WATER CIRCULATION AND YACHT CARRYING CAPACITY OF FETHIYE BAY

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

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ABSTRACT

WATER CIRCULATION AND YACHT CARRYING CAPACITY OF FETHIYE BAY

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Coastal regions provide a lot of resources and benefits for all the humankind. For economic growth, these resources are needed. On the other hand, coastal resources should be maintained and preserved in some limits. Sustainable development is aimed to set a balance between economic growth and preserving the nature. Determination of the yacht carrying capacity is a major step for sustainable development.

In this thesis study wind-induced water circulation in semi-enclosed basins are carried out in order to reach the yacht carrying capacity for Fethiye Bay. Hydrodynamics of bays is very complex, mainly affected by wind and wave climate and sea bottom topography. The sea bed profiles at the bay changes under winter and summer storms of different speeds and directions. This case study will be carried out with the developed methodology. The present structure of Fethiye Bay will be analyzed and necessary measurements will be proceeded. Moreover, two more cases will be studied besides the present conditions. Circulation models will be applied to the study case according to reached data. For this purpose, Finite Volume Coastal Ocean Model (FVCOM) numerical model will be used.

Keywords: Water Circulation, Integrated Coastal Zone Management, Yacht Carrying Capacity

ÖZ

FETHİYE KÖRFEZİNİN SU ÇEVİRİMİ VE YAT TAŞIMA KAPASİTESİ

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Kıyı bölgeleri, tüm insanlık için birçok kaynak ve fayda sağlamaktadır. Ekonomik gelişim için bu kaynaklara ihtiyaç duyulmaktadır. Öte yandan kıyı kaynaklarının devamlılığı sağlanmalı ve gerekli ölçülerde korunmalıdır. Sürdürülebilir kalkınmada hedef, ekonomik gelişme ve doğal kaynakları korunması arasında bir denge kurmaktır. Yat taşıma kapasitesinin belirlenmesi sürdürülebilir kalkınma açısından önemli bir adımdır.

Bu tez çalışmasında yat taşıma kapasitesinin hesaplanmasında, yarı kapalı basenlerde rüzgar kaynaklı su çevrimi analizi Fethiye Körfezi için uygulanacaktır. Körfezlerdeki hidrodinamik son derece karmaşıktır ve genelde rüzgar ve dalga iklimi, deniz tabanı eğimi ve katı madde özelliklerinden etkilenir. Deniz tabanı topografyası, kış ve yaz rüzgarları, farklı hız ve yönden esen rüzgarlardan, değişik olarak etkilenir. Fethiye Körfezinin şu anki durumu belirlenip, gerekli rüzgar analizleri yapılacaktır. Bunlara ek olarak, mevcut durumdan farklı olarak iki adet su çevirim modelleme çalışması yapılacaktır. Bu modelleme çalışmaları için Finite Volume Coastal Ocean Model (FVCOM) sayısal modeli kullanılacaktır.

Anahtar Kelimeler: Su Sirkülasyonu, Sürdürülebilir Kalkınma, Yat Taşıma Kapasitesi

To my Family

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CHAPTER 1

INTRODUCTION

Every country wants economic growth, better life standards and to have permanence in these two aspects. With industrial capacity, agricultural activities and tourism potentials they are trying their best to achieve this goal. Countries tend toward whatever their sources are and if possible, they try to increase income from all these areas. But achieving permanence in growth is not possible by trying to increase capacities without studying, examining and planning. Pushing limits without planning causes excessive consumption of natural sources. In progressive aspects, consumption will affect natural resources irreversibly.

Sustainable development is the solution for conflicts between economic growth and consumption of natural resources. Sustainable development criteria become very significant from the time communities realized resources are limited. Considering that 75% of the human population lives in coastal areas, it is obvious that conflict between economic growth and consumption puts a big pressure on these regions. As a solution, integrated coastal zone management should be applied in the most sensitive areas. An important part of integrated coastal zone management is determining the carrying capacity in order to set a balance between economic growth and consumption of local resources in order to achieve sustainable development.

Yacht carrying capacity is the number of yachts that can berth at a place at the same time without disturbing the environmental balance and ecological diversity of the place. Yacht carrying capacity of the Fethiye bay is determined in this thesis since Fethiye is one of the most popular touristic places in Turkey. In addition, the Fethiye bay is in need for sustainable development of the area.

In order to determine the carrying capacity of Fethiye Bay, yachts in the area should be counted and should be grouped according to their sizes and materials they are made of. This grouping is needed to calculate the wastewater amount released to the bay from yachts using the bay yearly. On the other hand, there exists water circulation in the bay due to the winds, tidal effects and freshwater entrance to the bay, which clears the bay from these wastewaters.

The water circulation is modeled for three different cases and for four different wind directions to calculate the water exchange capacity in the bay with the water circulation modeling program, Finite Volume Coastal Ocean Model - FVCOM. From the model results it is determined whether Fethiye bay has reached its capacity or not. The answer to the question if it is possible to accept more yachts in the area or current use is limit for sustainable development has been searched.

In Chapter 2, literature survey is given. Previous studies on water circulation, concepts, approaches towards the water circulation modeling and studies related with the Fethiye region are presented in this chapter.

In Chapter 3, study area is described. Tourism potential, properties of the area, and wind climate are given in this chapter.

In Chapter 4, circulation analysis and water exchange capacities are calculated for Fethiye bay under various circumstances.

In Chapter 5, yacht carrying capacity is determined for Fethiye bay by discussing the wastewater releases and dilution of water in the bay. Moreover, a new approach for the yacht carrying capacity calculation is proposed.

Finally, in Chapter 6, conclusions are presented and the results are discussed for this thesis and future recommendations are proposed.

CHAPTER 2

LITERATURE SURVEY

Studies related to water circulation for semi-enclosed basins, methodology and formulations of the studies, numerical models used during the process and case studies made until now is summarized in this section in the chronological order, to get information about previous studies made on similar subjects and decide what method to use in water circulation models for Fethiye bay.

A method is presented for “computing exchange rate and the exchange time of the water between a coastal basin and the adjacent sea” by Legović (1982). “The geometry of the cross section of the connecting channels and an approximation of the current field” are used for calculations. The methodology is applied to a case study of the Rijeka bay located on the northeast of the Croatia. It is observed that direction and intensity of the water exchange vary seasonally. Midwinter exchange value is determined as four times larger than the one calculated in midsummer (Legović, 1982).

In order to precisely predict the flow patterns in semi-enclosed water basins with free surfaces Li and Zhang (1998) developed a three-dimensional layer-integrated numerical model. In the model, the turbulence is parameterized using the k-ω equations. In the finite difference solution the governing equations are separated into three parts: “advection, dispersion and propagation”. While the advection equations are solved by “the four-node minimax-characteristics scheme”, the dispersion equations are solved by the central difference applications and the Gauss-Seidel iteration method. The results obtained from the model have been confirmed with the laboratory data on forced recirculating flow in a physical harbor model. In addition, the model has also been verified with “free recirculating flow in an experiment channel” (Li et al., 1998).

Kourafalou (2001) studied “semi enclosed regions with river discharge in the Mediterranean Sea”. In the research, where Po and Axios rivers are examined, “The development of the river discharges under the influence of the important circulation forcing mechanisms and under the guidance of the topographic controls” is studied. River simulations are carried out with the Princeton Ocean Model (POM). “General basin circulation influence on the discharge structure” is also examined. (Kourafalou, 2001).

Cookman et al. (2001) developed a MATLAB program called STORMSED1.0. The steady-state, linearized, horizontal momentum equations in the along-shelf and cross-shelf directions are solved for a linear shoreline given a constant stress, wind and waves of constant period and amplitude. A numerical relationship between sedimentation and storms is obtained from the model and it also provides a fast analytical approach which enables to quantify the sedimentation occurring because of coastal circulation. (Cookman et al., 2001).

Pietrzak et al. (2002) developed “a three-dimensional hydrostatic model that combines a generalized vertical coordinate system with an efficient implicit solution technique for the free surface.” The model enables maintaining high resolution in the surface and bottom boundary layers. Horizontal diffusion is solved using the “Smagorinsky formulation” and in the vertical $k-\varepsilon$ turbulence model is used. A number of tests were conducted using the model. Accordingly, it can be concluded that “the model is good at simulating shallow nearshore, estuarine flows as well as large-scale geophysical flows” (Pietrzak et al., 2002).

A 3-dimensional semi-implicit finite difference code is developed by Koçyiğit and Koçyiğit (2004) for water circulation. In order to take the effect of the vertical acceleration component into account, the non-hydrostatic pressure component and the conventional sigma coordinate system in the vertical direction were integrated into the model and the bathymetric changes were considered to be relatively important physical parameters of the circulation pattern. The developed numerical model was able to simulate wind-induced circulation in shallow enclosed water bodies and that “the effect of topography and wind stress on the circulation pattern was of primary importance while the non-hydrostatic pressure component did not have much effect” (Koçyiğit et al., 2004).

A “high horizontal resolution 3D hydrodynamic model SYMPHONIE” in a semi-enclosed bay at the west of the Mediterranean Sea is used by Ulses et al. (2005). In this study, “specific circulation patterns” and “scales of residence times” are defined. Typical wind forcing conditions are applied for performing idealized simulations. In the simulations, “actual conditions of Rhone river discharges” and “meteorological forcing” is used. Impacts of the adjacent formation, on general circulation are also taken into consideration. Model results are compared with the observations and results were satisfactory (Ulses et al., 2005).

Some simulations are made by Zhao et al. (2006) using the unstructured grid, finite-volume coastal ocean model (FVCOM), to model “tidal motion in Mt. Hope Bay and Narragansett Bay”. It is observed that FVCOM is able to deal sufficiently with the “high horizontal resolution”, “irregular coastlines” and “narrow channels”. (Zhao et al., 2006).

A three dimensional hydrodynamic model called COHERENS is developed by Marinov et al. (2006) for coastal and shelf seas. Resuspension, contaminant transport and biological models can be simulated and mesoscale to seasonal scale processes are resolved by the model. The simulation results for short observations are good. Currents and water surface elevations during high tide events are observed. Simulations and measurements gave parallel results. Model results were also parallel with the seasonal trends. Moreover, simulation results fit the detailed salinity and temperature measurements (Marinov et al., 2006).

In 2007, De Serio et al. examined the hydrodynamic processes of Mar Piccolo which is a coastal area of the Ionian Sea on the northern side of the Gulf of Taranto. In his studies, mainly mathematical modeling and field measurements are implemented with the “baroclinic conditions” and accordingly, the data prepared after the analysis is input in the 3-D Princeton Ocean Model. Furthermore the analysis accounted for the following phenomenon; “a simple tidal wave”, “a homogeneous and stationary wind field” “a constant outflow and vertical stratification of temperature and salinity”. Correspondingly velocity data obtained with the field surveys are compared with the results obtained with the numerical model results. (De Serio et al., 2007).

A two-dimensional (2-D) mathematical model is developed to investigate the impact of wind-induced motion on suspended sediment transport at Beijing’s 13-Ling Reservoir by Chen et al. (2007). Diagonal Cartesian Method (DCM) with a wetting-drying dynamic boundary is used in the model to trace variations in the water level. The simulation results are tested with in situ measurements. The model’s accuracy and agreement with the actual situation at the reservoir is confirmed by the measurements. The simulations indicate that wind stress is the key parameter in suspended sediment transport at Beijing’s 13-Ling Reservoir (Chen et al., 2007).

Sankaranarayanan (2007) applied a three-dimensional “Boundary-Fitted Hydrodynamic” model (BFHYDRO) to a bay called Buzzards Bay. Tidal forces are used for the open boundary forcing. For water surface driving, the wind force is used. Wind and tide-induced circulations are analyzed in detail. It is seen that wind forcing has a more dominant effect than the tidal forcing in the generation of the barotropic residual currents in the study location at the end of model simulations (Sankaranarayanan, 2007).

The tidal flooding and tidal drying process are studied for the Satilla River Estuary by Chen et al. (2008) using the finite-volume coastal ocean model (FVCOM). The FVCOM numerical model which is implemented by tidal forcing at the open boundary and river discharge at the upstream end, resulted in a solid conclusion for the tidal flushing in this estuarine tidal-creek intertidal salt-marsh complex. Accordingly, the results were acceptable in the aspect of the amplitudes and phases of the tidal wave, and salinity observed at mooring sites and along hydrographic transects (Chen et al., 2008).

In the Rías Baixas region (NW Spain), the circulation, in a coastal embayment called Ría de Muros, was examined by the Iglesias et al. (2008) using the numerical model of Delft3D-FLOW with the tide, wind and river inflows for the whole study area. Moreover, current velocity and direction, temperature and salinity of water, river discharges, wind velocity and direction information for the area are used. "Acoustic Doppler Current Profiler" and the numerical model gave similar results. Therefore it is understood that circulations are occurring mainly with the tide. Wind, and river inflows also have effects but the tidal effect is the most prevailing one for the Ría hydrodynamics" (Iglesias et al., 2008).

In 2008 for the Danshuei River adjacent to coastal sea in Taiwan, SELFE (a three-dimensional, time-dependent hydrodynamic model) was implemented for the whole estuarine system by the Liu et al.. The prevailing factors accounted in the analysis were the tidal elevations along the open boundary and freshwater flows from the mainstream and tributaries in the Danshuei River system. The model analysis gave consistent results with the field data (Liu et al., 2008).

In 2010, Maxam et al. examined a semi-enclosed bay, which is concluded in a fact that the inner bay water re-circled the reef according to the hydrodynamics of the bay. Mainly it is observed that the particular forcing conditions of wind and tide can either increase or decrease the activity of circulations. In other words, the relative importance of driving forces like variation in the wind regime or tides mainly controls the circulation and bay emanation (Maxam et al., 2010).

A case study is made for Fethiye bay by Akbaşoğlu (2011). FVCOM is used to process modeling in the semi-enclosed basin. Effects of wind, tide, Coriolis force and freshwater input are applied while modeling was processed. The results of this study are yearly water circulation capacity and sediment transported in the Fethiye bay (Akbaşoğlu, 2011).

CHAPTER 3

STUDY AREA GENERAL OVERVIEW

The study area is the Fethiye Bay on the Mediterranean coast of Turkey. The coordinates of Fethiye Bay are between 36.6164^0-36.6577^0N and 29.0834^0-29.1262^0E. Detailed information about study area, the bathymetry of the area, tourism potential and wind characteristics is presented in this chapter.

3.1 Fethiye Bay as Study Area

Fethiye Bay is located at the southwest of the Turkey and has a coast neighboring to the Mediterranean Sea, at the position where Aegean Sea intersects with the Mediterranean Sea (Figure 3.1).

Fethiye is a common visiting place for tourists from all around the world. All kinds of tourist attractions are available in the Fethiye area. For instance, many yachting tours have taken Fethiye in their routes and berths along coast and in the marinas located in the bay (Figure 3.2).

Fethiye area shows typical Eastern Mediterranean climate characteristics, summers are hot and dry, while winters are warm and rainy. Over 1000 mm rainfall/year is observed which is above Turkey’s average.

Geology of the region, especially hills within the 2 km from the shoreline, consists of marl and limestone. The area between the shoreline and these hills is flat and shows similar geological properties.

Being sheltered naturally due to Şovalye Island is the most important characteristic of the Fethiye Bay. A large area in the bay is protected from direct impacts of the open sea.

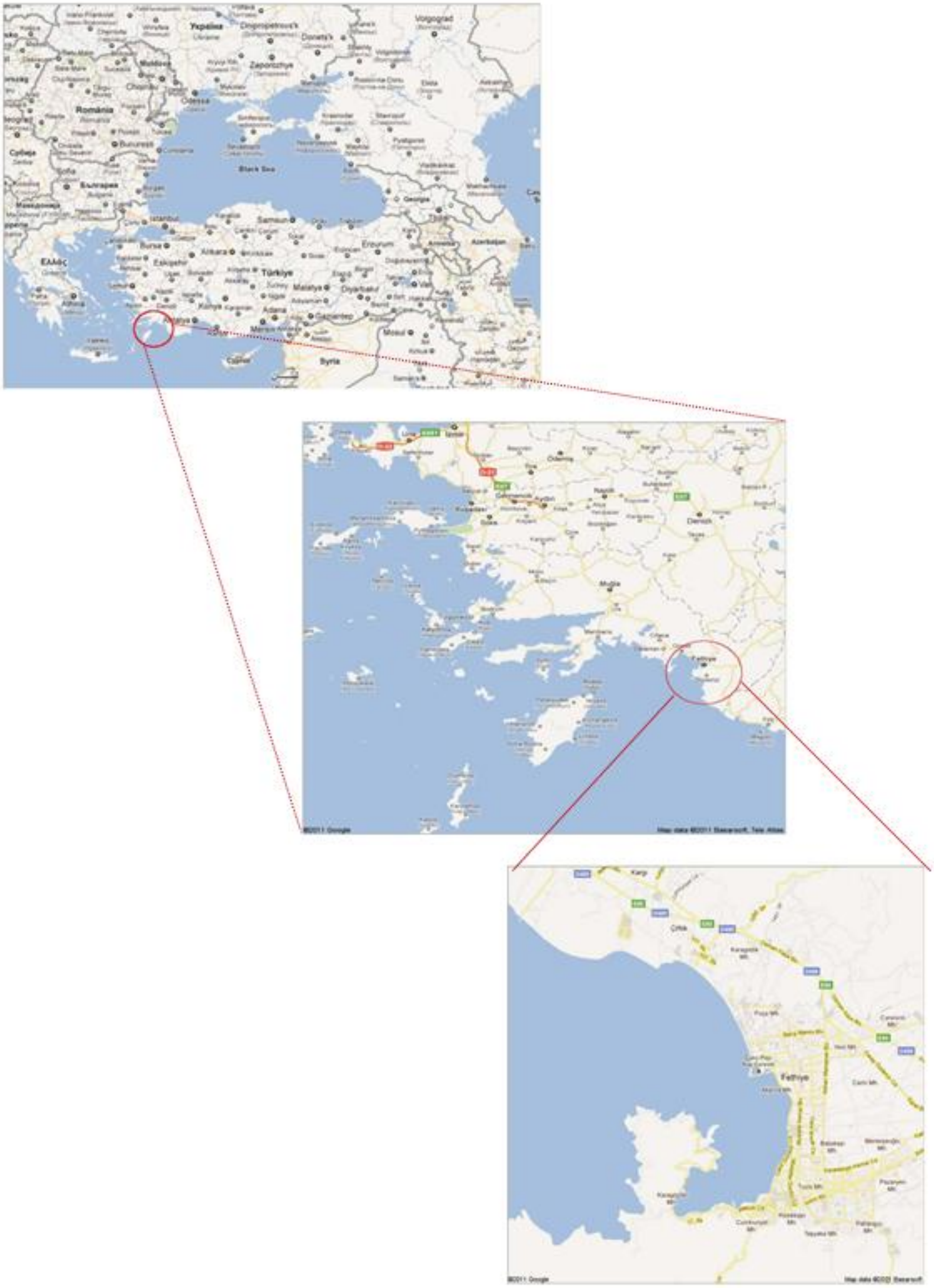

Figure 3.1: Location of Fethiye Bay

Figure 3.2 Closer look to Fethiye Bay (12.03.2012)

3.2 Bathymetry of the Fethiye Bay

Fethiye Bay's morphological characteristics are dependent on the position of the streams that are pouring fresh water and sediment in the bay. Two streams flow in into the Fethiye Bay; Murt brook located at the north east of the bay and the DSI T2 canal located at the south east of the bay. Due to sediment transported by these two streams, northeast, east and southeast of the bay is facing shoaling problem. In these areas, water depth falls as low as 2m at some points and 5m is measured at the deepest point. At the west of the bay, water depth is increasing rapidly due to high-sloped cliff formation. In the middle of the bay depth is changing between 15m to 25m (Figure 3.3). With this kind of bathymetry Fethiye bay is appropriate for yacht movement within the bay.

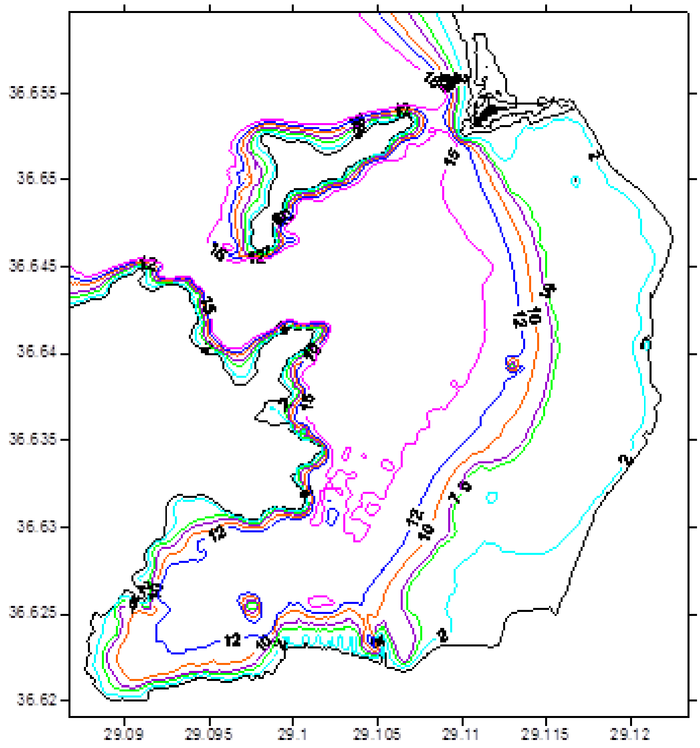

Figure 3.3 Fethiye Bay Bathymetry based METU, 2007 (Akbaşoğlu 2011)

3.3 Tourism potential of the Fethiye Bay

Fethiye Bay has a great potential for yacht tourism due to sheltered bay characteristics and geographical location. Fethiye Bay presently has a marina and a pier provided by the municipality. The entire Fethiye region consists of two-storey buildings and a number of them are serving as hotels, motels and apart hotels for accommodation.

