MODELING GROUNDWATER FLOW IN A RAW MATERIAL SITE OF A CEMENT FACTORY, KOCAELI-DARICA, TURKEY

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Approval of the Graduate School of Natural and Applied Sciences.

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

MODELING GROUNDWATER FLOW IN A RAW MATERIAL SITE OF A CEMENT FACTORY, KOCAELI-DARICA, TURKEY

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An areal numerical simulation has been carried out to investigate effects of below-sea-level (BSL) excavation in the raw material site of a cement factory in Turkey. A finite element model (585 nodes with 534 elements) is formed to solve for the head distribution in the quarry site upon quarry operation planned to be implemented in the near future. The model is calibrated to the field conditions and appropriate boundary conditions and the physical parameters are obtained to be used in future prediction studies.

After a successful calibration the model is run to estimate the water levels and the discharge rates required during below sea level quarry operations.

Above sea level (ASL) and below sea level (BSL) operations are simulated and water level contour maps are obtained both for above sea level (ASL) production for the 2000-2030 period, and for each BSL (-10m, -20m, -30m) production periods, which would totally take 13 years.

Estimation show that the proposed model runs properly and it calculates the water levels and discharge rates accurately for probable future quarry operations. It is clear that quarry operations would not create a serious problem in terms of water discharge from the quarry site.

Keywords: Simulation, Kocaeli – Darıca, Coastal Aquifer

ÖZ

KOCAELİ - DARICA, TÜRKİYE ÇİMENTO FABRİKASI HAM MADDE SAHASINDA YERALTI SUYU AKIŞ MODELLEMESİ

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Tez Yöneticisi: Prof.Dr. Nurkan KARAHANOĞLU

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Türkiyede bulunan çimento fabrikası ham madde sahasında deniz seviyesi altı kazılarının etkilerini araştırmak amacıyla alansal sayısal modellleme gerçekleştirilmiştir. Yakın gelecekte tamamlanacak taşocağı işletme planı üzerinde su dağılımını işletme sahasında çözümlemek üzere sonlu elemanlar (534 eleman ile 585 düğüm noktalı) modeli oluşturulmuştur. Model saha ve uygun sınır koşullarına göre kalibre edilerek ilerki tahmin çalışmalarında kullanılmak üzere fiziksel parametreler elde edilmiştir.

Başarılı bir kalibrasyondan sonra model deniz seviyesi altı işletme opersyonları sırasında gerekli su seviyeleri ve tahliye oranlarını tahmin amacıyla çalıştırılmıştır.

Deniz seviyesi üstü (ASL) ve deniz seviyesi altı (BSL) işletme modellemesi ve hem deniz seviyesi üzerinde üretim için 2001-2031 dönemi, hem de toplam 13 yıl alacak herbir deniz seviyesi altı (-10m, -20m, -30m) üretimi için eş su seviye haritaları elde edilmiştir.

Hesaplamalar ileri sürülen modelin düzgün bir şekilde çalıştığını ve olası gelecek madencilik işletme faaliyetleri için su seviyeleri ile tahliye oranlarını doğru olarak hesapladığını göstermektedir. İşletme faaliyetlerinin işletme sahasından su tahliyesi açısından ciddi problem yaratmayacağı açıktır.

Anahtar kelimeler: Benzeşim, Kocaeli-Darıca, Kıyı Akiferi

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I wish to express my most sincere appreciation to my supervisor Prof. Dr. Nurkan Karahanoglu for his guidance and advise during this research.

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CHAPTER 1

INTRODUCTION

1.1. Purpose and Scope

The main objective of this study is to formulate an areal finite element model to simulate groundwater flow in the raw material site of a cement factory upon below sea level (BSL) mining operations. Proposed model has been developed by considering previously formed two-dimensional cross sectional model (Karahanoğlu and Doyuran, 2003), which was located along a sea-to-land profile in the quarry site of the Kocaeli-Darıca Lafarge cement factory to simulate seawater intrusion into the site. In this research an areal model is proposed to model areal distribution of the groundwater flow for the same conditions. In this way it is expected to evaluate the changes in water levels in the quarry site along profiles other than the one used for the cross sectional model.

1.2. Location of The Study Area

The study area lies on the Kocaeli-Darıca Aslan Cement quarry, which is located at the south of Kocaeli peninsula, approximately 5-km southwest of Gebze and 2.5 km west of Darıca (Figure 1.1). The study area is easily accessible both from Istanbul and Ankara throughout the year.

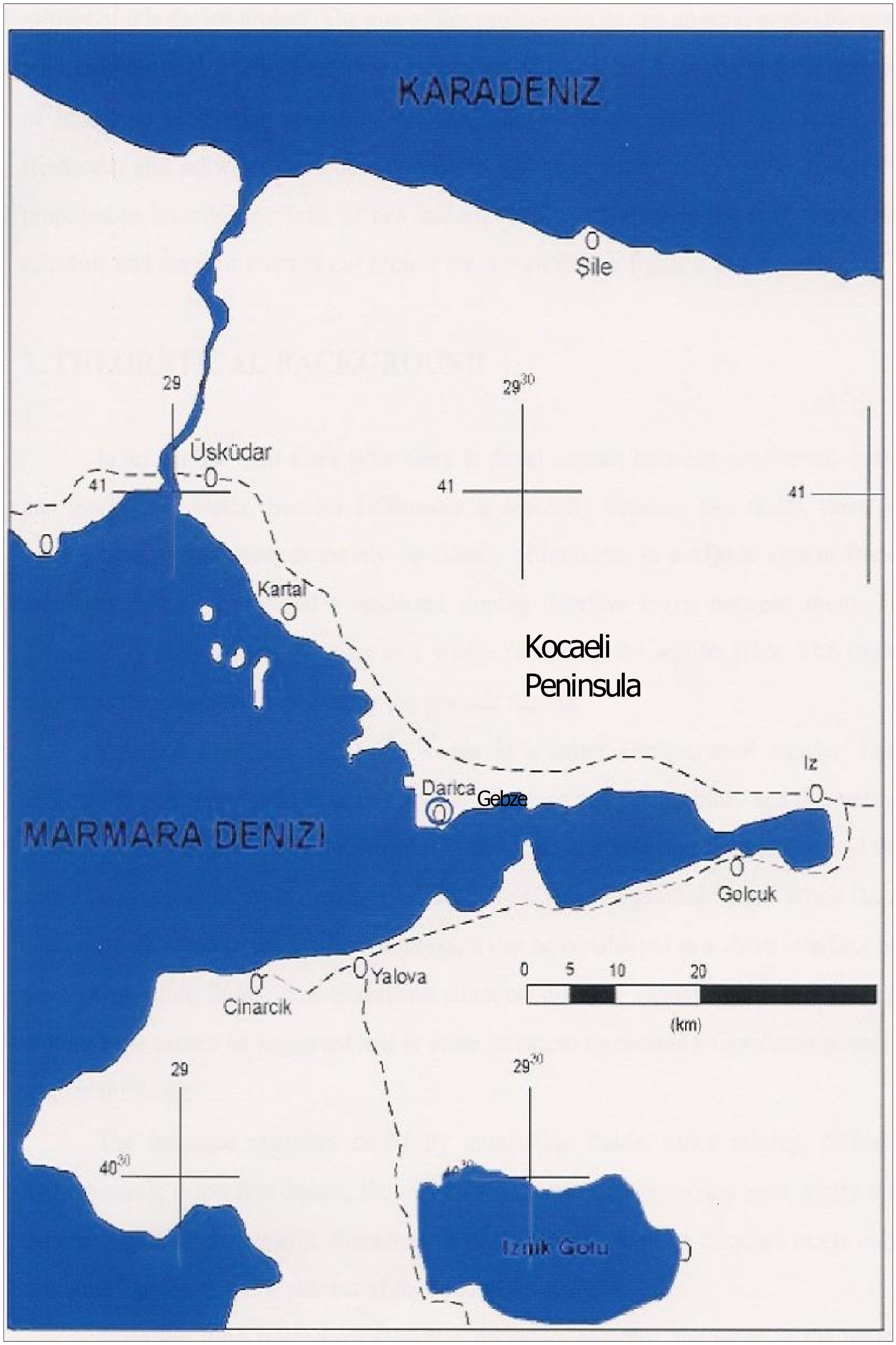

Figure 1.1 Location map of the study area (Doyuran et al , 2001)

1.3. Previous Studies

Several types of models have been used to study groundwater flow systems. They can be divided into three broad categories; sand tank models, analog models, including viscous fluid models and electrical models, and mathematical models, including analytical and numerical models. Mathematical models of groundwater flow have been used since late 1800s (Wang and Anderson, 1982). Numerical modeling of flow problems have been the focus of several researchers since 1970s with the advent of computers (Pinder and Frind, 1972; Trescott and Larson, 1977; Mercer and Faust, 1980; Premchitt and Gupta, 1981; Gupta et al, 1984; Koo and Leap, 1998). Since then aquifer contamination and seawater intrusion problems have introduced new dimensions to water related modeling problems.

Several studies have been conducted in the study area for investigation and parameter identification purposes. Some of them are listed below:

Gültekin (1983) performed cement raw material investigation studies around the field and provided detailed information about regional geology. Lafarge Aslan Cement periodically updates the geological map of the raw material area.

MTA (1991) conducted research in the area to investigate hydrogeology of the quarry site and near vicinity.

Several boreholes were drilled in the area and pumping tests were performed to determine hydraulic conductivity, transmissivity and storage coefficient values.

Yeraltı Aramacılık (1994) conducted geophysical investigations at the quarry site to determine saltwater freshwater interface and also to assess excavatability of the rocks. They prepared an iso-interface map for the site and determined depths to interface at different locations.

Gemmes (1997) developed a model for the west quarry site to investigate groundwater inflow rates and the migration of salt-water front. A two dimensional numerical model was formulated and applied in two different cross sections to predict future below sea level excavations by simulating the model for alternative scenarios.

Doyuran et al (2001) carried out a numerical research to investigate the hydrogeological and hydrochemical conditions at the west pit of Kocaeli-Darıca Lafarge Aslan Cement Quarry. A two dimensional numerical model (cross-sectional) is developed to estimate the amount of water discharge from the pit and also to determine the rate of advance of the salt-water front during BSL mining (Karahanoğlu and Doyuran, 2003). The cross sectional model formed along a sea-to-land profile and the effect of below sea level mining was extensively investigated for different quarry operations.

In view of these studies a two-dimensional-areal numerical model is presented in this research to investigate the areal effect of below sea level (BSL) mining in the study area.

CHAPTER 2

GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

This chapter is compiled from M.T.A (1991) and Doyuran et al (2001).

