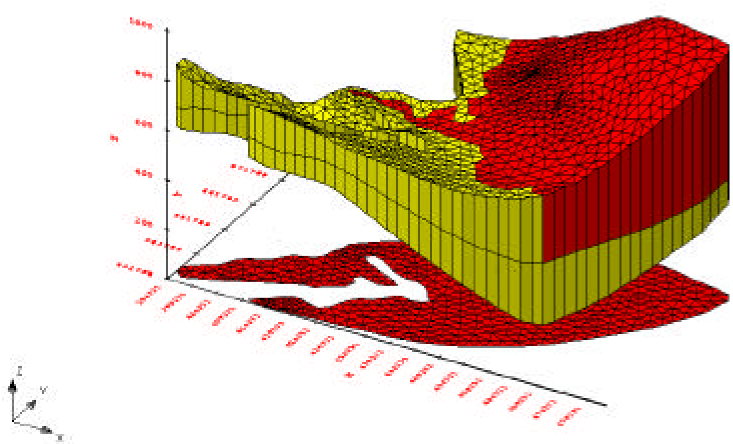
MINISTRY OF WATER AND IRRIGATION

Water Resource Policy Support

GROUNDWATER MANAGEMENT COMPONENT

HYDROGEOLOGICAL IMPACTS OF OVERPUMPING AND ASSESSMENT OF GROUNDWATER MANAGEMENT OPTIONS IN THE AMMAN-ZARQA HIGHLANDS



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EXECUTIVE SUMMARY

The Basalt and B2/A7 aquifers system is considered as the main groundwater resource in Amman-Zarqa basin (AZB) highlands. The total estimated annual recharge of this aquifer system is around 70MCM with 32 MCM as direct rainfall recharge within the basin and the rest as indirect recharge, mainly from the Arab Mountain area in Syria. Abstraction started in the early sixties in the Hallabat-Dulayl area with around 8.5 MCM in 1964. In the early eighties pumping expanded to the east, north and northeast. It exceeded safe yield by 55% in 1989, and increased to over 70% in 1998, according to Ministry of Water and Irrigation (MWI) database information. By 2001-2002, over-abstraction in the AZB highlands will reach nearly 100% with the development of the new Corridor wellfield located North of Hallabat, which is planned to supply an additional 10 MCM for Municipal and Industrial (M&I).

The main objective of the groundwater management component activity is the exploration of options for curtailing groundwater use in irrigated agriculture in Amman Zarqa Basin uplands. Following the Rapid Appraisal Survey of water and users in AZB highlands, and discussions with the Ministry of Water and Irrigation and other stakeholders, the following five reduction options are identified:

- Irrigation Advisory Service (5 MCM/year estimated reduction)
- Wells buy out (15-20 MCM/year)
- Enforcement of abstraction limit (10-15 MCM/year)
- Exchange of groundwater with treated wastewater (15 MCM/year: 10 MCM for irrigation and 5 MCM for industrial use)
- M&I reduction: 30 MCM, with10 MCM as regained Unaccounted for Water (UFW) resulting from reduction of physical losses due to rehabilitation of water conveyances and M&I water use saving by reducing water wastage by big industries, hotels, and households; and 20 MCM replaced by new water supplies from Disi, Wehda, Zara-Main, and AZB brackish water sources

A three-dimensional finite difference flow model was developed, using the Groundwater Modeling System (GMS), to predict the effects of over pumping and analyze the impacts of the above groundwater management options on the behavior of the B2-A7/Basalt aquifer system.

This report presents the development and results of the AZB highlands groundwater model for six water use scenarios. The first two scenarios are designed to predict the impacts of over-pumping by assuming no management action for the next 20 years. The other four scenarios represent alternatives for combining the above five groundwater use curtailment options.

The first no management scenario assumes a continuation of over-abstraction without being controlled. The model shows that this scenario is expected to

lead to a drying up of 70% of the wells (74 wells) in the Hashimiya-Dulayl-Hallabat area within the next 15 years, and a water table drop by an additional 10 to 30 meters in many parts of the aquifer, including the corridor wellfield with 16 meters drawdown.

The second no management scenario assumes a continuation of over-abstraction without being controlled at the Jordanian side, in addition to a decrease of 50% of indirect recharge from Mountain Arab area, as a result of a possible increase of abstraction in the Syrian side of the basin by 23.5 MCM. The model indicates that this scenario would result, within the next 15 years, in a drying up of 70% of the wells (74 wells) in the Hashimiya-Dulayl-Hallabat area and all the wells in Wellfield 13 located in the northwest of the corridor wells. In addition to a significant water table drop in Khaldiya, North Badia, and the corridor area.

The identified groundwater use reduction options were also grouped in four (4) scenarios, starting with a minimum reduction for scenario 1 and progressing to a maximum reduction for scenario 4. Scenarios 1 and 2 include three irrigation water use reduction options namely Irrigation Advisory Service (IAS), wells buy out, and enforcing abstraction limits. They correspond to a reduction of 30 MCM and 40 MCM for scenarios 1 and 2, respectively. Scenario 3 leads to a 55 MCM reduction, which encompasses the options of scenario 2 in addition to the 15 MCM of reuse option. Scenario 4 has a total reduction of 85 MCM including all options in scenario 3 in addition to 30 MCM M&I reduction. Scenario 4 would result in a sustainable abstraction from the highland aquifers equivalent to of 70 MCM/year.

The model shows that scenario 1 is expected to lead in the next 20 years to a moderate groundwater level recovery of around 2 meters in Hashimiya (Wellfield 3), and it would attenuate the rate of drawdown in the other basin areas, thus avoiding drying up of wells. Scenario 2 would further improve the groundwater situation, and slow down the water table decline in many parts of the basin, especially in the agricultural wellfield areas. For scenario 3 the model demonstrates that a groundwater mound is expected to form under the Hashimiya-Dulayl area as a direct result of significant groundwater use reduction due to the exchange of groundwater with treated wastewater; however, the water table in the remaining parts of the basin would almost the same behavior as that portrayed by scenario 2. Scenario 4 would improve significantly the water table in most parts of AZB highlands. The impact of scenario 4 is especially reflected in the moderate water level rise in the Sabha area (Wellfield 11), in the M&I wellfields at the outskirts of Amman (Wellfield 1) and south of Addafyaneh (wellfield 16), in addition to the formation of a groundwater mound under Hashimiya-Dulayl and the attenuation of water level decline in the north Badia (Wellfields 8, 9, 10, and 12), and Khaldiya (Wellfield 7).

The impacts of over-pumping on the groundwater salinity were also analyzed by applying the solute transport model of the Groundwater Modeling Software interface to the first no management scenario, described above. The model indicates that by 2015 the water salinity is expected to be between 1000 and 1500 ppm in North Badia; 1500 to 2500 ppm at the corridor wells; 3,000 to 3500 ppm in Hallabat and Hashmiya areas (Wellfields 3 and 5); and reaches 5000 ppm in Zarqa and Dulayl areas (Wellfields 2 and 4).

ACKNOWLEDGEMENTS

The model development and calibration is done by the MWI/ARD team, which is composed of Yahia Majali, Tareq Al Zabet, Jihad Al Abadi, and Nidal Khalifah. The description of the groundwater management scenarios and the interpretation of the modeling results is done by Mohamed Chebaane.

The effort and contribution of MWI and WAJ Counterparts are acknowledged and highly appreciated: Edward Qunqar, Director of Water Resources Planning, Mohammad Almomani, and Ali Subah.

1. INTRODUCTION

The Amman-Zarqa basin (AZB) is the most developed watershed in Jordan. It is the fastest growing region both industrially and in terms of population. New industries and irrigation projects are being implemented in the area. The Basalt and B2/A7 formations are considered the main hydrogeological formations in Amman-Zarqa basin. Both formations are in hydraulic connection and comprise one aquifer system. Groundwater flows from the north from Arab Mountain to the northwest towards the Yarmouk basin, to the southwest towards Zarqa river, and to the East towards the Azraq aquifer. Recharge occurs directly (rainfall) and indirectly (lateral flow). Total estimated annual recharge is around 70MCM with 32 MCM as direct rainfall recharge within the basin and the rest as indirect recharge, mainly from Arab Mountain area. Abstraction started in the early sixties in the Hallabat-Dulayl area with around 8.5 MCM in 1964. In the early eighties abstraction expanded to the east, north and northeast. It exceed safe yield by 55% in 1989, and increased to over 70% (150 MCM) in 1998, according to Ministry of Water and Irrigation (MWI) database information. By 2002, over-abstraction in the AZB highlands will reach nearly 100% with the development of the new Corridor wellfield located North of Hallabat, which is planned to supply an additional 10 MCM for Municipal and Industrial (Draft Groundwater Management Action Plan, June 2001).