Fethiye is a very attractive location for ‘’Mavi Yolculuk’’. This route is one of the most popular routes in the Eastern Mediterranean. Yachtsmen enjoy these routes for its natural beauties and historical sites. Many celebrities also travel around Aegean Sea including Fethiye. Around Fethiye region there are many places also available for diving and paragliding (Figure 3.4). For these and many more reasons, yacht owners prefer Fethiye and demand for new berthing places is increasing day by day.

The economy of the Fethiye is highly dependent on tourism incomes. With increasing tourism demand in the region, welfare of the people is tending to increase. High rates of youth population in the region are an advantage for Fethiye for meeting the demand as work force is needed in the area.

Figure 3.4 Paraglading in Fethiye (http://www.fethiyedays.com)

3.4 Water Resources

Under normal circumstances, a person requires 25lt of water consumption to provide own biological needs. However, when requirements of modern life such as fresh water for drinking, personal hygiene, cooking, laundry are taken into account daily water consumption in cities is an average of 150lt per person (WWF, 2007).

For a country to be classified as 'water rich country' water capacity of at least 8000-10.000 m^3 per person per year is needed. In Turkey, however this amount is 1430 m^3. In other words, Turkey is not a water rich country contrary to general opinion in Turkey.

According to DSI (State Hydraulic Works), Turkey will use own water resources with an efficiency rate of 100% in next 50 years. Nevertheless, according to WWF (2007), Turkey's estimate population will be 80 million people in the year of 2030. With predicted water capacity of 1.100 m^3 per person/year Turkey will have deficiency in water capacity. With consideration of these data in the near future, Turkey facing the serious water crisis seems to be inevitable. In order to avoid this kind of hazard water resources should be managed very carefully.

Even if the water seems to be a renewable resource, actually it is not. With constant, uncalculated water pollution, usable water resources is polluted and their usage availability is decreasing day by day. However, with the right treatment, increased awareness and controlled management, water resources could be the foundation of the sustainable development for all sectors included.

In order to use water resources in sustainable limits, all the underground and surface water resources should be identified. Still all the underground water resources and precipitation amount is not good for usage. Some amount of surface waters and precipitation is lost due to evaporation and there is an amount of water lost at underground resources. Besides these, water amount fluctuates through seasons. For instance, all the precipitation that occurs in autumn and winter joins the underground water resources in the spring and summer. Under these conditions, especially in the summer months, when yacht tourism peaks, the sustainable amount of water use should be specified. This information should be included in the studies which calculate the number of yachts using a specific area.

3.5 Economy of Fethiye

There is a wide range of sectors in the region. Existing potential made Fethiye more developed than the other places of the region especially those located inland. Fethiye is highly dependent on tourism income. Greatest income is provided by tourism in the region. Many tourist facilities (Figure 3.5) like hotels, motels, bars, restaurants provide services in the area. This provides many job opportunities for local people and other people willing to work in the tourism sector. Agriculture is the second largest economy in the region and half of the population is working in this area. Tomato is the most produced product of the region. However, tourism income in the region threatens agricultural landscapes. Some people in the region are willing to build new places in order to get some income from tourism and this intention causes agricultural lands to be sold for short-term income by the landowners. Besides tourism and agriculture, stockbreeding is another important sector. Except these sectors, there are also people working on apiculture, mining and wood chopping sectors.

Figure 3.5 Touristic Facility in Fethiye (12.03.2012)

3.6 Positive features of Fethiye Bay

- In Fethiye region, the tendency of government and municipal is to support the investments from investors on yacht tourism. These investments are considered to increase the economic well-being of the region that result in enliven the economy.
- Fethiye has a high rate of youth population that is an advantage for investments. Knowing that there exists a young workforce encourage the investors.
- Tourism potential is a great advantage for the Fethiye region as mentioned before.
- The region provides rich cultural and historical heritage that is surrounded by natural beauties. This attracts tourists to choose Fethiye rather than a place that provides only beaches.
- Fethiye is easy to reach by means of air, water and highway. Dalaman airport is 100km away from the center of Fethiye, which nowadays with better cars can take less than an hour to drive to reach. Also Fethiye has a long coastline which is easy to reach by sea. Moreover Fethiye is well connected with highways and has its own bus terminal.
- Fethiye is part of an Eastern Mediterranean yacht chain. Meaning, Fethiye gets tourists that are travelling worldwide popular places like Greek islands. Sheltered bay characteristics attract yacht owners to berth their yachts in the bay. In addition, existing marina and berthing places are advantageous for the region.
- Fethiye region is able to serve for tourists each season of a year. Since the region shows typical characteristics of Mediterranean climate, winters are considerably warm and welcoming comparing other cold climates.
- There are scientific studies made on the area. These studies will contribute in the development of the region if the requirements specified in these studies are applied.

3.7 Negative features of Fethiye Bay

- Low education level is a big problem that considers the area. In addition, low education level can be considered as the source of many man caused problems in the Fethiye region.
- Due to building permits given to irregular and higher storey constructions and permits given to unregistered plots, irregular developments have occurred. This irregularity occurs especially on the slopes facing the waterfront, in order to maintain rant for the participants. Low control, tendencies and not depending on the regulations of urban areas results in irregular masses causing visual pollution (Figure 3.6).
- There are many institutions working on and presenting opinions about Fethiye region. However, weak relations and lack of communication between these institutions decrease the impact of the research on the management of region.

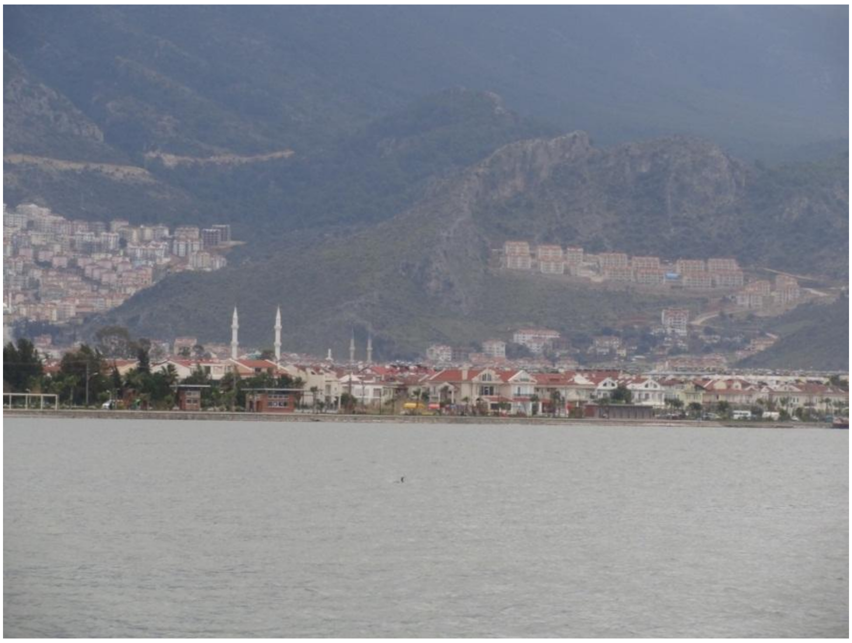

Figure 3.6 Unplanned Urbanization in Fethiye (12.032012)

- One of the main problems is the violation of prohibitions and lack of legal enforcements in various areas. For instance, uneducated people tend to throw solid wastes anywhere randomly. This might happen to be sea as well. Since this behavior is not fined, tendency grows to throw solid wastes randomly.
- Fethiye is on an earthquake zone 1. There have been many earthquakes in Fethiye history, some of them caused great damage in the city, and many lives are lost due to collapse of buildings.
- In peak season, which is summer, tourist population is at the highest rate and parallel to this, sea traffic is very busy.
- Excessive usage of the coastal zones causing harm to ecological and geomorphological texture of the bay.
- Economic opportunity causes an excessive population increase due to immigration from all around the Turkey.
- In area, lack of environmental awareness is a problem. There are communities aware of environmental issues but this is not enough by itself. Environmental awareness of the public should be increased to accomplish some goals.
- Excessive wood chopping for earning some extra money causes forest destruction.
- The constant conflict of interests on region makes problems stay as unsolved issues.

3.8 Wind Analysis of Fethiye Bay

Wind analysis has vital importance for studies in modeling. Fethiye Meteorological Station's measured wind data form year 1970 to 2011 has been analyzed for wind characteristics and for Fethiye region. Yearly and seasonal wind roses have been obtained by Akbaşoğlu (2011) and these are shown in Figures 3.7-3.11. From yearly and seasonal wind roses, it is observed that Fethiye bay is subject to mainly ENE, E, ESE, SSW, WSW, WNW winds.

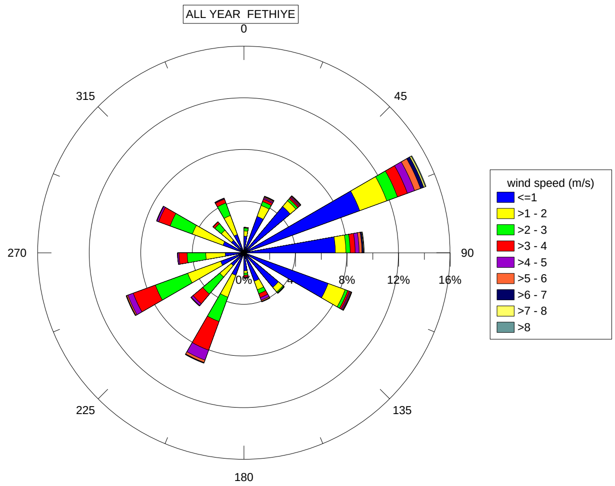

Figure 3.7 Wind rose of Fethiye for all year (Akbaşoğlu, 2011)

From Figure 3.7, the most dominant direction of the winds is wind blowing from ENE direction for all year wind distribution. 16% of the all winds blow from ENE direction. Other dominant wind directions are from E, WSW and SSW. Each of these wind directions are about 10 % of all the winds blowing in Fethiye region for all year distribution.

From wind rose for autumn (Figure 3.8), it is observed that wind distribution is similar to all year distribution. The most dominant winds are from ENE direction. Other dominant directions are WSW, E, SSW and ESE directions.

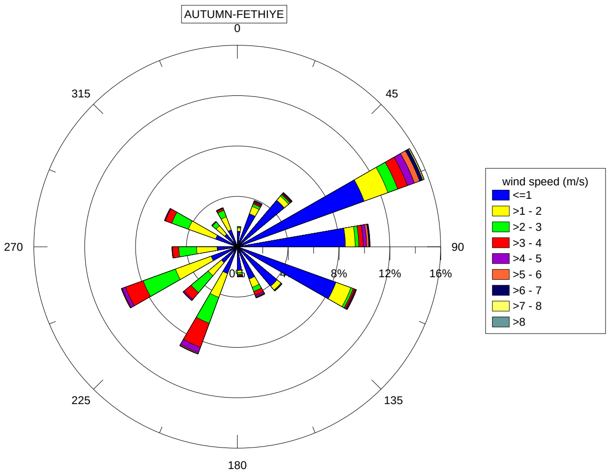

Figure 3.8 Wind rose of Fethiye for Autumn (Akbaşoğlu, 2011)

From wind rose for winter (Figure 3.9), it is observed that wind distribution is similar to all year distribution. The most dominant winds are from ENE direction and %16 of all wind are from this direction. Other dominant directions are WSW and ESE directions with 10% wind distribution.

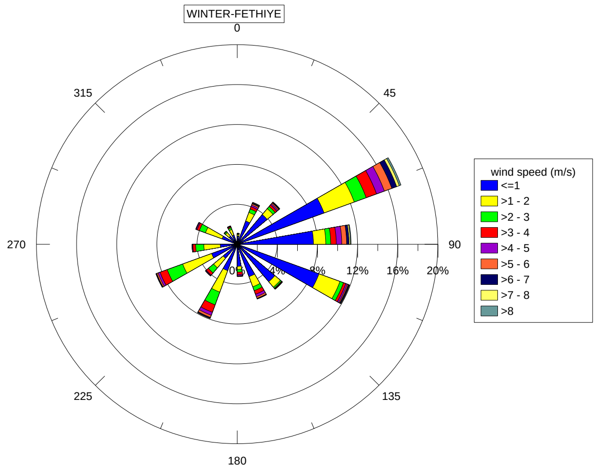

Figure 3.9 Wind rose of Fethiye for Winter (Akbaşoğlu, 2011)

From wind rose for spring (Figure 3.10), dominant wind direction is ENE with 14% of all winds. Nevertheless, winds from WSW and SSW are seen as dominant with 10% and 9% wind distribution respectively.

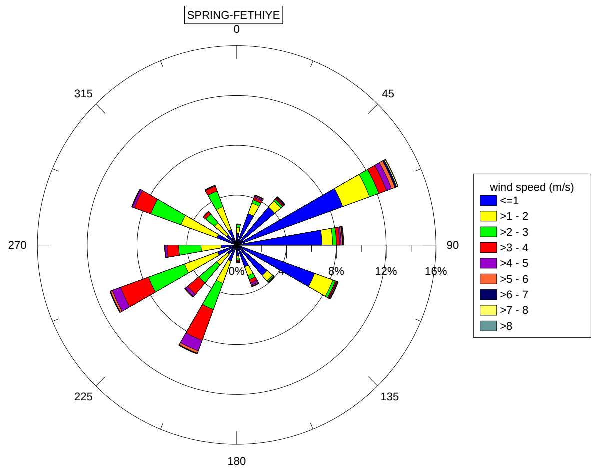

Figure 3.10 Wind rose of Fethiye for Spring (Akbaşoğlu, 2011)

From wind rose for summer (Figure 3.11), dominant wind direction is ENE (14%). Nevertheless, winds from WNW (9%), NNW (7%), WSW (9%) and SSW (10%) are seen as dominant. It is observed that except from ENE other dominant directions are west oriented.

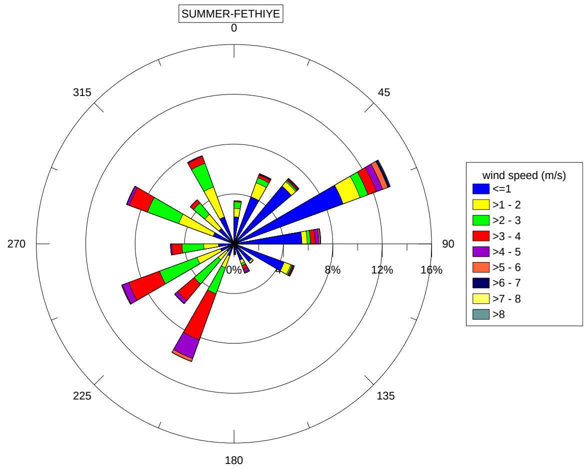

Figure 3.11 Wind rose of Fethiye for Summer (Akbaşoğlu, 2011)

Additionally, besides the wind roses, wind durations for each wind direction for 41 years is given in Table 3.1.a and Table 3.1.b. Data presented is taken from Fethiye Meteorological Station (Akbaşoğlu, 2011).

Table 3.1.a Blowing hours of winds for each direction for Fethiye Meteorological Station (Akbaşoğlu, 2011).

Wind speed (m/s)	N (hrs)	NNE (hrs)	NE (hrs)	ENE (hrs)	E (hrs)	ESE (hrs)	SE (hrs)	SSE (hrs)
0.0-0.5	2543	4247	8157	13112	13465	9767	5701	2801
0.5-1.0	2063	6460	8574	21074	11897	15079	6752	5555
1.0-1.5	855	2301	1524	5712	2228	4065	1342	1780
1.5-2.0	588	954	563	2266	700	947	326	742
2.0-2.5	480	675	372	1612	576	470	173	607
2.5-3.0	318	473	284	1551	620	317	103	551
3.0-3.5	127	341	236	1401	607	259	54	572
3.5-4.0	46	357	200	1532	765	222	51	590
1.0-4.5	15	190	158	1077	566	171	24	422
4.5-5.0	10	181	151	1052	536	139	24	330
5.0-5.5	3	132	130	876	402	118	22	191
5.5-6.0	5	141	95	873	368	102	8	137
6.0-6.5	2	91	77	572	195	67	13	73
6.5-7.0	1	48	46	391	150	52	17	45
7.0-7.5	3	52	28	263	97	28	6	28
7.5-8.0	4	26	27	187	80	24	6	10
8.0-8.5	4	23	16	112	47	16	5	9
8.5-	1	19	11	114	57	36	10	10

Table 3.1.b Blowing hours of winds for each direction for Fethiye Meteorological Station (Akbaşoğlu, 2011)..

Wind speed (m/s)	S (hrs)	SSW (hrs)	SW (hrs)	WSW (hrs)	W (hrs)	WNW (hrs)	NW (hrs)	NNW (hrs)
0.0-0.5	2435	2172	1957	1861	1917	1726	1896	2062
0.5-1.0	2539	4443	2647	4982	3259	4437	2589	3316
1.0-1.5	414	3564	1984	5372	2750	5177	2079	3182
1.5-2.0	248	2880	2155	4379	2664	3880	1632	2437
2.0-2.5	284	3307	3049	4788	2848	3519	1426	2096
2.5-3.0	279	3862	3107	4762	2332	3061	924	1596
3.0-3.5	231	4108	2205	3767	1498	2146	443	772
3.5-4.0	236	4346	1300	2778	756	1227	167	351
1.0-4.5	136	1981	468	1043	252	344	40	125
4.5-5.0	86	962	186	531	101	156	15	59
5.0-5.5	54	435	88	223	31	64	11	44
5.5-6.0	39	244	37	136	20	33	2	26
6.0-6.5	22	92	12	66	7	20	3	22
6.5-7.0	19	53	8	45	3	7	2	11
7.0-7.5	9	35	4	28	3	6	0	9
7.5-8.0	2	15	7	10	0	4	0	4
8.0-8.5	1	16	1	12	1	2	1	5
8.5-	2	10	4	7	1	2	0	3

From the tables 3.1.a and 3.1.b, wind has blown for 357704 hours in 41 years. ENE wind direction is calculated as 53777 hours of wind duration in 41 years. Also after analysis of tables, 15% of all winds blowing in Fethiye region are from the most dominant wind direction. Second most dominant wind direction is WSW with 34790 hours of wind duration in 41 years. Analysis has shown that 9.7% of all winds is form WSW direction. From the S wind direction 7036 hours wind has blown in 41 years, which represents 2% of all winds and makes S wind direction least dominant wind direction.

For model studies, four different wind directions are chosen to represent the wind climate of the region. ENE and WSW wind directions are chosen to represents the dominant wind directions and SSE and NNW wind directions are chosen to represent non-dominant wind directions. Chosen directions will represent their surrounding wind directions.

CHAPTER 4

WATER EXCHANGE CAPACITY

In this chapter, water circulation studies are proceeded in order to determine water exchange capacity of Fethiye bay. Water exchange capacity has vital importance in determination of yacht carrying capacity. Water circulation simulations are carried out for different case conditions considering the circulations caused by winds, tidal waves, and fresh water sources. An Unstructured Grid, Finite-Volume Coastal Ocean Model, shortly FVCOM, is used for these simulations. In the water circulation simulations, the effect of Coriolis force is included.

4.1 FVCOM

When numerical ocean circulation models are considered, two methods are widely used in the literature:

- The finite-difference method (Blumberg and Mellor, 1987; Blumberg, 1994; Haidvogel et al., 2000)
- The finite-element method (Lynch and Naimie, 1993; Naimie, 1996).

The most basic discrete scheme is the Finite-Difference Method and this method has the coding efficiency and computational advantage. Finite-Difference Model can fit in simple coastal areas but is incapable of resolving the highly irregular coastal geometries like inner shelf (Blumberg 1994; Chen et al. 2001; Chen et al. 2004a). Arbitrary spatially dependent sized triangular grid meshes are commonly used in this method, and can provide an accurate fitting of the irregular coastal boundary.

The P-type Finite-Element Method (Maday and Patera, 1988) or Discontinuous Galerkin Method (Reed and Hill, 1973; Cockburn *et al*., 1998) has been applied to ocean modeling and observed improve in both computational accuracy and efficiency.

Another model used in the literature uses 3-D unstructured-grid, free-surface, primitive equation, and it is called Finite-Volume Coastal Ocean Circulation Model (called FVCOM) (Chen et al. 2003a; Chen et al. 2004b). The differential form is used in finite-difference and finite-element models, however integral form of the governing equations are discretized by FVCOM. In other words, it can be said that FVCOM combines the best attributes of Finite-Difference Method and Finite-Element Method for simple discrete coding and efficiency of computations.

FVCOM is capable of solving water circulation in semi-enclosed basins, using unstructured grids. FVCOM solves water movement velocity by solution cells which are triangles produced by SMS (The Surface-water Modeling Solution by AQUAVEO).

FVCOM gives water velocities for each solution cell for every time step and depth represented. Time steps and number of depth section can be defined by the user. But with increasing number of triangles, depth sections and time steps the amount of data increases as well. So calculation time for each run and occupied memory increase drastically. Thus, models should be well selected to analyze optimum details in studies.

FVCOM is an open source code and has many modules like ice module and sediment module. FVCOM is also able to solve for sediment transport in semi-enclosed basins with its sediment module.

4.2 Data Collection and Modeling Studies

Data collection is basis of the water circulation studies. Data collection and manipulations are performed to be used as inputs for FVCOM modeling. Fethiye inner bay's dimensions are 2.5 km in width and 3.2 km in length and this area is large enough in order to get appropriate results from modeling.

The municipality informed us about possible future works related to the Bay. Two future scenarios were most possible ones among others; dredging of northeast and east of the bay to give more space for yachts and boats using the bay and opening of a canal at the southwest of the bay assuming that it will increase circulation of the bay considerably. In light of this information, Fethiye bay is modeled for three different case scenarios. First case is the present case study without any changes made to current conditions as a control case. Second case is for dredging of the northeast and east of the bay. Finally, third case is the opening of a canal at the southwest of the bay at the Karagözler location.