2.1 Geology

2.1.1 Stratigraphy

Stratigraphy of the area consists of both autochthonous and allochtonous units. Paleozoic (Devonian) basement rocks, dolomites and limestones of Triassic age, conglomerates, sandstones, lower marls, marly limestones, and cherty marls of Late Cretaceous age, dense marls (Paleocene) and Pliocene cover units form the autochthonous units (Figure 2.1 and 2.2). The allochtonous units comprise greywacke and limestone blocks of Carboniferous age. (Doyuran et al , 2001)

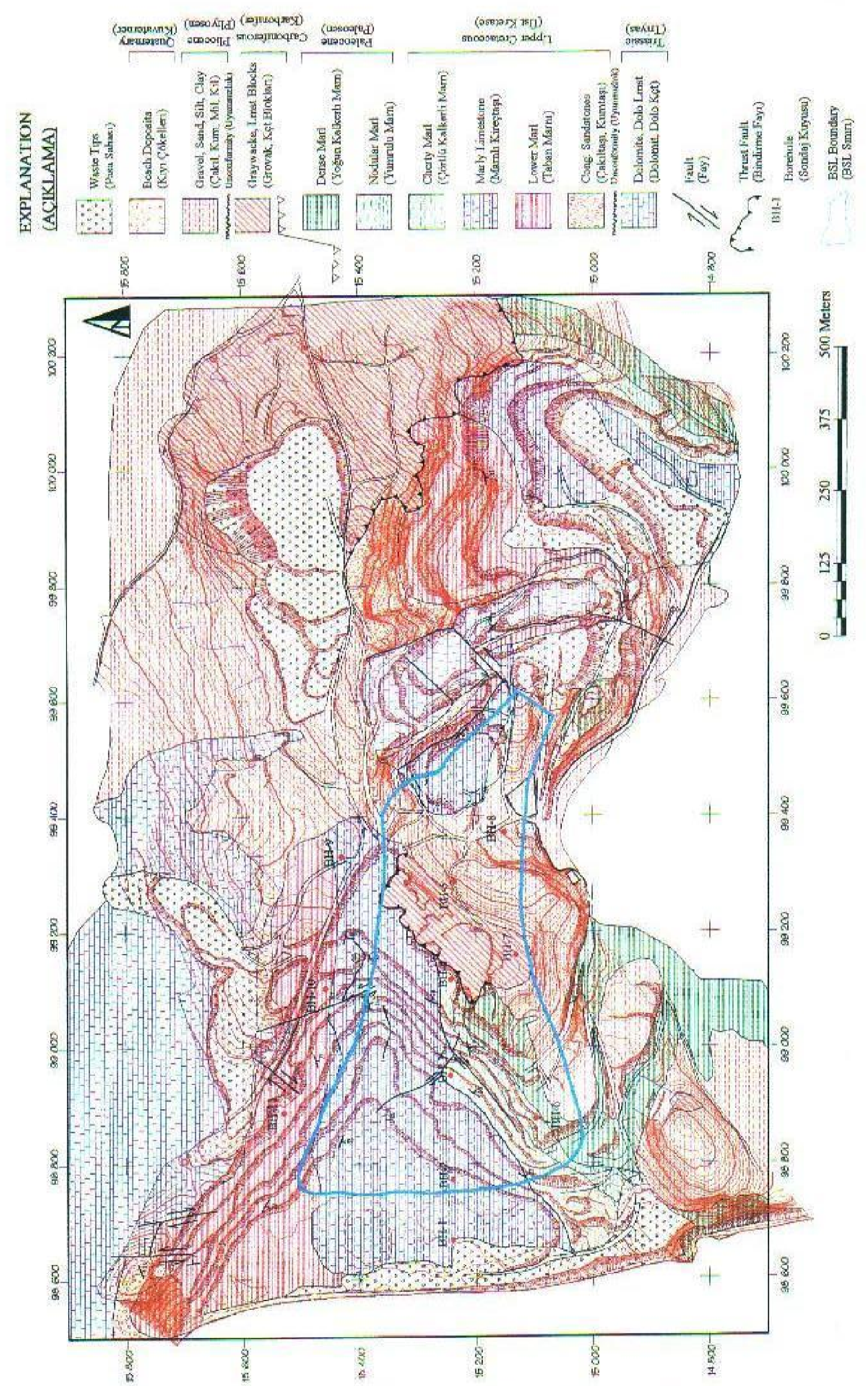

Figure 2.1 Geological map of the study area (Doyuran et al , 2001)

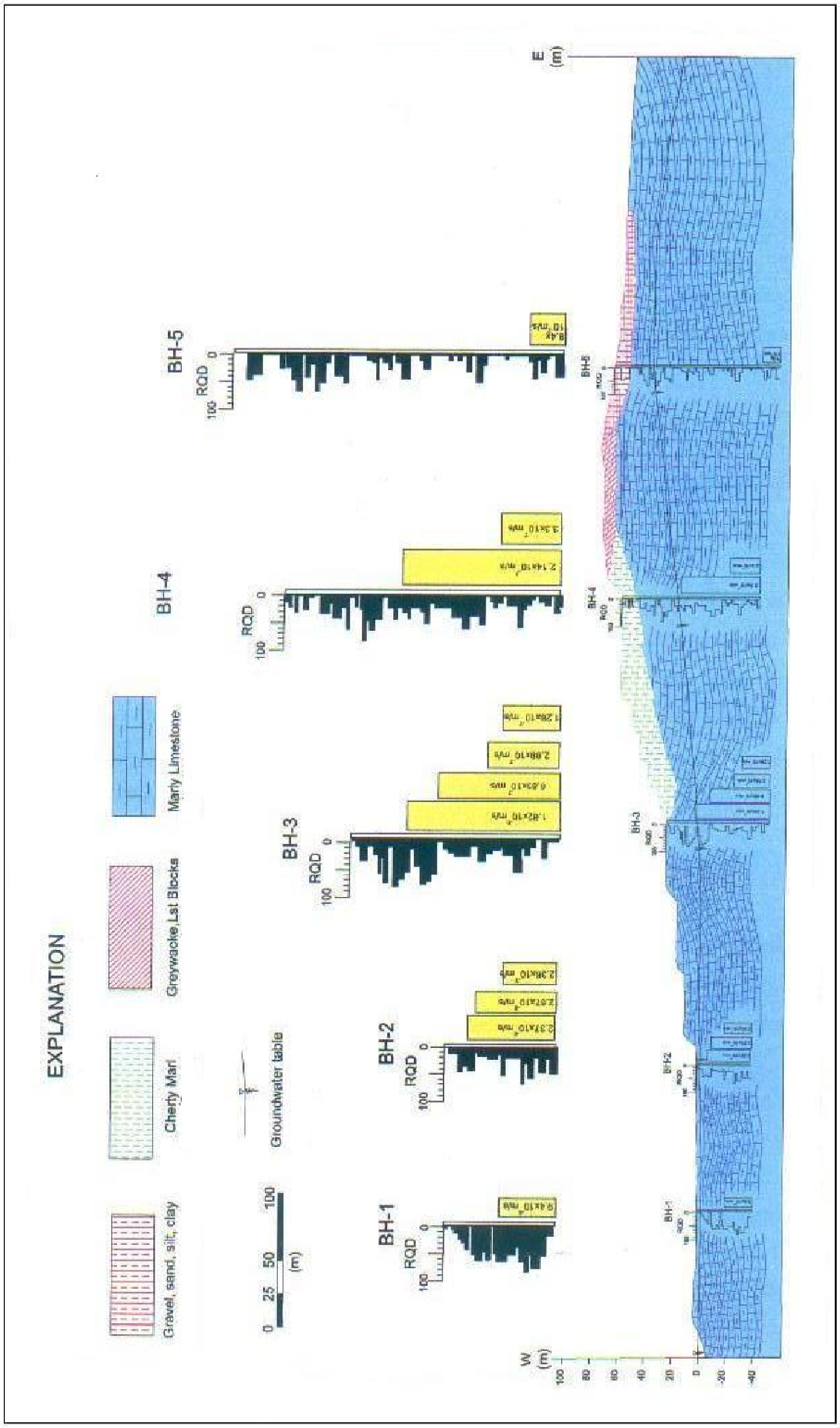

Figure 2.2 Hydrogeological cross section of the study area (Doyuran et al, 2001)

2.1.1.1 Paleozoic basement rocks

They crop out at the north of the study area (Figure 2.1). The unit consists of dark gray to black limestone, light gray, and locally brownish greywacke and shale and sandstone shale alteration of Devonian age.

2.1.1.2 Triassic Dolomites and Dolomitic Limestones

Widespread exposures are observed at the north and northwest of the quarry. The formation comprises massive, locally medium bedded, hard, intensely fractured, karstic, white to light gray dolomites and dolomitic limestones of Middle Triassic age.

2.1.1.3 Upper Cretaceous Units

The unit consists of;

Conglomerates and Sandstones: Constitute the base of the Upper Cretaceous units, which overlie the Triassic units unconformably. They are exposed at Ayazmetepe and Yeldeğirmenitepe as well as at the pit slopes. The conglomerates are reddish, cross-bedded, medium to thick bedded and locally lense shaped.

Lower marls: Overlie conglomerates and sandstones conformably.

They are exposed at the north and east of the quarry. They consist of dark gray, light green, beige, thin bedded and laminated marls.

Marly Limestones: Have a widespread exposure at the quarry. Best exposures can be observed at the west pit slopes. They consist of beige, greenish gray, thin to medium bedded, hard marly limestones and alternating dark gray, black, thin bedded, locally laminated claystones and sandstones. The joint and fracture surfaces are generally coated by clays and fissures with clay infilling are also common. Among Upper Cretaceous units the marly limestones contain the highest percentage of carbonate.

Cherty Marl: Overlie the marly limestones conformably and they are well exposed along the pit slopes. They are beige, light gray, medium to thick bedded, hard and friable.

2.1.1.4 Paleocene Units

The unit consists of;

Nodular Marl: Exposed at the south of west pits along pit slopes. They consist of nodular and calcareous marls with thin bands of clay and sandstone layers. They are cream colored to white, thin to medium bedded and locally show boudinage structure.

Dense Marl: Represent the uppermost levels of the series. They consist of dirty yellow, cream, thin to medium bedded dense marls.

2.1.1.5 Pliocene Cover Units

They unconformably overlie the older units. They consist of yellow, brown, weakly cemented, gravels, sands, silts, and clays of continental origin. The unit is mostly observed at the upper benches of the pit.

2.1.1.6 Allochthonous Units

These Paleozoic (Carboniferous) units are observed at the east of the study area and also around BH-7. They tectonically overlie the younger units. They consist of brown, greenish, gray graywackes and limestones in the form of bands, lenses, and blocks of various sizes. The limestones are generally dark gray to black.

2.1.2 Structural geology

The main tectonic features of the study area are;

Unconformities: Three unconformities are noted at the west pit area. These include, from oldest to youngest, Paleozoic-Triassic, Triassic-Upper Cretaceous, and Basement units- Pliocene unconformities.

Faults and Thrusts: Carboniferous units observed over the Upper Cretaceous and older units are most probably thrusted over during Neogene. The 1-3 m thick shear zones (fault gouge fault breccia) encountered in some previously drilled boreholes are regarded as thrust zones.

Discontinuities: They include bedding, joints, and shear zones/ faults. Measurements were conducted within marly limestones, cherty marl, and nodular marl. During field studies three different discontinuity types were distinguished.

Bedding: A total of 675 bedding measurements were taken. Spacing of beds ranges between 5cm-50 cm (close-moderate), locally 1-5 cm and 50cm-100cm. Their persistence is high. Apertures are generally 0-2 mm (tight to very narrow). This suggests that the units have very low permeability along beddings.

Joints: A total of 1603 joint orientation measurements were taken from the working benches of the pit. Spacing of joints ranges between 5cm- 50 cm (close –moderate), their persistence between 5-50 cm (very low) and the joints are generally bed confined. The apertures of joints range between 0-6 mm (tight narrow) which suggest low permeability.

Shear Zones-Faults: A total of 28 shear zones/faults measurements, 4 normal falts and 24 shear zones, were taken from the west pit area. The shear zones are not systematic throughout the area. Thus no statement about their spacing could be made. The width of the shear zones ranges between 2mm-200mm (moderate-very wide) and their persistence exceeds 10 m.

2.2 Hydrogeology

2.2.1 Water Bearing properties of Rocks

At the study area the carbonate rocks dominate the lithology (Doyuran et al., 2001). These are composed of limestones, dolomites and marls with occasional alterations of conglomerate, sandstones and claystones. Within this sequence it is very unlikely to expect productive aquifers. Main functions of an aquifer include water storage and water conduit. The storage function is controlled by the porosity (primary and secondary) and the conduit function by the permeability (primary and secondary) of the rocks.

2.2.2 Porosity

The primary porosity of the lithological unit of the study area is very low. The secondary porosity is controlled by joints, fractures, shear zones, etc. provide certain amount of storage function.

The marly limestone contains thin layers and/or lamina of calystones, which is also the main infilling material for the joints and fractures. No significant karstification is observed within marly limestones. Due to small primary and secondary porosities no significant amount of water storage may be expected within the sequence.

