ABSTRACT

The aim of this study is to model the behavior of the Yeşilköy aquifer, to evaluate the future predictions of the water levels, in order to identify the aquifer behavior and to provide a numerical equation for better understanding of ground water level fluctuations.

The model was applied by using the available static water level data to obtain an equation to predict the future water level positions.

The physical characteristics of the aquifer were determined via pump tests, and the change in static water levels within a long term monitoring program has been used for deriving a linear equation model. The input/output budget of the aquifer has shown that each year the volume of deficit is around $0.98 \times 10^6 m^3$. It was clear that although the consecutive arid years were the main reason of aquifer deficits, the drawdown of water levels was mainly due to the domestic water supply from the aquifer to the whole Karpaz Peninsula rather than the drawdown due to irrigation water use. The results show that under the same abstraction and recharging rates the static water level of the aquifer will drop approximately seven more meters within the coming ten years period.

ÖZET

Bu calışmanın hedefi Yeşilköy yeraltı su tabakasının davranış şekillerini inceleyip, ileride yeralti su değişimlerini tahmin etmek ve yeraltı su kaynaklarının davranışlarına matematiksel bir değer verip, su tabakasının degişme şekillerini daha iyi anlayabilmektir.

Bu model mevcut ve uzun dönem statik su seviyelerini gözetleyerek ileriye yönelik statik su seviyelerini tahmin etmektedir. Yeraltısuyu statik su seviyelerinin uzun süre gözetlenmesi sonucunda kurulan ilişkide kurak yıllarda akiferdeki net azalma 0.98×10^{6} m^{3} olarak hesaplanmıştır. Çalışmalar açıkca göstermektedir ki arka arkaya gelen kurak yıllarda karpaz yarımadası su kaynaklarındaki net düşüşüş en önemli etkeninin evlerde harcanan su kullanımından kaynaklanmaktadır. Ziraatta kullanılan su giderlerinin etkisi kıyasla daha az olmaktadır. Bulguların gösterdiğine göre yeraltı suyu kaynakları ileriki on yıl içerisinde yedi metre düşüş gösterecektir.

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CHAPTER 1

INTRODUCTION

1.1 OVERVEIW

The natural resources available around the Eastern Mediterranean Region, based on climate are severely suffering from the inevitable increment on temperature and drought weather conditions. Water is one of the most affected resource whose demanding position increases day by day due to population growth and tourism investments around the region. The attractive tourism development at the region, thus challenging farming industry and increased life standard of people exerts additional pressure on water resources at the region. Cyprus is the third largest island in the Mediterranean Sea, displaying long, dry and hot summer seasons extended into mid of spring and mid of autumn seasons. Winters are characterized by short rainfall periods and mild breeze creating slightly cold days.

A short overlook to the water resources of the Island shows that the precipitation for the whole Island, in a normal year is 500mm where the evaporation is around 2000 mm (Tsiourtis, 2001). The rainfall varies from 300 mm in the plains to 1200 mm on the Troodos range located entirely at the southwest part of the island with part of a drainage area flanking into the northern part of the island, specifically replenishing the groundwater resources of Güzelyurt

(Morphou) Aquifer which is one of the main water supplying aquifer. Most of the streams are ephemeral flowing in winter seasons, carrying the surface water of short duration precipitations conveying the water towards the sea or into the small earth dams. The stored water in dams is usually used for irrigation purposes since it lacks the quality standards for potable use. The only potable water available at the region is pumped from the karstic aquifer in Kyrenia range. However, due to over pumping, the quantity of groundwater is alarming for the future usage.

As a common destiny, all around the world, the organization and management of the groundwater resources lacks coherence. The existing management has been far below the level needed both for long and short-term sustainability of the existing groundwater resources.

According to the above problems, it is essential to initiate an assessment for the groundwater resources considering the supply and demand characteristics of the aquifers for quality and quantity point of view.

The first general water resources survey for Cyprus was held in 1961 by BGR funded by German Government. This study covered hydrogeologic and hydrologic studies. The outcome of the study verified an average annual precipitation of 450mm. It was also highlighted that 87% of the precipitation is evaporating, 6% flowing as a surface flow and 7% infiltrating into the soil. The report also underscores the availability of 65 water resources discharging 0.9 to 7700 million cubic meters of water per year (Gökmenoğlu *et al.*, 2002).

A report that has been done by UNDP 1970, covers engineering studies of the development of artificial storage reservoirs and some of conveyance canals, and also covers the problem of sedimentation of reservoirs, and salinity of flow of some rivers.

The conveyance of water from one region to the other was studied in Tylliria (Yayla)-Morphou (Güzelyurt) area, and in Polis area, it has been found that up to 40MCM of water can be diverted from Tylliria to the Morphou area, depending on developed storage and irrigation in Tylliria area. It appears that with the developed storage capacity of the order of 35 to 40 MCM the reliable flow diverted to Morphou may amount to about 20 MCM depending on the irrigation development in Tylliria.

The development of storage reservoirs was studied in Larnaca area, eastern and southern Mesaoria, and in region of Karpaz and Kyrenia (Dams of Cyprus,1974).

GökÇakuş, H, (1990) studied and evaluated the hyrdogeological and hydrogeochemical characteristics of the Güzelyurt Basin. He has found that there exist a bet decently of 28 million cubic meter in the storage of aquifer. He also mentioned that the increase in salinity is not only from salt intrusion but from bed rock contamination as well.

General Directorate of Mineral Research and Exploration of Republic of Turkey (Gökmenoğlu *et al.*, 2002), had a detailed study on the water resources of the northern part of the Island. The Research Group gathered all the previous studies and analyzed before carrying on the studies. Field studies accomplish this and hydrogeologic observations, geophysical studies, and monitoring well drilling studies conducted. All the permeable, impermeable and semi permeable formations are listed and classified in this report. The physical characteristics of water samples are analyzed and important findings were obtained at the end of geophysical measurements. The hydrogeologic findings were obtained through 26 monitoring wells drilled during the project.

1.2The aim and the Objective

The objective of this study is to carry a detailed study on one of the main aquifers in Karpaz Peninsula that is responsible to supply potable water for 14 villages of Karpaz Peunslina and irrigation water for Yeşilköy (Ayious Andronikos) Village. The drawdown observations for the last 10 years, monitoring and continues data of one well for the last one year has been studied, Meteorological conditions of the region are monitored daily for last three years, soil moisture of the region has been monitored for the last six months and an aquifer test is carried over on the Aquifer. Based on all factors a mathematical model has been improved to determine the available situation of the water table and model a scenario for the future prediction of the water table and thus the water balance of the aquifer.

CHAPTER 2

GROUNDWATER SOURCES OF CYPRUS

2.1 General

Water problems for islands are sensitive and should be considered under integrated management techniques. Water resources management of small and medium sized islands can have advantages, even though disadvantages are prevailing. Since the water basins are small, they can be handled and explored quite quickly. However, small basin means surface water sources (rivers, lakes, streams, springs) very soon reaches to the sea; and groundwater resources are always carries the risk of pollution, such as salt water intrusion from the oceans.

The water problems faced in the last 30 years have already reached a serious stage at North Cyprus, third largest island in Mediterranean. The problem is not only linked to the quantity or availability of water but also to water quality.

North Cyprus is located at Eastern Mediterranean with its 250 thousand populations living in 3299 km^2 of 9251 km^2 area of the whole Island. In relation to its topographic features, Cyprus can be divided into three main surface areas (Dreghorn, 1978):

(a) the Kyrenia Mountains stretching in East-West direction.

(b) the South, Trodos Mountains situated in the South-West region, and

(c) the Mesaoria Plain in between the two mountain ranges.

Low rainfall over the past few years highlighted the need for a systematic and comprehensive approach for the proper and effective management of the water resources of the North Cyprus. There is increasing evidence that the earth's climate is changing, affecting the water resources available on earth surface and its hydrologic cycle. Price *et al*. (1999), analyzed long term temperature data from two stations on the island of Cyprus and found increasing trends of approximately $1^{o}C/100$ years in the annual mean temperatures of the island. Results show the traces of slow devastating process in the island, which starts with a reduction in rainfall and depending on its severity, in time and areal extend may develop into a drought.

The main groundwater resources of North Cyprus is distributed on different basins; Güzelyurt (Morphou), Gazimağusa (Famagusta), Girne (Kyrenia) and Karpaz Peninsula. The water resources manegment of the aquifers located in these regions has not been seriously researched and analyzed since 20 years. However, according to the report of General Directorate of Mineral Research and Exploration of Republic of Turkey (Gökmenoğlu *et al*., 2002), total capacity of 93.85 million m^3/year water is available within these water bearing formations. Although the available water sources seems enough to afford water demand of North Cyprus, available potable water is polluted due to natural and anthropogenic activities. In addition, the uncontrolled and uncounted agricultural activities increases water demand enormously causing depletion of water table elevation and seawater intrusion.

Ergil , M, in 1999 also studied the water budget of the Güzelyurt costal aquifer. In his 3D approach both the water balance and the salt balance equations were integrated in space and in time.(Ergil, 1999).

Apart from the seawater intrusion, there are many other factors behind the degradation of groundwater resources quality at North Cyprus, such as:

(a) Contamination caused by mining remnants;

(b) Contamination caused by untreated wastes of small industries;

(c) Fertilizers used in agriculture aimed at increasing productivity and pesticides used against pests;

(d) Contamination caused by domestic wastes (solid and liquid);

(e) Contamination caused by geological formations and their soluble ingredients**.**

The contamination caused by salt water intrusion appears to be more significant than contamination from others.

2.2 Main Aquifers of North Cyprus

Groundwater is one of the North Cyprus's most important natural resources. It provides about 95% of the public water supply. In addition, Groundwater with earth dams is only source of water used for irrigation. From an overall national perspective, until recently the groundwater resource appears ample. However, the availability of groundwater varies widely. Moreover, only negligible part of the groundwater stored in the subsurface of the aquifers foster a long-term perspective management.

Several factors reinforce the need for a long-term perspective. First, groundwater is not a nonrenewable resource, such as mineral or petroleum deposit, nor is it completely renewable in the same manner and timeframe as solar energy. Recharge of groundwater from precipitation continually replenishes the groundwater resource but may do so at much smaller rates than the rates of groundwater withdrawals. Second, groundwater development may take place over many years; thus, the effects of both current and future development must be considered in any water management strategy. Third, the effects of groundwater pumping tend to manifest themselves slowly over time. For example, the full effects of pumping on surface water resources may not be evident for many years after pumping begins. Finally, losses from groundwater storage must be placed in the context of the period over which sustainability needs to be achieved (Alley *et al*, 1999).

This introductory discussion indicated that reviewing some pertinent facts and common concepts about groundwater resources available in North Cyprus will help to better characterize the overall situation and clearly understand the sustainability concerns of the stakeholders. Neglecting the size of the water bearing formations there are 12 groundwater bodies distributed all around the North Cyprus. Among these 12 bodies 5 of them has severe consequences to hydrologic and related environmental systems and therefore, carries the value judgment over the long-term sustainability concerns.

Table 1.1 The aquifers of North Cyprus.

No	Name of Groundwater Body
1	Güzelyürt (Morphou) Aquifer
2	Girne (Kyrenia Range) Aquifer
3	Girne (Kyrenia) Coastal Aquifer
4	Yeşilköy (Agios Andronikos) Aquifer
5	Büyükkonuk (Komikebir) Aquifer
6	Yeni Erenköy-Sipahi (Yalusa- Agia Triada) Aquifer
7	Doğu mesarya (Lapathos), (East Mesaoria)
8	Gazimağusa (Famagusta) Coastal Aquifer
9	Orta Mesarya (Central Mesaoria) Aquifer
10	Akdeniz/Koruçam (Agia Irıni/Kormakiti) Aquifer
11	Güneydoğu Mesarya (Southeastern Mesaroria)
12	Bati Mesarya (Western Mesaoria River Basins)

The focus of attention to characterize the 5 selected aquifers will be presented in the following pages. The available information for the aquifers are gathered from previous studies, reports, case studies and individual observations. Geological and Hydrogeological characteristics of the aquifers, their boundaries, types, thicknesses, and hydraulic conductivity and storativity properties are all searched and discussed. In addition the replenishment rate and abstraction values; annual average rate of overall recharge; the land use of the area, climate and vegetal cover are all gathered and summarized. The aim was to create a detailed information and full description of the main aquifers. However, due to lack of data and information, most of the aquifers are discussed only with rough information.

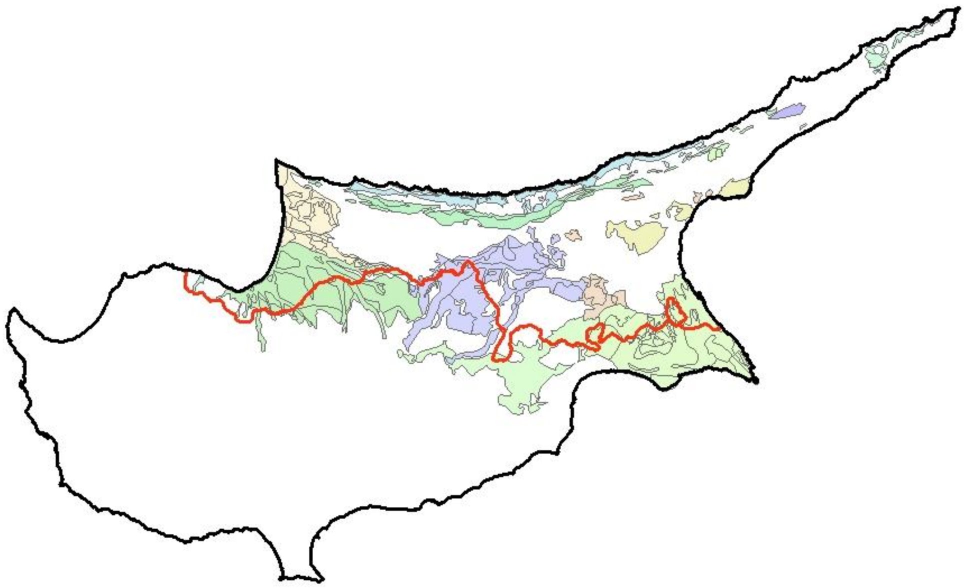


Figure 2.1 The map showing the position of Aquifers.

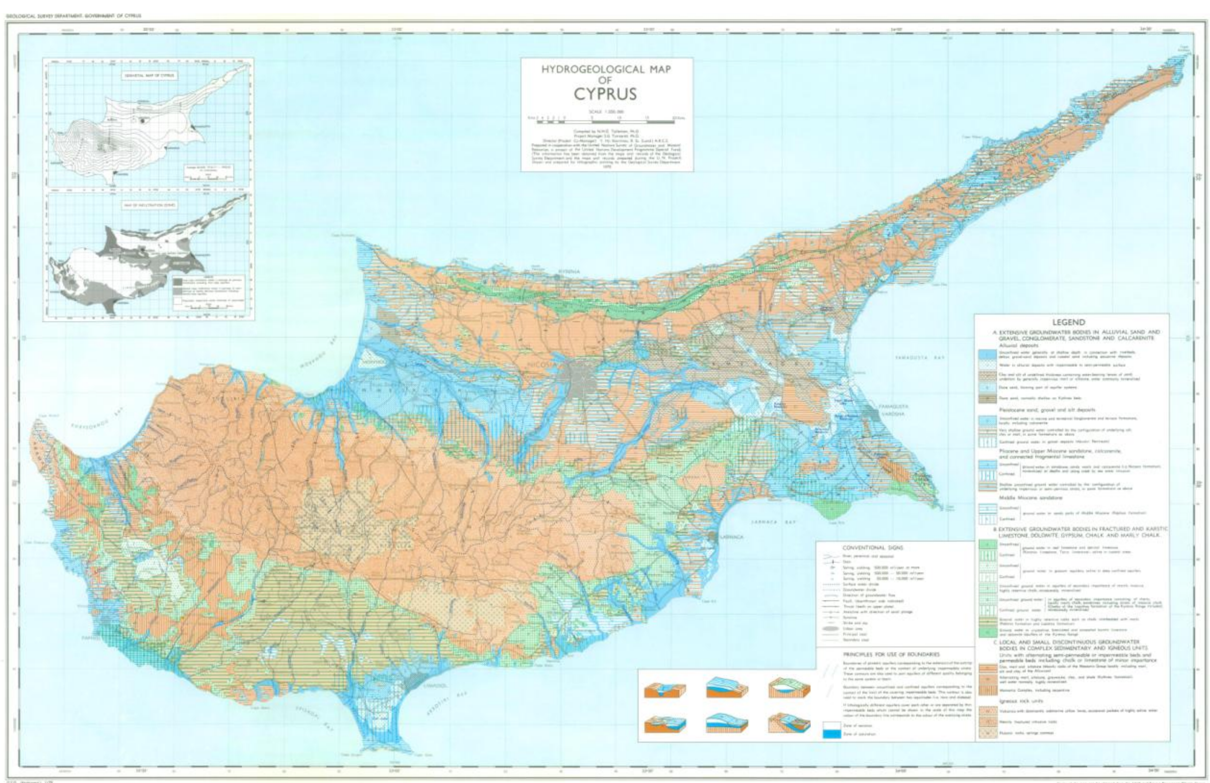


Figure 2.2 The Hydrogeological Map of Cyprus (Tullstrom and Tornqvist, 1970).

2.2.1 Güzelyurt (Morphou) Aquifer

It is the Largest aquifer at the North Cyprus. It used to be one of the most productive aquifer, supplying potable water to three main cities (Lefkoşa, Güzelyurt and Gazimağusa) and surrounding villages. However, extensive over-pumping during the last 50 to 60 years has resulted in a dramatic depletion of this aquifer. Part of this aquifer is outside the area under the control of North Cyprus Government. The type of the aquifer is phreatic. The aquifer is heterogenous and isotropic, carrying a risk of pollution from the Mediterranean Sea. Decreased rate of recharging and the physical disturbances due to human activities has increased the risk of pollution within the last decades.

2.2.1.1 Previous Studies

Electro-Watt company (1973) carried out a study in Güzelyurt region in order to establish a feasibility study on irrigation methods to minimize the problems at the region.

The Turkish State Water Works (DSİ) has established a comprehensive study about the aquifer late in 1976. They concentrate on the water balance of the aquifer taking into consideration the salt-water intrusion problems and proposing dams for recharging activities at the region. The result show that the Güzelyurt Aquifer is a first class unconfined aquifer built up of alluvium with an average depth of 100 to 130 meters. They also depicted that the specific yield of the aquifer is $37x10^6$ m^3/year.

A study has been done by Ergil (1999). The available freshwater volume within the aquifer and its remaining lifetime is roughly estimated with the help of the volumetric (3D) approach. The water balance and the salt balance equations are integrated both in space and time.

(Gökmenoğlu *et al.*, 2002), had a detailed study on the water resources of the northern part of the Island. The Research Group gathered all the previous studies and analyze them before carrying on the studies. Field studies accomplish this and hydrogeologic observations, geophysical studies, and monitoring well drilling studies conducted. All the permeable, impermeable and semi permeable formations are listed and classified. The physical characteristics of water samples are analyzed and important findings were obtained at the end of geophysical measurements. The hydrogeologic findings were obtained through 26 monitoring well drilled during the project.

2.2.1.2 Land and Topography Study

The area of interest is located at the west part of North Cyprus bridging the Mesaoria Basin and the Morphou Bay (Figure 1). Total basin area of the Aquifer is around 460 km^2 in which 1/3 of this area is under the control of Greek Cypriot Community and 2/3 is under the control of Turkish Cypriot Community Authorities.

Figure 2.3 the map showing the position of Güzelyurt Aquifer.

Within the area under consideration the main hills are Koca Tepe (332m), Karadağ Tepe (302m), Şapka Tepe (224m) and Erciv Tepe (206m). The approximate drainage area of the whole Aquifer is 900 km^2 in which most of this area is at the Greek Cypriot Community territory.

2.2.1.3 The Climate and the Vegetal Cover

The Mediterranean climate is dominated at the area of concern. The winters are warm and rainy whereas the summers are hot, arid and humid. According to the data obtained from Seven Meteorological Stations located at the site the average precipitation at the region is around 287.1mm. Within the summer months there is no precipitation in the area. The mean annual temperature is 18.2^oC. The minimum average monthly temperature is 10.9 ^oC and occurs on January whereas, the maximum average monthly temperature is 33.7 ^oC in August.

There are mass water dependent agricultural activities at the region. Thus, the main portion of the Groundwater resources is used for agricultural purposes. The Citrus trees are heavily distributed all around the area covering 40,000 donums (53.5km^2) of land. A considerably little amount of olive production and greenhouse cultivation works are carried on. Until mid 1998 the farmers use flooding irrigation methods whereas since than the governmental funding motivate them to change the technology into drip irrigation methods.

Gözen, (2006), has mentioned that 25 million cubic meter of water is lost due to old irrigation system used by the farmers which caused 40 million cubic meter of water gap in the aquifer.

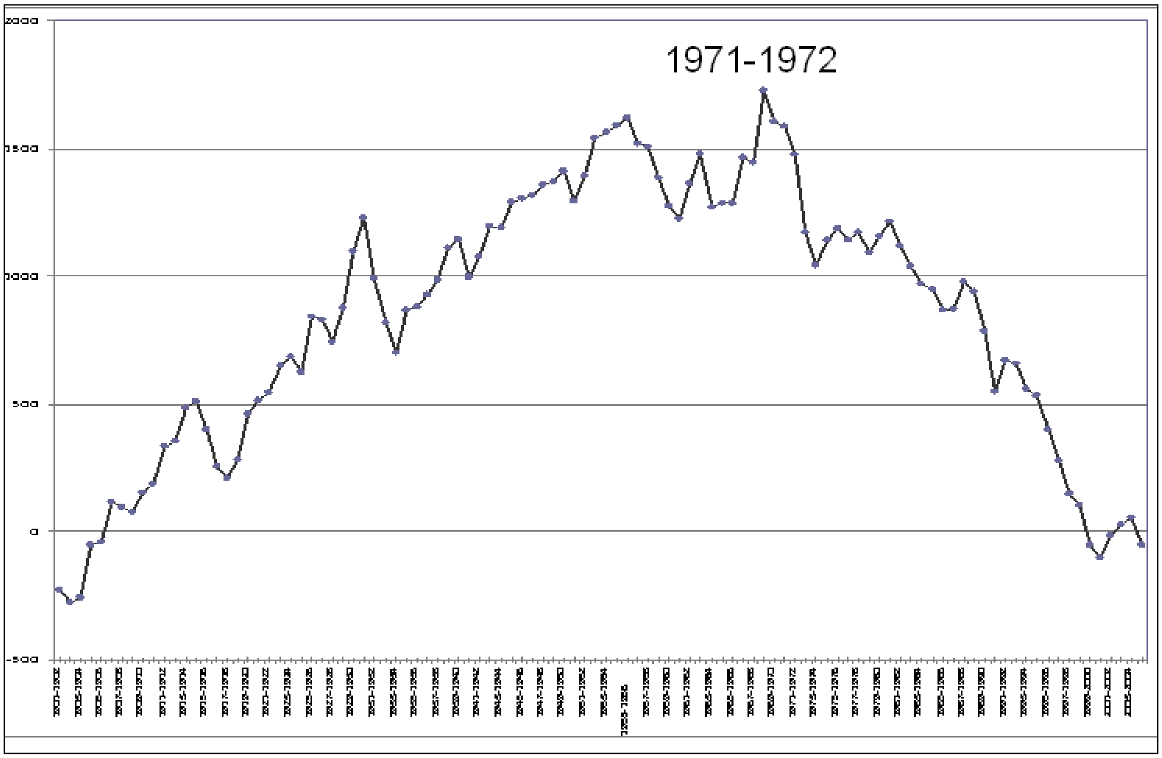


Figure 2.4 Cumulative departure from the average precipitation in Cyprus (mm) (Gokçekuş,2002).

2.2.1.4 Land use

The Güzelyurt region is Mediterranean's renowned citrus producing area. In the late 1960's Gazimağusa was the leading citrus producing area; finally abandoned for farming when the aquifer become desalted. The farmers shift to Güzelyurt and cultivated citrus fruits abstracting water from the Güzelyurt aquifer. Citrus production is very important to the economy. Increasing water deficits in the area greatly reduced both the number of farmers and the area under irrigation. Due to over pumping, the aquifer has been affected by seawater intrusion. More specifically, the most productive and deepest parts of the aquifer (Yayla, Kumköy, Gaziveran etc), have been affected. (Gökçekuş, *et al*, 2002).

2.2.1.5 The Geology

At the watershed of the Güzelyurt groundwater basin various lithological units of the Troodos massif (middle-Upper Cretaceous), Lapathos group (Oligocene-Lower Miocene), Dhali Group (Middle-Upper Miocene) and Mesaoria Group (Upper Miocene-Upper Pliocene) constitute the bedrock. The basin it self comprises flanglomerates (Plestocene) and Holocene deposits (Gökçekuş, 1990).

The Pre-Tertiary Troodos Massif rocks are the oldest units exposed within the watersheds of the Güzelyurt groundwater basin. In general, the Troodos Massif is a huge igneous body, which is exposed in the central part of Cyprus. It is made up to Troodos Plutonic Series, Sheeted Dyke Complex and Pillow Lava Series (Searle and Panayiotou, 1980).

Henson *et al*. described lapathos group in 1949. They divided the group as Lower Lapathos (Late Cretaceous), Middle Lapathos (Eocene) and Upper Lapathos (Oligocene-Early Miocene). In Güzelyurt region only the Upper Lapathos (Ovgos Formation) crops out.

The upper part of the Lapathos Group was named as Ovgos Formation by Wilson (1959) (in Ingham, 1957). The Formation is composed of marly and chalky units. It is well observed 3 km north of serhatköy. The Formation shows a tectonic contact relationship with the younger Formations (Moore, 1960).