4.2.1 Coastline Studies Under Present Conditions

FVCOM input data requirements start with coastline data production. QUICKBIRD 2020 image is used with GIS application programs for getting the coastline data and these data is approved with several checks to control whether coastline data fits to satellite image (Figure 4.1). Coastline seen on Figure 4.1 is used for present coastline case studies and dredged case conditions since there is no change in coastline for proposed dredging case. Coastline data is important for determining the boundaries detecting sea and land.

Figure 4.1: Coastline of Fethiye Bay

4.2.2 Bathymetry Processing For Present Conditions

The second step of the modeling is to develop bathymetric data in reliable resolution using the measurements. For coastline data produced, bathymetry is needed to be add on (Figure 4.2). For this application, coastline and bathymetry data should fit very well. If any discrepancy occurs, solution cells will not be correct which will cause errors in the results. The source of bathymetric data is based on recent studies (METU, 2007). Maximum water depth in the model domain is 90m outside the bay. However it is 26 m inside Fethiye bay.

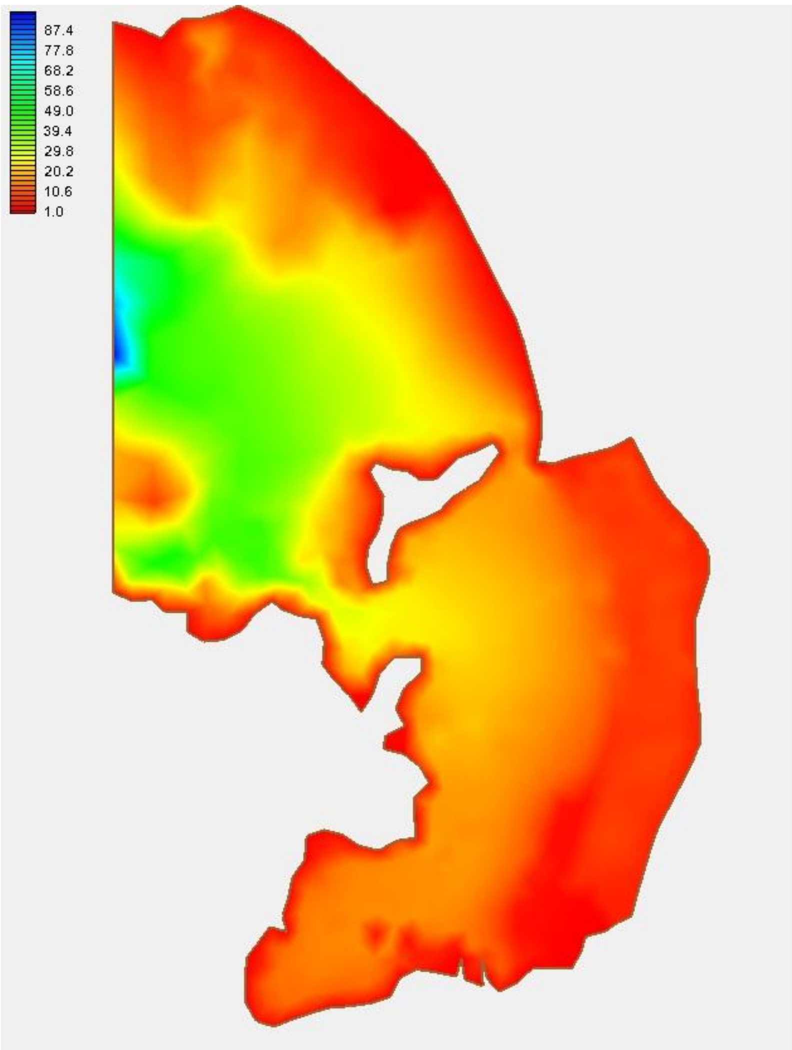

Figure 4.2: Bathymetry of Fethiye Bay

4.2.3 Triangulation-Solution Cells for Present Conditions

Most important part of bathymetry processing is to make triangulation and obtaining solution cells for the input to FVCOM. Bathymetry integrated coastline data is imported to triangulation software SMS. After defining open boundaries and quality checks to ensure that bathymetry has appropriate triangulation, modeling can be started. For present case and dredged case studies unstructured gird consisting of 876 nodes and 1576 triangle shaped solution cells is produced (Figure 4.3). Solution cells have average side length of 150m. Also, depth in each cell is divided in to 5 equal sigma layers.

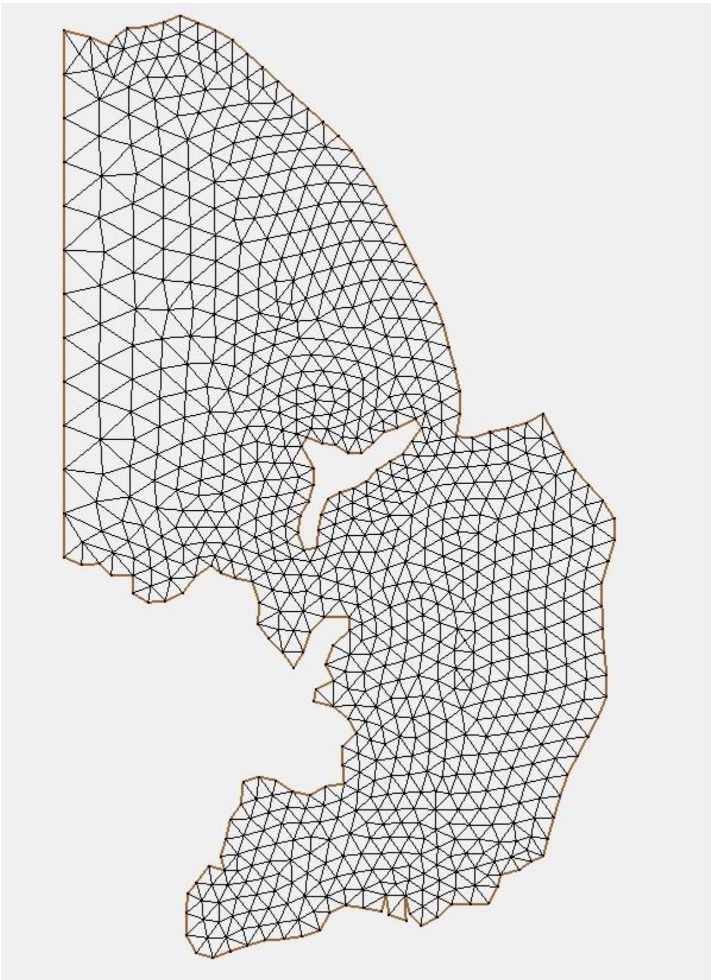

Figure 4.3: Solution cells of Fethiye Bay

4.2.4 Coastline Studies for Fethiye Bay with Planned Canal

FVCOM requirements for coastline data production is applied also for the case which a canal is planned to be built at the southwest of the inner bay at the Karagözler location. Planned canal is assumed to be 100m wide and connects inner bay with open sea. Google Earth image is used in GIS application programs for getting the coastline data and quality of coastline data is checked (Figure 4.4). Coastline seen on Figure 4.4 is used for canal case studies only. This coastline is quite longer than the one used in the present case studies. Since a third opening is added to inner bay, modeling a larger part deemed to be a necessity.

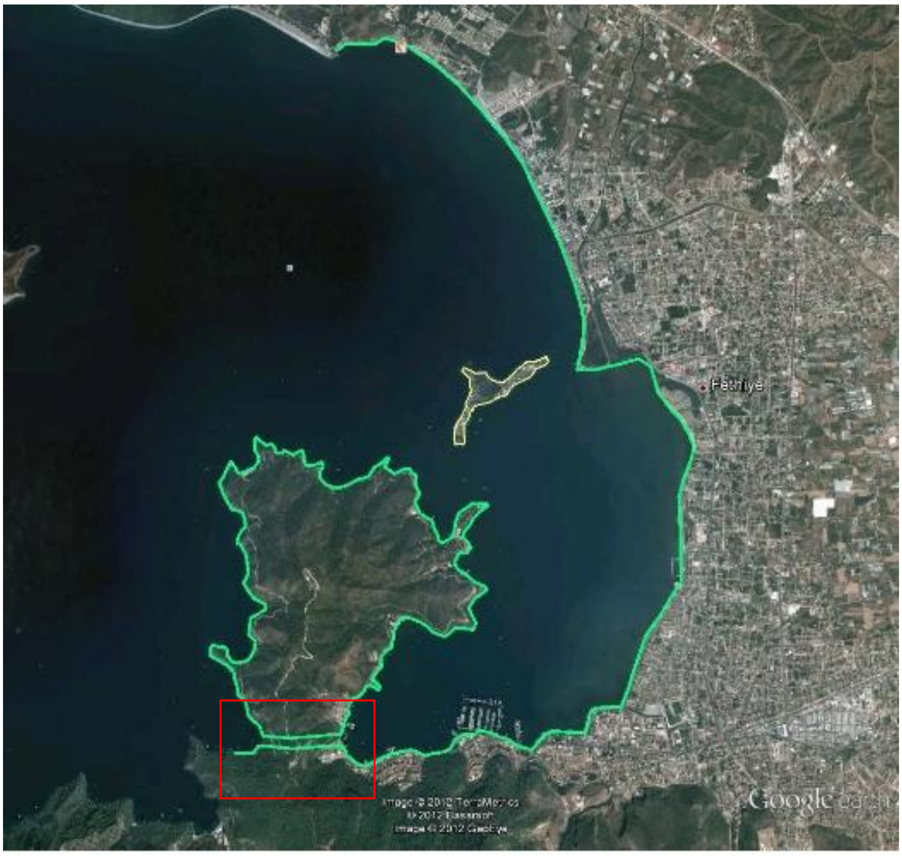

Figure 4.4: Coastline of Fethiye Bay with planned canal

4.2.5 Bathymetry Processing For Canal Added Case

Processing bathymetrical data is quite similar with the present case studies. For coastline data produced, bathymetry is needed to be add on, as in the present case (Figure 4.5). Quality check is performed to see if coastline data fits with bathymetry data. This bathymetry is used for canal case studies only. Water depth is between 1m to 26m in inner bay as in the present case studies and max depth value for model is 90m at the open sea. Canal depth is assumed constant and chosen as 5m for the whole canal as a preliminary study.

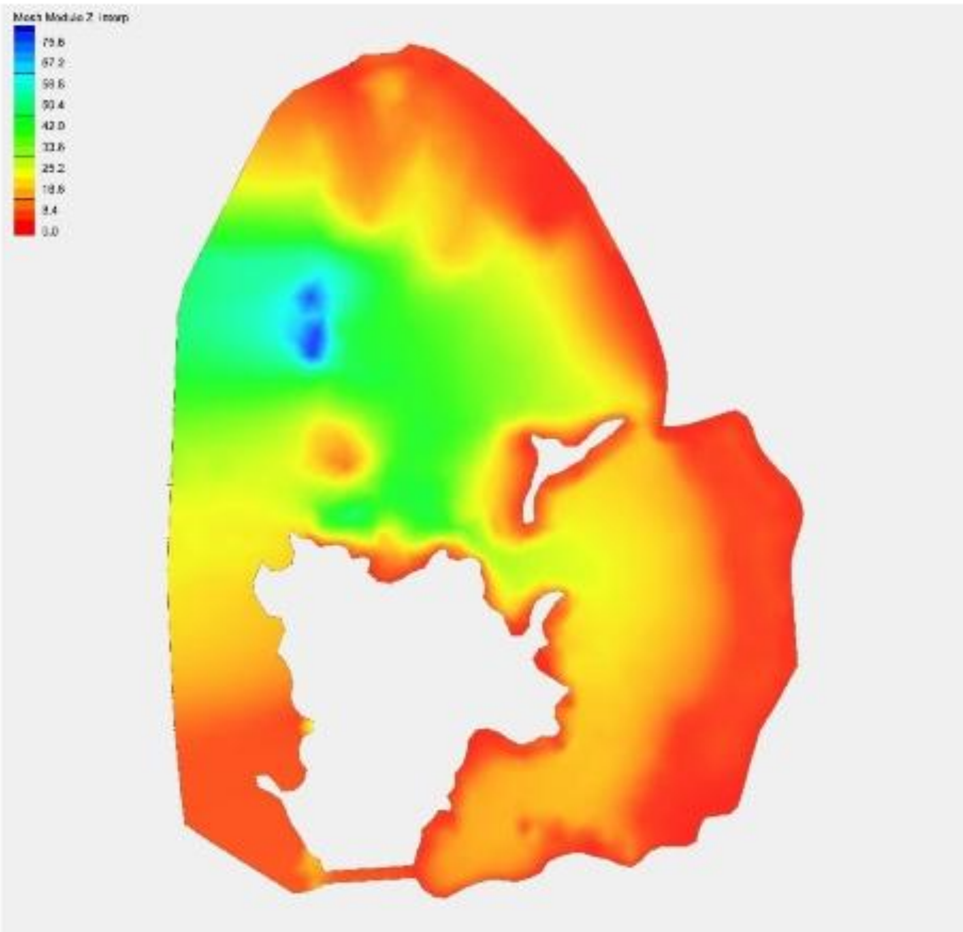

Figure 4.5: Bathymetry of Fethiye Bay with canal openned

4.2.6 Triangulation-Solution Cells For Canal Added Conditions

Triangulation and preparation of solution cells are part of data preparation for FVCOM. This procedure needed to done one more time since case data is different from the present case studies. Bathymetry integrated coastline of canal case data is imported to triangulation software SMS, similar to present case studies. After defining open boundaries and making sure that bathymetry is appropriate, triangulation process has started. For canal added case studies, model is larger than present case studies model and as a result unstructured grid is visibly larger, it has more nodes and solution cells. Model consists of 1934 nodes and 3564 triangle shaped solution cells (Figure 4.6). It could be seen that triangle are smaller than then the ones in present case and the dredged case studies and this causes unstructured grid data getting larger. As data gets larger calculation time of FVCOM elongates as well. Even though calculation time elongates, getting most accurate result is important for canal case since opening a canal needs a large amount of investment. So detailed solution should be used for most accurate results. Solution cells have average side length of 100m which also indicates that triangles are smaller than the ones in present case studies. Depth in each cell is divided in to 5 equal segments as in the present case studies.

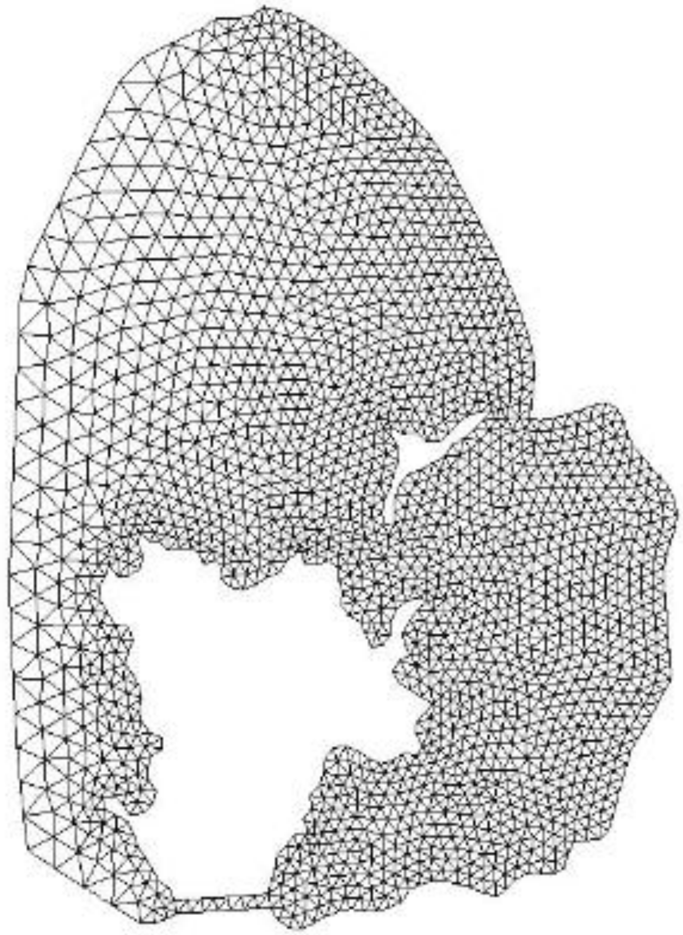

Figure 4.6: Solution cells of Fethiye Bay with canal opened

4.3 Results of Water Circulation Modeling Of Fethiye Bay

Three different case scenarios are modeled to study the Fethiye Bay. First case is the present case study without any change made. Second case is for dredging of the northeast and east of the bay. Finally, third case is the opening of a canal at the southwest of the bay at the Karagözler location. But canal case is studied just as a preliminary design. As a result of modeling, comparison between first two cases will be made. For comparing the results, simulations are made under same weather (temperature and wind) and sea conditions (salinity) but with different bathymetrical properties for same time durations. For four different wind directions, the model was run. These directions are NNW, SSE, ENE and WSW. For all directions, winds with 5m/s and 1,5m/s velocities and 10 hours duration are chosen. ENE and WSW are most dominant wind directions for Fethiye bay. For low wind velocities, 1,5m/s studies is assumed as representative and 5,0m/s studies is assumed as representative for high velocity winds in the analysis for yearly water exchange capacity. Also, in addition to the wind; tidal conditions are studied for Fethiye bay. Tidal case is modeled for 10 hours duration and for same salinity and temperature as wind cases.

4.3.1 Water Circulation Modeling For Tidal Conditions

Water circulation is modeled for winds. Even if tidal conditions are thought to be not as effective as wind for Fethiye, the amount caused by tides had to be calculated. So for present case, 10 cm tide amplitude and 10 hours length is modeled without any wind effect. In other words wind speed is set to “0.0” for this model. 10 cm tide amplitude is probable tide height for Fethiye bay. Process for getting circulation results is same as the wind applied cases and explained in detail in wind applied studies. The results of tide included circulations are given in Table 4.1.

Table 4.1:Water Exchange volumes for tidal case

m^3	TIDAL	
	OUT	*IN*
PRESENT	18.768	83.929

As seen on Table 4.1, effect of tide for Fethiye bay is considerably small. When results of tidal effects and wind effects are compared, it is seen that tide effect is not significant so can be ignored. As a result, the rest of the modeling studies did not include tide parameter.

4.3.2 Water Circulation Modeling for Present Situation

In order to calculate water exchange in the inner bay for present case, cross sections are taken from east side opening and west side opening of the bay. These openings could be defined as east and west of the Şovalye Island. Locations of cross sections are specified with a red line on the satellite image as seen on Figure 4.7 and Figure 4.9 for east side opening and west side opening correspondingly. Relative depth profiles are given just below the satellite images as seen Figure 4.8 and Figure 4.10.

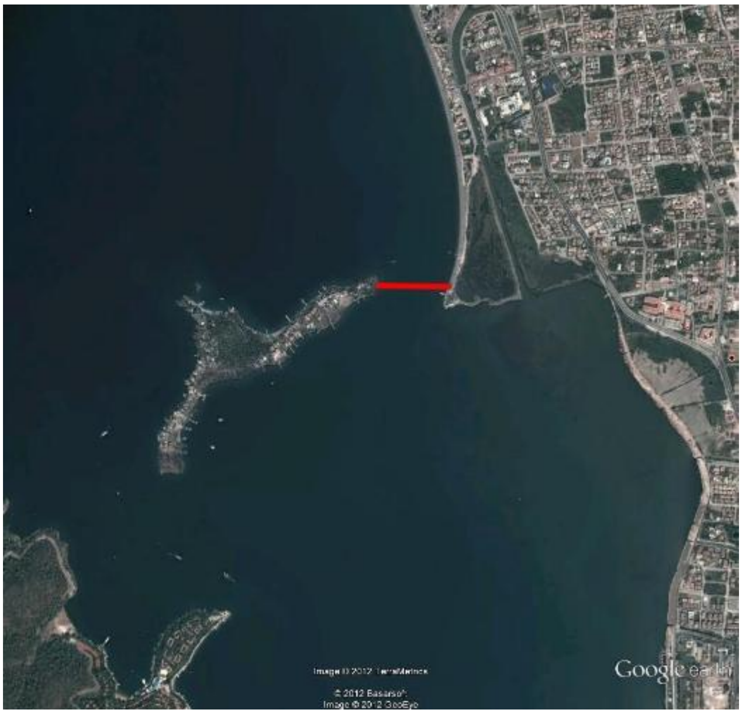

Figure 4.7: East side opening cross section location

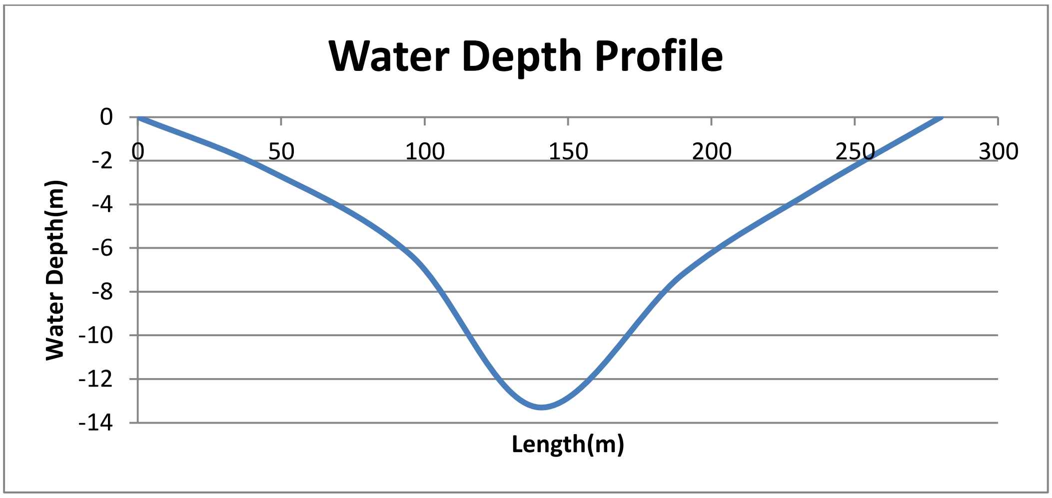

Figure 4.8: East side opening depth profile

As seen on the water depth profile on Figure 4.8, opening on east side of the Şovalye Island is 280m long and at the deepest point is 13.5 m deep.