1.1 Objectives

The main objective is to carry out a hydrogeological modeling of the B2-A7/Basalt aquifer system to predict the impacts of over-pumping on this main AZB highlands groundwater system. The results of the hydrogeological modeling will be used for the socio-economic analysis of these impacts.

The secondary aim of this modeling exercise is to analyze the response of the B2-A7/Basalt aquifer to the groundwater management options and scenarios presented in the Study of Water Use and Users in the Northeastern Amman-Zarqa Basin (MWI/ARD, January 2001).

1.2 Methodology

A two-Dimensional Arial view groundwater flow model was designed to simulate the field situation. The historical changes in the groundwater starting from equilibrium stage prior to 1965 were carefully incorporated into the model to represent as much as possible the current situation.

Future behavior of the aquifers was analyzed in detail based on different groundwater management scenarios, as detailed in section 5.

1.3 Location

The study area extends north to the Syrian boarders, the Azraq basin to the east, Yarmouk basin to the northwest, and Amman area to the southwest. The total area being modelled is 2140 km^2 (Fig. 1.1).

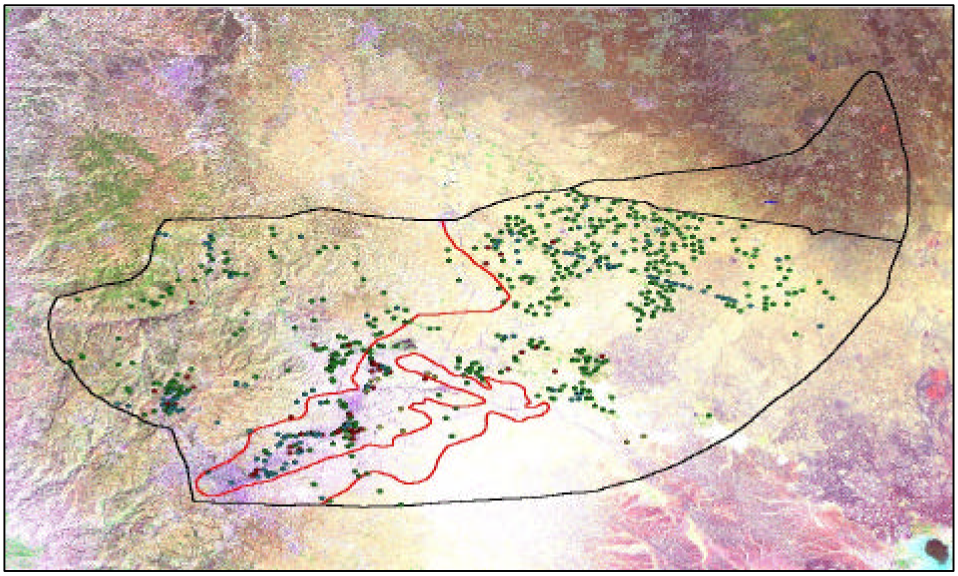


Figure 1.1: Location map of the study area

1.4 Topography

A sloping terrain, from 950m near the Arab Mountain to 620m near the Sukhna area and 735m southwest of Amman, characterizes the study area. The topography reflects the geology consisting mainly of a basaltic mount that slopes down to a central, gently rolling plateau bounded from north and south by rugged and dissected limestone hills (Fig. 1.2).

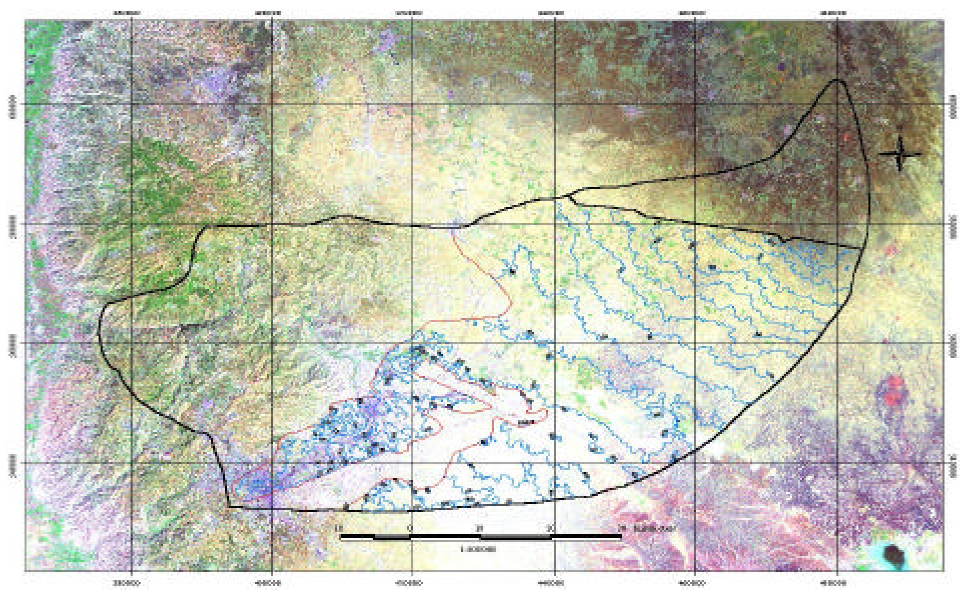


Figure 1.2: Topographic map of the study area

1.5 Climate

Jordan lies in the eastern side of the Mediterranean. The climate is semi-arid and characterized by cold humid winter with lower temperatures including moderate frosts during the nights and warm dry summer. According to the 50-years mean annual rainfall map, rainfall ranges between 100-500mm. The mean monthly surplus volumes are in December, January, February and March. Average evaporation constitutes approximately 90% of the total rainfall (WAJ, 1989). Average estimated infiltration rate is approximately 4-10% (WAJ, 1989; Mahamid, 1994).

2. GEOLOGY

2.1 Succession

The rock outcropping in the study area ranges in age from Creteaceous (Ajlun) to recent (Macdonald & Partners, 1964). The succession from top to bottom is given below:

Group	Formation	Description
Recent	Recent Alluvium	River gravels and superficials gravels, silts
Basalt	Basalt	Scoriacous basalt, volcanic plugs
Balqa	B2 -Amman	Limestone, marl, massive chert.
Ajlun	A7- Wadi Sir	Crystalline and chalky limestone

The outcropping of the basalt and B2/A7 formations is illustrated in the geological map Figure 2.1.

2.1.1 Wadi Sir Formation A7 (Turonian)

It is the upper most unit of the Ajlun group. It outcrops extensively both in the north, central and south parts of the area. The massive crystalline limestone is karstic and weathered in the top 20m of the formation. Below them there is a general increase in the marl chalky limestone and thin marl beds occur, indicating a transition into the underlying Shueib formation. The formation ranges in thickness between 50-250m dipping to the east and northeast.

2.1.2 Amman Formation B2 (Santonian_Campanian)

It is a cyclic deposit of chalk, phosphate, silicified phosphate, limestone and Chert. Its thickness ranges reaches 47m in the study area.

2.1.3 The Plateau Basalt (Oligocene-Pleistocene)

Basalt outcrops in the northeastern part of the basin. Six major flows have been identified in the study area. Thin layers of clay and gravel consisting of limestone and Chert pebbles have been encountered between the successive flows.

The basalt thickness in the northeastern part is 400m and wedges to the west towards the periphery of the flows.

2.1.4 Younger Alluvium Formation

The younger alluvial consists of thin deposits overlying the basalt in the cemented out-wash and the old river terraces.

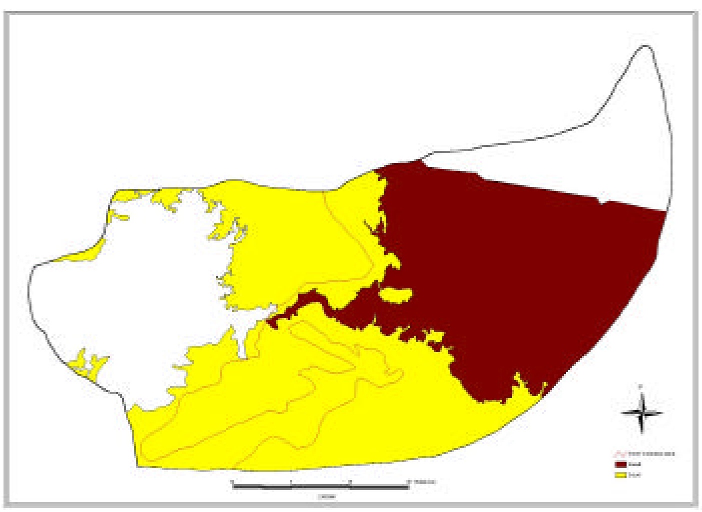


Figure 2.1: Outcropping formations in the study area

2.2 Structure

Generally low dips and gentle folding except for the abrupt flexures and associated faults characterize the study area. Such features mark the limits of the important synclines of Wadi Sayih and Muasher in the south and south-central parts. North of the Muasher syncline there appears to be another turndown of fault.