The Dhali group is represented by Miocene shallow marine environment. The Dahil Group unconformably overlies the Troodos Massif (late Cretaceous) and Upper Lapathos Formation. (Gökçekuş, 1990).

The Mesaoria Group was first introduced by Henson *et al*. (1949). At its type locality it was divided into five formations. From bottom to top they include the Myrtou, Pissuri, Nicosia, Kyrenia and Athallassa Formations. However because of lateral facies change within the group the Pissuri and Kyrenia Formations are not observed in the study area. The age of the group was determined as late Miocene-Late Pliocene(Cockbain, 1958; in Ingham, 1962).

The fanglomerates were first described by Bellamy and Jukes-Brown (1905; in Henson *et al.* ,1949). They consist of Conglomerates and intercalated sandstones and siltstones. They are well observed of the foot of Troodos Range and in the form of isolated hills in the Mesaoria plain. in Güzelyurt area the flanglomerates are well exposed at south of Güzelyurt and in the vicinity of doğancı and Cengizköy. They form gently dipping topographic slopes bordering the Güzelyurt groundwater basin in the south and southwest. The Conglomerates are essentially composed of poorly cemented and poorly sorted , subangular to subrounded boulders, cobbles and gravels which fan out from the Troodos Range toward the Mediterranean Sea. The diameter of the individual pebbles may be s large as 60 to 70 cm.

The components of the fanglomerates are derived from the Toodos Range and younger rocks of Tertiary are. Towards top, well developed caliche layers up to 5 m thick are observed. This is rather typical for semi-arid and arid climates. The maximum thickness of the fanglomerates is estimated as 80 m.

The Holocene deposits comprise alluviums, talus deposits, slopewash deposits, river terrace deposits, beach deposits and wind-blown sand deposits. They are however, undifferentiated on the geological map. The Holocene deposits consist mainly of gravels, sands, silts and clay of various proportions. They constitute the major valley fill of the Güzelyurt plain. The maximum thickness of these deposits is about 120m.

2.2.1.6 The Hydrogeology

An unfractured, unconfined aquifer is in direct contact with the sea it is composed of gravel, sand and calcareous sandstone with intercalations of silt and clay and lenses, showing abrupt vertical and lateral variation. The aquifer rest on impervious base formed by gently undulating Pliocene , marl and thick clay. The thickness of the aquifer is ranging from 45m at the far part to a maximum thickness of 100 m at the far western part. The thicker side is in direct contact with the coastline along Güzelyurt Bay and is totally under the mean sea level Ergil (1999).

The aquifer composed of confined and unconfined parts, the confined portion, which is only 10% of the total aquifer volume, its located along the south-western side but due to the present water levels, being well below the upper confining layer, the confined conditions no longer exist. (UNDP, 1970; DSİ., 1975).

The groundwater occurs under unconfined aquifer conditions within the superficial deposits and the conglomerates. The basin has a typical dendritic drainage pattern that comprises alluviums, talus, beach and slopewash, river terrace deposits and wind-blown with various proportions of gravel, sand, silts and clay. The low lying region of the aquifer at its northwestern part is underlain by marl and sandstone, which are highly susceptible to erosion. (Elctro-Watt, 1973).

The surrounding geological formations are divided into three according to their water bearing capacities; permeable, semi-permeable and impermeable.

The old Pliocene formation consisting of marl and clay forms the impermeable units of the aquifer. In addition to these units the massive volcanic formations of Troodos are also creating impermeable zones (Gökmenoğlu *et al.*, 2002).

The aquifer characteristics can be observed on Miocene age Lefke formation, the sandy and gravelly formation of Pliocene age Taşpınar formation and the sandy and calcarenite formation of Athalassa Formation (Gökmenoğlu *et al*., 2002).

The magmatic formations due to Troodos rocks and Potami Formation have the semi-permeable characteristics at the region (Gökmenoğlu *et al*., 2002).

The Cooper-Jacob method has shown that the hydraulic conductivity of the unconfined aquifer is $0.18m^3/day/m^2$ whereas the Transmissivity is $0.3x10^2m^3/day/m$ (Gökmenoğlu *et al*., 2002)

2.2.1.7Evaporation and Precipitation

Based on the data obtained from State Meteorological Department, based on the monthly evaporation rates, the average annual evapotranspiration rates is 2117.13mm (Based on 1986-1997 met data). The reason of such a high rates of evaporation is topographic elevation of the region (50-60m), high intensity of vegetal cover, the high temperature and the short and sudden precipitation at the area. Regarding to the precipitation rates recorded from seven met stations based on the monthly precipitation rates, the average annual precipitation is 267.97mm.

2.2.1.8 Point Sources

2.2.1.8.1 Rivers:

Some of the drainage flows from the Kyrenia range, but the major portion is derived from the northern slopes of the Troodos range. The watershed dividing the Güzelyurt

(Morphou) Basin from that of the Kanlıdere river runs south from Kırnı (Krini) village through Nicosia airport and almost to the banks of the Kanlıdere River itself.

All around the Mesaoria the rivers were flowing all around the year when it was in between 1950-1980. However, as the arid years started, the perennial river characteristics converted into intermittent and finally to ephemeral. Also, the flood control structures and dams constructed at the upstream points of the rivers has minimized the flow of water at the downstream parts of the rivers at the region. The main rivers situated at the region are Güzelyurt, Maden, Lefke and Doğancı. Doğancı and Lefke are flowing when there is an excess flooded water at the drainage area at which 15 lt/sec discharge has been estimated in Doğancı river in 1997 which continued for one and a half day (Gökmenoğlu *et al*., 2002).

On the drainage area of Güzelyurt river there are Güzelyurt and Serhatköy reservoirs. These two artificial reservoirs are constructed for groundwater recharging purposes. In addition, starting from the Gemikonağı (Xeros) Reservoir, there exists a derivation channel which crosses all the rivers and diverting the excess water to recharging area with 7000 cubic meters per day.

2.2.1.8.2 Springs and wells

Since the groundwater level is depleting each year, there is no spring discharging at the area. Only at the downhills of Troodos and at Lefke region there are some (5-6) small discharges from the high elevations with a capacity of 0.1 to 0.5 lt/sec.

Before and after 1974 since the irrigation of citrus fruit was facilitated at the region, the irrigation wells were drilled all around the aquifer. The total number of wells drilled until today registered on ENVIS database is 1019 and 87 of these well is belonging to WWD in which 27/87 is serving to Lefkosa and Famagusta and rest to surrounding villages. (personal communication with Turgay KARA). The depth of the wells is changing in between 80-150 meters. The diameters are around 8-10” with a discharge of 1 to 15 lt/sec.

2.2.1.8.3 Dams and Reservoirs

At the region four dams has been constructed. Güzelyurt and Serhatkkoy dams are constructed for groundwater recharging; Ovgos has been constructed for flood control and Gemikonağı has been constructed for irrigation purposes. Among those dams only Güzelyurt and Serhatkoy are affecting the aquifer water budget.

2.2.1.9 Chemical composition of the groundwater

Increasing groundwater withdrawals since 1957 have produced extensive drawdown throughout the aquifer, particularly in the central and costal and costal parts of the basin. Such overdrafts have caused sea water encroachment which resulted in the contamination of the costal aquifer. Additional source of contamination is due to bedrock (Gökçekuş, 1996).

2.2.2 Kyrenia Range Aquifer

Kyrenia Range Aquifer is the second largest aquifer of North Cyprus. It is used to be one of the most qualified aquifer on the island. Due to its karstic formation there exist 49 springs discharging from the aquifer. However, extensive over-pumping during the last 30 years has resulted in a dramatic depletion on the water levels such that most of the springs are dried up.

2.2.2.1Geology

When the Kyrenia range was first upthrust, it was far more distant from the Troodos range than it is to-day; it moved southwards and upwards all through the Miocene, and the more it was elevated, the more rapidly it was eroded. The debris was washed into the sea on either side and tended to fill it up; coarser material was deposited nearer the shore while finer sands, silts and marls were laid down further out to sea. On the south a depression or foredeep formed ahead of the rising range; the infilling of this foredeep with debris kept pace with the rate of sinking, so that the sea was always shallow, often cut off from the ocean by gravel and sand spits, and even by coral reefs which at this time were growing in the clear waters fringing the Troodos range (Burdon, 1952).

The Kyrenia range consists of semi-impermeable and impermeable units. The impermeable unit is lower Miocene age Kythrea Flysch. The karstification is limited through the deeper zones. The semi-permeable unit is chalk and lava units of upper cretaceous, known as Lapathos Group. The groundwater bearing units are divided into three different groups. Faulted and karstified Mesozoic age dlomitic, recrystallized limestones and breccia Formation.; Jurassic – Upper Cretaceous Hilarion Formation and Palexoic – Lower Triassic Dikmen (Dhikomo) Formation.

2.2.2.2Hydrogeological Data

The total area of the aquifer is 85 square kilometers, the average rainfall is 400-450mm and the thickness of the aquifer is 400m. The aquifer is showing karstic properties and thus hydraulic conductivity and the storage coefficient for the aquifer is not defined yet.

2.2.2.3 Land Use

The Kyrenia range is a forestry region in which in 1995 of the region was burnt due to a drastic fire. Since than the villas and summerhouses are constructed at the northern hills of the range, creating nitrite seepage due to lack of sewerage system.

2.2.2.4 Discharge and abstraction rates

Approximately, 58 boreholes are operating on this aquifer generally for domestic use. The depths of these boreholes are ranging between 150 to 260 meters. The typical diameters of the wells are 8-10 inches. During 80's the major springs such as Kythrea, Krini, Bellapais and Lapathos were used for Irrigation purposes. However, nowadays their discharges are low and sometimes even dried.

Dixey (1975) has estimated that 167mm direct seepage from the precipitation replenishes the aquifer by 11.5 million cubic meters per year. During the last decade, water levels within the aquifer have exhibited a depleting trend, which are a result of the reduced recharge and the increase of abstraction

2.2.3 Girne (Kyrenia) Coastal Aquifer

Girne coastal aquifer is a perched aquifer and developed along the coastal strip, stretching from Kyrenia Range. The aquifer has a mild slope towards the coast discharging towards the Mediterranean Sea. The aquitard is Miocene Kythrea Flysch in which the water bearing unit of the aquifer is limestone and calcarenite.

The total area of the aquifer is 160 square kilometers, the average rainfall is 350-400mm.The aquifer has a drainage area of 400 square kilometers. Fast urbanisation and tourist development in the area are causing rapid deterioration of this highly susceptible aquifer thus seriously endangering its future. Since there exists continuous flow towards the sea, the aquifer is evacuating itself during the dry seasons. The present storage of the aquifer is unknown, however. Depending on seasonal precipitation rates, the replenishment of the aquifer can vary from 1.5 to 10 million cubic meters per year. The abstraction from the surrounding wells is estimated to be 2 to 8 million cubic meters per year. (Gökmenoğlu *et al.*, 2002).

Microbiological contamination into groundwater from the sewerage disposal of urban areas is carrying high concentrations of Nitrate on water quality.

2.2.4 Gazimağusa (Famagusta) Coastal Aquifer

2.2.4.1 Geology

The oldest rocks revealed by drilling in the vicinity of Famagusta are black clays, sandy clays, sands, shell-beds and some white clays which are belong to the Kythrea Formation of Miocene age. The Miocene topography of the area is buried completely beneath varying thickness of Pliocene and Pleistocene calcareous sandstones and clay beds. The separation between the Pliocene and the Pleistocene but it is believed that most of the calcareous sandstones are of Pleistocene and Holocene age, and were deposited as sand-dunes. A bed of red clay can be faced at some locations which is possibly representing weathered top of the Pliocene, later covered by Aeolian sands, or may be an inter Pleistocene formation. (Burdon, 1952).

2.2.4.2 Hydrogeological Data

The aquifer area is around 362 km^2 in which 295km^2 is under the control of GCC authorities. The aquifer is phreatic. From the viewpoint of hydrogeology, the separation of the two formations, the Pliocene and the Pleistocene, is not necessary since both of them can be considered as one unit of porous calcareous sandstones which are good bearing and yielders of water. The Miocene strata extend towards great depths and consist of black clay with poor water yielding capacity. The permeable Pliocene and Pleistocene strata starts from ground surface and deepens up to 100-110 meters until it catches the impermeable Miocene strata.

2.2.4.3 Land Use

The aquifer area is covered with urban settlements.

2.2.4.4 Chemical composition of the Groundwater

The coastal area has been affected by seawater intrusion. High concentrations of nitrate exist locally where the main city is situated. Limited agricultural facility is sustained close to city. The microbiological contamination is observed due to septic wells at the urban settlements.

2.2.5 Yeşilköy (Agios Andronikos) Aquifer

The 5.46 square kilometer Yeşilkoy Aquifer is selected as the study area in this thesis. Therefore, all the detailed information and discussions will be covered in the next chapter.

CHAPTER 3

YEŞİLKÖY (AGIOS ANDRONIKOS) AQUIFER: CASE STUDY

3.1 Introduction

Groundwater is used extensively in the islands for drinking water, tourism, industry and agriculture. The alternative; surface water from river estuaries need large watersheds for storage, and seawater requires extensive treatment prior to use due to high total suspended soil content.

As it is all around the Cyprus, groundwater is used extensively in the Karpaz Peninsula for drinking water, tourism and agriculture. Yeşilköy (Agios Andronikos) Basin of Karpaz Peninsula has sustained a successful water-supplying task since late 1960s. The Basin is located 82 km northeast of Nicosia. It can be divided into two distinct geographic environments; the high plain to the southeast and the lower plain to the southwest. The high plain has elevations of 100 to 150 m, moderate relief and dendritic drainage. The gradient is $3.5x10^{-2}$ towards the southwest. The southwest drainage is identified by a naturally discharging spring evacuating towards the outlet of the basin. Therefore, agriculture predominate major economic activity at the study area.

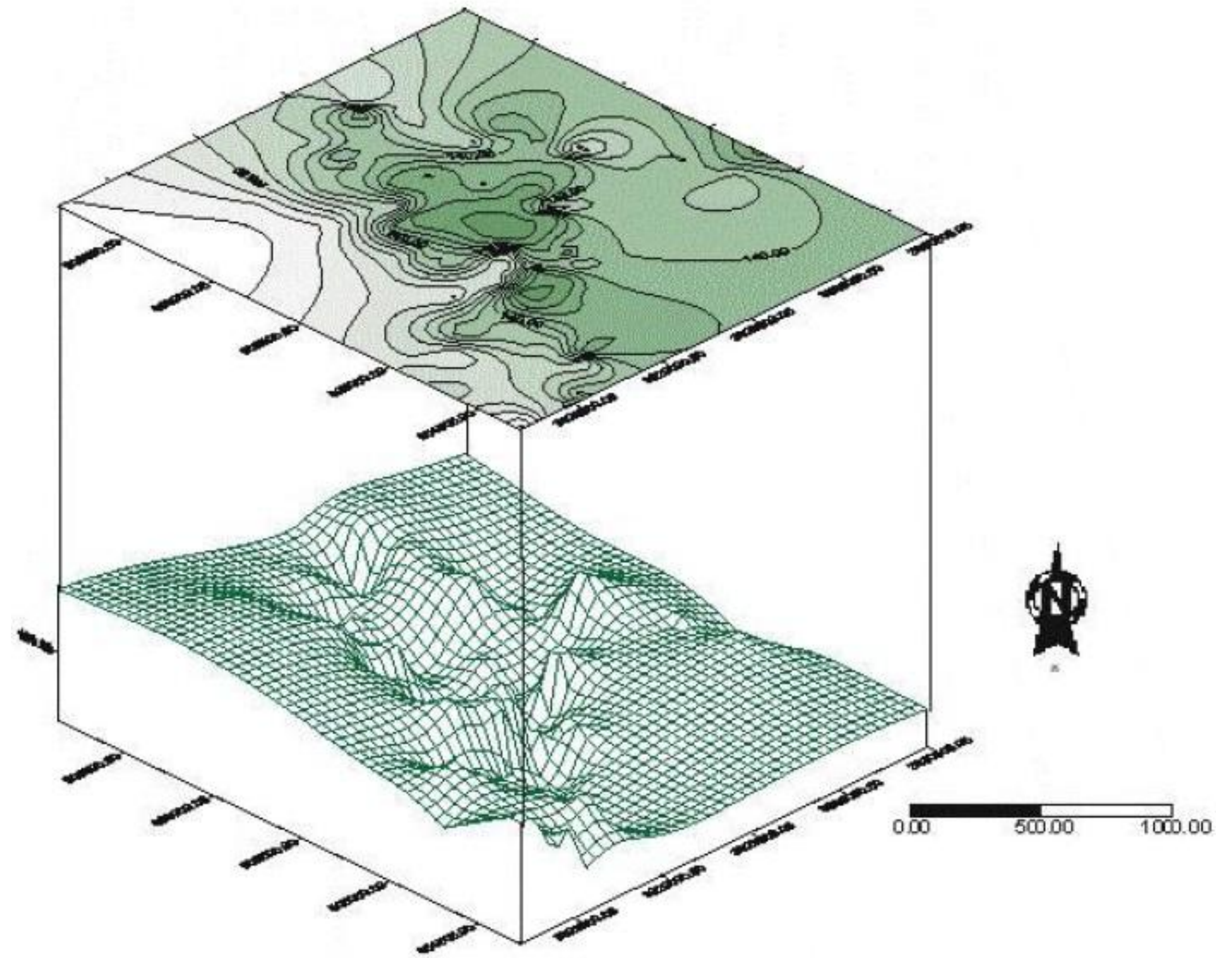
The region has sustained competitive agricultural activities on *Colocasia Esculent*a farming since late 1960s. Initially, the *Colocasia Esculenta* plantations thrived with qualified and quantified supply of water. Most of the irrigation wells were shallow and constructed by hand in alluvial deposits of alluvial coastal plain and river valleys. However, during the early 1990s, the depletion on groundwater table and improved drilling technologies allowed wells to be developed in the underlying Pleistocene and Pliocene Athalassa Formation. This was the depth of principle aquifer system with alternative aquitards.

At the turn of the century, around 120 wells were capable of supplying 260 ha of land with several thousand Cubic meters of irrigation water per day. However, a progressive depletion in groundwater level was observed. The problem was found to be particularly acute around the highly productive wells. These wells were working 24 hours a day, supplying drinking water to all the urban areas on the Karpaz Peninsula.

By the beginning of the century concerns for the agricultural future of the region was raised when yields of *Colocasia Esculent*a declined in response to the increased depletion on groundwater table. Most of the farmers were seriously deteriorated and the problem attracted the attention of the Agricultural Ministry of the government. The work carried out under the guide of ministry was focused on the crop pattern of the region. As a result *Colocasia Esculent*a plantations prohibited and the farmers motivated to plant *Solanum Tuberosum* (potatoes)which consumes less water and ripe with high quality due to the structure of the surrounding soil. The long term monitoring of wells also implemented to assess the effects of over pumping.

Photo 1: Cultivated (*Solanum Tuberosum*) areas of yeşilköy region

Consequently, the residents of Karpaz peninsula depend entirely on groundwater for public supply and agriculture. The sole source of potable water for those people is the Yeşilköy underlying aquifer system, which was once providing sufficient fresh water to meet the demands. Depletion on water table has begun to restrict its use in several areas, and forces the authorities to search for alternative water resources such as desalination. Neverthless, the 5.46 square kilometer confined Yesilkoy Aquifer with 6.39 square kilometer catchment area is alarming.



Figuer 3.1 3D view of the Yeşilköy Aquifer (Albayrak, 2009).

Understanding the relationships between the various parameters, and initiating attempts to resolve the origin of the problem will enable optimization of Yeşilköy groundwater resources. This study was based on a mathematical model to put forward the current situation of the aquifer and predict the future fate of the aquifer.

3.2 The Geology of the region

The Karpaz Peninsula has mainly impervious rocks of the kythera formation overlain by generally thin Pliocene-pleistonence sedimentary rocks, which are in part pervious. However, only at Yeşilköy and Dipkarpaz (Rizokarpoaso) are the layers thick enough to form small groundwater units. Water infiltrates into the limestone group, which forms the central backbone of the peninsula, later outflows via small springs. The individual compartments of limestone are in this area much smaller than in central part of Kyrenia range and their storage capacity is rather small. (UNDP, 1970). All individual compartments of limestone formations are minor aquifers and the water quality is unsatisfactory.

The hydrostratigraphy of the rocks (Table 3.1) underlying the Yeşilköy Valley consists of rocks from the lower Miocene ages to recent ages. Formations of concern, in terms of their hydrogeologic characteristics from oldest to youngest, belong to the Değirmenlik (Khytrea) and Mesarya (Mesaoria) Groups as well as sediments of recent age.

The Değirmenlik Group, which is roughly equivalent to the Lafkara Group, consists of sedimentary rocks of Oligocene to Miocene sedimentary rocks. These rocks consist of channel fill sandstones, marble fragments, and reef limestone with claystone, mudstone and gypsum. This group is separated into several different formations as defined by rock type. The principal formation underlying the study area is the Beylerbeyi which is late Oligocene in age. This formation consists of sandstone and shale with a middle layer of claystone and mudstone. The sandstone is light to dark brown and can be yellow to khaki in color. It is course to fine grained with lenses of microcoglomerate. The origin of the rock is from erosion of volcanic and carbonates sedimentary rocks. Claystones and mud stones are generally light brown, grey in color. This formation also contains marble fragments. These marbles are generally round with volcanic, ophiolitic metamorphic clasts , and churt (McKinney and Brown, 2007).

Table 3.1. Hydrogeologic section of the Yeşilköy Aquifer (Heft, J.R.C., 1990)

Stratigraphic Age	Geological Unit		Lithology	Thickness	Water-bearing Properties
Recent	Alluvium of coastal plain and river valleys		Sand, silt, gravel, and marl	Up to 15 m	Principal aquifer with alternative aquitards
Pleistocene	Fanglomerate Series		Clay, marl, sand, gravel	0 – 30 m	
Pliocene	Mesaoria	Athalassa Formation	Calcarenite, marl, sandstone	Approximately 200 m	
		Nicosia Formation	Marl, sand, gravel		
Upper Miocene		Myrtou Marl	Marl	800 m	Aquiclude
	Değirmenlik (Khytrea) Lefkara group	Gypsum Koronia Limestone	Gypsum alternating with marl	6 – 120 m	Karst aquifer, in some areas
			Reef limestone		
Middle Miocene		Pakhna Formation	Marl, chalky, marl, calcareous sandstone, calcarenite	12 – 300 m	Aquiclude, aquiferous section is certain areas
Lower Miocene to Maastrichtian	Lefkara Chalk Formation	Upper	Massive and flaggy chalk, marl, marly chalk	-	Aquiclude
		Middle	Flaggy chalk, marl	Up to > 300 m	Aquiclude, locally aquiferous
			Massive chalk, marly chalk		Aquiferous in fractures and fissures
					Aquiclude, locally aquiferous
			Chalk, chert, marl		
		Lower	Marl, chal, chert		Aquiclude
	Moni Formation		Clay, exotic blocks	-	Aquiclude

The Değirmenlik Group is stratigraphically below the Mesarya Group which is of Pliocene to early Pleistocene age. This group includes Çamlıbel, Nicosia, Taşpınar (Angolem), Gürpınar (Aymarina) and Bostancı (Zodya) Formations. Of primary concern in the Yeşilköy area is the Gürpınar (Aymarina) Formation. In the Karpaz region this unit contains small to medium sized, rounded, cemented marble fragments underlained by continuous calceranitic sandstone which has a yellowish grey color. . It consists of a course grained to pebble sized marble conglomerate in a sandstone matrix. The sandstone is gray to grayish green in color. Grains of marble range between angular to rounded in shape.

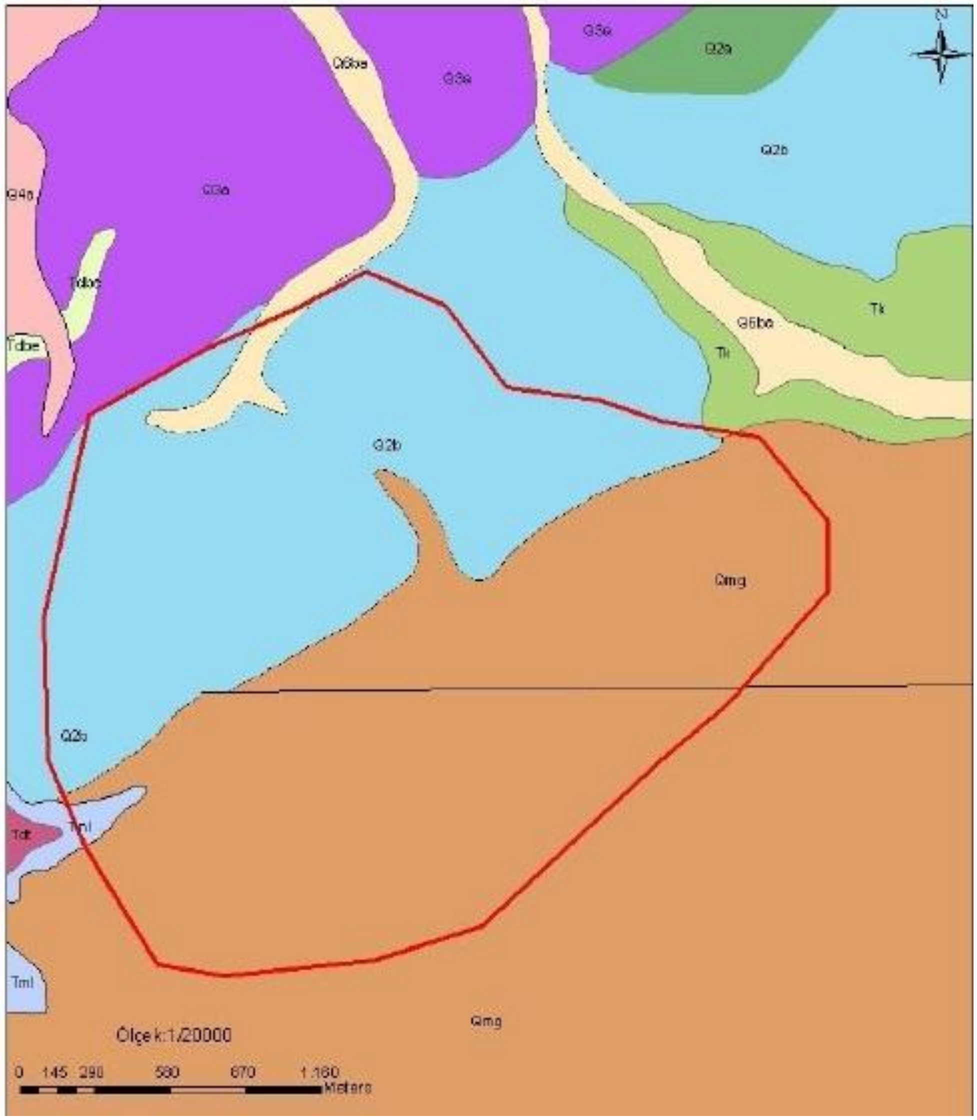


Figure 3.2 Geology map of the region (Albayrak, 2009).

