since this study is the first study in Turkey according to the literature review, the steps of calculation with relevant formulations are given in detail.

3.1.1 ***Molar Energy and Osmotic Energy (Van't Hoff Equation)***

Molar free energy for a solution is written as follows;

$$\mu_i = \mu_i^0 + \bar{v}_i \cdot \Delta p + RT \cdot ln(x_i) + |z_i| \cdot F \cdot \Delta\varphi \qquad \textit{(Eq. 1)}$$

Where;

μ	*Molar free energy*	*J/mol*
$\bar{v}$	*Partial molar volume at given temperature and pressure*	*m^3/mol*
Δp	*Pressure difference*	*Pa*
R	*Universal gas constant*	*8.314 J/mol.k*
T	*Temperature*	*Kelvin*
x	*Mole fraction*	*(unitless)*
z	*Valence of ions*	*(unitless)*
F	*Faraday constant*	*96.485 C/mol*
$\Delta\varphi$	*Electrochemical potential difference*	*V*

Gradient molar free energy in PRO system is;

$$\Delta\mu_{H_2O} = \mu_{H_2O,c} - \mu_{H_2O,d} \qquad \textit{(Eq. 2)}$$

$$\bar{v}_{H_2O,c} \cdot \Delta p_c + RT \cdot ln\left(x_{H_2O,c}\right) = RT \cdot ln\left(x_{H_2O,d}\right) \qquad \textit{(Eq. 3)}$$

where subscripts mean;

c	*Concentrated solution*
d	*Diluted solution*

Due to the nature of osmosis, there is a molar fraction change because of the flow of water molecules across semipermeable membrane. This ends up with hydraulic pressure difference across membrane that is expressed as:

$$\Delta p_c = \frac{RT}{\bar{v}_{H_2O,c}} \cdot \left(ln\left(x_{H_2O,d}\right) - ln\left(x_{H_2O,c}\right)\right) \qquad \textit{(Eq. 4)}$$

When the equilibrium is occurred between two solutions separated with a semipermeable membrane, molar energy of both sides is shown by Van't Hoff equation which is as follows:

$$\Delta\pi_{osm} = \frac{i \cdot R \cdot T}{M_i} \cdot (S_{i,c} - S_{i,d}) \qquad \textit{(Eq. 5)}$$

Where;

$\Delta\pi_{osm}$	*Osmotic pressure difference between solutions*	*bar/m*^{3}
i	*Ion concentration per dissociated solute molecule*	*(unitless)*
c	*Sea water*	*(subscript)*
d	*Freshwater.*	*(subscript)*
M_i	*The molar mass of salt compound*	*g/mol*
S	*The salinity*	*g/1*

(Naghiloo et al., 2015).

Theoretical osmotic energy difference for sea and river stream having different salinity and temperature is expressed as (Kleiterp, 2012):

$$\Delta\pi_{osm} = \frac{2 \cdot R}{M_{NaCl}} \cdot (T_c \cdot S_{NaCl,c} - T_d \cdot S_{NaCl,d}) \qquad \textit{(Eq. 6)}$$

3.1.2 *Molar Flux*

Free energy difference between solutions cause permeation water molecules towards semipermeable membrane. Higher the flux, more the energy produced.

Water flux through membrane J_w (mol/m^{2}s) is expressed as following equation:

$$J_w = A_w(\Delta\pi - \Delta p) \qquad \textit{(Eq. 7)}$$

Where;

A_w	*Membrane area*	*m*^{2}
J_w	*Volumetric water flux through membrane*	*mol/m*^{2}*s*

Molar flux is calculated from the volumetric water flux J_w:

$$J_{H_2O} = \frac{J_w}{V_c} = \frac{A_w}{V_c} \cdot (\Delta\pi_{eff} - \Delta p) \qquad \textit{(Eq. 8)}$$

where;

J_{H_2O}	*Molar flux*	*mol/m²s*
V	*Volume*	*m³*
$\Delta\pi_{eff}$	*Effective osmotic pressure*	*bar/m³*

Due to resistance of membrane, effective osmotic pressure is used:

$$\Delta\pi_{eff} = \pi_c - \pi_d \cdot exp(J_w \cdot k) \quad \textit{(Eq. 9)}$$

where;

k	*Resistance to salt diffusion through porous substrate*	*s/m*

(Kleiterp, 2012)

3.1.3 *Practical Osmotic Pressure Difference and Energy Equation*

Power density of PRO, W, is calculated from multiplication of water flux and hydraulic pressure:

$$W = J_w\Delta p = A_w(\Delta\pi - \Delta p)\Delta p \quad \textit{(Eq. 7)}$$

Ideal power density for feasible PRO is 4-6 W/m². In order to obtain maximum power density, first derivative of equation solved with respect to ΔP (Sabah et al., 2013):

$$W_{max} = A_w \frac{\Delta\pi^2}{4} \quad \textit{(Eq. 8)}$$

$$\Delta p = \frac{\Delta\pi_{eff}}{2} \quad \textit{(Eq. 9)}$$

Recalling the *(Eq. 9)*, effective osmotic pressure can be simplified as:

$$\Delta\pi_{eff} = \pi_c - \pi_d \quad \textit{(Eq. 10)}$$

$$exp(J_w \cdot k) \approx 1 \quad \textit{(Eq. 11)}$$

Since multiplication of flux (10^{-6} m/s) and salt diffusion resistance (10^{-5} s/m) is very small, exponential converges to 1. At the end, effective osmotic pressure becomes:

$$\Delta\pi_{eff} = \pi_c - \pi_d$$
$$\Delta p = \frac{1}{2}\Delta\pi_{eff} = \frac{1}{2}(\pi_c - \pi_d) \qquad \textit{(Eq. 12)}$$

Then, practical osmotic energy that is calculated for one cubic meter and for a given flowrate (Kleiterp, 2012):

$$E_{osm} = \Delta p \cdot 10^{-1} \qquad \textit{(Eq. 13)}$$
$$P_{power\ plant} = E_{osm} \cdot Q_{fresh} \qquad \textit{(Eq. 14)}$$

where;

E_{osm}	*Practical osmotic energy*	*Joule*
$P_{power\ plant}$	*Osmotic power plant power*	*Watt*

Average power density decreases due to osmosis; therefore, residence should be arranged in a way that average power density equals to optimum power density. The relationship between optimum power density and average power density is found with expression:

$$W_{avg} = \frac{\int_{t_0}^{t} W_{opt} dt}{t - t_0} \qquad \textit{(Eq. 15)}$$

3.1.4 *Flowrate Calculations*

In PRO required flowrate is calculated as:

$$Q_{fresh} = \frac{P_{powerplant}}{E_{osmotic}} \qquad \textit{(Eq. 16)}$$

In reality 10% of freshwater is rejected and sent for reuse. Therefore, 90% of water goes through membranes and *(Eq. 16)* becomes:

$$Q_{freshwater\ intake} = 0.9\frac{P_{powerplant}}{E_{osmotic}}$$ *(Eq. 17)*

Required saltwater for osmotic power plant is two times greater than the freshwater:

$$Q_{salt} = 2Q_{fresh}$$ *(Eq. 18)*

Brackish water, total water discharged out of the system, is calculated as (Naghiloo et al., 2015):

$$Q_{bracksih} = 0.9 \cdot Q_{fresh} + Q_{salt} = 2.9Q_{fresh}$$ *(Eq. 19)*

3.1.5 *Membrane Stack Calculation*

Membrane area depends on power plant capacity and power density. Related equation is:

$$A_m = \frac{P_{power\ plant}}{W}$$ *(Eq. 20)*

Volume of the membrane stack is calculated by the multiplication of area and length of a module

$$V_{module} = A_{module} \cdot L_{module} = \frac{\pi D_{module}^2}{4} \cdot L_{module}$$ *(Eq. 21)*

Where;

A_{module}	*Circular area of a module*	m^2
L_{module}	*Length of one membrane stack module*	*m*
D_{module}	*Diameter of module*	*m*

Next step is the stack number calculation:

$$n_{modules} = \frac{A_{module}}{pd \cdot V_{module}}$$ *(Eq. 22)*

where;

pd	Package density	*1/m*

(Kleiterp, 2012).

Power plant capacity can be calculated using *(Eq. 14)*. Today economically feasible power density is declared as 5 W/m^2 by Kim and Elimelech (2013).

CHAPTER 4

CALCULATIONS AND RESULTS

In this chapter, general properties of each river and related sea, discussion on possible construction site, and energy production recommendation of each site is given. The calculations of osmotic power potential for Asi (the Orontes) river have been shown in detail as an example. For the rest of the rivers, the results of the calculations are provided. Images of location of each river have been taken from the Google Earth. Possible locations of power plant have been plotted on satellite photos.

4.1 Source of Data

Parameters needed for osmotic power potential calculation have been mentioned earlier section. In order to obtain those parameters different sources in the literature have been used. Parameters and data source has been given in Table 2.

Table 2: Parameters and data sources

Parameter	Waterbody	Data Source
Temperature	Sea	NOAA ("World Sea Temperatures," n.d.)
	River	EPSRD (*Water Quality Data for Surface Water in Turkey*, 2003)
Salinity	Sea	NOAA (n.d.)
	River	EPSRD (*Water Quality Data for Surface Water in Turkey*, 2003)
Flowrate	River	SHW (SHW, 2009, 2010, 2011)

As it is mentioned before, one way to design a PRO system is to locate it at a river mouth. Then, the most important energy production criteria for Osmotic Power Plant are the salinity and available flowrate. That is, salinity of sea and the flowrate of river are the key elements for designing and obtaining energy production from PRO. Turkey is a peninsula surrounded by three main seas that are the Black Sea at the north, the Aegean Sea at the west and the Mediterranean Sea at the South of country. Additionally, there are many rivers discharging to these coastal waters Sixteen major rivers of Turkey are listed in Table 3. The Çoruh, The Tigris and The Euphrates which are trans boundary rivers are excluded from the study.

If a river has less than 10 m^3/s flow at least for three months, it is eliminated from potential evaluation in the thesis. On the other hand, some medium flowrate rivers have been also eliminated because of the salinity of sea like the Black Sea (~1018g/cm^3) where the salinity gradient is not high. Moreover, some other properties of rivers prevent to be used as energy source. Overall, rivers written in green in Table 3 have been chosen for potential evaluation calculation. Explanations are given why the related river has not been selected.

Table 3:Important rivers in Turkey and explanation if it is not suitable for PRO plant.

RIVER	AVAILABLE STREAM FLOWRATE (Avg)	SALINITY GRADIENT	INFRASTRUCTURE and GEOLOGY	PROFICIENCY
Asi	65 m^3/s	0.075-39 g/L	Suitable	☑
Büyük Menderes	NA	NA	Not Suitable	No data, not suitable for construction
Ceyhan	200 m^3/s	0.03-39 g/L	Suitable	☑
Çoruh	Transboundary			
Dalaman	30 m^3/s	0.01-37g/L	Suitable	☑
Dicle	Transboundary			
Fırat	Transboundary			
Gediz	30 m^3/s	0.04-32 g/L	Suitable	☑
Göksu	80 m^3/s	0.01-39 g/L	Suitable	☑
Kızılırmak	2.5 m^3/s	0.7-18 g/L	Not Suitable	Insufficient Flowrate (~5 m^3/s) and Old and Low Salinity, Hard Construction
Küçük Menderes	0.07 m^3/s	0.2 – 37 g/L	Maybe Suitable (Operations required)	Insufficient Flowrate
Manavgat	115 m^3/s	0.05-39 g/L	Suitable	☑
Meriç	Boundary between Turkey and Greece			
Sakarya	145 m^3/s	0.05-18 g/L	Suitable	☑
Seyhan	60 m^3/s	0.02-39 g/L	Suitable	☑
Yeşilırmak	140 m^3/s	0.01-18 g/L	Suitable	☑

In the end, nine rivers were considered as a potential source for osmotic power plant after the initial elimination process. In the next chapter, the assessment of individual rivers is given in detail with corresponding data used in the calculations

4.2 Asi (the Orontes) River

Asi river is in southwestern Anatolia, which is draining into the Mediterranean Sea. River born in Lebanon and goes into mountains of Syria. In Syria, some part of the river has been dammed to form Lake Qaṭṭīnah. Lastly it enters to Turkey, where it bends westward and empties into the sea near Samandağı. Water is generally used for irrigation but the amount is limited. (Encloypaedia Britannica, 2016).

4.2.1 *Flowrate Data of River*

Flowrate of rivers are recorded by State Hydraulic Works (SHW) in Turkey. In order to obtain relevant flowrates for PRO, closes station to the sea must be selected. In this case, the station is located very close to the Mediterranean Sea. It is Çöğürlü Station numbered as 1909 in Hatay near Samandağ. Elavation of the station from sea level is 11m. In the Figure 8, the station is shown by green colour.

Figure 8: SHW Çöğürlü Station on Asi River located at 36:4:39N - 36:0:14E (SHW, n.d.-a)

SHW takes average of flowrates obtained from the station and made a graph called *The Average Monthly Flows During The Observation.*

1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
					X	X	X	X	X	X	X
1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
X	X	X	X	X	X	X	X	X	X	X	X
1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
X	X	X		X	X	X					X
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
X			X	X	X	X	X	X	X	X	X
2012	2013	2014									
X	X	X									

Figure 9: Flowrate data which SHW has been processed to find average values used (SHW, n.d.-a).

In Figure 9, years have been checked are the dates in which flowrate data is recorded. From 1968 to 2014, 39 years of data has been recorded and these values are used to calculate the monthly average flowrate data given in the Figure 10. It is seen that flowrate is maximum in February and steadily decreases in August. In the summer, flowrates are very low. During August, flow nearly does not exist. When the fall comes, flowrate starts to increase. The reason why flowrates goes down harshly in summer could be the dam in Syria and the high demand in water for agriculture as summer times are generally very dry in the Middle East region.

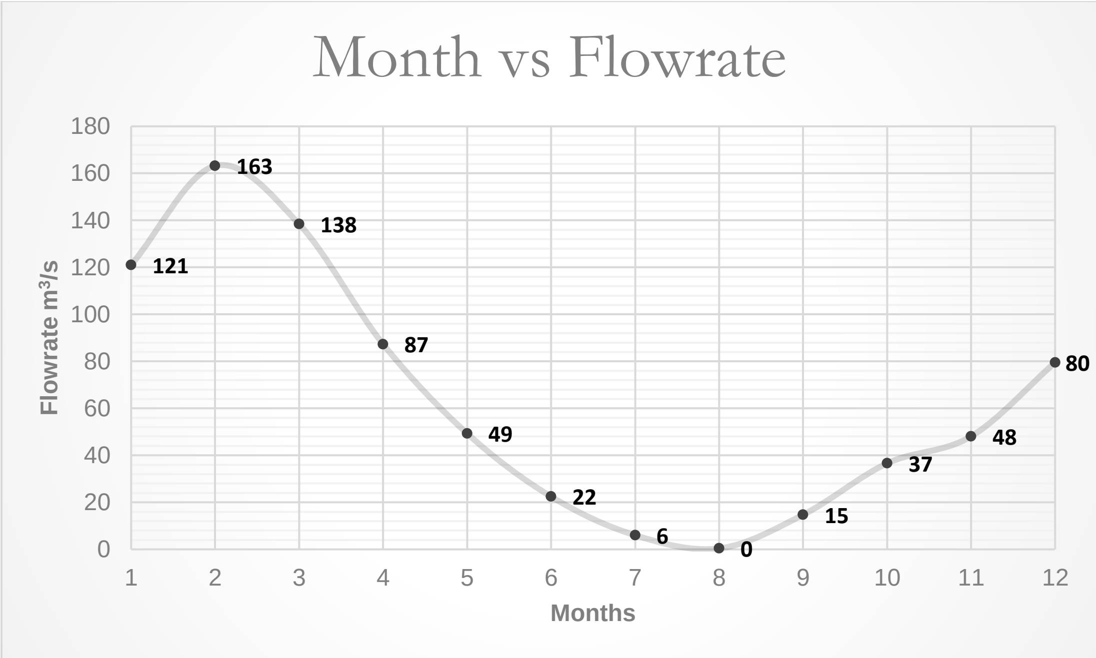

Figure 10: Average flowrate change month by month in Asi River.

4.2.2 *Temperature and Salinity*

River water temperatures had been recorded by General Directorate of Electrical Power Resources Survey and Development Administration (EPRSD) in Turkey. Recent data about temperature of river could not be found. Therefore, temperature data obtained is between 1997-2002 from book called *Water Quality Observation in Turkey Streams* by EPRSD.

Table 4: Average temperature in Asi River between 1997-2002, missing data is due to closure of station or lack of water due to drought. Temperature is in Centigrade ^oC.

Month/Year	1997	1998	1999	2000	2001	2002	AVG
JANUARY	**-**	12	14	12	14	9	**12.2**
FEBRUARY	**-**	8	14	11	15	14	**12.4**
MARCH	**-**	12	13	12	13	13	**12.6**
APRIL	**-**	19	13	16	18	15	**16.2**
MAY	**-**	13	23	19	-	17	**18**
JUNE	16	26	19	22	21	16	**20**
JULY	28	-	31	-	-	24	**27.7**
AUGUST	21	-	-	-	-	30	**25.5**

Table 4 (continued)

Month/Year	1997	1998	1999	2000	2001	2002	AVG
SEPTEMBER	20	19	22	21	-	23	**21**
OCTOBER	20	24	24	20	16	16	**20**
NOVEMBER	**-**	19	-	16	14	14	**15.8**
DECEMBER	12	13	16	13	13	10	**12.8**

Table 4 shows the temperature changes monthly in Asi River. Last column shows the average temperature, which is used for PRO potential calculations. Figure 11 temperature values have been graphed to see changes with respect to months

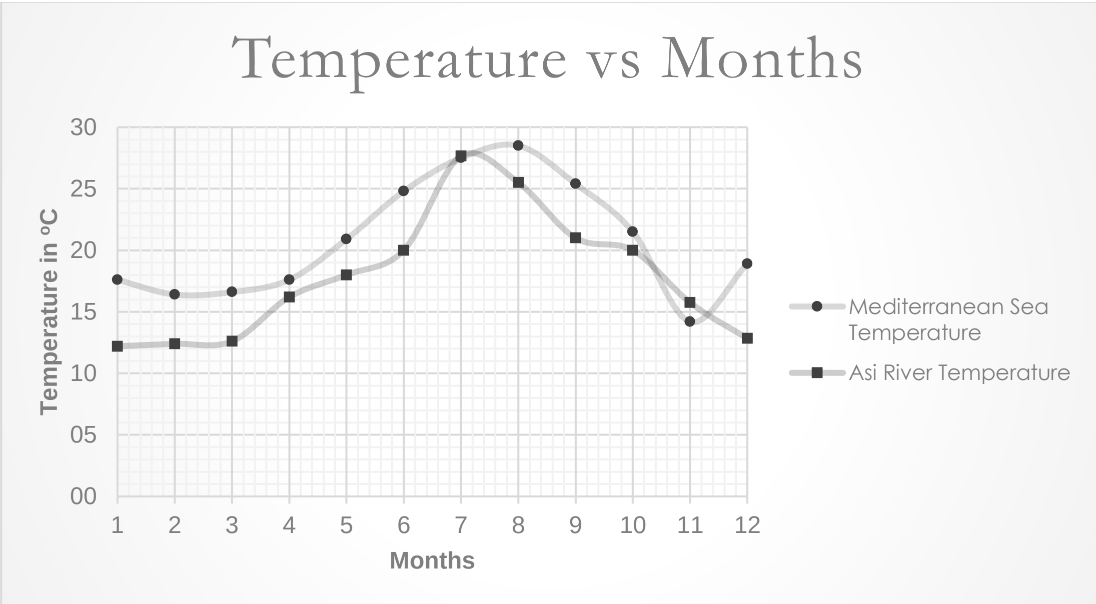

Figure 11: Temperature change with respect to months in Asi River and Mediterranean Sea

Sea temperature data has been recorded by NOAA (“World Sea Temperatures,” n.d.) satellite data, where average sea surface temperature average are expressed in there. As it is expected, river water temperature generally colder than the river water temperature.