The limestone north of the basalt formation is affected also by a flexure downloading the strata to the south. In the central part of the area the structures are covered by the basalt flow where the basalt filled a major synclinal structure having a pitch to southeast (Macdonald & Partners, 1965).

3. HYDROGEOLOGY

3.1 Aquifers Classification

Based on the geologic and structural features described in the pervious section, three main aquifers were identified:

3.1.1 The B2/A7 limestone aquifer

Most of this limestone formation is wholly within the limit of saturation. In areas where the formation is below the water level and fissures and joints exist, it was recorded as a potential aquifer. Also the degree of fracturing and secondary porosity controls the yield and availability of water.

3.1.2 The Basalt and the Older Alluvial aquifer

Both are considered one of the main aquifer systems in the study area and extends to the north and northeast. The alluvial deposits lie below the basalt, in the drainage channels and depressions of the former land surface and within the basalt sequence. They are considered as the major conduits carrying recharge water from the high rainfall areas into the Dhuliel and other groundwater provinces.

Apart from the interflow alluvial within the basalt, scoriaceous and jointed basalt in the east and central part is considered a very good aquifer.

Both formations are considered in hydraulic connection. Thus, they are considered as one unconfined aquifer system.

3.2 Hydraulic Parameters

3.2.1 Transmissivity

Structures are considered the main control factor for the location of high yield aquifers (100m^3/hr). Wells that were drilled by Macdonald & partners (1964) showed that the main synclinal structures are considered as potential aquifers.

Several wells were drilled in the B2/A7 aquifer and showed that the highest yield aquifers are located in the Muasher syncline. This formation has poor ability to transmit water and wells should be restricted to areas of the major structural deformations where high secondary permeability exists.

Limited number of wells that were drilled in this aquifer has transmissivity data. In order to calculate the transmissivity (T) for the remaining wells, regression statistical analysis was used to find out the correlation between the specific drawdown (S) and transmissivity (Fig.3.1).

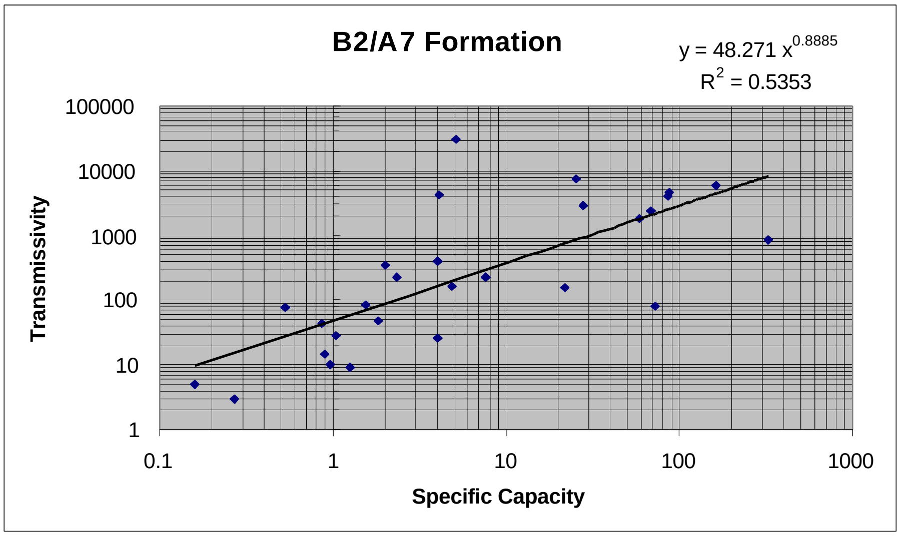


Figure 3.1: Correlation between transmissivity and specific drawdown for the B2/A7 formation.

The correlation equation for the Wadi Sir formation is illustrated by the following equation:

$$T = 48.27S^{0.88}$$

In regard to basalt, structures are considered the main control factor for the location of high yield aquifers ($100m^3/hr$). Wells that were drilled by Macdonald & partners (1964) showed that the main synclinal structures are considered as potential aquifers.

The main synclinal features are the Muasher in central part of the study area, the East-Abdalliah in the southwest, and the Hallabat in the northeast. As a result, a zone of scoriaceous basalt reaching to a thickness of 45m is considered to be the primary aquifer in basalt flows where the transmissivity values are considered very high. Away from the high yield areas, the basalt is made up of a series of semi-interdependent channels or pipes lying side-by-side giving the possibility to pump from one well without affecting the next. The correlation equation for the basalt formation is illustrated by the following equation:

$$T=223.55S^{0.64}$$

The regression analysis for the basalt formation is illustrated in Figure (3.2).

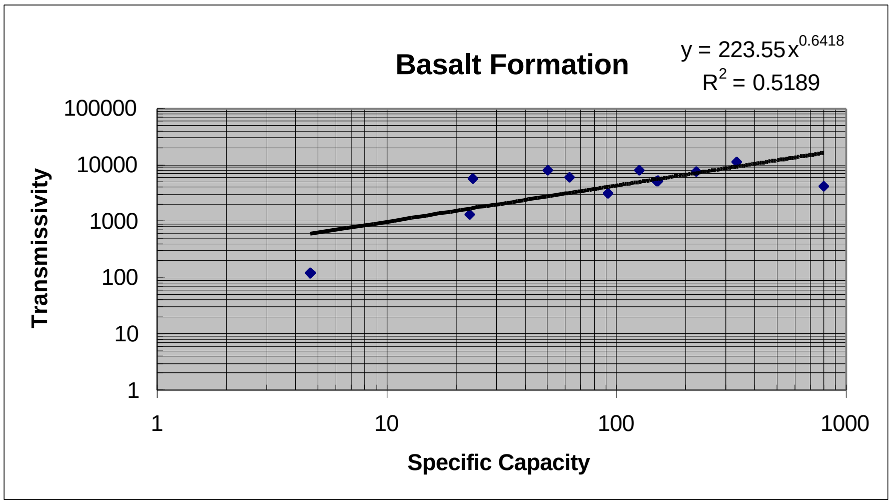


Figure 3.2: Correlation between transmissivity and specific drawdown for the Basalt formation

3.2.2 Specific-yield

Lack of observation wells in the study area prevented the obtaining of specific-yield values. Also the nature of basalt and the semi-interdependent channels make it very difficult to estimate the specific-yield for a large area. Nevertheless it is obvious that the few specific-yield values that were measured indicate that the system is under water-table conditions. Estimated values for specific-yield range between 0.05 and 0.40 and are shown in Figure 3.3.

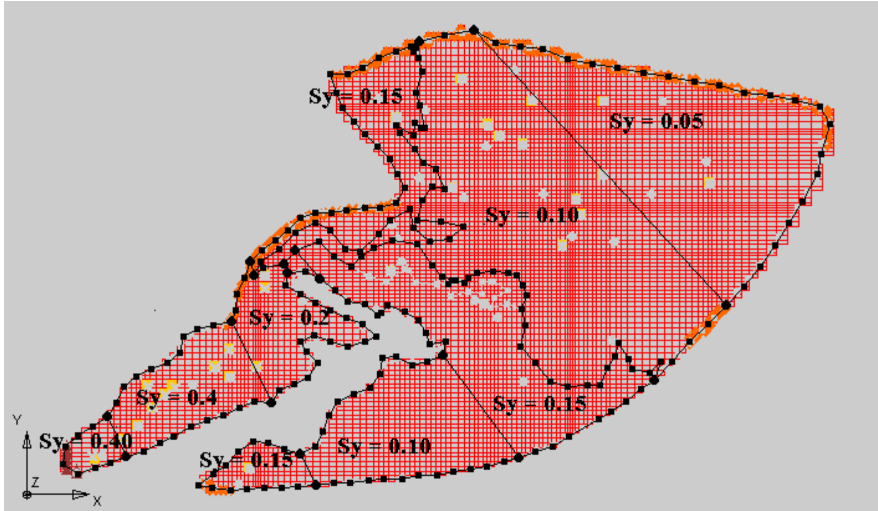


Figure 3.3: Specific yield distribution over the study area

The drawdown curves of the pumping wells indicate that, within the structural depressions, the specific yield is high enough to sustain high production wells with very small drawdown. Whereas, in other areas specific-yield is small with high transmissivity values acting as a conduit system.