3.3 The Hydrogeology of the region

The shape of the aquifer is following an elliptic surface and mainly consists of the Quaternary calcarenite and forms a permeable aquifer above relatively impermeable marl, which acts as an aquitard. Since 2000, local authorities initiated a monitoring program observing the water levels and quality in the wells of the aquifer. As a result, an excellent hydrogeological database was assembled. The database (ENVIS database) consists of lithology data of some wells as well as an extensive collection of static and dynamic water levels and water quality data. The ENVIS database is not only limited with Yeşilköy Aquifer, but also includes information of all the aquifers in Northern part of Cyprus. The minimum frequency of sampling and analysis for water intended for both human consumption and agricultural purposes is therefore accomplished at the area since 2000. The sampling frequency is twice a year.

Recharge to the aquifer system within the study area occurs chiefly as downward percolation of rainfall. Throughout most of the study area, recharge to the aquifer system occurs also as a result of infiltration of excess irrigation water. Although the water level intends to rise during the rainy season (mid-November to mid-March), recharging of the aquifer is not successfully achieved.

Discharge from the aquifer system occurs primarily by spring flows and withdrawals from the wells for irrigation and domestic water supply. The aquifer is supplying water to Yeşilkoy and 14 other villages. The total population served is 7802 who are the residents of Yeşilkoy, Kaleburnu (Galinoporni), Boltaşlı (Lythrangomi), Gelincik (Vasili), Derince (Vathylakas), Taşlıca (Neta), Avtepe (Ayios Symeon), Kuruova (Korovia), Ziyamet

(Leonarisso), Esenkoy (Kilanemos), Kumyalı (Koma tou Yialou), YeniErenkoy (Yialousa), Adaçay (Melanarka), and Sipahi (Ayias Trias).

There are two streams tangentially bypassing the aquifer boundary. These are the Göz and the Değirmen streams. Both of them are ephemeral and only flows intermittently in response to rainfall and the discharge of small springs. Due to impermeable Kythrea formation, these ephemeral streams mainly flow to the sea without recharging into the aquifer. In fact, when the water table of the aquifer was at higher elevations, the Göz Stream was replenished by a spring discharging from the aquifer.

3.4 Discharging and abstraction rates

183 boreholes are drilled on the aquifer. Among them, six of them are pumping 24 hours a day supplying domestic water to the villages of Karpaz Peninsula. The remaining boreholes are private which are used for irrigation, domestic and stockbreeding purposes. 15 of these wells are used for domestic and stockbreeding purposes; one well was used for water treatment facilities and 86 wells are used for irrigation. The remaining 75 boreholes are not operating, and sometimes used as an observation well or sometimes used as a stand-by. The capacity and the average depth of the wells can be classified in two different groups. At the northern, lowland part of the aquifer, the static water levels in the wells range between 6m to 10m below ground surface and the depth of these wells are around 12-15 meters. The location and the distribution of wells at the site are given on figure 3.3. The unsteady hydraulic conditions of those wells indicate the existence of subsurface gravitational flow following shallow aquifer characteristics. At the southern upland region the depth of the wells are around

75–100 meters with the capacity of 15-35 m^3/hr discharging from 30cm diameter boreholes. According to above-mentioned hydraulic characteristics of the region, the total water bearing units are divided into two sub basins working independent of each other, each aquifer boundary has one spring at the outlet of the basins discharging higher extractions from the aquifer.

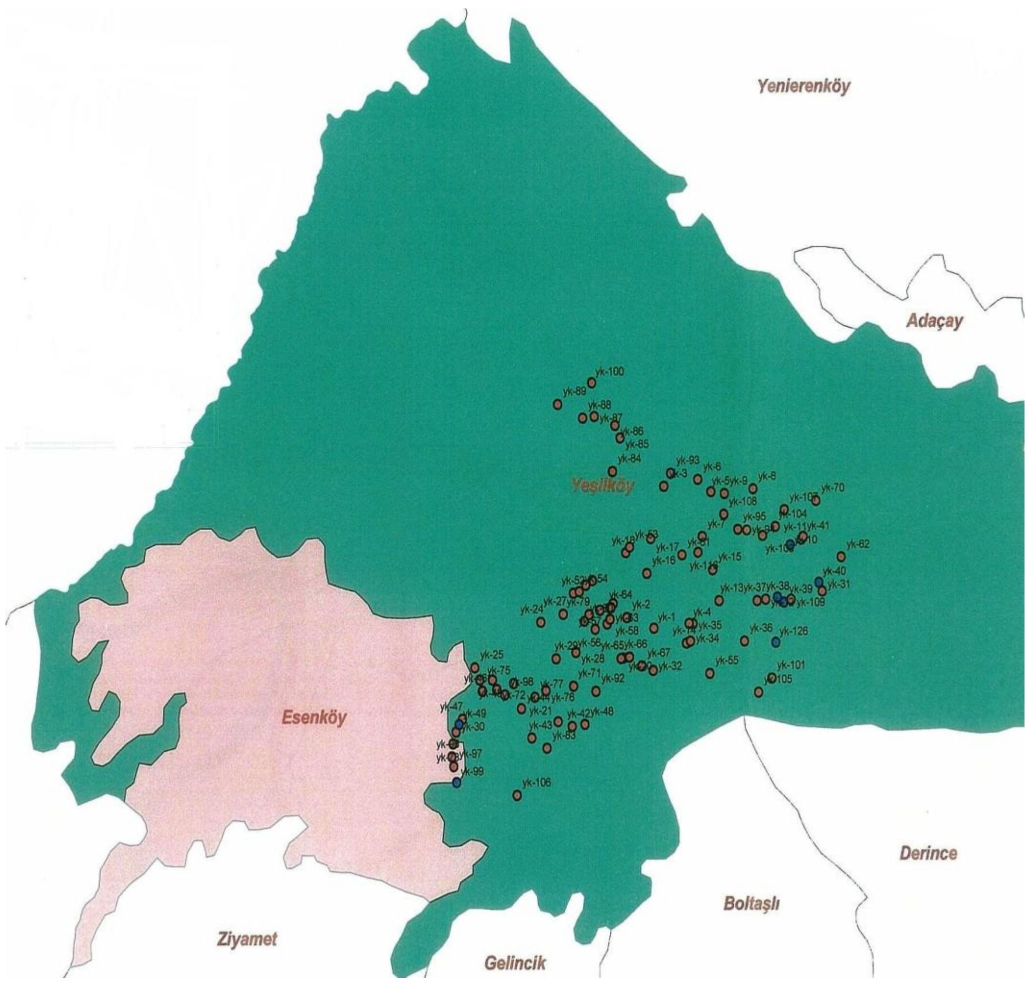


Figure 3.3 wells distribution at the area (Albayrak, 2009).

3.5 Water Quality

The intensive nature of the agriculture and the use of fertilizers in the area are endangering the quality of groundwater. Water samples are periodically taken from wells within the monitoring program under ENVIS database. The main sampling parameters are total dissolved solids, major cations and anions. The cations consisting of sodium (Na), magnesium (Mg), calcium (Ca), and potassium (K). Anions included chloride (Cl), sulfate (SO_4), carbonate ($_{CO2}$), and bicarbonate (HCO_3). The pH values and specific conductance are also measured. In addition, if the availability of Nitrates (>10ppm) or Nitrites (>1ppm) are observed in water samples, the microbiological tests are also performed for the possible occurrence of fecal coliforms. Based on a review of data, the results of the chemical analyses indicate that the water quality parameters of the Yeşilköy aquifer is matching with EU water directive on the quality of water intended for human consumption (98/83/EC) and suitable to be used for potable water with specific conductance ranging between 600 – 700 mmhos/cm^2 and salinity (NaCl) between 100 – 150 ppm. The water chemistry of the aquifer system exhibits considerable variability at the southeast portions and middle part. The water in the southeast portions of the aquifer is dominated by sodium and chloride and the middle portion of the aquifer is dominated by calcium, chloride, and carbonate. This indicates that a fault on the southeast side of the aquifer may restrict flow, allowing more retention time up gradient from the fault, causing a buildup of salts in the water (McKinney and Brown, 2007).

3.6 The Climate

The climate of the study area can be classified as semi-arid and is characterized by warm, relatively hot summers and mild winters. Temperatures commonly exceed 35^{o}C during May, June, July and August and fall below 4^{o}C for a few days in the winter months. The average annual temperature at Karpaz peninsula is about 20^{o}C.short term (1998-2003) annual Precipitation fluctuations at tow different gages, one installed at north east of area (YeniErenköy) and the other installed at south at (Ziyamet) is given in Figure 3.1. The ten years avarege of the stations is 443.6mm. During the winter, rainfall is associated with cold fronts and is more uniformly distributed than the rest of the year.

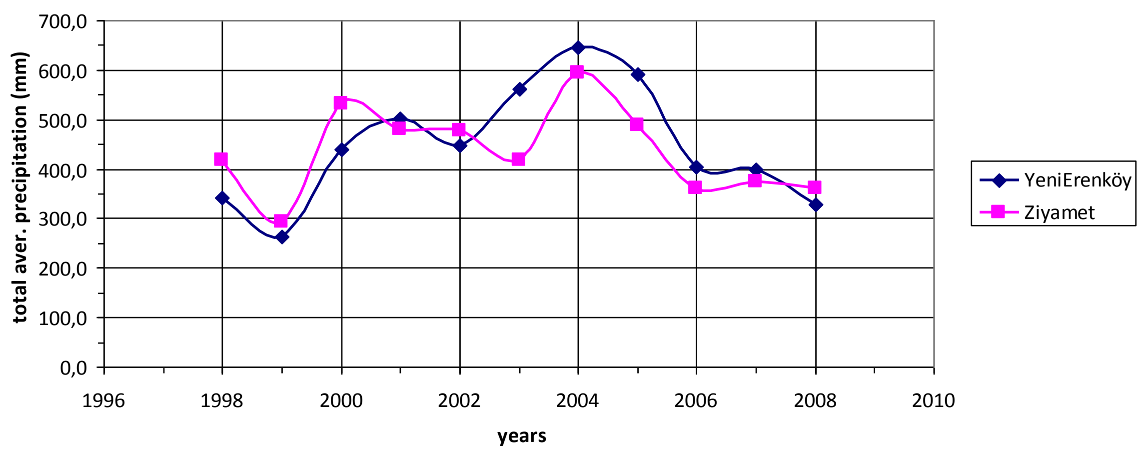


Figure 3.4 total average Precipitation (mm) with respect to years.

The evaporation is the most significant water loss from the catchment area of the region. Dense vegetal cover minimizes the evaporation rates, relative to the other parts of Cyprus, however became significant when evapotranspiration is considered. Evapotranspiration still remains difficult to quantify at the region since it varies greatly in space and time. Figure 3.2 represents the daily evaporation rates with respect to monthly averages for Yeşilköy. Boronina *et al*, (2005), has averaged the isotope values of rainfall samples of Cyprus and found that Deuterium excess decreases with decreasing altitude. Thus, the altitude effect in precipitation cannot be separated from the effect of evaporating of falling rain drops in Cyprus.

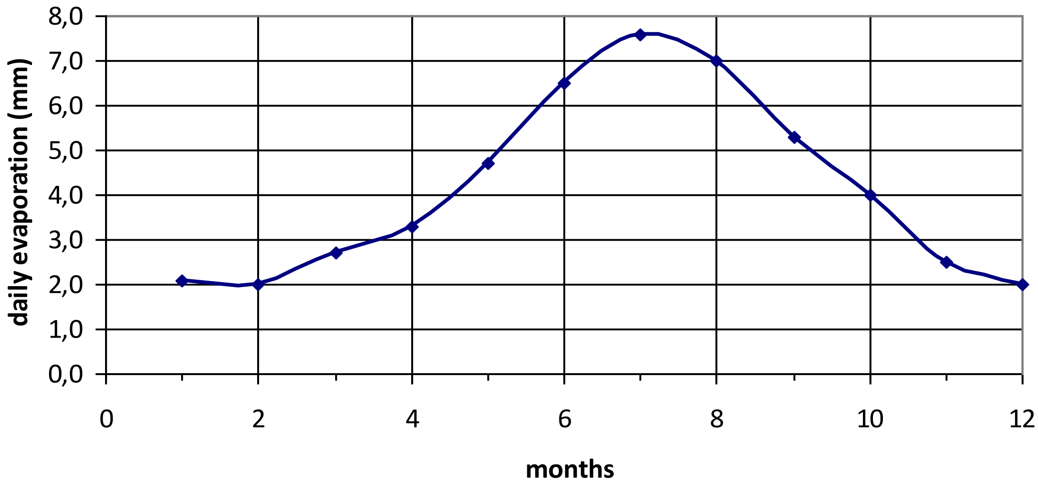


Figure 3.5 the daily evaporation rates with respect to monthly averages.

3.7 Vegetal Cover

The vegetal cover includes cultivated crops, ornamental plants around residential dwellings, Mediterranean grasses and shrubs, and pine forests. Around 150 farmers are active in the area. *Solanum Tuberosum* is the most common crop in the area, planted twice a year. The first plantation is in January and harvested in May, and irrigation occurs from January to May (depending on rate of precipitation). The second planting period is between August and December, and irrigation occurs from August to November, unless the precipitation occurs during October and November. The total amount of plantation during the second period is approximately half of the plantation in first period. The farming is mainly concentrated on *Solanum Tuberosum* since the marketing possibilities for other crops have declined in recent year. Farmers prefer sprinkler irrigation systems believing that drop irrigation will not be successful for growing *Solanum Tuberosum* both in quantity and quality point of view.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Aquifer Testing Programs

Various tests are used to obtain the hydraulic parameters characterizing an aquifer of interest. The most widely used of these aquifer tests have been the slug and pumping tests. Slug tests can be completed simply by applying a stress into a test well and observing subsequent water level variation over time. However, as is widely known, slug tests only give information about the hydraulic properties of the immediate surroundings of a test well. Pumping tests are known to be better than single well tests in estimation large-scale hydraulic parameters. However, they are more complex to perform, requiring a pumping device, electricity generator, and one or more observation well (Yong Lee and Kun Lee, 1999).

During the Yeşilköy aquifer static water level monitoring program, it became evident that most of the wells were preferentially connected. The negligible variation in observed aquifer hydraulic properties and responses to recharge and discharge is the first indication that the aquifer is closely homogenous.

Type-curve analyses of pumping test that was conducted in relatively homogenous, water table aquifer were carried out by (Deane and Phil, 2007).

The aquifer pumping test was conducted in April 2007. Water supply well YK-38 was used for the pumping well and YK- 109, located at a radial distance of 103 meters south of well YK-38 was used as an observation well. Both wells were 0.25meters in diameter and fully penetrating the calcarenite aquifer to a depth of approximately 120 meters below ground surface. The water table at the time of the test was located at a depth of about 68.73 meters below land surface in YK – 109 and the initial saturated thickness was 33 meters. The pumping test was performed at a constant discharge of 0.0073 m^3/sec. It was found that the transmissivity of the aquifer was about 633.6 m^2/day and the Storativity was 0.001. Their analyses were based on the Jacob model for flow to a full penetrating well (Jacob, 1950) that is pumped at a constant rate. The data were found to agree reasonably well with theoretical responses and unambiguous estimates of the aquifers hydraulic properties.

4.2 The pump test and aquifer characteristics

The storage coefficient and transmissivity play a significant role in the evaluation of groundwater resources, and the ground-water study must determine their values accurately. Determination of aquifer transmissivity dates back to 1906 (Thiem, 1906). Theis (1935) initiated the studies for the determination of storage coefficient. Since then, many theorectical and field studies have been carried out to deal with different types of aquifer, aquiclude and aquitard combinations.

Among the numerous methods developed to date, the Jacob straight-line method has found wide acceptance because of its simplicity and its application to confined and unconfined aquifers. The only data needed are late time – drawdown data. The Jacob method gives a straight line on semi-logarithmic paper. In practice, the Jacob straight line is taken for granted by ground-water hydrologists, hydrogeologists, and engineers, and applied almost universally.

Not every straight line on semi-logarithmic paper, however, warrants the application of the Jacob method. The Jacob method has physical restrictions (in addition to the mathematical requirements of having the dimensionless time factor, u, less than 0.01) which are ignored. As a result, determination of the storage coefficient and transmissivity from the semi-logarithmic plot of data yields either over or underestimations (Şen, 1988).

Jacob straight line method suggested determination of the transmissivity and storativity through the following two formulas:

$$\mathrm{T} = \frac{2.3\mathrm{Q}}{4\pi\Delta \mathrm{z}} \qquad (1)$$

$$S = \frac{2.25 t_o T}{r^2} \qquad (2)$$

Where Δz and t_o are the slope and time intercept of the straight line at zero drawdown. However, the method should satisfy the following conditions:

a) the same assumptions listed for Theis Method

b) the value of u should be small ($u<0.01$)

c) well storage is negligible.

The second condition is a mathematical requirement, which can be derived from the equation

$$u = \frac{r^2 S}{4tT} \qquad (3)$$

Which leads to two implied conditions that either the time, t, should be large or the distance, r, should be small (Şen, 1988). Unfortunately, both of the mathematical requirements are not satisfied on the applied pumping test conditions. Even though the maximum time period is considered, the u value never goes down the 0.06. Therefore, it is compulsory to use the well known Theis (1935) model to decide on the aquifer characteristics.

Assuming a fully penetrating well of infinitesimally small diameter in an aquifer of homogenous, isotropic, and uniform thickness, Theis (1935) developed a formula based on analogy with heat flow which introduced the time and storage coefficient into the aquifer test analysis. The Theis equations:

$$u = \frac{r^2 S}{4tT} \tag{4}$$

$$W(u) = \frac{4\pi T}{Q} z(r,t) \tag{5}$$

Are referred to as dimensionless time factor and well function, respectively, where, z(r,t) = drawdown at a distance r from the pumping well at time t; t = time since pumping started; Q(m^3/year)= constant well discharge; S= storage coefficient; and T = Transmissivity.

For most pumping tests, during the early time the observed drawdown is larger than that calculated from the Theis equation. Such a difference is believed to be caused by the difference between the real aquifer conditions and the assumptions behind the Theis equation. As pointed out by Kruseman and de Ridder(1990), the theoretical equation is based on the assumptions that the well discharge remains constant and that the release of the water stored in the aquifer is immediate and directly proportional to the rate of decline of the pressure head. In fact, there may be a time lag between the pressure decline and the release of stored water, and initially the well discharge may vary as the pump is adjusting itself to the changing head (Rushton and, Holt and, 1981; Driscoll, 1986). Under these circumstances, the aquifer characteristics are determined based on the late aquifer test data. Therefore, the effect of early drawdown data is ignored while deciding on the aquifer characteristics.

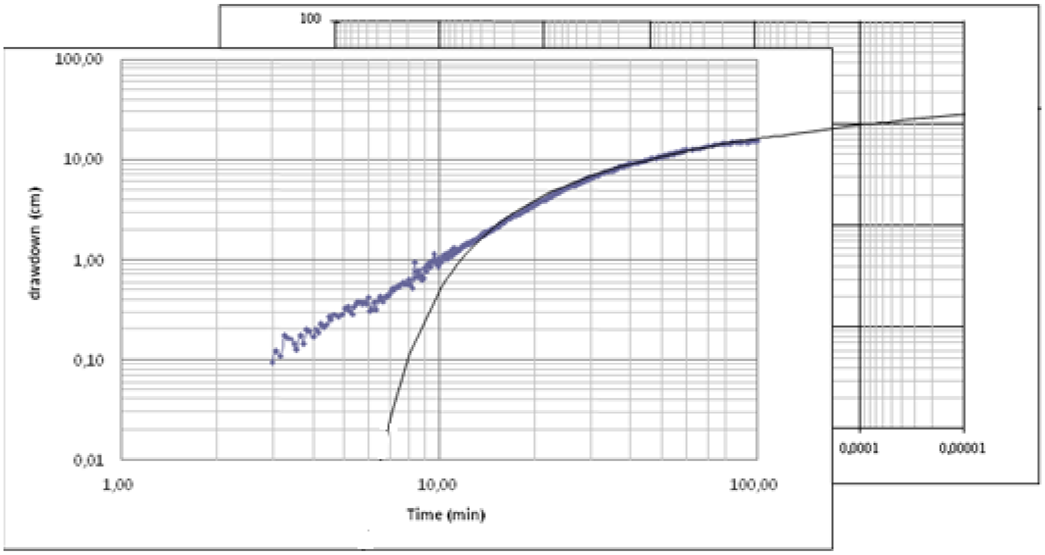


Figure 4.1 the W (u), Thies curve and the drawdown with respect to time in yeşilköy.

The late-time match between measured and theoretical drawdown is reasonably good but the measured drawdown at early time is significantly underestimated. The following table shows the values of the parameters obtained.

Table 4.1 the yeşilköy aquifer characteristics.

T (m^2/sec)	B (m)	K (m/sec)	Sy
2.34×10^{-2}	25	9.36×10^{-4}	0.0038

4.3 The drawdown rates and the depletion characteristics of the Aquifer.

The decline In water level measured from any well during an aquifer test is called drawdown. Drawdown increases over time and decreases with distance from production well.

The data been collected to calculate drawdown can be useful to give an idea about the water balance of the aquifer. Early detection of this can give time to explore alternative sources, establish conservation measures or take precautions. Drawdown measurements also give important information about the performance and efficiency of the wells. The drawdown data can be combined with well yield to evaluate the efficiency and performance of a well. (Michael J. Lytle., Paul Markowski.1989).

Accurate drawdown measurements depend on finding the distance from the surface to the water level in a well. If a group of well is monitored for a considerable time era, then the water levels can be compared with each other to discard the wrong or missing estimates. In Yeşilköy aquifer, around 42 wells were monitored constantly since 2000. The monitoring program was followed generally twice a year for each well. The result of the monitoring program is summarized on the following figure.

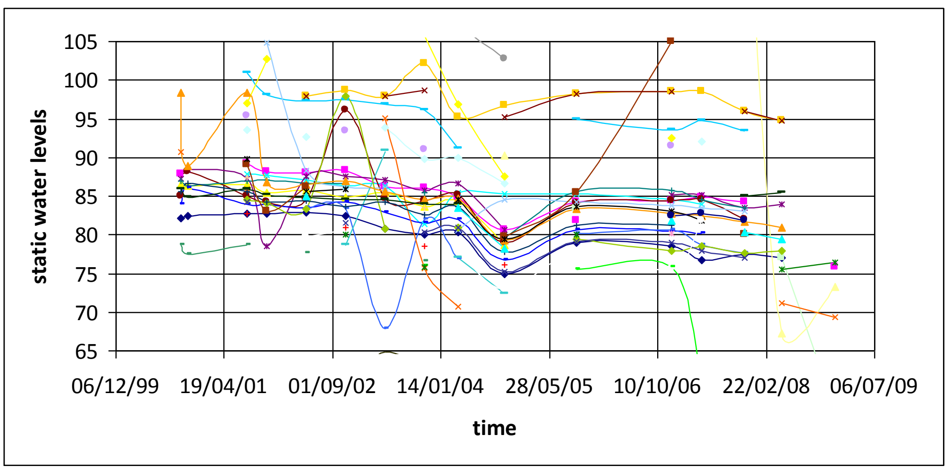


Figure 4.2 The changing in static water levels with respect to time

At the end of 10 years, 308 data is gathered from the well monitoring program. However, it is obvious from the above figure that, there is an irregular water level distribution all around the aquifer. Therefore, conversion from irregular to regular water level fluctuations is maintained by disregarding 12 measurements from all the data. The result is shown on Figure (4.3). It is apparent that at 2009 the groundwater level of the aquifer is fluctuating between 78 to 85 meters from the mean sea level.