In *Water Quality Observation in Turkey Streams (2003)* by EPRSD, salinity data is also available. In some studies, the river salinity was taken as null. Although it is not expected to have high salinity in the rivers compared to sea salinity, all sources have been used in this thesis to obtain realistic potential results.

Table 5: River salinity data obtained from 1997-2002 in meq/L and average salinity in unit of meq/L and g/L

Month/Year	1997	1998	1999	2000	2001	2002	AVG (meq/l)	AVG (g/L)
JANUARY	-	3.8	2.75	1.76	1.82	3.38	**2.70**	**0.096**
FEBRUARY	-	3.40	2.15	3.92	1.95	3.67	**3.02**	**0.107**
MARCH	-	2.35	3.05	4.05	3.77	4.57	**3.56**	**0.126**
APRIL	-	2.57	1.86	3.38	5.92	2.20	**3.19**	**0.113**
MAY	-	1.55	1.86	1.94	-	1.73	**1.77**	**0.063**
JUNE	1.52	1.97	1.70	1.52	2.02	1.51	**1.70**	**0.061**
JULY	2.00	-	1.74	-	-	1.07	**1.60**	**0.057**
AUGUST	1.28	-	-	-	-	1.48	**1.38**	**0.049**
SEPTEMBER	1.52	1.86	2.20	2.14	-	1.96	**1.93**	**0.069**
OCTOBER	1.54	1.60	1.60	1.68	3.06	1.20	**1.78**	**0.063**
NOVEMBER	**-**	1.32	-	1.32	1.54	1.24	**1.35**	**0.048**
DECEMBER	1.96	0.98	1.28	1.32	1.26	1.27	**1.34**	**0.048**

The Mediterranean Sea salinity could not be found in detail; therefore, it was taken as constant from literature which has the value of 39 gram/liter of NaCl.

Sea temperature data has been recorded by NOAA ("World Sea Temperatures," n.d.) satellite data, where average sea surface temperature average are expressed in there. As it is expected, river water temperature generally colder than the river water temperature.

In *Water Quality Observation in Turkey Streams (2003)* by EPRSD, salinity data is also available. In some studies, the river salinity was taken as null. Although it is not expected to have high salinity in the rivers compared to sea salinity, all sources have been used in this thesis to obtain realistic potential results.

Table 5 river salinity change with respect to months can be seen. Some of the data seems missing but in fact, due to drought or the reason declared about dam in Syria, the water did not discharge into the sea and measurement could not be carried out.

4.2.3 *Calculation of Potential*

Calculation of osmotic energy potential was given in detail in Section 3.1. Here, use of equations are shown step by step for the Asi River for demonstration. Recalling the first theoretical osmotic pressure difference equation *(Eq. 6*) was:

$$\Delta\pi_{osm} = \frac{2 \cdot R}{M_{NaCl}} \cdot (T_c \cdot S_{NaCl,c} - T_d \cdot S_{NaCl,d})$$

Implementation of equation by using the average values from Table 6, computation would be (when required unit changes were done; see Table 6):

$$\Delta\pi_{osm} = \frac{2 \cdot 0.08314}{58.44} \cdot (294 \cdot 0.6674 - 291 \cdot 0.0013)$$

$$\Delta\pi_{osm} = 32.56\ bar$$

Noting the fact that the optimal potential exists when;

$$\Delta P = \frac{\Delta\pi_{eff}}{2} = 16.28\ bar$$

Energy production in one cubic meter of water is:

$$E_{osm} = \Delta P \cdot 10^{-1} = 16.28\ \cdot 0.1 = 1.628\ MJ/m^3$$

Lastly the energy production is:

$$P_{powerplant} = E_{osm} \cdot Q_{freshwater} = 1.628 \cdot 12 = 19.5\ MW$$

4.2.4 *Annual Energy Production*

Annual energy production of PRO power plant can be calculated by the formula:

$$E_{produced} = E_{osmotic} \cdot Q_{river\ water} \cdot t_{hours/year} \qquad \textit{(Eq. 23)}$$

For Asi river, yearly energy production is

$$E_{produced} = 1.628 \frac{MJ}{m^3} \cdot 64 \frac{m^3}{sec} \cdot \frac{31536000\ sec}{1\ year} \cdot \frac{1KWh}{3.6MJ} \cdot \frac{10^{-6}GWh}{1KWh}$$

$$E_{produced} = 912\ GWh$$

4.2.5 *Conclusions*

Considering potential power plant capacity of Asi River, construction of PRO system does not seem very feasible. Because the fluctuations of flowrate and the absence of water in summer would result with closure of the possible existing power plant for long durations. In the future if PRO technology becomes feasible with fluctuation of such flowrates, it would be possible to have a power plant with annual capacity of 912 GWh.

Table 6: Calculation sheet where all required data written month by month to calculate PRO potential.

MONTHS	T_{sea}	T_{sea}	T_{river}	T_{river}	S_{sea}	S_{sea}	S_{river}	S_{river}	R	M_{NaCl}	$\Delta\pi_{osm}$	Δp	E_{osm}	$Q_{freshwater}$	$P_{powerplant}$
Units	*centigrate*	*Kelvin*	*centigrate*	*Kelvin*	*gram/liter*	*mol/liter*	*gram/liter*	*mol/liter*	*joule/mol.Kelvin*	*gram/mol*	*bar*	*bar*	*megajoules/metercube*	*metercube/second*	*megawatt*
JANUARY	17.6	291	12.2	285	39	0.6674	0.0959	0.0016	0.08314	58.44	32.19	16.09	1.6093	12	19.6
FEBRUARY	16.4	290	12.4	286	39	0.6674	0.1071	0.0018	0.08314	58.44	32.04	16.02	1.6022	163	261.5
MARCH	16.6	290	12.6	286	39	0.6674	0.1263	0.0022	0.08314	58.44	32.05	16.03	1.6025	138	221.8
APRIL	17.6	291	16.2	289	39	0.6674	0.1131	0.0019	0.08314	58.44	32.17	16.09	1.6085	87	140.4
MAY	20.9	294	18.0	291	39	0.6674	0.0628	0.0011	0.08314	58.44	32.58	16.29	1.6289	49	80.3
JUNE	24.8	298	20.0	293	39	0.6674	0.0606	0.0010	0.08314	58.44	33.01	16.51	1.6506	22	37.0
JULY	27.5	301	27.7	301	39	0.6674	0.0569	0.0010	0.08314	58.44	33.31	16.66	1.6657	6	10.0
AUGUST	28.5	302	25.5	299	39	0.6674	0.0490	0.0008	0.08314	58.44	33.43	16.72	1.6716	0	0.7
SEPTEMBER	25.4	299	21.0	294	39	0.6674	0.0687	0.0012	0.08314	58.44	33.07	16.54	1.6536	15	24.3
OCTOBER	21.5	295	20.0	293	39	0.6674	0.0632	0.0011	0.08314	58.44	32.64	16.32	1.6322	37	59.8
NOVEMBER	14.2	287	15.8	289	39	0.6674	0.0481	0.0008	0.08314	58.44	31.85	15.92	1.5923	48	76.6
DECEMBER	18.9	292	12.8	286	39	0.6674	0.0477	0.0008	0.08314	58.44	32.37	16.18	1.6185	80	128.7
AVERAGE	20.8	294	17.8	291	39	0.6674	0.0750	0.0013	0.08314	58.44	32.56	16.28	1.6280	55	88.4

4.3 The Ceyhan River

One of the biggest river of South Anatolia is Ceyhan. Source location of the water is mountains that covers Elbistan plain. Length of the river is 509km and precipitation area of basin is 20000km^2. It collects lots of water from the other smaller rivers. Place of river mouth is İskenderun Bay. The flowrate of river changes with respect to seasons. In the summer flow rate descends, however, after the February flowrate increases rapidly. At the downstream of the river height of the water is about 3 meters and length is around 100 meters. Peak flood of river is controlled by the dams made on it (“Ceyhan Nehri,” 2009).

4.3.1 *Flowrate*

Flowrate of the Ceyhan River has been found from the Flowrate Observation Yearbook 2009-2010-2011 (3 books) from the 2004th station. Moreover, from the SHW website, average of several years could be found and for the calculation those dataset has been used. The station code is Ceyhan 2004. Figure 12 shows the monthly flowrate change of the river. Even in the summer the flowrate of the river is decent enough to obtain high amount of energy. After the January, flowrate increases and peaks in April.

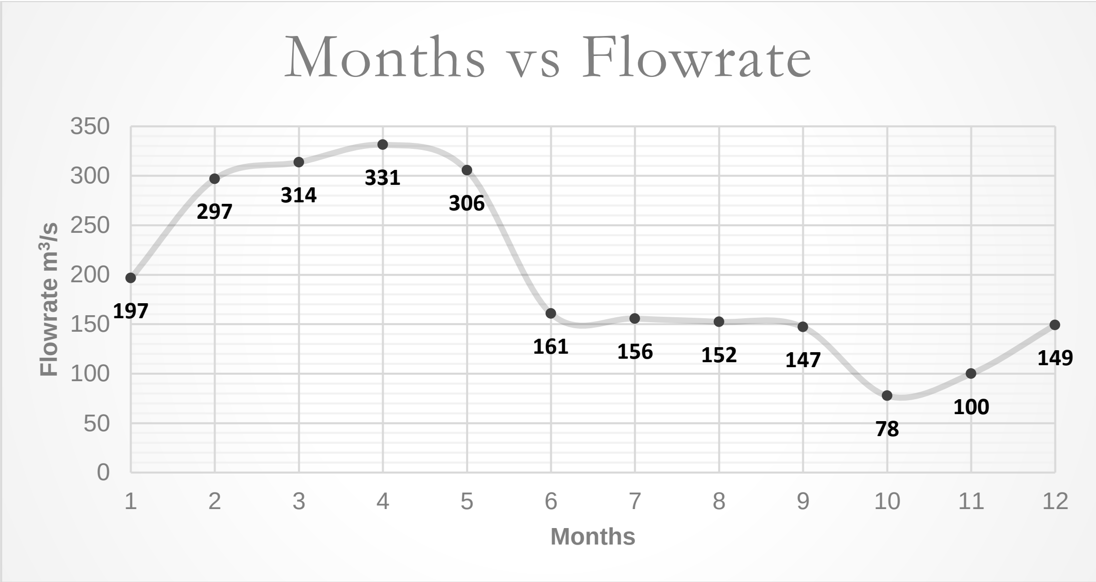

Figure 12:Monthly flowrate change in Ceyhan River

4.3.2 *Salinity and Temperature*

Mouth of The Ceyhan River is in Adana, one of the biggest city in Turkey. Moreover, Adana is one of the hottest city in there. In the summer temperature of river is over 20^{o}C, which is very hot for a river Table 7 shows temperature data between 1995-2002, and the average of those years at the last column.

Table 7: Average temperature in Ceyhan River between 1995-2002, temperature is in ^{o}C degree.

Month/Year	1995	1996	1997	1998	1999	2000	2001	2002	AVG
JANUARY	12	11	8	11	13	14	14	9	**11.5**
FEBRUARY	13	10	12	14	16	12	12	11	**12.5**
MARCH	15	11	12	15	13	9	15	13	**12.9**
APRIL	16	14	14	16	16	17	15	13	**15.1**
MAY	17	20	18	16	23	18	17	15	**18.0**
JUNE	20	19	18	18	20	19	18	16	**18.5**
JULY	21	20	22	26	19	22	21	22	**21.6**
AUGUST	19	21	21	23	26	27	23	21	**22.6**
SEPTEMBER	19	18	21	20	22	17	23	18	**19.8**
OCTOBER	18	19	16	16	18	20	18	17	**17.8**
NOVEMBER	15	16	15	17	14	14	15	16	**15.3**
DECEMBER	12	14	10	15	11	14	14	11	**12.6**

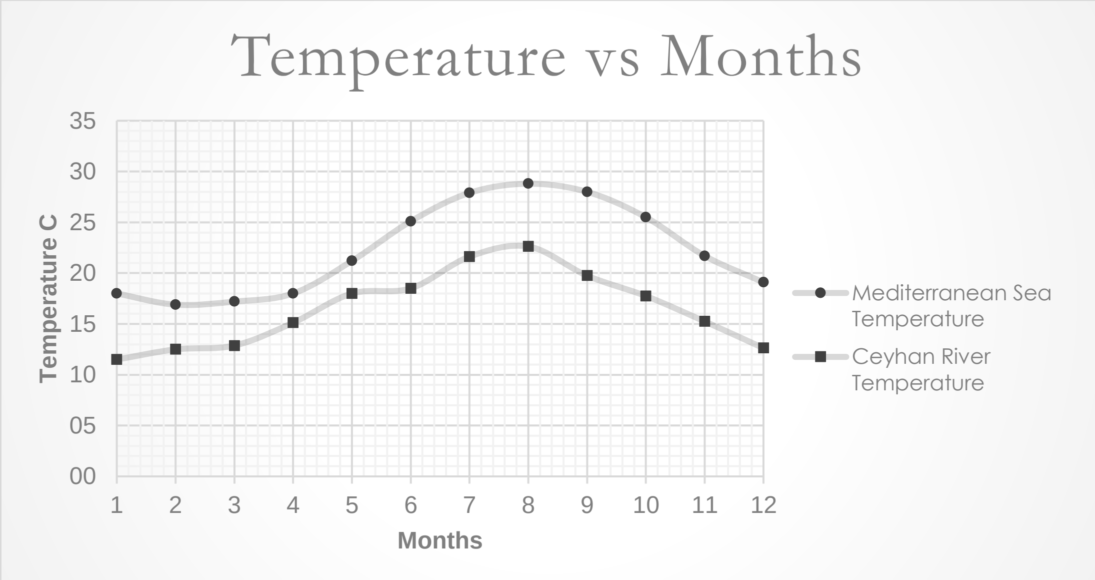

Figure 13: Ceyhan River and Mediterranean Sea temperature changes with respect to months.

When compared to temperature of sea, Ceyhan River shows direct proportion. Difference between sea and river temperature around 3 to 8 centigrade degrees (Figure 13). In the Table 8 salinity value of rivers can be seen. As it is expected, the average value of river salinity changes between 0.022-0.033g/L. with respect to sea salinity, it is quite low.

Table 8: River salinity data obtained from 1995-2002 in meq/L and average salinity in unit of meq/L and g/L.

Month/Year	1995	1996	1997	1998	1999	2000	2001	2002	AVG (meq/L)	AVG (g/L)
JANUARY	1.00	0.68	0.54	0.9	0.56	0.88	0.54	0.82	**0.74**	**0.026**
FEBRUARY	0.72	0.62	0.66	0.50	0.66	0.58	0.44	0.80	**0.62**	**0.022**
MARCH	0.96	0.46	0.94	0.76	0.74	0.60	0.84	0.72	**0.75**	**0.027**
APRIL	0.6	0.46	0.94	0.56	0.94	0.60	0.76	0.54	**0.68**	**0.024**
MAY	0.62	0.48	0.76	0.74	0.96	0.76	1.02	0.54	**0.74**	**0.026**
JUNE	0.82	0.5	0.74	0.87	0.76	0.68	0.62	0.50	**0.69**	**0.024**
JULY	0.92	0.84	0.66	1.01	1.06	0.76	0.92	0.80	**0.87**	**0.031**
AUGUST	1.00	0.90	1.08	1.02	1.16	0.68	0.80	0.76	**0.93**	**0.033**
SEPTEMBER	0.68	0.52	0.84	0.6	0.94	0.94	0.82	0.78	**0.77**	**0.027**
OCTOBER	0.68	0.40	0.86	0.74	0.76	0.94	0.70	1.24	**0.79**	**0.028**
NOVEMBER	0.58	0.36	0.72	0.65	1.36	0.58	0.7	0.46	**0.68**	**0.024**
DECEMBER	0.58	0.58	0.8	0.76	0.52	0.49	0.6	0.66	**0.62**	**0.022**

4.3.3 *Annual Energy Production*

By using the average month averages of the dataset (Table 8), energy produced can be calculated as follows:

$$E_{produced} = 1.638\frac{MJ}{m^3} \cdot 199\frac{m^3}{sec} \cdot \frac{31536000\ sec}{1\ year} \cdot \frac{1KWh}{3.6MJ} \cdot \frac{10^{-6}GWh}{1KWh}$$

$$E_{produced} = 2855\ GWh$$

4.3.4 *Conclusion*

In conclusion, results in Table 9 show that average output of Ceyhan is nearly 325 MW and 2855 GWh energy production annually, which is a very high amount of power. Taking advantage of salinity of the Mediterranean Sea and the considerable flowrate of river throughout months, Ceyhan seems to be a feasible place for constructing a PRO system.

Table 9: Calculation sheet for the Ceyhan River, all required data written month by month and computation done automatically by Microsoft Excel ®.

MONTHS	T_{sea}	T_{sea}	T_{river}	T_{river}	S_{sea}	S_{sea}	S_{river}	S_{river}	R	M_{NaCl}	$\Delta\pi_{osm}$	Δp	E_{osm}	$Q_{freshwater}$	$P_{powerplant}$
Units	*centigrate*	*Kelvin*	*centigrate*	*Kelvin*	*gram/liter*	*mol/liter*	*gram/liter*	*mol/liter*	*joule/mol.Kelvin*	*gram/mol*	*bar*	*bar*	*megajoules/metercube*	*metercube/second*	*megawatt*
JANUARY	18.0	291	11.5	285	39	0.6674	0.0263	0.0004	0.08314	58.44	32.29	16.14	1.6143	197	317.2
FEBRUARY	16.9	290	12.5	286	39	0.6674	0.0237	0.0004	0.08314	58.44	32.17	16.08	1.6083	297	477.4
MARCH	17.2	290	12.9	286	39	0.6674	0.0267	0.0005	0.08314	58.44	32.20	16.10	1.6099	314	505.0
APRIL	18.0	291	15.1	288	39	0.6674	0.0240	0.0004	0.08314	58.44	32.29	16.14	1.6144	331	534.9
MAY	21.2	294	18.0	291	39	0.6674	0.0261	0.0004	0.08314	58.44	32.64	16.32	1.6321	306	498.9
JUNE	25.1	298	18.5	292	39	0.6674	0.0244	0.0004	0.08314	58.44	33.08	16.54	1.6538	161	265.7
JULY	27.9	301	21.6	295	39	0.6674	0.0309	0.0005	0.08314	58.44	33.38	16.69	1.6690	156	259.8
AUGUST	28.8	302	22.6	296	39	0.6674	0.0328	0.0006	0.08314	58.44	33.48	16.74	1.6739	152	255.0
SEPTEMBER	28.0	301	19.8	293	39	0.6674	0.0272	0.0005	0.08314	58.44	33.40	16.70	1.6698	147	245.5
OCTOBER	25.5	299	17.8	291	39	0.6674	0.0280	0.0005	0.08314	58.44	33.12	16.56	1.6559	78	128.4
NOVEMBER	21.7	295	15.3	288	39	0.6674	0.0240	0.0004	0.08314	58.44	32.70	16.35	1.6349	100	163.2
DECEMBER	19.1	292	12.6	286	39	0.6674	0.0221	0.0004	0.08314	58.44	32.41	16.21	1.6206	149	241.7
AVERAGE	22.3	295	16.5	290	39	0.6674	0.0264	0.0005	0.08314	58.44	32.76	16.38	1.6381	199	324.4

4.4 The Dalaman Brook

The Dalaman Brook (Figure 14), antique name was Indos, born from Kocaş mountain close to Dirmil. It is located between Fethiye and Marmaris, where attracts lots of tourists in all seasons. Brook has length of 229 km, water colour is turquoise throughout the year. There are small waterfalls and suitable for rafting (Ministry of Culture and Tourism, 2015).

Figure 14: Dalaman brook is a very favoured place for rafting enthusiast ("Dalaman Çayı," n.d.)

4.4.1 *Flowrate*

Flowrate oscillation of The Dalaman Brook is smaller with respect to other rivers in Turkey. Maximum flowrate is observed in May and minimum is seen in December. Average flowrate is close to 30 m^3/s in one year. Data has been obtained from the 872^{nd} station of SHW in which averages are calculated from 1977-1980 and 1990-2001 data. Figure 15 shows the month vs flowrate values for entire year.