3.3 Flow-Net

Static-water level readings were obtained from more than 200 wells prior to 1980 when the system was in equilibrium. For the central and Hallabat areas, the year 1965 was the initial water level.

The groundwater flows from the northeast from Arab Mountain in Syria towards the west and northwest into the Yarmouk basin (Fig.3.4) and toward the east to the Azraq basin. The configuration of contour lines indicates the aquifer characteristics. The groundwater velocity varies through the study area considerably according to permeability.

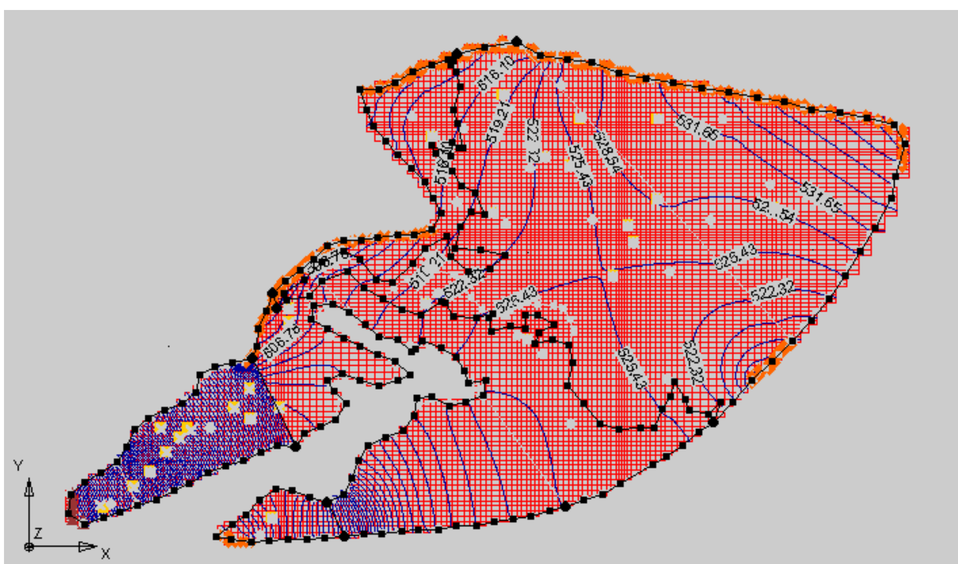


Figure 3.4: Measured steady state water-level map of the study area

3.4 Recharge

Recharge occurs through direct and indirect recharge in the study area. Direct recharge is due to direct rainfall infiltration on the study area. Indirect recharge consists of lateral flow from the high rainfall areas in the Arab Mountain.

Direct recharge within the study area was calculated by multiplying the 50-years average annual rainfall by the infiltration ratio. Previous studies have calculated the average infiltration rate based on the water budget method. In the Amman-Zarqa basin water resources study (1989), the calculated infiltration rate was 7.0%-10.0% of the total rainfall amount. Recent study by Mahamid (1998) showed that the infiltration rate ranges between 3%-6%. In this study an infiltration rate of 6% was used to calculate recharge. The annual rainfall in the study varies between 100 – 500mm. Estimated mean annual direct recharge in the study area totals to around 32MCM. The distribution of direct recharge is shown in Figure 3.5.

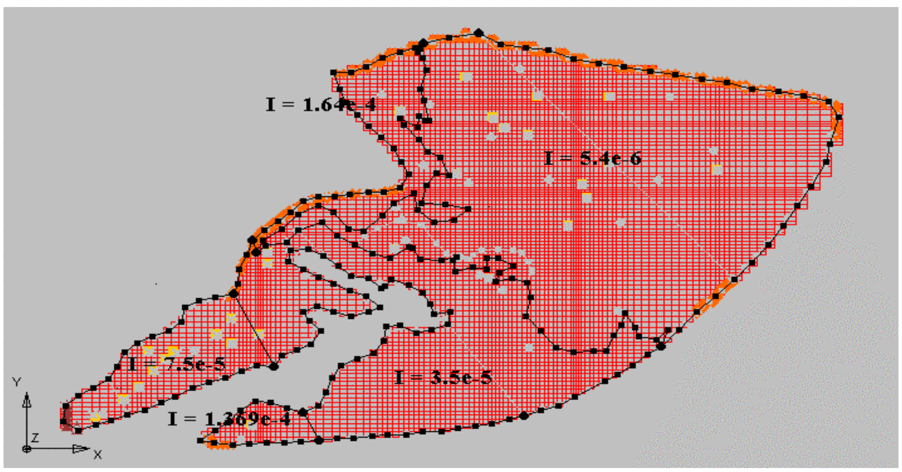


Figure 3.5 : Distribution of direct recharge over the model domain

Indirect recharge or lateral flow via the basalt and associated gravel was calculated according to Darcy's law in the model. Model Results showed that annual lateral recharge from the north is approximately 36.5 MCM. Total annual recharge to the study area was estimated to be 70 MCM.

3.5 Abstraction

Development in the study area started in the early sixties. Abstraction increased gradually from 8.46 MCM in 1965 to 123.4MCM in 1998.

The increase in abstraction from 1965-1975 was concentrated in the Dhuliel-Hallabat area where the abstraction reached to approximately 37 MCM/yr. Starting from 1980, a gradual expansion of the wells took place in the north and northeast. By the year 1995, another expansion to the east was noticed leading to increase in abstraction to 123.4MCM by 1998 as shown in Figures 3.6 and 3.7.

Total domestic and industrial abstraction is around 48.8MCM, representing 40% of the total production in the study area.

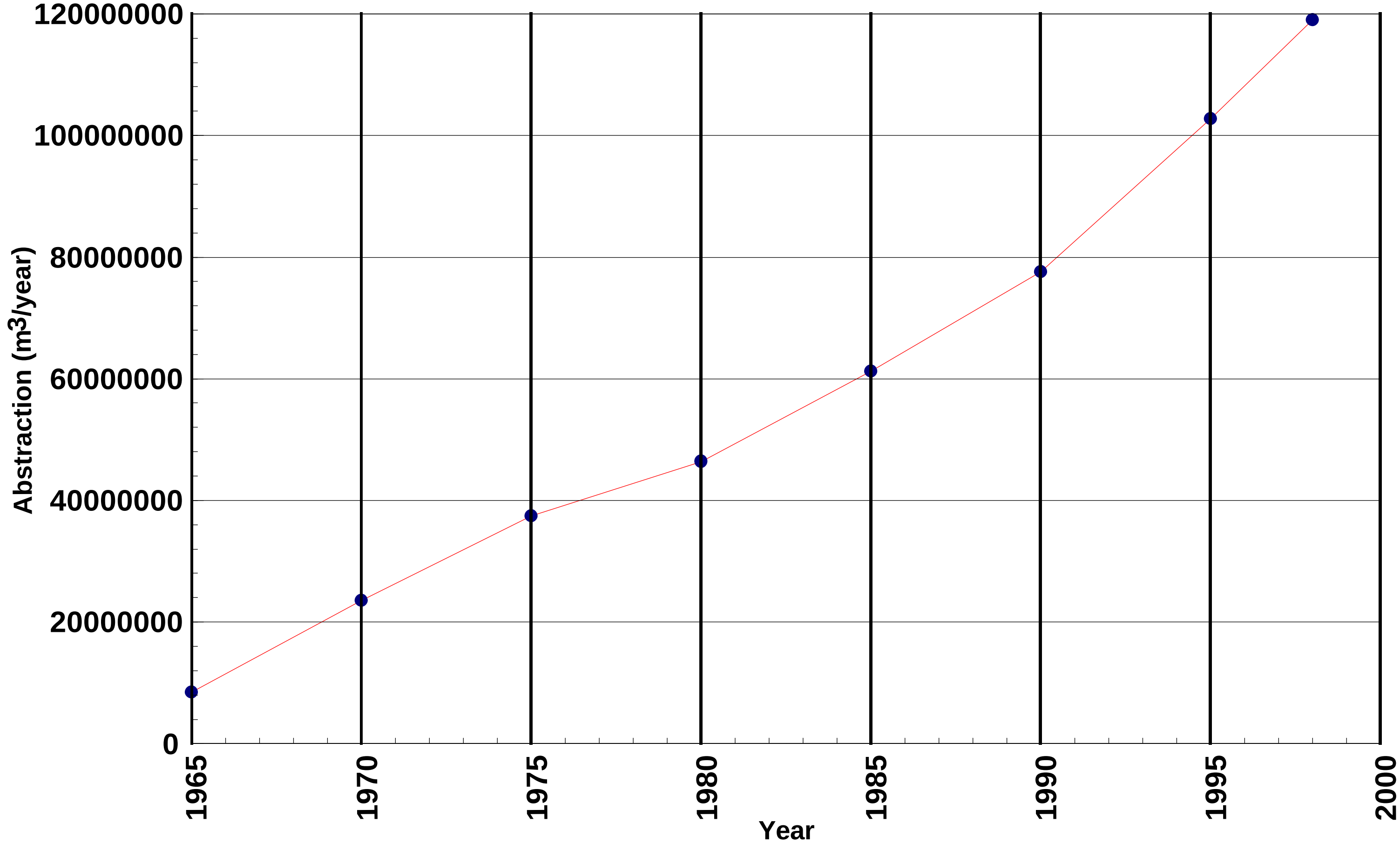


Figure 3.6: Groundwater abstraction (MCM/yr)

