ESTIMATION OF SUSPENDENT SEDIMENT CONCENTRATION USING ACOUSTIC METHODS

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By
Ramazan AYDIN

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We approve the thesis of **Ramazan AYDIN**

Assist. Prof. Dr. Şebnem ELÇİ
Supervisor

Prof. Dr. Gökmen TAYFUR
Committee Member

Assoc. Prof. Dr. Sevinç ÖZKUL
Committee Member

16 March 2009

Prof. Dr. Gökmen TAYFUR
Head of the Civil Engineering Department

Prof. Dr. Hasan BÖKE
Dean of the Graduate School of
Engineering and Science

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ABSTRACT

ESTIMATION OF SUSPENDENT SEDIMENT CONCENTRATION USING ACOUSTIC METHODS

Acoustic Doppler current meters (ADCP, ADP, and ADV) can provide information about the suspended sediment concentration (SSC) in the water; although, they are designed for flow velocity measurements. Contrary to conventional samplers, those are labor intensive for measuring SSC, when an acoustic instrument is calibrated for a water system; no additional sensor is needed to measure SSC, enabling the researchers to measure velocity and concentration simultaneously which is required for most sediment transport studies.

Recently, the acoustic instruments are investigated in different studies where signal to noise ratio (SNR) and SSC were related using different formulations. However, these studies were limited to single study site where neither the effect of particle size nor the effect of temperature was investigated. In the scope of this study, different parameters that affect the ADV's performance prediction of SSC were investigated. In order to investigate the reliability of ADV in different environments, SSC measurements were made in different streams. Soil samples were collected from all measuring stations and particle size analysis was conducted.

The multivariate data analysis was applied to the measurements to derive a relation formula between SNR and SSC. Multivariate analysis indicated that reported SSC values depended on at least three parameters; water temperature, mean diameter of the soil, and shape of the particle size distribution curve. Also, effect of high SSC conditions on ADV performance was investigated during and after rain events. Results indicated that ADV was not capable of measuring SSC when a limit concentration (SSC>400 mg/l) was exceeded.

ÖZET

ASKI HALİNDEKİ TORTU TAŞINIMININ AKUSTİK METOTLARLA TAHMİNİ

Asıl üretim amaçları akım hızı ölçümü olan Doppler akımölçerler (ADCP, ADP ve ADV), su içerisinde askı halinde bulunan zemin tanecik miktarı hakkında da bilgi verebilmektedir. Zahmetli olan geleneksel metotla sudan örnek alarak tortu miktarını ölçen aletlerin aksine, akustik aletin kalibrasyonunun yapıldığı su sistemlerinde, ek herhangi bir sensöre veya alete gerek duymadan su içerisinde askı halindeki tortu miktarı (SSC) tayini yapılabilmektedir. Bu durumda akım hızı ve tortu miktarının eş zamanlı olarak ölçülebilmesi, araştırmacılar için tortu taşınımı çalışmalarında gerekli olan önemli bir veriyi sağlamaktadır.

Son yıllarda yapılan çalışmalarda akustik aletlerin performansı araştırılarak akustik sinyal geri gelme oranı (SNR) ile SSC arasında değişik formüllerle ilişki kurulmaya çalışılmıştır. Ancak bu çalışmalar tek bir çalışma sahasıyla sınırlı olmakla beraber bu çalışmalarda tanecik büyüklüğü ve sıcaklık etkisi dikkate alınmamıştır. Bu çalışma kapsamında ADV'nin SSC tahminindeki performansına etki edecek parametreler araştırılmıştır. ADV'nin SSC tahminindeki güvenilirliğini araştırmak için farklı akarsularda değişik akım ve sıcaklık şartlarında ölçümler yapılmıştır. Ölçüm yapılan istasyonlardan toprak numuneleri alınarak zemin dane çapı analizleri yapılmıştır.

SSC ve SNR arasındaki ilişkiyi bir formülle ifade edebilmek için, ölçümlere etki eden tüm parametreler dikkate alınarak çoklu regresyon analizi yapılmıştır. Çoklu regresyon analizinin sonuçlarına göre hesaplanan SSC değerinin en az üç parametreye bağlı olduğu saptanmıştır ki, bunlar; su sıcaklığı, zeminin ortalama danecik büyüklüğü ve granulometri eğrisinin şeklidir. Ayrıca bu çalışma kapsamında akarsularda sel durumunun ve sıcaklığın ADV'nin SSC tahminindeki performansına etkisi araştırılmıştır. Sonuçlara bakıldığında, SSC'nin limit değerin (SSC>400 mg/l) üzerine çıktığı durumlarda, sel durumu gibi, ADV'nin SSC ölçümlerinde başarılı olamadığı gözlemlenmiştir.

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CHAPTER 1

INTRODUCTION

1.1. Objectives

Two thirds of the earth's surface is covered by water and more than 75 percent of the human body is consisted of water. Water is one of the primary elements responsible for life on earth. Water circulates through the land transporting, dissolving, replenishing nutrients and organic matter. Also, water is a key component in determining the quality of people lives. On the other hand, today, people are concerned about the quality of the water, because the water is polluted with hundreds of toxins and impurities. Water pollution is a major problem in the global context. It has been suggested that it is the leading worldwide cause of deaths and diseases (Hidaka and Yakovleva 2004). In addition to the acute problems of water pollution in developing countries, industrialized countries continue to struggle with pollution problems as well. Because of the deterioration of the quality of water by different sources of pollutants and unconsciousness of the people about sustainable use of water, the world’s fresh water resources have significantly diminished. Therefore, studies dealing with water quality and quantity have become important for the people and for the governments in recent years. Thus the parameters affecting the water resources should be carefully examined.

For centuries, rivers have become the most important fresh water resources. Now people believe that, civilization and the economic development of a society are closely related to the ability to maximize the benefits and minimize the damage caused by rivers. In order to sustain cultural and economic developments along a river, it is essential to understand the parameters those affect the water system. Sediment is one of the parameters affecting the water systems. The sediments have critical importance to understand overall condition and health of the complex system. Moreover, sediment processes are an extremely important part of many ecosystems, as well as of primary importance to particular species. For example, the sediments have effects on the aquatic habitat, engineering structures (bridges and dams…) and quality of the water. The amount of the sediment in water is important for water structures, especially for dams since, the lifetime of the dams depends on the amount of the sediment accumulation rate. It is also important in the formation of beaches, spits, sand bars and it provides substrates for aquatic plants and animals. Sediment also provides nutrients and minerals vital to the health of downstream ecosystems. Furthermore, a river frequently adjusts its cross-section, longitudinal profile, course of flow and pattern through the processes of sediment transport, scour and deposition. Therefore, the basic principles of the sediment should be understood so that these principles can be applied to the solution of engineering problems associated with natural disasters and human activities.

Sediment refers to the particles (such as sand and other soils) which settle, or deposit on the sides and bottom of water bodies. Sediment reaches aquatic areas in three main ways; watershed erosion, mass wasting events, such as landslides, and shoreline erosion. The key places that sediment comes from are the steep slopes with unstable or unprotected soils, landslide hazard areas and unarmored channels. The movements of sediment particles in the water can be defined usually in two modes; as bed load and suspended load. Bed load is defined as the part of the sedimentary load of the stream which moves, slides, rolls or saltates bed particles along the streambed by the flow or tractive force of the moving water and particles. The particles are in contact with the bed practically all of the time. Briefly, bed load is the material which moves over the bed. Other form of sediment movement is suspended load, which is the sediment that is supported by vertical components of the velocities in turbulent flow while being carried downstream by horizontal components of these velocities for appreciable lengths of time. Particles those are small enough to be in suspension shift up and down in the flow and presumably move readily into and out of the bed layer (Ongley 1996).

The subject of sediment transport has strong relation with the quality of the water and health of engineering structures. Therefore, the topic has been studied for centuries by engineers and river morphologists. Different approaches have been used to solve engineering problems. Results obtained from different approaches often differ drastically from each other and from observations in the field. Some of the basic concepts, their limits of applications, and the interrelationships among them have become clear only in recent years. So, today, sediment transport measurements in the rivers have critical importance for science and for practical applications conducted by governments. The governments spend a lot of time and money for sediment measurements. For example in Turkey, Electrical Power Resources Survey and Development Administration (EIEI) has executed the sediment transport measurement since 1970 in almost all rivers all around the country. EIEI regularly collects water samples using different methods and analyze for sediments. The results of the sediment measurements of rivers have been published every six years periods.

A wide variety of techniques have been used to measure suspended sediment concentration (SSC) in rivers, most common methods are conventional samplers, optical method instruments and acoustic Doppler instruments. The newer technique optical method instruments, use the turbidity of the water as an indicator for the concentration of suspended sediment in the water column. These instruments measure turbidity degree of the water to learn about quantity of suspended sediment. Briefly, turbidity stands for the degree of clearness of water. The greater the amount of total suspended solids in the water, the murkier it appears and the higher the measured turbidity. So, optical method instruments can measure SSC within acceptable error percentage for the strong relation of turbidity and suspended sediment.

The measurement of suspended sediment in a stream can be realized by using an indirect method, the conventional samplers (Figure 1.1). In this method, the concentration and velocity measurements are combined to obtain the suspended sediment. Therefore, samples taken by any sampler should truly represent the sediment concentration of streams at the measurement points. The sampling place in the water should be considered in order to realize the suspended load. Suspended load could be obtained by multiplying the mean concentration and the discharge in the cross-section. Therefore, sampling verticals in the cross-section should be selected carefully in order to obtain correct SSC measurement data.

There are two main sampling methods, namely, depth integrating method and point integration method used in sediment measurements. In depth integrating method, the sampler is moved first down and then up with selected velocity related to water velocity that during one cycle movement bottle of the sampler has to be fully filled. Averaged concentration along the depth of the water is obtained with this method of measurement. It is not necessary to force the down and up velocities equal, but keeping it constant along one way is recommended. If water depth is greater than 9 m, verticals are divided into several parts and samplers are taken for each part separately. In the other method, the point integration method, the samplers are placed at the points along verticals. These sampling points can be three points in the water column, one from surface, second from mid-depth and third from bottom. The average sediment concentration of these points is considered to be the suspended sediment concentration of that cross-section (Kumcu and Kökpınar 2004).

Figure 1.1. Conventional Sampler (Kumcu and Kökpınar 2004).

The suspended sediment samplers can be divided into two main groups depending on their type of operations, namely, the instantaneous suspended sediment samplers and the time integrating suspended sediment samplers. These samplers are designed and manufactured in such a form and geometry that they do not disturb water flow during sampling. The instantaneous suspended sediment samplers have many limitations for field use; therefore they are not preferred. The time integrating suspended sediment samplers can also be subdivided into two groups according to the sampling method which are depth integrating samplers and point integrating samplers. The point integrating samplers are designed to collect through time a sample at a given point in the stream vertical. Specially designed air compression chamber is added in the point integrating samplers to prevent initial sudden inrush. In this design, the air chamber and the sample container are interconnected and the air chamber has a permanent opening at the bottom. That design of the instrument helps to collect water sample with the intake velocity equal to the undisturbed flow velocity. Furthermore, at the end of the sampling, the dried sample measures the time-averaged sediment concentration. The depth integrating sampler transverse down and up with a selected constant velocity along the complete depth of the stream and collects a sample having the average concentration in the vertical. Therefore, a special attention has to be paid to the sampler velocity in the vertical. Finally, the conventional samplers have many commercial models classified with their use in stream depth and velocity (Kumcu and Kökpınar 2004).

The two techniques, the optical method instruments and conventional samplers, are frequently used for measurement of suspended sediment and also they have reasonably acceptable results. However, they are intrusive, labor intensive and expensive. All of these instruments require support or sensor cables and it is so difficult and dangerous to deploy them in deep flows. Moreover, often instruments have large uncertainty due to spatial and temporal variability of suspended sediment concentration in the water column. In addition, these instruments have many limitations in field applications. Therefore, there are many studies investigating different techniques to measure the amount of the suspended sediment in water. The starting point of these studies is that how can we prevent the harmful effects of the sediment transport and which methods can be utilized to measure the sediment concentration more accurately and in an easier way, while their primary use is for velocity measurements. The acoustic Doppler current meters (ADCP, ADP and ADV), provide information about the quantity and type of particulate matter in the water, after appropriate calibration. Acoustic Doppler current meters transmit focused pulses of sound, with known frequency, into the water, and the observed Doppler shift in the sound that is reflected back from suspended particles in the water is used to compute water velocities. Most acoustic instruments for measurement of flow velocities can measure water temperature. Since this is an easily measured scalar quantity and influences the speed of sound through the water, it must be known for accurate range-gating of the reflected signal which is used to compute velocities. The characteristics of the backscattered signal have also been used to infer information about the concentration of material suspended in the water.

Acoustic Doppler velocimeters (ADVs) of any design thus have the potential to simultaneously measure velocity, temperature, and suspended sediment concentration with a single instrument, in a minimally intrusive way, since they feature sampling volumes that are remote to the instrument. Moreover, instruments capable of resolving profiles can collect flow velocity and sediment concentration time series data over the whole water column. Recent research has been on the use of ADVs to measure SSC, since an acoustic instrument can replace conventional turbidity meters and provide information about velocity, temperature of water and sediment concentration time series simultaneously.

Using acoustic instruments for SSC measurements in shallow waters have many advantages. When an acoustic instrument is calibrated for a water system, no additional sensor is needed to measure SSC, which provides the researchers the simultaneous measurements of velocity and concentration required for most sediment transport studies. Also, SSC measuring instruments use optical methods which have limitations for biological fouling. In spite of the advantages, the primary barrier to the development of a comprehensive sediment concentration prediction methodology by acoustic methods has been the lack of sufficient coupled observations of SSC and acoustic Doppler velocity measurements to develop such a relation. One of the limitations of using ADV for SSC predictions is that; ADV measures the velocity of acoustic targets (e.g. solid particles) rather than the fluid velocity where the sediment and fluid are assumed to travel at the same velocity. This assumption is likely to be valid only when considering fine sediments, dominantly in suspension. For coarser particles (e.g. sand) this effect may introduce additional uncertainty. Another limitation is that; as the sediment concentration increases, acoustic waves are absorbed in sediment-laden flow and attenuated where the ADV can not operate properly in high sediment concentrations. These limitations should be taken into consideration when predicting SSC using acoustic methods. (Elci et al. 2009)

The main goal of the study is to improve the methodology for predicting SSC using ADV backscatter data in a quasi-steady scenario as found in a river or stream. The effects of water temperature and particle size distribution on predictive capability were investigated through measurements conducted in different streams in low flow and flood conditions. SSCs were predicted from SNR output from a handheld ADV by applying the sonar equation for sound scattering from fine particles (Sontek 1998). The acoustic signal strength is inversely proportional to the range (R) from the transducers, but also depends on the absorption coefficient of water. Thus, the signal strength is a function of sediment size and salinity, sound frequency and temperature. Carbo and Molero (2000) showed that the absorption coefficient for sound in water decreases as water temperature increases. Once the ADV is calibrated against a separate SSC measuring device, the changes in SNR can be related to SSC values. In this case, signal strength measurements reported by an ADV were compared to SSC estimates reported by a water quality meter.

In this study, a new equation was derived relating SSC to SNR, dimensionless mean sediment diameter, coefficient of gradation of particle size distribution, and water temperature dependent dimensionless absorption coefficient. The coefficients of the proposed equation were obtained using multivariate analysis.

1.2. Literature Review

Several researchers investigated acoustic instruments' performance to estimate suspended sediment concentration (SSC). Formulations were derived with relation of SNR (Signal to noise ratio) measured by an acoustic doppler velocimeter and SSC of the water. Kostaschuk et al., 2004 investigated the acoustic instrument capacities including velocity, bed load and sediment concentration measurements. They used acoustic Doppler current profiler (ADCP) as the acoustic instrument for deep water conditions. They tested the ADCP's water velocity, bed load and suspended load measurement capacities. They also investigated the advantages of ADV for the SSC measurement for the facility and reliability considerations. Traditional instruments which measure suspended sediment measurements require support and sensor cables and thus it is difficult and dangerous to deploy them in deep flows, and their exact position within the water column is often unknown. However, acoustic instrument can collect data in the whole water column in definite locations. Moreover, they pointed out that acoustic frequencies have different sensitivities to particle size.

There are many laboratory studies conducted for utilization of acoustic instruments for suspended sediment concentration Hosseini et al., 2005, used an experimental setup to explore ADVs performance. They compared the acoustic instrument to other traditional and optical method instruments. They observed strong relation between the concentration of the sediment and signal to noise ratio of the instrument. Although they stated the importance of the particle size of the sediment, the sediment composition was not included in their analysis. The main finding of the paper is the limitation of ADV in high sediment concentration of water system. They found that, when the sediment concentration increases up to 50 g/l, acoustic waves are absorbed in sediment-laden flow and attenuated. So the ADV can not operate properly for suspended sediment concentration measurements.

Wren et al., (2001), conducted experimental research to explore the ADVs capacity to measure SSC. The equipment and procedures used in developing hardware and software for the acoustic technique in two sets of laboratory flume experiments were presented. Both implicit and explicit methods were used to convert backscatter data into sediment concentrations.

Gartner et al., (2002), also compared the acoustic method with the optical method. They showed that, acoustic instruments are non-intrusive, much less susceptible to biological fouling than those from optical instruments, and provide time series of acoustic backscattered signal (SNR) profile for improved temporal resolution of SSC estimates. Successful estimates of SSC from SNR provides promise that this technique might be appropriate and useful for determining SSC from commercially available instruments such as acoustic Doppler current profilers (ADCPs). They also stated that, in spite of significant advantages to the method, users must be aware of important limitations of the technique. Gartner et al. 2002 emphasized that the method has some advantages over other methods but suffers from the same limitation as any single frequency sensor as far as being unable to differentiate between changes in size distribution and concentration.

Another comparison of optical method with acoustic method for measurement of SSC was conducted by Jay and Orton (1999). They utilized an ADV, pump samples and owen tube results to understand how intertidal variations in SSC properties affect the ADV-SSC relationship. They investigated the time variability of the relation between the ADV and concentration changes of sediment. Their research also showed the logistic problem of obtaining actual suspended sediment calibration samples in the near vicinity of an ADV. Moreover, they pointed out that the effects of salinity on the readings provided by the acoustic instrument. Although they recognized the effect of the salinity for the calibration of ADV to measure suspended sediment concentration, they did not provide a formulation for relating salinity to SSC.

Another important research was conducted by Creed et al., (2001) in the Newark bay. They compared the acoustic instrument with the optical instrument and laser forward scattering instrument in the field. Simultaneous measurements were made in the field with those three instruments. It is important to note that they could not directly calibrate the acoustic instrument with others, because the studied data of the acoustic instrument (close to bed) were not in the same sampling volume with other instruments. Instead they selected to examine the acoustic variation of the backscatter signal with respect to relative sediment concentration and, more importantly, to grain size distribution. The laser forward scattering instrument output voltage was correlated with the concentration for each of the 32 sediment size classes measured by the acoustic instrument to determine which grain size classes are most accurately measured by the acoustic instrument. They determined that the correlation between the two signals is greater than 0.7 for size classes between 0.075 mm and 0.25 mm. Finally, the paper indicated that the results for acoustic instrument could be used for the estimation of suspended sediment concentration in the 0.075 to 0.25 mm size class range.