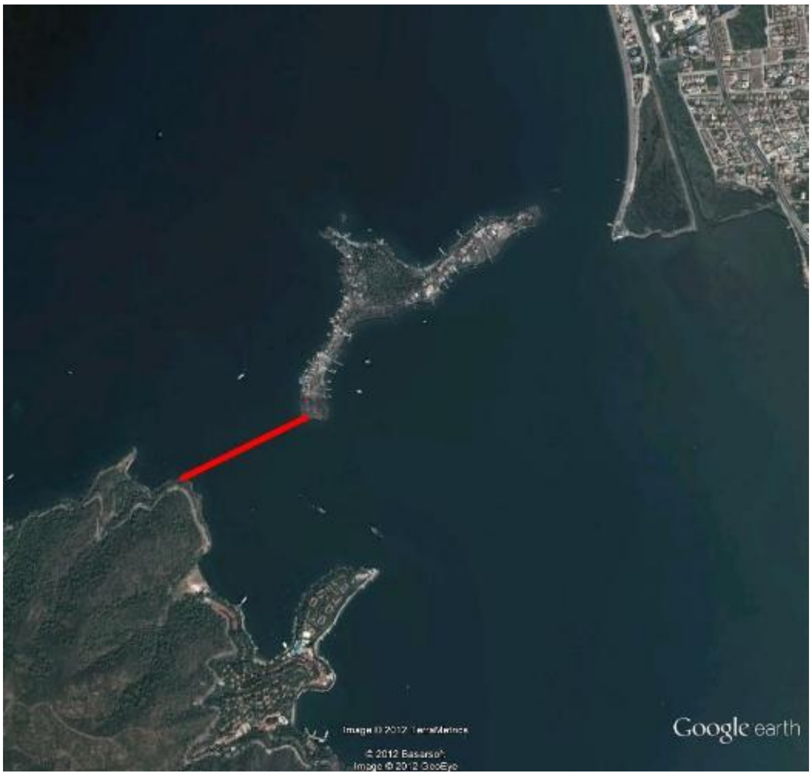

Figure 4.9: West side opening cross section location

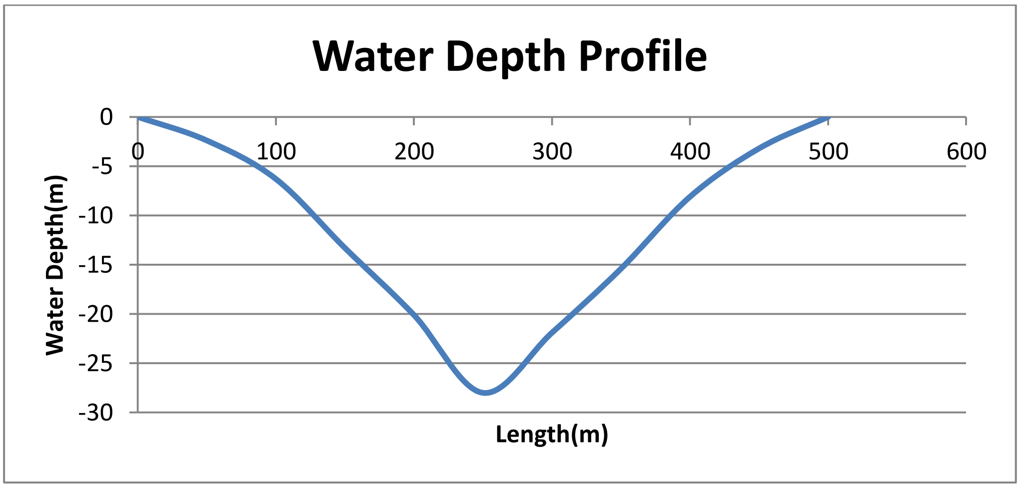

Figure 4.10: West side opening depth profile

As seen on the water depth profile on Figure 4.10, opening on west side of the Şovalye Island is quite larger than then opening on the east side. Cross section is 500m long and at the deepest point is 28 m deep.

Time variable water circulation is modeled for Fethiye bay under different wind conditions. Four different wind directions are chosen to be applied on the model. Two cases are chosen to be winds from dominant directions as ENE and WSW. And other two wind direction are chosen to be from less occurring directions as NNW and SSE.

Firstly, wind blowing from the NNW direction, with the 1,5m/s and 5 m/s velocities, for 10 hours is applied. For the sections closer to the sea bottom, water circulation is shown in the Figure 4.11. Representation of modeling results with 1,5m/s velocity are on the left side and 5,0m/s modeling results representation is on the right side.

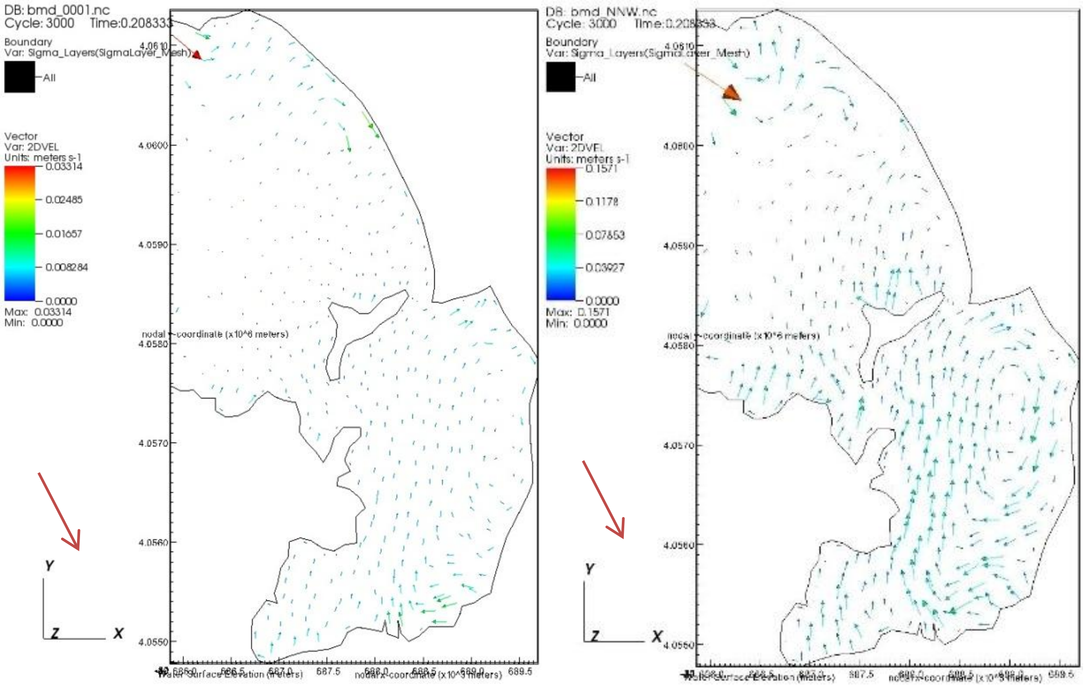

Figure 4.11: Water circulations for NNW wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the bottom of the sea

For all the water circulation figures (Figure 4.11-4.19.), Y-direction represents the North direction while X-direction represents the East direction. Also, red colored arrow on the left side of the drawing just over the X-Y coordinates shows the wind direction. For the sections closer to the water surface, water circulation is shown in the Figure 4.12.

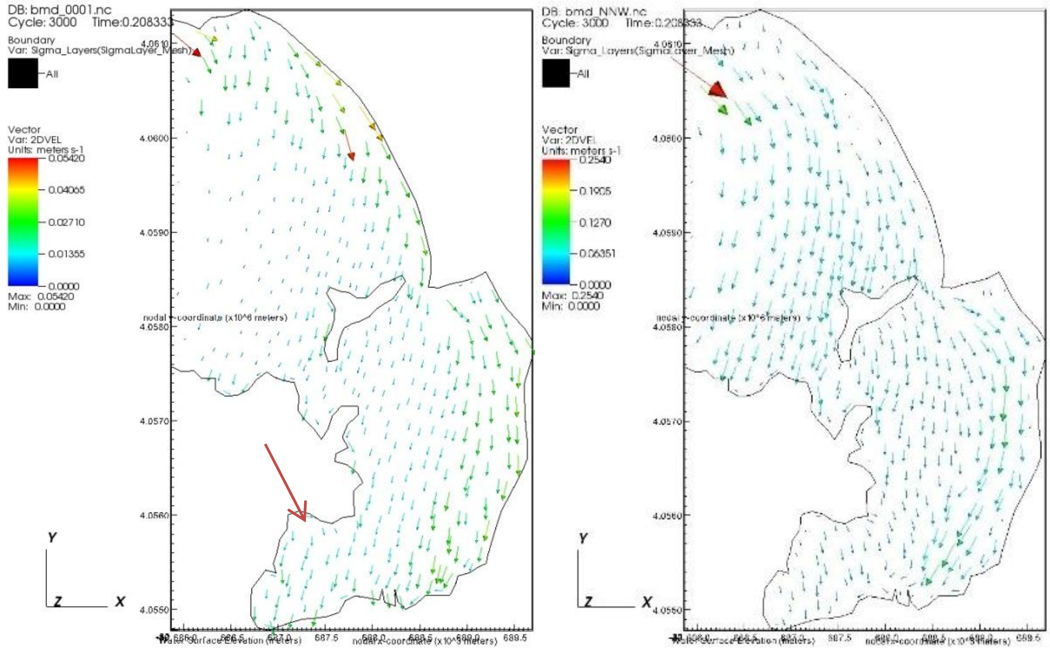

Figure 4.12: Water circulations for NNW wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the sea surface

From Figure 4.11 and 4.12, it is observed that at the section close to the sea surface, water circulation pattern is parallel to the wind direction and at the section close to the sea bottom, water circulation pattern is opposite of the one close the surface. This contrast produces the water circulation. At the places closer to sea bottom an eddy is observed in the inner bay.

Secondly, wind blowing from the SSE direction, with the 1,5m/s and 5 m/s velocities, for 10 hours is applied.

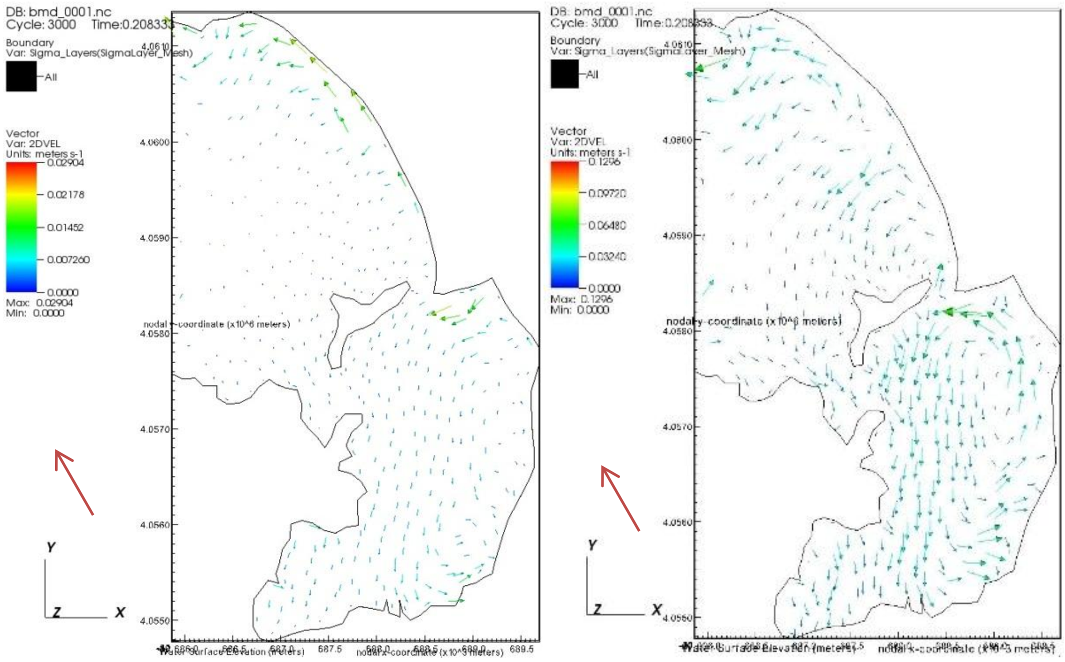

Figure 4.13: Water circulations for SSE wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the bottom of the sea

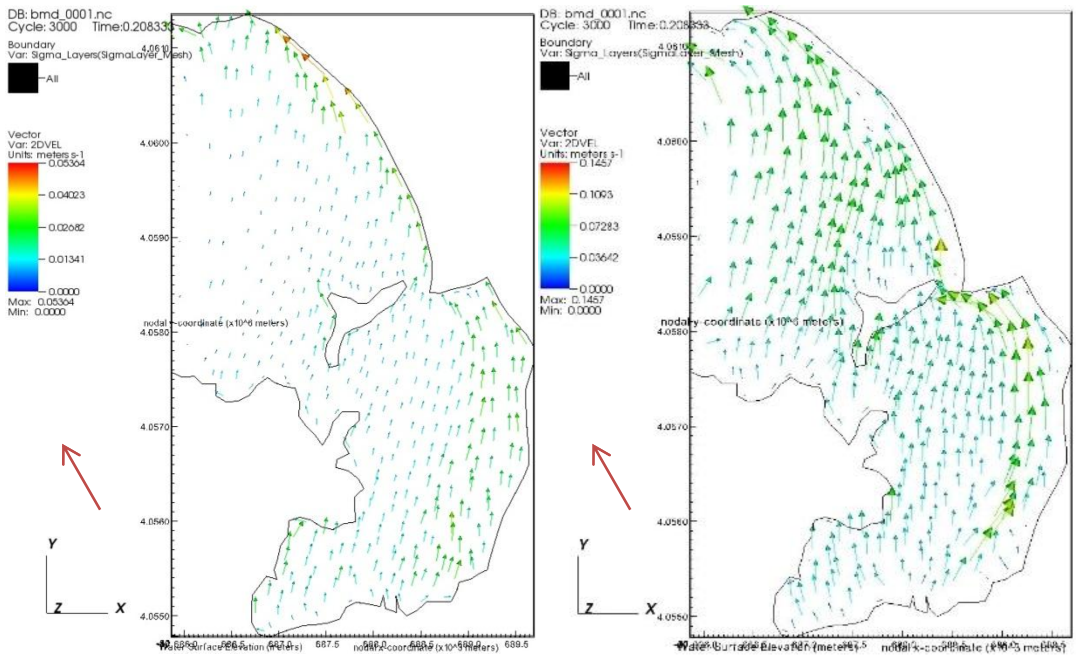

Figure 4.14: Water circulations for SSE wind direction, 5m/s velocity and 10 hour duration for places close to the sea surface

Same observations as NNW directions can be made for SSE direction applied model. Figure 4.13 and 4.14 show that at the section close to the sea surface, water circulation pattern is parallel to the wind direction and at the section close to the sea bottom, water circulation pattern is opposite of the one close the surface. This contrast produces the water circulation. Still water does not follow exactly the SSE direction and the reason for this is the Coriolis Force.

It is observed that at the east side of inner bay for SSE and NNW wind directions, eddies occurs at places closer to the sea bottom. Due to these eddies, water amount leaving the inner bay decreases. Also the eddies cause sediment amount increase in these areas.

For dominant wave directions ENE and WSW, same observations can be made. At the places closer to the water surface, water movement pattern follows the wind direction. For places closer to the bottom of the sea, water movement is opposite of the wind direction and the contradiction between top and bottom of the water elevation creates the water circulation.

Water circulation graphics for the ENE are given in the Figure 4.15 and Figure 4.16. ENE direction winds are the most frequent winds in Fethiye bay. Yearly 16% of all winds are from ENE direction. In other words, ENE case simulations are most probable to occur.

Water circulation graphics for the WSW are given in the Figure 4-17 and Figure 4.18.

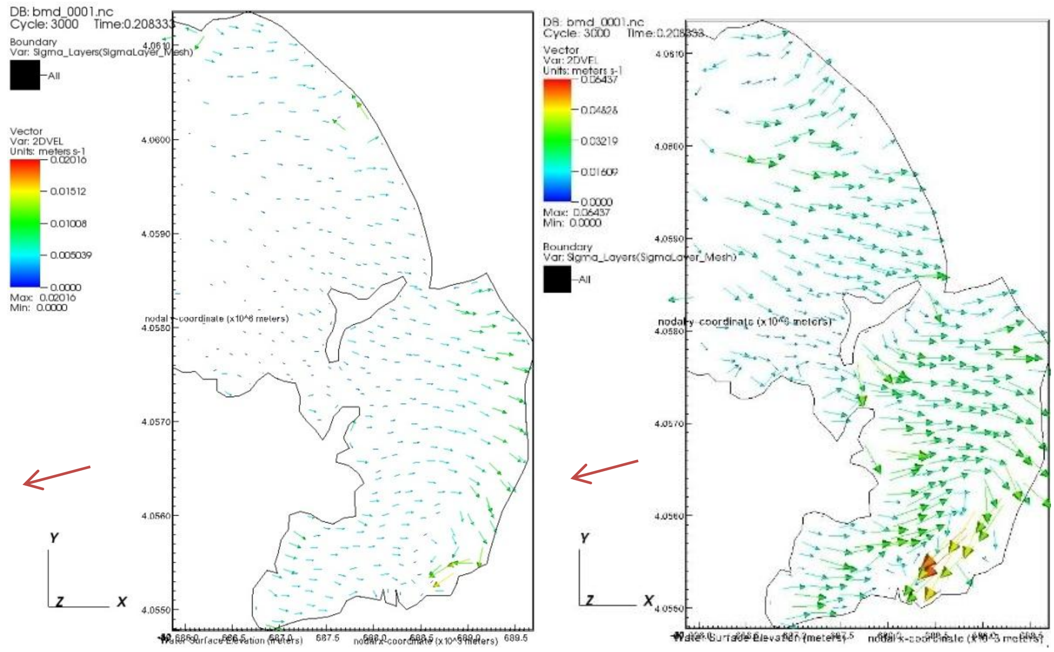

Figure 4.15: Water circulations for ENE wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the bottom of the sea

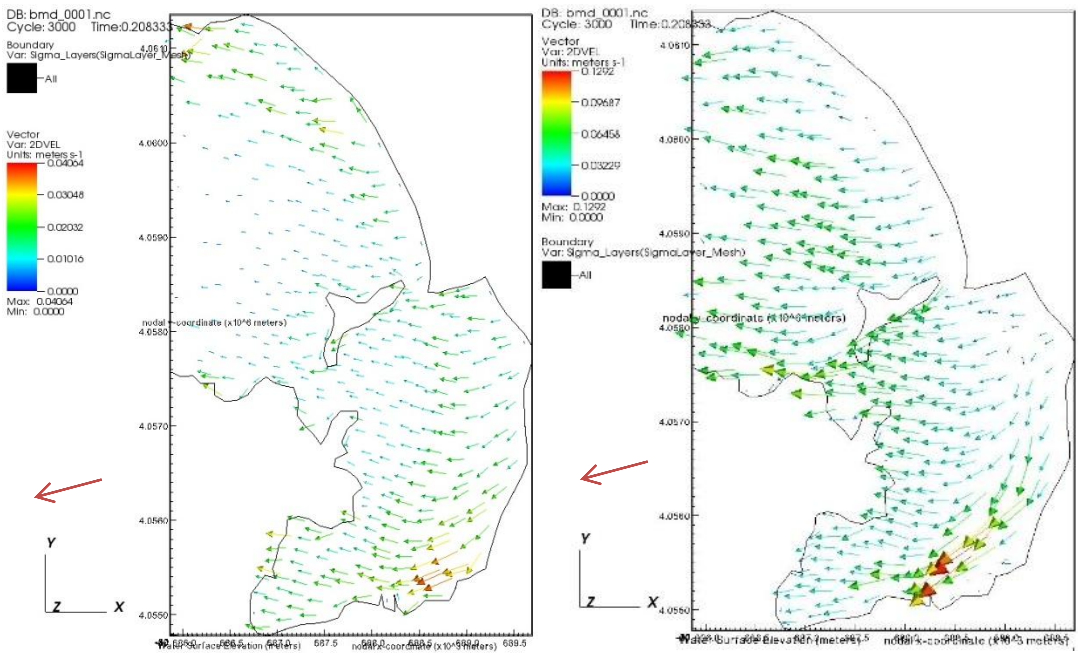

Figure 4.16: Water circulations for ENE wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the sea surface

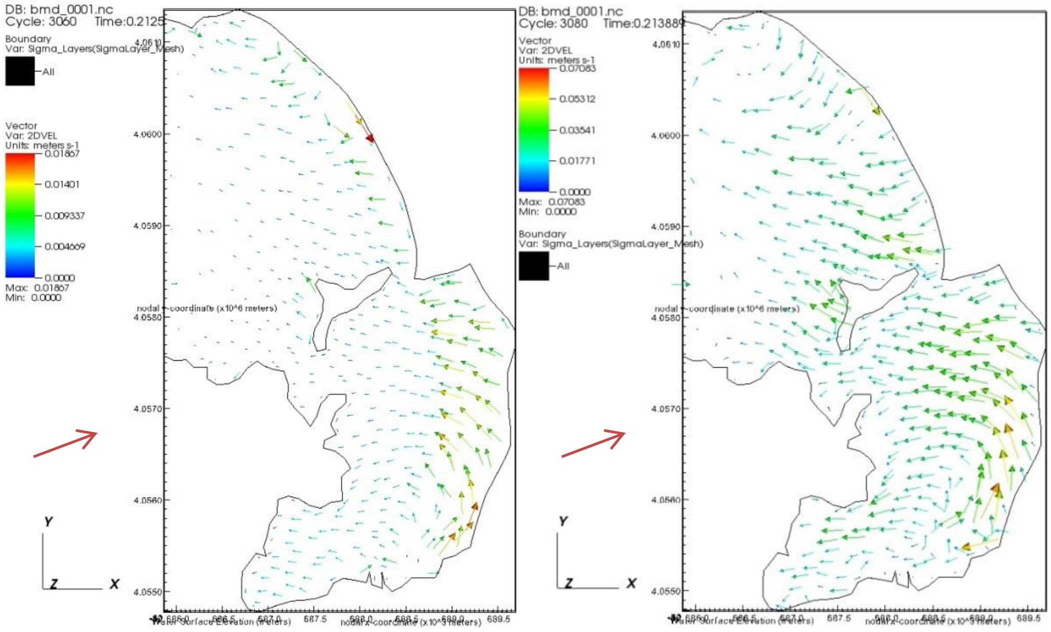

Figure 4.17: Water circulations for WSW wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the bottom of the sea