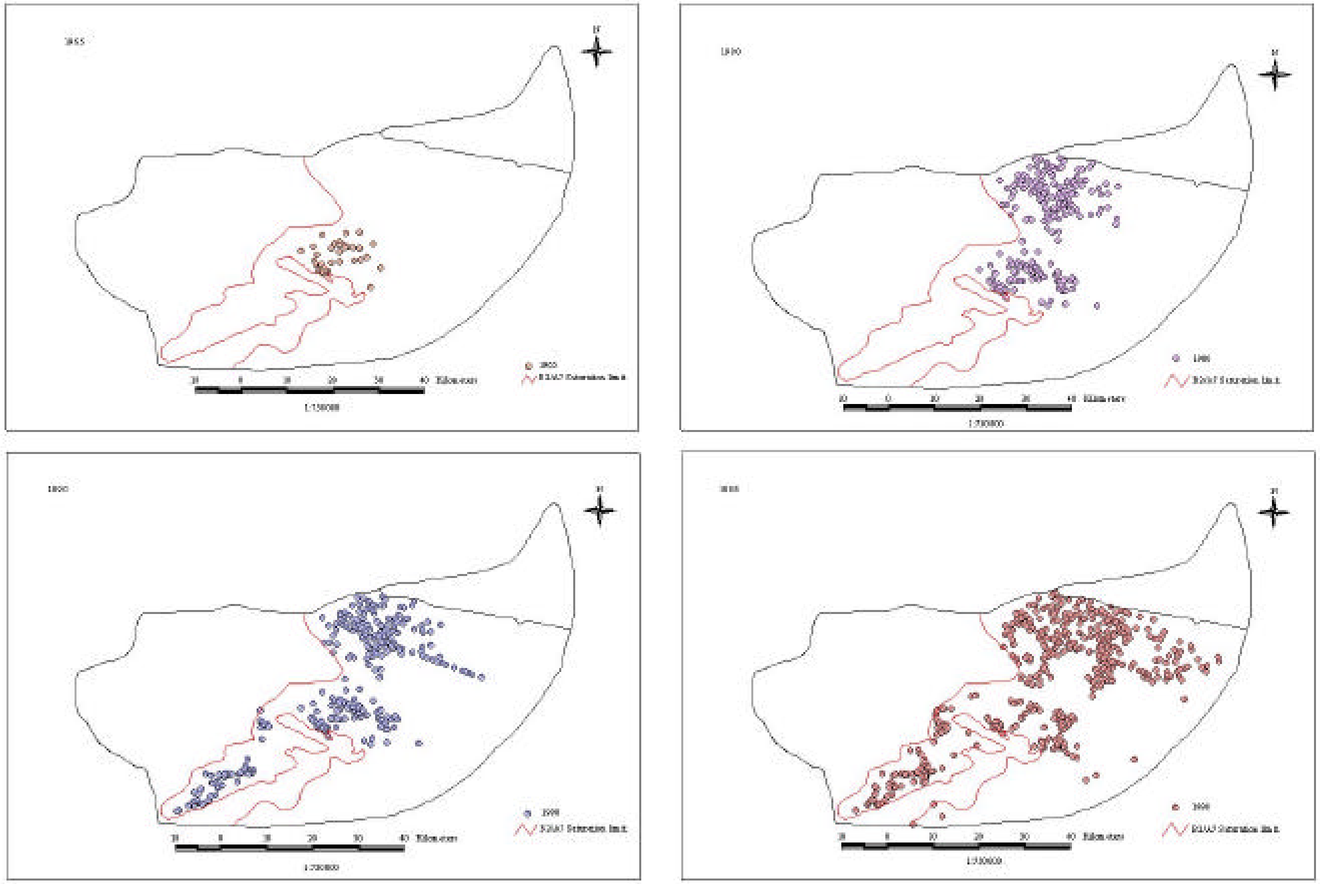


Figure 3.7: Increase in groundwater abstraction (1965-1998)

4. GROUNDWATER FLOW MODEL

4.1 Introduction

Groundwater flow models are one way to objectively evaluate the impact of existing or proposed activities on the groundwater aquifers. It is a tool to assess the field situation and to manage the water resources based on the aquifer behavior at present and in the future.

4.1 .1 Model Type

Based on the objectives of this study, a three dimensional finite difference model was selected to model the study area. Groundwater Modeling System (GMS) that includes a graphical interface to the groundwater model MODFLOW was used in the construction and running of the model. MODFLOW is a 3D, cell-centered, finite difference, saturated flow model developed by the United States Geological Survey (McDonald & Harbaugh, 1988). MODFLOW can perform both steady state and transient analyses and has a wide variety of boundary conditions and input options.

4.1.2 Building Approach

Two basic approaches are provided in GMS for constructing a MODFLOW model: (a) model can be completely defined using the tools in the 3D mesh module (the direct approach); or (b) with the aid of the GIS tools in the map module (the conceptual model approach).

The conceptual model is a high-level description of the site including sources/sinks, the boundary of the domain to be modeled, rainfall and seepage zones, and material zones within each of the layers.

The conceptual model is defined with GIS objects, including points, arcs, and polygons, and is constructed independently of a numerical grid. Once the conceptual model is complete, a grid is automatically constructed to fit the conceptual model, and the MODFLOW data are converted from the conceptual model to the grids and and grid faces. Once the model is constructed and the values are assigned to the grid, the dialogs and interactive editing tools in the MODFLOW menu can be used to edit or review the data, if desired.

4.2 The Conceptual Model

As stated earlier, the map of the study area was imported into GMS. Boundaries were identified, wells were located and materials were assigned. At the beginning, several attempts were done on the mesh size until satisfactory grid is reached

4.2.1 Formation Buildup

In order to build the Basalt and B2/A7 formations, topography of the study area was scanned, and digitized. Bottom of the basalt formation and B2/A7 limestone were obtained from the geological maps (BGR, 1995). These values were compared with the wells lithological logs found in the drilling log files. The thickness of the basalt formation is around 516.0m in the northeast part of the modeled area near the Arab Mountain, and it wedges out near the Sukhna area. The B2/A7 limestone formation ranges in thickness between 150 –240 m.

4.2.1 Boundary Conditions

The specification of the appropriate boundary is an essential part of the conceptual model. Within the scope of this study, three main boundary types were used: (1) constant head; (2) specified head boundaries; and (3) specified flux (Neuman). The constant head boundary (Dirichlet nodes) implies a uniform head value at all points along this surface, as well as through time. The specified head boundary occurs wherever head can be specified as a function of position and time over a part of the boundary surface of a groundwater system. Whereas the specified flux is used to simulate impermeable fault, limit of saturation, recharge and pumping wells.

The water level in the study area is under water-table conditions. The underlying formation “Shuieb” is considered as an aquiclude. Therefore, it is considered as a no-flow boundary. No-flow boundary also bounds the model in the south where the limit of saturation isolates the study area flow system. In the northwest of the study area another no-flow boundary limits the saturation of the B2/A7. In the north indirect recharge was assigned as constant head boundary. To the east and northwest, constant head boundaries were assigned resembling discharge.

Direct recharge (rainfall) was assigned as specified flux boundary. In the transient state abstraction was simulated as specified flux boundaries.

4.2.3 Initial Conditions

In the study area, initial heads values were for the groundwater flow system in the equilibrium phases (year: 1965) prior to aquifer disturbance due to pumping.

4.2 Model Run

Physical and functional understanding of the aquifer is necessary to improve the conceptual model of the aquifer system. This includes identifying sources of recharge and discharge, rate and direction of flow, variation of aquifer properties, hydraulic head, and boundary conditions. Thus, calibration is the process of adjusting model parameters and comparing the results until calculated head and flux values are closely in agreement with the measured values at selected points in the aquifer.

The calibration process is divided into two stages: steady state and transient state where the assumed initial heads are used for the calculation in the steady state calibration. The head results generated from the calibrated steady state were used as an initial condition for the transient computation.