Another study was performed by Alvarez and Jones (2002) where they studied the relation between the acoustic instruments backscattered acoustic signal strength and the optical instrument to measure suspended sediment concentration. Before the correlation of the SSC and backscatter data, acoustic instrument data was calibrated for the geometric spreading and range conditions. The measurements were made corresponding time and location with acoustic and optical instruments. A linear regression procedure was applied and the calibration curve was graphed. They provided regression parameters SSC and SNR given with 95 % confidence intervals and 0.80 regression coefficient.

Wall et al., (2006) investigated the performance of acoustic instrument on measuring suspended sediment concentration in Hudson River in New York. They focused more on the limitation of acoustic instruments. The major limitation of acoustic instrument was described as the single frequency level of the instrument that can not be seen rapidly in changing water conditions. Also, they considered the relation between the particle circumference and acoustic frequency differences as the limitation of instrument. They calculated the concentration of sediment with acoustic instrument by using some normalization in the acoustic data. They normalized the acoustic data by using the Sonar equation parameters like transmit power and length, geometric spreading and absorption of the water.

In a recent paper, Thorne and Meral (2007) used multi-frequency acoustic backscattered instrument in their research. The main topic of the research was to obtain the sediment parameters from the backscattered signals. Their aim was to provide coastal scientists, who use acoustics for sediment transport measurements, with simple expressions which best represent, the observed scattering properties of sandy sediments. To obtain simple formulation for the scattering properties all the published data available on scattering by suspensions of sandy sediments were collected. These data have also been augmented by some measurements taken on single irregularly shaped particles. All the data sets were formulated in terms of the form function and normalized total scattering cross-section. Briefly, they made a laboratory mechanism in this study that a laboratory tank was filled with water and a suspended sediment jet was formed with in the tank using a nozzle and pump arrangement. Acoustic backscattered measurements from the sediment jet were collected using beach sand sieved bed. The measurements of acoustic instrument compared with rigid movable sphere models. Within the error bars of the regression fit, there was essentially no significant difference between the predicted and observed values. They put forward formulations for the prediction of sediment particles sizes from the acoustic data for the sandy beds water.

With the exception of these studies, there are many studies which have been carried out for the acoustic instrument calibration to measure suspended sediment concentration. The major deficiency of these studies that they studied with restricted data. These studies were limited to a single river or basin and there is no chance to compare data in another water or bed condition. Almost every researcher and also the developers of the instrument mention that the particle size effect on the acoustic instrument could not be documented for different soil types. Furthermore, the combined effect of sound absorption and other parameters like salinity, temperature and particle size on ADV's performance for SSC prediction is still not completely understood. Based on these studies, the collection of as many data as possible from different water conditions and river beds are very important for developing a general equation relating backscatter data to SSC. Moreover, the granulations of suspended sediment have another key factor for the studies. In this study, we investigated ADV's capability for predicting suspended sediment concentration measurement with considerations of these factors, including water temperature and river bed soil type.

CHAPTER 2

MEASUREMENT SITES

The simultaneous suspended sediment concentration measurements with ADV and water quality meter were executed in Aegean region (Figure 2.1). Aegean Region is one of the 7 census-defined regions of Turkey. It is located at the western part of the country, bounded by Aegean Sea on the west. The region consists mainly of rolling plateau country well suited to agriculture. It receives about 520 millimeters of rainfall annually. The region occupies 11% of the total area of Turkey with its 79.000 square kilometers of land. Most of the population and cities are concentrated on the coast line because of its convenience for sea transportation and tourism. The Aegean region is also both industrialized and agriculturalized.

The Aegean region has fertile soils and a typical Mediterranean climate with mild, soft, verdant springs, hot summers, sunny autumns and warm winters. Aegean region has perpendicular mountains to its shores and many valleys between them, thus permitting the sea climate to reach inner parts of the region, although some of the provinces inland show characteristics of Continental climate. The broad, cultivated valley lowlands contain about half of the country's richest farmland and they are densely populated that the region contains the country's third largest city and a major manufacturing center. The K.Menderes, B.Menderes and Gediz plains named after the rivers flowing through them.

Observations were conducted in Gediz and B.Menderes rivers and Tahtali, Sasal, Alacati, Gulbahce and Cine streams in the Aegean region (Figure 2.2). B.Menderes is the largest river of the Aegean region. It is fed by many streams like Işıklı, Banaz, Çine, Çürüksu and Akçay along its journey. River has approximately 10,000 hm^3/year water capacity. The river also has the annual runoff in the order of 3 km^3 which accounts for 1.6% of Turkey’s water potential (MDA 2008). It rises on the Anatolian plateau south and west of Afyon and flows westward through a narrow valley and canyon. At Sarayköy it expands into a broad, flat-bottomed valley with a typical Mediterranean landscape, covered with fig trees, olive groves, and vineyards. Near the town of Aydın the river turns southwest, discharging into the Aegean Sea after a course of about 584 km. The ancient port of Miletus, which lay near its mouth, has long been landlocked and abandoned because of silting. The river's classical name, Maeander (whence the English *meander*), is derived from the winding course of its lower reaches (MDA 2008).

The Maeander is everywhere a very deep, but not very broad, so that in many parts its depth equals its breadth. Since it carries in a great quantity of mud, it is navigable only for small craft. It frequently overflowes its banks; and, in consequence of the quantity of its deposits at its mouth, the coast has been pushed about 314 or 471 meters further into the sea, so that several small islands off the coast have become united with the mainland (Ozcan 2008).

B.Menderes River is an essential water resource for production of olive and cotton, which are the main agricultural products of the river basin named after the river. B.Menderes river basin, an irrigation area of 24976 km^2 and 3.2% of the total area of the country, is located in the southwestern part of the Turkey (MDA 2008). It is an important agricultural source for Aydın province and lies from Denizli border to Aegean Sea. Mean annual precipitation in the river basin is 635 mm and total mean annual evaporation is 2122 mm. Precipitation occurs mainly in the winters while during the summer irrigation period there is very little rain (Ozcan 2008). B.Menderes basin is a graben area contains Paleozoic metamorphic formations consisting of gneiss, schist, cryistalline limestone. The land use in the B. Menderes river basin is as follows: 40% agriculture, 45% forest and scrubland, 10% meadow and pasture, 3% fallow lands, 1% settlement, 1% surface water (MDA 2008).

The basin is engineered into extensive water resources systems, including 13 dams and a large number of irrigation schemes. The total irrigated area in the basin is more than 88000 ha. The agricultural economy of the basin depends on the irrigated cotton cultivation, corn, fig and olives. Total population of the basin is 2.5 million. 37% of this population is involved in agricultural activities. The region is rich not only in terms of agriculture but also developing in industry, the major one being the textile industry, and in tourism. These activities indicate significant demand for water. Unfortunately, B.Menderes River has been polluted for the last ten years. Pesticides used in agriculture and uncontrolled wastewater discharge from factories are the main reason of the river pollution (UNDP 2007).

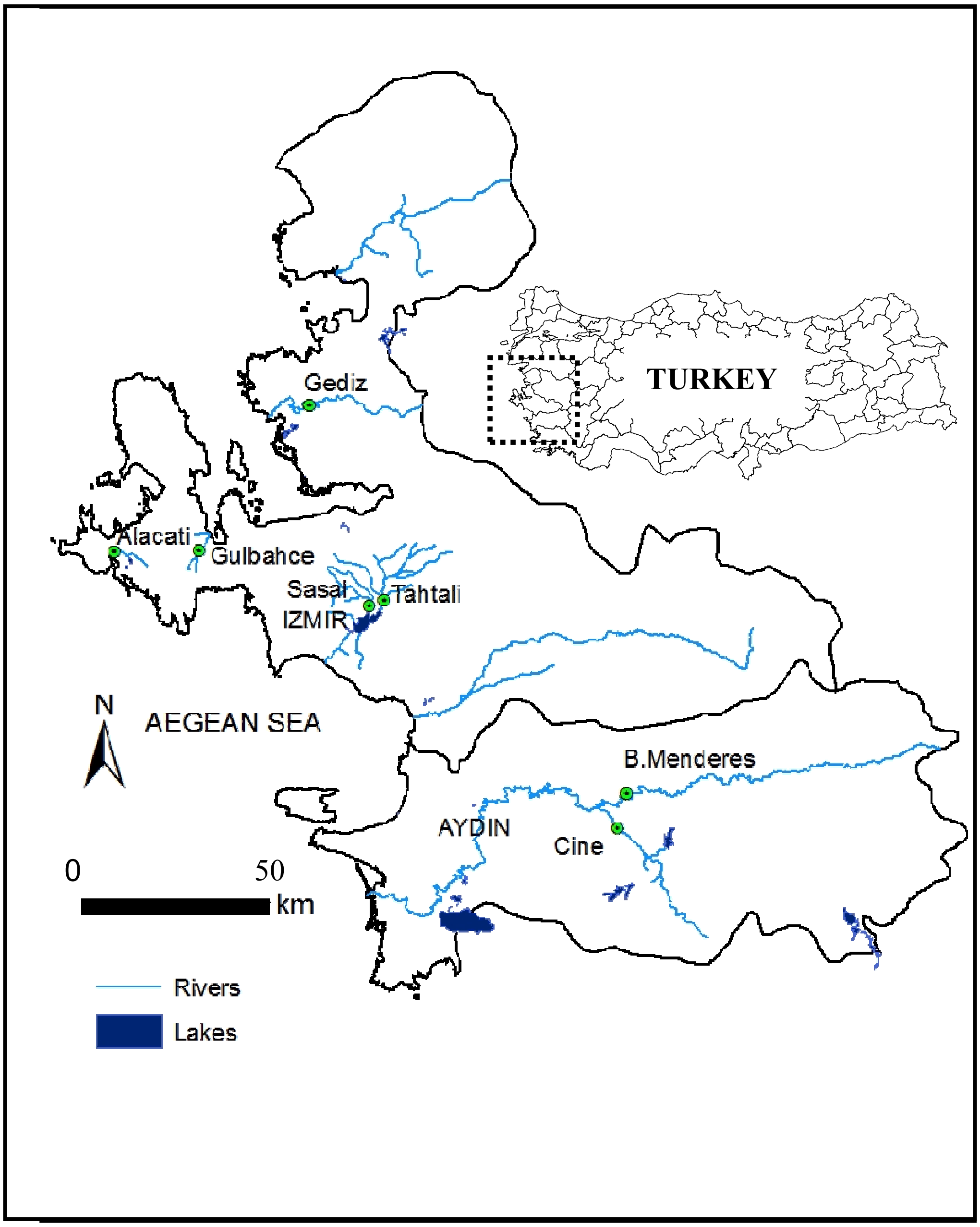


Figure 2.1. Measurement locations shown in a map

The Gediz River is the second largest river, after the B.Menderes, flowing from the Anatolian hinterland into the Aegean Sea (Figure 2.1). Rising from Murat mountain and Şaphane mountain in Kütahya Province, it flows through Manisa Province and discharges into the Gulf of Izmir near the village of Maltepe in the Menemen district. Gediz River is a very important water resource for the agriculture of the region. The length of the river is approximately 401 km and the area of river basin is 17,500 km^2. The river irrigates very fertile plains near Izmir and Manisa (MDA 2008).

Gediz River Basin, neighbors it the city of Izmir, where water scarcity is a significant problem is selected as it represents a typical case for a basin consisting of large scaled irrigation schemes with large agricultural water demands, suffering from water shortages in meteorological dry periods. Water allocation problems among various use mainly irrigation with a total command area of 110,000 ha versus the domestic and fast growing industrial demand in the coastal zone (MDA 2008). Gediz River is also currently considered as highly polluted, due to uncontrolled discharges from factories and sewage systems nearby. Although local governments and civilian societies struggle for the remediation of the river, it contains high amount of contaminants (Loon et al. 2007.)

The Mediterranean rainfall regime is dominant in the Gediz River basin. It has hot dry summers and cool winters. The average annual rainfall amount is aproaximately 500 mm, vary between 300 mm and 850 mm every year. Precipitation is concentrated in the winter period. Precipitation in the basin ranges from over 1 000 mm per year in the mountains to 500 mm per year near the Aegean coast (MDA 2008). In the mountains the precipitation mainly falls in the form of snow. The basin is bounded by mountain ranges in the northeast and in the south. The northeastern plateau gently slops southwestwards, with mountains over 2000 m elevation. Precipitation from the northeastern plateau drains into the Gediz River. The southern mountains have a steep drop on their northern flanks. The western part of the basin is a flat delta with elevations below 200 m (Fao-Aquastat 2004).

The Gediz river basin in western Turkey has long been an important center for agricultural production, dating back to the earliest civilizations of the Lydian kingdoms in the pre-Hellenic period. In terms of climate it is ideally suited for irrigation development (Fao-Aquastat 2004). In the spring, the combination of stored soil moisture and snowmelt has facilitated a long tradition of irrigated agriculture both from the main Gediz river and from tributary streams. Before the development of modern water resources infrastructure, there were several areas subjected to flooding during winter months which were used for summer rice cultivation, and winter wheat and barley that received some irrigation. Normally too little water was available for substantial summer cultivation or perennial agricultural crops. In tributary areas about 20,000 ha irrigation is small-scale, with extensive areas of fruit orchards and vegetables, plus wheat and barley cultivation. The Gediz river basin is one of the largest producers of raisin in the world. The basin also serves as the source of much of the drinking water for the city of Izmir, the third largest city in Turkey with a population exceeding 3 millions.

a) Sasal River **b)** Sasal River (Flood) **c)** Tahtali River

d) Gediz River **e)** Alacati Stream **f)** Gulbahce Stream

g) B.Menderes River **h)** Cine Stream

Figure. 2.2. Views from streams and rivers where measurements were conducted

Cine stream is the largest tributary of the B.Menderes River at the South-West part of Turkey (Figure 2.1). Cine stream has a length of 359 km that runs through the deep valleys. The water obtained from Cine stream is used for various purposes, such as irrigation, potable water and cooling water for Yatağan Thermic Station. The Cine stream was called as Marsyas in ancient times. The name came from the unfortunate poet of the ancient Greek mythology. The only reservoir of the stream called Cine reservoir and hydroelectric station with an expected capacity of 188 GWh/year under construction by 2009. The height of dam is 118 m and it has been planned for irrigation, flood control and hydropower. Dam site, valley sides, energy tunnel route and pen stock route are composed of metamorphic rocks (Dirican 2005).

Cine basin which has mediterranean climate with hot-dry summers and mild-wet winters. Although, Cine stream runs through the deep valleys, it irrigates fertile soils in Cine and Aydın plains (Dirican 2005). Cine stream has clear water except during winter. Water is polluted due to washing of olives by the farmers living by the stream. Also, olive production waste is dumped into the stream by the farmers. Therefore, Cine stream has very turbid water in the winter months, and fish can not survive in those months.

Tahtali and Sasal streams are located in the north of the Tahtali reservoir and are the major streams feeding the reservoir (Figure 2.1). The Tahtali and Sasal streams are the major water resources of fertile Tahtali plain. Tahtali Stream passes from between the hills to the southwest of the basin and flows into the Tahtali reservoir. Streams are nourished by water sources in mountains and precipitation and have very low flow rates during summer because of evaporation and use for irrigation. The lengths of the streams are approximately 30 km for Tahtali and 7 km for Sasal. Although Tahtali Stream was highly polluted in previous years, after the construction of the dam and the establishment of absolute protection zones, it now is mostly remediated. The water quality of the two streams can be accepted good as defined by the water quality index (Elci 2008)

The Tahtali reservoir was constructed, where Tahtali and Sasal streams merge, in 1996. The dam was constructed to supply 4.055 l/s domestic and industrial water for the city of Izmir. Also, the reservoir provides 40% of the fresh water used in the city of Izmir. The construction of Tahtali dam was completed in 1996. The topographical conditions were suitable for supplying clean water from the reservoir to the Izmir by gravity flow. The maximum reservoir capacity is 306.65 hm^3 and height of the dam from river bed is 54.50 m. The reservoir has 23.52 km^2 water surface areas and the deepest place of the dam is 27 m and the average depth of the water is 15 m.

The Tatar (Gulbahce) stream is placed at the north side of the Izmir city (Figure 2.1). The stream begins its journey from high hills around the Aegean Sea side. The stream nourishes from the precipitations and the insignificant water resources on the hills. While the main water resource of the stream is the rainfall, the stream is dry during low rainy mediterranean climate summer period. The stream is used for irrigation in very limited agricultural areas. Stream has non-polluted water capacity from the hill to the sea.

Alacati stream is the outflow of the Kutlu Aktas reservoir located in Izmir (Figure 2.1). At the time of measurements, reservoir water storage was significantly reduced and because of evaporation, no water was being released from the reservoir. On the other hand, stream bed becomes fen because of the sea water effect. Measurements were made 1 km upstream of the cross-section where the stream reaches the sea.

CHAPTER 3

INSTRUMENTATION

Measurements of suspended sediment concentration by a water quality meter (WQC) and flow velocities by acoustic Doppler velocimeter (ADV) (Figure 3.1) were conducted simultaneously in the streams (Figure 3.3). Sontek's Flowtracker (10,000 kHz ADV system) is utilized in this study. The Flowtracker Handheld ADV is a single-point Doppler current meter designed for field velocity measurements. The Flowtracker uses an adaptation of the Doppler principle to measure water velocity. Velocity can be determined by measuring the change in pitch of sound reflected from a moving target.

a) FLOWTRACKER (ADV) **b)** WATER QUALITY METER (WQC)

Figure 3.1. Instruments used in the study

Acoustic Doppler current meters (ADCP, ADP and ADV) are non-intrusive remote sensing systems designed for velocity measurements. Acoustic Doppler current meters transmit focused pulses of sound, with known frequency, into the water, and the observed Doppler shift in the sound reflected back from suspended particles in the water is used to compute water velocities. Most acoustic instruments for measurement of flow velocities include measurement of water temperature, since this is an easily measured scalar quantity and influences the speed of sound through the water. This must be known for accurate range-gating of the reflected signal used to compute velocities.

Acoustic Doppler current meters are attractive for measuring instantaneous water velocities enabling measurements of turbulence, Thus, they have been used in many studies involving measurements in rivers, streams, channels, lakes, reservoirs, ocean, coastline, harbors and also in the laboratory (Rennie et al. 2004, Kostachuk et al. 2004 and Hosseini et al. 2005)

The acoustic instruments are produced with modifications according to measured media; however, all of them use Doppler shift principle. For instance, acoustic Doppler current profilers, ADCPs, are utilized for flow measurements in deep water conditions. On the other hand, acoustic Doppler velocimeters, ADVs, are used for flow measurements in shallow water conditions. An ADCP measures the three dimensional velocity of water by dividing water column into cells. ADCP measures velocities and acoustic return signal strengths in all cells according to the depth of water. The measurement location within the water column from the ADCP transducer is a function of the time at which the return signal is sampled. By measuring the return signal at different times following the transmit pulse, the ADCP measures the profile of water velocity at many distances from the transducer. ADCP has limitation for water depth (blanking distance), since minimum water depth is required for ADCP applications. The blanking distance is a result of the inability of the instrument to measure velocity close to the transducer because the same transducer is used to both transmit and receive acoustic signal. The limitation of ADCP is that a short time delay is needed after transmitting signal to allow acoustic ringing to decline to the point that a received signal can be interpreted (Hosseini et al. 2005.)