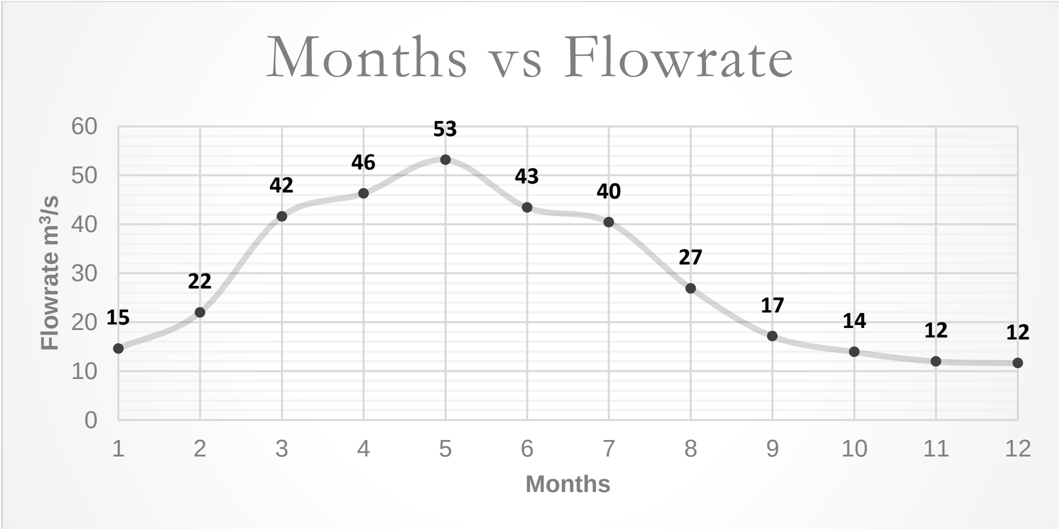

Figure 15: Flowrate change in Dalaman Brook with respect to months.

4.4.2 *Salinity and Temperature*

Thanks to its location Dalaman is using the advantage of flowing to Mediterranean Sea. Salinity of the sea slightly increases the power production potential of the stream. Salinity of river is quite similar to the other rivers of Turkey and represented in Table 10. Temperature of the creek can be classified as average. It is not high but not low either.

Table 10: River salinity data for Dalaman Creek

Month/Year	1995	1996	1997	1998	1999	2000	2001	2002	AVG (meq/L)	AVG (g/L)
JANUARY	0.37	0.30	0.28	0.26	0.23	0.32	0.26	0.28	**0.27**	**0.010**
FEBRUARY	0.34	0.28	0.26	0.38	0.28	0.28	0.26	0.28	**0.28**	**0.010**
MARCH	0.27	0.38	0.32	0.33	0.30	0.32	0.30	0.30	**0.31**	**0.011**
APRIL	0.30	0.32	0.30	0.36	0.28	0.28	0.24	0.30	**0.28**	**0.010**
MAY	0.5	0.28	0.28	0.36	0.27	0.26	0.28	0.32	**0.28**	**0.010**
JUNE	0.24	0.28	0.29	0.28	0.30	0.26	0.24	0.28	**0.27**	**0.009**
JULY	0.26	0.28	0.31	0.26	0.34	0.24	0.46	0.28	**0.33**	**0.011**
AUGUST	0.26	0.30	0.30	0.25	0.22	0.24	0.22	0.26	**0.24**	**0.008**
SEPTEMBER	0.24	0.30	0.22	0.2	0.23	0.26	0.24	0.32	**0.26**	**0.009**
OCTOBER	0.26	0.34	0.24	0.24	3.61	0.28	0.26	0.27	**1.11**	**0.039**
NOVEMBER	0.26	0.36	0.17	0.24	0.28	0.30	0.28	0.28	**0.29**	**0.010**
DECEMBER	0.18	0.30	0.2	0.20	0.30	0.30	0.26	0.27	**0.28**	**0.010**

On the other side temperature of sea always shows higher centigrade values than the brook. Temperature differences between two water bodies increase in winter and decrease when the summer comes. Figure 16 shows the annual temperature change of stream and sea.

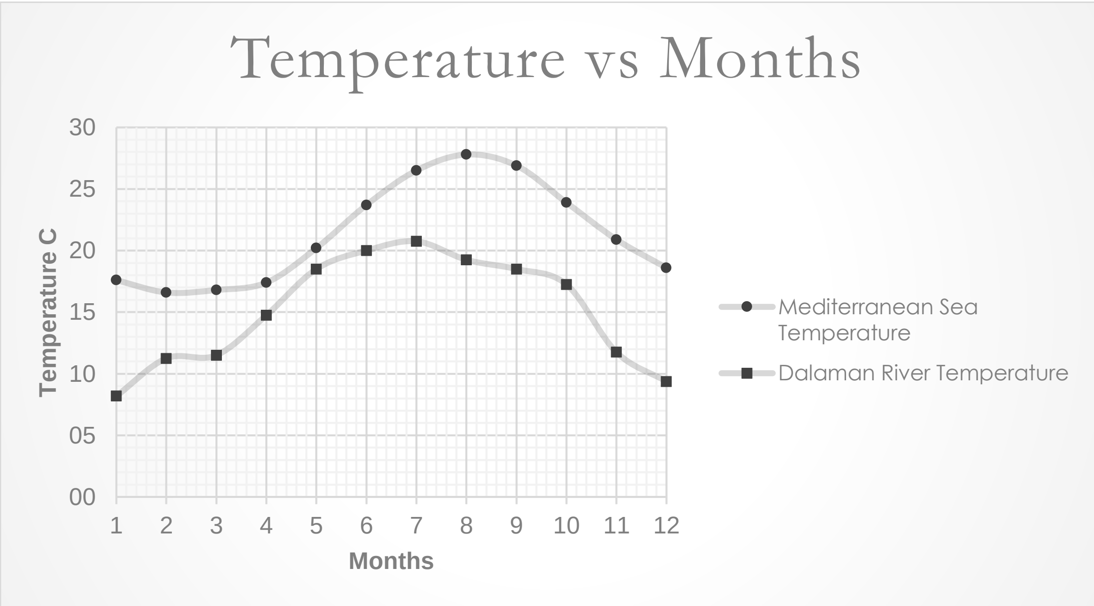

Figure 16: Annual temperature change graph of Dalaman Creek and Mediterranean Sea

4.4.3 *Annual Energy Production*

Considering the average osmotic energy per metercube and stream flowrate data (Table 11: Calculation sheet for Dalaman Creek., all required data written month by month and computation done automatically by Microsoft Excel ®.), annual energy production can be calculated as;

$$E_{produced} = 1.634\frac{MJ}{m^3} \cdot 29\frac{m^3}{sec} \cdot \frac{31536000\ sec}{1\ year} \cdot \frac{1KWh}{3.6MJ} \cdot \frac{10^{-6}GWh}{1KWh}$$

$$E_{produced} = 415\ GWh$$

4.4.4 *Conclusion*

Although, flowrate of the stream is not very high, advantage of the salinity due to Mediterranean results in high amount of osmotic power potential. Moreover, even if the flowrate decreases to 10 m^3/s in the summer, there is flow throughout the year, which is important for sustainability of PRO power plant. Total installed power capacity is 46.7 MW and yearly production is 415 GWh, which is high for a small creek.

Table 11: Calculation sheet for Dalaman Creek., all required data written month by month and computation done automatically by Microsoft Excel ®.

MONTHS	T_{sea}	T_{sea}	T_{river}	T_{river}	S_{sea}	S_{sea}	S_{river}	S_{river}	R	M_{NaCl}	$\Delta\pi_{osm}$	Δp	E_{osm}	$Q_{freshwater}$	$P_{powerplant}$
Units	*centigrate*	*Kelvin*	*centigrate*	*Kelvin*	*gram/liter*	*mol/liter*	*gram/liter*	*mol/liter*	*joule/mol.Kelvin*	*gram/mol*	*bar*	*bar*	*megajoules/metercube*	*metercube/second*	*megawatt*
JANUARY	17.6	291	8.2	281	39	0.6674	0.0097	0.0002	0.08314	58.44	32.26	16.13	1.6128	15	23.5
FEBRUARY	16.6	290	11.3	284	39	0.6674	0.0098	0.0002	0.08314	58.44	32.14	16.07	1.6072	22	35.3
MARCH	16.8	290	11.5	285	39	0.6674	0.0108	0.0002	0.08314	58.44	32.17	16.08	1.6083	42	66.9
APRIL	17.4	291	14.8	288	39	0.6674	0.0098	0.0002	0.08314	58.44	32.23	16.12	1.6117	46	74.7
MAY	20.2	293	18.5	292	39	0.6674	0.0100	0.0002	0.08314	58.44	32.54	16.27	1.6272	53	86.5
JUNE	23.7	297	20.0	293	39	0.6674	0.0096	0.0002	0.08314	58.44	32.93	16.47	1.6466	43	71.5
JULY	26.5	300	20.8	294	39	0.6674	0.0117	0.0002	0.08314	58.44	33.24	16.62	1.6621	40	67.1
AUGUST	27.8	301	19.3	292	39	0.6674	0.0083	0.0001	0.08314	58.44	33.39	16.69	1.6694	27	44.9
SEPTEMBER	26.9	300	18.5	292	39	0.6674	0.0093	0.0002	0.08314	58.44	33.29	16.64	1.6644	17	28.5
OCTOBER	23.9	297	17.3	290	39	0.6674	0.0392	0.0007	0.08314	58.44	32.93	16.47	1.6465	14	22.9
NOVEMBER	20.9	294	11.8	285	39	0.6674	0.0101	0.0002	0.08314	58.44	32.62	16.31	1.6311	12	19.5
DECEMBER	18.6	292	9.4	283	39	0.6674	0.0100	0.0002	0.08314	58.44	32.37	16.18	1.6183	12	18.8
AVERAGE	21.4	295	15.1	288	39	0.6674	0.0124	0.0002	0.08314	58.44	32.68	16.34	1.6338	29	46.7

4.5 The Gediz River

Source of the Gediz River is in Kütahya city boundaries from mountains of Murat and Şaphane. Mouth of the river disembogue to İzmir Bay between from the Foça and Çamaltı Tuzlası (Figure 17). River basin has an area of 17.500 km². Main stream of river has a length of 401 km with an average flowrate of 60.48 m³/s (Ministry of Forestry and Water Management, n.d.).

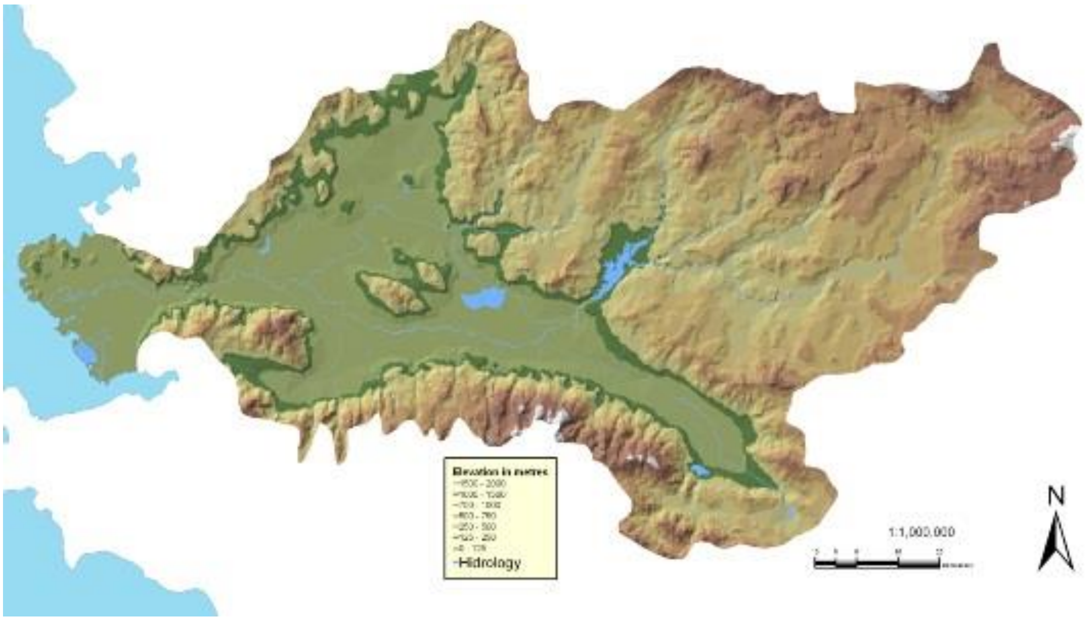

Figure 17: Geographical map of Gediz basin (SHW, n.d.-a).

4.5.1 *Flowrate*

Flowrate of Gediz River also has been found from the Flowrate Observation Yearbook 2009-2010-2011 (3 books) from the 518th station. Even though the average flowrate declared as 60.48 m^3/s, the monthly data is much smaller. The reason for that difference could be demand by agricultural activities and water used for irrigation. Additionally, on the Gediz River there is only one dam which is called Demirköprü constructed in 1960. According to data obtained, flowrate change in months is shown in the Figure 18. Especially in the fall, flowrate decreases significantly. In October and December discharge falls under 10m^3/s, which is an unwanted situation but overall value is sufficient for a sustainable PRO power plant.

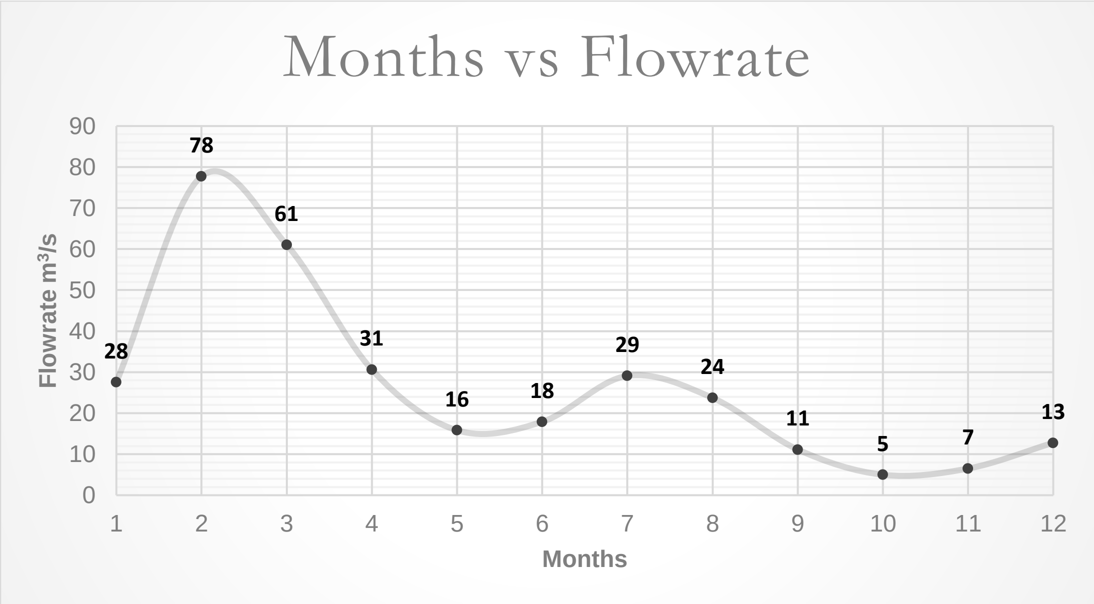

Figure 18: Flowrate fluctuation with respect to months in Gediz River.

4.5.2 *Salinity and Temperature*

Gediz River disembogues to the Aegean Sea having a significant amount of salinity. Sea temperature is quite high but is not higher than the Mediterranean. Since the salinity increases with increasing water temperature, osmotic potential increases with that order. Temperature comparison of Gediz River and Aegean Sea can be seen from Figure 19.

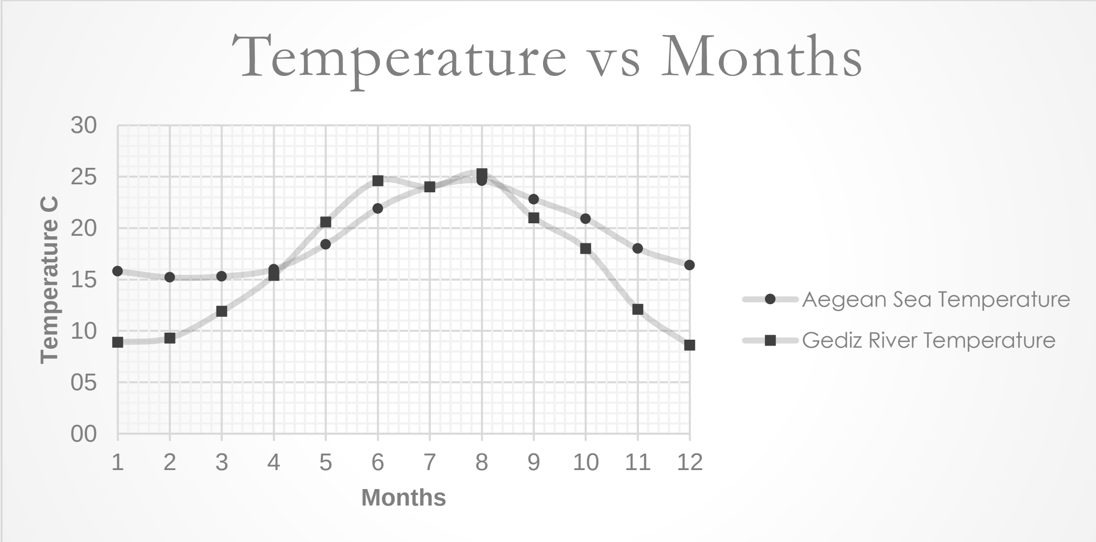

Figure 19: River and sea temperatures with respect to months.

Stream dataset again has been obtained from EPRSD, however, in that case there are averages of months from 1995-2000, which can be checked from Table 12. It should be noted that the salinity values cannot directly be obtained for the Gediz River. To overcome that issue Cl^- ion concentration have been considered as a whole solution of Sodium Chloride (NaCl). In fact, Cl^- ions may also make compound with other metals such as Potassium Chloride (KCl), FerrousandFerric Chloride ($FeCl_2$, $FeCl_3$) or Magnesium Chloride $MgCl_2$. However, all Chloride ion is thought to be in NaCl compound as if there are no other salt ions.

Table 12: Average temperature and Salinity of Gediz River data obtained between years 1995-2000.

Month/Year	Temperature (AVG in °C)	Salinity (AVG in g/L)
JANUARY	8.9	0.041
FEBRUARY	9.3	0.039
MARCH	11.9	0.034
APRIL	15.4	0.033
MAY	20.6	0.044
JUNE	24.6	0.057
JULY	24.0	0.032
AUGUST	25.3	0.023
SEPTEMBER	21.0	0.034
OCTOBER	18.0	0.059
NOVEMBER	12.1	0.060
DECEMBER	8.6	0.050

Whole calculation table can be found in Table 13. Flowrate of the Gediz River is not very high, but it can be said that stream has at least some continuity. Therefore, Gediz River has been evaluated for potential evaluation.

4.5.3 *Annual Energy Production*

When all average values are put into *(Eq. 14)* yearly energy production becomes;

$$E_{produced} = 1.537\,\frac{MJ}{m^3} \cdot 27\,\frac{m^3}{sec} \cdot \frac{31536000\ sec}{1\ year} \cdot \frac{1KWh}{3.6MJ} \cdot \frac{10^{-6}GWh}{1KWh}$$

$$E_{produced} = 364\ GWh$$

4.5.4 *Conclusion*

Gediz river can be evaluated as small PRO power plant potential. Except October, conditions show quite satisfactory results rest of the year. Average of 27 MW and annual 364 GWh energy production capacity power plant may be constructed in case of satisfactory feasibility.

Table 13: Calculation sheet for Gediz River, all required data written month by month and computation done automatically by Microsoft Excel ®.