4.3.1 Steady-State Calibration

Steady state calibration of the flow system is based on an important assumption that the system is in equilibrium and additional stresses on the system (e.g. abstraction) do not exist. This is before the development of the Dhuliel-Hallabat area in 1970, and the northeastern area in 1980.

In order to achieve this goal, permeability was adjusted by trial and error until the contours based on computed heads were in agreement with the observed contours in the study area. Hydraulic conductivity was successively and systematically modified from up gradient inflows to the down gradient. During this process specific yields were set to zero. Transmissivity values were obtained from pumping tests and the correlation method described in section 3.2.1. Permeability values were interpolated from transmissivity by dividing transmissivity by the saturation thickness. 18 Wells were used as observation points in the calibration process. The following parameters were calculated to evaluate the calibration:

- Mean error = 0.32 m
- Mean absolute error = 2.90 m
- Root mean square error = 3.58 m

The hydraulic conductivity for the calibrated model is shown in Figure 4.1 and the water budget calculated from the calibrated steady state model is shown in Figure 4.2.

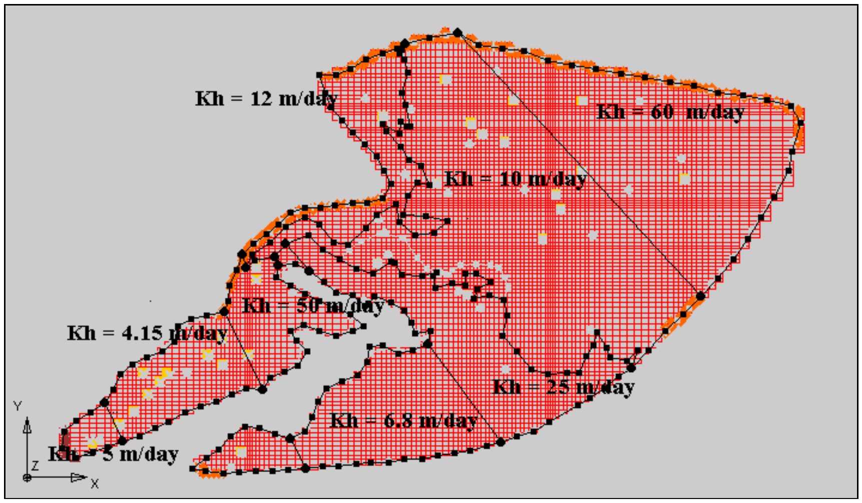


Figure 4.1: Hdyraulic conductivity distribution for the calibrated steady state model

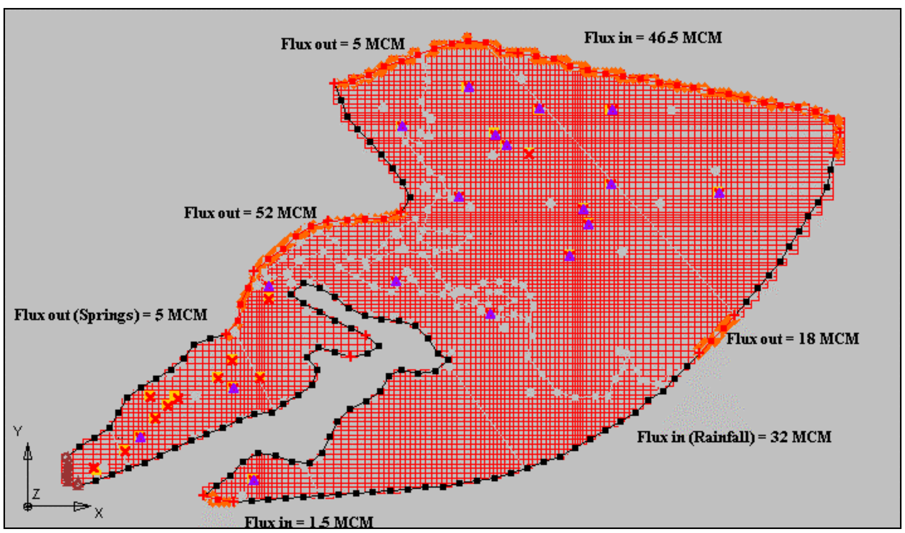


Figure 4.2: Steady state water budget

4.3.2 Transient State Calibration

The transient state calibration of the model is performed to estimate the specific yield by comparing the simulated drawdown with the historical drawdown reported in the monitoring wells.

The time period used for the non-steady state calibration is 33 years starting from 1965 and ending in 1998. Time unit used in the model is day and the length scale is meter. Seven monitoring wells were used in the non-steady calibration. The long-term average drawdown values were used to indicate the achievement of transient calibration. A list of the monitoring wells is shown in Table 4.1.

Table 4.1: Monitoring wells in the study area

Well-ID	Jordan East	Jordan_North	Start_Date	Last_date
AL1005	433311	556751	1974	1986
AL1521	432194	578201	1986	2000
AL1040	432555	562545	1968	2000
AL1043	449070	570942	1968	2000
AL2697	437908	575115	1986	1991
AL2698	442134	553671	1988	2000
AL3361	449070	570942	1988	1993

The production wells are distributed among 17 major wellfields, illustrated in Figure 4.3, and grouped approximately in three categories:

- M&I Wellfields with majority of wells are used for M&I purpose: This category includes Wellfields 1, 2, 13, 15, and 16.

- Irrigation Wellfields with majority of wells used for agricultural purpose: It includes Wellfields 3, 4, 5, 7, 8, 9, 10, 11, 12, and 14.

- Corridor Wellfield (number 17), which includes the M&I corridor wells which will be in production by 2001.

The historical development of the groundwater abstraction from 1965 to 1998 for each of the above wellfields is given in Table 4.2. Data previous to 1995 was collected from previous studies, while the 1995-98 is obtained from MWI Database.

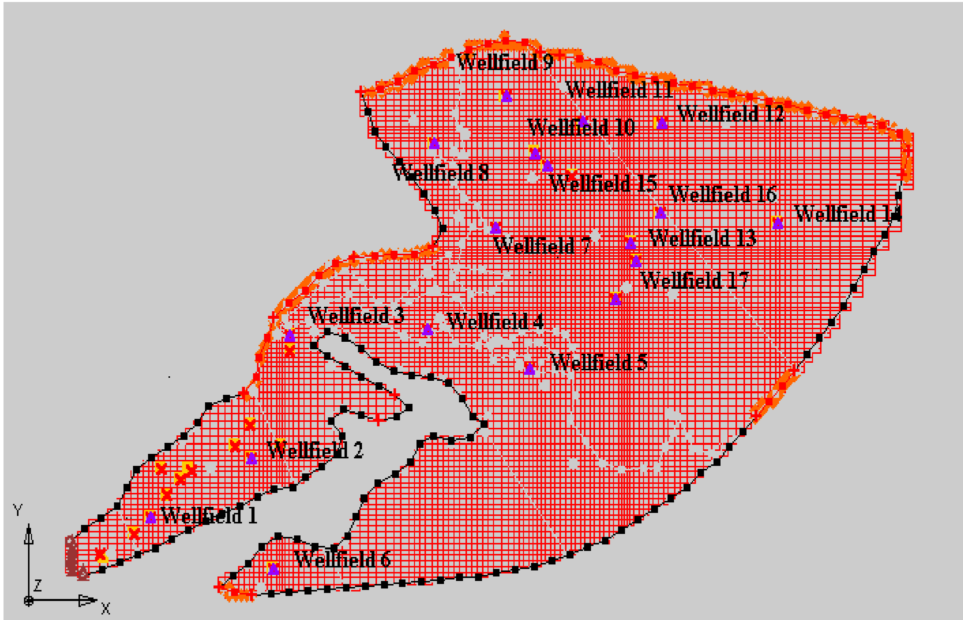


Figure 4.3: Wellfields distribution

In the transient state calibration, initial estimates of the specific-yield were adjusted until the model calculated and observed water level changes were in agreement. Specicif-yield values in the model area vary between 0.05 and 0.40.