2.2.3Permeability

Due to very low porosities and small pore spaces of rocks their primary permeabilities are very low. The discontinuities, which provide secondary permeability to the rocks, may permit groundwater circulation.

The sedimentary sequence observed at the study area generally dip toward south and southeast. These thin to medium thick-bedded carbonate rocks occasionally alternate with laminated claystones. Through undulating or broadly folded beds of the sequence no significant groundwater discharges are anticipated.

Systematic joint measurements yielded three joint sets. Their spacing are narrow to moderate, persistence is very low (bed confined) and apertures are tight to narrow. Main infilling is clayey soil and locally the joint surfaces contain iron oxide stains. Thus the joints do not contribute significantly to groundwater circulation.

During field studies some shear zones and faults were observed at the working benches. The field measurements revealed that they generally trend E-W and dip almost vertically.

The width of the shear zones range between 8 mm to 200 mm (moderate to very wide) their persistence exceed 10m, and infilling materials are clays, sands, and rarely breccia. Thus shear zones may be considered rather significant for groundwater circulation throughout the area.

During drilling of the boreholes it is seen that the shear zones control the groundwater flow. In the boreholes drilled by using air flash, locally water seepages are encountered and then the hole again progress in dry conditions. In the cored holes this rather obvious. The presence of iron oxide satining in the shear and/or highly fractured zones may be regarded as an indication of water circulation.

2.3 Drilling Activities

In order to determine the position of water table, to monitor groundwater level fluctuations, to conduct water pressure tests total of 11 boreholes with a total depth of 725 m were opened. Five of the cored boreholes (BH-1/BH-5) drilled along E-W axis where cross sectional model is applied. In borehole BH-6 water, in BH7-BH11 air is used as a flush. Information about boreholes is provided in Table 2.1.

Table 2.1 Borehole data (Doyuran et al, 2001)

Borehole No.	Coordinates		Elevation (m)	Depth (m)	Remarks
	East	North			
BH.1	98 665 00	15 239 83	1,95	40	Cored
BH.2	98 771 59	15 239 59	1,77	40	Cored
BH.3	98 951 22	15 243 09	25,04	75	Cored
BH.4	99 116 91	15 241 99	60,25	100	Cored
BH.5	99 287 83	15 236 34	63,69	120	Cored
BH.6	99 877 02	15 097 66	43,60	50	Rock bit
BH.7	99 158 87	15 131 69	72,10	75	Rock bit
BH.8	99 372 11	15 151 55	47,73	50	Rock bit
BH.9	99 331 36	15 427 80	78,20	80	Rock bit
BH.10	99 101 36	15 455 77	48,94	55	Rock bit
BH.11	98 888 33	15 527 70	36,31	40	Rock bit

2.4 Groundwater Level Measurements

In order to determine the position of the groundwater table the boreholes BH-1/BH-11 are equipped. In addition to these some of the existing wells are also used for groundwater monitoring. Fig 2.3 shows distribution of wells within the study area.

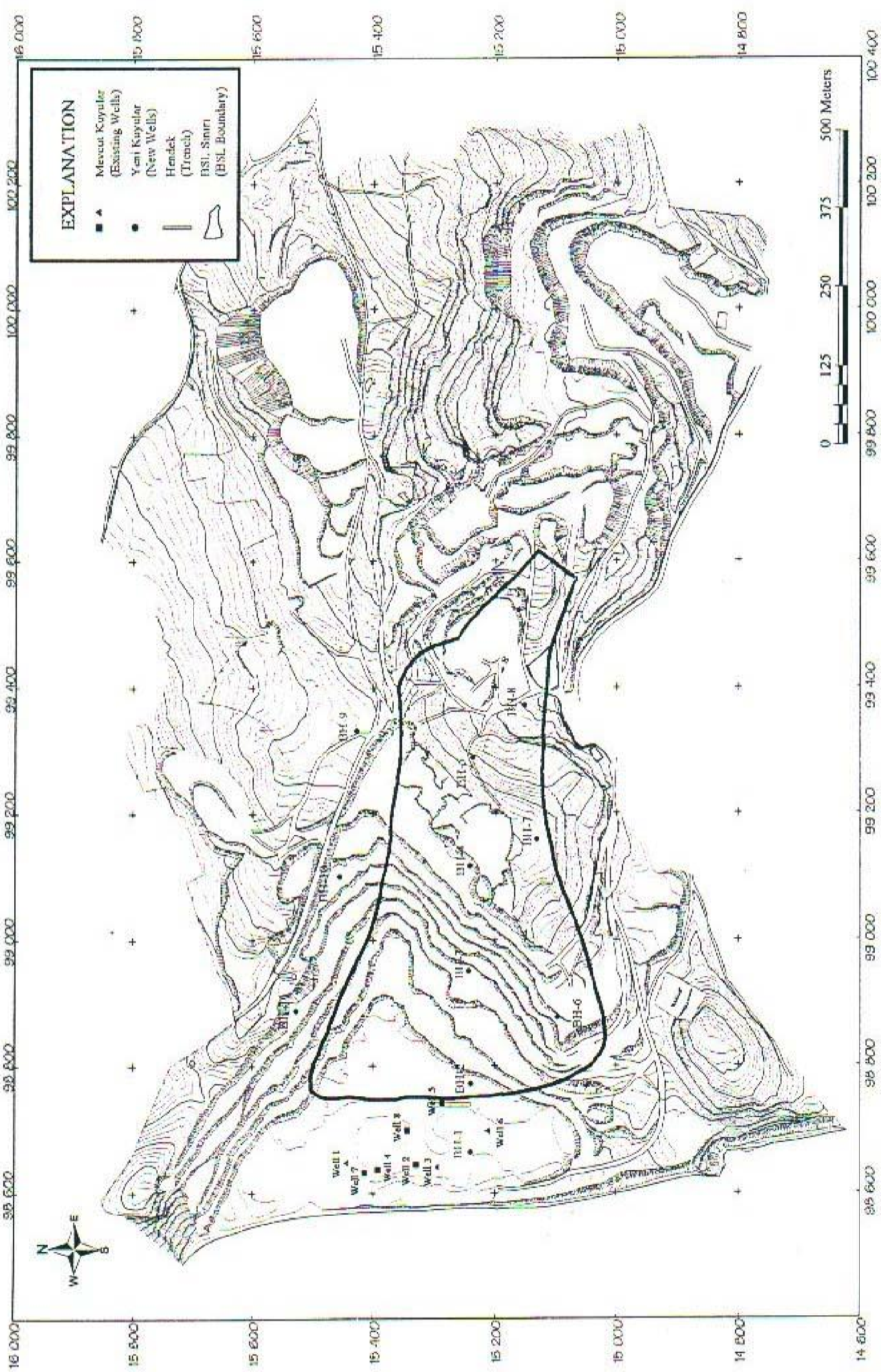

Figure 2.3 Distribution of wells within the study area (Doyuran et al , 2001)

CHAPTER 3

NUMERICAL MODELLING

3.1 Previous Cross Sectional Models

There are two simulation studies performed in the study area.

Gemmes (1997) performed a study to predict groundwater inflow rates and the migration of the salt-water front. During this research 6 pumping wells, 4 boreholes were drilled and a trench extending parallel to the shoreline was excavated. Based on pumping test results an iso-transmissivity contour map was prepared. A numerical flow and transport model is applied in the west quarry site along two E-W profiles with a depth of 100 m and the length of 1000m and used for simulation and alternative scenarios.

The results of the computations have shown that the computed values were greater than the observed values. The same model is applied 125 m away from the shoreline and 35 m deep.

As a conclusion, Gemmes (1997) stated that the amount of water to be drained during BSL mining would be small. The salt-water wedge should be located below the bottom of the excavation and would not migrate much toward east. However, it is understood that during calibration study water levels were not used in the calibration and the historical evaluation of the aquifer was not accounted for. Also the effects of such unrealistic excavation could not be seen in the salt-water mechanism in short time period.

Karahanoğlu and Doyuran (2003) developed a two-dimensional numerical model (cross sectional) to define the intrusion mechanism in the aquifer. 11 new wells with a total depth of 725 m have been drilled to determine the position of the water table and to monitor groundwater level fluctuations. These are later utilized to develop and calibrate the model to the field conditions. Numerical model is located along a sea-to-land profile (BH-1, BH-5 profile). The model is 1000 meter long and 100 meter deep and it has 3440 four-nodal finite elements with 3633 node points. The elements have (5mx5m) dimensions in the first 710-m from the coast and then they become (10mx5m) in the rest of the model to a distance of 1000 m.

Calibration of the numerical model to field conditions has been accomplished in a time dependent (transient) manner using the historical background of the aquifer.

Transient calibration (history matching) has been performed in three stages, starting from the virgin conditions of the aquifer and its historical evaluation during above sea level (ASL) production in the quarry.

The virgin conditions of the aquifer were simulated using a transient steady state approach and the equilibrium between seawater and fresh water was achieved by running the model for several years.

The model has estimated groundwater levels and the concentrations for the year 1990 by using the initial values of the variables at the end of first step calibration. It is thought that the quarried zone was far above the steady state water levels and excavations have not reached the water table in the aquifer. It is clear that the water levels in 1990 have been reached after the platform was formed and then aquifer started to loose water. This mechanism was simulated by the model and the second phase of the calibration was based on this assumption and the model was calibrated to the observed values of the year 1990.

The third phase of the calibration study aims at simulating the behaviour of the aquifer for the period between 1990 and 2001. A correlation analysis performed between the observed and the computed values of the variables calculates correlation coefficients of 0,9972 and 0,9934 respectively. In this way calibration of the finite element model has been successfully history matched to the field conditions and the model is made ready to be used for future predictions.

The calibrated model has been applied to the field in order to investigate the effects of BSL and ASL production in the quarry. Two alternative scenarios have been considered and probable effects of ASL and BSL excavations on seawater intrusion into the aquifer have been studied.

Future prediction studies are based on two production scenarios that assume 43 years of total production. (30 years of ASL and 13 years of BSL production). Scenario 1 assumes that starting from 2001 the next 30 years would be devoted only to ASL and then the rest 13 years would be spent for BSL production. At the end of 30 years of ASL production the quarry would be a flat platform (altitude of +2 to 3 m) and the BSL would start opening the first excavation at a depth of (-10m). The first BSL level would then be followed by excavating to levels (-20m) and (-30m) successively. Scenario 2 assumes simultaneous operations both at ASL and BSL levels for the next 43 years after 2001.During simulation runs it is assumed that BSL excavations are to be performed N-S as 10m×10m sections locating the first one at 170 m distance from the coast. This is due to that a buffer zone is defined between the coast and the location of the BSL excavation by the factory.

In order to advance the previous study (Karahanoğlu and Doyuran, 2003) and to see the behavior of changes in water levels in an areal field a two-dimensional areal model is formulated.

The previous model successfully simulated the groundwater flow upon BSL mining into the aquifer along a cross sectional profile. Present research, however, is proposed to further investigate the flow mechanism under the same conditions over the entire quarry.

This is to be accomplished by using an areal model. It is anticipated that areal model would simulate the hydraulic head distributions over the aquifer area upon BSL quarry operations. These results would then be integrated with those obtained from the previous cross sectional model to evaluate groundwater flow over the study area.

3.2 Proposed Areal Model

The study area is subdivided into several elements by using four-nodal finite elements. Construction of the finite element mesh resulted 534 elements with 585 nodal points. In doing this the observation wells and the proposed excavation area are included in the model area. Figure 3.1 shows the finite element mesh that is to be used in the simulation studies.

3.2.1 The Boundary Conditions

There are three different types of boundary conditions applied in the proposed model. The hydraulic heads along the coastline of the aquifer remained constant at all stages of the simulation study. This defined the sea boundary to be of constant head type and the nodes along this boundary are assigned zero hydraulic heads.