MONTHS	T_{sea}	T_{sea}	T_{river}	T_{river}	S_{sea}	S_{sea}	S_{river}	S_{river}	R	M_{NaCl}	$\Delta\pi_{osm}$	Δp	E_{osm}	$Q_{freshwater}$	$P_{powerplant}$
Units	*centigrate*	*Kelvin*	*centigrate*	*Kelvin*	*gram/liter*	*mol/liter*	*gram/liter*	*mol/liter*	*joule/mol.Kelvin*	*gram/mol*	*bar*	*bar*	*megajoules/metercube*	*metercube/second*	*megawatt*
JANUARY	15.8	289	8.9	282	37	0.6331	0.0408	0.0007	0.08314	58.44	30.39	15.19	1.5193	28	41.8
FEBRUARY	15.2	288	9.3	282	37	0.6331	0.0387	0.0007	0.08314	58.44	30.33	15.16	1.5163	78	117.9
MARCH	15.3	288	11.9	285	37	0.6331	0.0341	0.0006	0.08314	58.44	30.34	15.17	1.5170	61	92.6
APRIL	16.0	289	15.4	289	37	0.6331	0.0334	0.0006	0.08314	58.44	30.41	15.21	1.5207	31	46.6
MAY	18.4	292	20.6	294	37	0.6331	0.0437	0.0007	0.08314	58.44	30.66	15.33	1.5328	16	24.3
JUNE	21.9	295	24.6	298	37	0.6331	0.0568	0.0010	0.08314	58.44	31.01	15.51	1.5507	18	27.8
JULY	24.0	297	24.0	297	37	0.6331	0.0316	0.0005	0.08314	58.44	31.26	15.63	1.5628	29	45.5
AUGUST	24.6	298	25.3	298	37	0.6331	0.0234	0.0004	0.08314	58.44	31.33	15.66	1.5663	24	37.2
SEPTEMBER	22.8	296	21.0	294	37	0.6331	0.0344	0.0006	0.08314	58.44	31.13	15.56	1.5564	11	17.3
OCTOBER	20.9	294	18.0	291	37	0.6331	0.0589	0.0010	0.08314	58.44	30.91	15.45	1.5454	5	7.7
NOVEMBER	18.0	291	12.1	285	37	0.6331	0.0596	0.0010	0.08314	58.44	30.60	15.30	1.5301	7	11.0
DECEMBER	16.4	290	8.6	282	37	0.6331	0.0504	0.0009	0.08314	58.44	30.44	15.22	1.5221	13	19.5
AVERAGE	19.1	292	16.6	290	37	0.6331	0.0422	0.0007	0.08314	58.44	30.73	15.37	1.5367	27	40.8

4.6 The Göksu River

The Göksu River Basin located in Mediterranean region, on the West of Adana (Figure 20). It is administratively found in the boundary of Konya, Karaman and İçel cities. Starting point of upper conduits of river reaches to the summit of Middle Toros Mountains. Stream discharges to sea near Silifke through the delta which exist by its own flow (Buldur, Pinar, and Başaran, 2015).

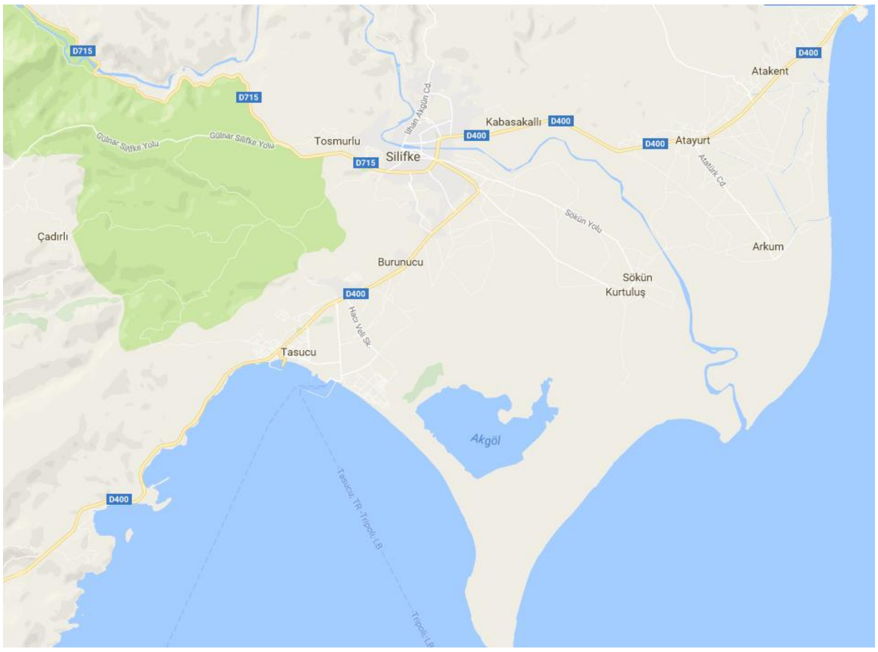

Figure 20: Silifke region and downstream of the Göksu River where it meets Mediterranean Sea

4.6.1 *Flowrate of River*

Flowrate of Gediz River has been found from the Flowrate Observation Yearbook 2009-2010-2011 (3 books) at the 1714th station. In the winter and spring, flowrate increases regularly and even in summer, stream does not show sharp decrease when compared to other rivers. Figure 21 shows the monthly flowrate change of the river.

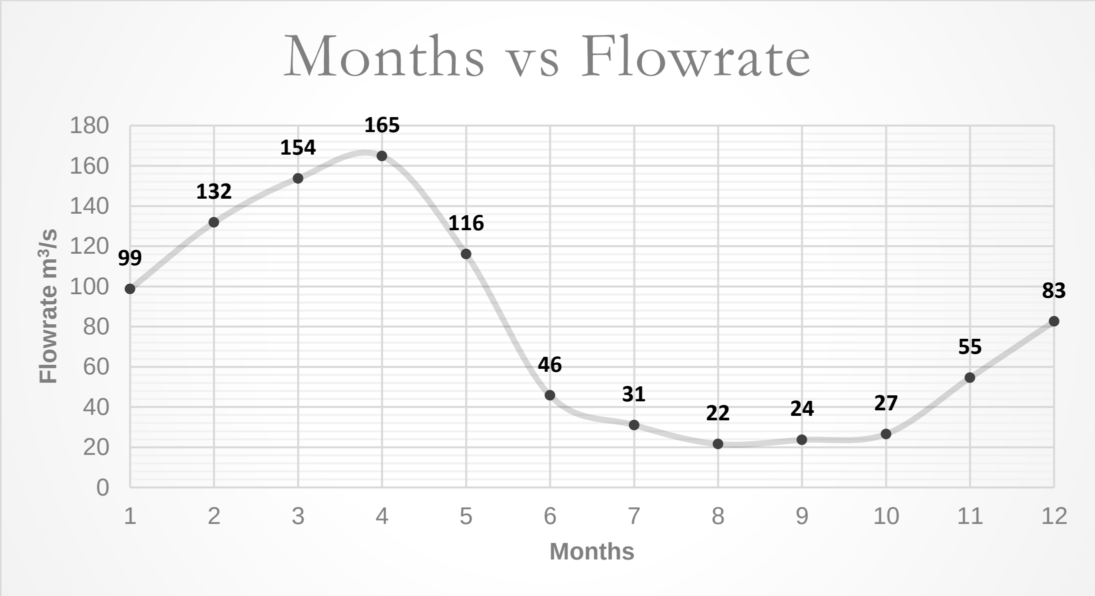

Figure 21:Flowrate fluctuation of Göksu River in one year

4.6.2 *Salinity and Temperature*

Mediterranean Sea is the hottest and the saltiest sea in Turkey. Göksu River follows the same temperature path with the Mediterranean Sea. Temperature difference between river and sea changes from 2 to 5 centigrade degrees. Temperature change in 12 month of a year is shown in the Figure 22.

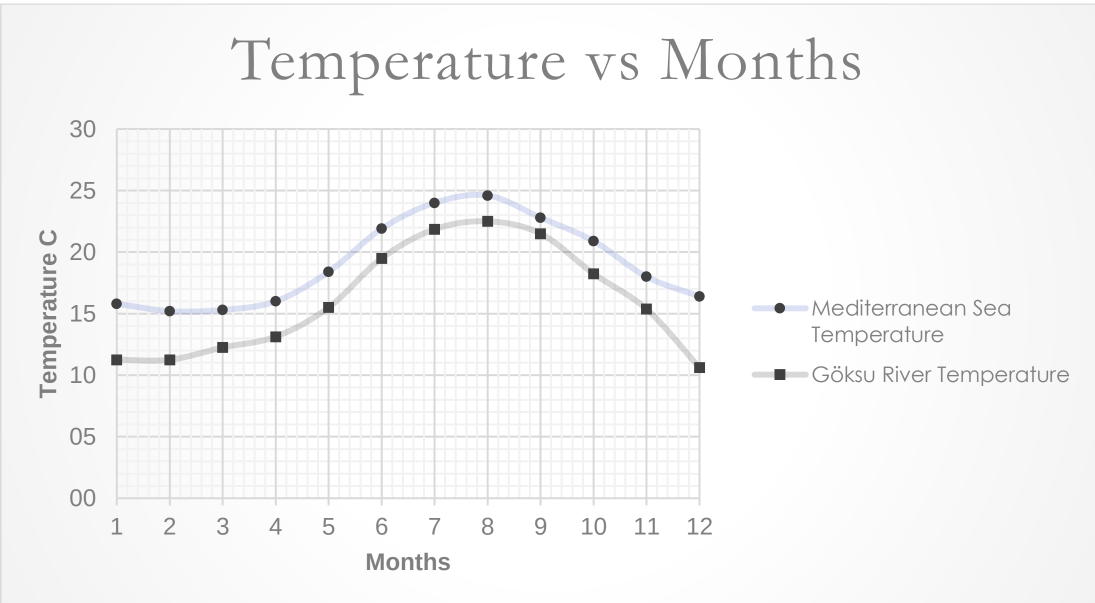

Figure 22: Temperature of Göksu and Mediterranean Sea with respect to months

River temperature and salinity dataset has been found between years 1995 to 2002. Average of salinity and temperature has been used for calculations of potential.

Table 14: Salinity dataset and average value of 8 years in meq/L and g/L

Month/Year	1995	1996	1997	1998	1999	2000	2001	2002	AVG (meq/L)	AVG (g/L)
JANUARY	0.23	0.39	0.34	0.35	0.32	0.4	0.39	0.38	**0.35**	**0.012**
FEBRUARY	0.33	0.25	0.42	0.26	0.28	0.4	0.42	0.38	**0.34**	**0.012**
MARCH	0.25	0.27	0.36	0.32	0.3	0.33	0.24	0.32	**0.30**	**0.011**
APRIL	0.24	0.2	0.3	0.27	0.36	0.32	0.23	0.34	**0.28**	**0.010**
MAY	0.28	0.28	0.32	0.3	0.34	0.25	0.3	0.3	**0.30**	**0.011**
JUNE	0.45	0.4	0.33	0.44	0.27	0.28	0.42	0.32	**0.36**	**0.013**
JULY	0.31	0.36	0.44	-	0.36	0.34	0.46	0.34	**0.37**	**0.013**
AUGUST	0.49	0.4	0.33	0.45	0.39	0.42	0.44	0.51	**0.43**	**0.015**
SEPTEMBER	0.32	0.32	0.52	0.45	0.41	0.48	0.54	0.49	**0.44**	**0.016**
OCTOBER	0.36	0.38	0.48	0.37	0.27	0.48	0.44	0.46	**0.41**	**0.014**
NOVEMBER	0.48	0.38	0.45	0.27	0.35	0.33	0.46	0.32	**0.38**	**0.013**
DECEMBER	0.37	0.34	0.23	0.33	0.4	0.39	0.3	0.34	**0.34**	**0.012**

Average salinity changes between values from 0.28 to 0.44 meq/L, which are rather smaller values than the other river studied so far. Table 14 shows whole point data about the salinity and their averages.

4.6.3 *Annual Energy Production*

Using the average values of E_{osm}=1.639 MJ/m^3, Q_{avg}=79m^3/s Annual energy production would be;

$$E_{produced} = 1.639\frac{MJ}{m^3}\cdot 79\frac{m^3}{sec}\cdot\frac{31536000\,sec}{1\,year}\cdot\frac{1KWh}{3.6MJ}\cdot\frac{10^{-6}GWh}{1KWh}$$

$$E_{produced} = 1128\,GWh$$

It is a quite good potential of energy.

4.6.4 *Conclusion*

By the help of its regular flowrate, Göksu River shows important potential for osmotic power plant. In addition, salinity value of river is very small for all months and it disembogues to Mediterranean Sea that has highest salinity and temperature as mentioned before. Installed capacity calculated for Göksu is 128.8 MW and annually production is found as 1128 GWh. More information is given in Table 15.

Table 15: Calculation sheet for Göksu River, all required data written month by month

MONTHS	T_{sea}	T_{sea}	T_{river}	T_{river}	S_{sea}	S_{sea}	S_{river}	S_{river}	R	M_{NaCl}	$\Delta\pi_{osm}$	Δp	E_{osm}	$Q_{freshwater}$	$P_{powerplant}$
Units	*centigrate*	*Kelvin*	*centigrate*	*Kelvin*	*gram/liter*	*mol/liter*	*gram/liter*	*mol/liter*	*joule/mol.Kelvin*	*gram/mol*	*bar*	*bar*	*megajoules/metercube*	*metercube/second*	*megawatt*
JANUARY	18.9	292	11.3	284	39	0.6674	0.0124	0.0002	0.08314	58.44	32.40	16.20	1.6199	99	159.9
FEBRUARY	16.9	290	11.3	284	39	0.6674	0.0122	0.0002	0.08314	58.44	32.18	16.09	1.6088	132	212.0
MARCH	17.2	290	12.3	285	39	0.6674	0.0106	0.0002	0.08314	58.44	32.21	16.11	1.6105	154	247.5
APRIL	18.0	291	13.1	286	39	0.6674	0.0100	0.0002	0.08314	58.44	32.30	16.15	1.6150	165	266.1
MAY	21.2	294	15.5	289	39	0.6674	0.0105	0.0002	0.08314	58.44	32.65	16.33	1.6327	116	189.5
JUNE	25.1	298	19.5	293	39	0.6674	0.0129	0.0002	0.08314	58.44	33.09	16.54	1.6543	46	75.7
JULY	27.9	301	21.9	295	39	0.6674	0.0132	0.0002	0.08314	58.44	33.40	16.70	1.6698	31	51.8
AUGUST	28.8	302	22.5	296	39	0.6674	0.0152	0.0003	0.08314	58.44	33.49	16.75	1.6747	22	36.1
SEPTEMBER	28.0	301	21.5	295	39	0.6674	0.0157	0.0003	0.08314	58.44	33.40	16.70	1.6702	24	39.5
OCTOBER	25.5	299	18.3	291	39	0.6674	0.0144	0.0002	0.08314	58.44	33.13	16.56	1.6564	27	44.0
NOVEMBER	21.7	295	15.4	289	39	0.6674	0.0135	0.0002	0.08314	58.44	32.71	16.35	1.6354	55	89.2
DECEMBER	19.1	292	10.6	284	39	0.6674	0.0120	0.0002	0.08314	58.44	32.42	16.21	1.6210	83	133.8
AVERAGE	22.4	296	16.1	289	39	0.6674	0.0127	0.0002	0.08314	58.44	32.78	16.39	1.6391	79	128.8

4.7 Manavgat River

The first waters of the Manavgat River consist of spring waters originating from the mountains south of Akdağ and Beyşehir Lake in the northwest of the Cevizli Township bounded by the Antalya-Akseki county and the waters south of the Gembos closed basin. The beginning of the Manavgat River, which is 1000-2000 meters above the sea level, is a small stream that dries in summer. Manavgat River formed by the merging of small rivers in this region. River disembogues to the Mediterranean Sea in Dalyan after a 90 km of journey between Manavgat district. Manavgat waterfall is well-known place attracting lots of tourists (Figure 23). There are lots of boats, social domain and small number of fish farms at the stream mouth (Lerzan and Ertan, 2012).

Figure 23: Manavgat waterfall on the river attracts lots of tourist every year (Kumbara Haber, 2016)

4.7.1 *Flowrate of the River*

In the past, river had a very high flowrate and peaked up to 500 m^3/s and minimum of 36 m^3/s was seen with an average flowrate of 147 m^3/s (Shuval and Dweik, 2007). Unfortunately, current numbers obtained from SHW (average of 1964 to 2014) shows that average flowrate decreased to 65 m^3/s. Flowrate oscillation of stream can be seen from the Figure 24: Flowrate change of Manavgat with respect to months.

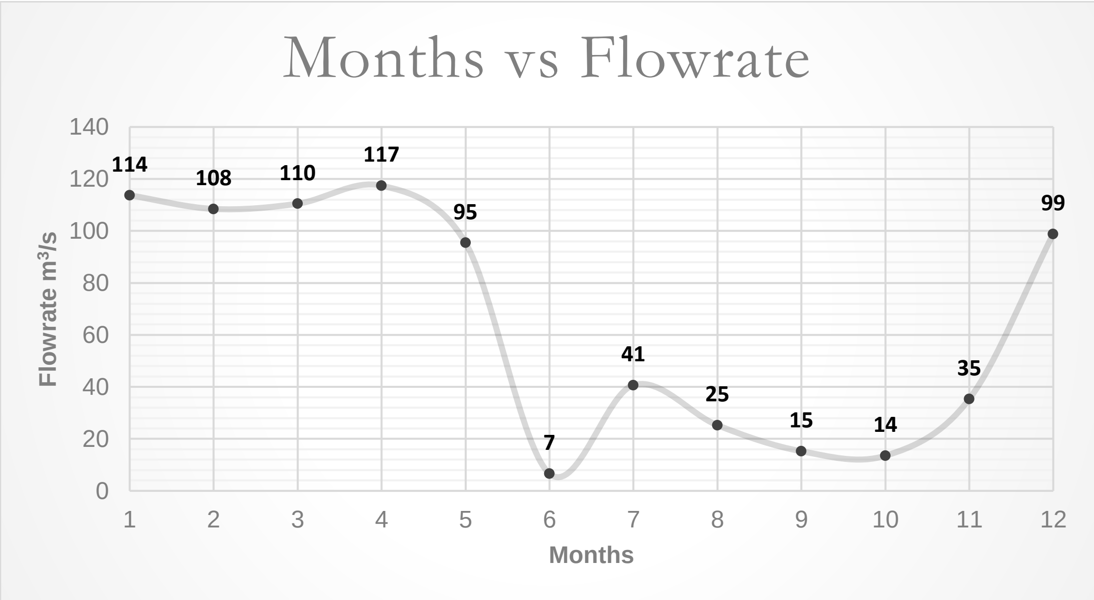

Figure 24: Flowrate change of Manavgat with respect to months.

4.7.2 *Salinity and Temperature*

The Manavgat river discharges to the Mediterranean and therefore it has the advantage of having high salinity value of the sea. Salinity of the river is low but higher than the other rivers done in the thesis. Salinity values can be checked from Table 16.

Table 16: Salinity dataset for the Manavgat River from the 912th station

Month/Year	1999	2000	2001	2002	AVG (meq/L)	AVG (g/L)
JANUARY	NA	0.24	0.21	0.16	**0.20**	**0.007**
FEBRUARY	NA	0.24	0.17	0.26	**0.22**	**0.008**
MARCH	NA	0.23	0.12	0.23	**0.19**	**0.007**
APRIL	NA	0.15	0.15	0.25	**0.18**	**0.007**
MAY	NA	0.20	0.19	0.22	**0.20**	**0.007**
JUNE	NA	0.18	0.23	0.14	**0.18**	**0.007**
JULY	0.13	0.20	0.23	0.14	**0.18**	**0.006**
AUGUST	0.22	0.30	0.25	0.23	**0.25**	**0.009**
SEPTEMBER	0.23	0.32	NA	0.28	**0.28**	**0.010**
OCTOBER	0.27	0.30	NA	0.29	**0.29**	**0.010**
NOVEMBER	0.30	0.24	0.20	0.31	**0.26**	**0.009**
DECEMBER	0.28	0.15	0.22	0.20	**0.21**	**0.008**

Sea temperature at that region shows a regular regime with respect to seasons. On the other hand, small fluctuations are seen in the water temperature of the river Figure 25 denotes the temperature change of Manavgat river and Mediterranean Sea by months.