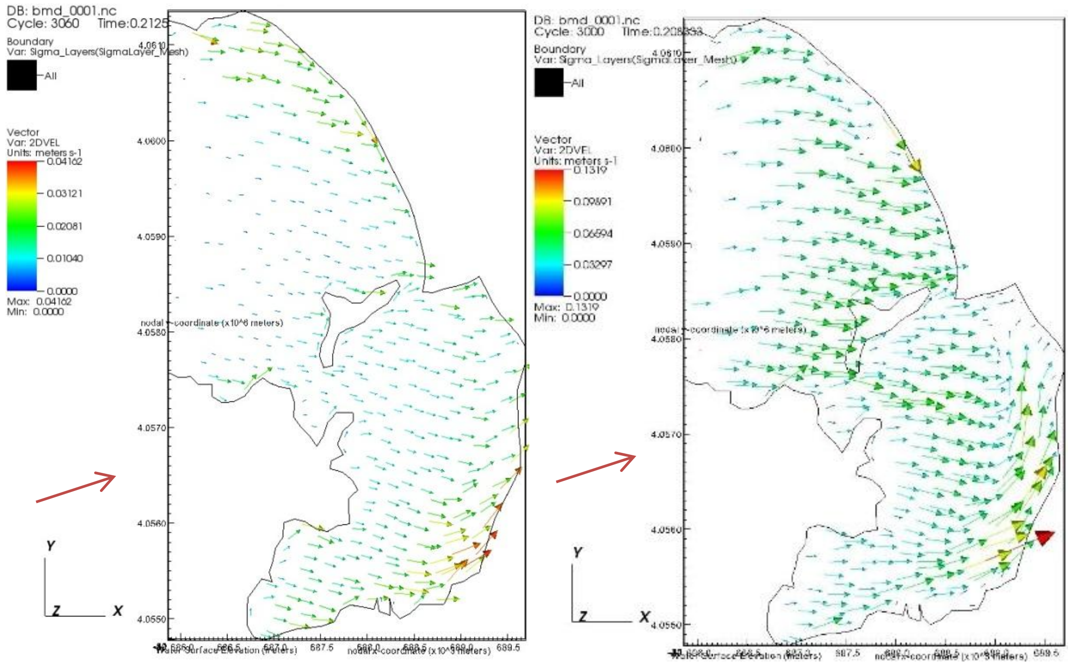

Figure 4.18: Water circulations for WSW wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the sea surface

After circulation modeling, obtained data should be processed to get the water exchange capacity of the bay each wind direction. To obtain water exchange capacity, west side and east side openings are analyzed for present situation. Since cross sections are already obtained (Figure 4.8 and 4.10), water movement velocity is needed at these locations. For water velocity measurement from models, two different options are examined. Firstly, along the both openings, all solution cells intersecting the red lines shown on Figure 4.7 and 4.9 are studied and representative depth is divided in five segments for each solution cell. Cross-section of right side opening divided to depth segments for all intersecting solution cells is given in Figure 4.19.

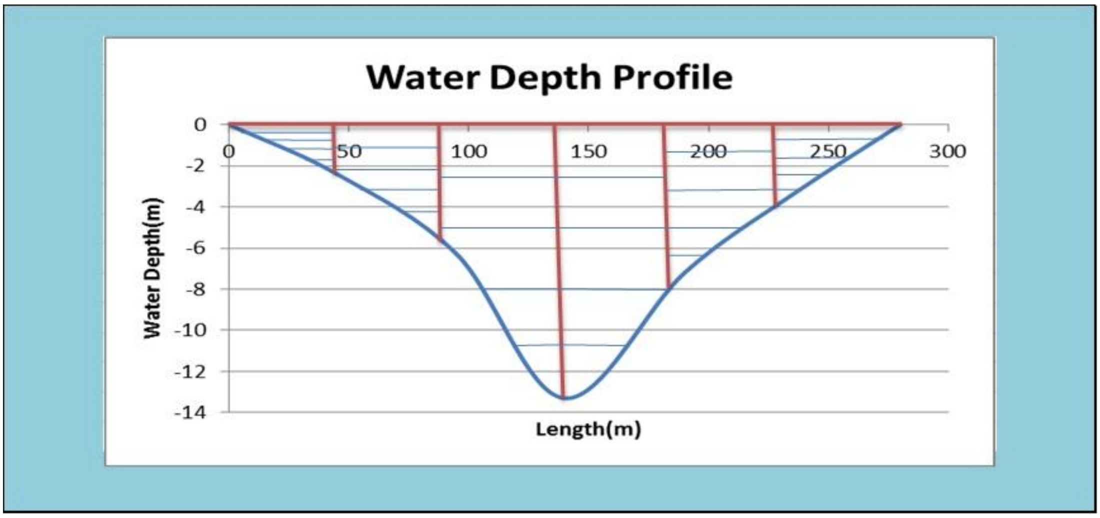

Figure 4.19: Water depth profile for one representative solution cell case

Secondly, appropriate places for measuring the water movement velocity at both openings are located (Figure 4.20) and solution cells representing the measurement points are detected. These locations are the midpoints of the each cross-section so velocities at these points are taken as representative for all section across the cross section part. In Figure 4.20 places with red dot are measurement locations. In Figure 4.21, cross section of right side opening is shown for one representative solution cell for each opening case.

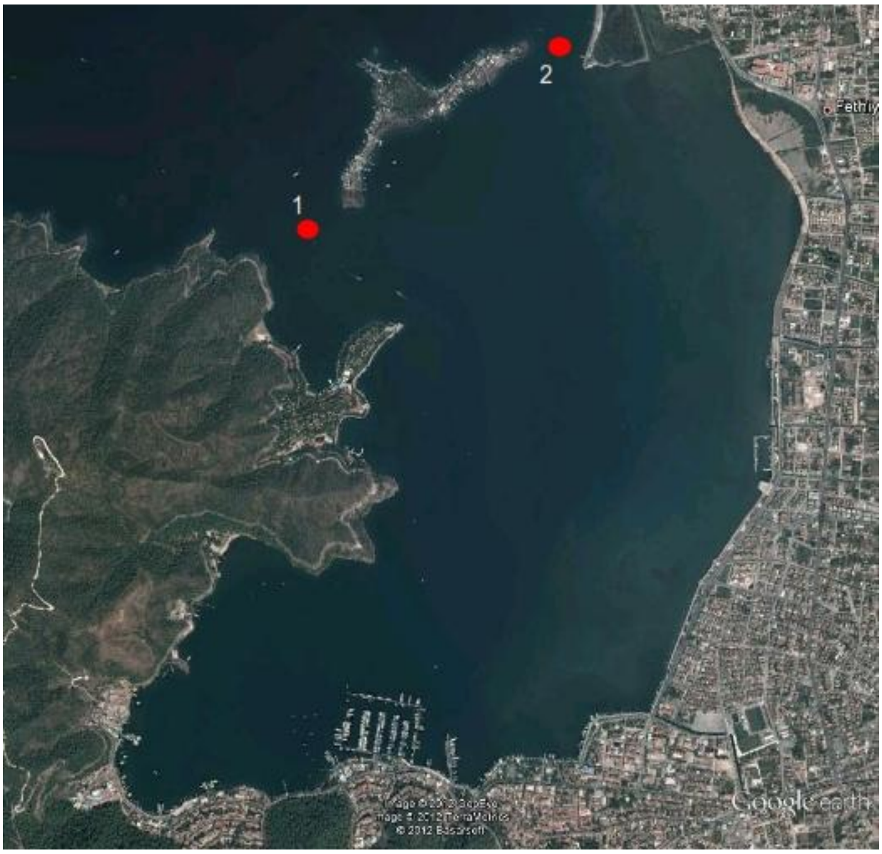

Figure 4.20: Water movement velocity measurement locations

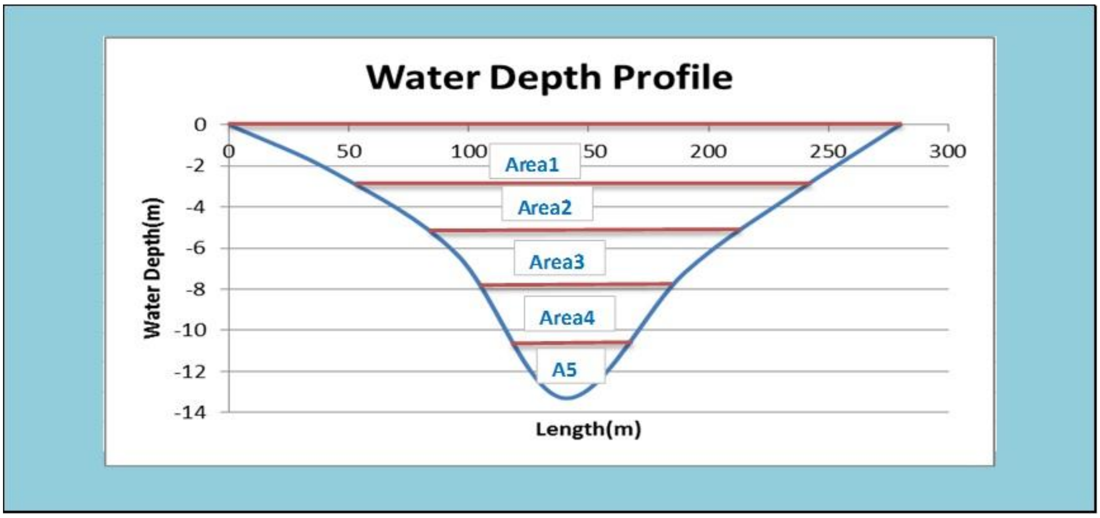

Figure 4.21: Water depth profile for all solution cells along entrence

When two different approaches are compared for most dominant wind directions, one representative solution cell for all cross section case has 15% more water exchange capacity for ENE wind direction and 10% more water exchange capacity for WSW direction as shown on the Table 4.2. This is due to the slower water movement at the low water depth locations close to shores.

Table 4.2:Water velocities for ENE wind, west side opening

	ENE WIND DIR.		WSW WIND DIR.	
	OUT	*IN*	*OUT*	*IN*
One Cell	1.339.421	6.155.205	5.544.583	1.510.650
All Cells	1.510.738	4.836.362	3.779.818	2.411.128

In the end, comparing the increase in calculation time and the amount of difference in water exchange capacity, one representative solution cell for each opening approach is chosen for yearly water exchange capacity calculations to represent the model circulation values.

To prevent unnecessary repeating, only for most dominant wind case ENE, explanations of calculations are shown.

Resultant water velocity for present situation, for the ENE wind direction, for 10 hour total duration and for west side opening for 1,5m/s wind velocity is given in the Table 4.3 and for 5,0m/s wind velocity is given in the Table 4.4.

Table 4.3:Water velocities for ENE wind, west side opening, 1,5 m/s case

PRESENT-ENE-Resultant-WEST OPENING					*velocities are in m/s
Section / Time	0	1	2	3	4
20	-0,00001	0,00000	0,00000	0,00000	0,00000
40	-0,00062	-0,00018	-0,00018	-0,00018	-0,00018
60	-0,00124	0,00019	0,00019	0,00019	0,00019
80	-0,00193	0,00034	0,00034	0,00034	0,00034
100	-0,00272	0,00043	0,00043	0,00043	0,00043
120	-0,00334	0,00063	0,00064	0,00064	0,00064
140	-0,00402	0,00078	0,00079	0,00079	0,00079
160	-0,00480	0,00084	0,00085	0,00085	0,00085
180	-0,00540	0,00102	0,00103	0,00103	0,00103
200	-0,00607	0,00112	0,00114	0,00114	0,00114
220	-0,00686	0,00110	0,00113	0,00113	0,00112
240	-0,00750	0,00122	0,00125	0,00125	0,00125
260	-0,00824	0,00126	0,00130	0,00130	0,00130
280	-0,00913	0,00118	0,00124	0,00124	0,00124
300	-0,00984	0,00128	0,00137	0,00137	0,00137
320	-0,01065	0,00127	0,00140	0,00141	0,00140
340	-0,01152	0,00115	0,00135	0,00135	0,00134
360	-0,01211	0,00123	0,00150	0,00151	0,00150
380	-0,01276	0,00115	0,00153	0,00154	0,00152
400	-0,01341	0,00099	0,00149	0,00150	0,00149
420	-0,01382	0,00100	0,00165	0,00167	0,00165
440	-0,01431	0,00086	0,00168	0,00171	0,00169
460	-0,01484	0,00067	0,00166	0,00170	0,00168
480	-0,01513	0,00064	0,00183	0,00189	0,00187
500	-0,01549	0,00055	0,00188	0,00196	0,00194
520	-0,01585	-0,00054	0,00188	0,00200	0,00198
540	-0,01593	-0,00064	0,00207	0,00223	0,00221
560	-0,01610	-0,00081	0,00214	0,00235	0,00233
580	-0,01623	-0,00104	0,00220	0,00247	0,00244
600	-0,01613	-0,00115	0,00240	0,00273	0,00271

Table 4.4: Water velocities for ENE wind, west side opening, 5,0m/s case

PRESENT-ENE-Resultant-WEST OPENING					*velocities are in m/s
Time \ Section	0	1	2	3	4
20	-0.00007	0.00001	0.00001	0.00001	0.00001
40	-0.00533	0.00075	0.00083	0.00083	0.00083
60	-0.01221	0.00185	0.00258	0.00258	0.00258
80	-0.01863	0.00244	0.00430	0.00431	0.00430
100	-0.02491	0.00224	0.00540	0.00543	0.00540
120	-0.03052	0.00194	0.00653	0.00656	0.00651
140	-0.03543	0.00145	0.00744	0.00745	0.00737
160	-0.03967	-0.00112	0.00794	0.00791	0.00779
180	-0.04311	-0.00113	0.00856	0.00856	0.00839
200	-0.04629	-0.00184	0.00889	0.00917	0.00891
220	-0.04863	-0.00273	0.00929	0.01035	0.00997
240	-0.05090	-0.00443	0.00906	0.01162	0.01111
260	-0.05264	-0.00617	0.00861	0.01326	0.01278
280	-0.05367	-0.00751	0.00872	0.01548	0.01537
300	-0.05519	-0.00917	0.00814	0.01643	0.01710
320	-0.05653	-0.01086	0.00827	0.01700	0.01877
340	-0.05768	-0.01250	0.00863	0.01676	0.01995
360	-0.05824	-0.01366	0.00901	0.01607	0.02093
380	-0.05882	-0.01508	-0.00981	0.01518	0.02140
400	-0.05895	-0.01586	-0.01017	0.01423	0.02134
420	-0.05886	-0.01650	-0.01071	0.01368	0.02096
440	-0.05881	-0.01689	-0.01079	0.01283	0.01994
460	-0.05835	-0.01708	-0.01107	0.01261	0.01928
480	-0.05795	-0.01716	-0.01112	0.01224	0.01848
500	-0.05736	-0.01693	-0.01083	0.01178	0.01777
520	-0.05726	-0.01721	-0.01097	0.01139	0.01687
540	-0.05644	-0.01687	-0.01082	0.01138	0.01672
560	-0.05635	-0.01708	-0.01088	0.01103	0.01598
580	-0.05591	-0.01694	-0.01069	0.01072	0.01553
600	-0.05553	-0.01679	-0.01047	0.01037	0.01507

Since water depth is divided in to five equal pieces and duration is 10hours velocities are obtained for each elevation segment and for every 20 minute time intervals. Time is shown in the first column in minutes. Water elevation sections are shown from 0 to 4 in the Table 4.3 and 4.4., ‘0’ represents the section closest to the water surface and

‘4’ represents the section closest to the sea bottom. Velocities are given in m/s. In velocities, negative values represent the direction in to the bay on the other hand, positive values represent the direction outside the bay.

Since velocities are now obtained in m/s, total water exchange values after 10 hours of winds is next step to calculate. While calculating water exchange values, time intervals and areas of divided cross section parts are used.

The water exchange volumes for each time interval and total water exchange after 10 hours of wind for only west side opening is shown in the Table 4.5 and Table 4.6 for representative wind velocities.

Table 4.5:Water Exchange volumes for ENE wind at the west side opening, 1,5 m/s case

Circulation Present Situation-ESE-West Opening					
Time \ Section	0	1	2	3	4
20	-951,1	-210,5	-149,9	-89,9	-30,0
40	-2820,0	9,6	8,5	5,1	1,7
60	-4792,8	614,5	442,7	265,6	88,5
80	-7026,5	897,3	648,1	388,9	129,6
100	-9164,0	1240,0	897,7	538,6	179,4
120	-11135,3	1656,6	1199,8	719,9	239,6
140	-13334,9	1904,1	1380,5	828,3	275,6
160	-15420,9	2183,2	1583,8	950,3	316,1
180	-17352,1	2515,2	1826,2	1095,7	364,6
200	-19558,5	2612,5	1903,0	1141,8	379,6
220	-21717,5	2730,3	1997,4	1198,9	398,1
240	-23804,3	2915,2	2147,1	1288,8	427,9
260	-26267,0	2865,4	2139,2	1283,5	426,0
280	-28688,3	2887,8	2197,0	1318,2	437,2
300	-30991,9	2991,5	2332,6	1400,1	464,1
320	-33519,6	2844,9	2314,3	1390,2	460,4
340	-35726,6	2798,4	2397,6	1441,9	477,0
360	-37607,0	2795,8	2548,0	1534,4	507,4
380	-39561,5	2517,3	2540,3	1532,7	506,5
400	-41163,7	2338,7	2641,1	1598,7	527,9
420	-42533,4	2190,1	2800,2	1702,8	562,1
440	-44075,1	1798,4	2808,8	1720,3	567,4
460	-45311,4	1536,2	2929,4	1809,9	596,6
480	-46297,6	1394,5	3110,7	1941,7	640,1
500	-47381,4	5,5	3154,2	1997,8	658,1
520	-48051,5	-1384,7	3319,1	2134,5	703,2
540	-48430,1	-1700,4	3539,2	2312,2	762,4
560	-48880,0	-2174,7	3646,7	2429,5	801,8
580	-48928,0	-2578,6	3862,4	2621,5	866,5
600	-48772,5	-2710,3	4028,5	2755,7	911,7
Positive values are to outside of the bay while negative ones are to inside					
After 10 hours total circulations			**169.611**	**-900.293**	m^3

Table 4.6:Water Exchange volumes for ENE wind at the west side opening, 5,0m/s case

Circulation Present Situation-ESE-West Opening					
Time \ Section	0	1	2	3	4
20	-8166.7	896.4	704.2	422.5	140.8
40	-26519.4	3061.9	2863.2	1719.0	572.6
60	-46622.1	5041.0	5778.8	3475.2	1156.2
80	-65838.0	5502.5	8145.7	4909.0	1630.0
100	-83808.9	4920.5	10017.2	6042.7	2001.0
120	-99710.2	3991.5	11733.8	7063.6	2332.6
140	-113554.6	388.7	12919.1	7742.3	2548.0
160	-125172.9	-2647.2	13859.3	8301.0	2719.0
180	-135175.5	-3492.1	14659.9	8936.3	2907.2
200	-143518.5	-5379.4	15272.6	9837.4	3171.7
220	-150486.3	-8428.4	15413.0	11070.6	3540.5
240	-156548.1	-12469.5	14842.8	12536.1	4012.9
260	-160737.5	-16090.5	14554.6	14484.4	4729.4
280	-164592.6	-19621.1	14161.2	16085.3	5455.4
300	-168929.7	-23556.2	13788.1	16848.3	6025.3
320	-172699.5	-27466.7	14197.5	17011.0	6503.7
340	-175280.3	-30762.6	14815.1	16543.8	6867.7
360	-177002.1	-33799.9	-675.4	15751.7	7111.8
380	-178066.2	-36390.0	-16788.8	14822.1	7180.7
400	-178115.6	-38061.2	-17545.4	14063.4	7107.1
420	-177907.5	-39271.9	-18063.5	13360.4	6871.9
440	-177142.8	-39950.7	-18364.9	12823.8	6590.0
460	-175844.7	-40269.4	-18641.0	12528.1	6343.7
480	-174340.7	-40097.1	-18441.4	12109.7	6089.9
500	-173299.0	-40155.8	-18311.5	11679.5	5820.5
520	-171918.5	-40080.8	-18296.6	11477.2	5643.7
540	-170541.0	-39924.8	-18223.2	11294.0	5493.5
560	-169741.5	-40004.1	-18115.2	10961.8	5293.4
580	-168510.0	-39659.1	-17770.8	10629.6	5140.0
600	-167935.9	-39486.4	-17586.7	10450.9	5062.1
Positive values are to outside of the bay while negative ones are to inside					
After 10 hours total circulations			**682,572**	**-5,131,615**	m^3

In Table 4.5 and 4.6, time column and sections row is same with Table 4.3 and 4.4. However, in Table 4.5, values given in the cells are water exchange capacities for 20 min time interval, .

The results show that 0.9×10^6 m^3 water gets inside the bay and meanwhile 0.17×10^6 m^3 water gets outside the bay after 10 hours of wind blowing from ENE direction from west side opening for 1.5 m/s wind velocity modeling.

Additionally, 5.1×10^6 m^3 water gets inside the bay and meanwhile 0.7×10^6 m^3 water gets outside the bay after 10 hours of wind blowing from ENE direction from west side opening for 5.0 m/s wind velocity modeling.