In shallow waters (less than 1 m), ADV is more useful than ADCP because ADCP can not correctly measure for a certain depth (blanking distance ~ 0.5 m). ADV is a high-precision instrument which measures three dimensional water velocities by 1% precision at the water column. However, ADV is a single point Doppler current instrument whereas water velocity must be measured at several points along a cross section to obtain flow rate in a stream. ADV, which is useful for shallow water systems such as; rivers, channels and streams, can measure the water velocity at any depth of water. There are currently several manufacturers of commercial ADVs (e.g. SonTek, RDI, and Nortek) and several types of ADV systems with different frequencies. In this study, a 10 MHz ADV system, (Flowtracker) designed for streams is used. Other types of ADVs include microADVs designed for laboratory use and triton ADVs designed specifically for low-flow water systems.

The Flowtracker is a bistatic Doppler current meter. Bistatic means separate acoustic transducers are used for transmitter and receiver. The transmitter generates sound concentrated in a narrow beam. The receivers are sensitive to sound coming from a narrow beam. The receivers are mounted such that the beams intersect at a volume of water located a fixed distance (10 cm) from the tip of the probe. The beam intersection determines the location of the sampling volume (the volume of water in which measurements are made).

The ADV measures the change in frequency (Doppler shift) to measure water velocity (Figure 3.2). The transmitter generates a short pulse of sound at a known frequency. The sound travels through the water along the transmitter beam axis. As the pulse passes through the sampling volume, sound is reflected in all directions by particulate matter (sediment, small organisms, and bubbles). Some portion of the reflected energy travels back along the receiver beam axes. The reflected signal is sampled by the acoustic receivers (Rehmel 2007).

The Doppler shift is proportional to the velocity of the particles along the bistatic axis of the receiver and transmitter. The bistatic axis is located halfway between transmit and receive axes. Knowing the relative orientation of the bistatic axes allows the ADV to calculate 2D or 3D water velocity.

The Flowtracker collects a burst of velocity data at each measurement location. All data is recorded to the ADV's internal recorder. The user is prompted to enter location, depth, and other data at each measurement location to document the data set. The system collects a fixed-length time-series of velocity at each measurement location. The averaging time at each location is user-specified (10 to 1000 seconds). Velocity data is recorded once per second during the averaging time. For river discharge measurements, the Flowtracker combines velocity data with station location, water depth, and other data to determine total discharge in real-time. When each measurement location is complete, the user is presented with a summary of the velocity and quality control data. All data is stored to the internal recorder for later downloading to a computer for display, archiving, and further analysis (SonTek 1998).

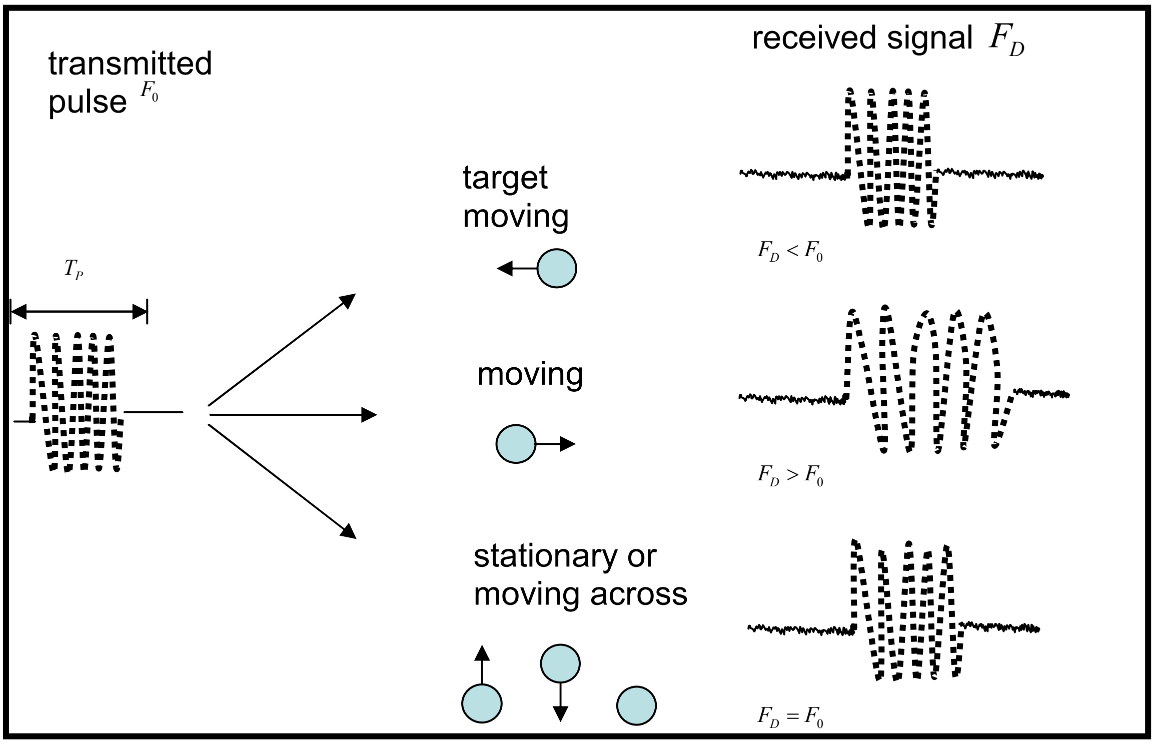


Figure 3.2. The Doppler Shift Effect

Signal-to-noise ratio (SNR) is a measure of the strength of the reflected acoustic signal relative to the ambient noise level of the Flowtracker. SNR is reported in logarithmic units (dB). SNR is recorded with each one-second velocity sample, and mean values are recorded for each measurement location. For the best operating conditions, SNR should be greater than 10 dB (Sontek 1998). The ADV can operate reliably with SNR as low as 3 dB, although the noise in individual measurements will increase. Low SNR indicates a lack of particulate matter. Most field applications have sufficient natural scattering material.

Figure 3.3. Picture from the measurements in the river with ADV and WQC

SNR is primarily a function of the amount and type of particulate matter in the water. While SNR cannot be immediately converted to sediment concentration, it provides an excellent qualitative picture of sediment fluctuations and, with proper calibration, can be used to estimate sediment concentration.

The ADV has a potential for acoustic interference from underwater objects. The system automatically tries to avoid this interference, but the user must be aware of system limitations. Reflections can occur from the bottom, the water surface, or from submerged obstacles such as rocks or logs. The ADV measures velocity in a sampling volume located 10 cm from the tip of the probe (Hosseini et al. 2005). If the sampling volume is on top of or beyond an underwater object, velocity data would be meaningless. When working in very shallow water or near underwater obstacles with the sampling volume within 15 cm, acoustic reflections can potentially affect velocity data.

Doppler current meters, such as the Flowtracker, do not measure movement of water, but actually the movement of particles in the water. We must assume that the movement of the particles in the water is representative of the movement of the water itself. This actually turns out to be a very safe assumption. As such, if you have a body of water where no particles (other than the water molecules themselves) are present, Doppler current meters would not work. Thankfully, natural streams almost always have something else other than just “water” (even if just tiny air bubbles), and the technology is such that even a small amount of particles in the water is usually enough for good measurements (Elci et al. 2009).

The multi parameter water quality meter, WQC-24 developed by DKK-TOA was utilized in this study to measure the suspended sediment concentration of water. The 45 mm outer diameter sensor probe can provide measurement of up to 11 parameters simultaneously out of a total of 17 available parameters up to 100 meters water depth (Table 3.1). The instrument also features an interface part for connection to a global positioning system (GPS), local area network (LAN) printer, cellular phone or other data communication peripherals. Moreover, WQC-24 has data logging storage capacity longer than one month for continuous measurements. WQC built in memory stores data for 35 days of continuous measurements (based on measurements every 15 minutes) (WQC 2006).

Table 3.1. Measuring Parameters and Capabilities of WQC

Parameters	**Display range**	**Repeatability**	**Measurement method**
pH	0~14	+/- 0.05 pH	Glass electrode
Dissolved Oxygen (DO)	0~20 mg/l	+/- 0.1 mg/l	Galvanic membrane electrode
Conductivity	0~10 S/m	+/- 1 % FS	AC-4 electrodes
Salt	0~4 %	+/- 1%	Converted from conductivity value
Total Dissolved Solids	0~100 g/l	+/- 2 g/l	
Seawater Specific gravity	0~50 σt	+/- 0.1 σt	
Temperature	-5~50 °C	+/- 0.25 °C	Thin film platinum resistance
Turbidity	0~800 NTU	+/- 3 % FS	Transmitted scattered light

The multiparameter water quality meter, WQC, can also provide measurement of pH with other parameters simultaneously. WQC measures pH using glass electrode method. In the glass-electrode method, the known pH of a reference solution is determined by using two electrodes, a glass electrode and a reference electrode, and measuring the voltage (difference in potential) generated between the two electrodes. The difference in pH between solutions inside and outside the thin glass membrane creates electromotive force in proportion to this difference in pH. This thin membrane is called the electrode membrane. Normally, when the temperature of the solution is 30 °C, if the pH inside is different from that of outside by 1, it would create approximately 60 mV of electromotive force. The liquid inside the glass electrode usually has a pH of 7. Thus, if one measures the electromotive force generated at the electrode membrane, the pH of the test solution can be found by calculation. In other words, a glass electrode is devised to generate accurate electromotive force due to the difference in pH (Horiba 2009).

WQC measures dissolved oxygen of water, DO, using galvanic membrane electrode method. The galvanic membrane electrode provides an excellent method for DO analysis in polluted waters, highly colored waters, and strong waste effluents. Oxygen-sensitive membrane electrodes of the galvanic type are composed of two solid metal electrodes in contact with supporting electrolyte separated from the test solution by a selective membrane. The basic system of the galvanic electrode is that in the former the electrode reaction is spontaneous (similar to that in a fuel cell), while in the latter an external source of applied voltage is needed to polarize the indicator electrode. In galvanic membrane electrode method and also all of other methods the "diffusion current" is linearly proportional to the concentration of molecular oxygen. The current can be converted easily to concentration units (e.g., milligrams per liter) by a number of calibration procedures. Membrane electrodes exhibit a relatively high temperature coefficient largely due to changes in the membrane permeability. Therefore, temperature range is important for reliable measurements (Hai et al. 2007).

Electrical conductivity of the water is measured simultaneously by WQC using AC-4 electrodes method. The principle of the method is that, a voltage is applied to flat plates immersed in the solution and the resulting current is measured. AC-4 electrodes conductivity measurements contain two drive (current) electrodes and two sense (voltage) electrodes. The drive electrodes are powered by an alternating voltage, and the alternating current that flow is measured to determine the conductivity. 4-electrode conductivity method offers the user significant advantages by minimizing the effect on measurement accuracy from electrode polarization and contamination, as well as eliminating error from cable resistance and connector resistance. The WQC calculate the parameters, salt, total dissolved solids (TDS) and sea water specific gravity by using the conductivity measurement results. (Rika et al. 2001)

Water quality meters (WQC) measure turbidity by using scattered light measurement method (Optical method). Turbidity measurements provide a reading of the amount of scattered light. Turbidity is expressed in terms of the optical property causing the light beam passing through the sample of the fluid to be scattered and absorbed rather than transmitted through the sample. The relationship between the suspended solids in the liquid and the light intensity due to particle scatter is determined by the calibration of the instrument. (Figure 3.4).

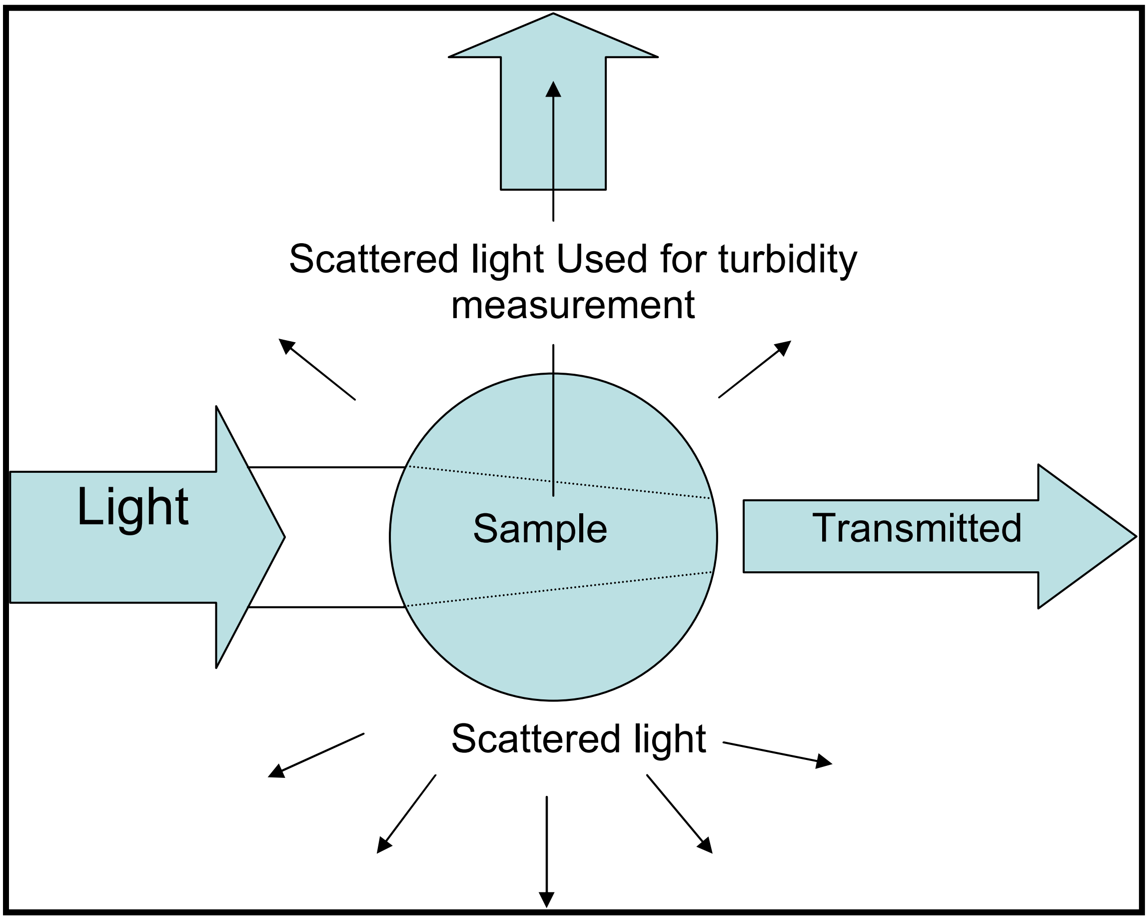


Figure 3.4. Optical Method (Light scattering method) to measure Turbidity

The measuring turbidity refers to how the water is clear. The greater the amount of total suspended solids in the water, the murkier it appears and the higher the measured turbidity. Contrary to the open water zones where the major source of turbidity is typically phytoplankton, resuspended bottom sediments such as clays and silts are the major source of turbidity for shallow water systems. High concentration of the turbidity can modify light penetration and affect the aquatic habitat. Also, turbidity adds real costs to the treatment of surface water supplies and engineering structures. Usually turbidity is measured by nephelometric units (NTUs). The term Nephelometric refers to the way the instrument estimates how light is scattered by suspended particulate material in the water. Especially in river systems turbidity measurements generally provide a very good correlation with the concentration of particles in the water (Water on the web 2006). Furthermore, the relation between the suspended solids in the liquid and the light intensity due to particle scatter is determined by the factory calibration of the instrument (1 NTU of turbidity corresponds to 1 mg/L of SSC). In this study the relationship between suspended sediment concentration, SSC, and turbidity was tested in the laboratory and calibration of a linear relationship was confirmed (Figure 3.5). According to the laboratory tests 1 NTU of turbidity corresponds to 1 mg/L of SSC.

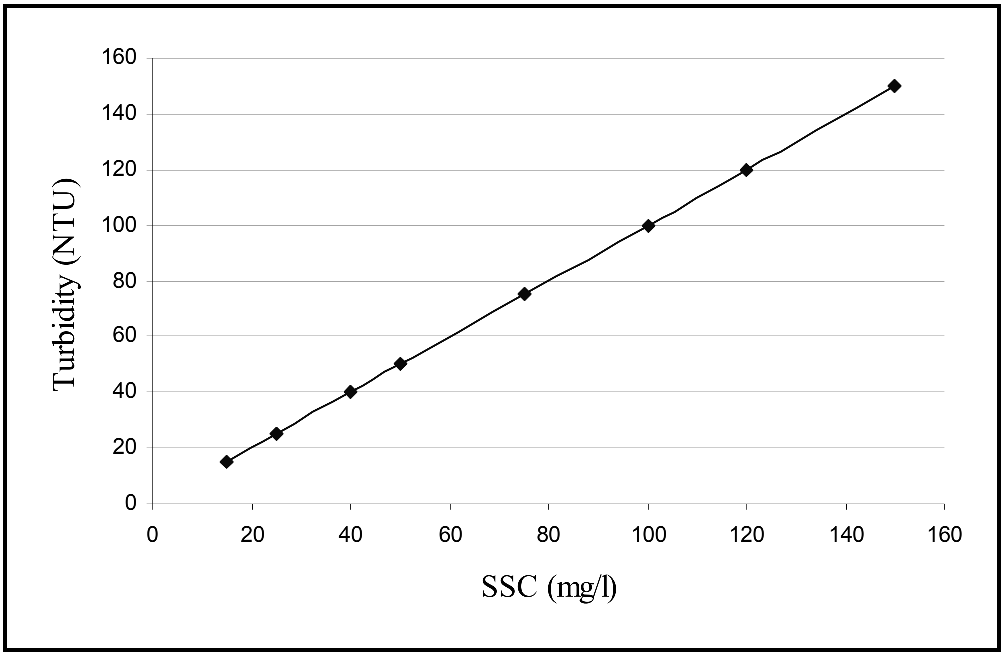


Figure 3.5. Laboratory test results (Turbidity and SSC) (Turbidity=SSC, R^2=1)

CHAPTER 4

METHODOLOGY

Relating scattered signal to suspended sediment concentration in rivers was investigated in this chapter. The methodology was presented in three main sections. The first section includes measurement in rivers with simultaneous data collection. In the second section, principles of the application were described. The principles of the Doppler shift effect and sonar equation were given in this section. Also, sediment properties and analysis were described in this section. Multivariate regression analysis and verification of the formulations were presented in the last section. Furthermore, the flood condition of the rivers was investigated in this section, too.