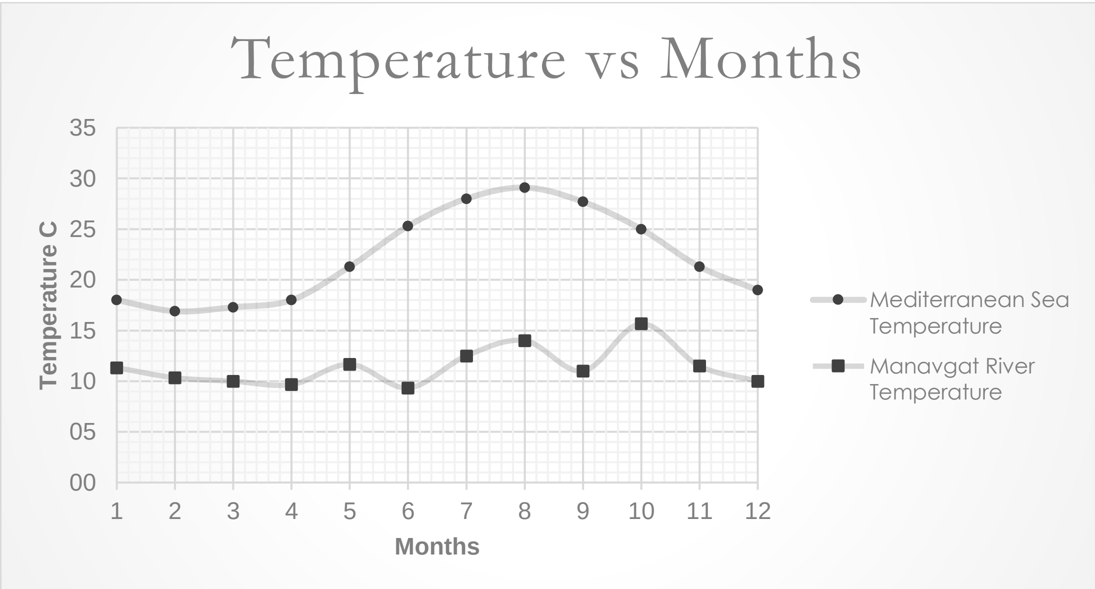

Figure 25:Monthly temperature change of Mediterranean Sea and Manavgat river .

4.7.3 *Annual Energy Production*

Average monthly value of 105MW and needed flowrate around 65 m^3/s and E_{osm}=1.639 MJ/m^3. Annual energy production would be;

$$E_{produced} = 1.639\,\frac{MJ}{m^3} \cdot 65\,\frac{m^3}{sec} \cdot \frac{31536000\,sec}{1\,year} \cdot \frac{1KWh}{3.6MJ} \cdot \frac{10^{-6}GWh}{1KWh}$$

$$E_{produced} = 925\,GWh.$$

4.7.4 *Conclusion*

Table 17 shows that Manavgat has a sufficient potential for osmotic power plant. Even though the flowrate in fall is very low, place has high potential to be important for PRO and should be evaluated in the future. Installed power plant capacity is calculated as 46.7 MW and annual production is 925 GWh, which is not much but sustainable.

Table 17: Detailed Excel sheet of Manavgat river including calculation of monthly power output.

MONTHS	T_{sea}	T_{sea}	T_{river}	T_{river}	S_{sea}	S_{sea}	S_{river}	S_{river}	R	M_{NaCl}	$\Delta\pi_{osm}$	Δp	E_{osm}	$Q_{freshwater}$	$P_{powerplant}$
Units	*centigrate*	*Kelvin*	*centigrate*	*Kelvin*	*gram/liter*	*mol/liter*	*gram/liter*	*mol/liter*	*joule/mol.Kelvin*	*gram/mol*	*bar*	*bar*	*megajoules/metercube*	*metercube/second*	*megawatt*
JANUARY	18.0	291	11.3	284	39	0.6674	0.0072	0.0001	0.08314	58.44	32.30	16.15	1.6151	114	183.7
FEBRUARY	16.9	290	10.3	283	39	0.6674	0.0079	0.0001	0.08314	58.44	32.18	16.09	1.6090	108	174.5
MARCH	17.3	290	10.0	283	39	0.6674	0.0069	0.0001	0.08314	58.44	32.22	16.11	1.6112	110	178.0
APRIL	18.0	291	9.7	283	39	0.6674	0.0065	0.0001	0.08314	58.44	32.30	16.15	1.6151	117	189.7
MAY	21.3	294	11.7	285	39	0.6674	0.0072	0.0001	0.08314	58.44	32.67	16.33	1.6334	95	155.9
JUNE	25.3	298	9.3	282	39	0.6674	0.0065	0.0001	0.08314	58.44	33.11	16.56	1.6556	7	11.0
JULY	28.0	301	12.5	286	39	0.6674	0.0062	0.0001	0.08314	58.44	33.41	16.71	1.6706	41	68.0
AUGUST	29.1	302	14.0	287	39	0.6674	0.0089	0.0002	0.08314	58.44	33.53	16.77	1.6766	25	42.3
SEPTEMBER	27.7	301	11.0	284	39	0.6674	0.0098	0.0002	0.08314	58.44	33.38	16.69	1.6688	15	25.4
OCTOBER	25.0	298	15.7	289	39	0.6674	0.0102	0.0002	0.08314	58.44	33.08	16.54	1.6538	14	22.4
NOVEMBER	21.3	294	11.5	285	39	0.6674	0.0093	0.0002	0.08314	58.44	32.67	16.33	1.6333	35	57.8
DECEMBER	19.0	292	10.0	283	39	0.6674	0.0075	0.0001	0.08314	58.44	32.41	16.21	1.6206	99	160.2
AVERAGE	22.2	295	11.4	285	39	0.6674	0.0078	0.0001	0.08314	58.44	32.77	16.39	1.6386	65	105.7

4.8 The Sakarya River

The Sakarya River (Figure 26) has 58200km^2 of drainage basin that is 7.49% of land of Turkey and total of 824 km length. Annual average water volume is above 4 billion meter cube ("Sakarya nehri Sistemi Ephemeroptera limnofaunası belirlenmesi üzerinde araştırmalar.pdf," 1995).Basin generally has small roughness topography. Important branches of river are mainly Porsuk and Ankara brook and smaller ones are Seydisuyu, Çarksuyu, Karasu, Girmir Brook, Göynük Brook, Mudurnu Brook and Göksu. Cities which involves the boundary of basin are Ankara, Eskişehir, Kütahya, Bilecik and Sakarya. Lots of projects have been developed in the area about irrigation, drinking and tap water and energy production. Water pollution problem in the area has been rapidly increasing due to industrialization and population (Şengörür B., 2001).

Figure 26: The point where Sakarya River meets the Black Sea (Öztürk, 2008).

4.8.1 *Flowrate of River*

The Sakarya River is one of the biggest river in Turkey. Flowrate is quite high in entire year. Especially in winter and spring, flowrate increase over 200 m^3/s. River flowrate has been obtained from the 1257th station of SHW, between years 2003-2011 and 2014 as an average.

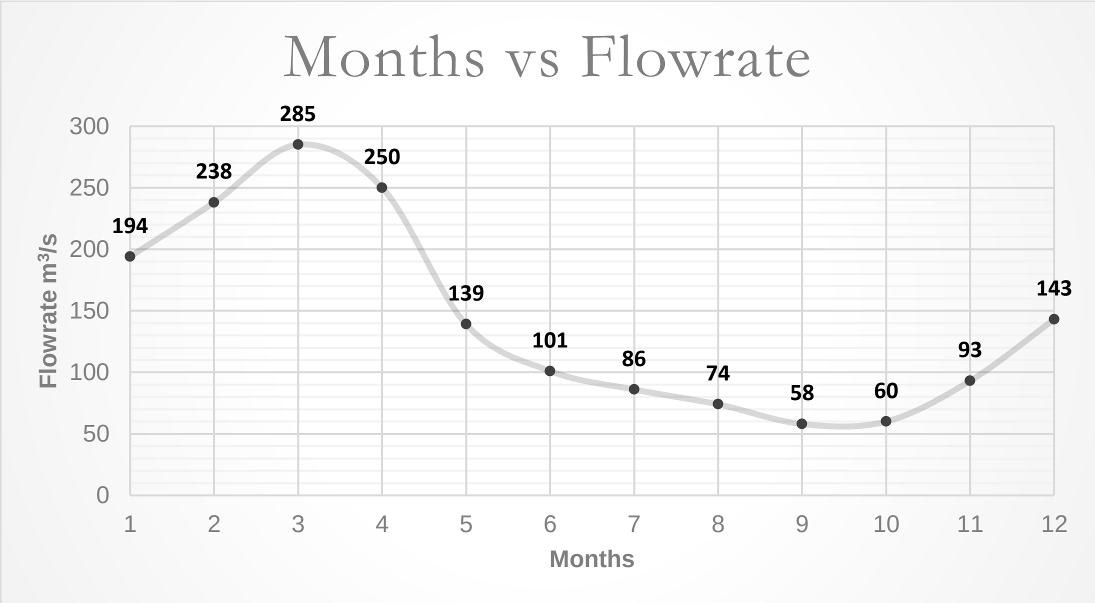

Figure 27: Sakarya River flowrate fluctuation within one year as average.

In the August, as shown in Figure 27, flowrate descend under 60 m^3/s, but it is not a low value when compared to other rivers. Consequently, flowrate regime seems sufficient for producing osmotic energy above 60 m^3/s.

4.8.2 *Salinity and Temperature*

Since Black Sea is located Northern side of Turkey, it is colder than Mediterranean and Aegean Sea, therefore salinity of sea is lower as expected. Sakarya river's average temperature is 15.5^{o}C, lower than the other rivers studied.

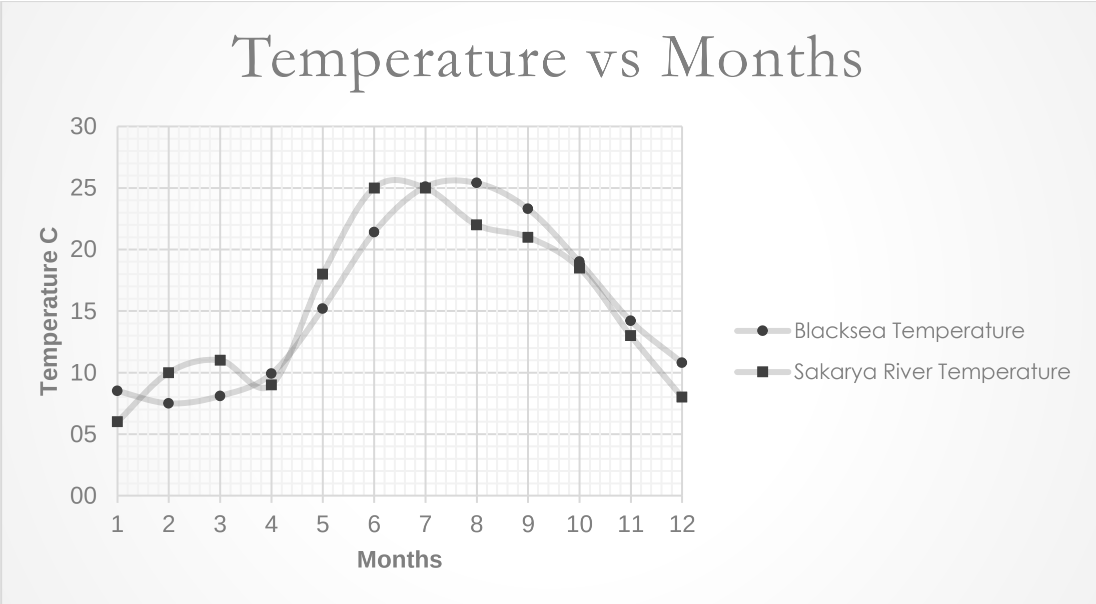

Figure 28: Monthly surface water temperature for Black Sea and Sakarya River.

Sakarya river temperature data only could be found for 2001 and 2002, therefore the accuracy of the data is not very good. Still, the data shows that the river and the sea temperatures are very close to each other (Figure 28).

Salinity of the river has been found between years only for 2001-2002 like the temperature (Table 18). Sakarya salinity changes between the values of 0.46-1.70 meq/L. Black Sea salinity has been taken of general value which is 18g/L.

Table 18: Salinity dataset of Sakarya River for 2001-2002, and averages in different units.

Month/Year	2001	2002	AVG (meq/L)	AVG (g/L)
JANUARY	NA	1.26	**1.26**	**0.045**
FEBRUARY	NA	1.16	**1.16**	**0.041**
MARCH	NA	1.04	**1.04**	**0.037**
APRIL	NA	0.46	**0.46**	**0.016**
MAY	NA	1.38	**1.38**	**0.049**
JUNE	NA	1.38	**1.38**	**0.049**
JULY	NA	1.43	**1.43**	**0.051**
AUGUST	NA	1.7	**1.70**	**0.060**
SEPTEMBER	1.77	1.42	**1.55**	**0.057**
OCTOBER	1.94	1.44	**1.69**	**0.060**
NOVEMBER	1.64	1.32	**1.48**	**0.053**
DECEMBER	1.06	1.39	**1.23**	**0.043**

4.8.3 *Annual Energy Production*

Using the average energy production value of 105 MW which need flowrate around 143 m^3/s and E_{osm}=0.738 MJ/m^3. Annual energy production would be;

$$E_{produced} = 0.738\,\frac{MJ}{m^3}\cdot 143\,\frac{m^3}{sec}\cdot\frac{31536000\ sec}{1\ year}\cdot\frac{1KWh}{3.6MJ}\cdot\frac{10^{-6}GWh}{1KWh}$$

$$E_{produced} = 925\ GWh$$

is found.

4.8.4 *Conclusion*

Overall calculation result for Sakarya river can be checked from the Table 19. As mentioned previous chapter, flowrate regime is very satisfactory to obtain energy from osmosis. Unfortunately, due to low salinity of Black Sea, power potential is little lower when compared to the other rivers with similar flowrates discharging to Mediterranean and Aegean Sea. However, 925 GWh annual energy production is significant for Turkey. Minimum power production is calculated as 44 MW prevailed in September and installed capacity is around 105 MW.

Table 19: Osmotic calculation sheet for the Sakarya River, where power potential is very good.

MONTHS	T_{sea}	T_{sea}	T_{river}	T_{river}	S_{sea}	S_{sea}	S_{river}	S_{river}	R	M_{NaCl}	$\Delta\pi_{osm}$	Δp	E_{osm}	$Q_{freshwater}$	$P_{powerplant}$
Units	*centigrate*	*Kelvin*	*centigrate*	*Kelvin*	*gram/liter*	*mol/liter*	*gram/liter*	*mol/liter*	*joule/mol.Kelvin*	*gram/mol*	*bar*	*bar*	*megajoules/metercube*	*metercube/second*	*megawatt*
JANUARY	8.5	282	6.0	279	18	0.3080	0.0447	0.0008	0.08314	58.44	14.39	7.19	0.7195	194	139.6
FEBRUARY	7.5	281	10.0	283	18	0.3080	0.0412	0.0007	0.08314	58.44	14.34	7.17	0.7170	238	170.7
MARCH	8.1	281	11.0	284	18	0.3080	0.0369	0.0006	0.08314	58.44	14.37	7.19	0.7187	285	204.8
APRIL	9.9	283	9.0	282	18	0.3080	0.0163	0.0003	0.08314	58.44	14.48	7.24	0.7242	250	181.0
MAY	15.2	288	18.0	291	18	0.3080	0.0490	0.0008	0.08314	58.44	14.73	7.36	0.7364	139	102.4
JUNE	21.4	295	25.0	298	18	0.3080	0.0490	0.0008	0.08314	58.44	15.04	7.52	0.7522	101	76.0
JULY	25.1	298	25.0	298	18	0.3080	0.0508	0.0009	0.08314	58.44	15.23	7.62	0.7616	86	65.5
AUGUST	25.4	299	22.0	295	18	0.3080	0.0604	0.0010	0.08314	58.44	15.24	7.62	0.7620	74	56.4
SEPTEMBER	23.3	296	21.0	294	18	0.3080	0.0566	0.0010	0.08314	58.44	15.14	7.57	0.7568	58	43.9
OCTOBER	19.0	292	18.5	292	18	0.3080	0.0600	0.0010	0.08314	58.44	14.91	7.46	0.7456	60	44.7
NOVEMBER	14.2	287	13.0	286	18	0.3080	0.0525	0.0009	0.08314	58.44	14.67	7.34	0.7337	93	68.2
DECEMBER	10.8	284	8.0	281	18	0.3080	0.0435	0.0007	0.08314	58.44	14.51	7.25	0.7254	143	103.7
AVERAGE	15.7	289	15.5	289	18	0.3080	0.0467	0.0008	0.08314	58.44	14.76	7.38	0.7378	143	104.7

4.9 The Seyhan River

Seyhan is an important river for Turkey (Figure 29) having approximate length of 560km and born in Kayseri. River basin consist of 20,731 km^2 and end with Çukurova plain where population density is high and has effective agricultural land use (Davutluoglu, Seckin, Ersu, Yilmaz, and Sari, 2011).

Figure 29: Photography of Seyhan River flowing in Adana, one of the biggest city in Turkey (Şimşek, 2015)

4.9.1 *Flowrate of River*

Data average of The Seyhan had been taken between 2010-2014 from the SHW 1845^{th} numbered station. As it can be seen from Figure 30, flowrate goes up to 166 m^3/s and falls down to 9 m^3/s in summer. In summer, water volume harshly decreases under 20 m^3/s.

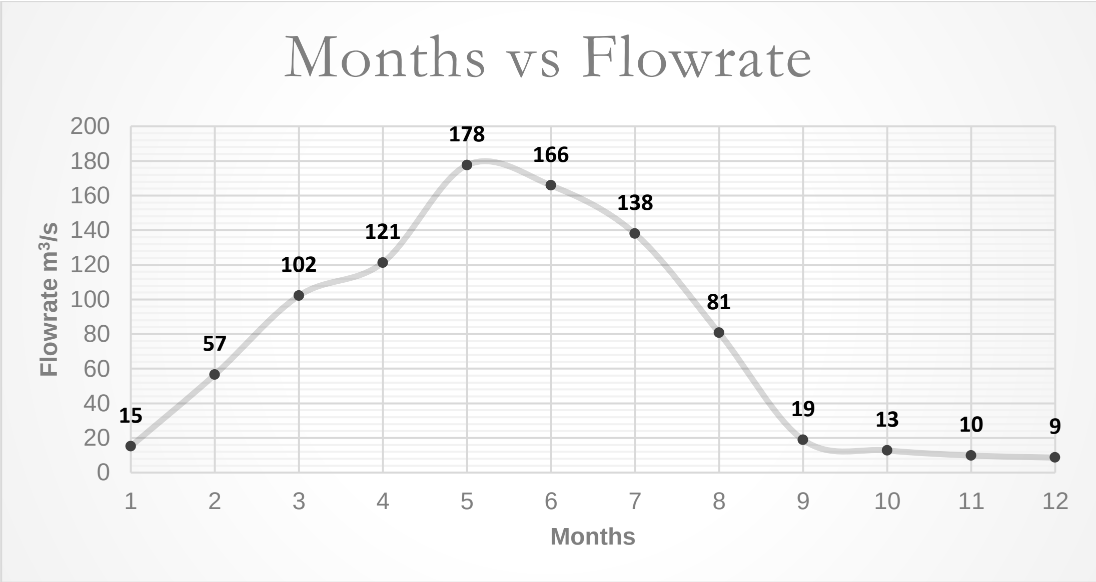

Figure 30: Seyhan River flowrate up and downs within one-year period.