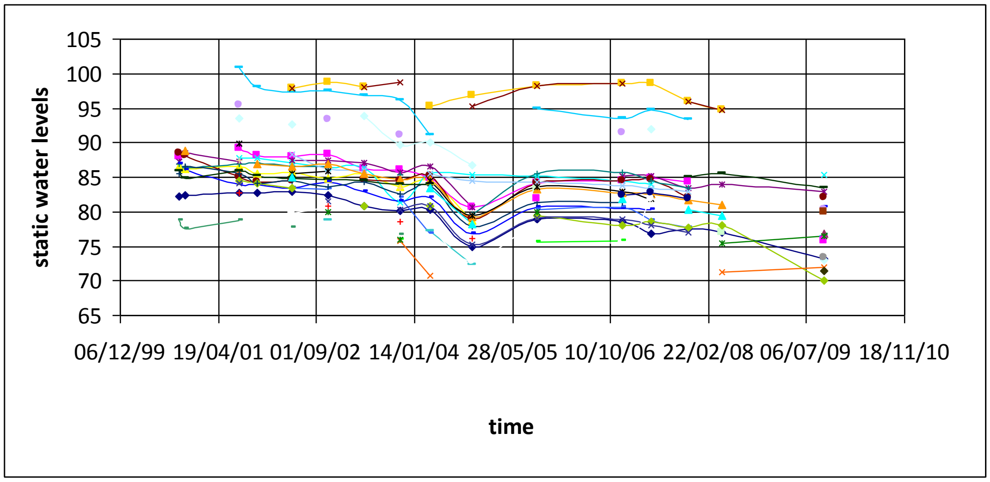


Figure 4.3 after disregarding 12 measurements, the changing in static water level with respect to time.

The time-Static water level curve in figure 4.3 is shown that the wells in the aquifer are preferentially connected with each other. The negligible variation on static water levels of wells on respond to recharge and discharge is indicating that the aquifer is homogenous.

As a result, the depleting trend of the water level is obvious and can be formulated as a power relationship.

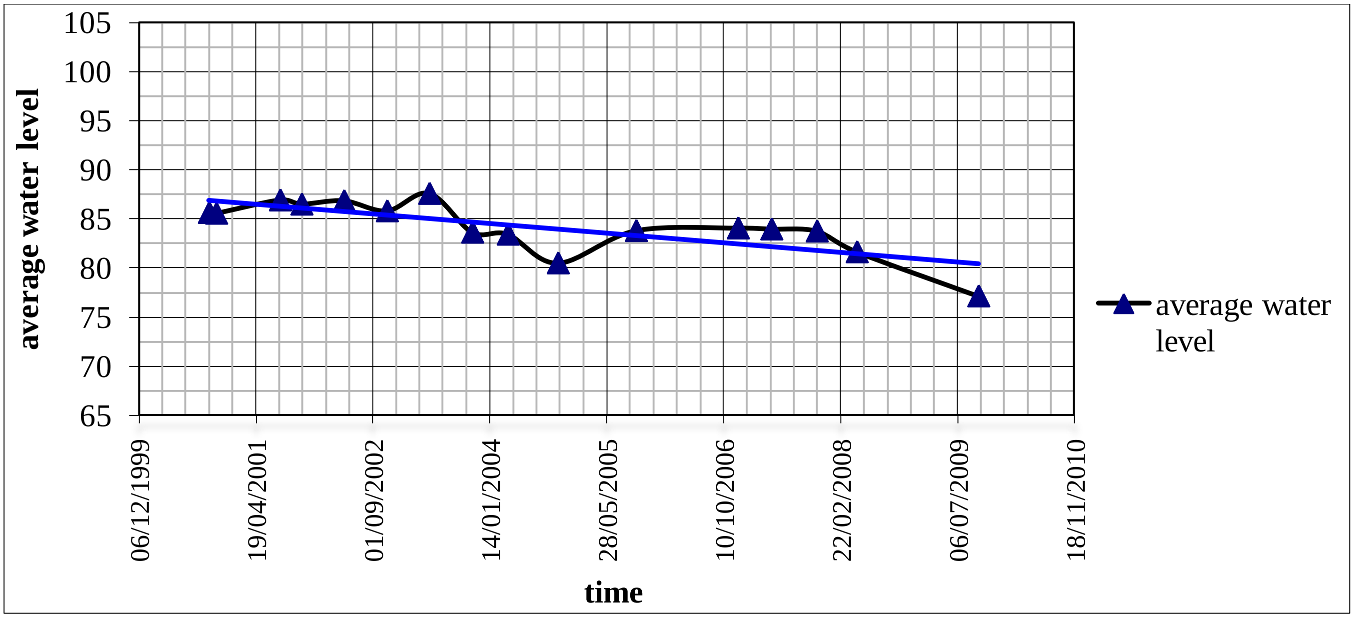


Figure 4.4 the depleting of average water level with respect to time

The depletion on the average water level (swl) with change in time is;

$$swl_{avg} = 10^{6} t^{-0.9} \tag{6}$$

where t is the time.

At mid March 2008, two data loggers are installed into two observation wells YK-109 and YK 21. The aim was to provide a continuous monitoring program for the two wells. This was to enhance the groundwater modeling efforts for the aquifer. The monitoring also provided a daily discussion on the respond of the aquifer system for irrigation and recharging.

Figure 4.5 The two location of observation wells donated by data logger, YK 21 and YK 109 Aquifer.

The calcarenite property of the top layer of the aquifer is sensitive to the hydraulic flow within the aquifer. Especially, YK 109 was chosen since the pump test in 2007 was held on this well, and thus the geologic formations and the properties of the well is well known. The location of the wells within the area of concern is given in the above figure. The water levels in those two wells are observed since 2000's. All the data is available in ENVIS database. Therefore, the depletion of static water levels within the wells can easily be examined. Since the well YK 109 is close to Governmental wells supplying domestic water to 14 surrounding villages all along the year, the depletion of static water level is more in this well, than YK 21.

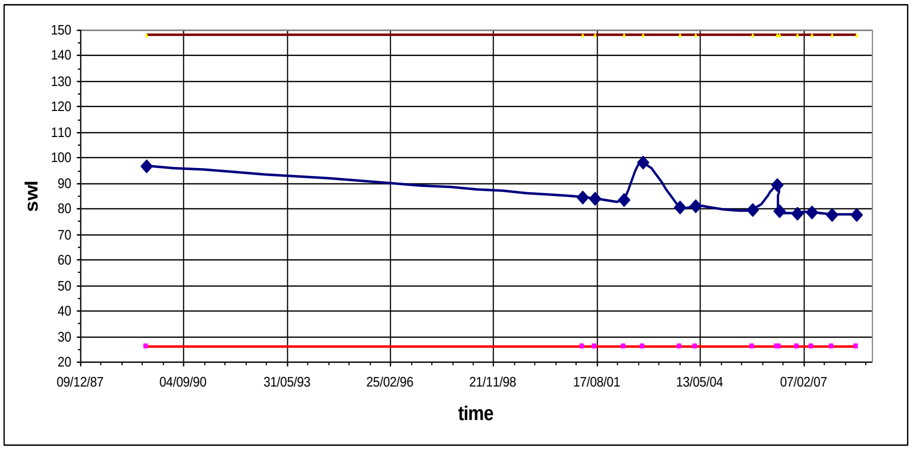


Figure 4.6 The change in water levels on YK109 by years.

Within the passing years the static level of YK 109 collapsed from 99 meters to 78 meters, whereas the drop in static water level of YK 21 is estimated to from 90 to 85 meters.

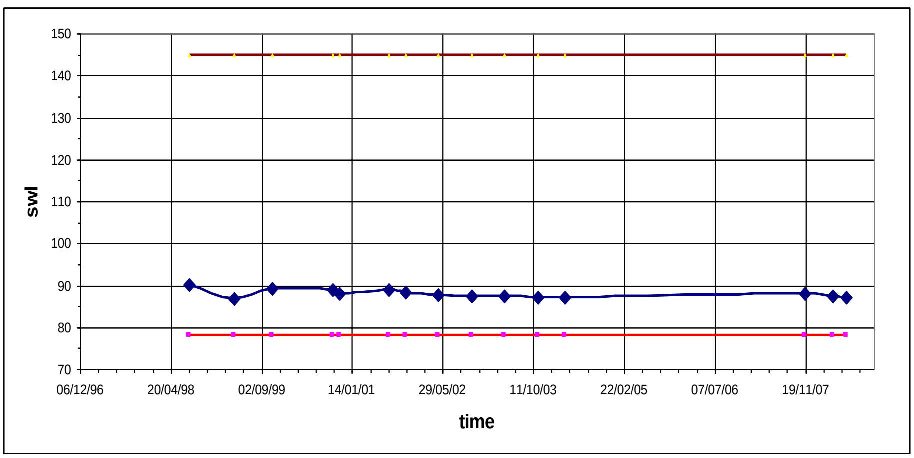


Figure 4.7 The drop in water levels on YK21 by years.

Unfortunately after a drought season in 2008 the continuously water supplying well (YK-38) dried. Therefore, the observation well YK-109 converted into a pumping well, removing the data logger from the system. The static water level of YK-109 was depleted around 80cm.

The change in water level in YK-21 and YK-109 during the continues observations is given in the following figures, figure 4.8 and figure 4.9

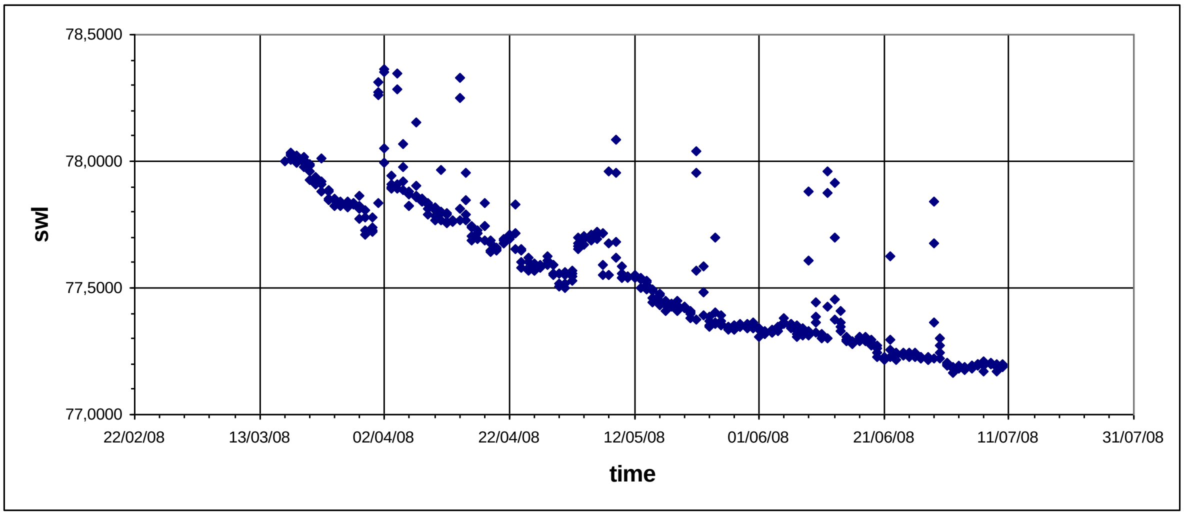


Figure 4.8 The drop in water levels on YK109 until the end of June 2008.

YK-21 is still used as an observation well and the logger is still installed in the well. The static water level in YK-21 has dropped 59 cm within the first three months of the observation period.

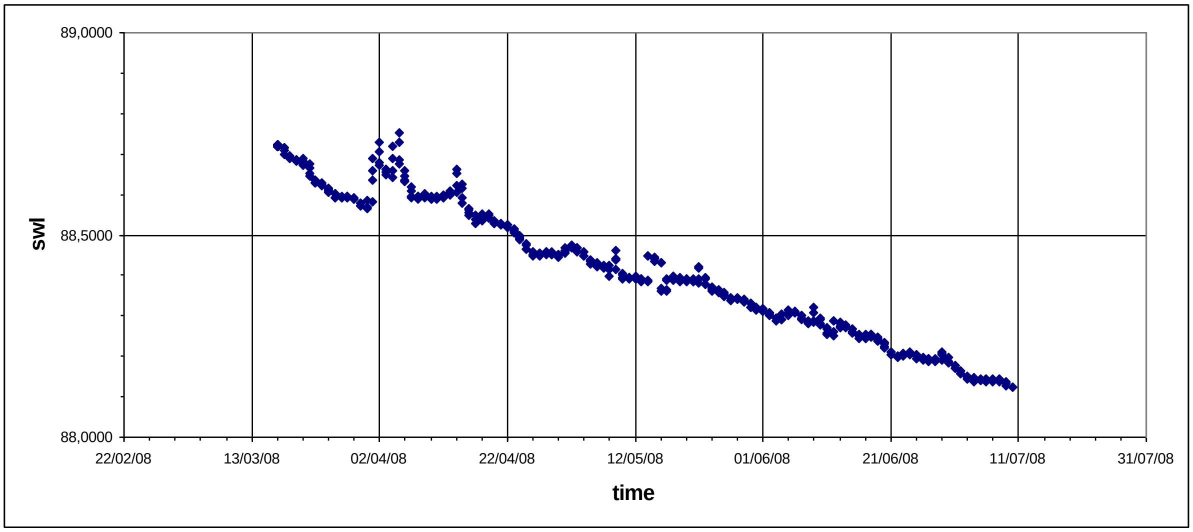


Figure 4.9 The drop in water levels on YK21 until the end of June 2008.

In both of the wells it is apparent that the static water levels follows depleting trend with respect to time; sometimes an increase in water level as a daily monitoring is observed.(see figure 4.8 and figure 4.9). The main reason of daily increments might be the recharging of the aquifer due to precipitation at the region. In order to confirm this the precipitation dates of March, April, May and June 2008 are compared with the above figures. The precipitation dates at Ziyamet and Yenierenköy meteorological stations were matching with the fluctuation data of the drawdown curves.

Table 4.2 The precipitation dates at Ziyamet and Yenierenkoy meteorological stations.

Date	Station Name	Total Precipitation (mm)
March 14, 2008	Ziyamet	7,3
March 14, 2008	Yenierenköy	10,1
April 1,2,4, 2008	Ziyamet	28,2
April 1,2,4, 2008	Yenierenköy	15,0
May 9,15, 2008	Ziyamet	20,7
May 9,15, 2008	Yenierenköy	23,0

The continuity of data collection in YK-21 has shown that the water level in the borehole has dropped 1.5 meters since March 2008.

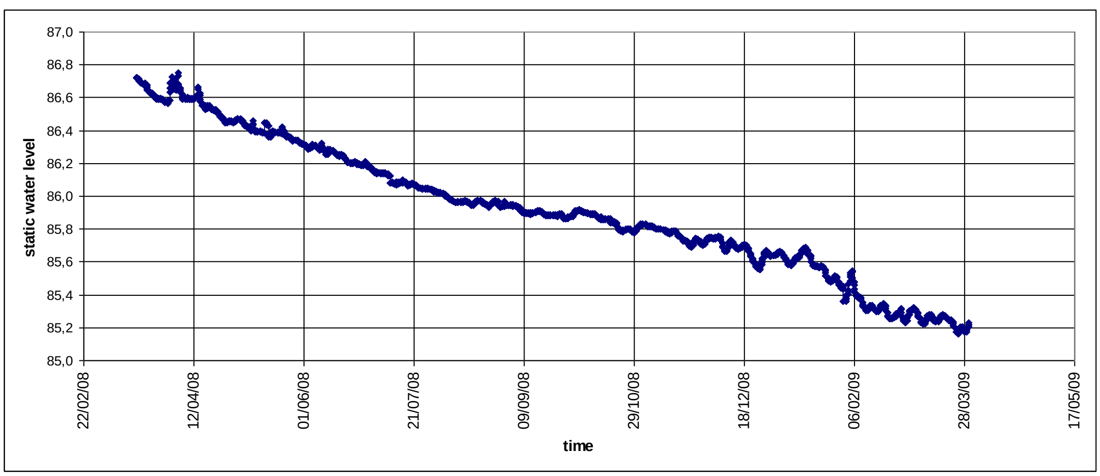


Figure 4.10 The drop in water levels on YK21 until the end of February 2009.

The static water level at the middle March 2008 was 86.72 meters from mean sea level, whereas the static water level by the end of March 2009 was measured to be 85.22 meters from mean sea level.

4.4 The agricultural water consumption

The agricultural analysis started with field survey analyses. This study involves tracing of all the agricultural fields that has been planted. The observation of planted areas was traced on a 30 meter satellite map. Later all these traces are digitalized by the help of Arcgis software. The result was a useful information to verify the total area of plantation at the region. By this way, the total area of different kinds of crops that has been cultivated at the area is calculated. The outcomes of the study are summarized in the following figures.

About 150 farmers are active in the area. *Solanum Tuberosum* is the most common crop in the area, occupying 840 donums out of 1700 donums planted in 2008. Barley is the second leading crop, occupying 38% of the planted areas. The total area of barley is estimated to be 757 donums. The other crops such as citrus and other fruits cover only 7 % of the total area. The cultivated land that was waiting for crops was 235 donums, occupying 12 % of the total area.

Solanum Tuberosum is planted twice a year, one in February and second in August. Whereas, planting during August is more or less half of the amount planted at February. Irrigated farming, except for *Solanum Tuberosum*, has been decreasing in recent years due to various market forces. Farmers irrigate crops with sprinkler systems as opposed to drip irrigation. The results of crop survey are given in the following figures.

Figure 4.11 the aerial distribution of different crop types in Yeşilköy

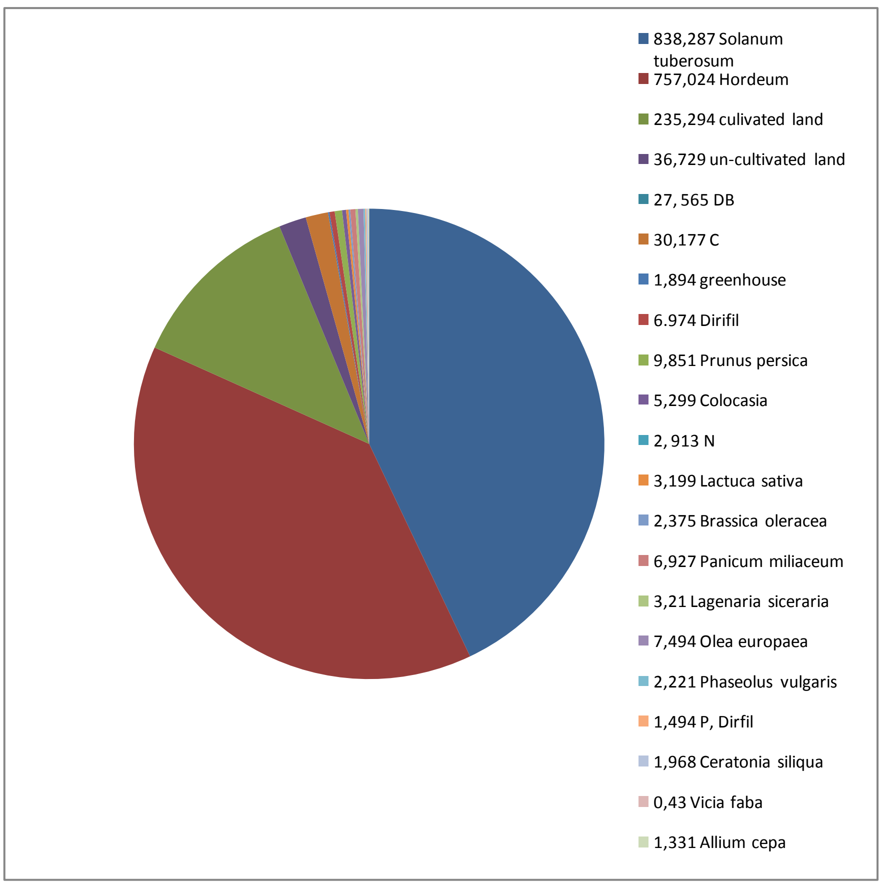


Figure 4.12 the distribution of different crop types in Yeşilköy irrigation area, areas are given in donums.

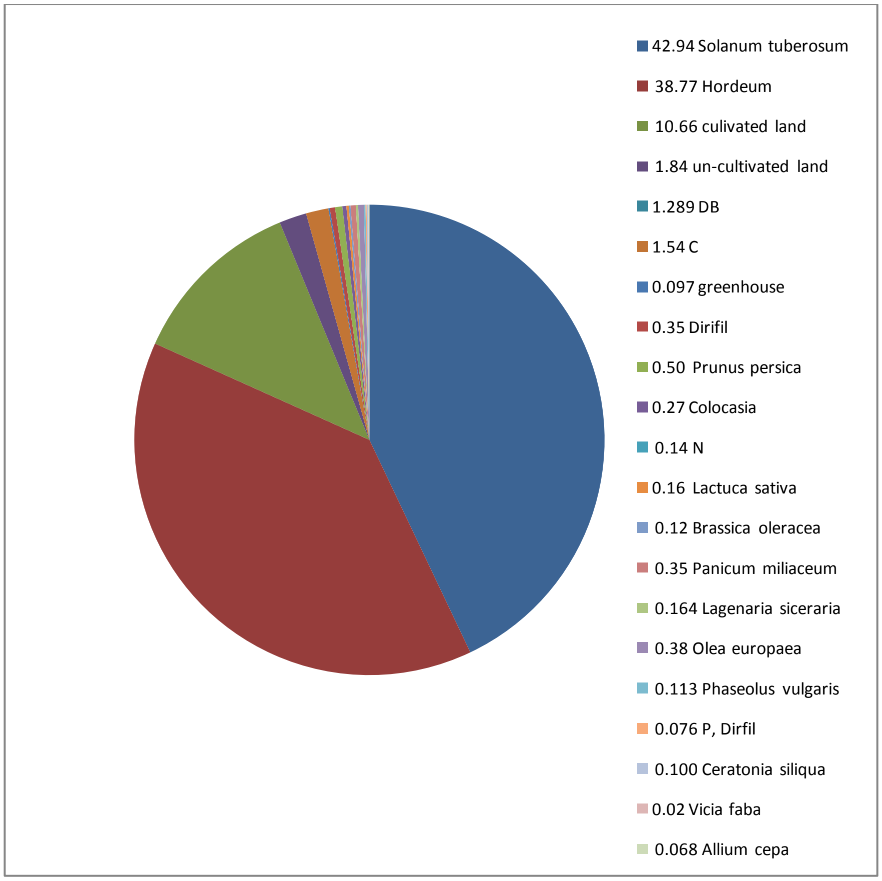


Figure 4.13 The percentage distribution of different crop types in Yeşilköy irrigation area

4.4.1 The pumping rates from the aquifer

The farmers at yeşilköy are irrigating their lands by supplying water from the wells. Since there are no metering devices on these wells yet it is not known how much water they consume for irrigation. Therefore, a well survey has been applied at the region to understand the water consumption from each well. The results of well survey show that there are 86 wells serving for agricultural purpose. Among those 86 wells merely 62 wells are operating efficiently which has a considerable effect on groundwater budget estimation. The rate of pumping is between 15 to 35 cubic meters per hour. Some of them work 16 hours a week, whereas some work 48 hours a week. According to the working hours and pumping rates per week for each well of 86 wells, its possible to estimate the total water consumption from the aquifer for agricultural purposes. The surveying results show that during the irrigation season between March 15 and June 01, the total water consumption is, 0.602×10^6 cubic meters, whereas during the season of August – November, the consumption is nearly half of what is found during first irrigation period (0.301×10^6 cubic meters).

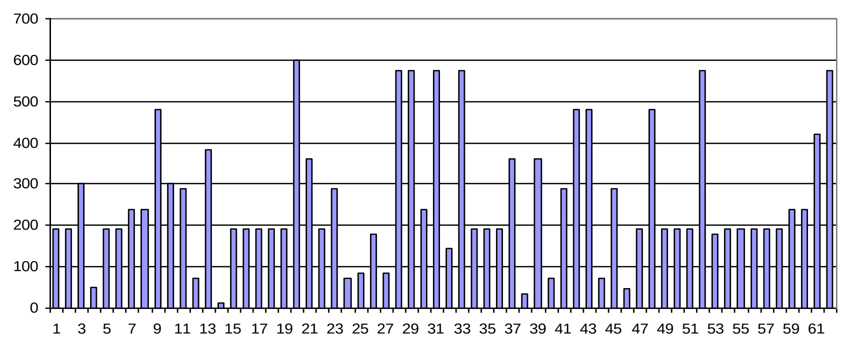


Figure 4.14 working hours of each well that is used to irrigate Solanum Tuberosum in a season of Feb-June.

Therefore, the result shows that the total water consumption for irrigation is approximately, 0.903×10^6 cubic meters per year. In the following part of this Thesis the water consumption for agricultural purposes will be calculated via the theoretical models, to compare it with survey results.

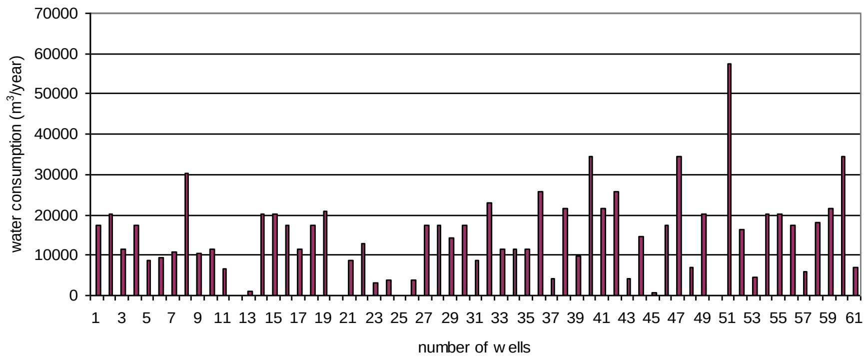


Figure 4.15 Total consumption of each well within a year.

4.4.2 Evapotranspiration

The rates of evaporation can be calculated by means of different methods. One of these methods is Blaney-Criddle at which one can easily estimate the amount of evapotranspiration. Another well known method is Penman-Monteith method which is used for calculating reference crop evapotranspiration.