After same calculations are made for east side opening, values are added to find total water exchange volume.

These calculations, represented in Table 4.3-4.6, are made for all wind directions selected for study. For present situation, under 1,5m/s and 5,0m/s winds from selected directions for 10 hour of wind duration total water exchange capacities are given in Table 4.7. Values in Table 4.7 are in m^3.

Table 4.7:Water Exchange volumes for selected winds for present situation

PRESENT	ENE WIND DIR.		WSW WIND DIR.		NNW WIND DIR.		SSE WIND DIR.	
	OUT	*IN*	*OUT*	*IN*	*OUT*	*IN*	*OUT*	*IN*
1,5m/s	296.100	1.166.445	970.907	499.710	196.917	1.604.260	1.455.386	347.726
5,0m/s	1.339.421	6.155.205	5.544.583	1.510.650	2.271.362	5.849.556	7.822.492	1.219.849

4.3.3 Water Circulation Modeling for Dredged Case

In the Fethiye bay, shoaling is a problem especially at the east and southeast of the bay. The reason for shoaling is anticipated as sediment transported from streams pouring in the bay. The municipality has planned to dredge these areas as a solution to shoaling in that area.

Since only change in the bathymetry is due to dredging, same coastline data is used as in the present case studies (Figure 4.1).

Bathymetry is similar with present case studies except from the dredged places. Dredged areas can be seen on Figure 4.22 as the area within the yellow marked line is the dredged areas. A total of 1,165,500m^2 surface area is selected for dredging for 3m. Which means water depth is 3m more at the selected areas than the present case. With a simple calculation total dredged volume can be found;

$$\text{Volume} = \text{Surface Area x Depth}$$

$$\text{Total Dredged Volume} = 1{,}165{,}500\text{m}^2 \text{ x } 3\text{m} = 3{,}496{,}500 \text{ m}^3$$

With this calculation, total dredged volume is calculated as 3,5x10^6 m^3.

Figure 4.22: Dredged areas in Fethiye Bay

In order to calculate water exchange in the inner bay for dredged case conditions, same cross sections are used as in the present situation case from east side opening and west side opening of the bay (Figure 4.7-4.10).

Time variable water circulation is modeled for Fethiye bay, under different wind conditions for dredging applied bathymetrical conditions. In order to observe change in water exchange capacity, same meteorological conditions are applied with the present situation studies. In other words, four different wind directions are applied on the model. NNW, SSE, ENE and WSW wind directions are used for modeling. Firstly, wind blowing from the NNW direction, for two different wind velocities; 1.5 m/s and 5 m/s velocities, for 10 hours is applied. In addition, with the same order, written modeling results are given for places closer to the bottom of the sea and for places closer to the water surface in Figure 4.23 – 4.30. In these figures, left side shows pattern of model results from 1,5m/s wind velocity and right side shows the ones from the 5,0m/s wind velocity.

If circulation models of present case and dredged case are compared it is observed that circulation patterns are similar with each other. In both cases for the same wind directions at the same depths, results are very similar to each other. For NNW and SSE cases, at the east side of the inner bay, eddies occur. For all the wind cases, water at places closer to the sea surface and water at places closer to the sea bottom moves to the opposite directions which results in water circulation.

So far, when present case and dredged cases are compared, dredging of shown areas does not have an impact to the water circulation patterns. Whether dredging has an influence on water exchange capacities will be revealed after exchange capacity calculations.

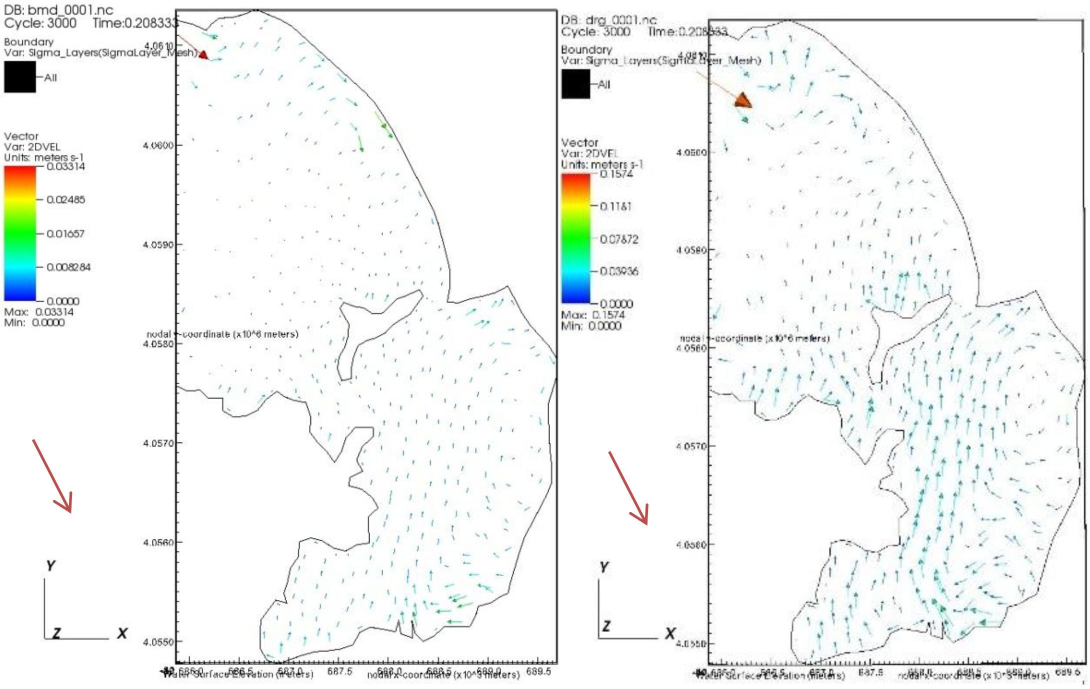

Figure 4.23: Water circulations for NNW wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the bottom of the sea for dredged contions

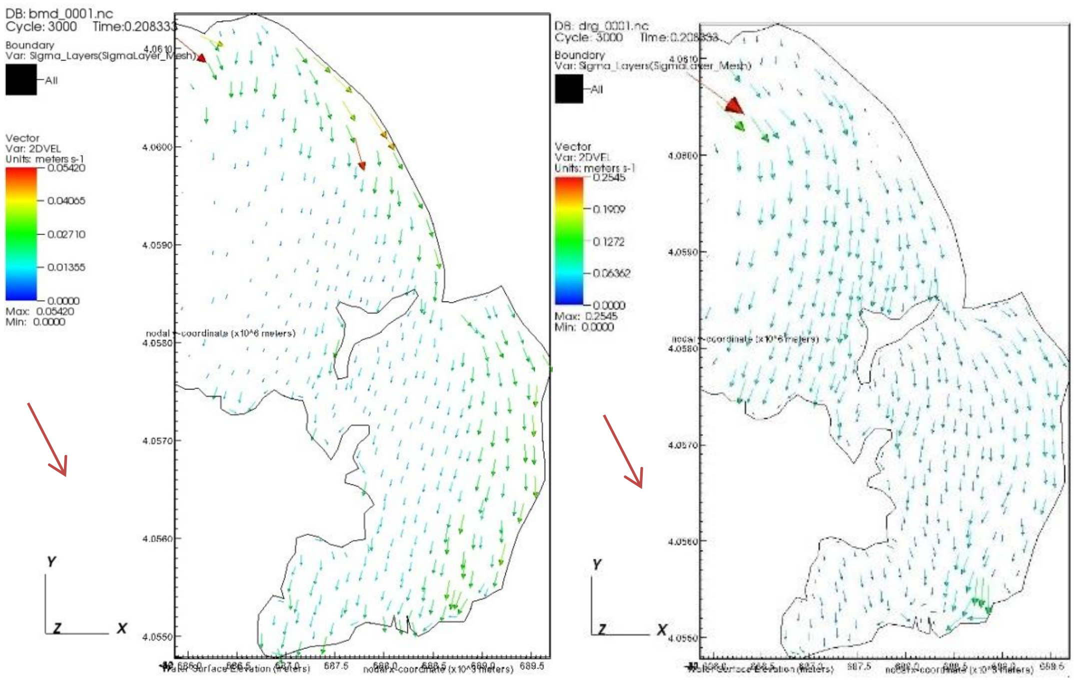

Figure 4.24: Water circulations for NNW wind direction, 1,5m/s and5m/s velocity and 10 hour duration for places close to the sea surface for dredged contions

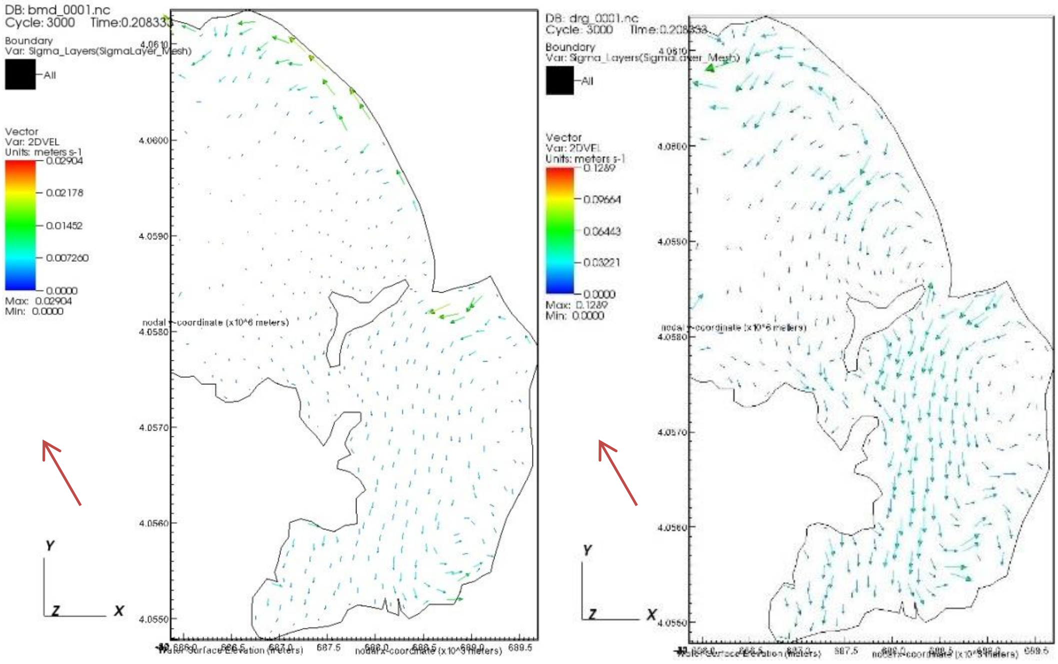

Figure 4.25: Water circulations for SSE wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the bottom of the sea for dredged contions

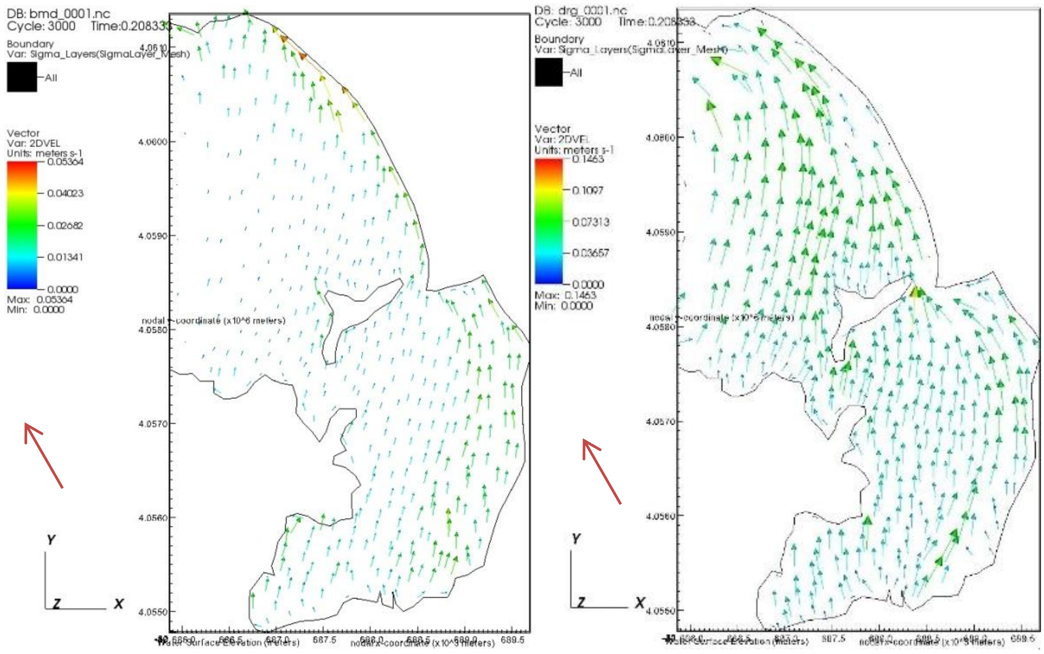

Figure 4.26: Water circulations for SSE wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the sea surface for dredged contions

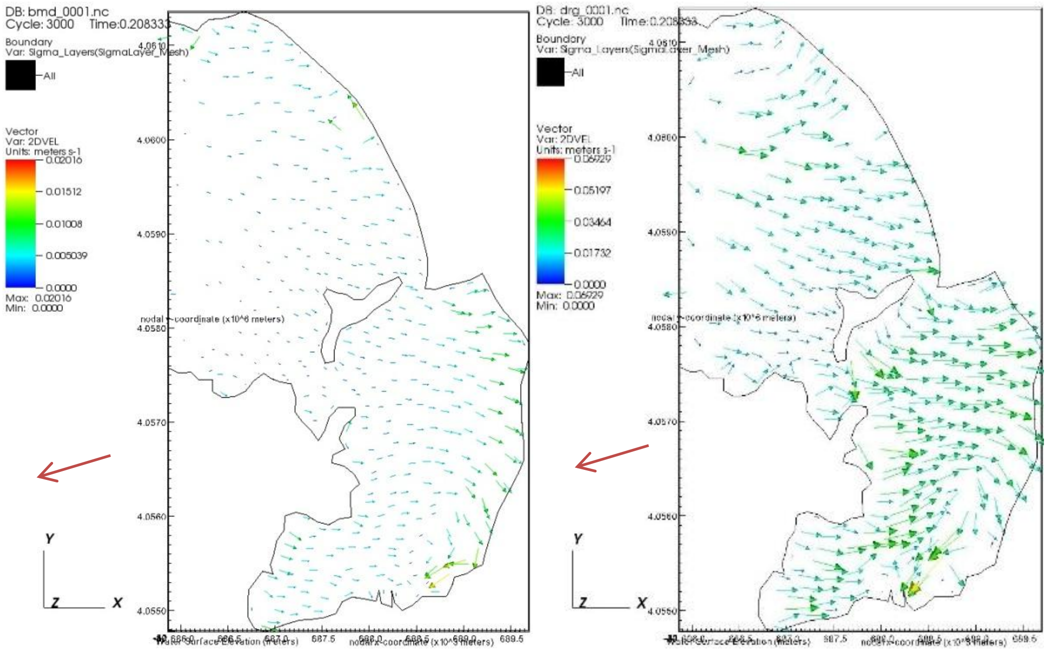

Figure 4.27: Water circulations for ENE wind direction,1,5m/s and 5m/s velocity and 10 hour duration for places close to the bottom of the sea for dredged contions

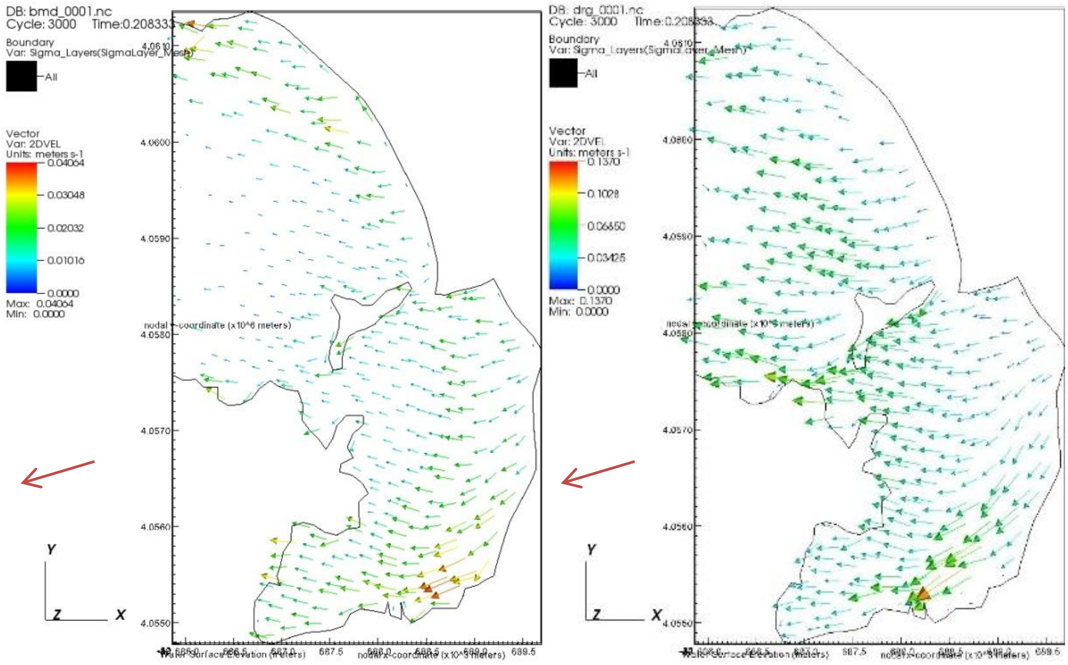

Figure 4.28: Water circulations for ENE wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the sea surface for dredged contions

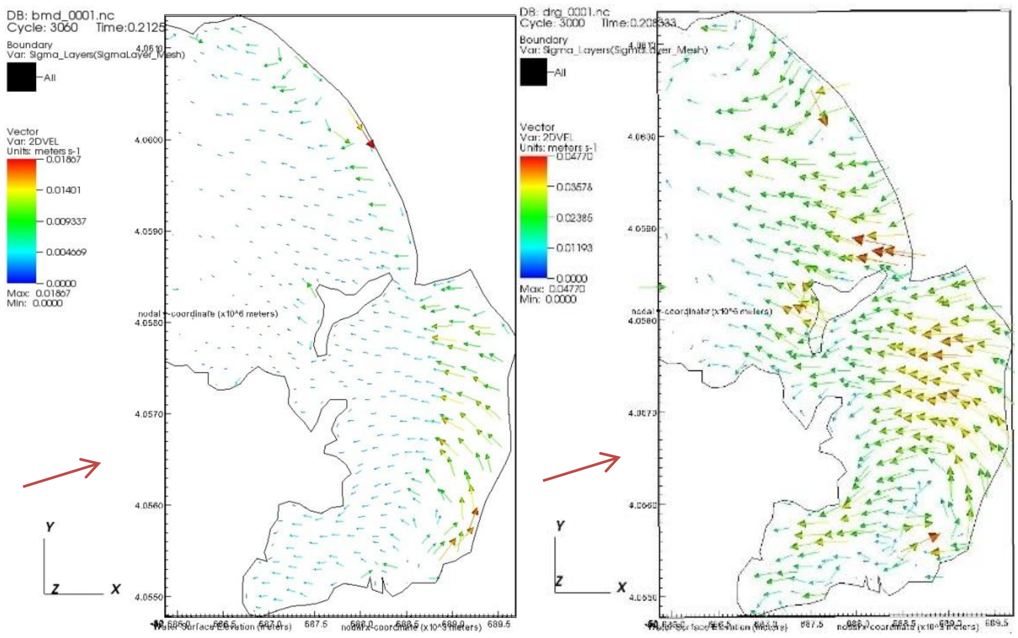

Figure 4.29: Water circulations for WSW wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the bottom of the sea for dredged contions

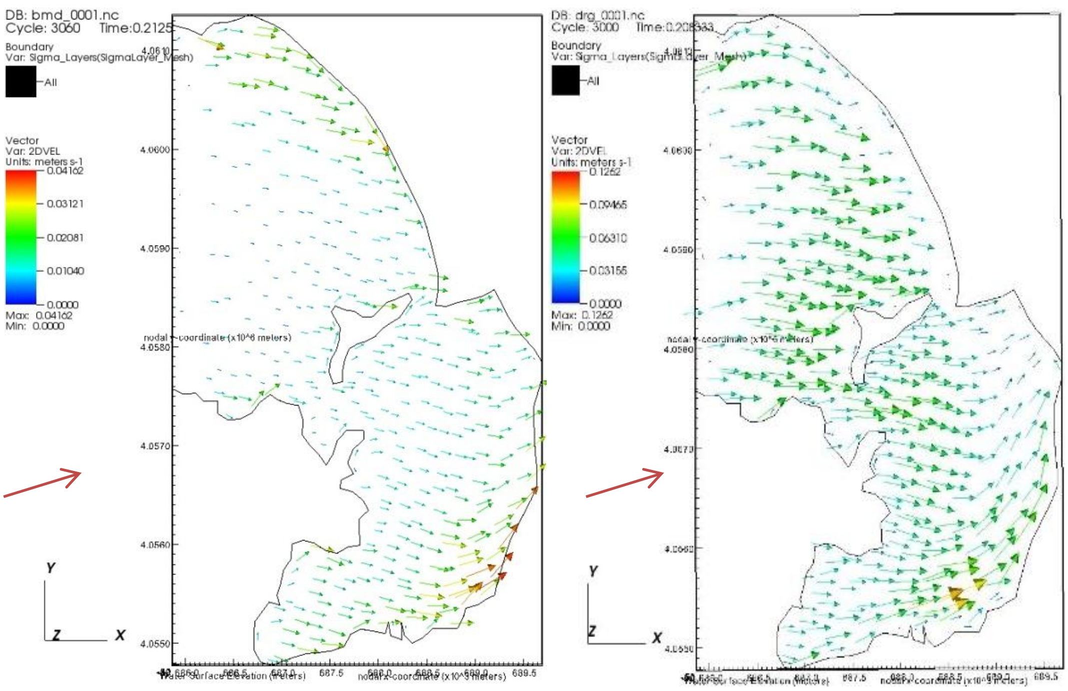

Figure 4.30: Water circulations for WSW wind direction, 1,5m/s and 5m/s velocity and 10 hour duration for places close to the sea surface for dredged contions

Obtained results are manipulated similar to the present case studies. After same calculations are performed, the following results are obtained. For dredged case, under 5m/s wind from selected directions for 10 hour of wind duration, total water exchange capacities are given in Table 4.4. Values in Table 4.4 are in m^3. Comparison of all the water exchange volumes for three different cases are given in Chapter 4.4.