Field observations revealed that the hydraulic heads increase towards inland reaching to values of 28 m at the farthest distance from the sea. On the other very low values (almost 0 heads) were recorded along the south and southeast boundary. This required the aquifer to be defined as recharging from the eastern boundary and discharging from the southern boundaries (Figure 3.2).

Observation wells closer to northern parts yield hydraulic heads that are conformable with the general trend of the hydraulic heads and therefore this boundary is defined as a free surface boundary.

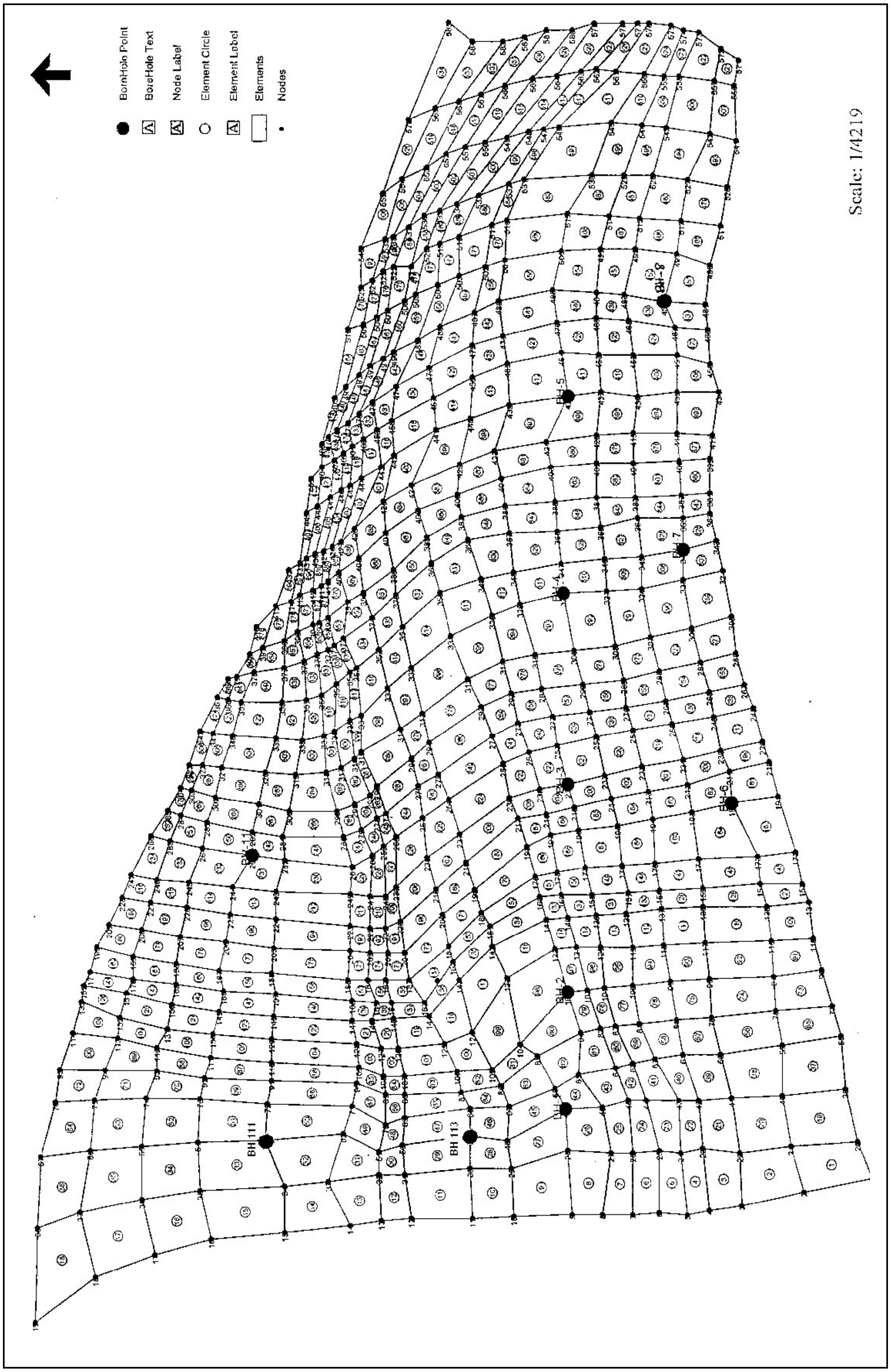

Figure 3.1 Finite element mesh of the study area

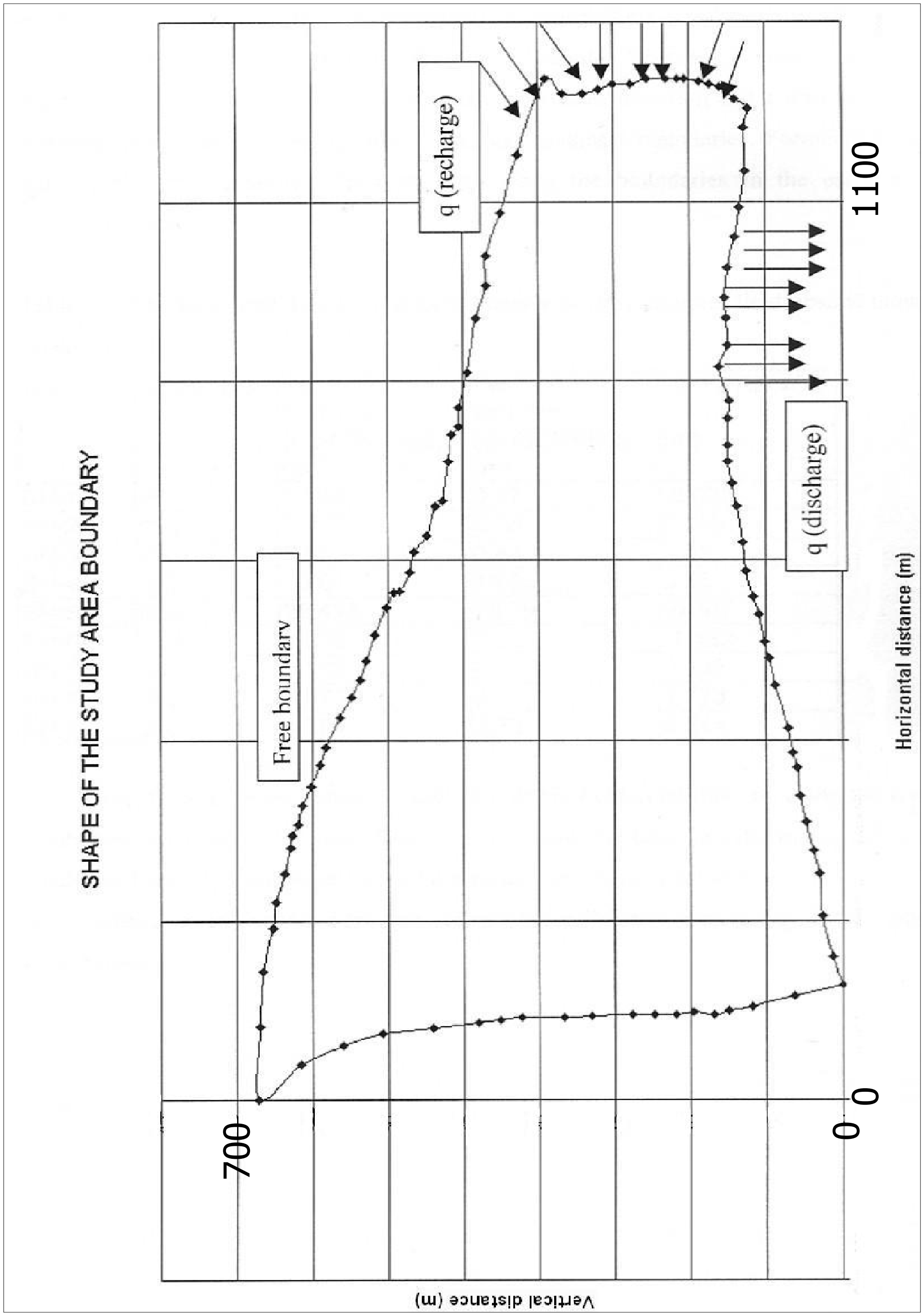

Figure 3.2 Boundary conditions of the study area

3.2.2 Calibration of Areal Model

The areal model is calibrated to the field conditions by using different physical parameters and boundary conditions. During calibration studies steady state conditions are assumed and the computed values are compared against the observed groundwater levels in July 2001 in the cross sectional model (Table 3.1). Several steady state runs were made by trying different physical parameters (Table 3.2) and boundary conditions (recharge/discharge values). Calibration studies continued until a reasonable difference is obtained between the computed and the observed hydraulic heads. Table 3.3 lists the deviations between the observed and the computed heads and the average error associated to the calibration studies. A regression analysis is made between the observed and computed values of the hydraulic heads and a regression constant of 0,9977 is computed which indicates a very successful calibration. (Figure 3.3 and Table 3.4).

Table 3.1 Ground water level measurements (Doyuran et al, 2001)

Well	**Well elevation (m)**	**Groundwater Level a.m.s.l(m)**					
		Oct. 2000	**Jan. 2001**	**Mar. 2001**	**May. 2001**	**July. 2001**	**Sept. 2001**
BH 1	1,95			-	0,27	0,37	0,48
BH 2	1,77			-	0,68	0,58	1,17
BH 3	25,04			2,84	1,34	0,64	1,92
BH 4	60,25			-	-	18,05	22,37
BH 5	63,69			31,39	30,39	28,79	31,22
BH 6	43,60			11,27	4,69	3,04	Dry
BH 7	72,10			-3,15	-2,33	-1,93	11,04
BH 8	47,73			-0,91	-0,27	-0,17	0,46
BH 9	78,20			65,58	65,28	64,69	63,53
BH 10	48,94			9,16	6,29	5,28	24,75
BH 11	36,31			-0,89	4,01	3,76	5,21
111	1,45		0,55	-	0,43	0,39	0,75
2	1,75	0,37	0,43	0,47	0,39	-	-
113	1,69		0,95	0,99	0,73	0,32	0,42

Table 3.2 Physical parameters used in the calibration

Fluid viscosity, μ_f	0.001 m^2/s
Fluid base density, ρ_f	1.000 kg/m^3
Porosity, η	0.002
Permeability, k	Varies within range ($0\text{-}1.3265\times10^{-13}$) m^2

Table 3.3 Results of calibration

Well	Node	Computed Head(M)	Observed Head (M)	Difference (M)
BH – 1	47	0,343	0,37	- 0,027
BH – 113	49	0,251	0,32	- 0,069
BH – 111	53	0,217	0,39	- 0,173
BH – 2	103	0,777	0,58	0,197
BH – 3	234	1,657	0,64	1,017
BH – 4	328	18,343	18,05	0,293
BH – 5	438	28,011	28,79	-0,779
BH – 6	192	1,981	3,04	-1,059
BH – 7	344	-0,201	0,00	-0,201
BH – 8	482	1,139	0,00	1,139
BH – 11	263	4,254	3,76	0,494

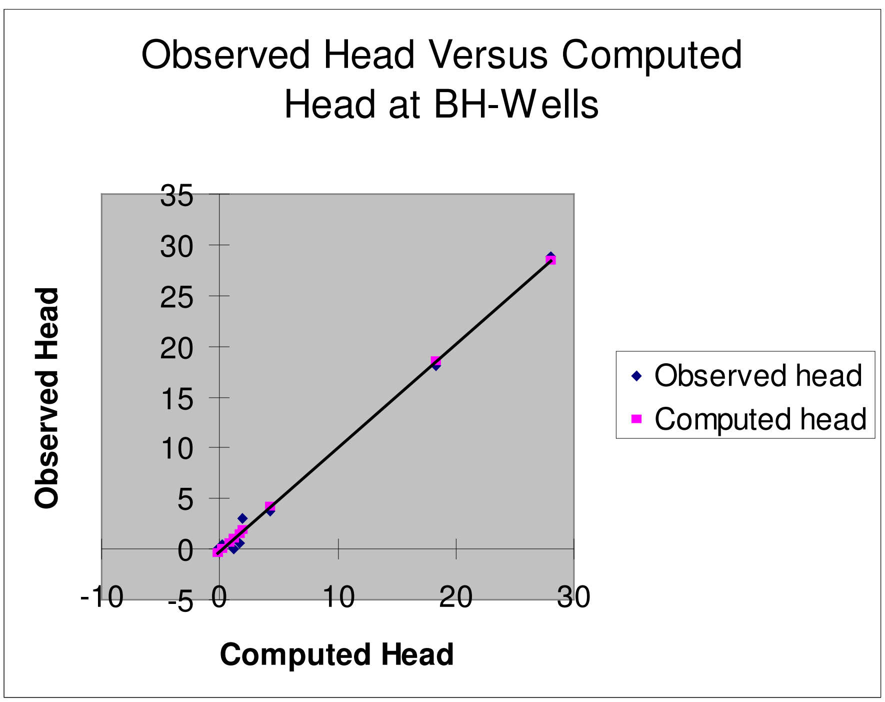

Figure 3.3 Comparison of field data oriented heads and the corresponding computed head values.