In this study, CropWat 4 for Windows software that uses the FAO (1992) Penman-Monteith method for calculating reference crop evapotranspiration is used. The software is capable to calculate yearly evapotranspiration rates, water requirements of different crop types and frequency of their irrigation. The software requires an input data for the calculation of evapotranspiration rates and irrigation period, representing the meteorological information of the region. Since there are two governmental meteorological stations close to the region, namely Ziyamet and Yenierenköy, the data is compiled from State Meteorology Department. The gathered data was very useful for the calculation of Evapotranspiration and Irrigation Frequency. These input data were monthly mean maximum temperature (^{o}C), monthly mean minimum temperature (^{o}C), monthly air humidity (%), monthly wind speed (m/s), and monthly daily sunshine (hrs). Eventually the evapotranspiration and precipitation curves are drawn, and also the irrigation schedule and total irrigation requirement for mature crops are specified.

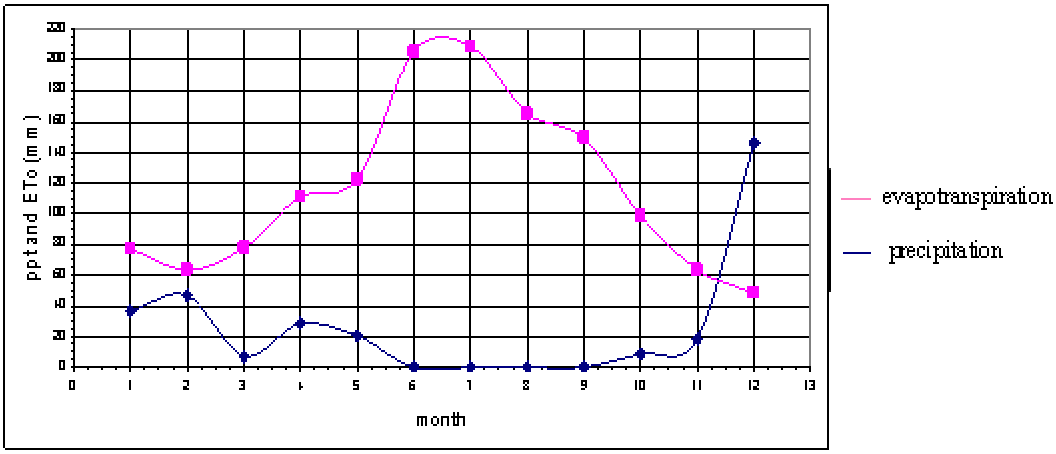


Figure 4.16 The total precipitation and evapotranspiration rates for Yeşilköy basin.

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)	User Adj. (mm)
23/3	48,1	12,4	0,0	0,0	1,5	100,0%	13,1	8	13,1	0.0	
26/3	50,4	13,1	1,7	1,7	1,6	100,0%	3,0				
31/3	54,2	14,3	2,9	2,9	1,7	100,0%	8,4				
4/4	57,3	15,4	0,0	0,0	1,8	100,0%	15,4	12	15,4	0.0	
5/4	58,0	15,6	3,8	0,0	1,8	100,0%	1,8				
10/4	61,9	16,9	4,4	4,4	2,1	100,0%	7,0				
15/4	65,7	18,3	4,8	4,8	2,6	100,0%	14,2				
17/4	67,2	18,8	0,0	0,0	2,9	100,0%	19,8	13	19,8	0.0	
20/4	69,5	19,6	5,0	5,0	3,2	100,0%	4,3				
25/4	73,3	21,1	5,0	5,0	3,9	100,0%	17,4				
26/4	74,1	21,3	0,0	0,0	4,0	100,0%	21,4	9	21,4	0.0	
30/4	77,1	22,5	4,7	4,7	4,6	100,0%	12,7				
3/5	79,4	23,4	0,0	0,0	5,0	100,0%	27,2	7	27,2	0.0	
5/5	80,9	24,0	4,3	4,3	5,3	100,0%	6,1				
9/5	84,0	25,2	0,0	0,0	5,8	100,0%	28,7	6	28,7	0.0	
10/5	84,0	25,2	3,7	0,0	5,8	100,0%	5,8				
14/5	84,0	25,2	0,0	0,0	6,0	100,0%	29,5	5	29,5	0.0	
15/5	84,0	25,2	3,0	0,0	6,0	100,0%	6,0				
19/5	84,0	25,2	0,0	0,0	6,2	100,0%	30,6	5	30,6	0.0	
20/5	84,0	25,2	2,3	0,0	6,2	100,0%	6,2				
24/5	84,0	25,2	0,0	0,0	6,4	100,0%	31,5	5	31,5	0.0	
25/5	84,0	25,2	1,5	0,0	6,4	100,0%	6,4				
28/5	84,0	25,2	0,0	0,0	6,5	100,0%	25,9	4	25,9	0.0	
30/5	84,0	25,2	0,6	0,6	6,6	100,0%	12,5				
1/6	84,0	25,2	0,0	0,0	6,6	100,0%	25,8	4	25,8	0.0	
4/6	84,0	25,2	0,0	0,0	6,7	100,0%	20,1				
5/6	84,0	25,2	0,0	0,0	6,8	100,0%	26,9	4	26,9	0.0	
9/6	84,0	25,2	0,0	0,0	6,9	100,0%	27,3	4	27,3	0.0	
13/6	84,0	25,2	0,0	0,0	7,0	100,0%	27,7	4	27,7	0.0	
17/6	84,0	25,2	0,0	0,0	7,0	100,0%	28,1	4	28,1	0.0	
21/6	84,0	25,2	0,0	0,0	7,1	100,0%	28,3	4	28,3	0.0	
25/6	84,0	26,9	0,0	0,0	6,9	100,0%	28,1	4	28,1	0.0	
30/6	84,0	29,7	0,0	0,0	6,5	100,0%	33,5	5	33,5	0.0	
6/7	84,0	33,0	0,0	0,0	6,1	100,0%	37,6	6	37,6	0.0	
13/7	84,0	37,0	0,0	0,0	5,5	100,0%	40,1	7	40,1	0.0	
22/7	84,0	42,0	0,0	0,0	4,7	100,0%	45,3	9	45,3	0.0	
Total			47,7	33,4	625,2	100,0%			591,7	0,0	0,0

Figure 4.17 The total evapotranpiration and irrigation requirement for irrigation between February 2009 and June 2009.

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)	User Adj. (mm)
4/8	44,3	11,2	0,0	0,0	3,0	100,0%	12,1	3	12,1	0.0	
9/8	48,1	12,4	0,0	0,0	3,0	100,0%	14,9	5	14,9	0.0	
14/8	51,9	13,6	0,0	0,0	2,9	100,0%	14,6	5	14,6	0.0	
20/8	56,5	15,1	0,0	0,0	2,8	100,0%	17,1	6	17,1	0.0	
26/8	61,1	16,7	0,0	0,0	2,8	100,0%	16,7	6	16,7	0.0	
1/9	65,7	18,3	0,0	0,0	3,4	100,0%	19,1	6	19,1	0.0	
7/9	70,3	19,9	0,0	0,0	3,9	100,0%	22,3	6	22,3	0.0	
13/9	74,8	21,6	0,0	0,0	4,4	100,0%	25,1	6	25,1	0.0	
19/9	79,4	23,4	0,0	0,0	4,7	100,0%	27,5	6	27,5	0.0	
25/9	84,0	25,2	0,0	0,0	4,9	100,0%	29,4	6	29,4	0.0	
1/10	84,0	25,2	0,0	0,0	4,7	100,0%	28,7	6	28,7	0.0	
7/10	84,0	25,2	0,0	0,0	4,4	100,0%	27,0	6	27,0	0.0	
13/10	84,0	25,2	0,0	0,0	4,1	100,0%	25,2	6	25,2	0.0	
20/10	84,0	25,2	0,0	0,0	3,8	100,0%	27,3	7	27,3	0.0	
26/10	84,0	25,2	0,3	0,3	3,5	100,0%	21,4				
28/10	84,0	25,2	0,0	0,0	3,4	100,0%	28,3	8	28,3	0.0	
5/11	84,0	25,2	0,0	0,0	3,1	100,0%	25,9	8	25,9	0.0	
12/11	84,0	27,4	2,1	2,1	2,7	100,0%	18,2				
17/11	84,0	30,2	7,3	7,3	2,4	100,0%	23,6				
21/11	84,0	32,5	0,0	0,0	2,2	100,0%	32,6	16	32,6	0.0	
22/11	84,0	33,0	12,5	0,0	2,1	100,0%	2,1				
27/11	84,0	35,8	17,1	10,2	1,9	100,0%	1,9				
2/12	84,0	38,6	20,6	9,0	1,7	100,0%	1,7				
7/12	84,0	41,4	22,8	8,0	1,5	100,0%	1,5				
Total			82,8	36,9	433,8	100,0%			394,0	0,0	0,0

Figure 4.18 The total evapotranpiration and irrigation requirement for irrigation between August and Nov 2009.

As it can be read from the above tables, the total water requirement for the region, for agricultural purposes, considering the precipitation, evapotranspiration and all the other meteorological conditions is (591.7 + 394.0) 985.7 mm. This irrigation guarantees optimum *Solanum Tuberosum* production at the region. The total agricultural field dedicated for *Solanum Tuberosum* production is 838 donums which in turn equivalent to 1090 square meters. Multiplication of the depth of irrigation with total irrigation area results in total volume of water required for irrigation, 1.03 x 10^6 cubic meters per year. The result of the studies has proved that yearly water consumption from the Yeşilköy aquifer for irrigation is one million cubic meters.

On the other hand the six governmental wells, supplying domestic water demands of all the Karpaz peninsula are discharging water to all the 0.66 x 10^6 cubic meter per year.

Table 4.3 the annual Discharge (m^3/year) in six governmental wells.

Well Name	Daily Discharge (m^3/day)	annual Discharge (m^3/year)
YK-38	720	262,800
YK-120	120	43,800
YK-10	320	116,800
YK-99	160	58,400
YK-39	336	122,640
YK-42	160	58,400
Total discharge:	1816	662,840

The total discharge from the Yeşilköy aquifer is therefore around 1,69 x 10^6 cubic meter per year.

The domestic water demand for the village and the surrounding villages is estimated to be 0.83 million cubic meters and irrigation demand is estimated to be 0.93 million cubic meters per year.

Based on annual rainfall of 440 mm, the basin area of the Yesilkoy Aquifer receives approximately 2.84 million m^3 of water. Only about 25% (and likely less) of annual rainfall is assumed to infiltrate into the aquifer. The remaining part of precipitation evaporates or drains out of the aquifer basin, or taken up by plants and trees. Thus, annual recharge to the aquifer is around 0.71 million cubic meters per year.

On the other hand, the results of monitoring since 2000 has yielded 10-12 meters of drawdown on the saturated zone of the aquifer. Therefore, 1.2 meters of yearly drawdown is accepted to be logic occupying multiply by the area of the aquifer

$(1.2)\times(5.46\times10^{6})=6.55\times10^{6}\,\mathrm{m}^{3}$, volume of soil. The porosity of the Calcarenite layer is around 15%, resulting in:

$$(0.15)\times(6.55\times10^{6})=0.98\times10^{6}m^{3} \tag{8}$$

loss from the aquifer. This is the total deficit from the aquifer each year. This is also confirmed by the difference between the total pumping and recharging rates from the aquifer.

Total discharge – Total infiltration = Total Loss

$$(1.69\times10^{6})-(0.71\times10^{6})=0.98\times10^{6}m^{3} \tag{9}$$

4.5 The Theoretical Analysis.

4.5.1 drawdown rates and the depletion characteristics of the Aquifer.

The early developments of wells occur largely in the arid areas of the world like in Mediterranean area, several thousands years ago. In order to expand the agricultural production, infiltration galleries were developed in Eastern Mediterranean, Egypt, 4000 years ago. During the roman occupation to Europe several wells were dug in order to serve the armies and the cites.(Michael. K, 2001).

Until the beginnings of 18th century, the wells were constructed by the experience and non written laws. It was Hagen (1839) and Poideuille (1840) who studied that the flow is proportional to hydraulic gradient. Darcy (1856) verified these concepts to develop the first fundamental theory of flow through a porous media.

Further work was done by Adolph Theim (1870), using the Darcy law to develop an equation to relate distance and drawdown around a well for steady state flow. Theis (1935) develop an equation for unsteady groundwater flow based on similarity with heat flow equation. Wenzel (1942) and Cooper and Jacob in 1946 develop the Theis's equation to simplify and make it user friendly.

Several methods and theories had described the mathematical solutions to a given set of groundwater conditions.

The knowledge of well hydraulics is essential to proper well design and construction, and optimum performance of the well/aquifer system. Many investigators have derived useful solutions for defining ideal flow through porous media modified by assumed initial and boundary conditions. The solutions are based upon simplified assumptions and approximations of field conditions. They have been proved sufficiently accurate to promote good ground water planning and well design.

4.7.2 The Theis Equation

The Theis equation has been widely used to study the transient movement of groundwater as a result of pumping in a confined aquifer. It is well known that the observed drawdown at early times has an obvious departure from the theoretical drawdown based on the Theis equation. The Theis equation was derived under the assumption that total stress in the aquifer was constant and the mechanical behavior of the confining unit was neglected. However, most geological formations, especially those which are well consolidated, have rigidity and therefore may bend like a plate to a certain extent. The increase in the effective stress in the aquifer due to pumping may not contribute entirely to the compression of the aquifer, but may be partially cancelled out by bending of the overlying aquitard. This means only a part of the total stress is used to compact the aquifer, or the aquifer cannot produce as much water as estimated from the Theis equation (W. Xu Sheng *et al* ,2004).

Theis equation and its derivatives are the most often applied equations in transient ground water hydraulics. The Theis equation is given as;

$$z(r,t) = \frac{Q}{4\pi T} W(u) \tag{10}$$

Where z(r,t) is drawdown at distance (r) at time (t) after start of pumping, (L). Q is the discharge of flow ($L^3\ T^{-1}$); W(u) is the well function of which is defined as an exponential series

$$W(u) = \int_u^\infty \frac{e^{-y}}{y} dy = -\psi - \log_e u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \dots + \frac{u^n}{n.n!} \tag{11}$$

Where ψ is the Euler constant equivalent to 0.5772 and,

$$\mathrm{u} = \frac{\mathrm{r^2 S}}{\mathrm{4tT}} \tag{12}$$

Where t is the time since pumping started (T), T is the transmissivity (L^2/T), S is the storativity and r is the distance from pumping well to the point where drawdown is measured (L).

4.8 The drawdown modeling

On the basis of the studies and assumptions of thesis Equation it is apparent that the drawdown in the well can be defined as

$$h(t) = f(r, s, T, t, Q, \Delta t) \tag{13}$$

The application of the Buckingam π-theorem on the representation of dependent and independent parameters results in the relation between tow dimensionless parameters given as

$$\frac{Th(t)}{Q} \& \frac{\Delta t}{t} \tag{14}$$

In which T is tranmisivity ; Q is the Discharge from the wells *h(t)* is the static water level from the mean sea level. Δt is the time deference between the tow consecutive monitoring period and *t* is the total monitoring period (10 years). On the other hand, the data of previously monitored 42 wells were used to verify the relationship between $\frac{Th(t)}{Q} \& \frac{\Delta t}{t}$**.** The individual drawdown-time curves of 42 wells are given in appendix (A).

The average head of static water levels of 42 wells are then worked out as given in table 4.4 and Figure 4.19.

Table 4.4 the average static water level with respect to dates.

Time	average SWL(m) (from mean sea level)
10/1/2000	85.65
11/1/2000	85.57
8/1/2001	86.92
11/1/2001	86.5
5/1/2002	86.85
11/1/2002	85.82
5/1/2003	87.59
11/1/2003	83.64
4/1/2004	83.44
11/1/2004	80.51
10/1/2005	83.8
12/11/2006	84.07
5/3/2007	83.97
11/13/2007	83.76
5/2/2008	81.64

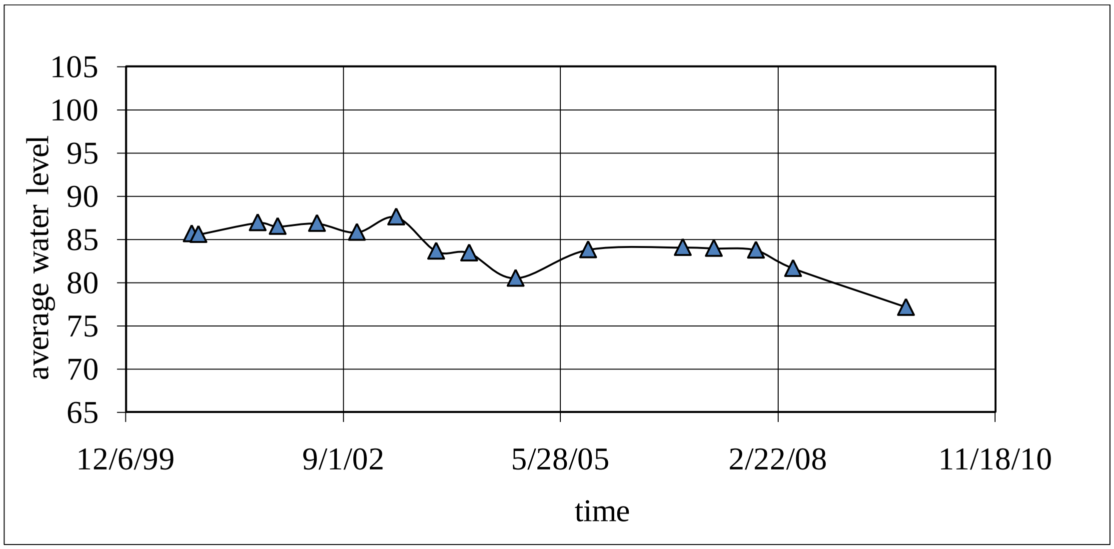


Figure 4.19 the average water level with respect to time in the aquifer

The objective is to drive an equation to defined the change in static water level in the aquifer with respect to dependent parameters using the relationship of 308 monitored data of 42 wells the relationship between $\frac{Th(t)}{Q}$ & $\frac{\Delta t}{t}$ is given as:

$$\left(\frac{T}{Q}\right) * h(t) = -330 * \left(\frac{\Delta t}{t}\right) + 2103.8 \qquad (15)$$

Where

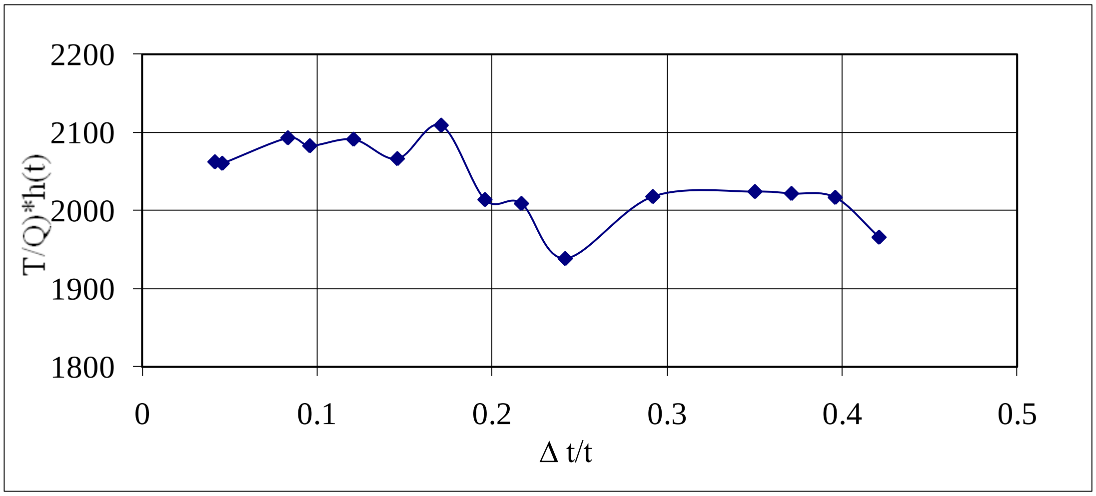
T =Tasmisivity (m^2/day)

Q = average discharge (m^3/day)

$h(t)$= static water level (m)

$\frac{\Delta t}{t}$ =changing in time over the total time of tested data (unitless)

The relationship between the tow dimensionless parameter is shown in figure 4.20



Figur 4.20 the relation between Δ *t/t* and *(T/Q)*h(t)*.

Therefore, the final form of the equation can be written as

$$h(t) = (Q/T) * (-330 * \left(\frac{\Delta t}{t}\right) + 2103.8) \qquad (16)$$

Above equation invokes the tow important assumptions; (*i*) the discharge from the aquifer is constant, (*ii*) the equation is valid for limited time era, representing future assessment of the next ten years.

Therefore based on Equation (16), the average static water level in the aquifer for the next 10 years is as given in the following table

Table 4.5 the Expected static water level with respect to time.

YEAR	Expected static water level (m) (from mean sea level)
2009	80.45
2010	79.77
2011	79.08
2012	78.40
2013	77.71
2014	77.03
2015	76.69
2016	75.89
2017	75.20
2018	74.52
2019	73.83

CHAPTER 5

CONCLUSIONS

In this thesis, the results of modeling studies for the Yeşilköy aquifer in the Karpaz peninsula region was described. Previously several works were carried about the aquifer in order to understand the concepts of hydrogeology of the region. However, the lack of useful data forced this research to start the modeling studies via data collection. The results of this study is to transform the knowledge of these efforts from a strictly field work to an accurate analytical model which will be useful to the local water resources managers for the future.

The results of the studies show that within a few years the aquifer static water level will continue to deplete with time. The forecast assumption based on the past in true, all of the calculations were done by using the data available about Yeşilköy wells data. The studies carried over forms the methodology of this study which can be summarized as;

a) Aquifer test at the field,
b) Monitoring of two wells through data loggers
c) Well survey analyses at the area
d) Crop survey analyses for the region

The aquifer test at the field was aiming to develop water balance studies specially the Safe Yield of the aquifer. The test provided useful information such as aquifer storativity and transmissivity values. The continuous monitoring of data loggers help to understand the reaction of the aquifer on the pumping rates and precipitation recharge. The change in static water level with respect to time was better understood after the continuous monitoring. Well survey analysis and the crop analysis help to match the farmer survey results with the crop survey results. The result was considerably successful, and helped to confirm the real pumping rates resulted from the well survey studies.

The missing part of the study is mainly based on aquifer boundary. It is believed that the aquifer boundary is not limited with the boundary concerned in this study but it extends to a larger area. However, in order to put out the real boundary; it is necessary to implement geophysical studies on the area.

Although, the pumping rates from each well is worked out via the survey at the field; and it is verified with crop irrigation requirements, it is compulsory to implement metering to each well used for irrigation.

CHAPTER 6

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Appendix

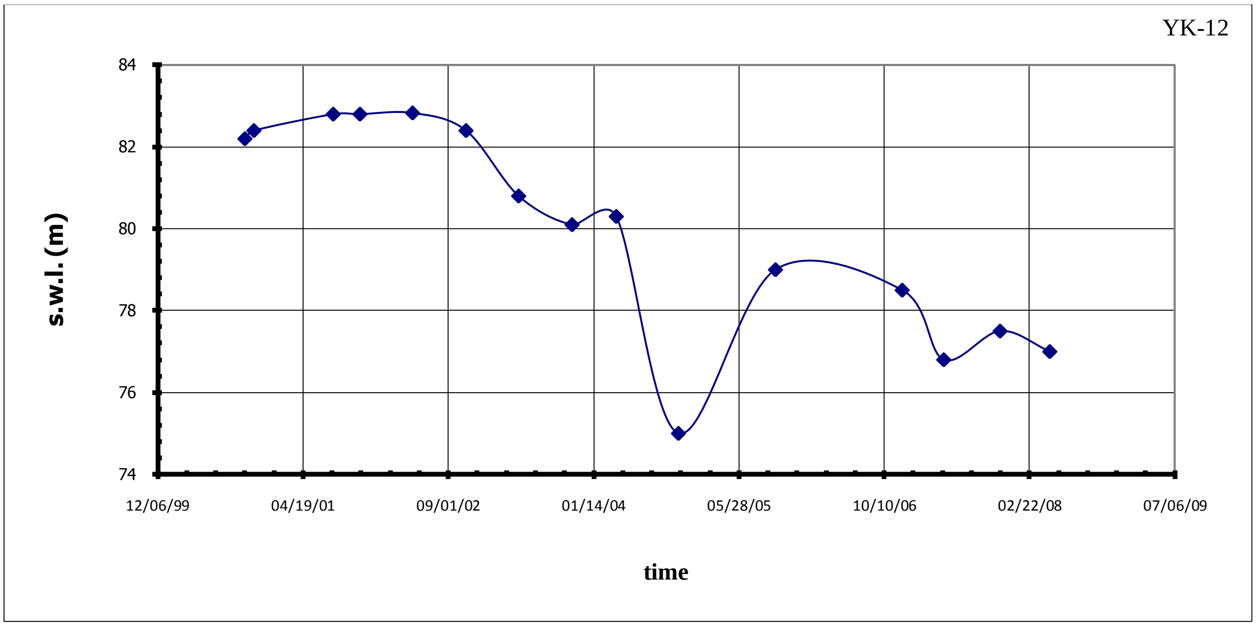

Figure A1.1 drawdown in static water level in YK-12 with time.