4.1. Data Collection

Simultaneous measurements were made using Water Quality Meter (WQC) and Acoustic Doppler velocimeter, ADV (Flowtracker) at each river site. The measurements were conducted on different dates at the same locations. The Signal to Noise Ratio (SNR) data, an indicator of scattered particles in water were obtained from ADV and suspended sediment concentrations (SSC) were measured by WQC. Measurements of SSC were conducted with WQC every 5 seconds, whereas Flowtracker measured flow velocity by averaging SNR data every 20 seconds. While SNR values were measured continuously, the results were given by the averaging of values for 20 seconds interval. SSC values were collected manually for five seconds intervals by WQC and the averaged SSC value was calculated by averaging of those four SSC data. Averaged SSC and SNR data were compared and the correlations of the data were investigated using the least squares method.

The simultaneous SSC and SNR data were collected in different water conditions from seven rivers in Aegean region. Different rivers were selected in the analysis to investigate the effect of river-bed soil types. Also, measurements were made on different dates where the temperature of the river water varied from $4^{o}C$ to $28\,^{o}C$.

4.2. Doppler Shift Effect

The Doppler effect (or Doppler shift) was named after Christian Doppler, who first came up with the idea in 1842. He thought that sound waves would have a higher frequency if the source was moving toward the observer and a lower frequency if the source was moving away from the observer (Wikipedia 2008). In other words, Doppler effect is the change in frequency and wavelength of a wave for an observer moving relative to the source of the waves. A commonly used example is a train. When a train is approaching, the whistle has a higher pitch than normal. You can hear the change in pitch as the train passes. The same is true with sirens on police cars and the engines of race cars. For waves that propagate in a medium, such as sound waves, the velocity of the observer and of the source is relative to the medium in which the waves are transmitted. The total Doppler Effect may therefore result from motion of the source, motion of the observer, or motion of the medium. Each of these effects is analyzed separately. For waves which do not require a medium, such as light or gravity in special relativity, only the relative difference in velocity between the observer and the source needs to be considered (Sontek 1998).

The ADV also uses Doppler shift principle to measure velocity of the water. If a source of sound is moving relative to the receiver, the frequency of the sound at the receiver is shifted from the transmit frequency. For ADV the reflection of sound from scatterers (particles) in the water is observed. The change in frequency is proportional to the velocity of the water. ADV measures the suspended particle velocity in the water and assume the flow velocity equal to the particle velocity. This assumption is almost valid for the finer particles which are in the suspended form in the water. The basic operation of a Doppler current meter such as ADV was shown in Figure 3.2.

The change in frequency is calculated by the equation below.

$$F_{doppler} = -2F_{source}\frac{V}{C} \tag{4.1}$$

Where;

$F_{doppler}$ = Change in received frequency (Doppler shift)

F_{source} = Frequency of transmitted sound.

V = Relative velocity of particles

C = Speed of sound

The velocity (V) represents the relative speed between the source and scatterers. The distance between the particles and scatterers affect the frequency. If the distance decreases, frequency increases. The measurement location is a function of the time at which the return signal is sampled.

4.3. Sonar Equation and Acoustic Properties

The strength of the acoustic return signal is a function of the instrument used and condition of the water. The first step when analyzing acoustic signal strength data is to account for instrument specific parameters, making the data instrument independent (or as close to as practical). The data is then analyzed with respect to what is known about the conditions in the water. For this purpose, the Flowtracker uses specifically modified version of the Sonar equation. The Sonar equation, illustrating how instrument's specific variables affect signal strength data, is used to describe the signal strength of the acoustic instrument (Sontek 1998).

$$EL = SL + 10 \times \log(PL) - 20 \times \log(R) - 2 \times \alpha \times R + Sv + RS \tag{4.2}$$

Where;

EL = "Echo Level" is the signal strength as measured by the instrument;

SL = "Source Level" is a measure of transmitted acoustic power;

PL = "Pulse Length" is the length of the acoustic pulse;

R = Range between the transducer and the measurement volume;

α = Sound absorption coefficient (dB/meter);

Sv = Volume scattering strength (dB);

S = "Receive Sensitivity" expresses the relationship between pressure at transducer face and measured signal strength.

The most important aspects of the sonar equation, are the effects of geometric spreading ("$-20*\log_{10}(R)$") and absorption ("$-2*\alpha*R$"). Although sonar equation deals with the instrument specific variables, it also depends on measured signal strength water condition by the term of sound absorption coefficient of water.

The absorption coefficient of water is a function of frequency of acoustic instrument, salinity, temperature and pressure. Pressure does not have considerable effect on absorption coefficient for shallow water systems (depth ≤ 20 m) (Alvarez et al, 2002). Absorption coefficients (α) of water used in signal strength calculations of ADV for different temperature and salinity values were estimated by the formula defined by Shulkin and Marsh (1962).

$$\alpha = \left(\frac{SAf_t f^2}{{f_T}^2 + f^2} + \frac{3.38 \times 10^{-6} f^2}{21.9 \times 10^{6-[1520/T+273]}} \right) (1 - 6.54 \times 10^{-4} P) \tag{4.3}$$

Where;

α = Absorption coefficient, in nepers per meter;

S = Salinity, in parts per thousand;

P = Water pressure, in atmospheres;

f = The acoustic frequency, in kilocycles per second (f=10,000);

T = Water temperature, in degrees (^{o}C);

A = Constant for the MgSO$_4$ ionic relaxation process in sea water ($A = 2.34 \times 10^{-6}$);

f_T = Temperature dependent relaxation frequency in kHz at atmospheric pressure as;

$$f_T = 21.9 \times 10^{(6 - \frac{1520}{T+273})} \tag{4.4}$$

The pressure term is insignificant for depths less than 20 m, and the salinity term is neglected for freshwaters, and absorption coefficient depend on only temperature changes for the same water conditions resulting in:

$$\alpha = 8.687 \times \frac{3.38 \times 10^{-6} f^2}{21.9 \times 10^{6-[1520/(T+273)]}} \tag{4.5}$$

Where, 8.687 is the conversion factor from nepers to decibels.

4.4. Sediment Properties and Analysis

4.4.1. Particle Size Effect

Sediment properties such as size distribution affect the signal strength readings received by an ADV. Therefore the effect of particle type on signal strength readings recorded by ADV and thus on estimated SSC were investigated in this study.

Acoustic instruments have different sensitivities to particle size. Each acoustic frequency has a particle size for which it possesses peak sensitivity and a minimum detectable particle diameter. The studies up to now show that theoretically the best results are obtained when $d*k=1$ that the circumference of the particle is equal to acoustic wavelength, where d is the diameter of the particle, and k is the acoustic wave number ($2\pi/\lambda$). For the instrument used in this study, the corresponding acoustic wavelength λ is equal to 0.157 mm and best sensitivity is expected for particle diameter close to 0.025 mm, meaning that ADV would give best results for SNR in streams having the highest percentage of soils close to this diameter.

Scattering strength of the equipment depends on particle size as provided by a simple model shown in Figure 4.1. (Sontek 1998). As can be seen in the Figure 4.1., for small particles ($d*k \leq 1$) or for particles smaller than 0.025 mm sensitivity is proportional to radius to the fourth power so that scattering strength decreases rapidly. For bigger particles sensitivity of the instrument decreases but not the same rapidity as finer particles. Typical minimum particle size was detected as 0.001 mm for the ADV used in this study.

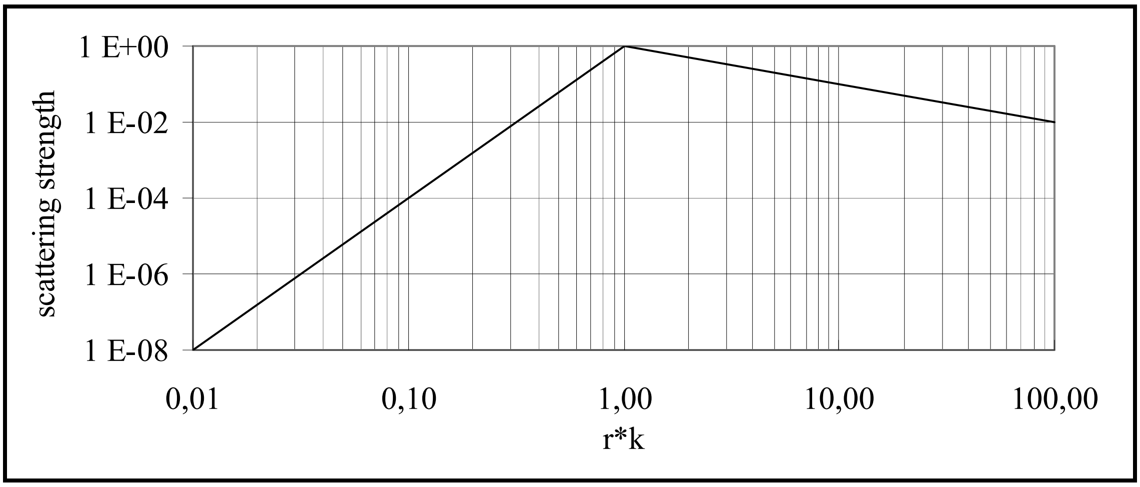


Figure 4.1. Variation of scattering strength of the equipment in terms of particle size (Sontek, 1998)

4.4.2. Particle Size Analysis

Soil samples were collected from the river beds along the transects where measurement were made. Samples were analyzed to describe particle size distribution of rivers. The particle size distributions of the suspended sediments are presumed comparable to those of the bed material, although some differences would exist due to armoring process and flocculation.

The collected bed materials were dried in room temperature. The dried samples were lightly granulated to apply the sieve analysis. Sieve analysis was applied to sediments finer than 2 mm to find the distribution of sediment particles suspended in water. Sieve analysis was conducted considering the American Society for Testing and Materials Standards (ASTM) for the range of soils from 2 mm to 0.075 mm. The sieve numbers 8 (2.360 mm), 16 (1.180 mm), 30 (0.600 mm), 50 (0.300 mm), 100 (0.150 mm) and 200 (0.075 mm) were used as provided in the ASTM standard.

The lightly granulated soil samples were sieved with dry sieve method. Approximately 150 grams of soil samples were used in the analysis for each river. The finer particles passing through each sieve were weighted in every level of the analysis and the results were graphed for each river.

After the sieve analysis, hydrometer analysis was applied to 50 grams of the soil sample finer than 0.075 mm (sieve number 200) to determine the distribution of the finer sediment particles. Hydrometer analyses were also made following ASTM standards. The principle of the analysis is to group these particles into separate ranges of sizes and so that the relative proportion by weight of each size range can be determined. The method employs sieving and sedimentation of a soil/water dispersant suspension to separate particles. The sedimentation technique is based on an application of Stokes' law to a soil/water suspension and periodic measurement of the density of the suspension. The apparatus of the test are;

- Soil hydrometer (ASTM 152H hydrometer preferred)
- Uniform set of sedimentation cylinders with internal depth of 340 mm (+- 20 mm) and capacity of 1 L. (Tape measure)
- Interval timer
- End-over-end shaker
- Constant temperature pool
- 25% sodium hexametaphosphate solution (Dissolve 250 g of sodium hexametaphosphate in 900 ml warm deionised water).

The sample preparation is the most important part of the test. Sample should pass the sieves as showed in ASTM standard and no aggregates should retain on the sieve. The soil samples were prepared for the hydrometer analysis from particles finer than 200 number sieve (0.075 mm). 50 grams of soil sample was placed into a shaker bottle. Half of the bottle was filled with hot tap (200 ml) distilled water and 20 ml 25% Sodium Hexametaphosphate solution. The sample was mixed thirty minutes until homogeneous solution was obtained. The mixing sample was poured into the 1000 ml tape measure and pure water was added until the 1000 ml line. Later on, the mixture was placed into the constant temperature pool and hydrometer analysis was performed for 48 hours (readings were taken at 0", 15", 30", 1', 2', 4', 8', 15', 30', 1h, 2h, 4h, 8h, 16h, 24h, 48h) as given in the ASTM. The hydrometer was placed in the suspension 20 seconds prior to each reading.

Hydrometer analysis is composed of two parts as the settlement of soil and calculations. The hydrometer should be calibrated before the calculations. First of all the volume of the hydrometer (Vb) was calculated. Hydrometer was put in 800 ml water in a cylinder and rising of the water level was monitored. If the volume of the neck part of the hydrometer is neglected, the rising volume of the water is equal to the volume of the hydrometer. The cross-section area (A) of the tape measure was found. The distance between 900 ml and 100 ml level line was measured on the tape measure. The volume was divided into that distance to measure the cross-section area of the tape. The distances between the bottom level line of the neck point of the hydrometer and the top and bottom of the hydrometer were measured (L_1, L_2). The distance between the neck point of the hydrometer and nearest level line was measured (N). The distance from neck point of the hydrometer to bottom of the hydrometer was measured. The effective depth of every main divided lines were calculated one by one and were graphed. The formulation of the graph was utilized for all readings of the hydrometer.

$$Hr = (L_1 + N) + \frac{1}{2}(L_2 - \frac{Vb}{A}) \tag{4.6}$$

Where;

Hr = Effective depth (mm);

L_1 = Distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading (mm);

L_2 = Overall length of the hydrometer bulb (mm);

N = Distance between the neck point of the hydrometer and nearest level line (mm);

Vb = Volume of the hydrometer bulb (cm^3);

A = Cross-sectional area of sedimentation cylinder (cm^2);

Hydrometer has corrections different from the calibration. Each reading R'_h must be applied to four corrections as follows: Meniscus correction, C_m, Temperature correction, M_t, Dispersing agent correction, x, and Water density correction, C_w.

1) Meniscus correction: While hydrometer is calibrated to read correctly at the surface of the liquid in which it is immersed, soil suspensions are not transparent enough to permit a reading to be taken at this level; the scale has to be read at the upper rim of the meniscus. Therefore, C_m can be taken +0.5 for hydrometer readings correction for most conditions.
2) Temperature correction; since the hydrometers are calibrated at 20 ^oC, when the test is carried out at a different temperature, both density of the water and the density of the hydrometer will be different. If the

hydrometer analysis is applied in 25 °C temperature, M_t should be taken as +1.00.

3) Dispersing agent correction; this correction is independent from temperature, and is typically 3.5-4.0 for the standard dispersing agent. The value can be taken as 3.5 if non-standard dispersion solution is not used.

4) Water density correction is applied when the density of the water is different than that pure water at 4 °C, at which the density is at its maximum. At higher temperature it is less than 1 and correction is applied for the 30 °C temperature in hydrometer analysis. Therefore C_w can be taken -1.80 for conditions described in our analysis

The fully corrected hydrometer reading R is given by;

$$R = R_h^{'} + C_m + M_t - x + 1.8 \qquad (4.7)$$

Where;

R = Fully corrected hydrometer reading;
R_h' = Hydrometer readings;
C_m = Meniscus correction;
M_t = Temperature correction;
x = Dispersing agent correction;

The total of the four corrections at different temperatures is given in the Table 4.1. It is interesting to observe that at 25 °C the total correction is -0.2, which for most practical purposes may be taken as zero. Thus, at 25 °C, provided that the standard dispersant is used, together with a standard hydrometer, the observed top of meniscus readings may be taken to be the same as the fully corrected readings R. This is one advantage of conducting the test at 25 °C as the standard constant temperature.

Table 4.1. Hydrometer Reading Corrections

Temperature ^oC	C_m	M_t	C_w	x	Total Calculated	Correction rounded
15	+0.5	-0.75	+1.8	-3.5	-1.95	-2
20	+0.5	0	+1.8	3.5	-1.20	-1
25	+0.5	+1.0	+1.8	3.5	-0.20	0
30	+0.5	+2.3	+1.8	3.5	+1.10	+1

After the readings of the hydrometer are completed, fully corrected reading, R, and effective depth of the main divided lines, H_r, were calculated. The equivalent particle diameter, D, for every hydrometer reading, at a known depth and after a certain time interval from the start of the sedimentation was calculated from the following equation.

$$D = 4.064\sqrt{\frac{Hr}{t}} \tag{4.8}$$

Where;

D = Equivalent particle diameter (D=μm)

H_r = Effective depth (mm)

t = Elapsed time (min)

The final calculation of the hydrometer analysis was the particle finer percentage, K. The percentage, by mass, of particles smaller than the equivalent particle diameter, D, is denoted by K. This percentage is equivalent to the percentage passing in sieve analysis. It is given by the equation

$$K = \frac{Gs}{m(Gs-1)} \cdot R \cdot 100 \tag{4.9}$$

Where;

K = Particle finer percentage

G_s = Specific gravity of soil particles

m = Mass of dry soil after pretreatment

R = Fully corrected hydrometer reading

The value of K was calculated for each hydrometer reading, and was plotted against the corresponding particle size, drawn to a logarithmic scale, exactly as for a grading curve determined by sieving (Table 4.2). A smooth curve was drawn through the plotted points. If a sieving analysis has also been carried out, a single continuous curve is drawn to give the particle size distribution of the whole sample (Figure 4.2.).

Table 4.2. Particle size distribution of the rivers. R_{min} refers to minimum detectable particle radius.

Station	Sand (%)	Silt (%)	Clay (%)	% finer than R_{min}
Sasal	23.39	45.80	30.81	12.22
Tahtali	30.93	27.41	41.66	28.26
Gediz	49.78	20.78	29.44	18.24
Gulbahce	96.54	1.43	2.03	1.26
Alacati	50.67	26.74	22.59	9.54
B.Menderes	74.12	16.81	9.07	3.81
Cine	42.24	49.40	8.36	7.28

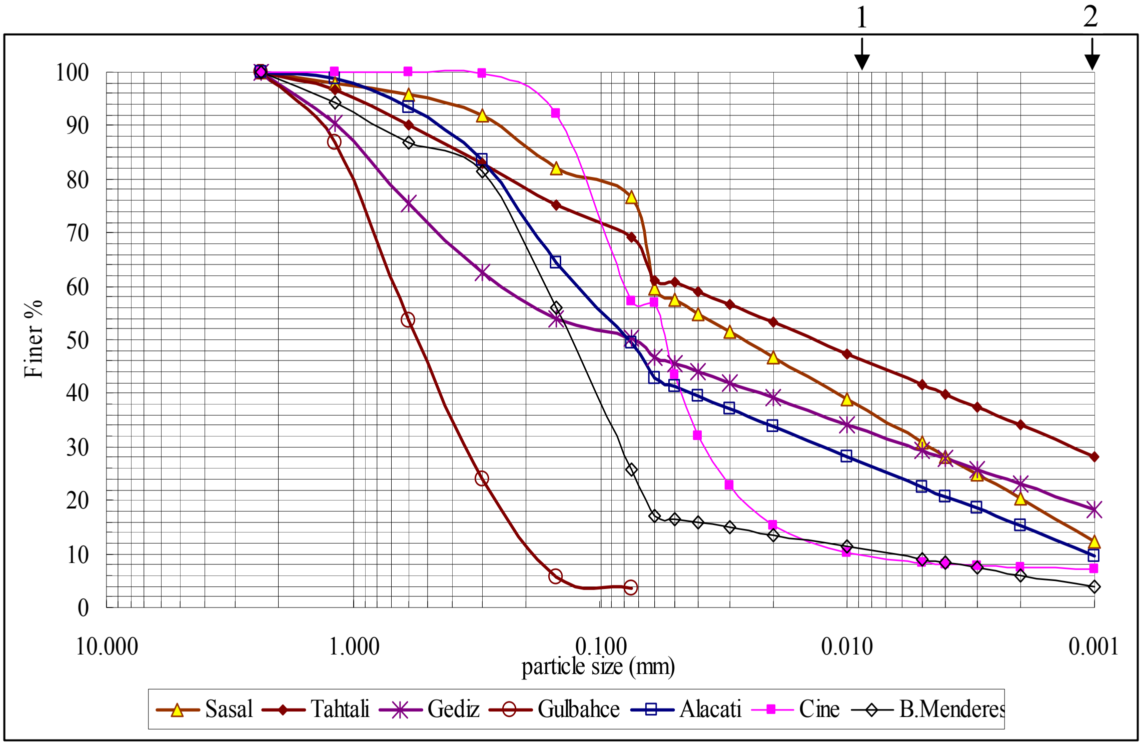


Figure 4.2. Particle granulometry of the soils sampled in the measurement sites. Arrow (1) shows the best sensitivity particle size (0.025 mm) and arrow (2) shows minimum particle size to be detected (0.001 mm) by the ADV used in this study.