4.9.2 *Temperature and Salinity*

River temperature and salinity data has been obtained from 1818th station of SHW. Available dataset has been measured between 1995-2002. Comparison between Seyhan temperature and Mediterranean Sea temperature can be checked from the Figure 31. Temperature difference between sea and river changes between 4-9^{o}C.

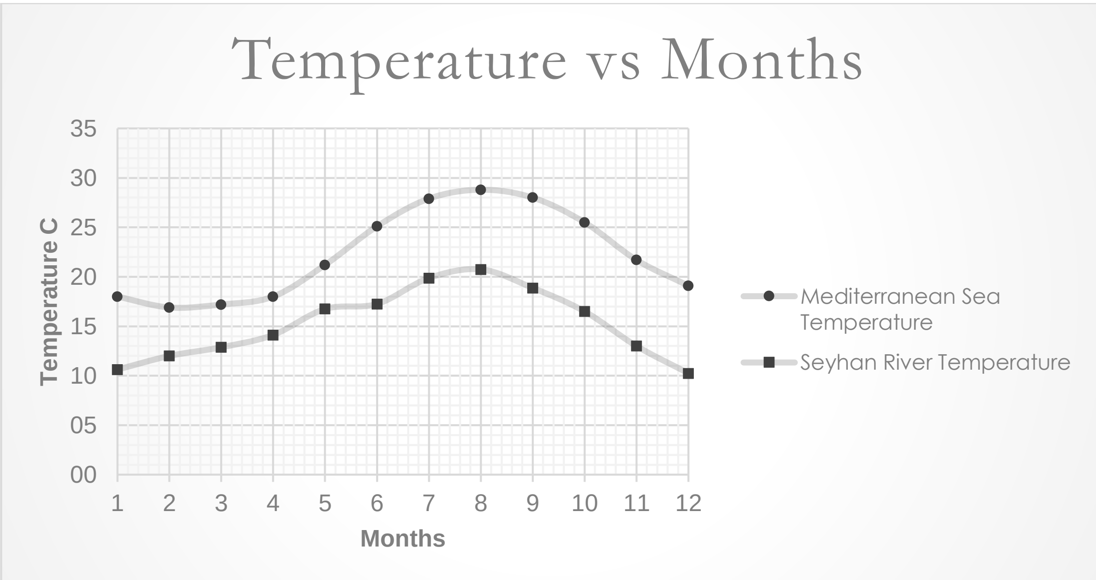

Figure 31: Comparison and monthly temperature change of Mediterranean Sea and Seyhan River.

As expected, river salinity is low with respect to Mediterranean Sea salinity that is 39g/L mentioned in previous cases. Salinity dataset can confer from the Table 20.

Table 20: Seyhan River salinity dataset is shown as monthly averages in meq/L and g/L

Month/Year	1995	1996	1997	1998	1999	2000	2001	2002	AVG (meq/L)	AVG (g/L)
JANUARY	0.41	0.35	0.68	0.64	0.59	0.70	0.86	0.52	**0.59**	**0.021**
FEBRUARY	0.57	0.51	0.58	0.54	0.47	0.70	0.76	0.52	**0.58**	**0.021**
MARCH	0.43	0.34	0.62	0.42	0.54	0.52	0.60	0.46	**0.49**	**0.017**
APRIL	0.33	0.36	0.32	0.36	0.47	0.39	0.58	0.34	**0.39**	**0.014**
MAY	0.39	0.44	0.54	0.46	0.64	0.33	0.22	0.44	**0.43**	**0.015**
JUNE	0.30	0.54	0.54	0.60	0.61	0.49	0.68	0.46	**0.53**	**0.019**
JULY	0.66	0.64	0.63	0.59	0.65	0.68	0.78	0.61	**0.66**	**0.023**
AUGUST	0.70	0.72	0.70	0.77	0.75	0.74	0.78	0.62	**0.72**	**0.026**
SEPTEMBER	0.80	0.74	0.77	0.80	0.76	0.76	0.82	0.73	**0.77**	**0.027**
OCTOBER	0.72	0.72	0.59	0.76	0.78	0.80	0.92	0.76	**0.76**	**0.027**
NOVEMBER	0.54	0.70	0.34	0.81	0.82	0.90	0.88	0.74	**0.72**	**0.025**
DECEMBER	0.60	0.64	0.32	0.50	0.82	0.88	0.56	0.76	**0.64**	**0.023**

4.9.3 *Annual Energy Production*

E_{osm} equals to 1.638 which is annual average of unit energy. Average flowrate is 76 m^3/s and then annual energy production is;

$$E_{produced} = 1.638\frac{MJ}{m^3}\cdot 76\frac{m^3}{sec}\cdot\frac{31536000\,sec}{1\,year}\cdot\frac{1KWh}{3.6MJ}\cdot\frac{10^{-6}GWh}{1KWh}$$

$$E_{produced} = 1090\ GWh$$

is found.

4.9.4 *Conclusion*

One of the huge advantage of Seyhan River is that it disembogues into Mediterranean Sea. Salinity is very convenient in Mediterranean to obtain serious amount of energy from PRO as mentioned previous chapters. Potential calculation of Seyhan River has been prepared in Table 21. Although flowrate of Seyhan River is not very high, due to advantage of high salinity of the sea it is possible to construct a feasible power plant here. Installed capacity calculated for Seyhan is 124 MW and annual production of 1090 GWh, which is one of the greatest energy potential found in the thesis.

Table 21:Osmotic calculation sheet for the Seyhan River. The potential is quite good for energy production.

MONTHS	T_{sea}	T_{sea}	T_{river}	T_{river}	S_{sea}	S_{sea}	S_{river}	S_{river}	R	M_{NaCl}	$\Delta\pi_{osm}$	Δp	E_{osm}	$Q_{freshwater}$	$P_{powerplant}$
Units	*centigrate*	*Kelvin*	*centigrate*	*Kelvin*	*gram/liter*	*mol/liter*	*gram/liter*	*mol/liter*	*joule/mol.Kelvin*	*gram/mol*	*bar*	*bar*	*megajoules/metercube*	*metercube/second*	*megawatt*
JANUARY	18.0	291	10.6	284	39	0.6674	0.0211	0.0004	0.08314	58.44	32.29	16.15	1.6146	15	24.5
FEBRUARY	16.9	290	12.0	285	39	0.6674	0.0206	0.0004	0.08314	58.44	32.17	16.08	1.6085	57	90.9
MARCH	17.2	290	12.9	286	39	0.6674	0.0174	0.0003	0.08314	58.44	32.21	16.10	1.6103	102	164.5
APRIL	18.0	291	14.1	287	39	0.6674	0.0140	0.0002	0.08314	58.44	32.30	16.15	1.6148	121	195.8
MAY	21.2	294	16.8	290	39	0.6674	0.0154	0.0003	0.08314	58.44	32.65	16.33	1.6325	178	289.9
JUNE	25.1	298	17.3	290	39	0.6674	0.0187	0.0003	0.08314	58.44	33.08	16.54	1.6540	166	274.3
JULY	27.9	301	19.9	293	39	0.6674	0.0233	0.0004	0.08314	58.44	33.39	16.69	1.6694	138	230.3
AUGUST	28.8	302	20.8	294	39	0.6674	0.0256	0.0004	0.08314	58.44	33.49	16.74	1.6743	81	135.1
SEPTEMBER	28.0	301	18.9	292	39	0.6674	0.0274	0.0005	0.08314	58.44	33.39	16.70	1.6697	19	31.6
OCTOBER	25.5	299	16.5	290	39	0.6674	0.0268	0.0005	0.08314	58.44	33.12	16.56	1.6559	13	21.2
NOVEMBER	21.7	295	13.0	286	39	0.6674	0.0254	0.0004	0.08314	58.44	32.70	16.35	1.6349	10	16.1
DECEMBER	19.1	292	10.3	283	39	0.6674	0.0225	0.0004	0.08314	58.44	32.41	16.21	1.6206	9	14.0
AVERAGE	22.3	295	15.2	288	39	0.6674	0.0215	0.0004	0.08314	58.44	32.77	16.38	1.6383	76	124.0

4.10 The Yeşilırmak River

The Yeşilırmak River has a total basin area of 2352.8 m^2 519 km in length, where the large part of it lies in Tokat city. Stream has been polluted by industrial wastewater heavily (Tüzen, 2003). The River discharges to the Black Sea with an average flowrate of 140 m^3/s, according to the SHW stream station.

4.10.1 *Flowrate*

Flowrate of the river is rather good with respect to other rivers in Turkey. SHW stream flowrate averages between 2009-2014 from the station numbered 14179 have been used for calculations. Annual flowrate change can be seen in Figure 32. Stream regime is regular when compared to the other rivers discussed in the thesis. The River reaches peak flowrate in April and bottom out in October. Average flowrate of the stream is 158 m^3/s which is a significant flow rate.

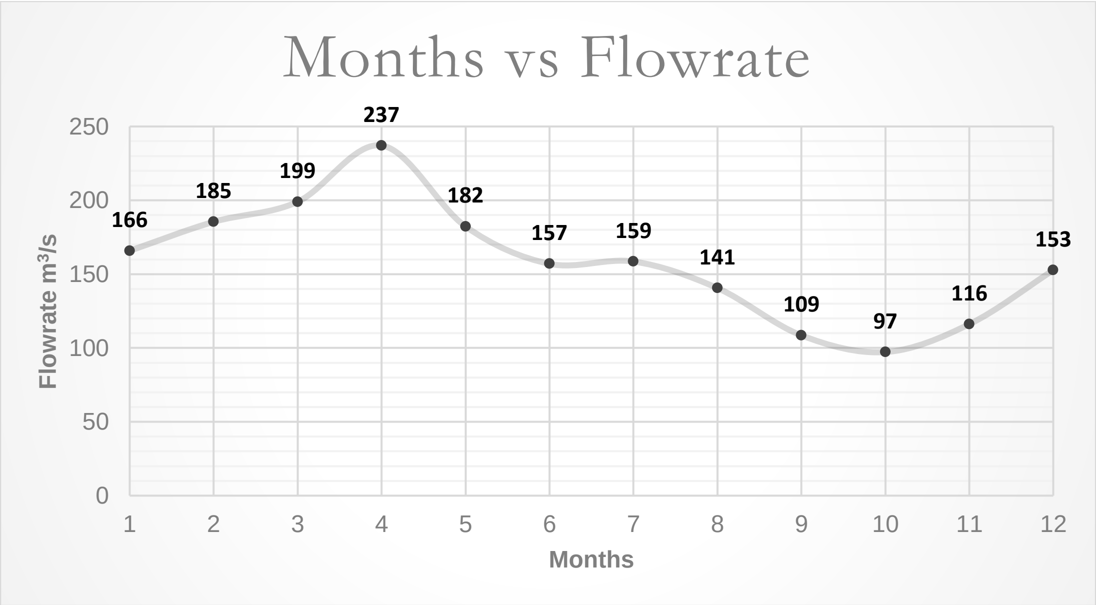

Figure 32: Annual flowrate averages of Yeşilırmak River between 2009-2014.

4.10.2 *Temperature and Salinity*

Temperatures of river and Black Sea show similar relationship for entire year. Temperature of river and sea comes very close to each other in April but difference increases in August. River temperature data has been taken from 1408th station of SHW. Annual temperature change can be compared from Figure 33.

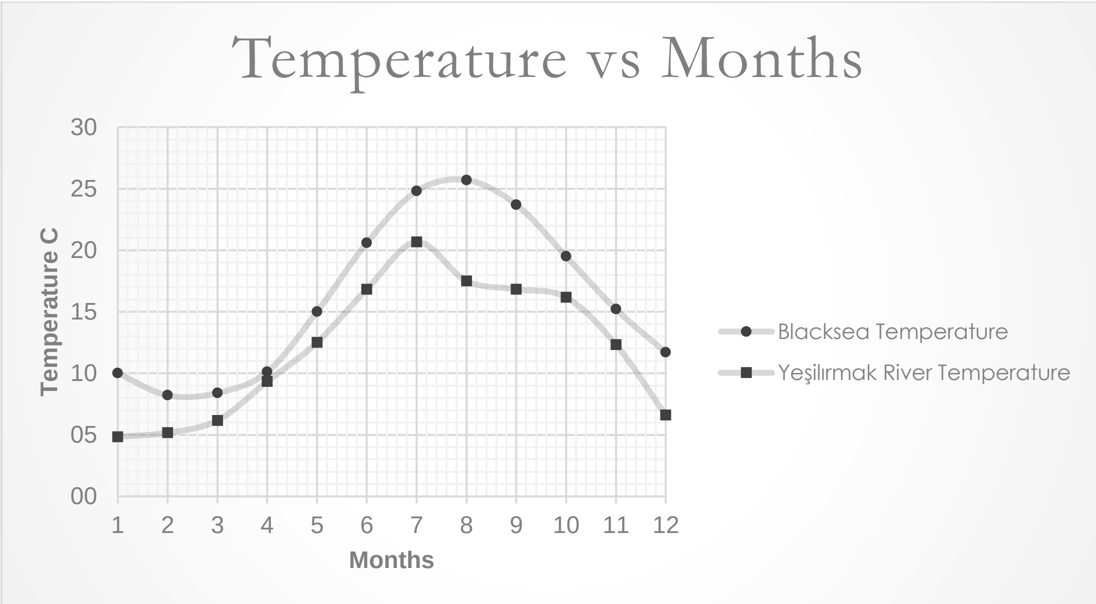

Figure 33:Temperature change of Black Sea and Yeşilırmak River with respect to months

The Yeşilırmak disembogues to the Black Sea therefore, salinity of the sea is low, which negatively affects the osmosis process. River salinity is low and maybe classified as average with respect to other discussed rivers in the thesis. Dataset available has been shared in Table 22.

Table 22: Salinity dataset for Yeşilırmak river

Month/Year	1995	1996	1997	1998	1999	2000	AVG (meq/L)	AVG (g/L)
JANUARY	0.42	0.40	0.40	0.36	0.23	0.44	**0.38**	**0.013**
FEBRUARY	0.42	0.42	0.38	0.34	0.40	0.54	**0.42**	**0.015**
MARCH	0.42	0.43	0.36	0.34	0.42	0.52	**0.42**	**0.015**
APRIL	0.36	0.33	0.35	0.34	0.40	0.28	**0.34**	**0.012**
MAY	0.34	0.46	0.31	0.33	0.50	0.32	**0.38**	**0.013**
JUNE	0.40	0.50	0.35	0.33	0.42	0.34	**0.39**	**0.014**
JULY	0.40	0.40	0.44	0.32	0.37	0.92	**0.48**	**0.017**

Table 22 (continued)

Month/Year	1995	1996	1997	1998	1999	2000	AVG (meq/L)	AVG (g/L)
AUGUST	0.42	0.40	0.40	0.33	0.31	1.44	**0.55**	**0.020**
SEPTEMBER	1.28	0.40	0.40	0.27	0.31	0.40	**0.51**	**0.018**
OCTOBER	0.34	0.36	0.38	0.31	0.41	0.84	**0.44**	**0.016**
NOVEMBER	0.32	0.30	0.38	0.40	0.42	0.48	**0.38**	**0.014**
DECEMBER	0.36	0.34	0.36	0.26	0.60	NA	**0.38**	**0.014**

4.10.3 *Annual Energy Production*

For Yeşilırmak average unit energy E_{osm} equals to 0.74 and average flowrate is 158 m^3/s so that the energy production is:

$$E_{produced} = 0.74\frac{MJ}{m^3}\cdot 158\frac{m^3}{sec}\cdot\frac{31536000\,sec}{1\,year}\cdot\frac{1KWh}{3.6MJ}\cdot\frac{10^{-6}GWh}{1KWh}$$

$$E_{produced} = 1020\ GWh$$

4.10.4 *Conclusion*

In fact, flowrate potential of the Yeşilırmak is very convenient however, salinity of the sea is not that suitable for optimal osmotic energy production conditions. Total installed capacity for the Yeşilırmak is 116.8 MW and annual energy production is 1020 GWh. Potential could be much higher if it was located in the Mediterranean region. Despite this disadvantage, energy potential is prominently good. For more information Table 23 has been prepared.

Table 23: Yeşilırmak River calculation and dataset table prepared in Excel ®.

MONTHS	T_{sea}	T_{sea}	T_{river}	T_{river}	S_{sea}	S_{sea}	S_{river}	S_{river}	R	M_{NaCl}	$\Delta\pi_{osm}$	Δp	E_{osm}	$Q_{freshwater}$	$P_{powerplant}$
Units	*centigrate*	*Kelvin*	*centigrate*	*Kelvin*	*gram/liter*	*mol/liter*	*gram/liter*	*mol/liter*	*joule/mol.Kelvin*	*gram/mol*	*bar*	*bar*	*megajoules/metercube*	*metercube/second*	*megawatt*
JANUARY	10.0	283	4.8	278	18	0.3080	0.0133	0.0002	0.08314	58.44	14.49	7.25	0.7246	166	120.2
FEBRUARY	8.2	281	5.2	278	18	0.3080	0.0148	0.0003	0.08314	58.44	14.40	7.20	0.7199	185	133.5
MARCH	8.4	282	6.2	279	18	0.3080	0.0147	0.0003	0.08314	58.44	14.41	7.20	0.7204	199	143.3
APRIL	10.1	283	9.3	282	18	0.3080	0.0122	0.0002	0.08314	58.44	14.50	7.25	0.7249	237	171.9
MAY	15.0	288	12.5	286	18	0.3080	0.0134	0.0002	0.08314	58.44	14.75	7.37	0.7373	182	134.4
JUNE	20.6	294	16.8	290	18	0.3080	0.0138	0.0002	0.08314	58.44	15.03	7.52	0.7517	157	118.0
JULY	24.8	298	20.7	294	18	0.3080	0.0169	0.0003	0.08314	58.44	15.25	7.62	0.7623	159	120.9
AUGUST	25.7	299	17.5	291	18	0.3080	0.0195	0.0003	0.08314	58.44	15.29	7.64	0.7645	141	107.5
SEPTEMBER	23.7	297	16.8	290	18	0.3080	0.0181	0.0003	0.08314	58.44	15.19	7.59	0.7594	109	82.4
OCTOBER	19.5	293	16.2	289	18	0.3080	0.0156	0.0003	0.08314	58.44	14.98	7.49	0.7488	97	72.8
NOVEMBER	15.2	288	12.3	285	18	0.3080	0.0136	0.0002	0.08314	58.44	14.76	7.38	0.7378	116	85.7
DECEMBER	11.7	285	6.6	280	18	0.3080	0.0136	0.0002	0.08314	58.44	14.58	7.29	0.7289	153	111.3
AVERAGE	16.1	289	12.1	285	18	0.3080	0.0150	0.0003	0.08314	58.44	14.80	7.40	0.7400	158	116.8

4.11 Osmotic Energy Potential of Turkey

It is totally eight rivers have been analysed for calculation of osmotic potential of Turkey (Table 24). It should be remarked that; these calculations have been done according to the available information and under ideal conditions without considering the limitation in the membrane technology. If a technology which provides continuous and feasible energy production in variable flowrates becomes available, the total potential would be significantly higher. It can be said that only small portion of real potential can be used in today's condition.

Table 24: Maximum potential capacity of Turkey when the technology is suitable for variable conditions (numbers have been rounded)

River	Capital Capacity (MW)	Annual Energy Production (GWh)
Ceyhan	325	2840
Dalaman	45	415
Gediz	40	355
Göksu	130	1130
Manavgat	105	925
Sakarya	105	915
Seyhan	125	1090
Yeşilırmak	115	1020
TOTAL	**990**	**8690**

On the other hand, even if the technology advances further, there is the issue of river water usage in PRO considering the climate change. The impacts of climate change on the precipitation is expected to decrease the river flowrates and therefore, the energy production may become less.

CHAPTER 5

DIMENSIONS AND LOCATIONS OF POSSIBLE PRO PLANTS

5.1 Membrane Area

The membrane is reported to be the most important component of an osmotic power plant. When Loeb first designed the PRO system, membrane power densities were of only 0.1 W/m^2 , but now there are some laboratory scale membranes which achieved 10 W/m^2 that are higher than the commercially feasible power density of 5 W/m^2 (Fouad, Maisonneuve, La, and Pillay, 2015).