Table 3.4 Regression statistics for the correlation between the computed and the observed heads

Regression Statistics	
Multiple R	0,9977
R Square	0,9954
Adjusted R Square	0,9949
Standard Error	0,6580
Observations	11

After the regression analysis a water level contour map of the calibrated model is obtained. (Figure 3.4)

Figure 3.4 Water level contour map of the calibrated model

3.3 Areal Simulation Studies

Areal simulation studies have been planned to investigate areal head distribution in the modelling area. Simulation runs have been performed in a similar way as they had been done for the cross sectional modelling. This required following the same modelling operations of the cross sectional simulations.

After the calibration studies the two scenarios in the cross sectional model (Doyuran et al ,2001) applied to the areal model.The alternative production scenarios were scenario I (30 years of ASL and 13 years of BSL) and scenario II (both ASL and BSL for the next 43 years).

Scenario I of the cross sectional model was designed to excavate below sea level after completion of the above sea level quarry operations. Therefore the simulator is required to run for 30 years (expected time duration for ASL production) to complete ASL and then it is run for the next 13 years for simulating BSL operations (Doyuran et al, 2001)

The first scenario has been accomplished by utilizing the calibrated model and the water level contours are obtained in the entire study area.

In the scenario II, however, it is planned to simulate simultaneous progress of the ASL and BSL operations the results were the same with the first scenario, because the water level has reached the steady-state condition and don't change with time.

Thus in the areal model only the results of the first scenario is given.

3.3.1 Results of Areal Simulation Studies

Similar to Scenario I in the cross sectional model the proposed areal model had been run for 30 years, starting from 2001, to simulate areal head distributions before BSL quarry is started. In this period the whole quarry area is expected to be flattened and transformed into a platform having elevations of about 2-3 m above sea level. This period have been simulated by running the calibrated areal model and water head distributions have been determined for every 5-year simulation intervals. For this reason the simulation area was subdivided into six approximately equal areas and the runs were made accordingly. Figure 3.5 shows ASL production sub-sections used in the model runs. It was assumed that water was lost from the aquifer due to evaporation during ASL quarry operations. Following this assumption the simulator was given nodal discharges and the nodal heads were computed for each period.

By utilizing the calibrated numerical areal model the simulator was run for each section and the water heads of the areal model has been compared with the cross sectional model.

The recharge, discharge and evaporation values have been readjusted and the runs have been repeated to minimize squared deviations between the areal and cross sectional model results. Figure 3.6, Figure 3.7, Figure 3.8, Figure 3.9, and Figure3.10 show results of the cross sectional model versus areal model in the studied periods.

The results show a good agreement between the cross sectional and the areal model simulations (Table 3.5). Successful match between the cross sectional and the areal model results are indicated by very large values of the goodness of fit (R^2) and related very low significance. Although the last period results show a different value than the others it is within statistically acceptable range of 5 % significance level.

Table 3.5 Comparison of areal and cross sectional model results for 2001-2031 period.

Period	**R^2**	**Significance F**
*2001-2006	0,990	0,00041
2006-2011	0,935	0,00161
♦2011-2021	0,941	0,00131
2021-2026	0,917	0,00263
2026-2031	0,656	0,05060

*The borehole 19 is not included in the calculations because of the absence of the data

♦ Because of the absence of the data the period is taken as 10 year.

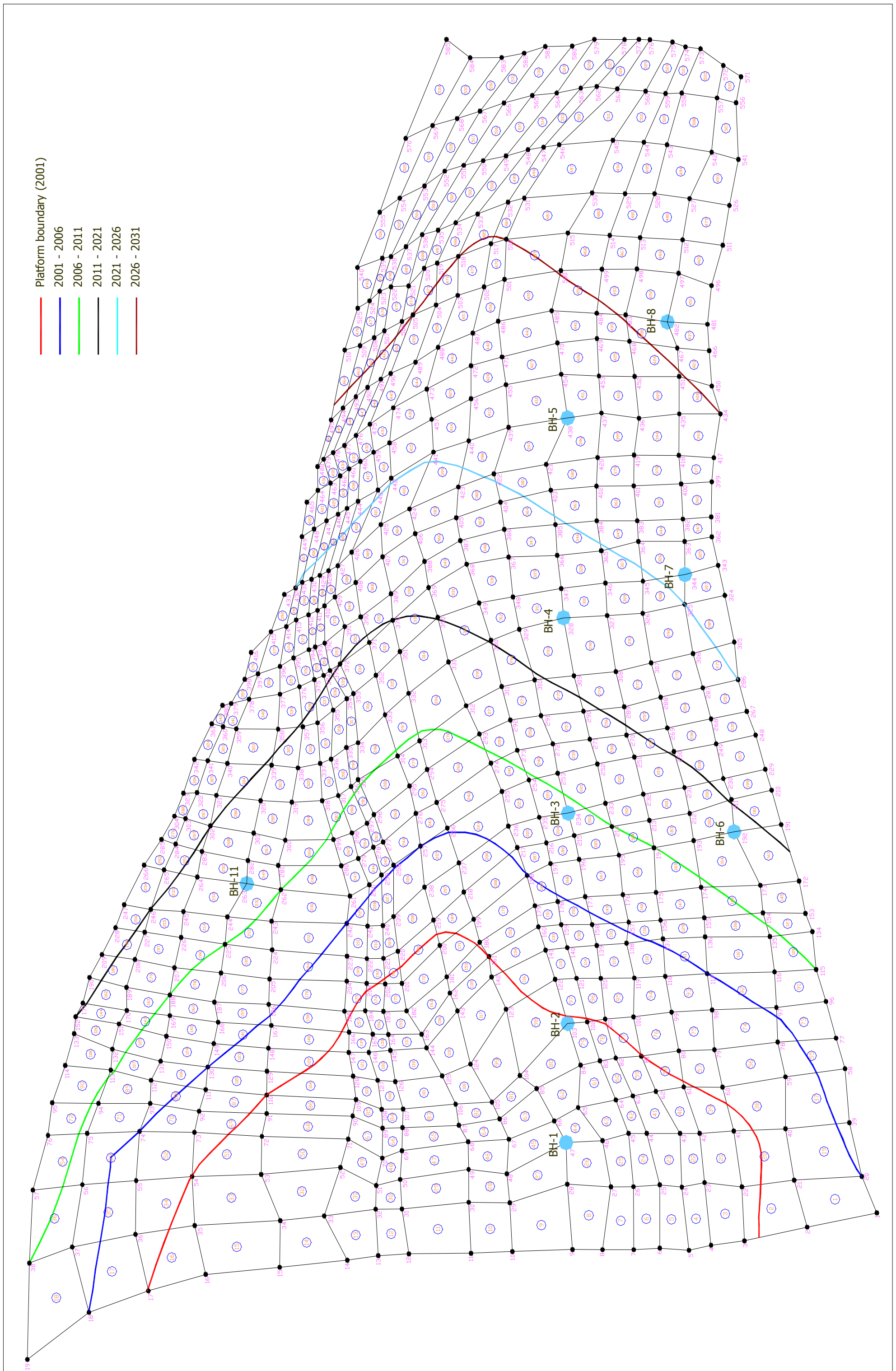

Figure 3.5 ASL production sections for 2001 – 2031 periods

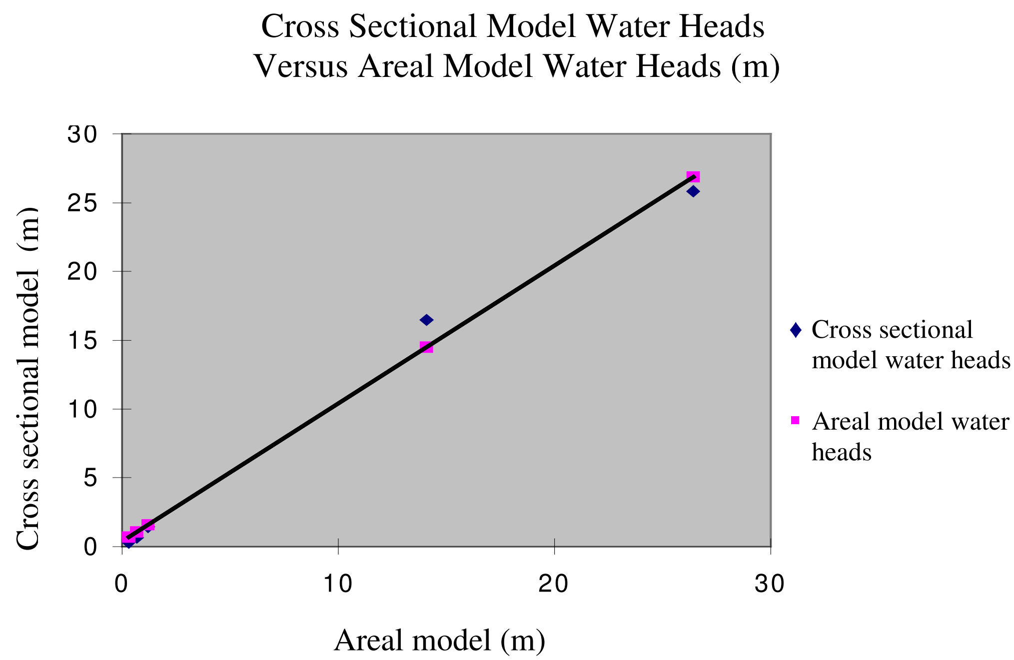

Figure 3.6 2006 Comparison of areal and cross sectional model results for 2001-period