4.5. Relating Scattered Signal to Suspended Sediment Concentration

Relation between acoustic instruments scattered signal strength and sediment concentration of water have been investigated in many studies. Moreover, A few relation formulas have been derived in those studies. For instance, Alvarez et al. (2002), derived relation formula between SNR and SSC as;

$$LogSSC = 1.1186 + 0.024 \times SNR \tag{4.10}$$

Formulation is accounted for 80% of the variance in the data. Furthermore, Hosseini et al. (2005) investigated SNR and SSC relation and obtained a proportion formula in the laboratory studies. They used ADV in the study and correlated known suspended sediment concentrations with ADV's SNR degrees in the laboratory.

$$SSC \alpha 10^{0.0434 \times SNR} \tag{4.11}$$

Another research was conducted by Jay and Orton (1999) to find a relation formula between SSC and SNR. The measurements were performed in the laboratory and relation formula was found as;

$$LogSSC = 1.7 \times SNR \quad (R^2=0.83) \tag{4.12}$$

The major deficiency of these studies formulations do not include the temperature and soil type parameters which have effect on the relation between SNR and SSC.

In this study, examples of field applications are provided in rivers where 10,000 kHz ADV system and multiparameter water quality meter were deployed to investigate the relation between SNR data measured by ADV and the SSC data measured by the WQC. Table 4.3 gives the water characteristics measured by the water quality meter at each measurement location. The relation between SNR and SSC values was assessed using statistical analysis. Sieve and hydrometer analysis were applied to each soil sample collected at the measurement stations. ADV's performance was tested to find the effect of temperature, particle size distribution, mean diameter and instrument intensity at various ranges of sediment concentrations.

Table 4.3. The water characteristics of the rivers at measurement stations. T_w is water temperature, DO is dissolved oxygen, EC is conductivity and S is salinity.

No	Station	Date	Depth * (m)	T_w (^oC)	DO (mg/l)	EC (S/m)	pH	S (mg/l)	Water Condition
1	Sasal	20.10.2006	0.3	15.7	10.6	0.05	8.1	0.2	Clear
2	Sasal	04.11.2006	0.8	12.5	9.4	0.04	8.2	0.1	Flood
3	Sasal	26.11.2006	0.7	13.5	9.6	0.05	8.3	0.2	Clear
4	Sasal	14.03.2007	0.6	8.5	12.0	0.04	8.2	0.2	Clear
5	Tahtali	04.11.2006	0.6	12.7	9.3	0.04	8.2	0.2	Flood
6	Tahtali	26.11.2006	0.4	15.1	15.0	0.05	7.9	0.2	Clear
7	Tahtali	28.12.2006	0.8	3.9	14.3	0.07	8.3	0.3	Clear
8	Tahtali	14.03.2007	0.5	9.5	14.0	0.06	8.2	0.4	Clear
9	Gediz	16.12.2006	0.8	10.9	3.1	0.10	7.7	0.6	Muddy
10	Gediz	23.12.2006	0.8	10.2	0.4	0.10	7.5	0.6	Muddy
11	Gulbahce	01.11.2006	0.2	17.3	5.1	0.03	7.2	0.1	Clear
12	Gulbahce	31.01.2007	0.2	11.6	5.6	0.03	7.3	0.1	Clear
13	Alacati	31.01.2007	0.2	8.6	12.4	0.05	8.5	29.0	Muddy
14	B. Mend.	06.02.2007	0.3	9.2	1.5	0.20	7.3	0.8	Flood
15	Cine	06.02.2007	0.2	7.7	1.6	0.05	7.8	0.2	Muddy

* indicates the mean depth of the cross section.

The simultaneous SSC and SNR measurements were made in Sasal stream in different water temperature degrees change between 8.5 ^oC and 15.7 ^oC. When the SNR data were compared to the SSC data, the best relation between the SNR and SSC data was obtained in Sasal Stream on 20.10.2006 (R^2=0.90); however, temperature changes were not considered in the relation (Figure 4.3). The predicted SSC is given by the following formula:

$$(Estimated)\ SSC = 1.49 \times SNR - 13.5 \tag{4.13}$$

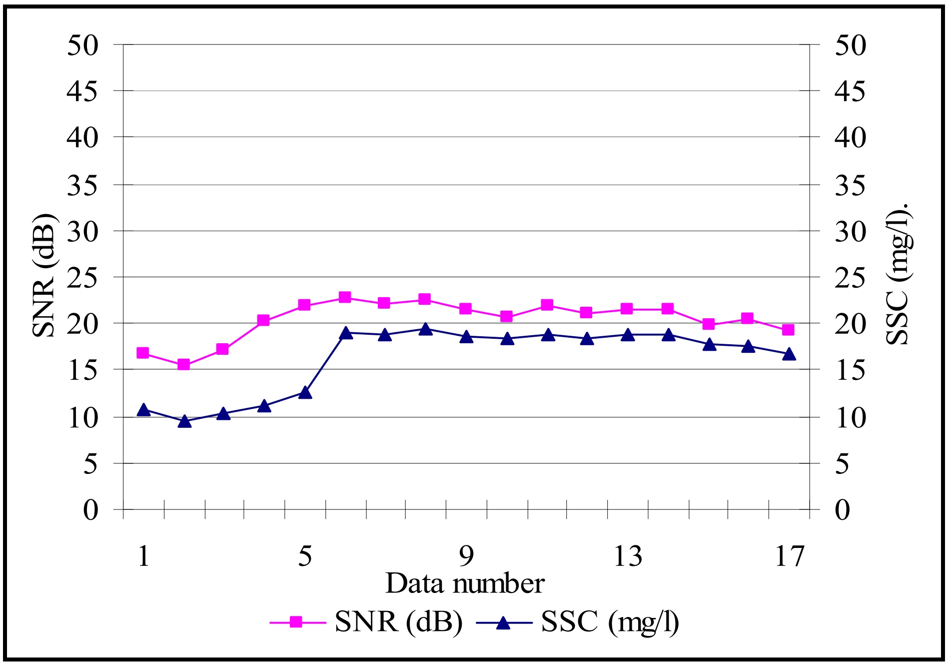


Figure 4.3. ADV and WQC measurements of Sasal Stream ($R^2 = 0.9$)

Several measurements were made in the Tahtali stream with the water temperature varying between 3.9 ^{o}C and 15.1 ^{o}C, and a good relation of SNR and SSC data was also observed. SNR measurements by the ADV responded well to introduce disturbance creating SSC variations during observations. As can be seen in Figure 4.4, SNR measurements followed closely the SSC peaks observed in the river. This would be expected since Tahtali and Sasal Streams have the highest amount of suspended particles falling into the best sensitivity range of ADV, explaining the good relation between the data. The linear regression formula of the Tahtali stream was found only depending on SNR and SSC data:

$$(Estimated)\ SSC = 1.784 \times SNR - 5.729 \tag{4.14}$$

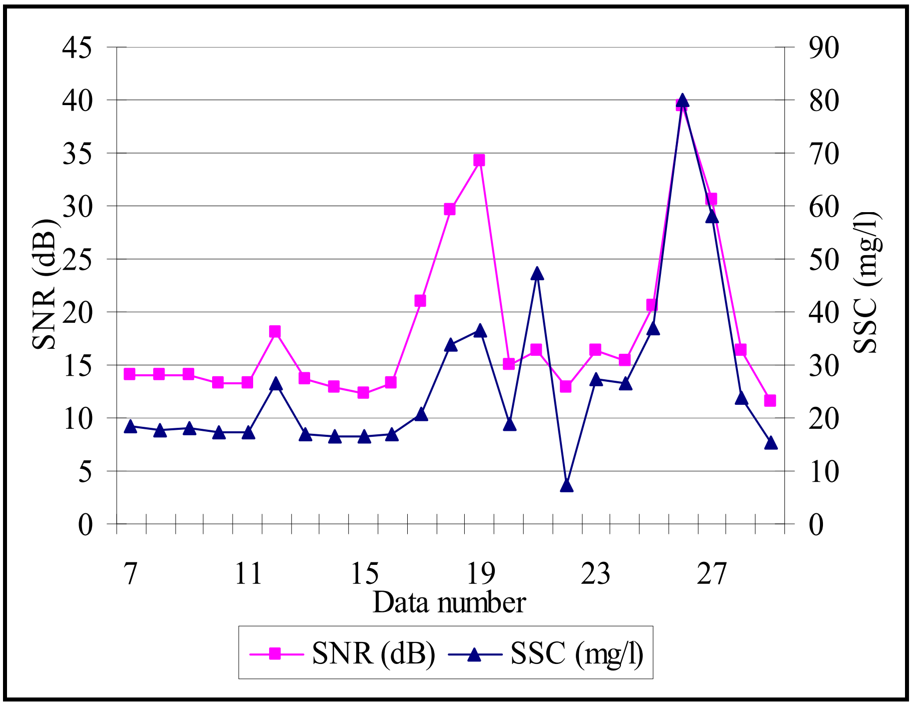


Figure 4.4. ADV and WQC measurements of Tahtali Stream ($R^2 = 0.7$)

Although the Gediz River is a highly polluted river, low suspended sediment concentration values were observed. Measurements were also conducted in Gediz River on two different days, where water quality parameters in two days including temperature were almost the same. However, SNR changes followed to SSC variations closely in those two days of measurements in Gediz River, The lowest correlation degree was obtained (Figure 4.5).

$$(Estimated)\ SSC = 1.816 \times SNR - 14.793 \tag{4.15}$$

Measurements of SNR and SSC were conducted both at the Gulbahce and Alacati Streams showing also good relations (Figure 4.6 and Figure 4.7). Analysis of the soil sample collected at the sites showed that almost all of the suspended sediment particles of the stream were coarser than ADV's detectable particle size at Gulbahce and approximately 90 percent of particles were coarser than the detectable particle size of the ADV at Alacati. SSC estimation formulas were derived using linear regression analysis only depending on SNR data.

(Gulbahce) $$(Estimated)\ SSC = 1.376 \times SNR - 12.319 \tag{4.16}$$

(Alacati) $$(Estimated)\ SSC = 1.284 \times SNR - 11.085 \tag{4.17}$$

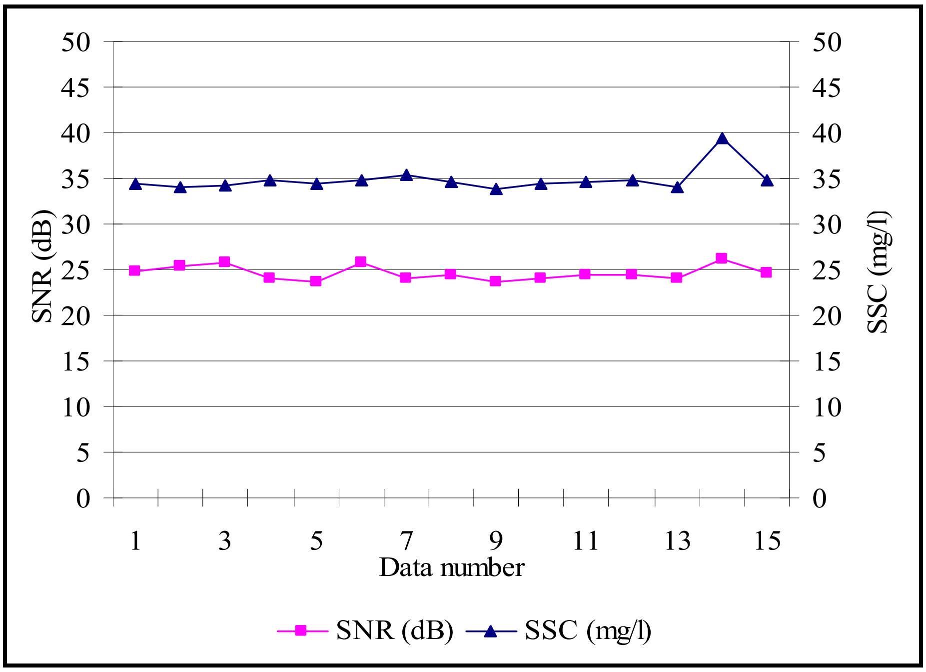


Figure 4.5. ADV and WQC measurements of Gediz River ($R^2 = 0.26$)

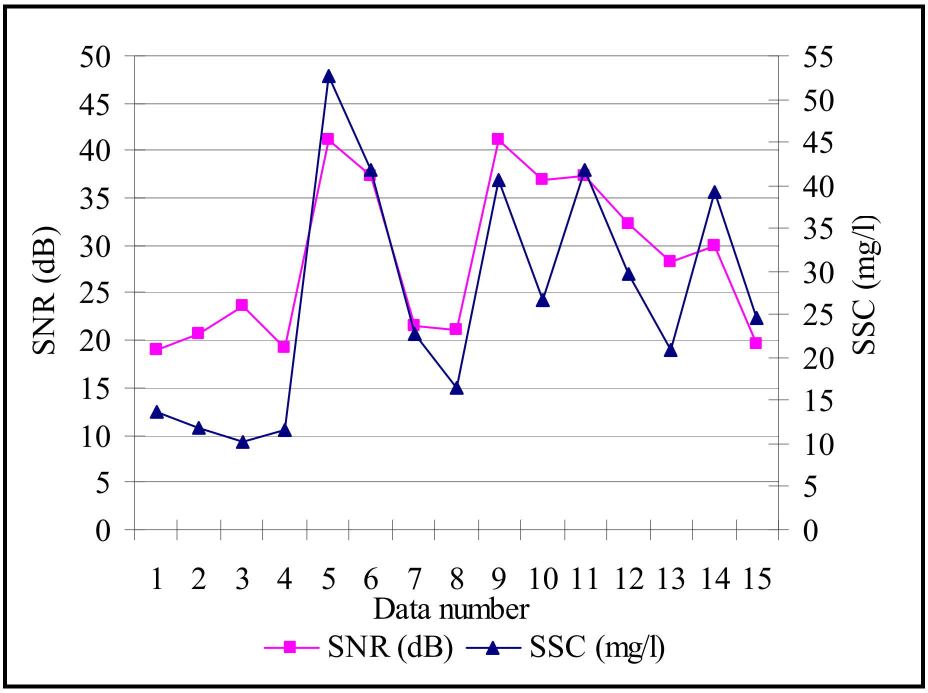


Figure 4.6. ADV and WQC measurements of Gulbahce stream ($R^2 = 0.75$)

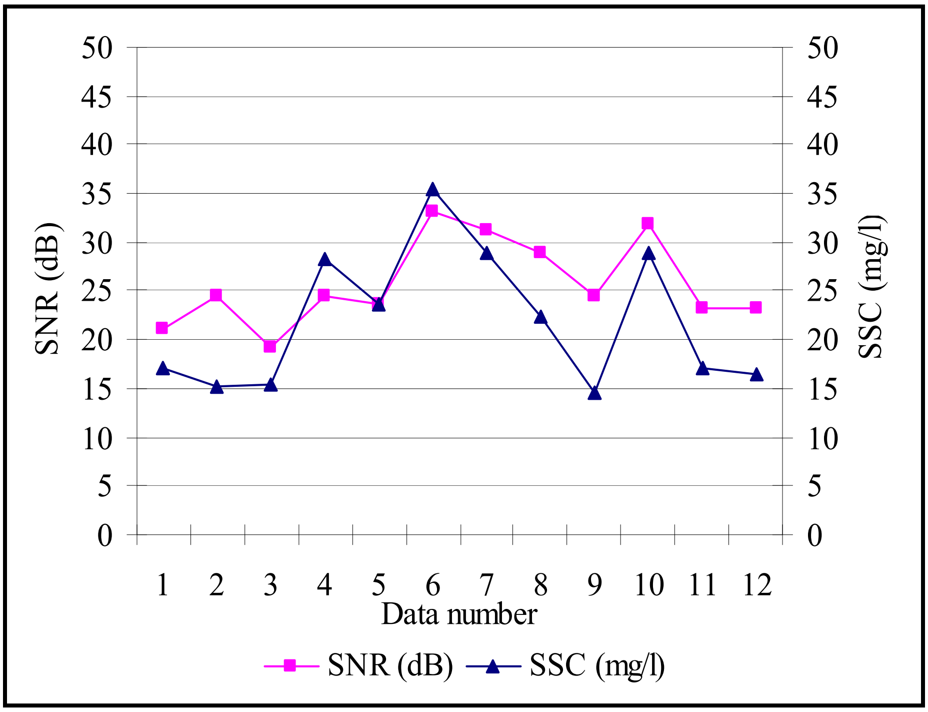


Figure 4.7. ADV and WQC measurements of Alacati Stream ($R^2 = 0.66$)

The effect of riverbed soil particle to ADV's performance for the prediction of suspended sediment concentration was investigated. The soil samples were collected from all measuring stations and analyzed to describe particle size, type and distribution of each river. Also, uniformity of the riverbed soils was calculated for each river. The particle size distributions of the suspended sediments were presumed comparable to those of the bed material, although some differences existed due to armoring process and flocculation.