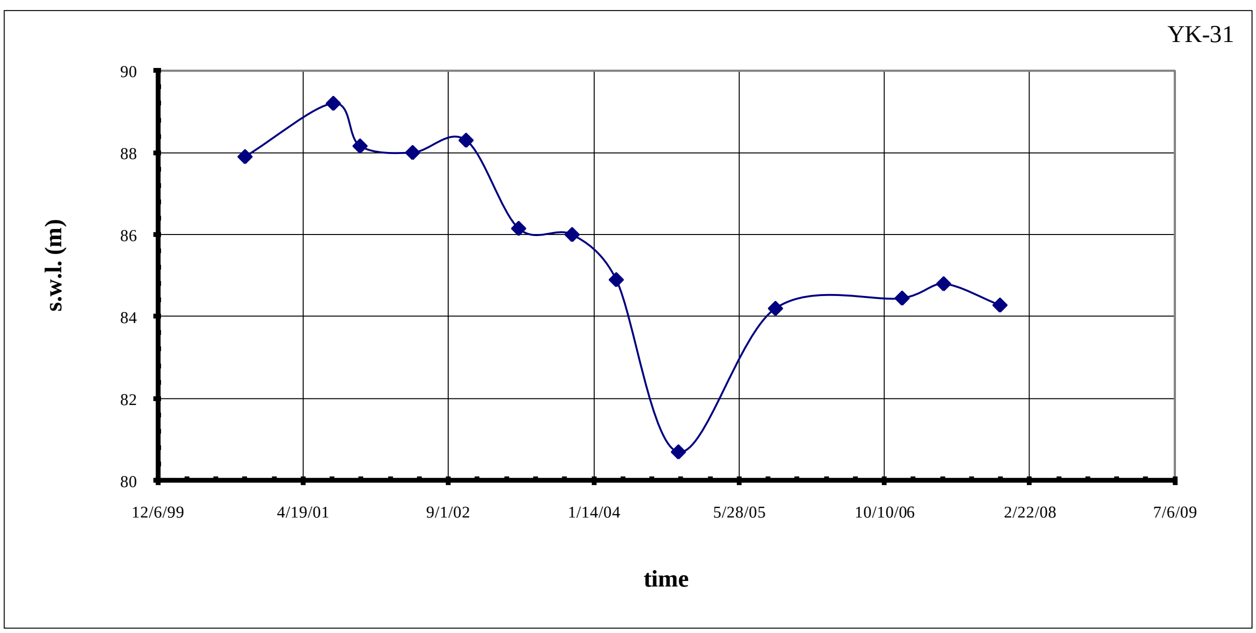

Figure A1.2 drawdown in static water level in YK-31 with time.

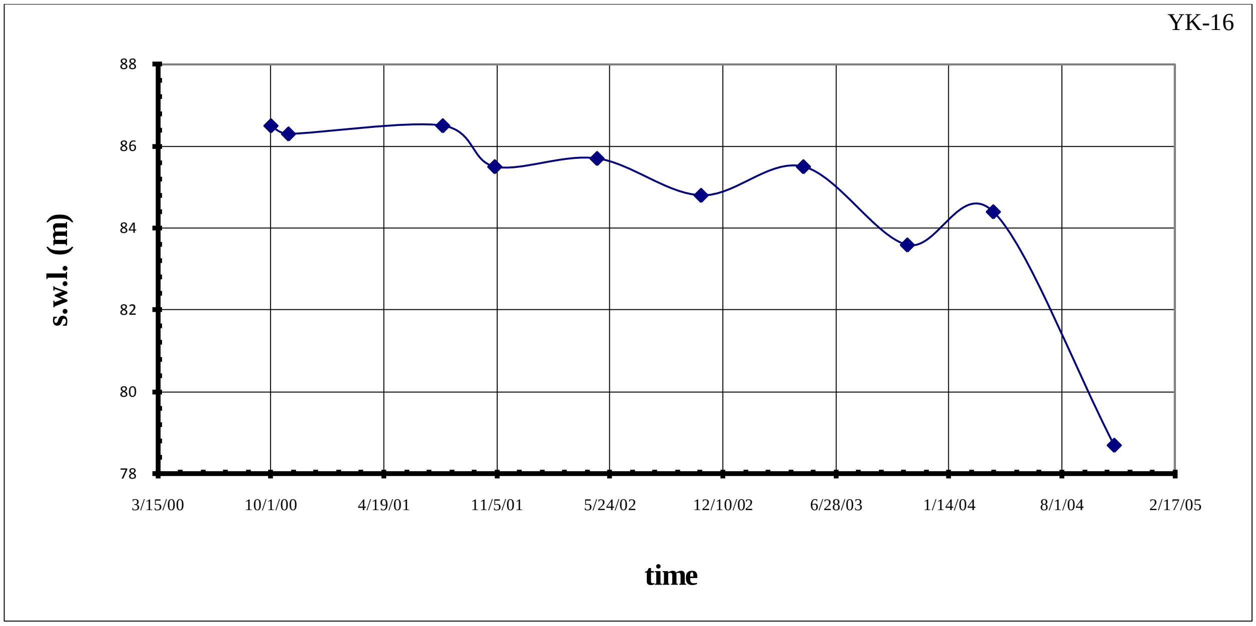

Figure A1.3 drawdown in static water level in YK-16 with time.

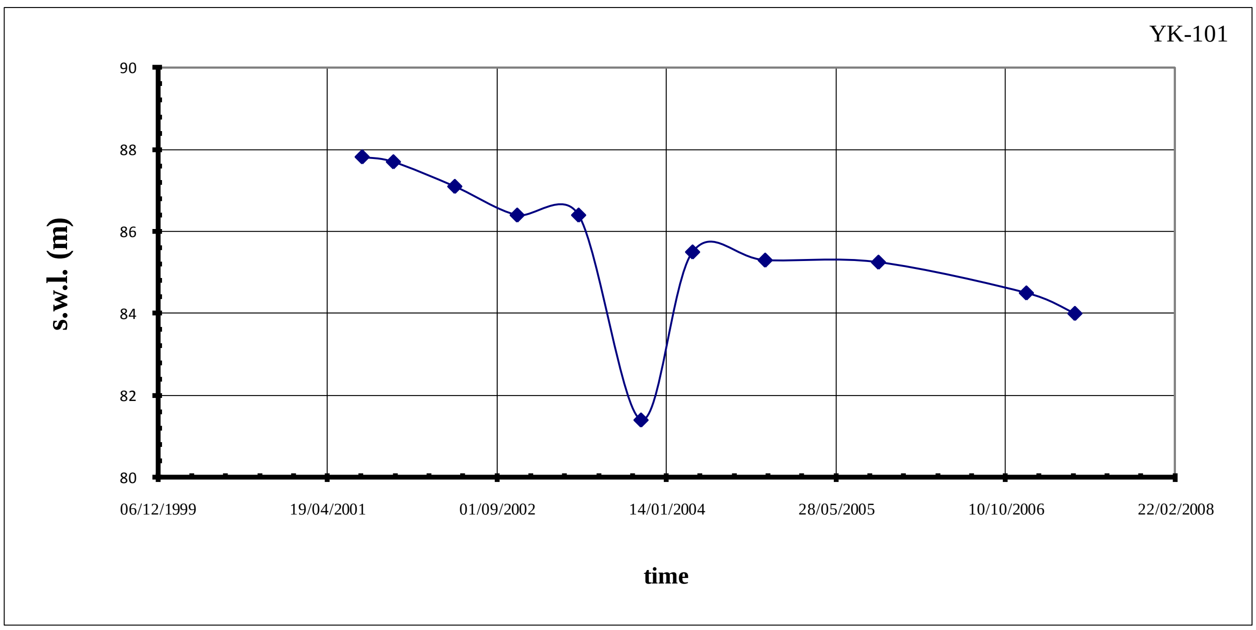

Figure A1.4 drawdown in static water level in YK-101 with time.

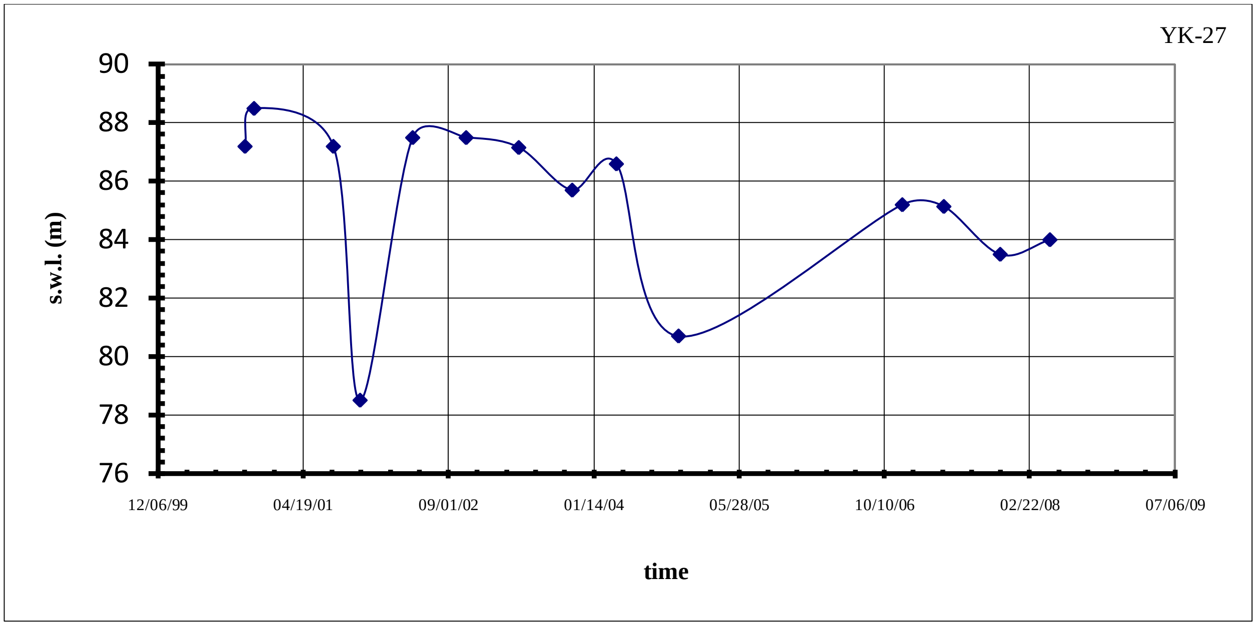

Figure A1.5 drawdown in static water level in YK-27 with time.

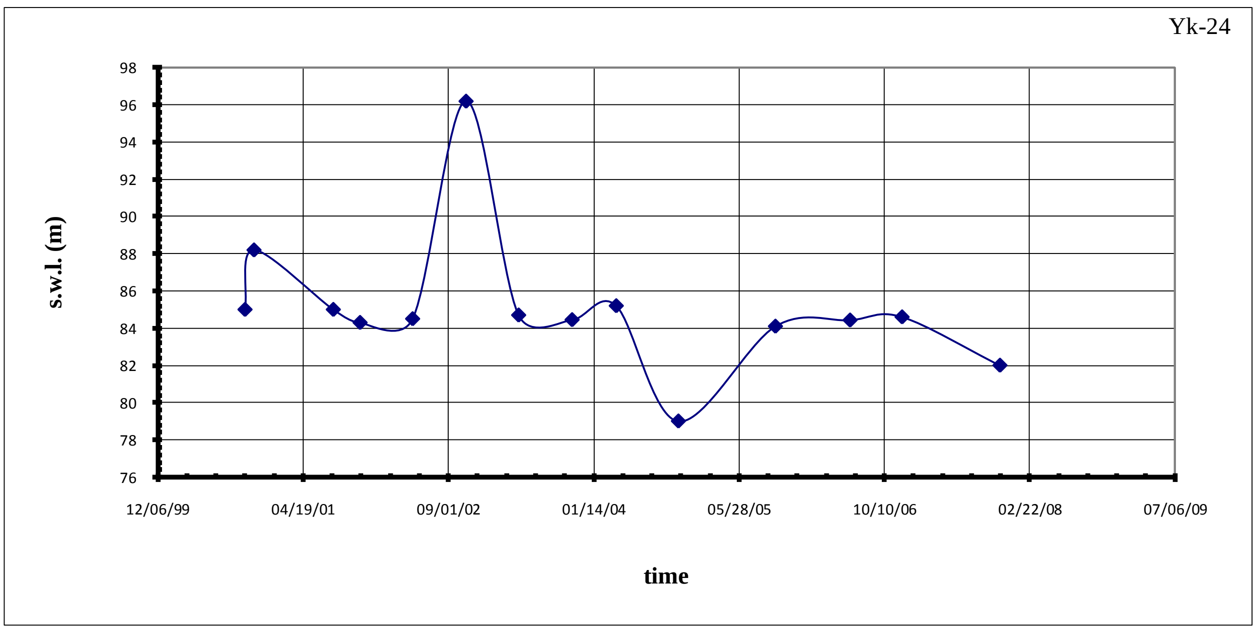

Figure A1.6 drawdown in static water level in YK-24 with time.

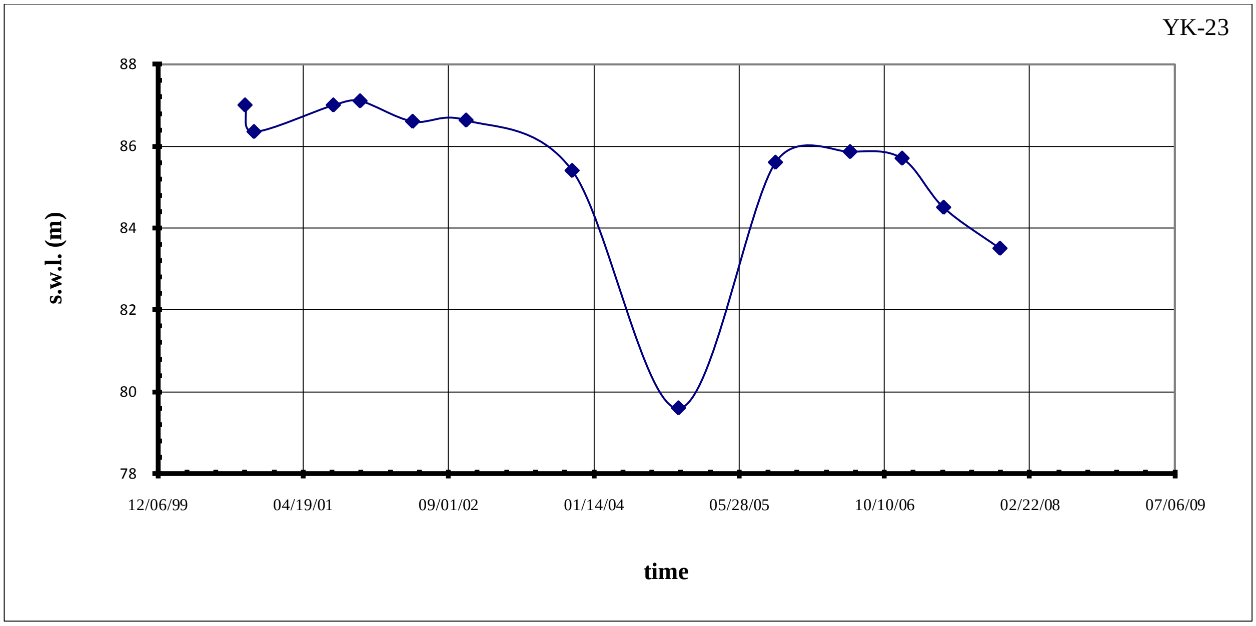

Figure A1.7 drawdown in static water level in YK-23 with time.

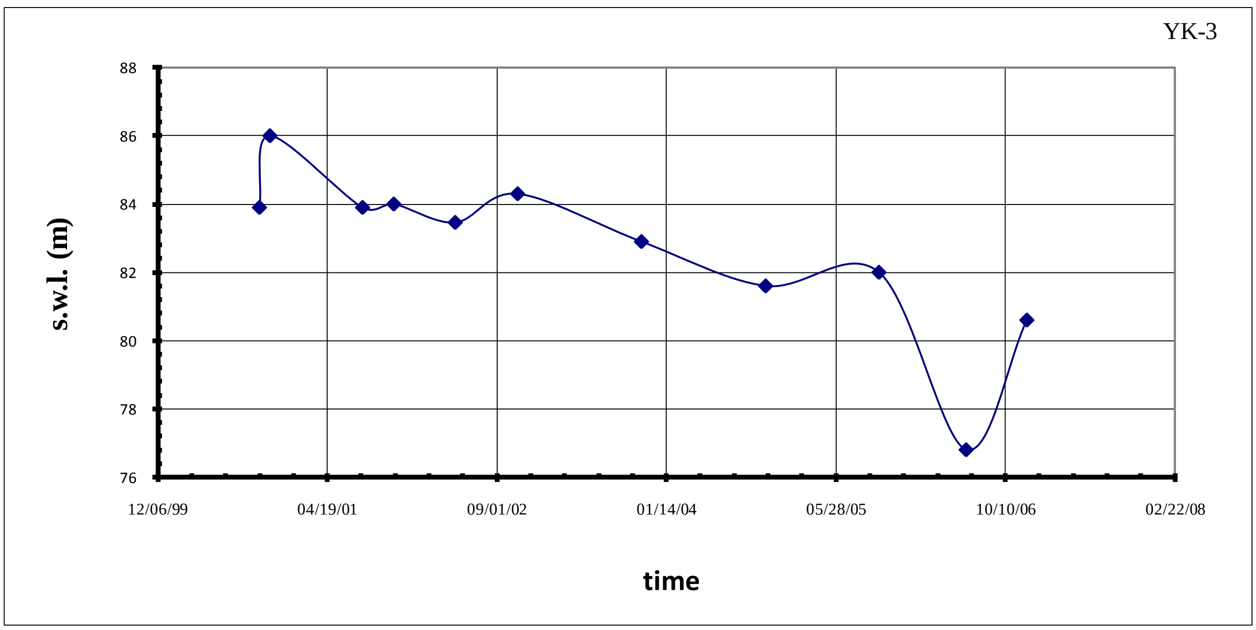

Figure A1.8 drawdown in static water level in YK-3 with time.

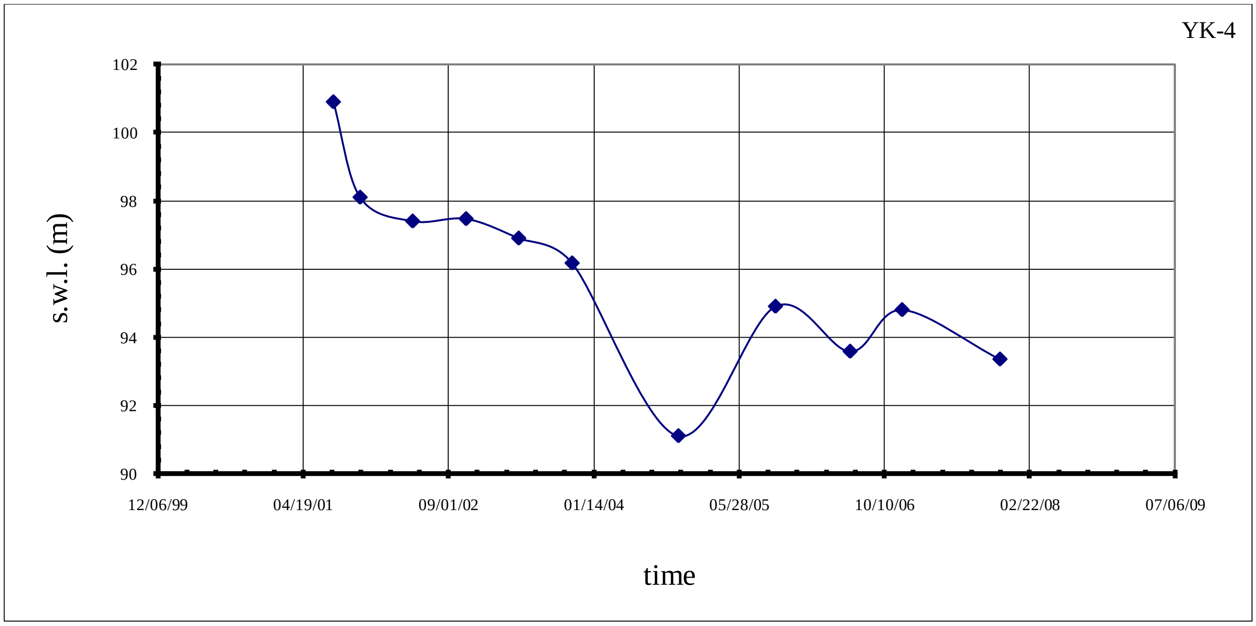

Figure A1.9 drawdown in static water level in YK-4 with time.

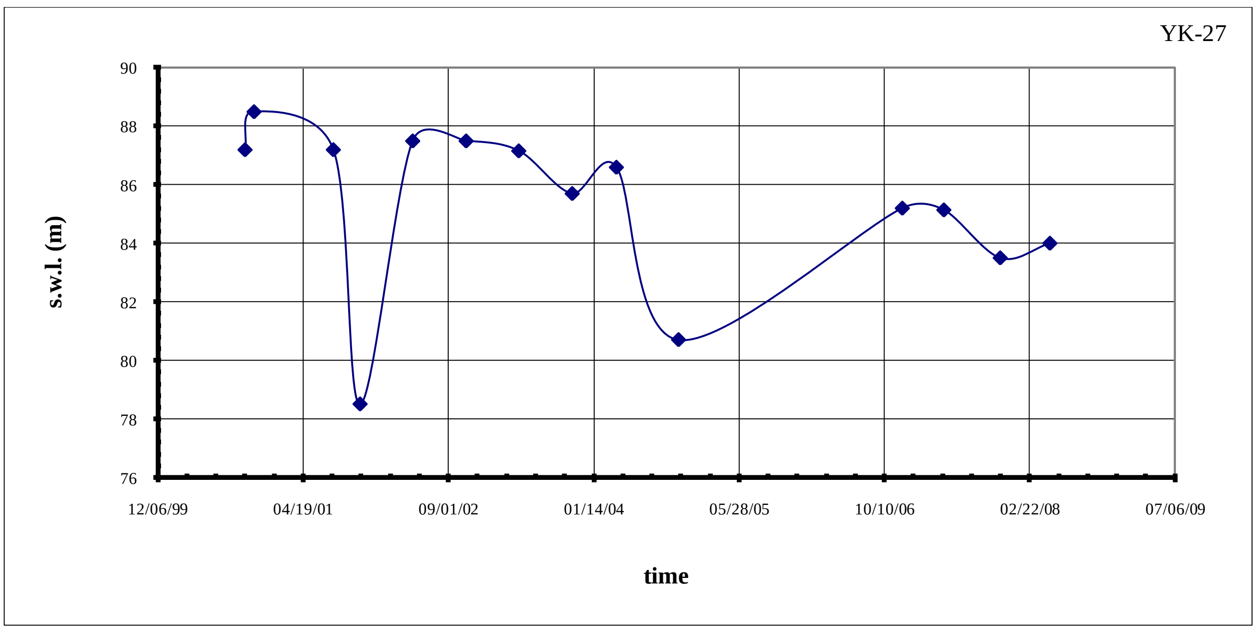

Figure A1.10 drawdown in static water level in YK-27 with time.

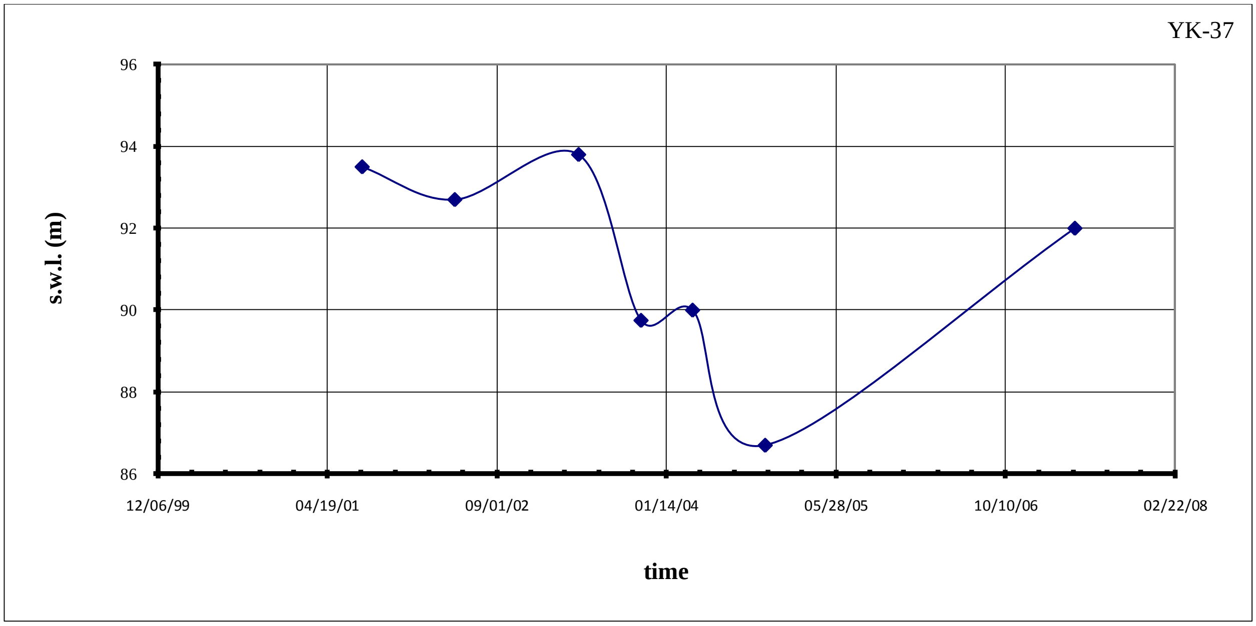

Figure A1.11 drawdown in static water level in YK-37 with time.