There are still no commercial membranes for osmotic power generation in the industry because there have not any PRO built yet. Considering that osmotic power will become feasible in the next 20 years, the membrane characteristic has been chosen with higher power densities.

Calculation of membrane area and numbers of modules are very prominent. PRO consist of lots of membranes and it covers huge areas with respect to capacity of power plant. In case of probable construction of power plants, these calculations are thought to be helpful for interested parties.

5.1.1 *Membrane Characteristic*

As mentioned in earlier chapters, commercial membranes have not been produced yet. To conduct studies on applicability of osmotic power generation, sensitivity analysis and performance evaluation, researchers generally have used commercial forward osmosis and reverse osmosis membranes. From experiments done, experts determined the ideal membrane characteristic for PRO plants.

One of the recent articles *"Progress in pressure retarded osmosis (PRO) membranes for osmotic power generation"* by Han presents very detailed information about membrane properties. Some important membrane parameters are shown in the Table 25 where A is water permeability coefficient (m /s.bar), B is salt permeability coefficient (m/s) and S is membrane structural parameter (m) calculated by using the thickness of the support layer, the tortuosity of the support layer and the porosity of the support layer.

Table 25: TFC-PRO Hollow fiber membrane transport properties (Han, Zhang, Li, and Chung, 2015)

Membrane	A (10^{-9} m s^{-1} kPa^{-1})	B (10^{-7} m s^{-1})	W_{max} (W/m^2)	Burst pressure (bar)	S (μm)
TFC-1	11.94	1.30	16.5	>16	640
TFC-2	10.00	2.03	14.0	>16	640
TFC-3	9.22	0.39	110.6	9.5	460
TFC-4	4.22	0.67	20.9	16.5	610
TFC-5	2.52	0.24	12.0	24	685
TFC-6	9.17	0.86	24.3	21	450
TFC-7	3.89	0.33	13.0	17.5	510
TFC-8	2.50	1.11	7.3	20	540

Where;

A	*Water permeability coefficient*	*m/s.bar*
B	*Salt permeability*	*m/s*
S	*Membrane structural parameter*	*m*

There are different types of membrane modules existing, which are

- Spiral-wounded
- Hollow fine fibres
- Capillary fibres
- Plate- and frame
- Tubular

The most convenient membrane for PRO system is spiral wounded membranes (Figure 34). Because it can resist to high pressure, and fouling is less favoured compared to other type of membranes (Kleiterp, 2012).

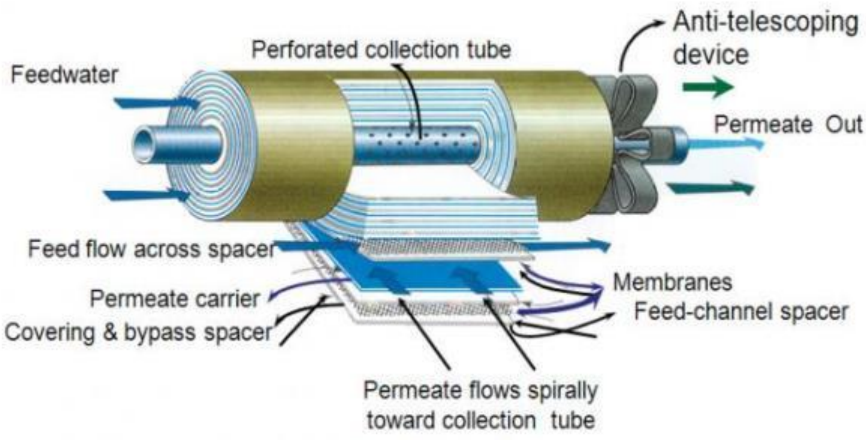

Figure 34: Spiral wounded RO membrane module explanation layer by layer (Buecker, 2016)

Thinking the future conditions an imaginary membrane is chosen for calculation of membrane area. Properties of imaginary membrane are given in Table 26.

Table 26: Imaginary spiral wounded fiber membrane properties

Parameters	Imaginary Membrane Values	Unit
Power Density (W)	10	W/m^2
Packing Density (pd)	1000	m^2/m^3
Module Length (L)	1	m
Module Diameter (D)	0.2	m

In laboratory scale, over 20W/m^2 power density is reached (Sarp, Li, and Saththasivam, 2016). Hence, power density of 10W/m^2 commercial membrane is expected to be available in the future. Packing density is defined as the number of membrane area in a specific volume. It is related to orientation of membranes in osmotic power plant. Spiral wounded membrane module length and diameter have been selected considering commercial membrane dimensions.

5.1.2 *Membrane Stack and Layout*

In general, any kind of operation which includes membranes is arranged by stacks (Figure 35). Stacks number can be determined by the pressure valve properties, headloss in pipes and capital cost. Generally 5-7 membrane can be housed in to one pressure vessel (Kleiterp, 2012). In the thesis, 7 membranes are assumed to be in one pressure vessel. In one stack 25 membranes have been assumed to be placed in one row and 13 membranes placed in on column. So that total of 2275 membrane are fitted in each stack

Figure 35: Desalination RO plant in Israel. Stacks can be seen on both sides (Picow, 2010)

It has been assumed that between two adjacent membrane there is a 10cm gap in x and y axis. The distance between two consecutive membrane stacks has been assumed as 10m and adjacent membrane stack distance has been assumed as 1m. General properties of membrane stacks are given in Table 27.

Table 27: Membrane stack properties used in calculations.

Parameter	Value	Unit
Number of vertical membrane	13	
Number of horizontal membrane	25	
Number of lateral membrane	7	
Height of stack	4.1	m
Length of stack	7.4	m
Width of stack	7	m
Longitudinal distance between stacks	1	m
Lateral distance between group stacks	10	m
Distance between membranes	0.1	m
Stack area	51.8	m^2
Effective stack area	142.8	m^2
Membrane number for each stack	2275	

In the Figure 36 visual explanation of single stack is seen. To check dimension in stack configuration Table 27 also would be helpful.

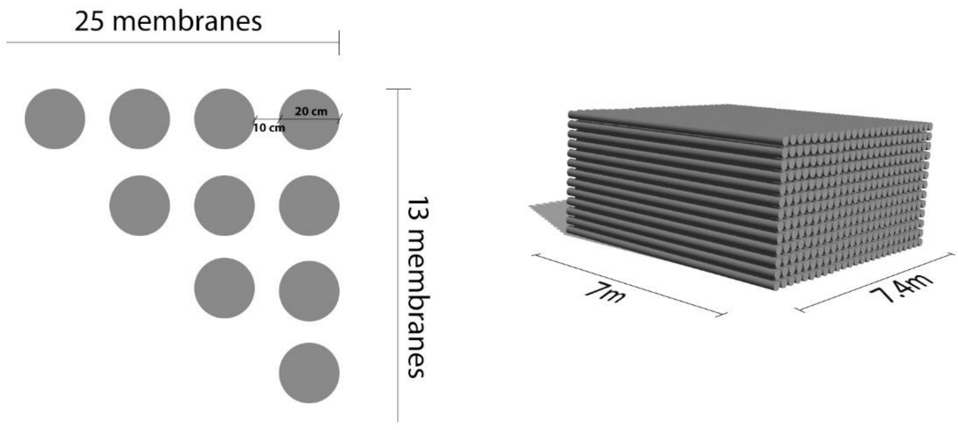

Figure 36: Membrane configuration and dimensions in stack

5.1.3 *Total Membrane Area Calculation*

In Chapter 3.1.5 membrane and stack calculation equations were given. Using these equations (*(Eq. 20)*, *(Eq. 21)*, *(Eq. 22)*) total area required for the membranes are calculated and shown in Table 28:

Table 28: Membrane stack calculation results for each river

River	Potential (MW)	Total Membrane Area (m^2)	Required Module	Required Stacks	Total Area Required (m^2)
Ceyhan	325	32,500,000	1034507	455	64935
Dalaman	45	4,500,000	143239	63	8991
Gediz	40	4,000,000	127324	56	7992
Göksu	130	13,000,000	413803	182	25974
Manavgat	105	10,500,000	334225	147	20979
Sakarya	105	10,500,000	334225	147	20979
Seyhan	125	12,500,000	397887	175	24975
Yeşilırmak	115	11,500,000	366056	161	22977

One of the most significant steps for PRO plant design is the position of membrane stacks. Since the membrane stacks cover large areas, the area for the overall PRO plant can be optimized by arranging the positions of stacks.

For this thesis configuration of membrane stacks are assumed as given in Figure 37.

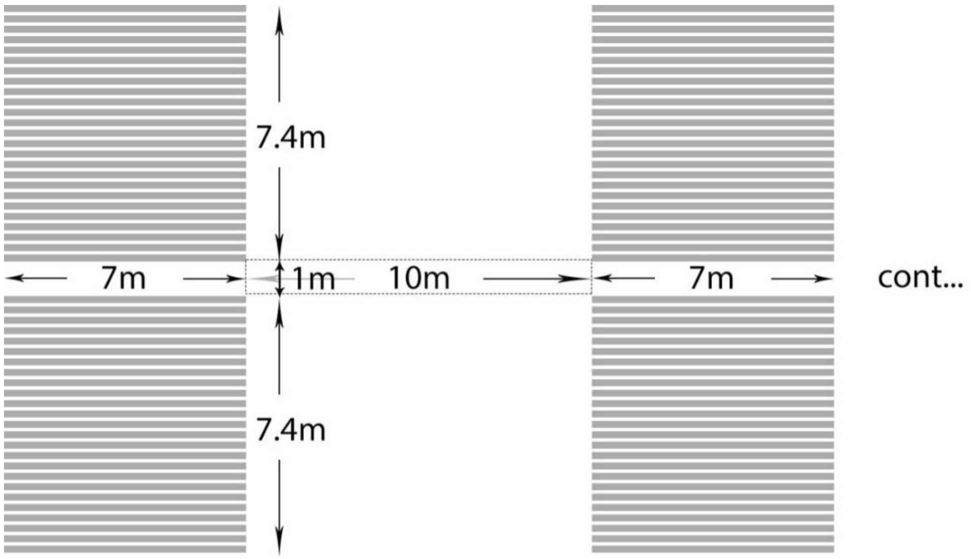

Figure 37: Top views of stack configuration and distances between each of them.

Membrane stacks should be positioned in a way that there are some spaces between them due to operational reasons. When calculating area requirement, effective membrane area term is used to determine the actual area needed. Figure 38 illustrates the concept of effective stack area and single stack area.

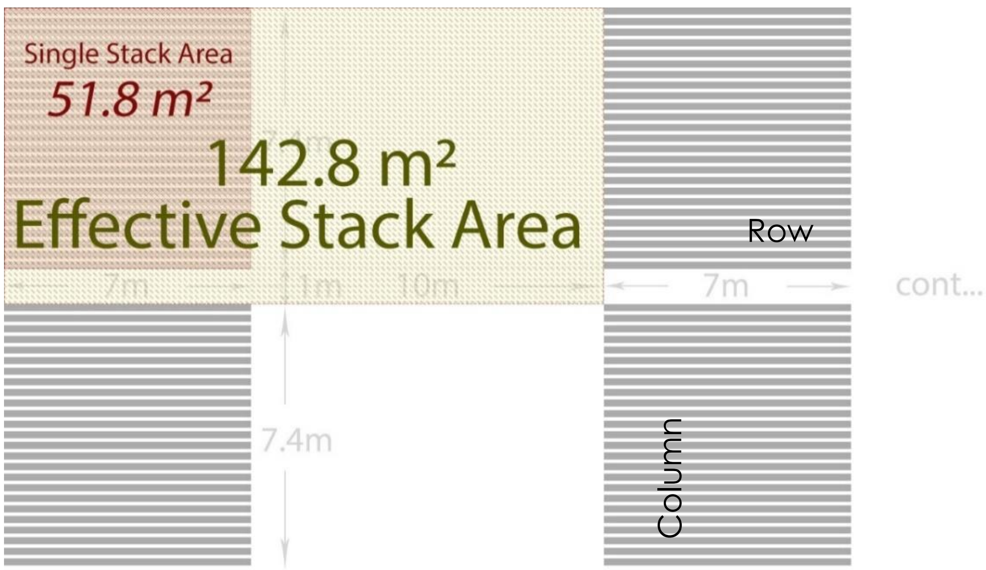

Figure 38: Representation of stack area and effective stack area.

In the Table 28, total stack area has been calculated by using the effective stack area. To obtain the dimensions of the membrane stack area, regular series of membrane stacks which forms square or rectangle were assumed and number of stacks were distributed across columns and rows using Eq. 27 and Eq.28.

The effective stack area dimensions become 8.4m in width and 17m in length. That is, length is 2.02 times larger than the width; It can be written;

$$Total\ Stack\ Number = n \times 2.02n = 2.02n^2 \qquad (Eq.\ 24)$$

$$n = \sqrt{\frac{Total\ Stack\ Number}{2.02}} \qquad (Eq.\ 25)$$

Where;

n *Number of stacks in one column* *(Unitless)*

Table 29: Results of stack number in columns and rows.

River	Total Number of Stacks	Row	Column
Ceyhan	455	15.1	30.2
Dalaman	63	5.6	11.2
Gediz	56	5.3	10.6
Göksu	182	9.5	19.1
Manavgat	147	8.6	17.1
Sakarya	147	8.6	17.1
Seyhan	175	9.4	18.7
Yeşilırmak	161	9.0	17.9

Number of stacks and corresponding row and column numbers (ie, dimensions of the land area) are presented in Table 29. The numbers for rows and columns are rounded to the closer value and they must not be under the total number stacks stated.

Table 30: Total number of stacks needed for each river after rounding the row and columns

River	Total Number of Stacks	Row	Column	Row (Rounded)	Column (Rounded)	Exact Number of Stacks
Ceyhan	455	15.1	30.2	**16**	**30**	**480**
Dalaman	63	5.6	11.2	**6**	**11**	**66**
Gediz	56	5.3	10.6	**6**	**10**	**60**
Göksu	182	9.5	19.1	**10**	**19**	**190**
Manavgat	147	8.6	17.1	**9**	**17**	**153**
Sakarya	147	8.6	17.1	**9**	**17**	**153**
Seyhan	175	9.4	18.7	**10**	**18**	**180**
Yeşilırmak	161	9.0	17.9	**10**	**17**	**170**

Higher number of stacks in the final calculations present one important advantage. Membranes should be maintained regularly therefore the stack that needs overhaul must be turned off while remaining ones are working. Rounding up row and column numbers, which can be checked from Table 30, provide that service flexibility.

5.1.4 *Total Membrane Stack Area*

In the previous section, stack numbers have been determined. Estimating total membrane area for all rivers can be calculated as follows and the results are given in Table 31:

$$Total\ Membrane\ Area = x \cdot y \qquad (Eq.\ 26)$$

$$x = 17m \cdot C \qquad (Eq.\ 27)$$

$$y = 8.4m \cdot R \qquad (Eq.\ 28)$$

Where;

x	*dimension of power plant in x-axis*	*m*
y	*dimension of power plant in y-axis*	*m*
C	*number of stacks in Column (x-axis)*	*(Unitless)*
R	*number of stacks in Row (y-axis)*	*(Unitless)*

Table 31: Total membrane area for all rivers

River	Row (Rounded)	Column (Rounded)	Dimensions x/y (m)
Ceyhan	16	30	272 / 252
Dalaman	6	11	102 / 92
Gediz	6	10	102 / 84
Göksu	10	19	170 / 160
Manavgat	9	17	153 / 143
Sakarya	9	17	153 / 143
Seyhan	10	18	170 / 151
Yeşilırmak	10	17	170 / 143

Finally, power plant area depends also on several other components like water treatment structures, hydraulic structures and topographic conditions. Therefore, the areas calculated in this section should not be taken as the final dimensions (Table 31).

5.2 Possible Locations for Osmotic Power Plants in Turkey

Location and overall area of osmotic power plant depends on the energy potential, land availability and water supply efficiency. For that reason, such design decisions should be performed for each river case carefully. In this study, possible locations for PRO plants are discussed considering land availability and water supply. The area for the plant was taken as the area of the membrane stacks as this part of the PRO plant has the largest dimensions in the overall design. Still, it should be emphasized that figures shown in this chapter do not represent the whole PRO system area.

5.2.1 *Ceyhan Plant*

Ceyhan river is in the city of Adana. Due to high potential of river the biggest power plant dimension belongs to Ceyhan River. Possible location for osmotic power plant has been shown in Figure 39. The area selected is flat, where is approximately 3-4m above from sea level. It is closer to agricultural estates. Soil seems dry; however, groundwater may affect the construction. Moreover, infrastructure for water supply may be costly because of distance to river and sea. Actual power plant may be much larger than membrane stacks but, area availability around Ceyhan stream mouth can said to be flexible. Unfortunately, wetlands close to river mouth do not suitable for osmotic power plant.

Figure 39: Membrane stack place determined for generation of PRO near Ceyhan River and Mediterranean Sea.[2]

[2] *Coordinates, Karatas/Adana: 36°35'58.5"N 35°35'24.8"E (36.599574, 35.590209)*

5.2.2 *Dalaman Plant*

Dalaman is a small district of city of Muğla. The potential of Dalaman river is not very high with respect to other rivers discussed. County attracts lots of tourist from Turkey and rest of the world. Hence, there are lots of hotels and summer houses (Figure 40). One side of the river mouth is used for hotels. Pools can be seen from figure in a light blue color. For that reason, other side of the stream should be used for power plant construction. However, there are trees and a small lagoon, which are located closer to the Aegean Sea. So that, potential power plant should be located further inland.

It should be noted that area around the region is highly important for tourism development and part of the coast may be commercial land. Price of such terrain may be very high. In addition, hydraulic costs for intake and outlet would be substantial due to position of power plant.

Figure 40: Location thought for osmotic power plant near Dalaman River. Total membrane stack area is shown in red.[3]

[3] *Coordinates Dalaman/Muğla: 36°42'34.8"N 28°43'42.3"E (36.709665, 28.728405)*

5.2.3 *Gediz Plant*

Gediz river mouth located at the İzmir where is the Turkey's one of the biggest city. Possible place for PRO near Gediz can be seen from Figure 41. Location options for osmotic power plant in Gediz is insufficient. There are lots of lagoons, small lakes and water bodies exist around the river. Selected place may not be appropriate because of the soil conditions and erosion possibilities. Moreover, construction stage may be very hard due to lack of transportation opportunities.

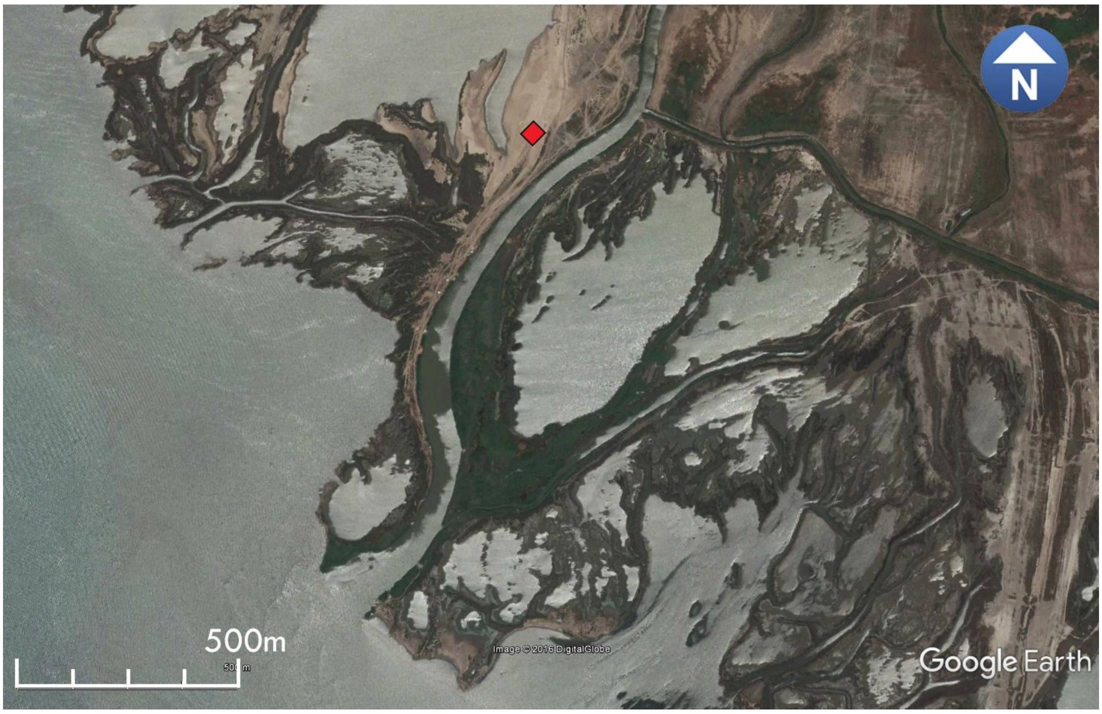

Figure 41: Possible osmotic power plant location for Gediz River.[4]

Onsite investigation should be done carefully before designing osmotic power plant. Although place is not a protected area, there may be environmental effects that should be considered in detail.