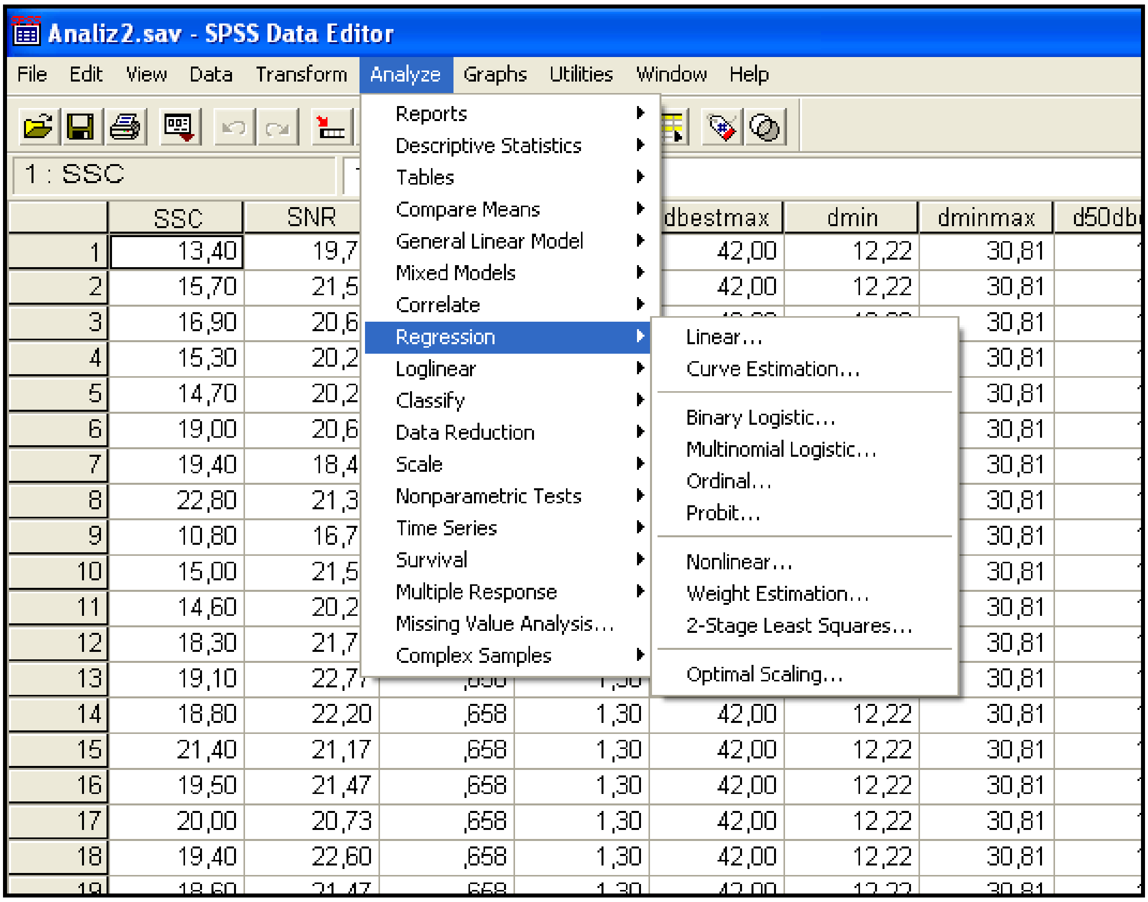
4.5.1. Multivariate Analysis

The multivariate data analysis refers to any statistical technique used to analyze data arising from more than one variable. This essentially models reality where each situation, product, or decision involves more than a single variable. The developments in the technology have resulted in collection of massive data in every field of research. Despite the available data, the ability to make use of this data making intelligent decisions is a challenge. When available information is stored in database tables containing rows and columns, Multivariate Analysis can be used to process the information in a meaningful fashion.

The analysis was applied to all of the collected data from rivers. The main goal of the multivariate analysis in this study was to investigate the effect of water temperature and soil type on acoustic signal and develop a relation between SNR and SSC in the water column. The multivariate data analysis was conducted with the dependent variable SSC of the water and independent variables of acoustic signal, temperature and river-bed soil properties.

The statistical method of multivariate regression was used for the multivariate data analysis. In statistics, regression analysis is a collective name for techniques for the modeling and analysis of numerical data consisting of values of a dependent variable (also called response variable or measurement) and of one or more independent variables (also known as explanatory variables or predictors). The dependent variable in the regression equation is modeled as a function of the independent variables, corresponding parameters ("constants"), and an error term. The error term is treated as a random variable. It represents unexplained variation in the dependent variable. The parameters are estimated so as to give a "best fit" of the data. Most commonly the best fit is evaluated by using the least squares method, but other criteria have also been used. Regression can be used for prediction (including forecasting of time-series data), inference, hypothesis testing, and modeling of causal relationships. These uses of regression rely heavily on the underlying assumptions being satisfied. Regression analysis has been criticized as being misused for these purposes in many cases where the appropriate assumptions cannot be verified to hold. One factor contributing to the misuse of regression is that it can take considerably more skill to critique a model than to fit a model.

The multivariate regression analysis was utilized in this study using computer program SPSS “*__S__tatistical __P__ackage for the __S__ocial __S__ciences”.* SPSS is used by market researchers, health researchers, survey companies, government, education researchers, marketing organizations and others. In addition to statistical analysis, data management (case selection, file reshaping, creating derived data) and data documentation (a metadata dictionary is stored with the data) are features of the base software. The many features of SPSS are accessible via pull-down menus or can be programmed with a proprietary 4GL *command syntax language*. Command syntax programming has the benefits of reproducibility and handling complex data manipulations and analyses. The pull-down menu interface also generates command syntax, though the default settings have to be changed to make the syntax visible to the user (Figure 4.8). Programs can be run interactively or unattended using the supplied Production Job Facility. Additionally a "macro" language can be used to write command language subroutines and a Python programmability extension can access the information in the data dictionary and data and dynamically build command syntax programs. (ESRI 2007)



	SSC	SNR			dbestmax	dmin	dminmax	d50db
1	13,40	19,7			42,00	12,22	30,81	
2	15,70	21,5			42,00	12,22	30,81	
3	16,90	20,6					30,81	
4	15,30	20,2					30,81	
5	14,70	20,2					30,81	
6	19,00	20,6					30,81	
7	19,40	18,4					30,81	
8	22,80	21,3					30,81	
9	10,80	16,7					30,81	
10	15,00	21,5					30,81	
11	14,60	20,2					30,81	
12	18,30	21,7					30,81	
13	19,10	22,7					30,81	
14	18,80	22,20	,658	1,30	42,00	12,22	30,81	
15	21,40	21,17	,658	1,30	42,00	12,22	30,81	
16	19,50	21,47	,658	1,30	42,00	12,22	30,81	
17	20,00	20,73	,658	1,30	42,00	12,22	30,81	
18	19,40	22,60	,658	1,30	42,00	12,22	30,81	
19	18,60	21,47	,658	1,30	42,00	12,22	30,81	

Figure 4.8. SPSS interface and pull-down menus

SPSS places constraints on internal file structure, data types, data processing and matching files, which together considerably simplify programming. SPSS datasets have a 2-dimensional table structure where the rows typically represent cases (such as rivers) and the columns represent measurements (such as SNR, SSC and temperature). Only 2 data types are defined: numeric and text (or "string"). All data processing occurs sequentially case-by-case through the file. Files can be matched one-to-one and one-to-many, but not many-to-many.

SPSS uses multiple regression model and its formulations in calculations. The multiple regression model is a direct extension of a polynomial regression model in one independent variable, relates a dependent variable Y to a set of quantitative independent variables (x_i). The general structure of the multiple linear model is given;

$$Y = X\beta + E \tag{4.18}$$

Where Y is a $(n \times p)$ data matrix containing the response variables, X is a $(n \times q)$ data matrix containing the factors, β is a $(q \times p)$ data matrix containing the factor coefficients (model parameters), and E is a $(n \times p)$ data matrix containing the noise terms ($p \geq 1$). Any of the independent variables may be the powers of the other independent variables, cross product of the other terms or logarithm of another term. The only restriction is that no x is perfect linear function of any other x. Moreover, the least square estimates for the beta parameters are obtained by solving the normal equations as in multiple regressions. To avoid having large uncertainties in the estimates of the beta parameters, it is important to ensure that the matrix ($X^{'} X$) is well-conditioned. (Kovacic 1994)

The graphical user interface has two views which can be toggled by clicking on one of the two tabs in the bottom left of the SPSS window. The 'Data View' shows a spreadsheet view of the cases (rows) and variables (columns). The 'Variable View' displays the metadata dictionary where each row represents a variable and shows the variable name, variable label, value label(s), print width, measurement type and a variety of other characteristics. Cells in both views can be manually edited, defining the file structure and allowing data entry without using command syntax. This may be sufficient for small datasets. Larger datasets such as statistical surveys are more often created in data entry software, or entered during computer-assisted personal interviewing, by scanning and using optical character recognition and optical mark recognition software, or by direct capture from online questionnaires. These datasets are then read into SPSS

SPSS can read and write data from ASCII text files (including hierarchical files), other statistics packages, spreadsheets and databases. SPSS can read and write to external relational database tables via ODBC and SQL. Statistical output is to a proprietary file format (*.spo file, supporting pivot tables) for which, in addition to the in-package viewer, a stand-alone reader is provided. The proprietary output can be exported to text or Microsoft Word. Alternatively, output can be captured as data (using the OMS command), as text, tab-delimited text, HTML, XML, SPSS dataset or a variety of graphic image formats (JPEG, PNG, BMP and EMF) (ESRI 2007).

The regression analysis of the river data was made with SPSS program with the dependent variable SSC and independent variables temperature and river-bed soil type. The independent variables were used in different forms. For example temperature effect was represented in absorption coefficient of water "α". This assumption was acceptable for temperature effect since absorption coefficient of water only depends on temperature changes (formulation 4.5) for shallow water conditions. In regression analysis, to nondimensionalize parameters, the absorption coefficients of the rivers (α) were divided by the critical value of absorption coefficient (α_c) corresponding to absorption coefficient estimated for the calibration water temperature (4 ^oC). In the analysis, the ($\frac{\alpha}{\alpha_c}$) value was used to represent the effect of temperature.

The particle distribution of the sediments suspended in the water column was represented in different forms in multiple regression analysis. The uniformity coefficients of the soils "Cu" and "Cc" was used in different analysis cases, where $Cu = \frac{D_{60}}{D_{10}}$ and $Cc = \frac{D_{30}{}^{2}}{D_{10} \times D_{60}}$. The parameter D_{10}, D_{30} and D_{60} are the particle diameters of the soil in described percent. The uniformity coefficient of the soil gives information about the homogeneity of soil granulation that is important for soil studies. The accuracy of soil analysis directly depends on uniformity of soil.

Soil parameters are also represented in the analysis with the relation of ADV's capability versus particle size (Figure 4.1). The ADV's sensitivity to particle size affects the ADV's SNR readings accuracy. Therefore, the effect of soil particles represented %dmin, %dbest, %$dbest_{max}$, %$dmin_{max}$ parameters as non-dimensional percentages. Where;

%dmin; the percent of soil particles that finer than minimum diameter that the instrument can detect ($R \leq 0.001$ mm).

%dbest; particle diameter corresponding to predicted maximum sensitivity for the ADV (R=0.025 mm).

%$dbest_{max}$; the percent of soil particles at the ten percent range of the maximum sensitivity for the ADV ($0.0138 \text{ mm} \leq R \leq 0.200$ mm)

$\%dmin_{max}$; the percent of soil particles at the ten percent range of the minimum diameter that the instrument can detect.

Soil properties were represented by four different non-dimensional parameters in the regression analysis. The regression analysis with dependent variable was selected as measured values of suspended sediment concentration (SSC) in the water column and independent variables were selected as signal to noise ratio (SNR), absorption coefficient parameters depending on temperature (α/α_c), coefficients of graduation (Cu and Cc) and ADV's particle size sensitivity parameters (%d50/%dbest, $\%dbest_{max}$, and $\%dmin_{max}$). Also logarithmic transformation of SNR and SSC were applied to the analysis to find the best fit.

The multivariate data analysis was made with multiple data groups and multiple analysis cases. The data which was collected from rivers was classified in four different groups in the analysis. All analysis cases applied those four data groups. The data groups consisted of every measurement conducted at the rivers (all data), mean of the measurements (mean data), two filtered data of measurements (filtered data1 and filtered data2).

First group "all data"; the whole data which were collected simultaneously with ADV and water quality meter, were taken for the regression analysis with no filtration.

Mean of the measurements "mean data"; the mean values of the measurements were taken as analysis data for all different measuring station.

Third group "Filtered data1"; consist of data which have higher than 40% error for SNR and SSC equation of that station were eliminated.

Fourth group "Filtered data2"; consist of data were used after the data which have higher than 20% error for SNR and SSC were eliminated.

The analysis cases were determined to represent temperature and river-bed soil effect in all cases. Twelve analysis cases were constituted with two dependent variables and seven independent variables (Table 4.4.). These analysis cases were applied four data groups in regression analysis. As a result 48 regression analyses were made with computer program SPSS and R^2 degrees were calculated (Table 4.5.).

Table 4.4. Analysis cases in the regression analysis

Parameters \ Cases	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
SSC *(Dependent)*	✓	✓	✓	✓	✓	✓	✓					
Log SSC *(Dependent)*								✓	✓	✓	✓	✓
SNR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$\boldsymbol{\alpha/\alpha_c}$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cu				✓		✓	✓			✓	✓	✓
Cc					✓							
d50/dbest			✓						✓			
%dbest$_{max}$	✓	✓				✓	✓	✓			✓	✓
%dmin$_{max}$	✓						✓	✓				✓
Max. R^2	0.788	0.635	0.779	0.854	0.638	0.856	0.865	0.752	0.701	0.806	0.812	0.815

As the aim of the regression analysis was to find a relation formula between SNR and SSC, the SNR values were used in all analysis cases. Also, SSC values were used in all cases. Furthermore, in some cases, logarithmic value of the SSC was used as dependent variable of regression analysis; because, according to the previous studies SNR and SSC have logarithmic relations. Moreover, the fact that temperature effect was represented as absorption coefficient of water and as analysis form "α/α_c", the term was used in all analysis cases.

The river-bed soil effect was represented with five parameters in the regression analysis. The analysis cases which have d_{min} and d_{best} parameters were eliminated because they did not have a significant effect where R^2 degrees were lower than 0.500. The parameters %$d_{bestmax}$, %d_{minmax} were used instead of d_{min} and d_{best} parameters which depend on ADV's particle size sensitivity graphic.

Uniformity coefficient of soils Cu and Cc were also used in analysis cases. The analysis cases which include Cu and Cc together were eliminated because of lower R^2

degree. Also, only one case which includes Cc could passed 0.500 R^2 value limit, so, other analysis cases were not considered.

Table 4.5. Analysis cases and R^2 values in regression analysis

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
All Data	0.634	0.586	0.684	0.733	0.567	0.742	0.743	0.628	0.600	0.742	0.742	0.742
Mean Data	0.669	0.635	0.670	0.854	0.638	0.856	0.865	0.672	0.701	0.806	0.812	0.815
Filtered 1 Data	0.788	0.607	0.590	0.689	0.589	0.704	0.710	0.599	0.581	0.695	0.698	0.699
Filtered 2 Data	0.786	0.619	0.779	0.797	0.597	0.819	0.829	0.752	0.603	0.702	0.796	0.798

The regression analysis were completed with computer program SPSS. The twelve cases which have correlation higher than (R^2= 0.5) were chosen as analysis cases (Table 4.4). The maximum R^2 values were calculated for all data groups with those twelve analysis cases. As a result four linear relations were accepted for the formulation. The four formulations were taken from the cases which have the best correlation of the four data groups (Table 4.6).

After SPSS analysis, the four linear regression formulas which have maximum correlation were investigated with the river measurements. First of all, those four linear formulations which describe the relation between SNR and SSC including temperature and soil effect, were applied all of the river data. Furthermore, the error percentage between the measuring SSC and calculating SSC were calculated for each river measurements. The correlations between SNR and SSC were investigated for the four linear regression formula applications (Table 4.7)

Table 4.6. Maximum R^2 values for data groups

	Data Group	**R^2**	**Analysis Case**
Linear regression formula 1 (F. 1)	All Data	0.743	7
Linear regression formula (F. 2)	Mean Data	0.865	7
Linear regression formula (F. 3)	Filtered 1 Data	0.710	7
Linear regression formula (F. 4)	Filtered 2 Data	0.829	7

The error percentages of the formulas were calculated. The research showed that usually errors are approximately the same for all the measurements. When these data were eliminated the average error percentages of all formulas approximately decrease to half of the previous error percentages degrees.

In that case, a part of the measurement data which have higher than 40% error for all formulas were eliminated and new measurement data group was formed. This is called filtered data three. The multiple regression analysis was applied on new data group with same twelve analysis cases. R^2 degrees were increased in all cases in those new regression analyses. Also, the maximum R^2 degree was obtained in case 7 as the degree of 0.930 which was the best R^2 degree of the whole multivariate data analysis. The linear regression formulation called as new formulation was obtained in those analysis.

$$SSC = -6.979 + 0.822 SNR + 15.868 \frac{\alpha}{\alpha_c} + 0.051 Cu - 0.106 d_{best\,\max} - 0.03 d_{\min\max} \tag{4.19}$$

As a result of the multivariate regression analysis, totally five formulations were derived to describe SNR and SSC relations for all rivers. The five linear regression formulas were applied to every measurement conducted at the rivers (All data). In this study, the last formulation (4.19) which was obtained from rivers filtered data three had the best regression in all rivers stations and also averages of the measurements. The formulation (4.19) has averagely 17% error in all measurements. The error degree decreased approximately 8.5% when the data which have higher than 40% error was eliminated. Moreover, if the same filtration is applied on river measurements, the error percentages of formulation decreased 4.64% for Sasal, 5.05% for Tahtali and 1.87% for Gediz, respectively. In that case if the uncertainty of measurements is considered as 3%, the regression formula (4.19) could be accepted for SNR and SSC relations.

Table 4.7. Application of formulations and average error percentages (%)

	All Data	**Mean Data**	**Filt. 1 Data**	**Filt. 2 Data**	**Sasal***	**Tahtali***	**Gediz***	**Gulbahce***
F. 1	34.04	30.79	34.59	35.96	39.80	31.14	25.96	38.26
F. 2	18.10	18.59	18.96	16.85	18.71	21.70	3.17	28.15
F. 3	19.98	21.47	19.77	16.93	21.37	28.43	3.34	26.06
F. 4	19.07	19.07	19.22	16.39	18.95	27.63	3.52	26.19
F.(N)	17.74	18.08	17.83	15.05	20.78	17.05	3.04	27.74

* All of the measurement data were used.

The best linear regression formula between SNR and SSC formulation (4.19) contains five parameters such as; SNR, Cu, α/α_c, $\%dbest_{max}$, $\%dmin_{max}$ (Figure 4.9).