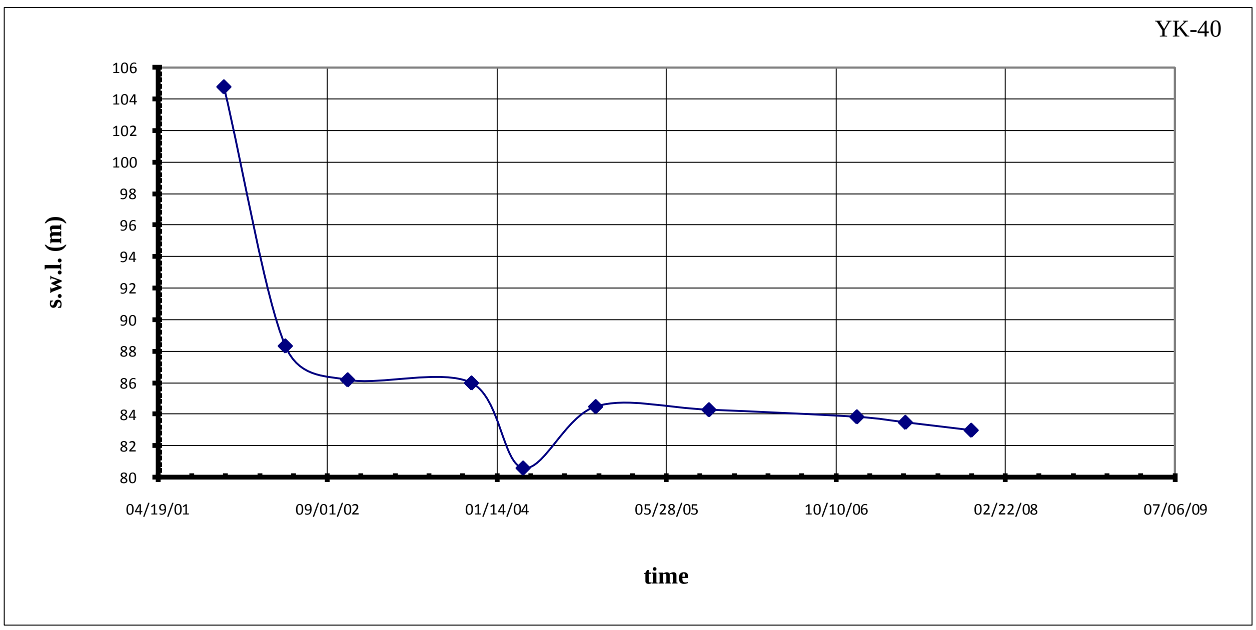

Figure A1.12 drawdown in static water level in YK-40 with time.

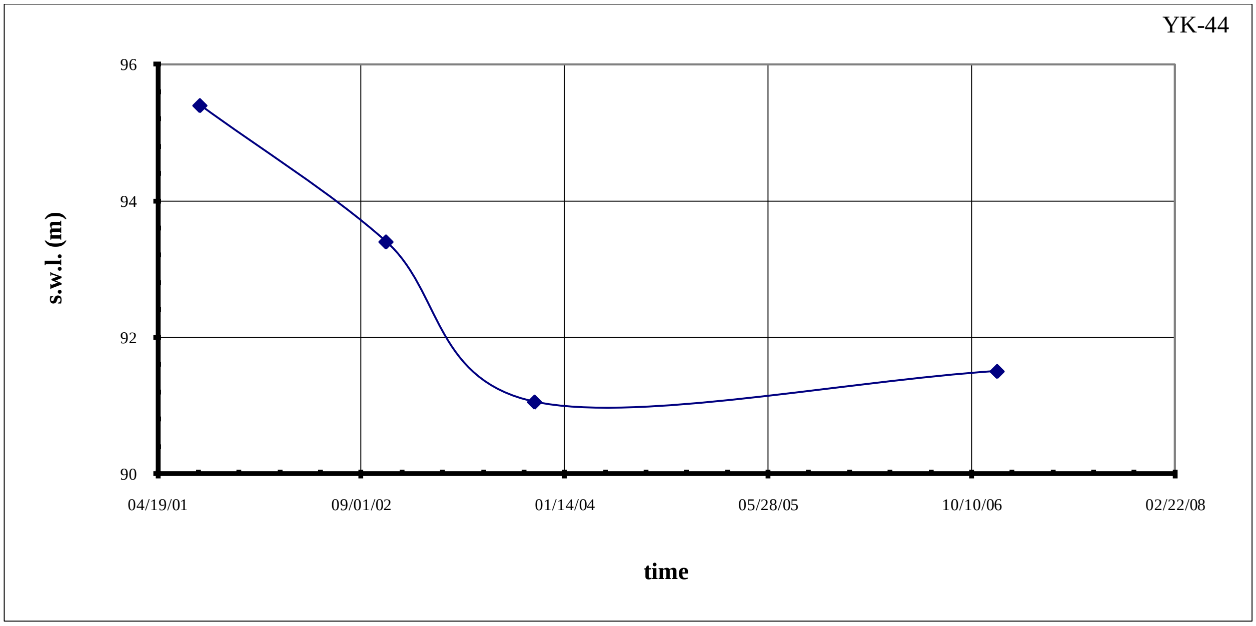

Figure A1.13 drawdown in static water level in YK-44 with time.

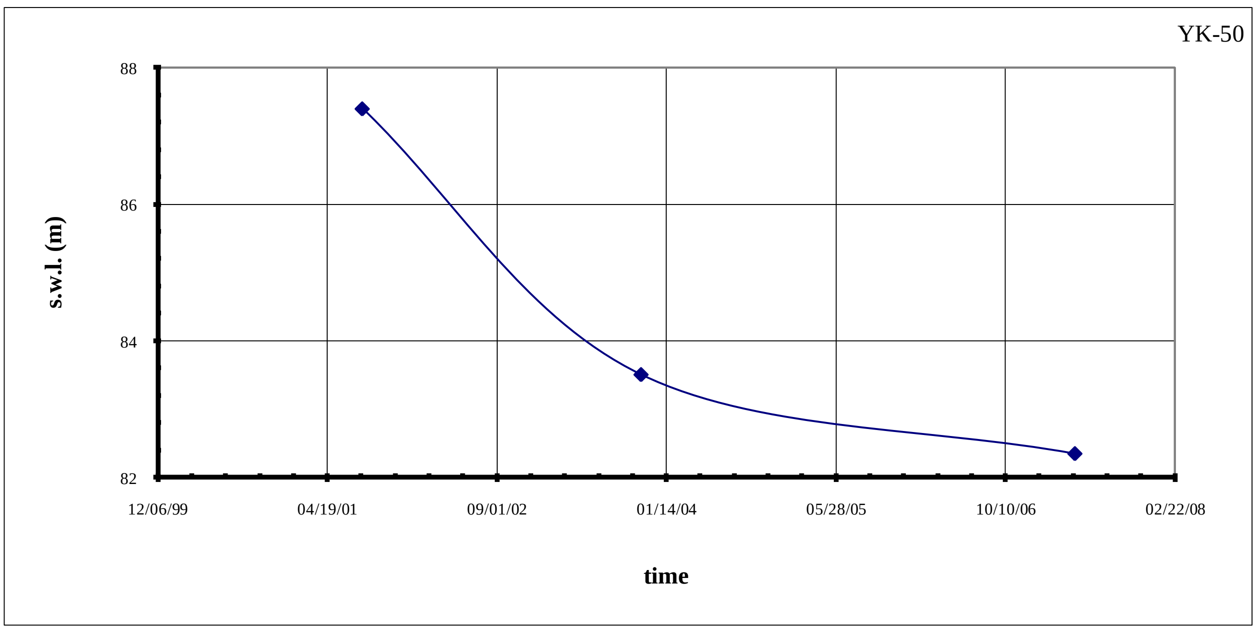

Figure A1.14 drawdown in static water level in YK-50 with time.

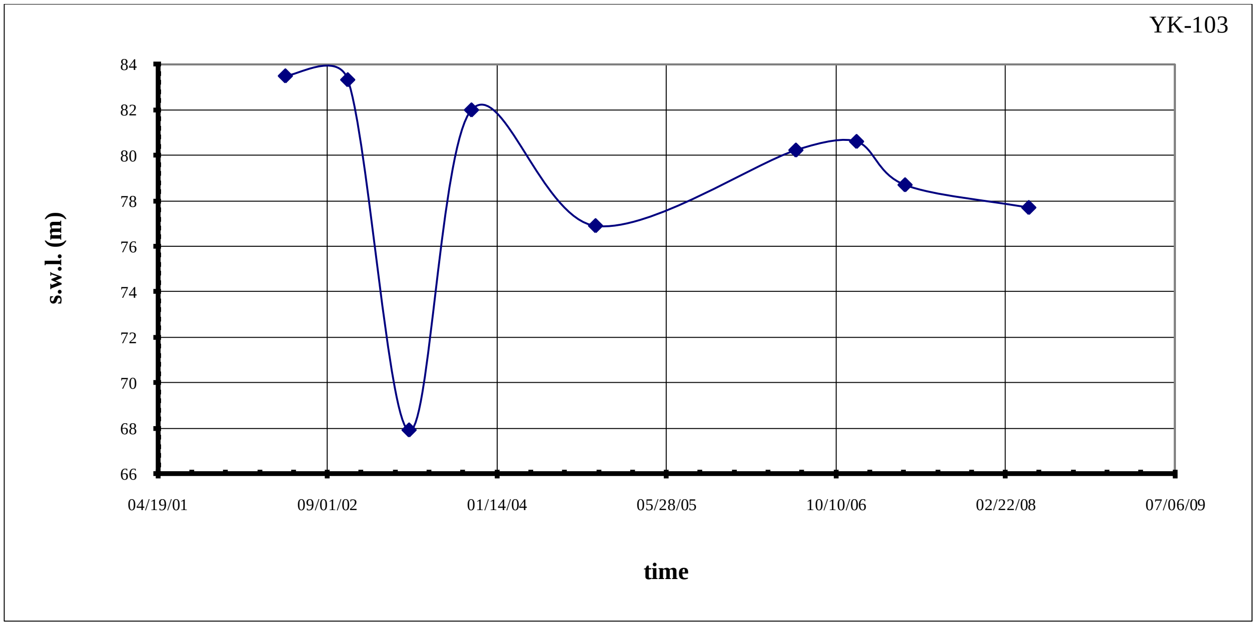

Figure A1.15 drawdown in static water level in YK-103 with time.

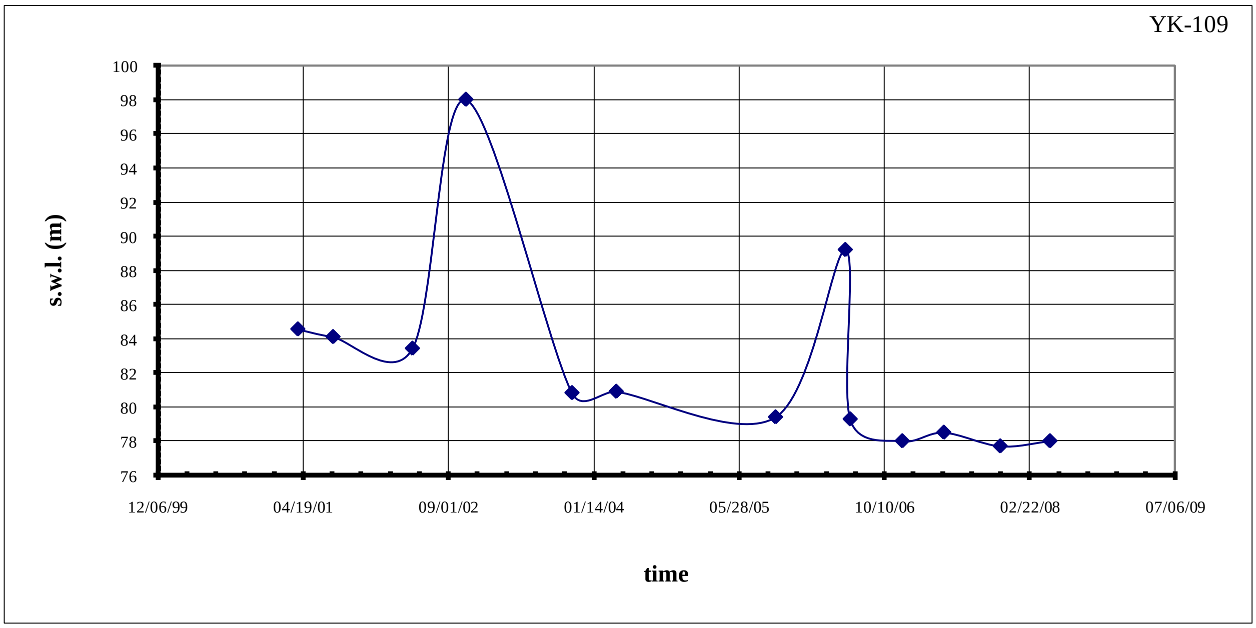

Figure A1.16 drawdown in static water level in YK-109 with time.

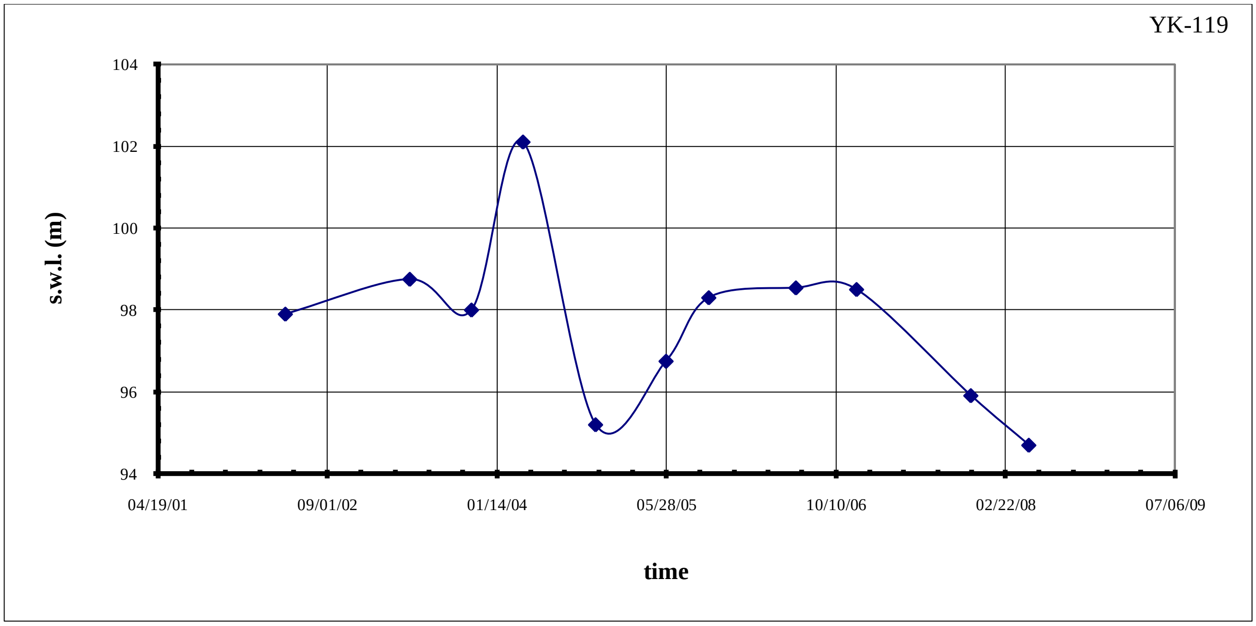

Figure A1.17 drawdown in static water level in YK-119 with time.

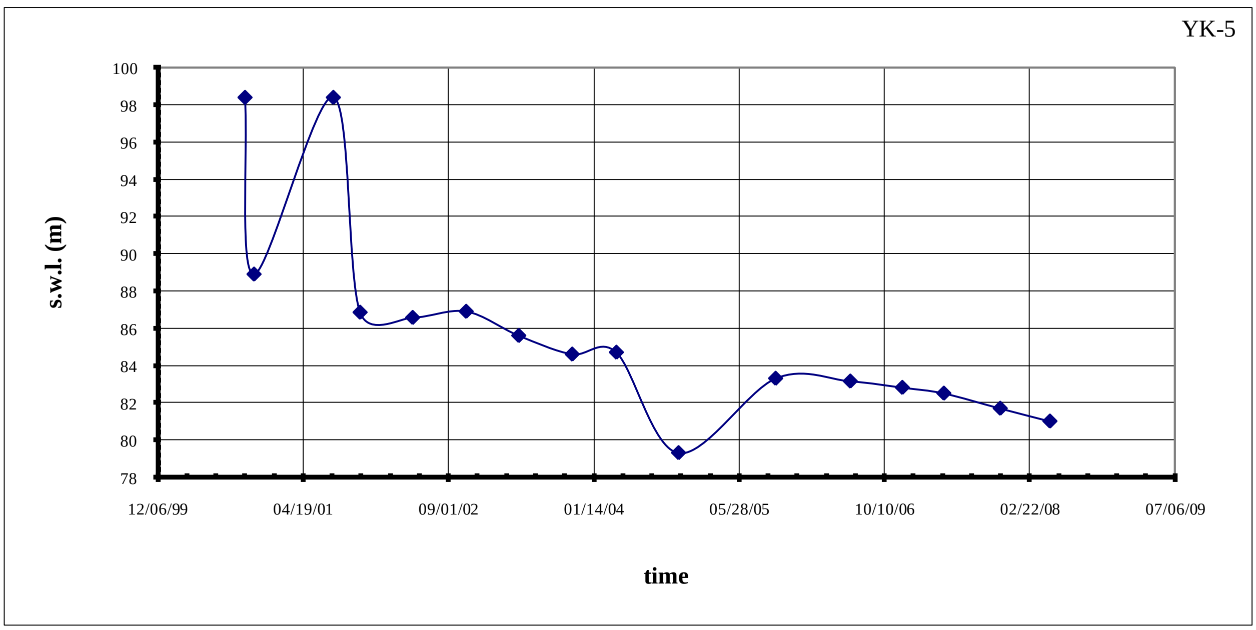

Figure A1.18 drawdown in static water level in YK-5 with time.

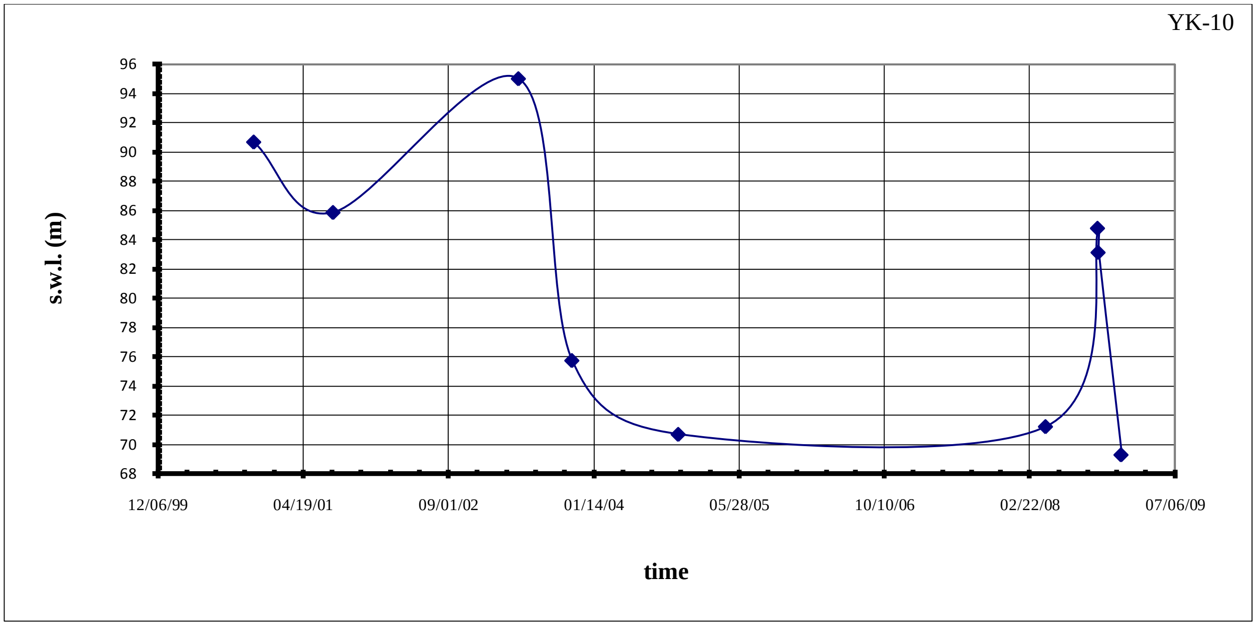

Figure A1.19 drawdown in static water level in YK-10 with time.

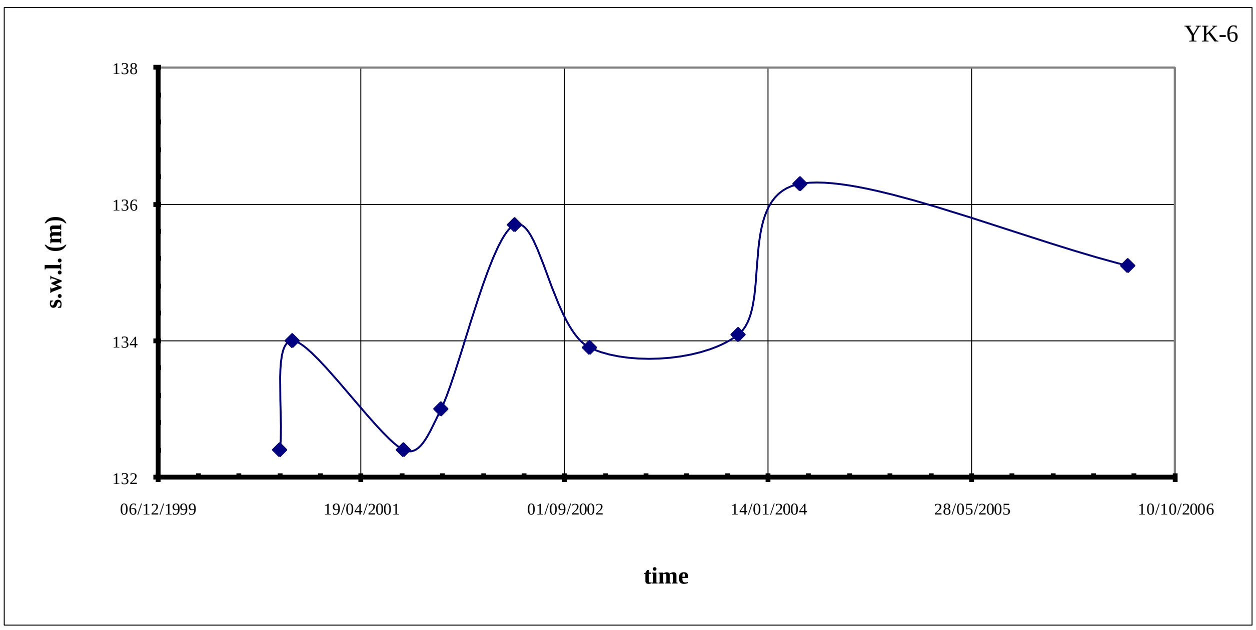

Figure A1.20 drawdown in static water level in YK-6 with time.

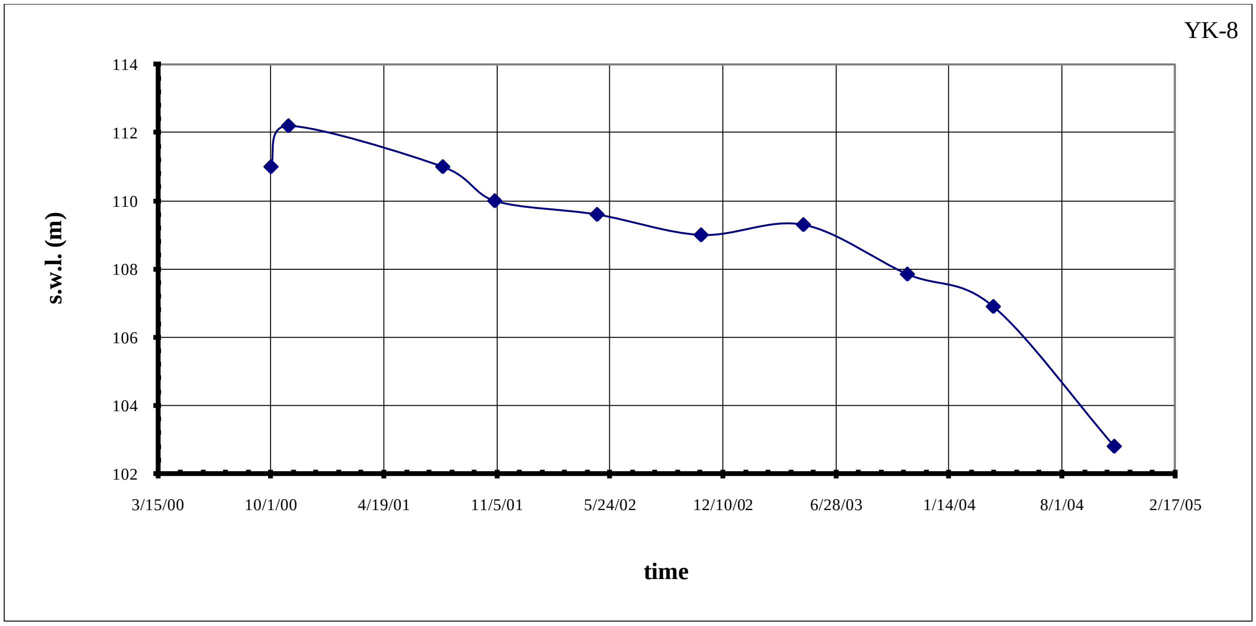

Figure A1.21 drawdown in static water level in YK-8 with time.