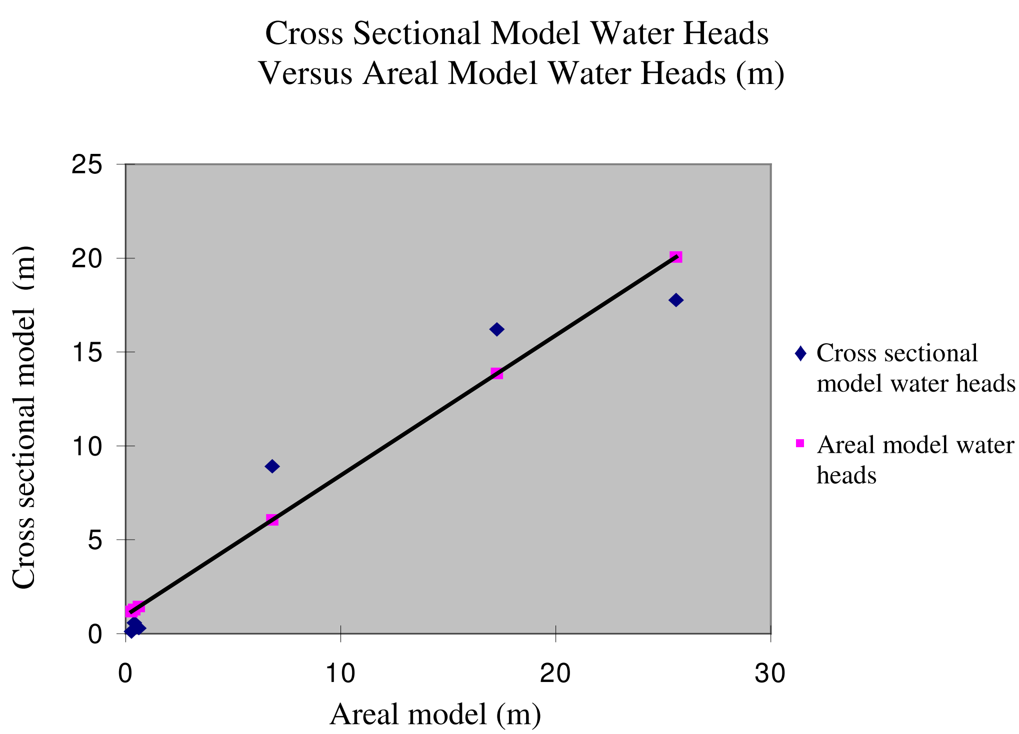

Figure 3.7 2011 Comparison of areal and cross sectional model results for 2006-period

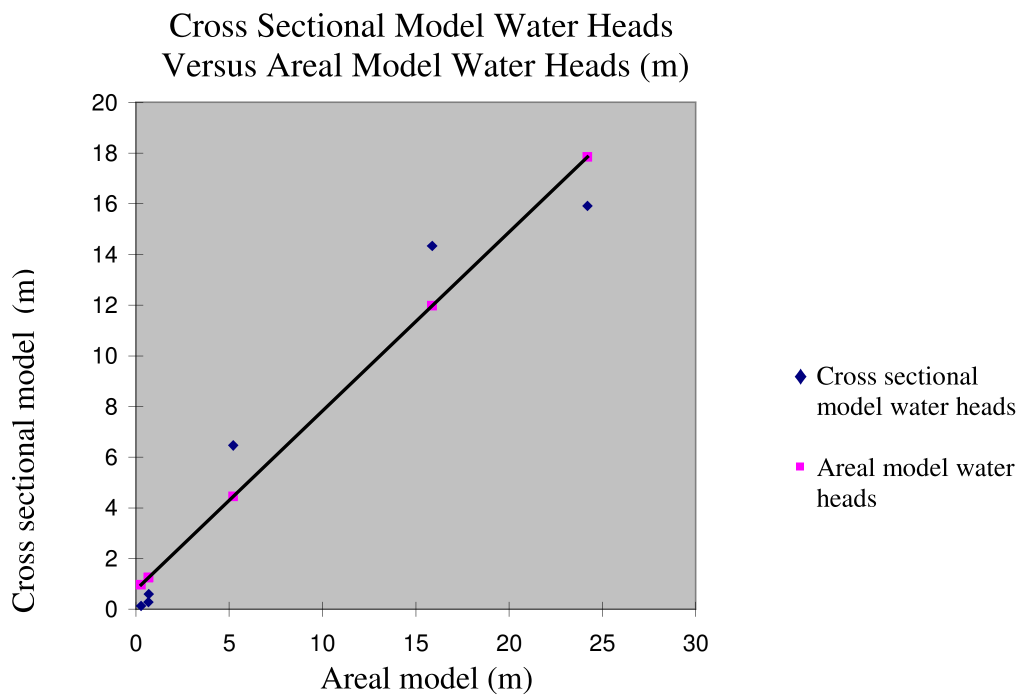

Figure 3.8 Comparison of areal and cross sectional model results for 2011-2021 period

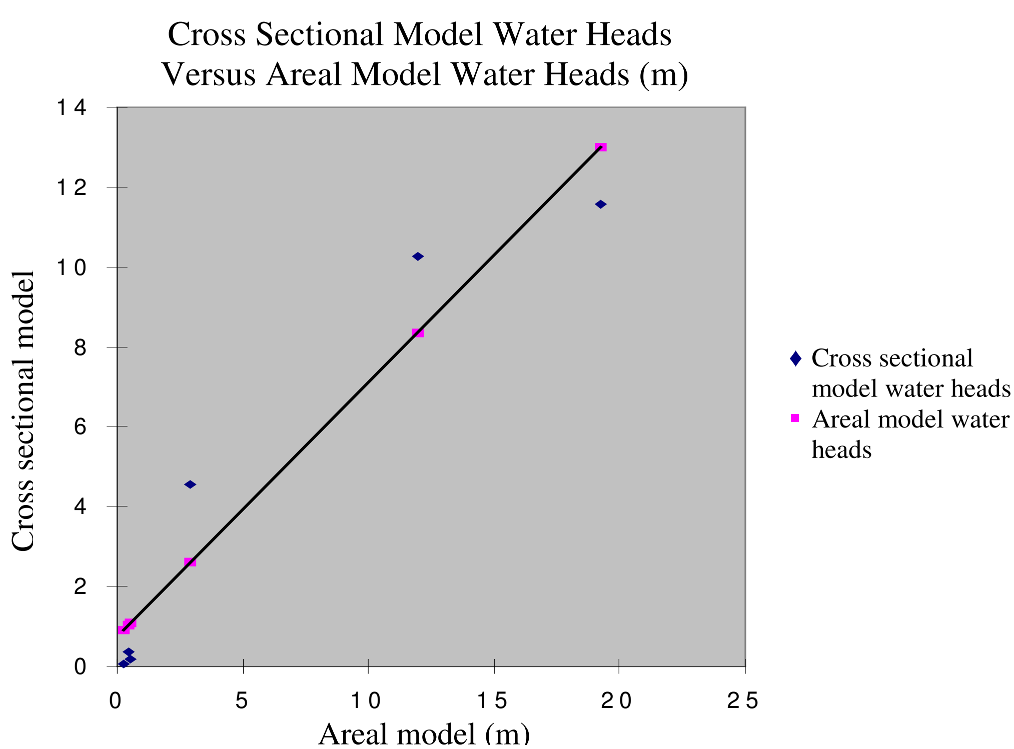

Figure 3.9 Comparison of areal and cross sectional model results for 2021-2026 period

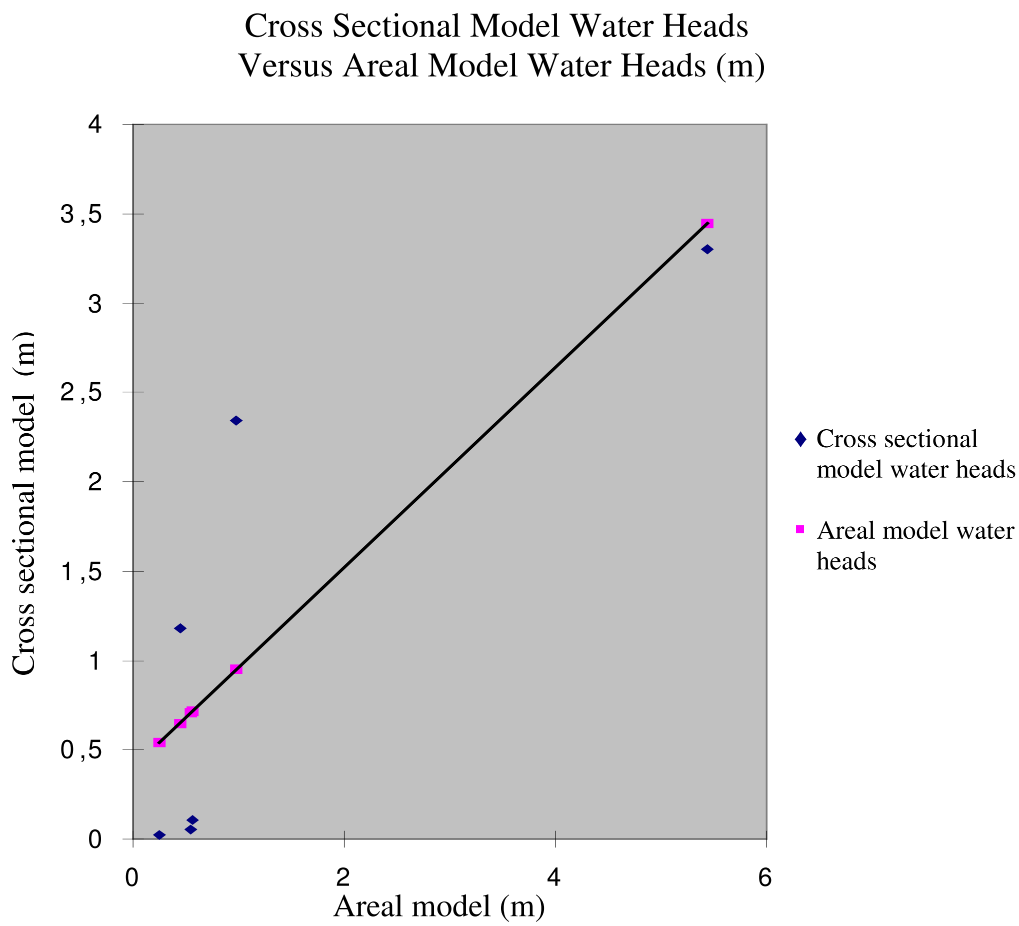

Figure 3.10 Comparison of areal and cross sectional model results for 2026-2031 period

At the end of the year 2031 unlike the cross sectional model the water heads of the whole study area is obtained. The contour maps of the model are presented in Figure 3.11, Figure 3.12, Figure 3.13, Figure 3.14,and Figure 3.15. In these figures we can clearly see the decline of the water levels.

After completion of the 30 year ASL production 13 years of BSL excavation is started. During the simulation it is assumed that the BSL excavations would start at 170m distance from the coast and with a 30-m bench width. According to scenario I BSL would start opening the first excavation at a depth of (-10m). Then in the same way levels of (-20m) and (-30m) would follow the first BSL platform. Figure 3.16 and Figure 3.17 show the boundary of –10m, -20m, -30m excavation platforms.

The model is simulated and the water level is decreased to –10 m. Aim of this process was to obtain –10m water level inside the boundary of –10m and it is achieved by readjusting the water levels in the simulation runs. Figure 3.18 shows the simulated water level contours for –10m-BSL excavation.

After the whole platform is excavated down to –10m level the second BSL excavation level (-20 m level) is started. Same procedure is performed and the water levels are decreased to –20m only inside the boundary of –20m and the simulation results are shown in Figure 3.19.

The third BSL excavation level is opened within – 20m level platform and the simulated water level contours are shown in the Figure 3.20.

During BSL production steps the model is used to compute discharge amounts. Table 3.6 shows the total amount of water to be discharged from the whole study area.