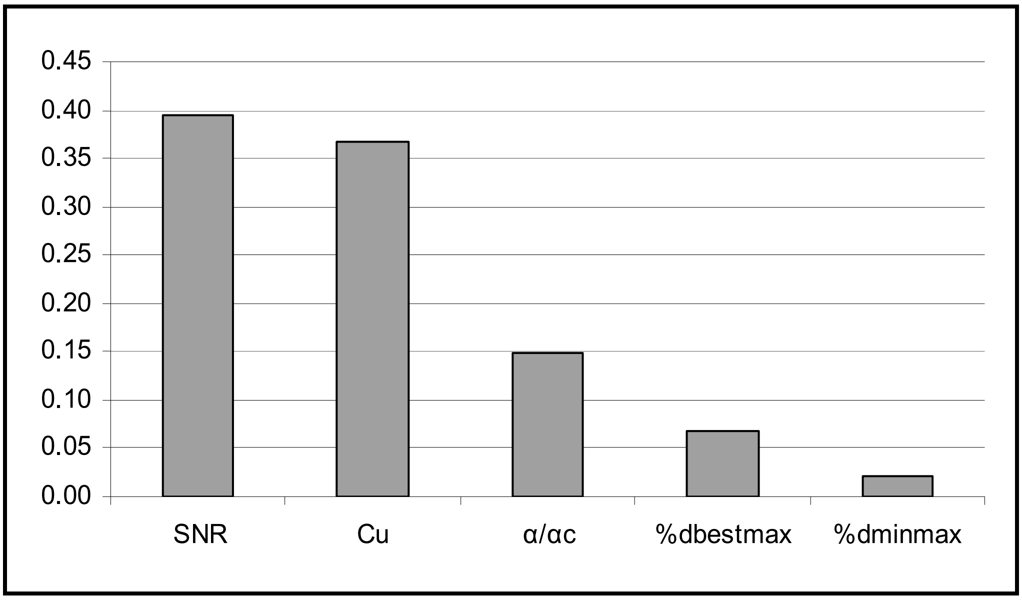


Figure 4.9. Importance of variables used in the multivariate analysis for formulation (4.19)

The contributions of the parameters to the regression were calculated with SPSS computer program. The highest contributions approximately 75% come from SNR and Cu show that the health of the regression formula especially depends on quality of the field measurements and the uniformity of river-bed soil.

In the study the multivariate data analysis was applied Sasal and Tahtali stream separately. The new linear regression formulas were obtained for only Tahtali and Sasal streams. The higher regression coefficients were observed in the analysis that R square degrees were obtained 0.946 for Tahtali (Figure 4.10) and 0.929 for Sasal (Figure 4.11). The formulation (4.20) which was obtained for Tahtali stream in the multivariate regression analysis has averagely 16% error for all measurements data. If filtration was applied on the measurements, the error percentage of the formulation was decrease 3.60%. Moreover, the formulation (4.21) which was obtained for Sasal stream has averagely 25% error for all measurement data. If the same filtration was applied on the data, the error percentage of the formulation was decrease 7.33%.

$$SSC = -8.399 + 0.934SNR + 13.067\frac{\alpha}{\alpha_c} + 0.048Cu - 0.069dbest_{\max} \qquad (4.20)$$

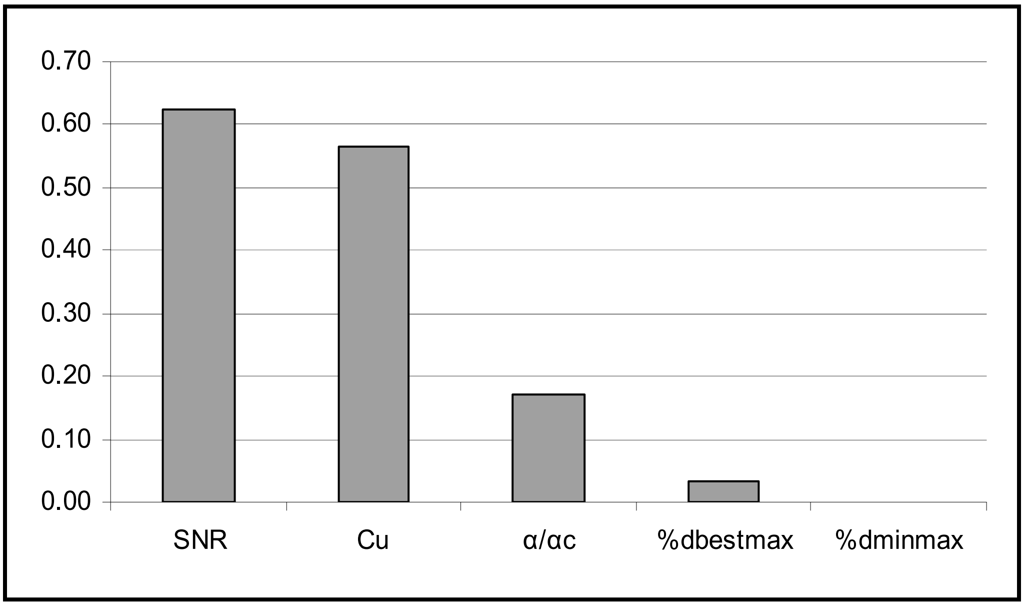


Figure 4.10. Importance of variables used in the multivariate analysis In Tahtali stream for formulation (4.20)

$$SSC = -16.436 + 0.805SNR + 31.258\frac{\alpha}{\alpha_c} + 0.043Cu - 0.124dbest_{\max} \qquad (4.21)$$

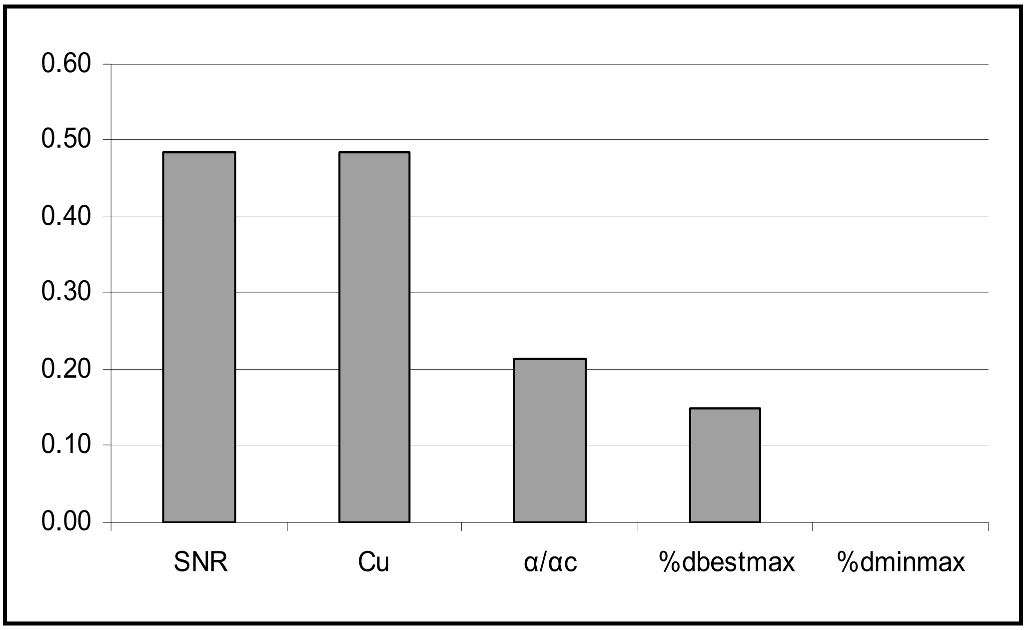


Figure 4.11. Importance of variables used in the multivariate analysis in Sasal stream for formulation (4.21)

4.6. Verification of the derived equations

In this study the verification of the formulations were made for Tahtali and Sasal streams. The simultaneous SNR and SSC measurements were made on those rivers to collect new dataset on 03.02.2009 which was not used in the derivation of the equations mentioned earlier (Table 4.8). The formulation (4.19) was applied to these new data to calculate calibrated SSC degrees that calculations had 13.28% error for Sasal (Figure 4.12) stream and 13.26% error for Tahtali (Figure 4.13) stream.

Moreover, formulation (4.20) was applied on the new measurement data in Tahtali and 13.61% errors were obtained for the verification. Also, formulation (4.21) was applied on verification data and %13.15 errors were observed.

Table 4.8. The verification data and results of the formulation (4.19) for Tahtali and Sasal streams

TAHTALI					SASAL				
SSC	**SNR**	**T**	**SSCc**	**%err**	**SSC**	**SNR**	**T**	**SSCc**	**%err**
27.20	30.50	14.60	25.92	-4.94%	14.10	19.30	13.50	17.11	17.58%
31.00	31.80	14.60	26.99	-14.86%	15.30	20.20	13.50	17.85	14.27%
30.80	31.80	14.60	26.99	-14.12%	17.80	20.60	13.50	18.18	2.07%
28.80	30.50	14.60	25.92	-11.11%	15.10	24.50	13.50	21.38	29.38%
28.80	30.50	14.60	25.92	-11.11%	15.80	22.30	13.50	19.57	19.28%
28.50	30.00	14.60	25.51	-11.72%	16.10	21.00	13.50	18.50	13.00%
27.90	29.60	14.60	25.18	-10.80%	16.40	21.00	13.50	18.50	11.37%
28.40	30.20	14.60	25.67	-10.62%	17.50	21.00	13.50	18.50	5.43%
27.60	30.50	14.60	25.92	-6.48%	17.80	20.60	13.60	18.18	2.07%
25.80	29.60	14.60	25.18	-2.46%	19.90	23.20	13.60	20.31	2.03%
26.20	30.00	14.60	25.51	-2.71%	18.40	23.60	13.60	20.64	10.86%
29.20	31.30	14.60	26.58	-9.86%	17.20	22.30	13.50	19.57	12.13%
27.60	30.50	14.60	25.92	-6.48%	16.30	21.00	13.50	18.50	11.91%
28.70	28.30	14.70	24.11	-19.03%	15.20	26.20	13.60	22.78	33.27%
19.60	28.80	14.70	24.52	20.08%	14.00	24.00	13.60	20.97	33.24%
19.40	28.80	14.70	24.52	20.89%	15.70	21.50	13.60	18.92	17.00%
19.00	28.80	14.70	24.52	22.52%	20.90	24.90	13.60	21.71	3.73%
19.70	28.30	14.70	24.11	18.30%	15.60	25.30	13.50	22.04	29.22%
19.40	29.20	14.70	24.85	21.94%	21.10	23.60	13.50	20.64	-2.22%
19.80	29.40	14.70	25.02	20.85%	19.70	23.60	13.50	20.64	4.56%
19.20	28.60	14.70	24.36	21.18%	18.80	24.50	13.50	21.38	12.07%
19.70	29.20	14.70	24.85	20.73%	22.90	24.90	13.60	21.71	-5.48%
19.20	29.20	14.70	24.85	22.74%	***Average error***				13.28%
19.80	28.80	14.80	24.52	19.26%					
21.60	29.60	14.80	25.18	14.22%					
22.50	29.60	14.80	25.18	10.65%					
25.50	30.50	14.80	25.92	1.62%					
25.50	30.00	14.80	25.51	0.04%					
Average error				13.26%					

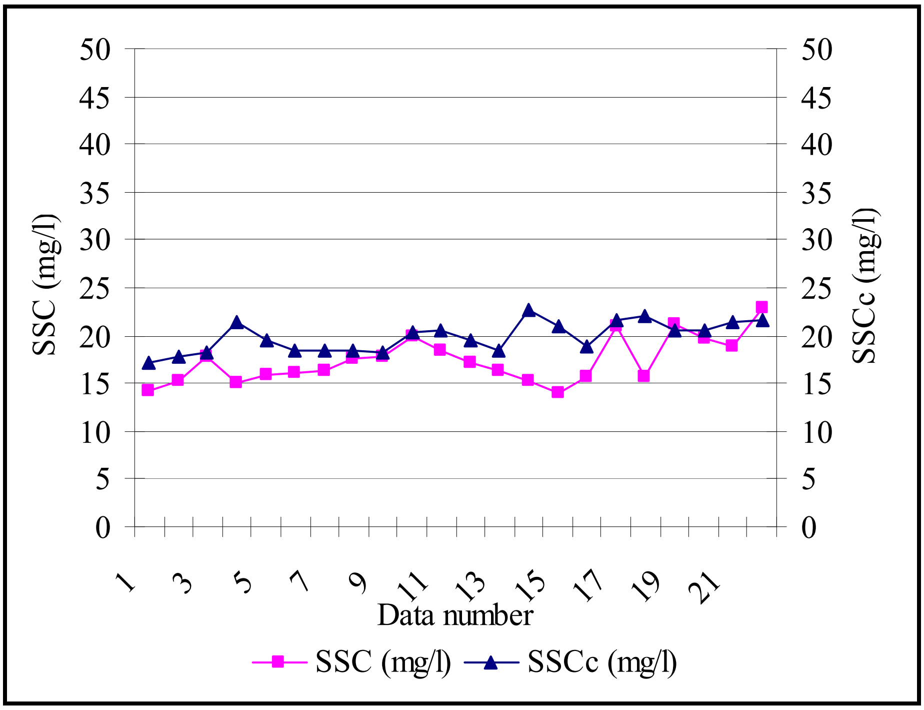


Figure 4.12. Regression of SSC and calculated SSC in Sasal stream for formulation (4.19)

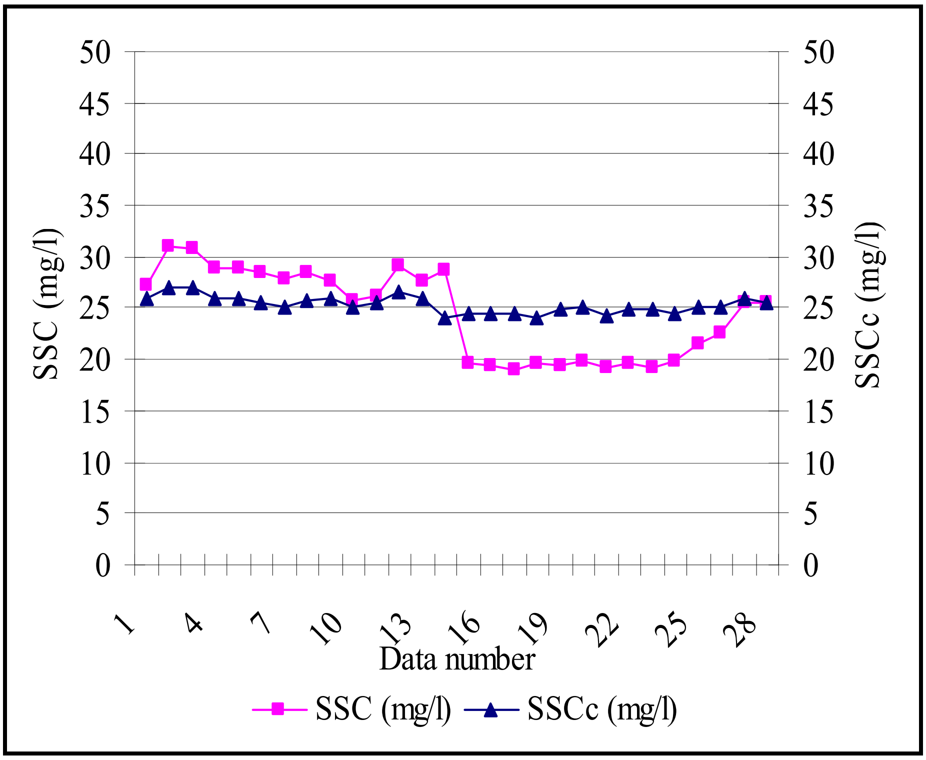


Figure 4.13. Regression of SSC and calculated SSC in Tahtali stream for formulation (4.19)

4.7. Flood Effect

Measurements were made during and after rain events to investigate the performance of ADV to predict the suspended sediment concentration. ADV failed to predict SSC in high turbid conditions in all measurements. As can be seen in fiures (Figure 4.14 and Figure 4.15) for higher SSC values ($SSC \approx 230$ mg/l), ADV could not follow the changes in SSC and SNR values remained constant at 28 dB in Tahtali and Sasal Streams, which are located at the same basin. In the Cine Stream and the B.Menderes River which are also located in the same basin, similarly SNR values remained constant at 48 dB during flood conditions ($SSC \approx 400$ mg/l). Maximum SNR readings obtained from ADV depend on particle size distribution. Soils of Tahtali and Sasal Streams had finer sediments and higher percent of fine particles less than detectable size, as compared to Cine and B.Menderes. The measurements showed clearly that ADV readings are not dependable for SSC prediction in high-turbid water conditions.

However, ADV was not successful in high-turbid waters as SSC is higher than a limit concentration determined by the soil size distribution of the measurement site. Monitoring water and sediment flow by ADVs has a number of advantages over other instruments; providing three dimensional flow velocity, temperature and suspended sediment concentration time series with one instrument.

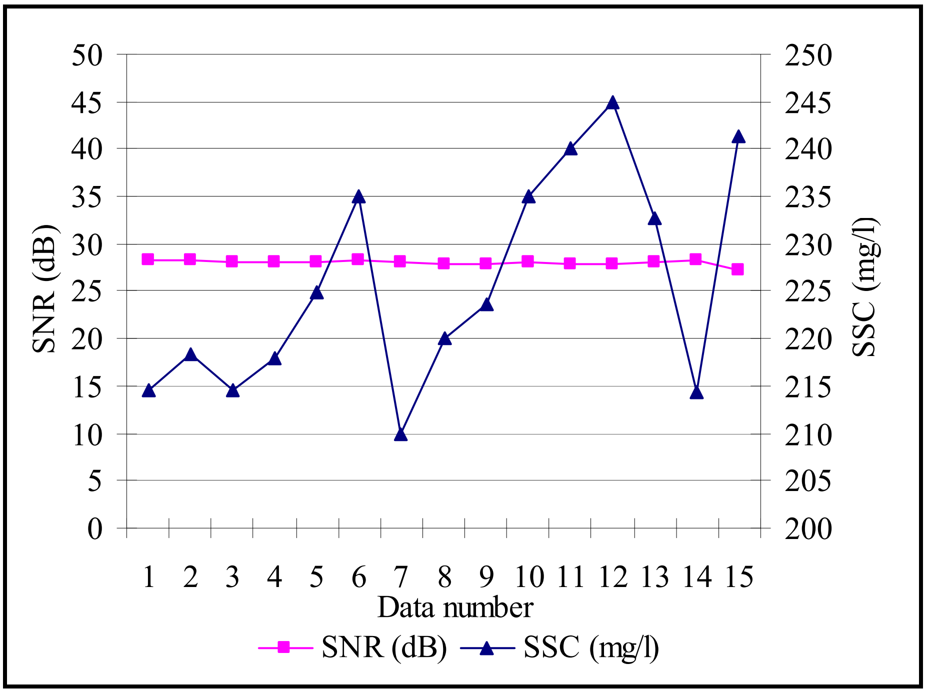


Figure 4.14. ADV and WQC measurements of Sasal stream on flood condition

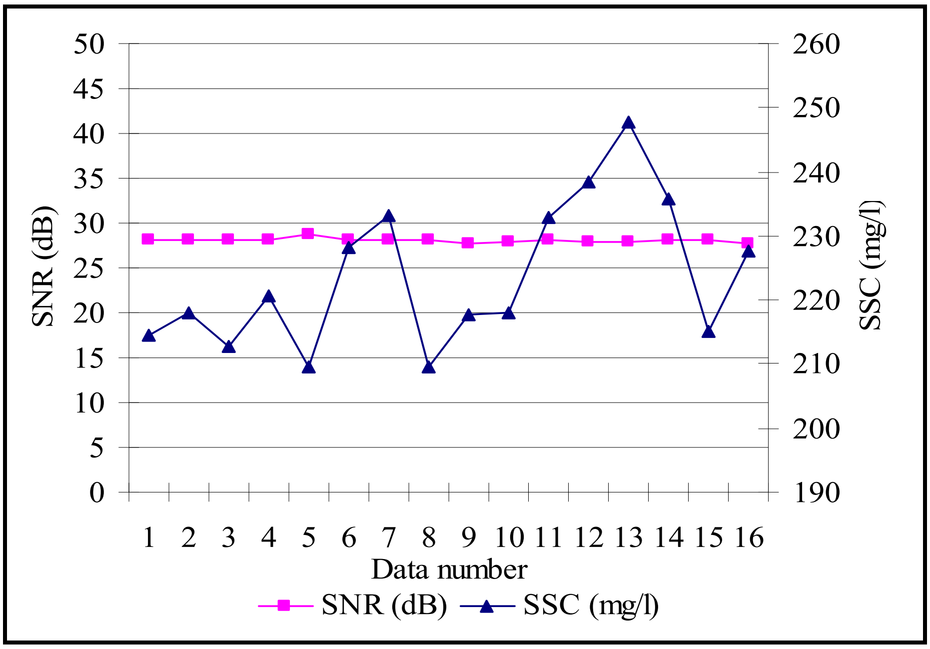


Figure 4.15. ADV and WQC measurements of Tahtali stream on flood conditions

CHAPTER 5

SUMMARY AND CONCLUSION

A methodology was developed and applied to allow the use of an acoustic Doppler velocimeter (ADV) for estimation of suspended sediment concentration (SSC) in different streams and rivers located in the Aegean region of Turkey. Simultaneous measurements were made using a water quality meter (WQC) and an ADV at each site. The signal to noise ratio (SNR) reported by the ADV was compared measured SSC data. While the comparison of SNR and SSC was made in different streams and rivers, the parameters affecting the relation between SNR and SSC were investigated. The Doppler shift effect and the sonar equation were studied carefully to minimize outside effects on the relation.