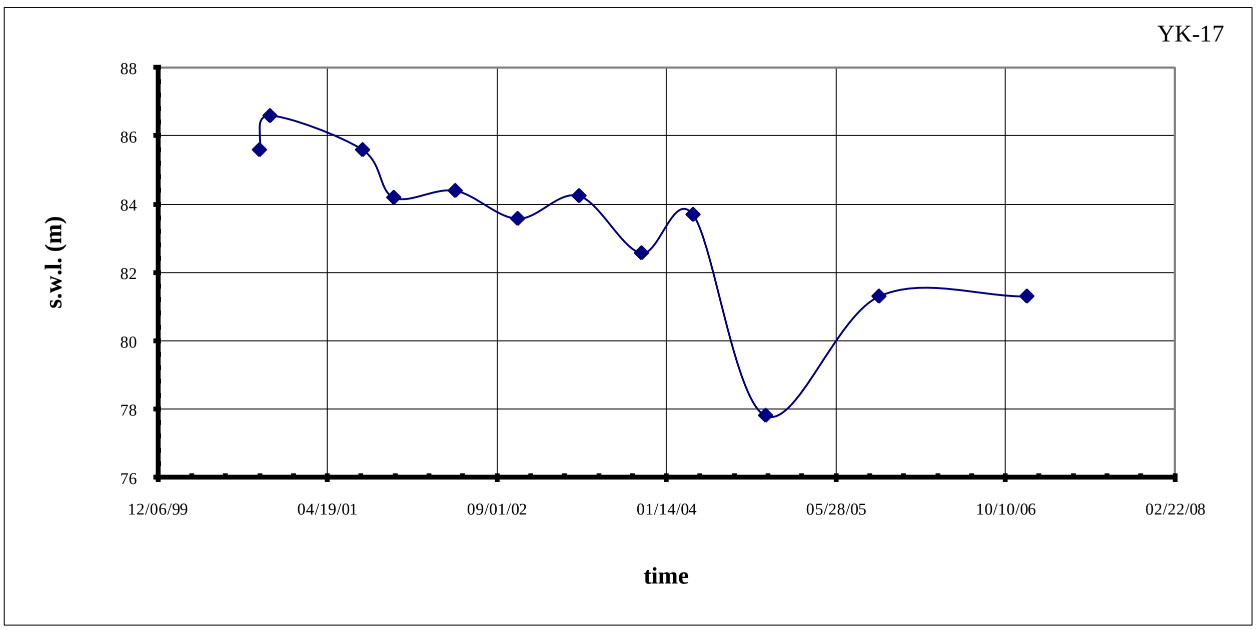

Figure A1.22 drawdown in static water level in YK-17 with time.

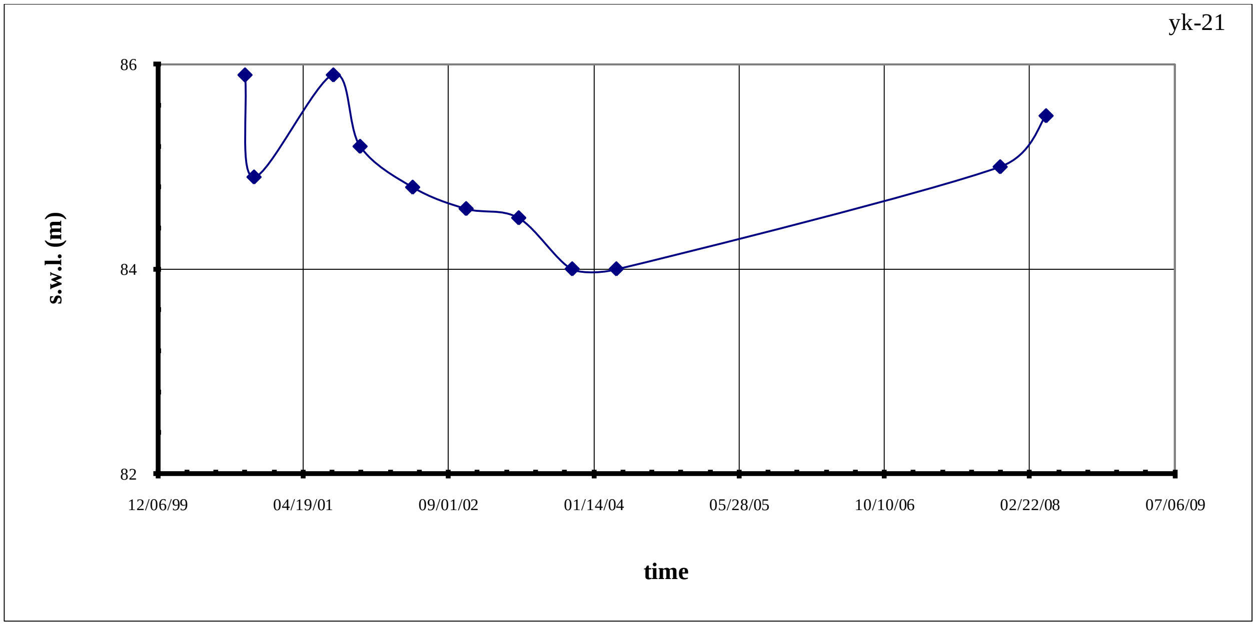

Figure A1.22 drawdown in static water level in YK-21 with time.

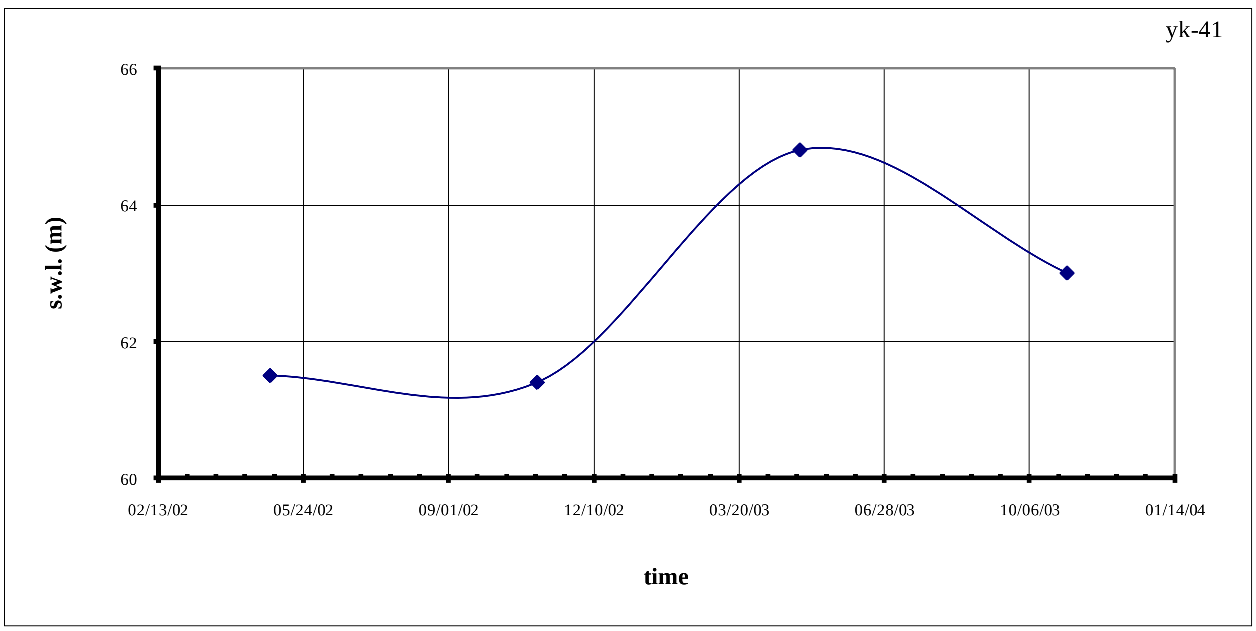

Figure A1.23 drawdown in static water level in YK-41 with time.

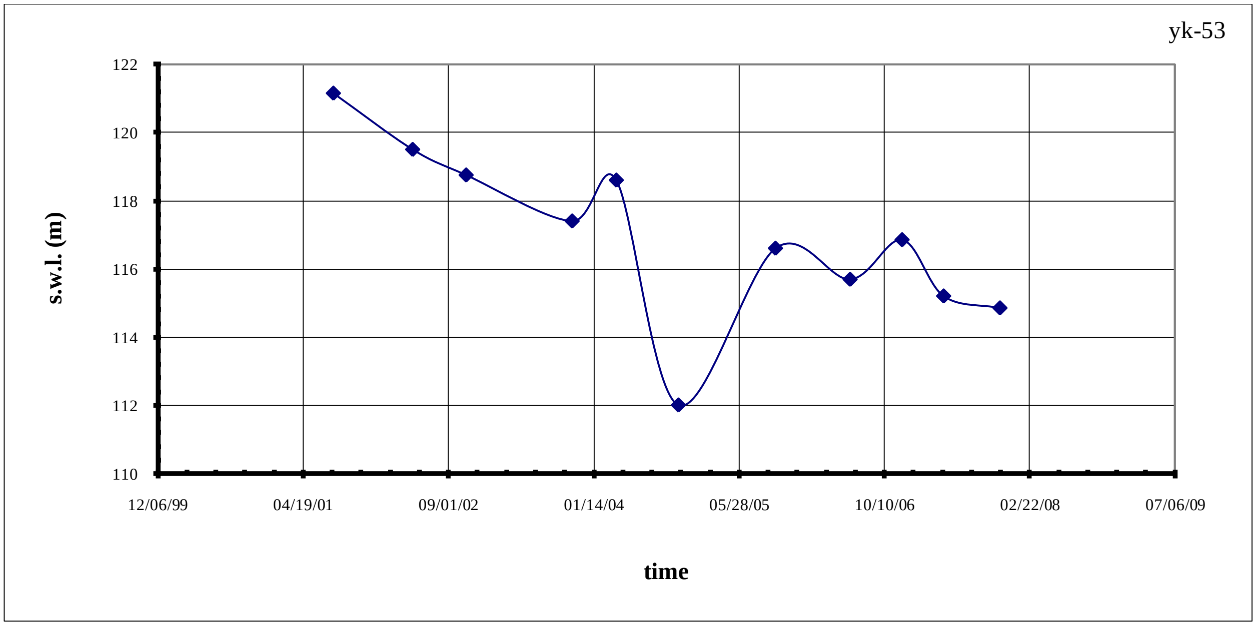

Figure A1.24 drawdown in static water level in YK-53 with time.

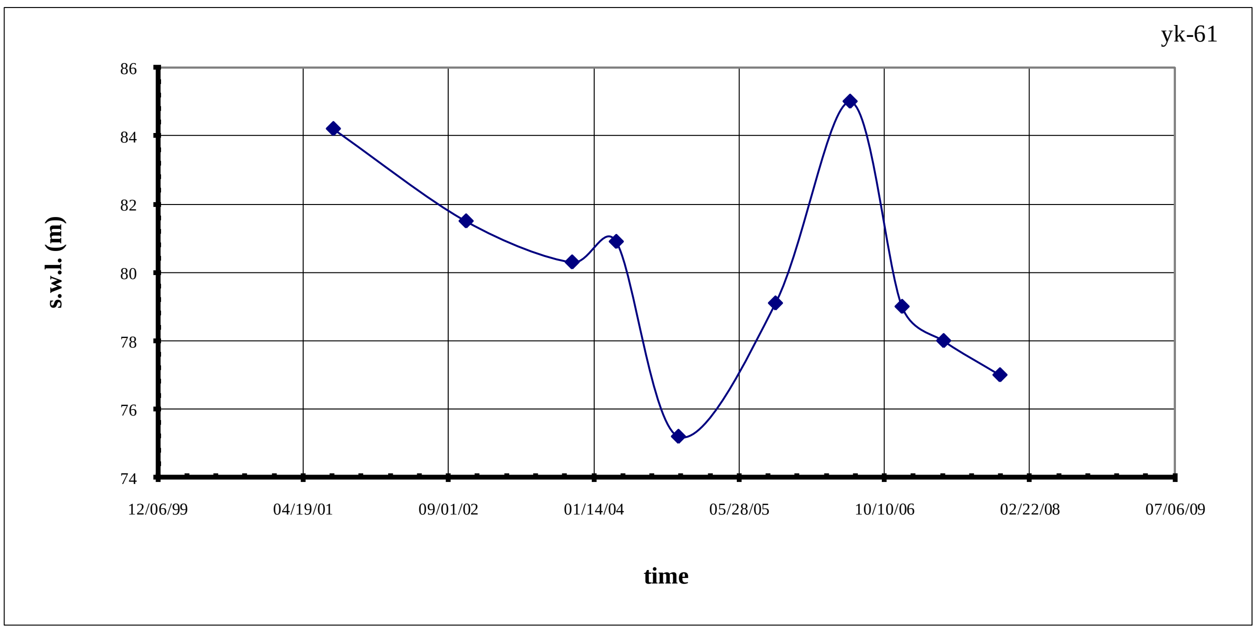

Figure A1.25 drawdown in static water level in YK-61 with time.

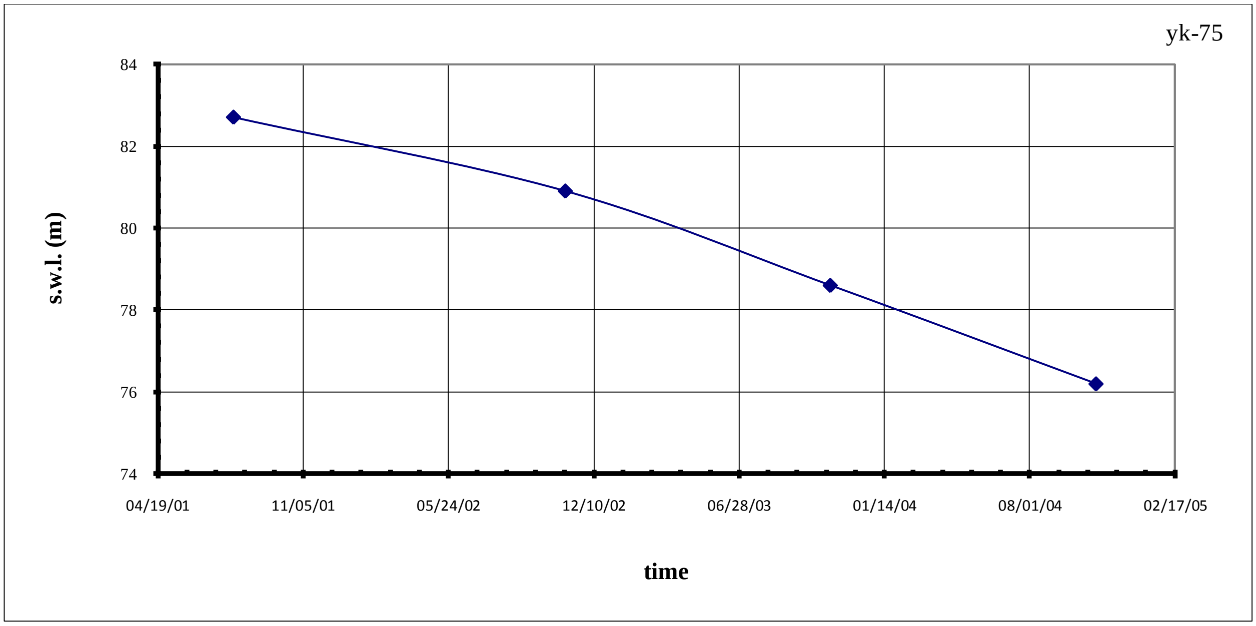

Figure A1.26 drawdown in static water level in YK-75 with time.

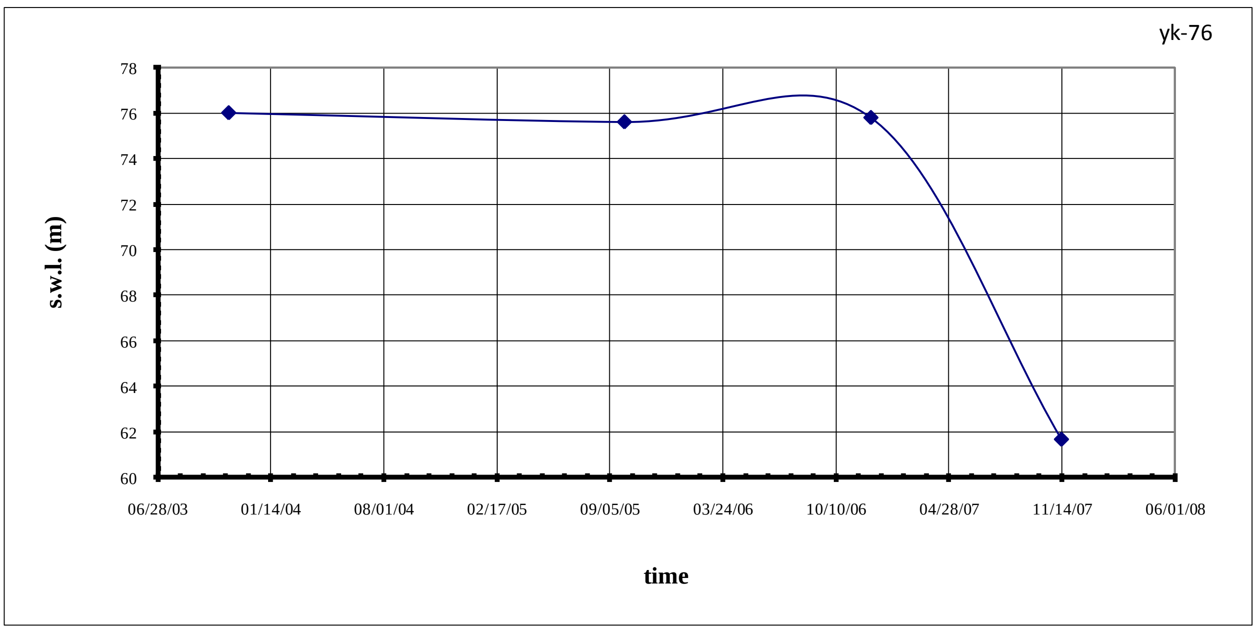

Figure A1.27 drawdown in static water level in YK-76 with time.

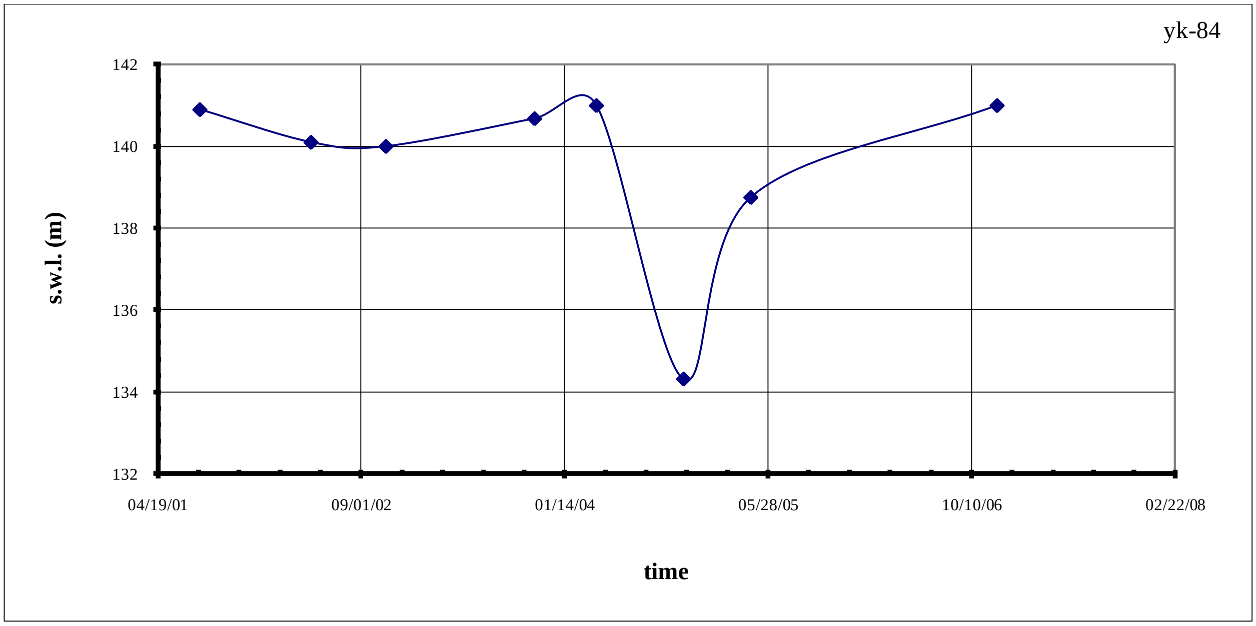

Figure A1.28 drawdown in static water level in YK-84 with time.

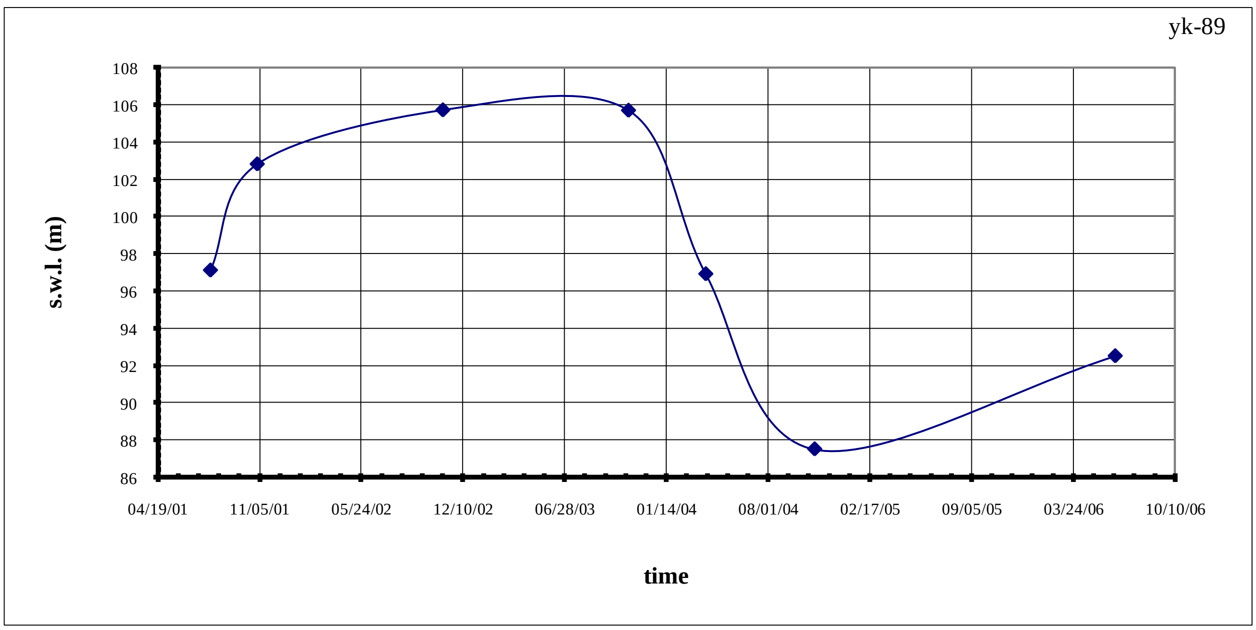

Figure A1.29 drawdown in static water level in YK-89 with time.

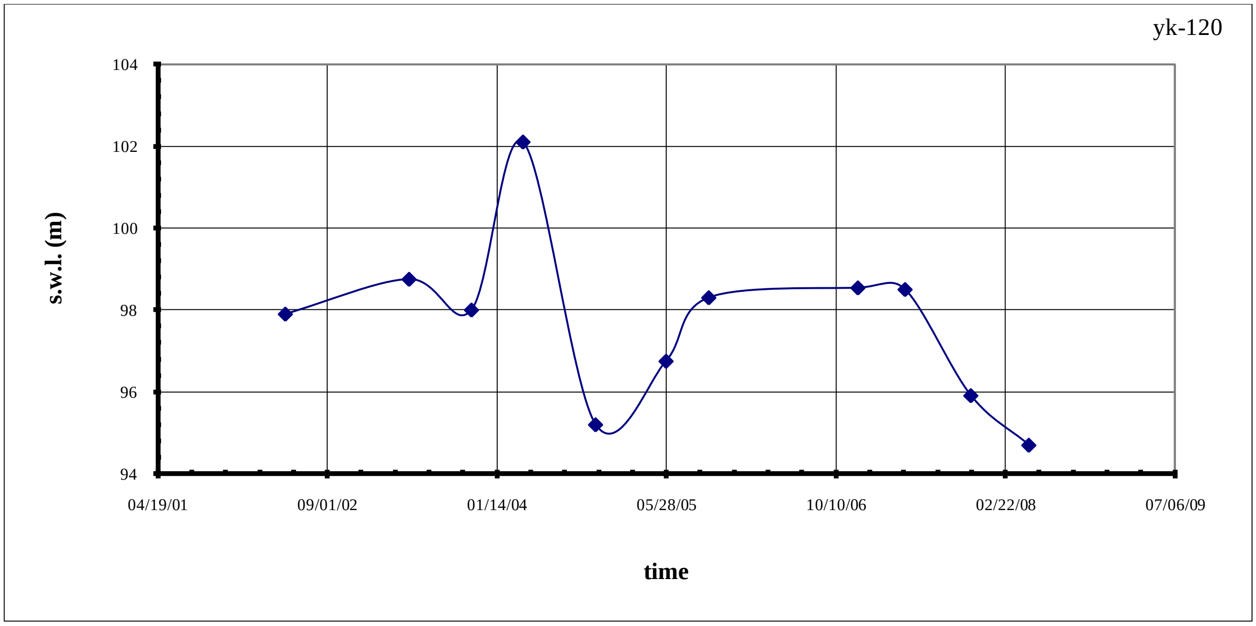

Figure A1.30 drawdown in static water level in YK-120 with time.