Table 4.8:Water Exchange volumes for selected winds for dredged case

	ENE WIND DIR.		WSW WIND DIR.		NNW WIND DIR.		SSE WIND DIR.	
m^3	*OUT*	*IN*	*OUT*	*IN*	*OUT*	*IN*	*OUT*	*IN*
DREDGED	1,350,616	6,159,736	5,588,337	1,480,672	2,335,881	5,859,780	7,770,935	1,348,491

4.3.4 Water Circulation Modeling for Canal Added Case

Canal added case is a preliminary study for a possible future development scenario. In order to calculate water exchange in the inner bay for canal case, same cross sections are used from east side opening and west side opening of the bay. Locations of cross sections are specified with a red line on the satellite image as seen on Figure 4.7 and Figure 4.9 for east side opening and west side opening correspondingly. Relative depth profiles are given just below the satellite images as seen Figure 4.8 and Figure 4.10. In addition to these cross sections, in this case, there is third opening connecting bay with the open sea, which is the canal. For this preliminary study, canal is placed at the southwest of the Fethiye bay as it is seen on Figure 4.4. Canal is proposed as 100m wide, 5m deep and 750m long for this preliminary study. Cross section of the canal is given in the Figure 4.31.

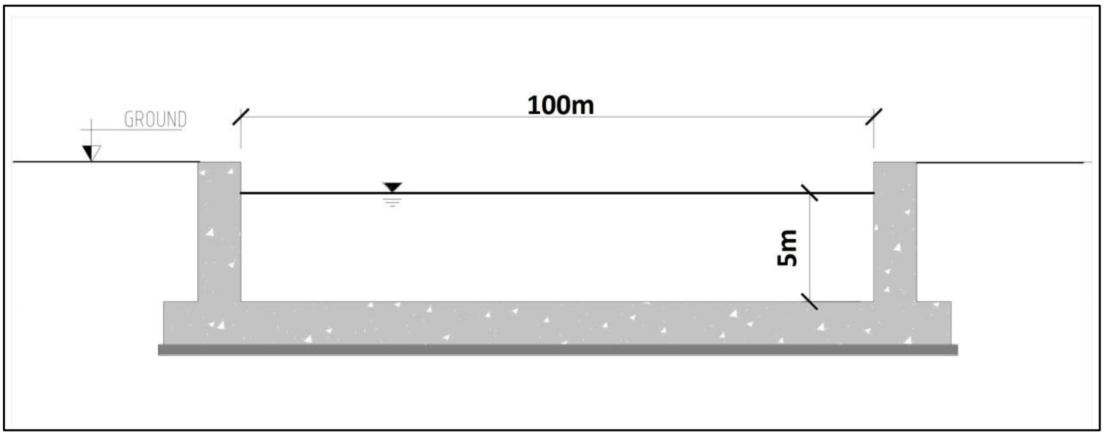

Figure 4.31: Cross section for planned canal in Fethiye Bay

Time variable water circulation is modeled for Fethiye bay, under different wind conditions for canal added data. In order to observe change in water exchange capacity, same meteorological conditions are applied with the present situation and dredged case studies. As previous studies, four different wind directions NNW, SSE, ENE and WSW are used for modeling. Wind is blowing from these directions with the 1,5m/s and 5 m/s velocities, for 10 hours duration. The modeling results are not analyzed in detail. But preliminary studies has shown that water circulation pattern is not affected. To make any further canal related comments detailed studies should be carried on considering more aspects like the ecological effects of canal in the area and effects of wave characteristics in the region, to the entrance from the open sea side of the canal.

4.4 Water Circulation Modeling Summary

Water circulation modeling is performed for two different cases. These cases are present situation and dredging applied case. These cases are examined for four different wind directions that are ENE, WSW, NNW, and SSE. Present and dredged cases are studied for 1,5m/s and 5m/s wind velocities and 10 hours of wind duration. In order to observe the differences between cases, total water exchange values for each wind direction are given in Table 4.9 as amounts entering the bay and leaving the bay. Also hourly cumulative water exchange values for 5m/s wind velocity models are put on graphs on Figure 4.32-4.35. Just in these figures positive values represent the water entering the bay and negative values represent the water amount leaving the bay.

Table 4.9:Water Exchange volumes for selected winds for all cases

	ENE WIND DIR.		WSW WIND DIR.		NNW WIND DIR.		SSE WIND DIR.	
5m/s	*OUT*	*IN*	*OUT*	*IN*	*OUT*	*IN*	*OUT*	*IN*
PRESENT	1.339.421	6.155.205	5.544.583	1.510.650	2.271.362	5.849.556	7.822.492	1.219.849
DREDGED	1.350.616	6.159.736	5.588.337	1.480.672	2.335.881	5.859.780	7.770.935	1.348.491

All values in the table 4.6 are in m^3 and values represent total water exchange capacities after 10 hours.

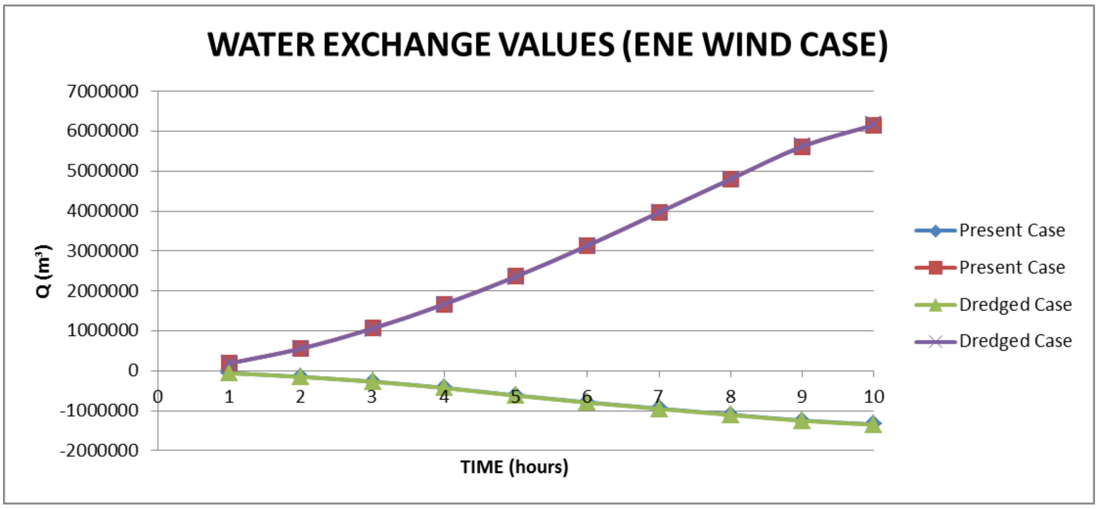

Figure 4.32: Cumulative water exchange values for ENE wind direction for all cases

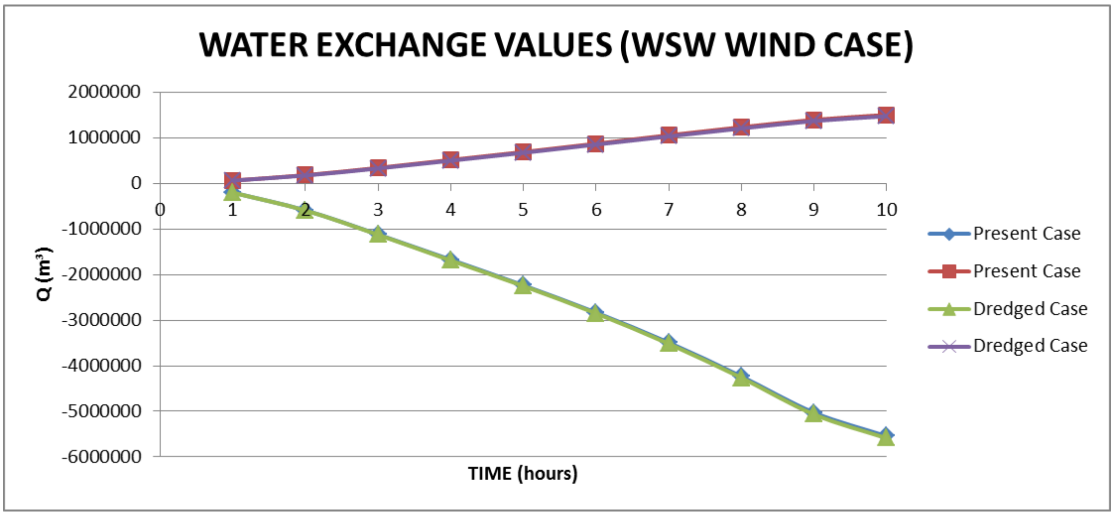

Figure 4.33: Cumulative water exchange values for WSW wind direction for all cases

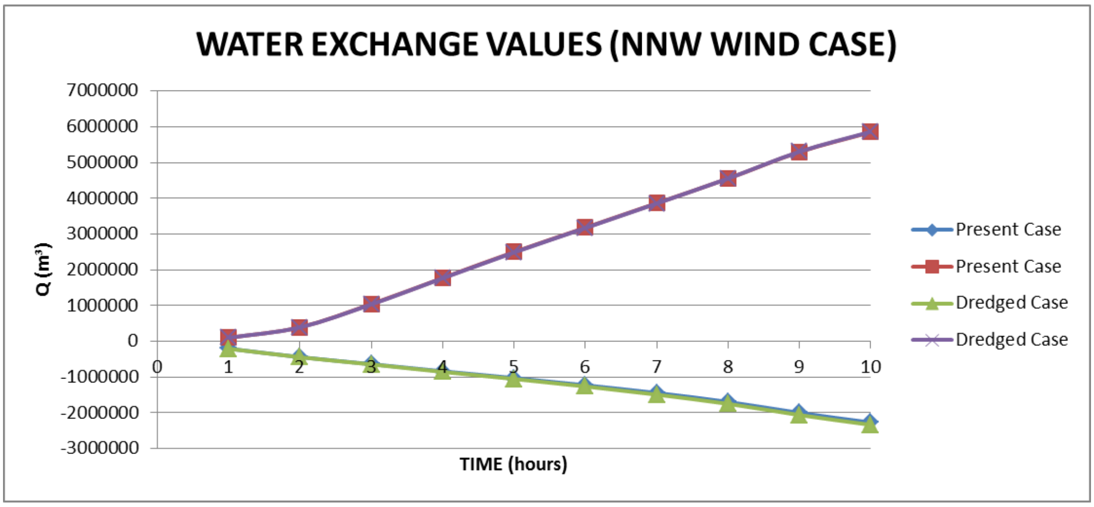

Figure 4.34: Cumulative water exchange values for NNW wind direction for all cases

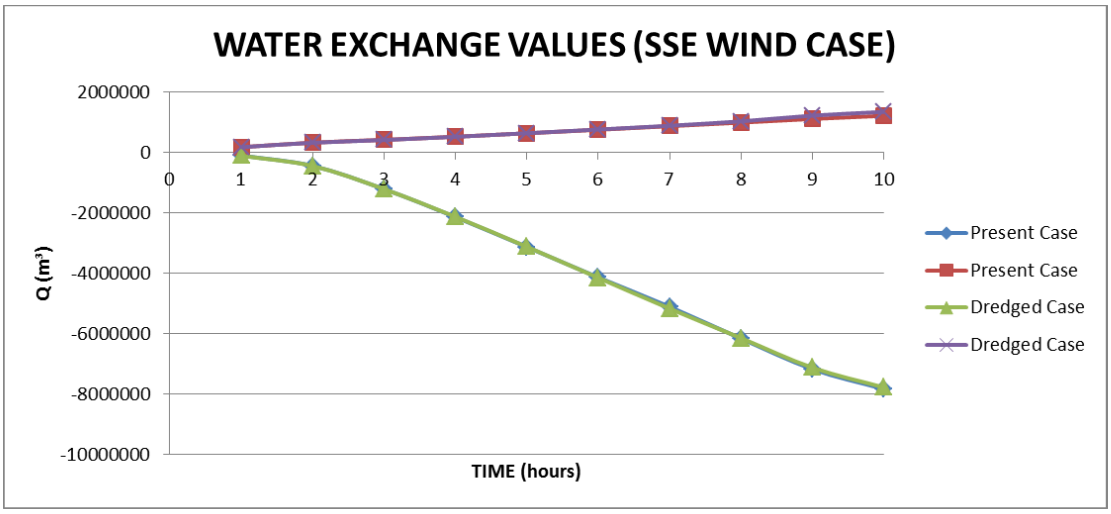

Figure 4.35: Cumulative water exchange values for SSE wind direction for all cases

In graphs (Figures 4.32-4.35), it is observed that dredging does not increase water exchange capacities. For all wind directions, difference in amounts of exchangefor present conditions and dredged case are small so that it can be ignored. This observation is made for both water amount getting inside bay and water amount leaving the bay.

Preliminary study canal added case has shown that opening a canal at the southwest of the Fethiye bay at the Karagözler location will not affect the water circulation pattern inside the bay.

Building a canal at Karagözler location will cause ecological damage at the surrounding environment. Environmental balance of locations will be disturbed.

Finally, due to the water velocity in canal, at the ends of the canal, flushing may occur. This, flushing may result in water foaming in surrounding waters. Foaming in the inner bay will disturb the yacht owners and sailors travelling in area. Thus in repeating on phenomena, yacht owners will not visit Fethiye again.

4.5 Water Exchange Capacity for Fethiye Bay

Present case studies are chosen to calculate yearly water exchange capacity for Fethiye bay for reasons stated previously. Akbaşoğlu (2011) has given wind durations for each wind direction for 41 years for Fethiye. This data has been taken from Fethiye Meteorological Station. For 41 years, 357704 hours of wind duration is observed from this data. Then yearly 8724 hours of wind is observed.

Since it is modeled for four wind cases, dominant wind cases WSW and ENE are assumed to be representative for their surrounding dominant wind directions and similarly, non-dominant wind directions SSE and NNW are assumed to be representative for their surrounding wind directions. So non-modeled wind directions are taken into calculations are integrated through this assumption. Thus by this assumption, ENE wind direction represents 43,7% of all winds, WSW represents 36,6%, SSE represents 10.1% and NNW represents 9.6% of all winds.

In water exchange capacity calculations, winds up to 1.0 m/s velocity are considered as not effective for water circulation. It is assumed that 1.5m/s wind velocity is representative for wind with low velocities and long yearly durations. On the other hand, 5m/s is assumed as representative for high velocity and short durations of yearly wind data. Water exchange values of 1,5m/s and 5m/s for 10 hours durations and for the present case conditions are given in Table 4.7.

For all wind directions, considering the percentages and durations, yearly water exchange capacity of Fethiye bay is 1672×10^6 m^3. Since wind cases are modeled fresh water entrance is considered, separate calculations for freshwater does not have to be added to this value.

CHAPTER 5

YACHT CARRYING CAPACITY

5.1 Sustainable Development

Economic development for increasing life quality is a necessity in the modern communities. However, when the level of development extends beyond the limits of the nature, development will be short-termed. The natural resources will be over-exploited in an irreversible manner and finally this will result in environmental destruction and economic failure. Sustainable development is a way to provide the needs of people within the environmental limits. While proposals are put forward for economic growth, this should cause minimal or no damage to environmental systems. Main purpose of sustainable development is to provide our needs while making sure that we left the future generations economic and environmental conditions so that they are able to provide their needs.

5.1.1 Integrated Coastal Zone Management

Currently, 75% of the world population is living in the coastal areas and immigration to coastal areas is going on constantly. Demand is not expected to stop on coastal areas any time soon. That puts a great environmental pressure on coastal zones. Pressure on the developed, industrially improved coasts is a bigger problem since part of industrial improvement is building structures in coastal zones like power plants, ports, marinas that might cause disruption in environmental systems. Moreover, tourism activities put an extra stress on existing conditions. Air and sea pollution in coastal areas is mainly caused by these activities.

Integrated coastal zone management intends all participants to work in harmony for coastal improvement under the sustainable development conditions namely balancing exploitation and conservation. Participants are policy makers, investors, industry presenters, planners and managers of coastal zones and local citizens. In integrated coastal zone management, involvement of multiple-sectors is an obligation for sustainable development. For benefit of all participants, goals should be set properly to reverse negative incidents.

5.2 Carrying Capacity Assessment

In many coastal zones, people living in that area are dependent on tourism income. Since tourism is such an important sector for coastal areas and it is highly dependent on ecology, tourism and ecology cannot be treated separately. If an increasing tourism income is desired, ecology should also be preserved. Because, nobody especially a tourist wants to face air and seawater pollution during his/her visit.

Yacht tourism, especially, makes up a big percentage of tourism income of a country within coastal areas. Since yachting is an expensive pursuit and correspondingly yachtsmen are rich people who spends a lot money. Yachting is usually made with midsize boats on a random route that yachtsmen decide. In addition, yachting can be defined as joyful, restful, entertaining sporting experience. Yachtsmen are always looking for new places to visit. Spain, France and Italy are most popular places in Europe among the yachtsmen. However, these countries almost reached or has already reached their carrying capacities and yachtsmen are looking for new places to explore. Turkey Riviera offers the clearest waters in the eastern Mediterranean and invests in the yacht tourism. However, with excessive usage, yachting can cause environmental damage as previously mentioned.

Seawater pollution level depends on liquid wastes disposed from yachts, solid wastes threw randomly instead of solid waste collecting equipment. On the other hand, water circulation capacity stands as cleaning factor against polluters. A balance is needed to be set between pollution due to usage and natural cleaning. At this point yacht carrying capacity determination is needed. With carrying capacity assessment, damaging impacts of yacht tourism can be minimized and a balance will be set between usage and preservation of nature.

With carrying capacity assessment, integrated coastal zone management can be applied for region, development can be adapted with conservation, maximum benefits can be achieved with optimum use of natural resources with minimum or no environmental damage. Only then, yacht tourism can be planned as a solid sector and sustainable development will be reached. Moreover, plans related with considered zones should be made depending on results of carrying capacity assessment.

5.3 Yacht Carrying Capacity of Fethiye Bay

Yacht carrying capacity also can be defined as; number of yachts using a regions for a time duration without disturbing biological ecological balance and geomorphological structure of region.

It is mentioned before that, yachts using the area are classified according to their sizes and from which material they are made of. Pollution amounts are assigned according to this grouping in order to calculate current wastewater production of yachts using the bay.

Linear approach is carried out for yacht carrying capacity calculations. In linear approach coastline appropriate for berthing is calculated rather than coastal areas. For linear approach three steps are taken; physical yacht carrying capacity, natural yacht carrying capacity and finally present berthing distribution.

5.3.1 Physical Yacht Carrying Capacity

Physical carrying capacity (PCC) is a preliminary calculation in which whole coastline the study area is taken into account whether it is available or not for berthing due to geomorphological reasons or legal aspects. It is calculated as ;

PCC = Total length of shoreline / Representative yacht berthing width………(1)

In equation 1, representative yacht berthing width is equal to 1.5x representative yacht width. Representative yacht width is defined as 4m since it is observed that most of the yachts visiting the area are in between the 10-15m length and their wide is chosen as 4m as representative for all yacht in the area.

The total length of the study area in Fethiye (Figure 4.1) is calculated with GIS application programs as 21939m. So;

PCC = 21939m / (1.5x4m) = 3656 yachts

5.3.2 Natural Carrying Capacity of Fethiye Bay

While physical carrying capacity is calculated, natural (river mouth, beach, reefs) and legal limitations that prevents a place from berthing are not considered. However while present yacht usage is calculated, these limitations and other restrictions preventing yachts from berthing at that location are considered. When places unavailable for berthing are subtracted, Natural Carrying Capacity is obtained. At the study area, Karagözler location (Figure 5.1) and Belediye Marine and nearby locations (Figure 5.2) are considered as only appropriate berthing locations except existing coastal structure like marinas and fishing ports. The places that are extracted from calculation are given in Figure 5.3 with relevant reasons on figure.

Figure 5.1: Karagözler location shores

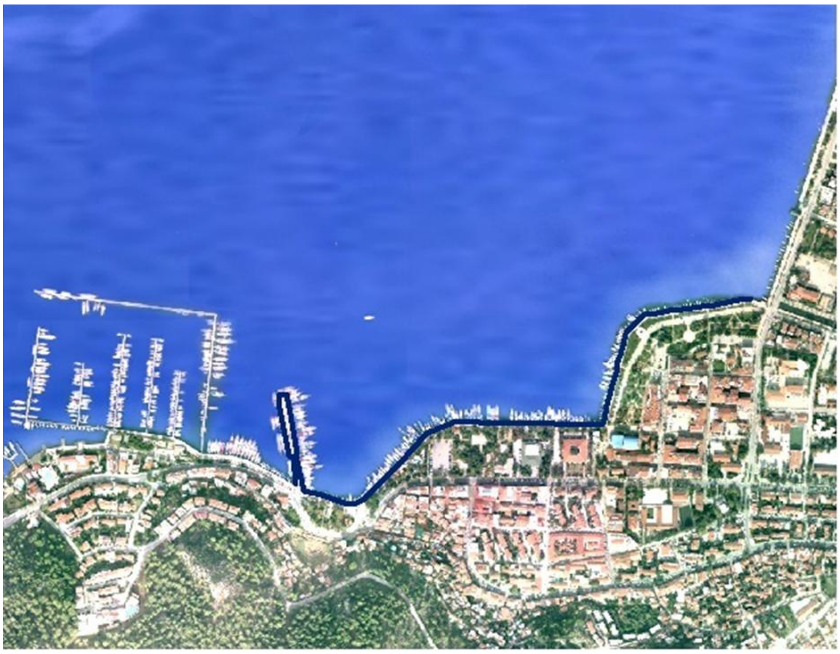

Figure 5.2: Belediye Marina and close shores

Figure 5.3: Extracted locations with reasons

Places marked with blue line at Figure 5.1 and Figure 5.2 is places that are available for berthing.