The sonar equation showed that absorption coefficient of the water has critical importance for the signal to noise ratio data of ADV. The absorption coefficient of water only depends on temperature in streams and rivers. Therefore, variation of temperature affecting the absorption coefficient of water and thus the signal strength reported by the ADV was also investigated. Moreover, sonar equation also indicates that the particle size and diatribution has effect on returning signal strength of ADV. In this study to investigate the effect of particle size of sediments on the relation between SNR and SSC, soil samples were collected from each measurement stations. Both sieve and hydrometer analysis were applied to the collected samples and the particle size distributions of soils were obtained. The mean diameter of the sediment samples varied between 0.015 to 0.55 mm for all streams and rivers. In this approach, it was assumed that suspended sediment particles come from the river-bed soil, and have the same composition.

Measurements showed that the ADV can be used to estimate SSC in low-turbid (SSC<200mg/l) water systems. When SSC values were plotted against SNR values the regression coefficients varied between 0.7 and 0.9 for four steams. For any acoustic sensor relying on reflected sound for measurements, there is a particle size that will result in maximum instrument sensitivity. As the fraction of suspended particles near this particle size (d=0.025mm in this study) increased, the regression coefficient of SNR and SSC values approached unity.

Owing to the fact that there are many parameters affecting the SNR and SSC relation, the multivariate data analysis was applied to the measurement data to determine the effective parameters in the regression. Multivariate analysis indicated that reported SSC values depended on at least three parameters; water temperature, mean diameter of the soil, and shape of the particle size distribution curve. A model consisting of these parameters predicted SSC values in different streams having different soil properties and water temperatures with high predictive ability (R^2=0.93), calculated from the sum of squared errors for the whole dataset. Moreover, the formulations which derived from multivariate data analysis had averagely 17% error in all measurements. Also, the calculated SSC error decreased approximately 8.5% when the data filtration was applied. In this study the verification of the formulations were conducted using new set simultaneous SNR measurements. The derived formulations were applied to these new dataset and suspended sediment concentrations estimated had averagely 13% error.

The predictive equation developed in this study has general applicability since it is not site-specific. It includes the effects of particle size distribution and water temperature in the prediction of SSC by acoustic methods. This methodology does not consider either the effect of organic material or the effect of sediment density.

ADV predictions of SSC were not possible when a limit concentration (SSC>400mg/l) determined by the sediment size distribution for the measurement site was exceeded. Monitoring water and sediment flow by ADVs has a number of advantages over other instruments; and after appropriate calibration, three-dimensional flow velocity, temperature, and suspended sediment concentration time series could be obtained with one instrument.

As a result, three formulations were derived in this study. The formulation (4.19) is general formulation to estimate SSC in all rivers. Also, Formulation (4.20) was obtained for Tahtali stream and formulation (4.21) obtained for Sasal stream. Table 5.1. shows these formulations.

Table 5.1. The derived Formulations

	Formulations
All rivers	$SSC = -6.979 + 0.822SNR + 15.868\frac{\alpha}{\alpha_c} + 0.051Cu - 0.106dbest_{\max} - 0.03d\min_{\max}$
Tahtali	$SSC = -8.399 + 0.934SNR + 13.067\frac{\alpha}{\alpha_c} + 0.048Cu - 0.069dbest_{\max}$
Sasal	$SSC = -16.436 + 0.805SNR + 31.258\frac{\alpha}{\alpha_c} + 0.043Cu - 0.124dbest_{\max}$

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APPENDIX A

Measurement Data and Derived Formulations

		SSC	SNR	T	SSCc1	%er	SSCc 2	%er	SSCc 3	%er	SSCc 4	%er	SSCc n.	%er
SASAL	1	13.40	19.70	15.60	28.29	53%	16.70	20%	16.63	19%	16.28	18%	16.55	19%
	2	15.70	21.50	15.60	30.40	48%	18.26	14%	18.40	15%	17.91	12%	18.03	13%
	3	16.90	20.60	15.70	29.28	42%	17.42	3%	17.45	3%	17.03	1%	17.25	2%
	4	15.30	20.20	15.70	28.81	47%	17.07	10%	17.06	10%	16.67	8%	16.92	10%
	5	14.70	20.20	15.70	28.81	49%	17.07	14%	17.06	14%	16.67	12%	16.92	13%
	6	19.00	20.60	15.80	29.22	35%	17.35	-9%	17.39	-9%	16.96	-12%	17.21	-10%
	7	19.40	18.40	15.80	26.63	27%	15.44	-26%	15.23	-27%	14.97	-30%	15.40	-26%
	8	22.80	21.30	15.90	29.98	24%	17.90	-27%	18.01	-27%	17.52	-30%	17.74	-28%
	9	10.80	16.70	13.50	26.16	59%	15.50	30%	15.06	28%	15.14	29%	14.97	28%
	10	9.60	15.40	13.50	24.63	61%	14.37	33%	13.78	30%	13.97	31%	13.90	31%
	11	10.30	17.10	13.50	26.63	61%	15.85	35%	15.45	33%	15.50	34%	15.30	33%
	12	11.10	20.20	13.50	30.27	63%	18.54	40%	18.49	40%	18.29	39%	17.85	38%
	13	12.70	21.90	13.50	32.27	61%	20.02	37%	20.16	37%	19.83	36%	19.24	34%
	14	15.00	21.50	13.50	31.80	53%	19.67	24%	19.77	24%	19.47	23%	18.92	21%
	15	14.60	20.20	13.50	30.27	52%	18.54	21%	18.49	21%	18.29	20%	17.85	18%
	16	18.30	21.73	13.50	32.07	43%	19.87	8%	20.00	8%	19.67	7%	19.10	4%
	17	19.10	22.77	13.50	33.30	43%	20.78	8%	21.02	9%	20.61	7%	19.96	4%
	18	18.80	22.20	13.50	32.63	42%	20.28	7%	20.46	8%	20.10	6%	19.49	4%
	19	21.40	21.17	13.50	31.42	32%	19.39	-10%	19.45	-10%	19.17	-12%	18.64	-15%
	20	19.50	21.47	13.50	31.77	39%	19.65	1%	19.74	1%	19.44	0%	18.89	-3%
	21	20.00	20.73	13.50	30.90	35%	19.00	-5%	19.01	-5%	18.77	-7%	18.28	-9%
	22	19.40	22.60	13.50	33.10	41%	20.63	6%	20.85	7%	20.46	5%	19.82	2%
	23	18.60	21.47	13.50	31.77	41%	19.65	5%	19.74	6%	19.44	4%	18.89	2%
	24	18.30	20.57	13.50	30.71	40%	18.87	3%	18.86	3%	18.63	2%	18.15	-1%
	25	18.80	21.87	13.50	32.24	42%	19.99	6%	20.13	7%	19.80	5%	19.22	2%
	26	18.40	21.00	13.50	31.22	41%	19.24	4%	19.28	5%	19.01	3%	18.50	1%
	27	18.90	21.43	13.50	31.72	40%	19.61	4%	19.70	4%	19.40	3%	18.86	0%
	28	19.50	27.43	13.50	38.78	50%	24.83	21%	25.59	24%	24.81	21%	23.79	18%
	29	18.70	21.43	13.50	31.72	41%	19.61	5%	19.70	5%	19.40	4%	18.86	1%
	30	17.70	19.90	13.50	29.92	41%	18.28	3%	18.20	3%	18.02	2%	17.60	-1%
	31	17.60	20.47	13.50	30.59	42%	18.78	6%	18.76	6%	18.54	5%	18.07	3%
	32	16.80	19.27	13.50	29.18	42%	17.74	5%	17.58	4%	17.46	4%	17.08	2%
TAHTALI	33	15.40	16.30	15.10	22.41	31%	13.58	-13%	12.43	-24%	12.32	-25%	14.25	-8%
	34	15.40	16.30	15.10	22.41	31%	13.58	-13%	12.43	-24%	12.32	-25%	14.25	-8%
	35	14.10	18.00	15.10	24.41	42%	15.06	6%	14.10	0%	13.85	-2%	15.65	10%
	36	14.40	15.40	15.00	21.42	33%	12.86	-12%	11.61	-24%	11.58	-24%	13.55	-6%
	37	16.60	17.00	15.00	23.30	29%	14.25	-16%	13.18	-26%	13.02	-27%	14.86	-12%

TAHTALI	38	15.40	15.03	15.10	20.92	26%	12.47	-23%	11.18	-38%	11.18	-38%	13.20	-17%
	39	15.60	18.60	15.10	25.12	38%	15.58	0%	14.69	-6%	14.39	-8%	16.14	3%
	40	15.60	17.60	15.10	23.94	35%	14.71	-6%	13.70	-14%	13.49	-16%	15.32	-2%
	41	16.70	13.30	3.80	28.77	42%	20.93	20%	19.18	13%	20.61	19%	18.04	7%
	42	17.50	12.90	3.90	28.18	38%	20.47	14%	18.67	6%	20.12	13%	17.64	1%
	43	18.40	14.10	3.90	29.59	38%	21.51	14%	19.85	7%	21.20	13%	18.63	1%
	44	17.80	14.10	4.00	29.48	40%	21.40	17%	19.74	10%	21.08	16%	18.56	4%
	45	18.20	14.10	4.00	29.48	38%	21.40	15%	19.74	8%	21.08	14%	18.56	2%
	46	17.50	13.30	4.00	28.54	39%	20.70	15%	18.95	8%	20.35	14%	17.90	2%
	47	17.20	13.30	4.00	28.54	40%	20.70	17%	18.95	9%	20.35	15%	17.90	4%
	48	17.00	13.70	3.90	29.12	42%	21.16	20%	19.46	13%	20.84	18%	18.30	7%
	49	16.60	12.90	3.90	28.18	41%	20.47	19%	18.67	11%	20.12	18%	17.64	6%
	50	16.40	12.40	3.90	27.59	41%	20.03	18%	18.18	10%	19.67	17%	17.23	5%
	51	16.80	13.30	4.00	28.54	41%	20.70	19%	18.95	11%	20.35	17%	17.90	6%
	52	18.70	15.00	4.00	30.54	39%	22.18	16%	20.62	9%	21.89	15%	19.30	3%
	53	17.40	13.53	3.90	28.93	40%	21.02	17%	19.29	10%	20.69	16%	18.16	4%
GEDIZ	54	34.00	23.60	10.90	46.45	27%	34.18	1%	34.18	1%	33.69	-1%	34.35	1%
	55	34.30	23.47	10.90	46.30	26%	34.07	-1%	34.05	-1%	33.57	-2%	34.24	0%
	56	34.50	24.03	10.90	46.96	27%	34.55	0%	34.60	0%	34.07	-1%	34.70	1%
	57	35.00	23.77	10.90	46.65	25%	34.33	-2%	34.35	-2%	33.84	-3%	34.49	-1%
	58	35.00	22.87	10.90	45.59	23%	33.55	-4%	33.47	-5%	33.03	-6%	33.75	-4%
	59	35.20	22.60	10.90	45.28	22%	33.31	-6%	33.20	-6%	32.79	-7%	33.53	-5%
	60	35.10	22.47	10.90	45.12	22%	33.20	-6%	33.07	-6%	32.67	-7%	33.42	-5%
	61	34.70	22.60	10.90	45.28	23%	33.31	-4%	33.20	-5%	32.79	-6%	33.53	-4%
	62	35.50	22.60	10.90	45.28	22%	33.31	-7%	33.20	-7%	32.79	-8%	33.53	-6%
	63	35.30	23.00	10.90	45.75	23%	33.66	-5%	33.59	-5%	33.15	-6%	33.86	-4%
	64	35.10	22.87	10.90	45.59	23%	33.55	-5%	33.47	-5%	33.03	-6%	33.75	-4%
	65	35.40	22.87	10.90	45.59	22%	33.55	-6%	33.47	-6%	33.03	-7%	33.75	-5%
	66	35.00	22.60	10.90	45.28	23%	33.31	-5%	33.20	-5%	32.79	-7%	33.53	-4%
	67	33.20	22.60	10.90	45.28	27%	33.31	0%	33.20	0%	32.79	-1%	33.53	1%
	68	33.10	23.17	10.90	45.95	28%	33.81	2%	33.76	2%	33.30	1%	33.99	3%
	69	32.90	22.31	10.90	44.93	27%	33.06	0%	32.92	0%	32.53	-1%	33.29	1%
	70	32.40	22.73	10.90	45.43	29%	33.42	3%	33.33	3%	32.90	2%	33.63	4%
	71	34.50	24.90	10.20	48.55	29%	35.88	4%	36.02	4%	35.49	3%	35.78	4%
	72	34.10	25.30	10.20	49.02	30%	36.23	6%	36.41	6%	35.85	5%	36.11	6%
	73	34.30	25.80	10.20	49.61	31%	36.67	6%	36.90	7%	36.30	6%	36.52	6%
	74	34.90	24.00	10.20	47.49	27%	35.10	1%	35.13	1%	34.68	-1%	35.04	0%
	75	34.50	23.60	10.20	47.02	27%	34.75	1%	34.74	1%	34.32	-1%	34.71	1%
	76	34.90	25.80	10.20	49.61	30%	36.67	5%	36.90	5%	36.30	4%	36.52	4%
	77	35.40	24.00	10.20	47.49	25%	35.10	-1%	35.13	-1%	34.68	-2%	35.04	-1%
	78	34.60	24.50	10.20	48.08	28%	35.54	3%	35.63	3%	35.13	2%	35.45	2%
	79	33.90	23.60	10.20	47.02	28%	34.75	2%	34.74	2%	34.32	1%	34.71	2%
	80	34.50	24.00	10.20	47.49	27%	35.10	2%	35.13	2%	34.68	1%	35.04	2%
	81	34.70	24.50	10.20	48.08	28%	35.54	2%	35.63	3%	35.13	1%	35.45	2%

GEDIZ	82	34.80	24.50	10.20	48.08	28%	35.54	2%	35.63	2%	35.13	1%	35.45	2%
	83	34.00	24.00	10.20	47.49	28%	35.10	3%	35.13	3%	34.68	2%	35.04	3%
	84	39.40	26.20	10.20	50.08	21%	37.01	-6%	37.29	-6%	36.66	-7%	36.85	-7%
	85	34.89	24.62	10.20	48.22	28%	35.64	2%	35.74	2%	35.24	1%	35.55	2%
GULBAHCE	86	10.25	9.53	17.30	14.48	29%	7.16	-43%	8.07	-27%	7.86	-30%	8.28	-24%
	87	9.80	10.87	17.30	16.05	39%	8.33	-18%	9.39	-4%	9.07	-8%	9.38	-4%
	88	9.70	11.27	17.30	16.52	41%	8.67	-12%	9.78	1%	9.43	-3%	9.71	0%
	89	9.50	11.13	17.30	16.36	42%	8.55	-11%	9.64	1%	9.30	-2%	9.60	1%
	90	9.40	8.83	17.30	13.65	31%	6.55	-43%	7.38	-27%	7.23	-30%	7.71	-22%
	91	9.60	17.43	17.30	23.77	60%	14.03	32%	15.83	39%	14.98	36%	14.78	35%
	92	9.30	11.57	17.30	16.87	45%	8.93	-4%	10.07	8%	9.70	4%	9.96	7%
	93	15.00	28.17	17.30	36.40	59%	23.36	36%	26.38	43%	24.66	39%	23.60	36%
	94	9.10	16.87	17.30	23.11	61%	13.54	33%	15.28	40%	14.47	37%	14.32	36%
	95	8.80	14.00	17.30	19.73	55%	11.05	20%	12.46	29%	11.89	26%	11.96	26%
	96	15.70	24.07	17.30	31.57	50%	19.80	21%	22.35	30%	20.96	25%	20.23	22%
	97	13.70	18.90	11.60	29.33	53%	19.17	29%	21.03	35%	20.57	33%	18.41	26%
	98	11.90	20.60	11.60	31.33	62%	20.64	42%	22.70	48%	22.10	46%	19.81	40%
	99	11.50	19.30	11.60	29.80	61%	19.52	41%	21.43	46%	20.93	45%	18.74	39%
	100	52.60	41.20	11.60	55.55	5%	38.55	-36%	42.93	-23%	40.66	-29%	36.74	-43%
	101	41.80	37.40	11.60	51.08	18%	35.24	-19%	39.20	-7%	37.24	-12%	33.62	-24%
	102	22.70	21.50	11.60	32.39	30%	21.43	-6%	23.59	4%	22.91	1%	20.55	-10%
	103	16.40	21.00	11.60	31.80	48%	20.99	22%	23.10	29%	22.46	27%	20.14	19%
	104	40.50	41.20	11.60	55.55	27%	38.55	-5%	42.93	6%	40.66	0%	36.74	-10%
	105	26.70	36.90	11.60	50.50	47%	34.81	23%	38.71	31%	36.79	27%	33.21	20%
	106	41.80	37.40	11.60	51.08	18%	35.24	-19%	39.20	-7%	37.24	-12%	33.62	-24%
	107	29.70	32.20	11.60	44.97	34%	30.73	3%	34.10	13%	32.55	9%	29.35	-1%
	108	21.00	28.30	11.60	40.38	48%	27.34	23%	30.27	31%	29.04	28%	26.14	20%
	109	39.30	30.00	11.60	42.38	7%	28.81	-36%	31.93	-23%	30.57	-29%	27.54	-43%
					R^2=0.865		R^2=0.743		R^2=0.786		R^2=0.710		R^2=0.930	