Table 4.2: Annual Abstraction in Cubic Meters from 1965 to 1998 for all the wellfields 1 to 16								
Well Field	**production 65**	**production 70**	**production 75**	**production 80**	**production 85**	**production 90**	**production 95**	**Production 98**
1	1,350,000.00	4,291,896.00	9,440,232.00	11,512,128.00	12,112,128.00	12,410,004.50	12,707,881.00	15,196,033.71
2	2,230,404.00	2,714,628.00	4,690,008.00	4,707,432.00	5,107,428.00	7,302,777.00	10,339,292.00	12,131,041.71
3	1,080,108.00	2,017,956.00	2,827,032.00	3,435,336.00	4,683,516.00	6,175,308.00	7,907,328.00	9,690,001.71
4	3,235,354.43	9,614,618.12	14,022,587.52	12,304,488.69	10,586,389.85	7,859,160.00	7,951,620.00	8,919,445.71
5	564,645.57	4,735,381.88	5,977,412.48	7,695,511.31	9,413,610.15	11,901,534.57	14,389,459.00	15,716,017.71
6				4,896.00	26,700.00	150,245.00	150,245.00	47,700.00
7		195,522.31	488,791.88	740,304.00	1,688,160.00	2,040,660.00	2,146,248.00	3,337,117.71
8				345,828.00	1,667,256.00	2,009,460.00	2,813,076.00	3,466,009.71
9				163,008.00	3,031,536.00	4,119,732.00	4,918,692.00	5,247,961.71
10				1,594,620.00	2,244,690.66	2,456,544.00	2,527,218.00	2,877,649.71
11				235,200.00	2,745,672.00	3,990,240.00	5,411,856.00	6,290,521.71
12				553,428.00	1,048,560.00	1,921,116.00	4,931,400.00	6,620,905.71
13						109,200.00	2,852,148.00	4,675,165.71
14							4,823,412.00	3,906,072.00
15				2,850,012.00	5,728,680.00	6,678,684.00	8,326,356.00	9,720,097.71
16				251,976.00	1,201,980.00	8,478,753.00	10,598,877.00	11,905,345.71
Total	8,460,512.00	23,570,002.31	37,446,063.88	46,394,168.00	61,286,306.66	77,603,418.07	102,795,108.00	119,747,088.00

5. MODEL PROJECTION

5.1 Impacts of Over-pumping

Two over-pumping scenarios are analyzed.

5.1.1 Scenario NM1

The NM1 or no management one scenario assumes a continuation of over-abstraction without being controlled. The AZB highlands abstraction from the B2-A7/Basalt aquifers system is projected to continue at the 1998 level of 145 MCM/year up to 2001, then it reaches 155 MCM in 2002 considering an additional 10 MCM as a result of the development of M&I corridor wells, and continues at 155 MCM/year until 2020, as shown in Table 5.1. The 145 MCM pumping at 2001 includes 63 MCM for M&I, 2 MCM for pastoral use, and 80 MCM for irrigation. Note that the irrigation water use was adjusted from 60 MCM (1988 MWI database) to 80 MCM, as indicated in the Preliminary Groundwater Management Action Plan (MWI/ARD, April 2001).

Results of the 20 year projection for the scenario NM1 over-pumping pattern indicate a drying up of 70% of the wells (74 wells) in the Hashimiya-Dulayl-Hallabat area within the next 15 years, and a water table drop by an additional 10 to 30 meters in many parts of the aquifer, including the corridor wellfield with 16 meters drawdown, as shown in Appendix 1, Figure 5.1, and Figure 5.3. This also corresponds to a relative drawdown (Appendix 2), which is the ratio of drawdown and the staurated thickness, in the year 2020 exceeding 0.3 in Dulayl (Wellfield 4), Ba'ij (Wellfield 9), Za'tari (Wellfield 15), and northwest of the corridor wells (Wellfied 13); and reaching 1 (drying up) in Hashimiya and Hallabat (Figure 5.2).