According to Figure 5.1 and 5.2 rest of the coastline should be subtracted from carrying capacity calculations. Some places are not available due to the geomorphological reasons and some are due to legal restrictions. So total length of coastline that should be subtracted is 19596m. So total coastline available for berthing is;

Available Coastline = 21939 – 19596 = 2343m

And Natural Carrying Capacity (NCC) can be calculated as;

NCC = Available Coastline for Berthing / Representative yacht approach width…(2)

NCC = 2343m / 6m = 390 yachts

5.3.3 Present Berthing Distribution Of Fethiye Bay

Present yacht usage can be defined as available marine structures' capacity added on the Natural Carrying Capacity. Capacity of the available marine structures is given in Table 5.1.

Table 5.1: Available Coastal Structures and Berthing places

Location	Yacht Capacity
Ece Marine	350
Fishing Port	100
Private berths of local hotels	15
Inside Murt Brook	45
Service Boats (Ferries, Coast Guard Boats)	7

As seen on Table 5.1, total capacity of existing structures is 517 yachts. From this values present yacht usage of Fethiye bay can be defined as ;

Present Yacht Usage = NCC + Capacity of Available Coastal Structures……(3)

Present Yacht Usage = 390 + 517 = 907 yachts

5.3.5 Areal Approach to the Carrying Capacity Calculations

When calculating Physical Yacht Carrying Capacity (PCC) with the areal approach Representative Yacht Berthing Area is used. Representative Yacht Berthing Area is calculated as 15m x (15*2) m = 450 m^2 that is an area needed for yacht with the representative yacht length to enjoy the berthing at the bay without disturbance and maneuvering easily. Representative yacht length is chosen as 15m because, among yachts visiting the area, 10m - 20m size yachts are the most frequent. Moreover, factor of safety is used as 2. So PCC with areal approach can be calculated as;

PCC = Total Bay Area / Representative Yacht Berthing Area………………….(4)

In order to calculate PCC with areal approach, peninsula at the southwest of the bay is studied. Since, inner bay is not suitable for areal approach, in the inner bay linear approach calculations are retained. However, peninsula on the southwest of the bay is appropriate for areal approach application. There are many bays located in peninsula that are convenient for PCC calculation with areal approach. Bay areas in the study area are shown in the Figure 5.4 with light blue fill. Coastline of the representing bays is given in the Figure 5.5 with the red line.

Figure 5.4: Bay areas for areal approach study

Figure 5.5: Coastline of bay used in the areal approach studies

Bays shown on the Figure 5.3 is north of the peninsula. Total of the areas shown in Figure 5.3 is 276894 m^2. If formula (4) is applied;

PCC = 276894 m^2 / 450 m^2 = 615 yachts

On the other hand, coastline shown with red line on the Figure 5.5 has total length of 2847 m. So PCC with linear approach is;

PCC = 2847m / 6m = 474 yachts

When two approaches are compared, yacht capacity for areal approach is 141 yachts more than the capacity for linear approach.

So with areal approach, PCC = 3656 +141 = 3797 yachts for Fethiye bay.

However, for Fethiye bay, natural carrying capacity and present berthing distribution are not calculated with areal approach because due to the legal restrictions (touristic facility locations), small bays located on the peninsula are not allowed for yacht berthing which are also most appropriate for the areal approach calculations. However, these restrictions are case specific, in Turkey, yachts are berthing at the similar bays. Moreover, when berthing, they are not berthing along the coastline but they are spread at the whole surface area.

5.3.4 Wastewater Volume Due To Yacht Usage of Fethiye Bay

All calculations related with water circulation, water pollution and capacity increase would depend on the present yacht usage of Fethiye bay. Not every yacht produces same amount of wastewater. It differs with respect to user, size of yacht and material of the yacht. Since it is not possible to predict each user's water usage habits, yachts are classified according to their materials and sizes. The following classification is proposed by METU at 2007 and it is given in the Table 5.2.

Table 5.2: Yacht classifications according to their sizes and material (METU, 2007)

YAHCT TYPE		SIZE
WOOODEN	FIBER	S SIZE (m) < 10 m
		M 10m < SIZE (m) < 16m
		L 16m < SIZE (m) < 26m
		XL 28m < SIZE (m) < 32m
		XXL 32m < SIZE (m)

In the table 5.2; S represents small, M represents medium, L represents large, XL represents extra-large and XXL represent extra-extra-large yacht sizes.

In the Fethiye bay, berthed yachts are observed and after observations, number of people working as crew and number of passengers are determined according to yacht sizes. In addition, when data of type, material and size of yacht and number of people using yacht are combined, wastewater production volumes could be determined for each yacht category. With this categorization, yearly wastewater volume produced by yachts using Fethiye Bay is calculated (Table 5.3).

Table 5.3: Total wastewater produces by yachts using Fethiye Bay

					Number of Yachts								
Type	**Size**	**Number of Passangers on Board**	**Number of Crew on Board**	**Waste Water Production Volume of Yacht per day when boat is berthed lt/day**	**Ece Marina**	**Belediye**	**Karagözler**	**Hotels**	**Fising Port**	**Inside Brook**	**Yacht distrubition according to sizes in the Fethiye bay**	**Total Waste Water Produced By Yachts in Fethiye Bay**	
Fiber	S	1-3	0	0	81		32			25	138	**0**	
Fiber	M	2-4	1	25	190		76	15		20	301	**7525**	
Fiber	L	2-6	2	100	69		28				97	**9700**	
Fiber	XL	4-8	3	150	7		4				11	**1650**	
Fiber	XXL	6-12	4	150	1						1	**150**	
Cruise		3000	1030		2						2	**0**	
Fisher	S	0	2	60					100		100	**6000**	
Wooden	S	1-3	0	0		39					39	**0**	
Wooden	M	2-6	1	50		102					102	**5100**	
Wooden	L	4-8	1	50		45					45	**2250**	
Wooden	XL	6-18	2	100		9					9	**900**	
Wooden	XXL	8-24	3	150							0	**0**	
Service Boats				75		7					7	**525**	
Tour Boat	Various	25-120	3	100		55					55	**5500**	
				Total	350	257	140	15	100	45	**907**	**39300**	**lt/day**
											Yearly	**3,93E+01**	**m3/day**
												1,08E+04	**m3/year**

In Table 5.3, categorization according to size and material of yacht, purpose of usage (Tour Boats, Service Boats and Fisher), number of passengers using yacht, crew working on yacht including captain of yachts using Fethiye are shown and number of yachts are distributed according to their berthing locations. When, yearly wastewater volume produced is calculated, not the whole year is taken into account but only three seasons are calculated. Because during winter, there are just a few people using their yachts so that it can be ignored in wastewater volume calculations. Additionally, there are no cruises using Fethiye bay at present but there are some plans to adapt the Fethiye to cruise routes. Still, cruises do not release any wastewater to the bay with the technology they are using.

As seen on Table 5.3, yearly $1.08x10^4$ m^3 wastewater is assumed to be released to the bay from 907 yachts.

CHAPTER 6

DISCUSSION OF RESULTS AND CONCLUSION

Fethiye is one of the most visited touristic locations in the Turkey. Tourism is the greatest income of the region. Determination of yacht carrying capacity in Fethiye bay has vital importance for local and national economy. As a part of succession in the sustainable development, yacht carrying capacity had to be determined.

In order to calculate the yacht carrying capacity firstly water circulation analysis are made so that yearly water exchange capacity is reached. For the water circulation modeling, three different cases are analyzed by utilizing FVCOM. All of the models are time dependent and wind included circulation models for a semi-enclosed area, Fethiye bay. Firstly modeling studies are prepared for the present situation. Due to the conversations with municipality authorities, it is learnt that dredging at the east and southeast of the bay and canal opening at the Karagözler location are two of their possible future projects. Moreover, these changes may change the water exchange capacity. So, secondly, dredging is applied at the east and southeast of the bay. A total of 3,5 x 10^6 m^3 dredging of sediment is modeled. Finally, as a preliminary study, a canal is added to the present bathymetry at the southeast of the bay at the Karagözler location. Present case and canal added case are examined under four different wind directions with 1,5m/s and 5m/s wind velocities and for 10 hours of wind durations. The wind directions used in the modeling are NNW, SSE, ENE and WSW directions.

Results and comparison of the two cases indicate that dredging does not contribute significantly to the water exchange capacity of the bay. Also, canal case preliminary studies has shown that water circulation pattern is not affected due to opening a canal at the southwest of the bay.

When yacht carrying capacity is calculated present situation is considered. Firstly, volume of wastewater released by yachts currently using bay is determined as $1.08x10^4$ m^3 yearly.

For possible yacht capacity increase, biological studies should be made considering the dilution rate of the bay. Two important parameter are presented in this thesis for dilution rate studies which are yearly wastewater release from yachts and yearly water exchange capacity of Fethiye bay.

If any berthing capacity increase will be made after further biological studies, while extra capacity being distributed, sustainable development should be considered. The extra capacity provided will be only applicable if extra berthing capacity is concentrated at some locations, through high standard, modern equipped marinas. It is important because marinas provide services that prevent negative impacts of yachts, like picking up solid wastes. In addition, some marinas are separating the recyclable solid wastes and delivers to the authorized institutions. Another service that marinas provide is to draw the wastewater from the yachts and sent to the sewer systems. This contributes to the dilution rate of the bay.

When locations for new marinas are decided, it is important that sea traffic is not disturbed due to high concentration at a place in the bay.

A new concept for yacht carrying capacity studies is proposed as areal approach. Due to the legal restrictions (touristic facilities at the location), this approach was not able to applied to be the Fethiye bay. But results shown that areal approach gives safer results than the linear approach. Areal approach for calculating the carrying capacity is proposed to be used for places where geomorphologic structure is consisting from dense bay formation.

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APPENDIX A

WATER CIRCULATION MODELING RESULTS FOR DIFFERENT WIND DIRECTIONS

A.1 Circulation Calculations for WSW wind direction

Table A.1: Circulation for present case, west side opening

Circulation Present Situation-WSW-West Opening					
	0	1	2	3	4
20	7291	-1474	-1126	-676	-225
40	24671	-4271	-3782	-2270	-756
60	44798	-5902	-6701	-4027	-1339
80	63699	-5743	-9504	-5720	-1897
100	81449	-4648	-12743	-7675	-2536
120	98424	-2809	-16395	-9896	-3251
140	112423	-482	-20554	-12580	-4100
160	123992	3266	-23499	-15036	-4856
180	133148	7245	-24381	-17120	-5511
200	137657	8508	-24469	-19488	-6374
220	140037	8372	-23377	-21132	-7205
240	141302	7781	-21975	-21767	-7900
260	142733	8213	-20541	-21448	-8334
280	144832	9702	-19237	-20680	-8513
300	145647	10567	-19188	-20438	-8725
320	145607	11484	-20071	-20650	-8991
340	147508	13879	-20515	-20526	-9067
360	149810	16558	-20926	-20478	-9118
380	152415	19628	-21771	-20726	-9229
400	156078	22524	-22252	-20847	-9315
420	159879	24655	-22660	-21050	-9466
440	166347	27879	-22365	-20657	-9388
460	173926	31220	-21846	-20018	-9184
480	180829	33696	-21554	-19620	-9053
500	188001	35671	-20750	-18936	-8831
520	193429	37132	-20120	-18341	-8625
540	196109	38304	-19938	-17848	-8415
560	195157	38375	-19977	-17558	-8264
580	191359	37112	-20138	-17536	-8206
600	189575	36579	-20190	-17450	-8140
Positive values are to outside of the bay while negative ones are to inside					
After 10 hours total circulations			**4,616,480**	**-1,284,886**	m^3

Table A.2: Circulation for present case, east side opening

Circulation Present Situation-WSW-East Opening					
	0	1	2	3	4
20	3186	-391	-394	-237	-79
40	9795	-737	-1301	-837	-278
60	15956	815	-2159	-1676	-556
80	21556	3365	-2661	-2311	-764
100	24406	5276	-2634	-2783	-917
120	24786	6501	-1820	-3614	-1213
140	29163	8560	-1535	-3943	-1366
160	32393	10329	-1210	-3496	-1242
180	29480	9361	-916	-3493	-1291
200	26563	7752	-1043	-4111	-1675
220	28143	7109	-1331	-3978	-1741
240	28711	6874	-1995	-3460	-1546
260	28088	6595	-2489	-3382	-1490
280	27202	6277	-3320	-3601	-1518
300	25116	5718	-3711	-3863	-1616
320	25804	5518	-3932	-3771	-1549
340	26499	5915	-4525	-3738	-1457
360	26065	6113	-4901	-3824	-1459
380	25727	6207	-5077	-3895	-1478
400	26612	6387	-4810	-3707	-1412
420	27680	6570	-4167	-3341	-1296
440	27178	6738	-4276	-3400	-1316
460	25539	6566	-4526	-3616	-1396
480	26072	6388	-4041	-3493	-1396
500	28362	6623	-3729	-3254	-1320
520	27443	6733	-3486	-3056	-1238
540	25767	5979	-3128	-3101	-1291
560	25987	5441	-3194	-3264	-1362
580	25818	5795	-3358	-3460	-1451
600	25447	6053	-3371	-3633	-1548
Positive values are to outside of the bay while negative ones are to inside					
After 10 hours total circulations			**928,102**	**-225,763**	m^3

Table A.3: Circulation for canal case, canal opening

Circulation Canal Case-WSW-Canal Opening					
	0	1	2	3	4
20	1605	1405	1254	314	294
40	5549	5211	4867	1142	831
60	9308	8903	8347	3828	1963
80	11984	11512	10779	7331	4293
100	14760	14266	13488	9922	6725
120	17363	16835	15973	12144	8446
140	19327	18766	17821	13768	9678
160	20845	20256	19243	15013	10602
180	22255	21643	20574	16206	11535
200	23335	22706	21595	17125	12260
220	23828	23188	22047	17507	12517
240	24319	23669	22504	17912	12838
260	24815	24159	22978	18348	13176
280	24946	24288	23102	18459	13255
300	24721	24061	22873	18225	13035
320	24653	23993	22802	18148	12948
340	24915	24255	23064	18410	13205
360	24893	24235	23048	18402	13204
380	24770	24112	22927	18285	13105
400	25021	24364	23180	18542	13357
420	24880	24223	23042	18411	13222
440	24676	24020	22838	18203	13021
460	24889	24234	23055	18424	13252
480	24725	24071	22896	18273	13120
500	24777	24122	22944	18319	13158
520	24900	24243	23061	18427	13242
540	24753	24099	22922	18301	13129
560	24835	24182	23007	18395	13237
580	24907	24251	23070	18439	13256
600	24857	24201	23019	18381	13185
Positive values are to inside of the bay while pozitive ones are to inside					
After 10 hours total circulations			**2,648,893**	**0**	m^3

Table A.4: Circulation for canal case, west side opening

Circulation Canal Case-WSW-West Opening					
	0	1	2	3	4
20	9994	-1774	-1514	-908	-303
40	32524	-3728	-4866	-2934	-976
60	55600	-4079	-9098	-5566	-1845
80	74992	1264	-13318	-8492	-2799
100	92264	9481	-16187	-11253	-3696
120	109793	15209	-17849	-14017	-4673
140	128518	20203	-18974	-16999	-5914
160	146315	24722	-17800	-18937	-6999
180	160994	29200	-13412	-18741	-7492
200	170425	31783	-8965	-17479	-7608
220	175992	33513	-6816	-16076	-7480
240	180633	36502	1267	-14770	-7207
260	184043	39916	10547	-14033	-7037
280	187423	44346	14664	-14082	-6987
300	190986	48983	18760	-14697	-7039
320	195437	53046	21971	-15563	-7176
340	203189	58216	25299	-16487	-7313
360	214119	64630	28872	-17396	-7406
380	225449	70740	31897	-18095	-7479
400	235564	75742	33952	-45	-7470
420	245915	80452	35614	18244	-7368
440	256565	84281	36410	17773	-7250
460	263595	86271	35802	16543	-7061
480	260867	85106	34137	644	-6902
500	251118	82353	32976	-14361	-6757
520	239110	78629	31718	-14001	-6595
540	226522	73274	29227	-13671	-6568
560	216203	68148	26454	-13270	-6553
580	209007	64101	23985	-12724	-6459
600	206136	62319	22904	-12517	-6421
Positive values are to outside of the bay while negative ones are to inside					
After 10 hours total circulations			**7,321,380**	**-658,328**	m^3

Table A.5: Circulation for canal case, east side opening

Circulation Canal Case-WSW-East Opening					
	0	1	2	3	4
20	2948	-543	-454	-272	-91
40	9439	-1324	-1500	-904	-301
60	16162	-2090	-2782	-1680	-556
80	21162	528	-3986	-2449	-803
100	24356	4343	-4638	-3201	-1037
120	27028	5793	-4421	-4022	-1378
140	29285	6942	-3870	-4804	-1944
160	30811	7794	-3930	-5313	-2556
180	31959	8167	-4308	-5376	-2790
200	33007	8093	-4563	-5162	-2679
220	34062	8032	-4648	-4904	-2538
240	35159	8134	-4474	-4592	-2423
260	36019	8419	-4243	-4282	-2345
280	37483	8676	-4026	-4081	-2322
300	38664	8664	-3912	-4130	-2394
320	39646	8761	-3708	-4020	-2376
340	42088	9212	-3344	-3641	-2205
360	44203	9507	-3009	-3423	-2133
380	44340	9980	256	-3346	-2188
400	44415	10396	3468	-3355	-2197
420	44639	10604	3707	-3384	-2138
440	44500	10839	3848	-3338	-2098
460	44527	10986	3873	-3279	-2085
480	43790	11177	4268	-3502	-2164
500	43597	11347	4557	-3640	-2217
520	43552	11331	4676	-3777	-2260
540	42874	11353	4946	-3934	-2272
560	43346	11597	5064	-3857	-2187
580	43798	11999	5363	-3965	-2190
600	43479	12235	5601	-4081	-2228
Positive values are to outside of the bay while negative ones are to inside					
After 10 hours total circulations			**1,354,871**	**-238,584**	m^3

Table A.6: Circulation for dredged case, west side opening

Circulation Dredged Case-WSW-West Opening					
	0	1	2	3	4
20	7302	-1463	-1117	-670	-223
40	24785	-4176	-3713	-2229	-742
60	45006	-5681	-6557	-3941	-1311
80	63733	-5670	-9470	-5701	-1891
100	81626	-4522	-12651	-7621	-2519
120	99348	-2403	-15865	-9581	-3148
140	114065	629	-19551	-11981	-3904
160	125282	4564	-22636	-14512	-4688
180	133336	7695	-24154	-16966	-5468
200	138102	9264	-24089	-19256	-6303
220	140785	9445	-22823	-20819	-7102
240	142462	9284	-21217	-21341	-7760
260	143137	9167	-20164	-21245	-8271
280	143331	9334	-19872	-21072	-8651
300	144185	10708	-19888	-20853	-8869
320	146339	12950	-19822	-20431	-8918
340	149356	15767	-19787	-19971	-8880
360	150679	18283	-20869	-20289	-9045
380	153050	20926	-21689	-20546	-9164
400	157427	23560	-21646	-20354	-9149
420	162517	26532	-21829	-20256	-9168
440	168238	29514	-21884	-20090	-9164
460	174461	31979	-21609	-19754	-9088
480	181915	34829	-21342	-19265	-8911
500	189114	37053	-20851	-18694	-8708
520	195112	39206	-20770	-18223	-8503
540	197411	39695	-20278	-17709	-8315
560	195785	38638	-19685	-17325	-8187
580	193539	38371	-19797	-17031	-8010
600	192501	38269	-19718	-16763	-7876
Positive values are to outside of the bay while negative ones are to inside					
After 10 hours total circulations			**4,669,592**	**-1,265,687**	m^3

Table A.6: Circulation for dredged case, east side opening

Circulation Dredged Case-WSW-East Opening					
	0	1	2	3	4
20	3182	-390	-395	-237	-79
40	9806	-756	-1306	-841	-279
60	17131	789	-2158	-1546	-513
80	22439	3379	-2655	-2120	-702
100	23941	5182	-2395	-2613	-862
120	24181	6112	-1408	-3342	-1123
140	27837	7468	-768	-3816	-1334
160	30030	9175	-520	-3671	-1332
180	28753	9155	-519	-3726	-1438
200	30206	8402	-893	-3586	-1494
220	31010	8076	-1315	-3127	-1381
240	29562	7330	-1893	-3113	-1389
260	27937	6602	-2308	-3208	-1413
280	26802	6426	-2601	-3228	-1396
300	24668	5830	-3101	-3692	-1601
320	24575	5530	-3826	-4006	-1701
340	25351	5705	-4461	-3916	-1570
360	24680	5235	-4337	-3964	-1605
380	25787	5395	-4367	-3868	-1564
400	26800	6207	-4509	-3601	-1408
420	27328	6398	-4090	-3344	-1318
440	26326	6319	-3950	-3358	-1338
460	24672	6212	-3919	-3593	-1477
480	25699	6072	-3630	-3521	-1497
500	27375	6232	-3741	-3304	-1360
520	28176	6456	-3922	-3238	-1278
540	27475	6321	-3414	-3075	-1235
560	25010	5617	-2966	-3221	-1364
580	24397	5333	-2633	-3544	-1654
600	25031	5622	-2329	-3598	-1791
Positive values are to outside of the bay while negative ones are to inside					
After 10 hours total circulations			**918,745**	**-214,985**	m^3