Table 3.6 Pumping rates for BSL levels

	Amount of discharge of water	
BSL levels	Kg/ sn	Ton/ day
-10m	-.338	29.20
-20m	-.538	46.48
-30m	-.718	62.03

Figure 3.11 Contour map of water levels for ASL production between the year 2001-2006

Figure 3.12 Contour map of water levels for ASL production between the year 2006-2011

Figure 3.13 Contour map of water levels for ASL production between the year 2011-2021

Figure 3.14 Contour map of water levels for ASL production between the year 2021-2026

Figure 3.15 Contour map of water levels for ASL production between the year 2026-2031

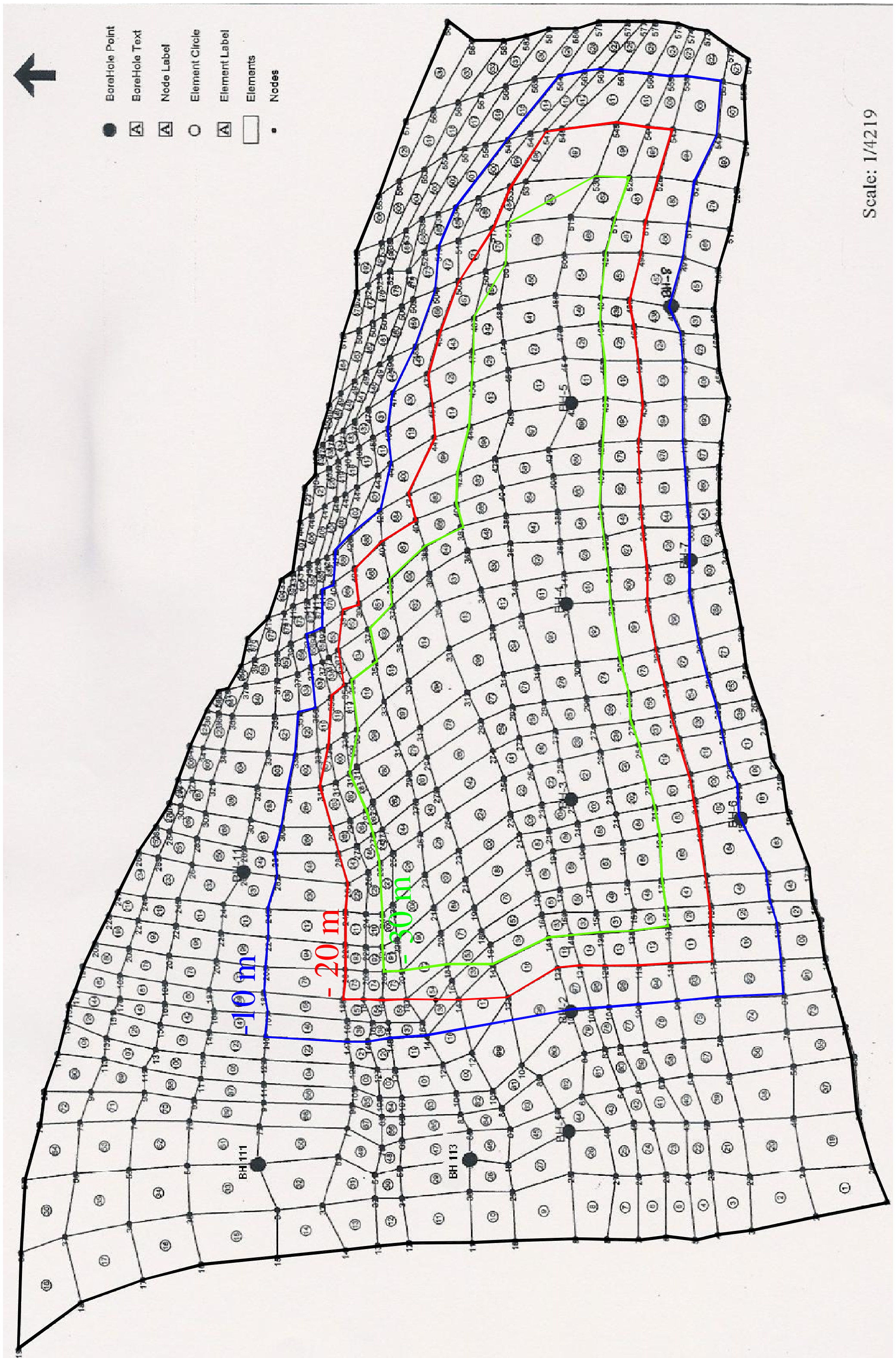

Figure 3.16 Boundary of BSL excavation for –10m, -20m, -30m

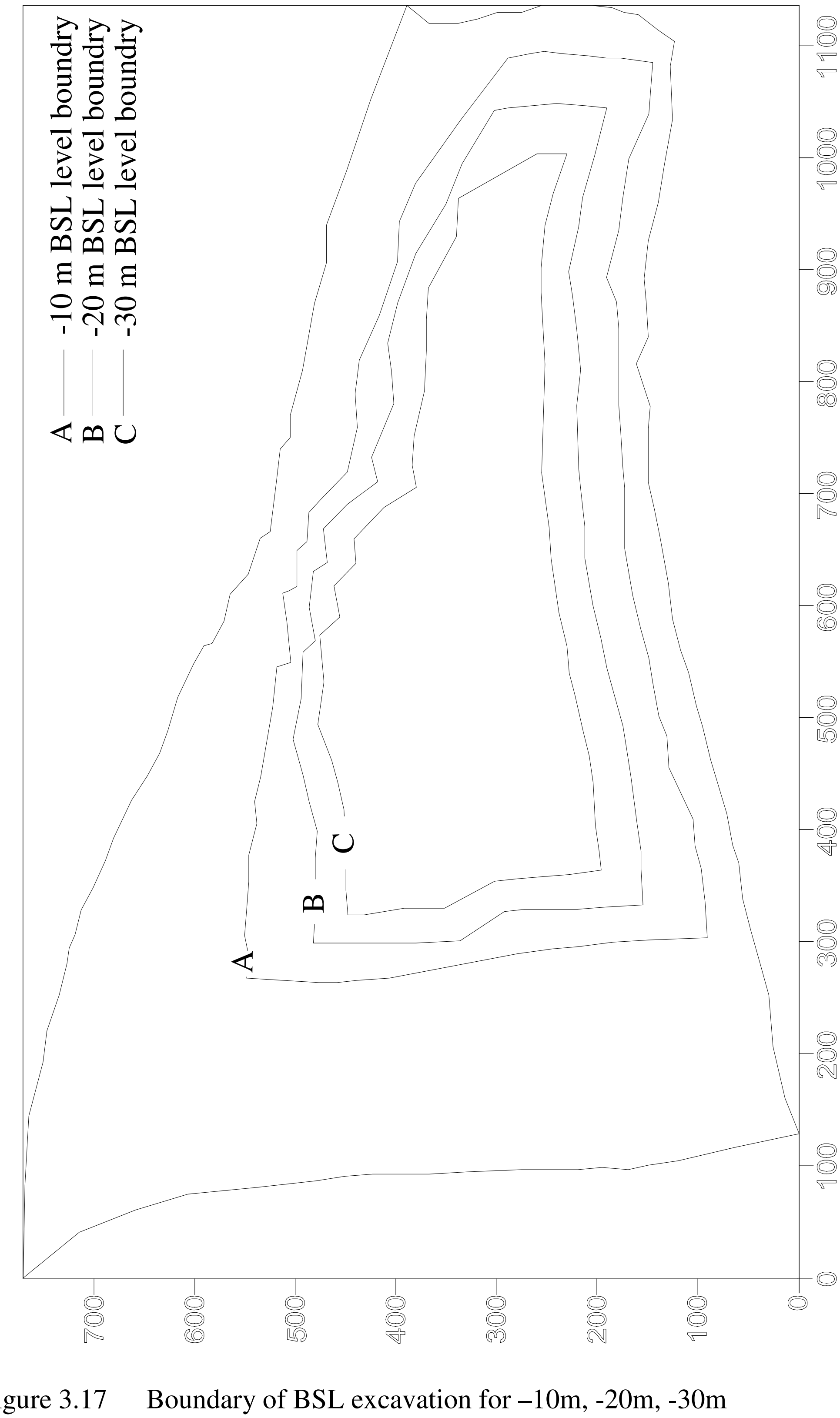

Figure 3.17 Boundary of BSL excavation for –10m, -20m, -30m

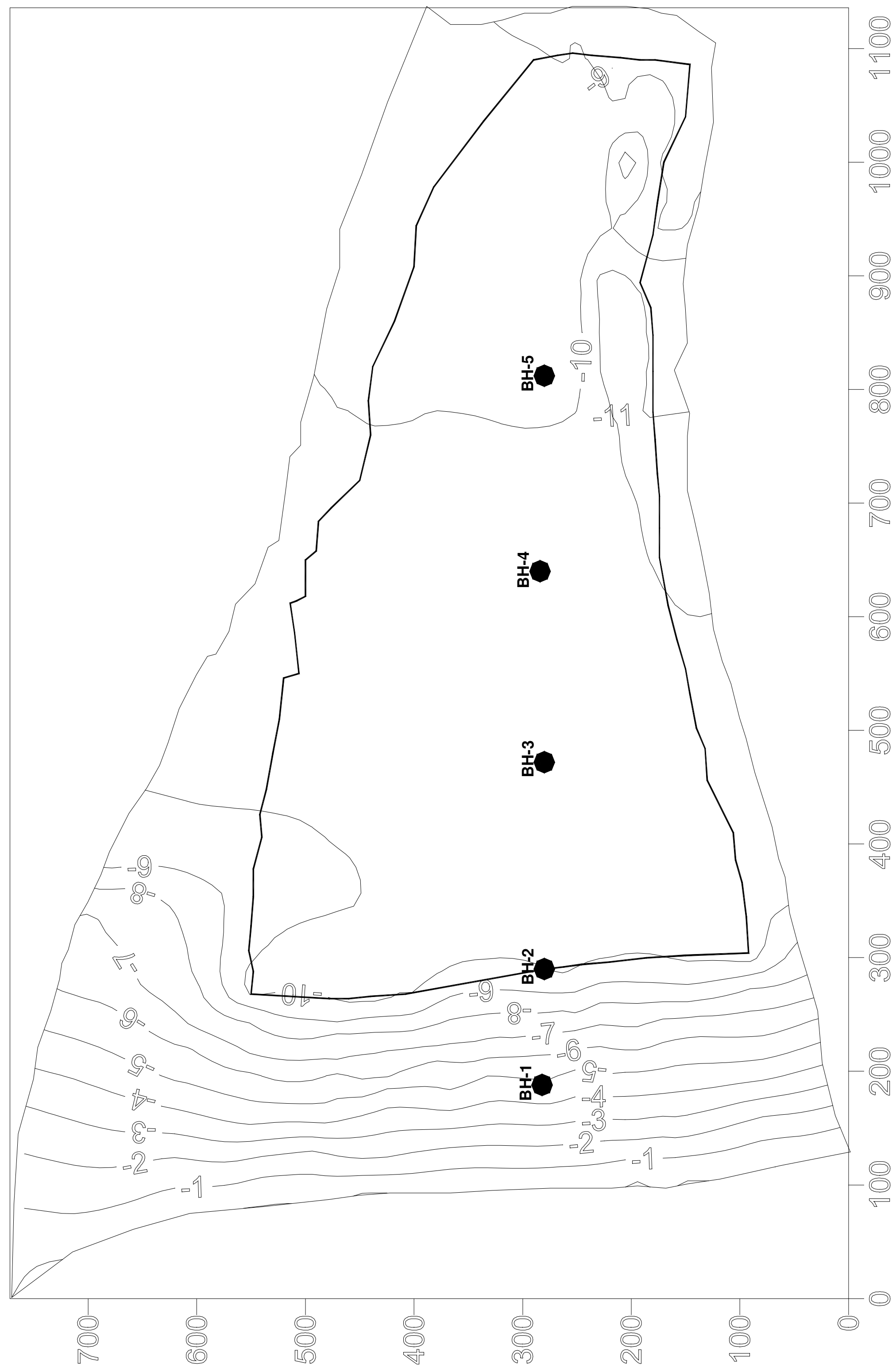

Figure 3.18 Water level contour map of BSL production for –10m

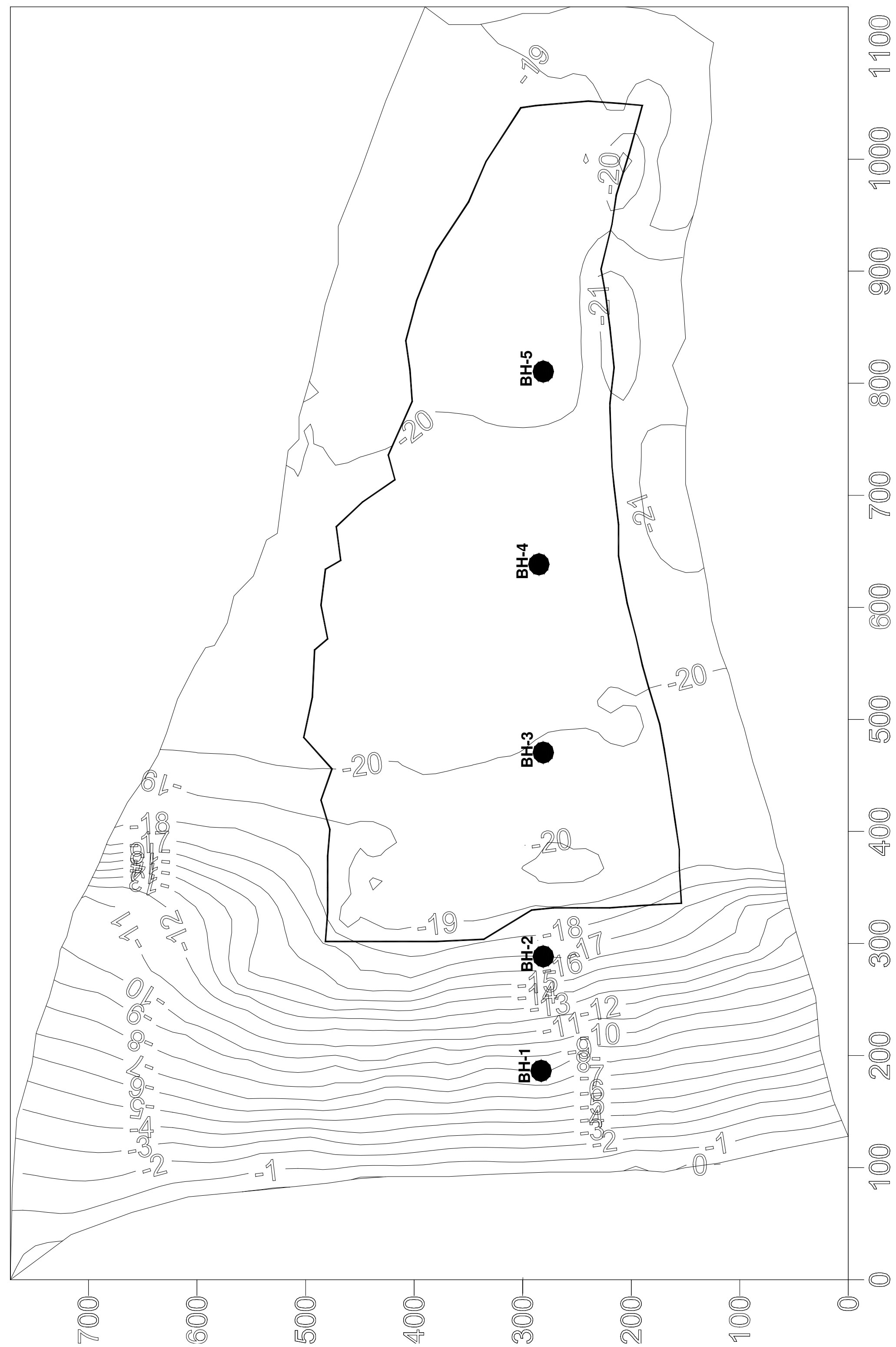

Figure 3.19 Water level contour map of BSL production for –20m

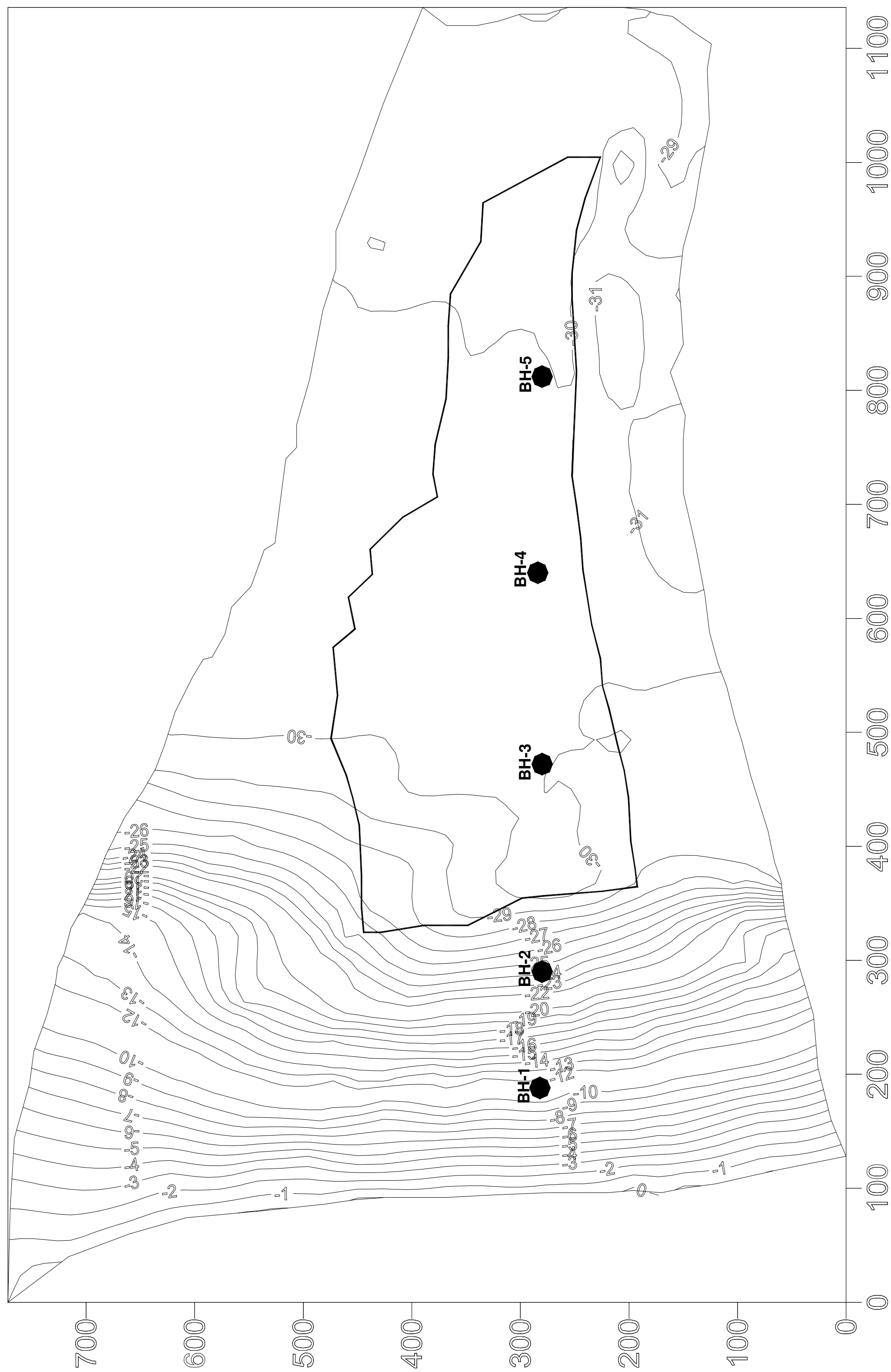

Figure 3.20 Water level contour map of BSL production for –30m

CHAPTER 4

RESULTS, DISCUSSIONS,CONCLUSIONS AND RECOMMENDATION

4.1 Results

A groundwater flow model has been developed to study water levels upon BSL excavation in the quarry site of the Lafarge Kocaeli-Darıca Cement Factory.

The studied model has been successfully calibrated by using groundwater level measurements of 2001. The measurements of 2001 are used because it is assumed that there is not any significant change expected in the hydrodynamic conditions in the area. These measurements were also used in the cross sectional model, which forms a basis for the areal simulation studies.

A correlation analysis is made between the computed and observed head values and very high correlation coefficients were obtained (0,9977) which emphasizes a successful calibration.

So the model is considered as reliable to simulate future prediction scenarios to see the effects of below sea level (BSL) and above sea level (ASL) productions.

The calibrated model has been applied to investigate the effects of ASL and BSL productions in the quarry. Two alternative scenarios have been aimed to be performed as scenario I (30 years of ASL and 13 years of BSL) and scenario II (simultaneous ASL and BSL for the next 43 years). Simulation runs yield similar results for the two scenarios, and therefore, the first scenario has been chosen for the future runs. The applied scenario requires 43 years of total production where ASL production to be completed within the next 30 years to start BSL excavations.

According to ASL mining the study area is divided into 6 equal parts (according to area) each part representing a 5-year production. And in each production period the water level of areal model is simulated with respect to cross sectional model water levels in the determined boreholes. The water level contours of each section are prepared and the whole study area is defined with water levels.

After the ASL production BSL excavations started. The first excavation is to be opened at 170-m inland just like in the cross sectional model and to be enlarged to complete -10m BSL level.

After –10m, -20m and –30 m levels are accomplished. For each level water level contour maps are prepared.

In the water level contour maps of BSL levels it is clear that the contours are not parallel to each other. In the water level contour map for –10m the behaviour of the water level contours is clear. It can be seen that the water loss is greater in north of the map than the south of the map in the first –10m level contour, but in the second –10m contour it became reverse. The difference is mainly due to the hydraulic conductivity values taken in the calibration runs to balance the water levels in the observed boreholes.