[4] *Coordinates Foça/İzmir: 38°35'41.2"N 26°49'00.6"E (38.594784, 26.816835)*

5.2.4 *Göksu Plant*

Göksu River disembogue to Mediterranean Sea so that power potential is rather good. Area availability for the region is not bad. However, area is protected by Ministry of Environment and Urbanization. Location of possible power plant has been marked on Figure 42. However, construction of a power plant may not be permitted. In terms of construction transportation of water would be costly because, distance of power plant and water sources are far away each other. Erosion danger should be also evaluated to have a safe osmotic power plant.

Figure 42: Location chosen for osmotic power plant near Göksu River and Mediterranean Sea.[5]

5.2.5 *Manavgat Plant*

Manavgat River mouth is located in Antalya, which is one of the most famous city in Turkey. There are lots of hotels around the place. As it seen from the Figure 43, there are some unpaved roads and many property around there. Moreover, area shown may not be sufficient while thinking other related construction needed for osmotic power plant. More, water pipeline or hydraulic channel required for gathering sea water

[5] *Coordinates Arkum/Silifke/Mersin: 36°18'40.0"N 34°02'40.3"E (36.311122, 34.044535)*

would probably pass over other properties around. Green field also can be spotted on the Figure 43. In conclusion, construction of an osmotic power plant is not easy. Despite, urbanization is quite sufficient for transportation of materials to the region.

Figure 43: Osmotic power plant area located near Manavgat River mouth.[6]

5.2.6 ***Sakarya Plant***

Sakarya River disembogues to Black Sea and has worthy flowrate.

Figure 44: Osmatic power plant location deemed for Sakarya River.[7]

[6] *Coordinates Doğançam/Manavgat/Antalya: 36°44'20.6"N 31°29'39.8"E (36.739050, 31.494389)*

Urbanization around stream mouth can be said to be well developed. Total membrane stack area and osmotic power plant location is shown in the Figure 44. West side of the river has been selected because of east side consists considerable number of houses.

5.2.7 *Seyhan Plant*

Seyhan river disembogues at the intersection point of Mersin and Adana. Seyhan plays provincial border role for that cities. The satellite photo reveals that terrain of the region is wetlands and cotton field that are reflected as white colour. Region has areas for construction of possible osmotic power plant. However, agricultural activities and wet soil areas must be avoided. Potential construction area is shown in Figure 45. Unfortunately, infrastructure costs would be high due to distance between power plant and water sources.

Figure 45: Membrane stacks area located for possible osmotic power plant of Seyhan River.[8]

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[7] *Coordinates İhsaniye/Karasu/Sakarya 41°07'26.3"N 30°38'42.7"E (41.123961, 30.645203)*
[8] *Coordinates Tabaklar/Karataş/Adana 36°43'53.6"N 34°55'30.8"E (36.731550, 34.925219)*

5.2.8 *Yeşilırmak Plant*

Another river Yeşilırmak from Black Sea has important potential. Unfortunately, topography of the region would create some problems for construction of an osmotic power plant. Terrain for the place, in the Figure 46, is a question mark. East side of the river carries group of trees. West side of the river has some land but there are water lagoons which can be flooded within high flowrate season. In addition, coastal erosion is significant along the river mouth which increases the difficulty for finding a location for the power plant. The best place for possible osmotic energy plant has been selected on dry ground of west part of the river but this location will require additional protection both for erosion and flooding which would increase the overall cost significantly. Another possible option could be locating the power plant further inland along the river and compare the feasibility with the construction at the river mouth.

Figure 46: Membrane stack area and possible power plant place for Yeşilırmak.[9]

[9] *Coordinates Samsun: 41°22'51.2"N 36°39'30.6"E (41.380902, 36.658511)*

CHAPTER 6

FURTHER OPPORTUNITIES AND ENVIRONMENTAL CONSIDERATIONS

So far potential of osmotic energy in Turkey focusing river-sea interaction, number of membrane required, total membrane stack area, and possible locations for PRO plant have been evaluated. However, river-sea interface is not the only source for feasible PRO design. There are rather new techniques presented for PRO systems such as combination of RO and PRO, RO and PRO with different water sources (i.e. effluent wastewater) and PRO with stages. A summary of recent literature is discussed for further studies on the topic in this chapter. Additionally, like the other sources of renewable energy, osmotic energy also has weaknesses and environmental effects. However, these issues are discussed theoretically as there is no commercial scale osmotic power plant running in the world.

6.1 RO and PRO Combination with Different Sources

Even though Turkey does not have any RO plant for producing fresh water yet the future conditions may require obtaining fresh water from sea considering the severe effects of climate change on Turkey. Today, Turkey has available water of 1500 m^3/year per capita, and classified as water shortage country. In 2030 this number is expected to go down 1100 m^3/year per capita and the country will become water poor according to WWF. Therefore, hybridization of RO and PRO could be a significant research area.

RO is a well-known process for obtaining drinking water in dry countries. It is in fact the opposite of the PRO. Sea water is exposed to extreme pressure for water molecules to pass fresh water side by the help of membranes. However, it is very costly to produce fresh water by RO. In addition, critical environment effects and electricity consumption is declared (Tadeo, 2015).

Combination of PRO and desalination especially for RO and FO is likely because, it has a potential for reducing cost and lessening the environmental impacts such as brine discharge to sea. General concept for hybrid PRO-RO system is shown in Figure 47 (Altaee and Sharif, 2015).

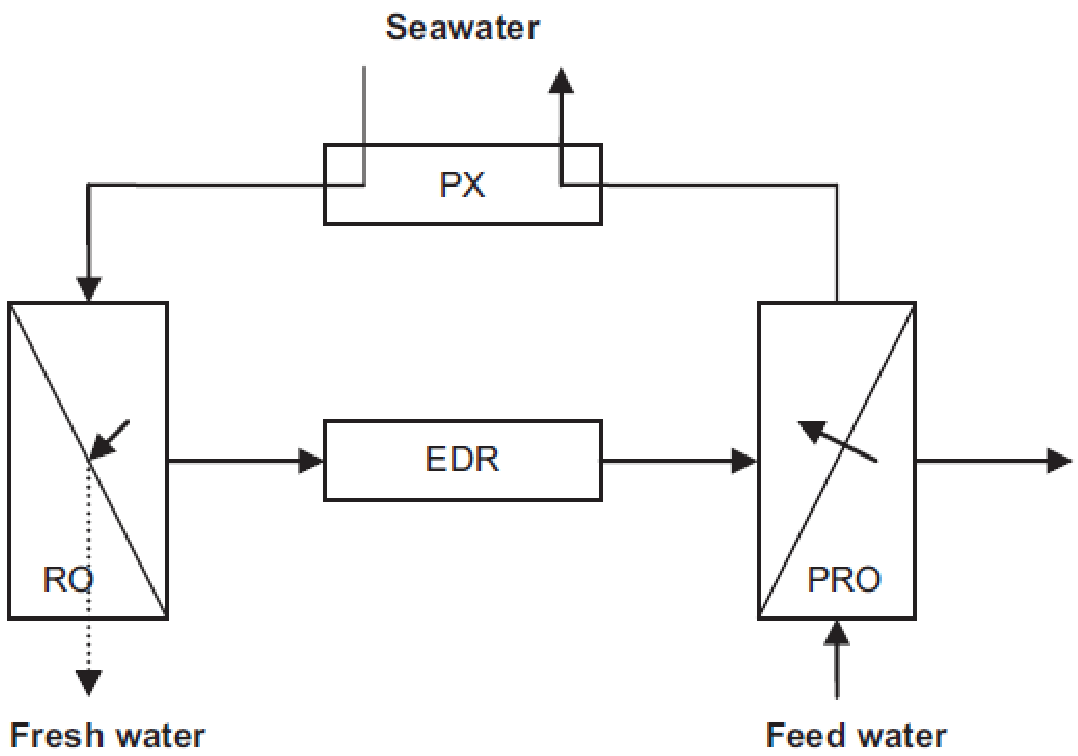

Figure 47:Simple representation of hybrid PRO and RO system (Altaee and Sharif, 2015)

PX expresses pressure exchanger, ERD is energy recovery device. Sea water initially goes into pressure exchanger to become pressurized. After RO process, fresh water and brine water are composed. Pressure of brine water goes ERD in order have a desirable concentration for PRO. After that brine water is used as draw solution in PRO. Feed flow is any kind of low salinity water such as river water. Fresh water that is feed flow permeates through to brine water in PRO. By the help of pressure exchanger produced energy is used for sustaining pressurized seawater feed (Altaee and Sharif, 2015).

Another article by Senthil and Senthilmurugan (2016) shows six different combination of PRO-RO system and discusses the feasibility of each combination considering the effect on reducing the energy consumption and dilution of seawater by hybridization.

6.2 PRO with Stages

After mixing of two solutions in PRO system, still diluted seawater can have considerable salinity. Therefore, a second stage can be designed for producing more energy from osmotic power potential. Altae and Nihal (2015) evaluate dual stage PRO system with old and new design. They tried to improve staged PRO and compare the old one with respect to new one (Figure 48).

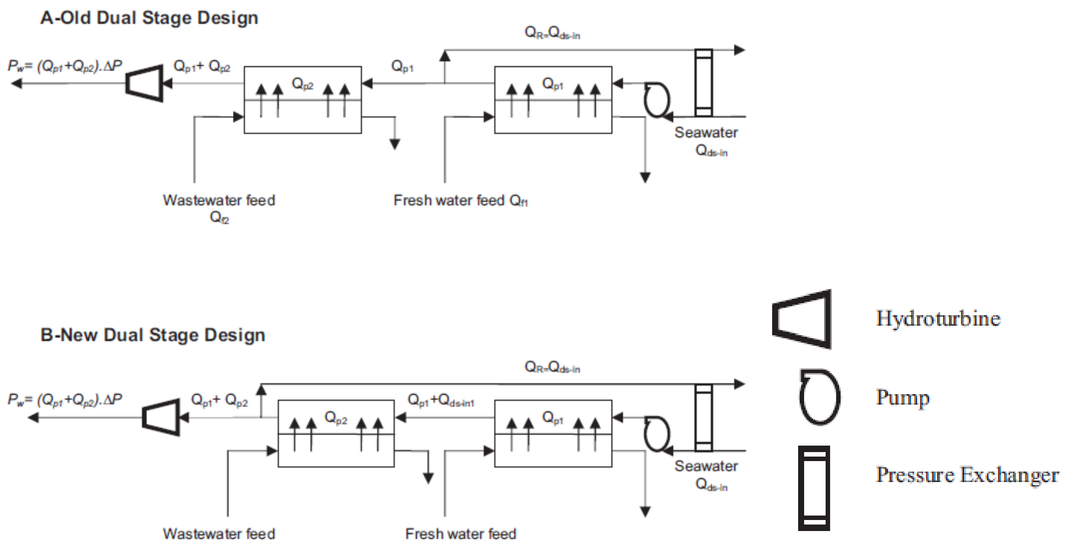

Figure 48 : Comparison of old and new dual stage design for PRO (Altaee and Hilal, 2015)

where;

P_w: Power kW/day

$Q_{ds\text{-}in}$: Draw solution flow rate m^3/h

Q_R: Recycle flow to PX m^3/h

V_1: Permeate flow rate in first stage m^3/h

V_2: Permeate flow rate in second stage m^3/h

$Q_{f\text{-}in}$: Feed flow rate m^3/h

The first part of those two system are the same, a regular PRO process is used. However, after freshwater flows into seawater by osmosis, bleed is separated to two parts; recycled to pressure exchanger and sent to turbine. The new one also has the same separation but recycling is provided after then the second stage osmotic process.

To see the effect of draw solution TDS on the process performance those two configurations have been tested with seawater salinities which are between 32 g/L and 45 g/L. Higher salinity experiments showed better results as expected. The new staged version of PRO showed 17.4% greater power density than the old one. Moreover, specific power consumption is 8% less than the old design. To conclude, new staged PRO system is cost efficient and cheaper (Altaee and Hilal, 2015).

6.3 PRO and Sewage Treatment Systems

Another option for energy production is wastewater treatment plants (WTP). Especially in big cities, there is huge amount of water treated and discharged to the water bodies such as river and seas. Flowrate of WTP is rather regular than the river of Turkey. In addition to that, water is clean in the sense of suspended solids. So that initial treatment that would be required for conventional PRO systems will not be necessary which reduces the main cost of PRO. This option should also be thought for the near future energy production of osmotic power.

6.4 Environmental Considerations

There is always a trade-off between environment and energy production. It can be said that trade-off for renewable energy sources are much less than non-renewable sources. PRO is one of the cleaner energy production method (Figure 49), however, there are some environmental effects to be considered.

PRO does not emit CO_2 or any other GHG emissions during operation. Hopefully, PRO is estimated to reduce GHG globally by 2741 megatons by 2030 with the help of environmental policies, according to the IEA. EU reached a compromise that emissions in 2030 will be cut of 40% with respect to 1990 levels. Annual coal-fired generation is expected to be two times higher from 7,400 TWh in 2006 to 9,500 TWh in 2015 and 13,600TWh in 2030.If active coal-fired plants are replaced by salinity power plants (forty percent of energy conversion), it can reduce GHG emissions by 10 Pg CO_2-eq/year which is approximately 1010 tonnes/year (Tadeo, 2015).

In addition, system implementation is quiet enough so that noise pollution is not a problem for residential areas or the environment.

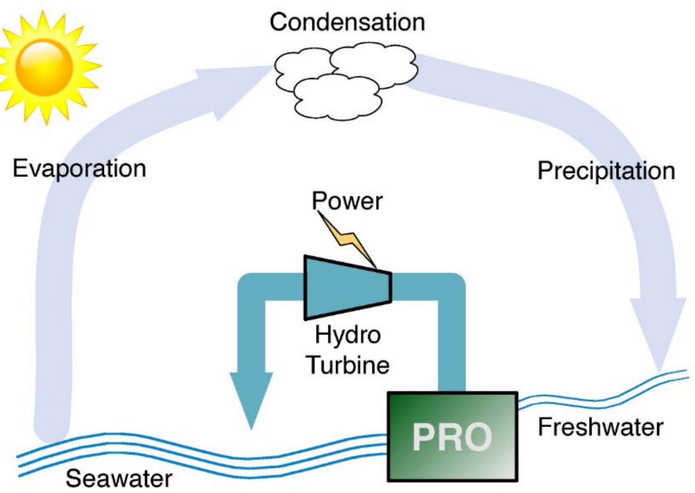

Figure 49: LCA representation of PRO, a renewable source

In general, river mouths are urbanized locations mostly therefore, the construction and land use for osmotic power plants does not harm natural areas (Tadeo, 2015). However, for Turkey this is not the case. Most of the river mouths are wetland areas and agricultural locations with protection status therefore the construction phase needs to be evaluated in terms of environmental impacts.

Cumulative rejection of brine water can harm aquatic environment of sea. Dilution of brine water should be done before discharged into sea. Therefore, environmental impact assessment is needed for investigating the required flow rate, flowrate of osmotic power plant intake and outlet of brackish water. There are some impacts on marine vegetation near osmotic power plants. Brackish water is polluted by concentration polarization, fouling and scaling so that it requires chemical cleaning before discharged out. However, 3 years' pilot study of Statkraft showed that no impact was seen on local benthic communities (Tadeo, 2015).

Another significant environmental consideration is the use of freshwater. While calculating freshwater requirement, the whole river flow is assumed to be directed to PRO, which cannot be the actual implementation as agricultural activities, human uses and ecosystem needs to be considered. Part of the river discharge must be kept all the time for ecosystem functions. This amount must be determined by environmental impact assessments and operation of PRO intake systems must be designed accordingly. Additionally, the human uses in the future including climate change impact on river discharge must be assessed critically for sustainable PRO design.

CHAPTER 7

CONCLUSION

Turkey's three quarters of energy demand is supplied from foreign countries. In the long term this situation would generate significant economic, sustainability, reliability and dependence problems. Therefore, Turkey should produce energy by using its national resources as much as possible.

There are two kinds of energy; Renewable and Non-Renewable. Renewable sources like wind, wave or solar energy are in demand because the sources are not limited in time. On the other hand, non-renewable sources will die out at the end due to limited source. Moreover, generation mechanism of energy from renewable sources do not emit carbon emissions which are the driving factors of global climate change, so the renewable sources are also classified as environmentally friendly. Therefore, a lot of research and investments are being channelled to renewable energy sources at present.

Osmotic power is a brand new renewable energy source which is still in research and development phase. Main mechanism of osmotic power plant is osmosis that is defined as movement of water from concentrated solution to less concentrated solution in a place where two solutions are separated by selectively permeable membrane. This process creates osmotic power pressure difference between two sides. The most common technique for producing energy by osmosis is pressure retarded osmosis (PRO). In that particular system, two different water sources having different salinity such as river water and sea water are used. Osmosis takes place in series of spiral wounded membranes called stacks. Pressure increment is observed by concentrated solution after osmosis. To produce energy, high pressure concentrated water is sent to the hydro turbines. There is not any commercial scale osmotic power plant yet. However, future of osmotic power is promising.

Turkey is a suitable place to operate osmotic power plants. Country is a peninsula and there are lots of rivers discharging to coastal waters. These coastal waters have a variety of salinity and temperature characteristics which enables a range of possibilities for osmotic power plants. However, not all the rivers are suitable for producing energy as many of these rivers show strong seasonality such that flowrates can become less than 10 m^3/s.

In this thesis, rivers of Turkey were assessed and several rivers were eliminated with respect to its flowrate, site availability, geopolitical conditions (Table 3). In the final assessment for osmotic energy potential, eight rivers selected for potential calculations by equations used for PRO. It is found that the total potential of osmotic capacity of Turkey is nearly 1000MW and total annual production is close to 8700GWh potentially.

In addition, possible places for PRO system is discussed in the thesis. One of the main problems for site location is unstable soil conditions near areas around river mouth. Moreover, there are protected areas such as Göksu where construction of a power plant may not be permitted. Furthermore, it is seen that most convenient places are usually far away from both river and coastal waters. Therefore, infrastructure and construction costs may be high.

In environmental point of view, osmotic energy production may affect the aquatic fauna and marine vegetation around the region. Fish passage or similar structure may be required to sustain the natural river flow. Brackish water is polluted by concentration polarization, fouling and scaling so that it requires chemical cleaning before discharged out. Despite all, pilot PRO plant made by Statkraft showed there were not any significant effects to the coastal environment in its lifespan.

In the future, hybrid PRO systems should also be evaluated such as PRO and RO combinations, staged PRO systems and PRO with sewage treatment system. Sewage treatment systems near sea are favourable to produce osmotic power. Staged PRO system increases the production rate of power plants.

As future studies, it is suggested that monitoring studies for related parameters should be performed starting from today. In addition, sensitivity and optimization study of main parameters which are flowrate, salinity and flowrate should be analysed for each river case.

The last important issue is legal requirements for osmotic power installation. Since such regulation does not exist at present, rules and regulations have to be developed for licensing and permission of building an osmotic power plant.

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