The same opposition can be seen in the water level contour map of –20m and –30m water level contour maps. Generally for the water level contour maps for BSL levels it starts with greater water level in the southwest but ends with smaller in the southeast of the map.

The amounts of discharge of water during BSL excavations are computed. Discharge amounts for the levels –10m, -20m, -30m is given in Table 3.5. The results show a good agreement with the results of discharge amounts of cross sectional model. In both models the amounts are so low that water discharge from BSL levels would not create important problem.

Finally areal groundwater flow model is prepared which is useful to observe the behavior of the water levels in the entire quarry.

4.2 Discussions

The proposed model is planned to simulate the effects of ASL and BSL quarry operations on the groundwater flow in the whole study area. During calibration runs the model results are correlated by using the results of the previous cross sectional model located along E-W profile. Although it was not possible to compare the computed heads over the whole aquifer area, the computed heads are found to be conformable with the cross sectional model results.

The proposed model has been successfully used in predicting the water levels during BSL quarry operations. The impact of – 10 m, -20 m and – 30 m BSL excavations have been obtained over the aquifer area. A slight difference has been noticed in some parts (especially in the coastal regions), between the results of the areal and the cross sectional models. This is explained by the difference in considering the physical parameters in the cross sectional and the areal models. The physical parameters in the areal model are assumed to be constant with respect to depth, whereas they are treated as variables in the cross sectional model. Another reason for this difference is that the effect of saltwater intrusion is not taken into consideration in the areal model.

4.3 Conclusions and Recommendation

The following conclusions are drawn as a result of this research:

1) Groundwater flow of the entire study area is obtained by combining the results of the previous cross sectional with the proposed areal model. Hence the areal distribution of the water levels are determined for different quarry operations.

2) A calibration is made and as a result of the calibration a good match between the observed and computed water levels were found. Successfully calibrated model is used to simulate future prediction scenarios to observe the effects of production scenarios for below sea level and above sea level mining in the quarry.

3) The production scenario, which requires ASL production and then BSL production, is performed. Water level contour maps for ASL production sections are obtained. At the end of BSL production water level contour maps for –10m, -20m, -30 m BSL levels are formed for the total study area.

4) The amounts of discharge of water during BSL excavations are computed for different BSL levels. The results show a good agreement with the results of the cross sectional model. In both models the amounts are so low that water discharge from BSL levels would not create important problem.

It is recommended that, another cross sectional profile in the northern part of the area can be performed in order to supply more information about areal interpretation of the study.

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