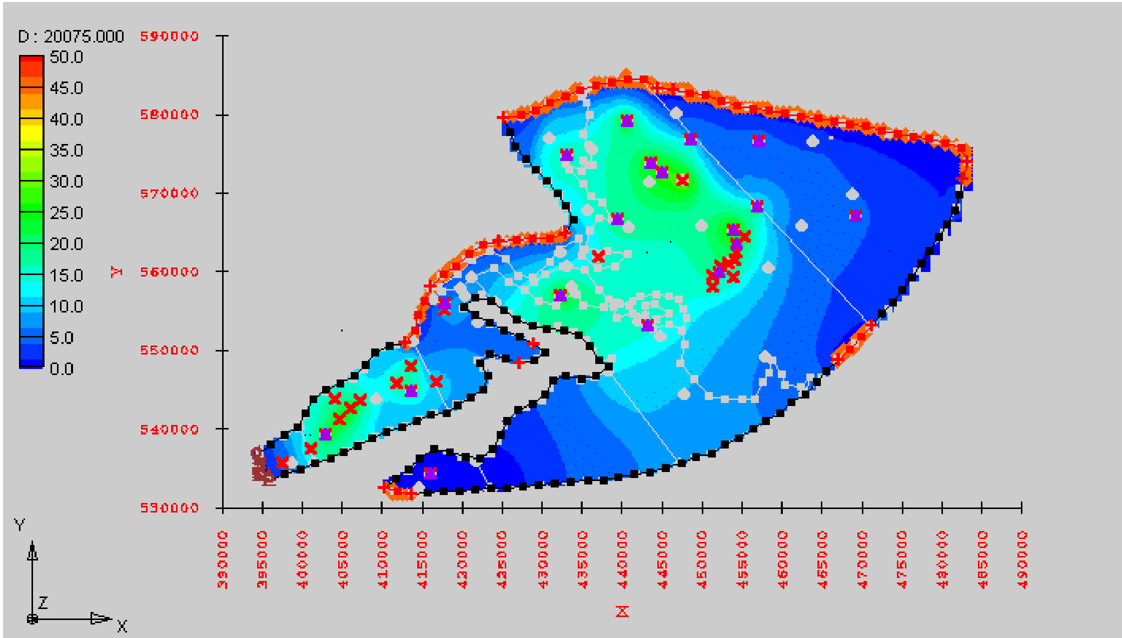


Figure 5.1: Drawdown map for the year 2020 based on Scenario NM1 abstraction

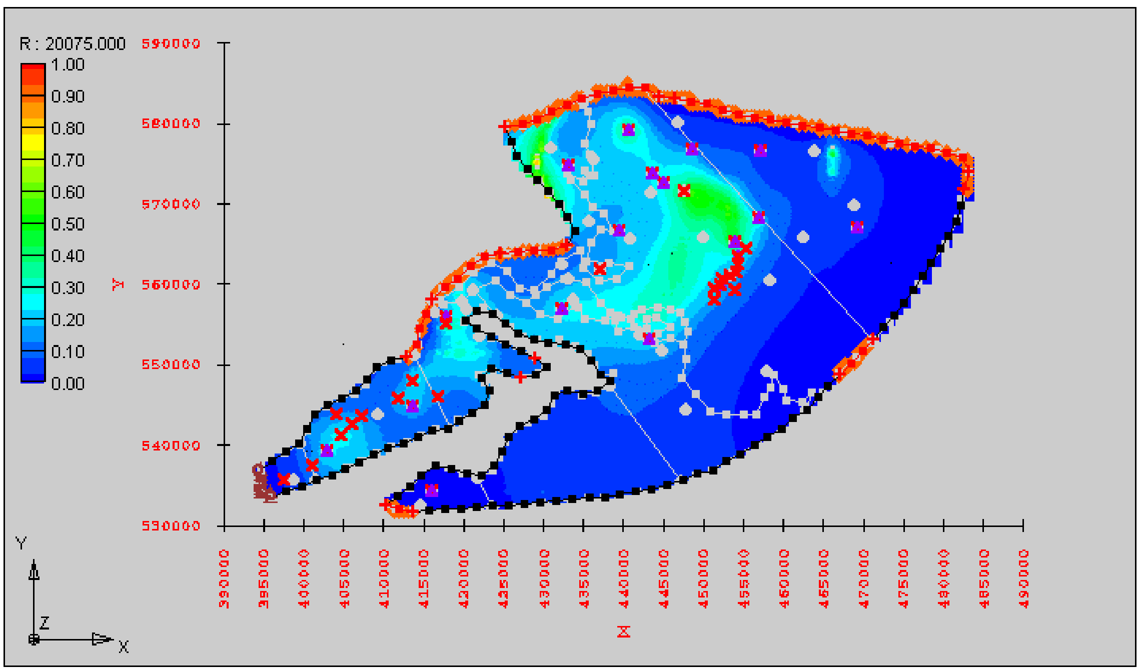
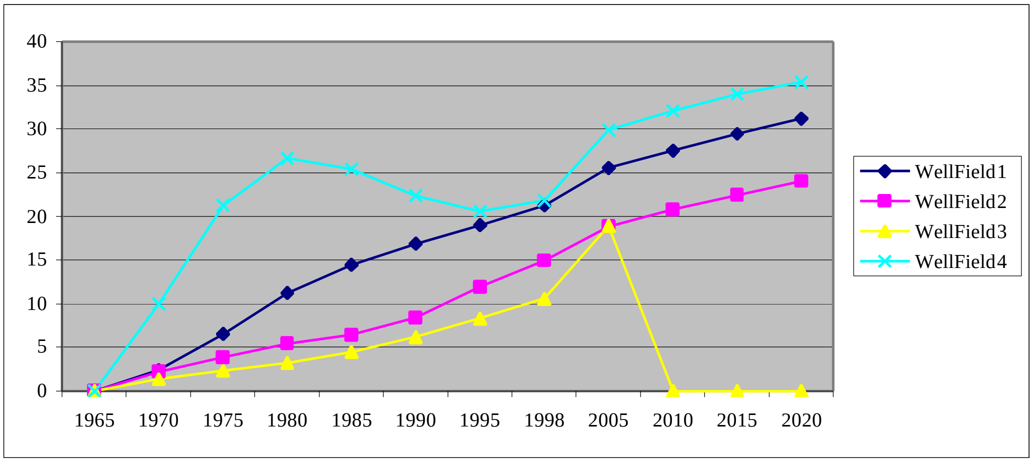
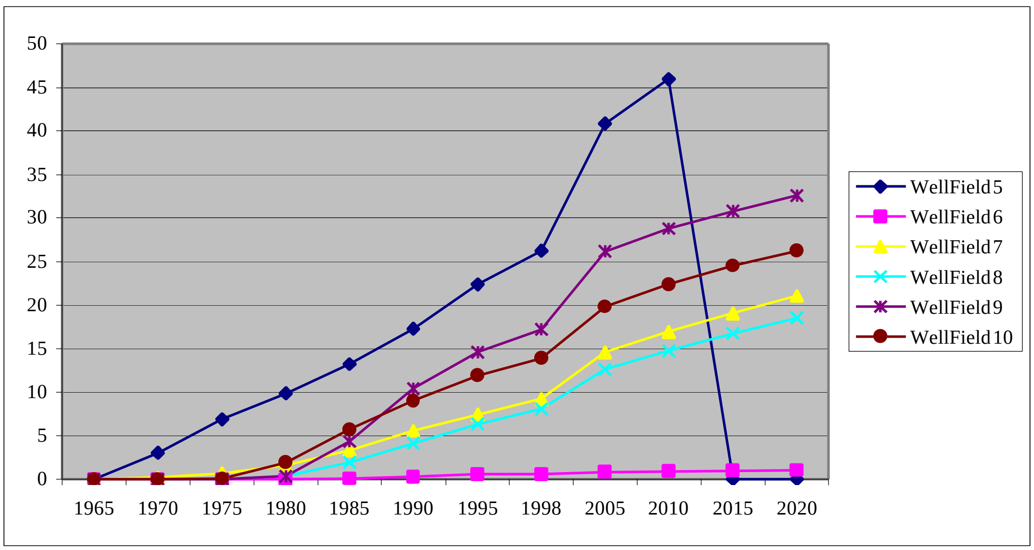
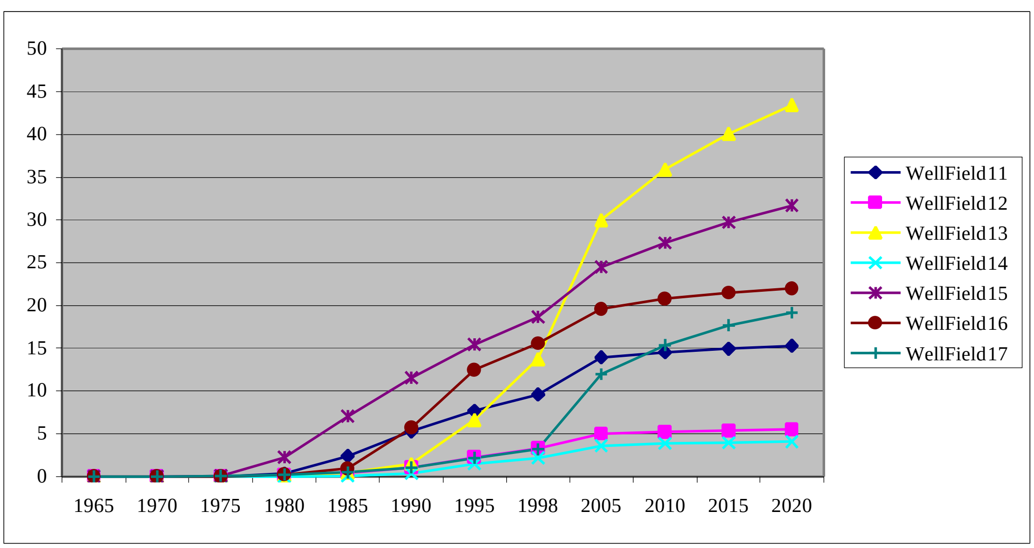


Figure 5.2: Relative drawdown map for the year 2020 based on Scenario NM1 abstraction

Figure 5.3: Scenario NM1 drawdown plot for wellfields 1 to 17 from 1965 – 2020







5.1.2 Scenario NM2

The NM2 or no management two scenario assumes a continuation of over-abstraction without being controlled at the Jordanian side, as in scenario NM1, in addition to a decrease of 50% of indirect recharge from Mountain Arab area, as a result of a possible increase of abstraction in the Syrian side of the basin by 23.5 MCM.

The model shows that this scenario is expected to result in a drying up of 70% of the wells (74 wells) in the Hashimiya-Dulayl-Hallabat area and the in the northwest of the corridor wells (Wellfield 13), within the next 15 years. And a water table drop by an additional 10.7 to 25.4 meters in Khaldiya and the North Badia area, and around 18 meters in the corridor area; as indicated in Appendix 1, Figure 5.4, and Figure 5.6. The relative drawdown (Appendix 2) in the year 2020 is expected also to approach or surpass 0.3 in Dulayl (Wellfield 4), Ba'ij (Wellfield 9), Za'tari (Wellfield 10), Umm Jimal (Wellfield 11), Northwest of the corridor wells (Wellfield 13), and Zatari (Wellfield15); and reach 1 (drying up) in Hashimiya, Hallabat, and northwest of the corridor wells (Figure 5.5).

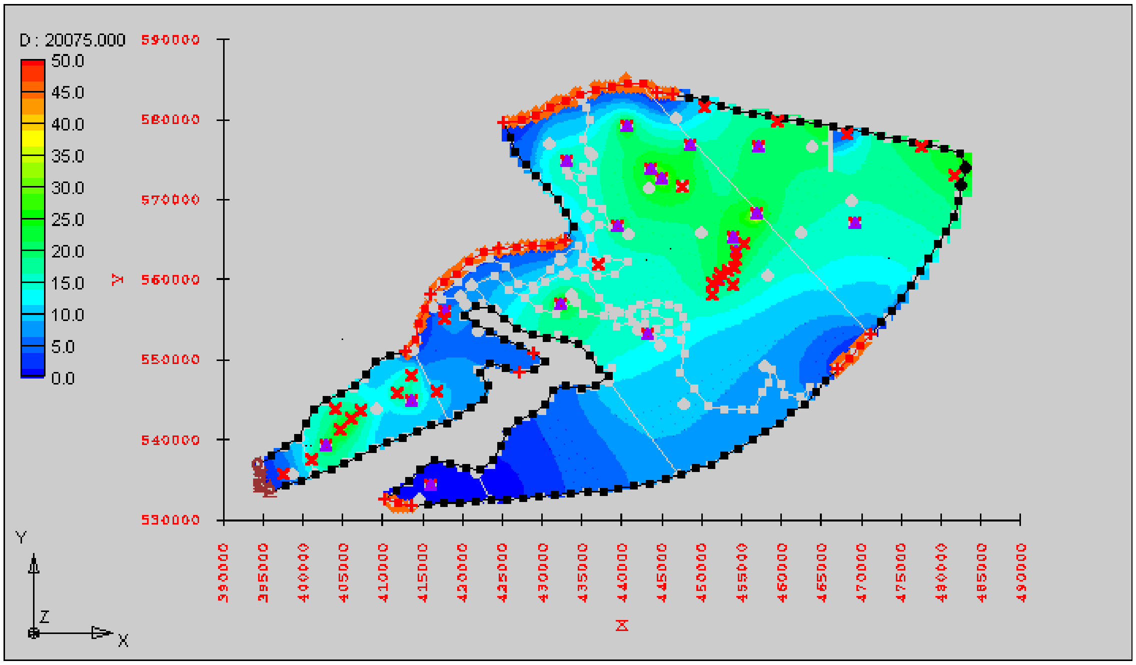


Figure 5.4: Drawdown map for the year 2020 based on Scenario NM2 abstraction

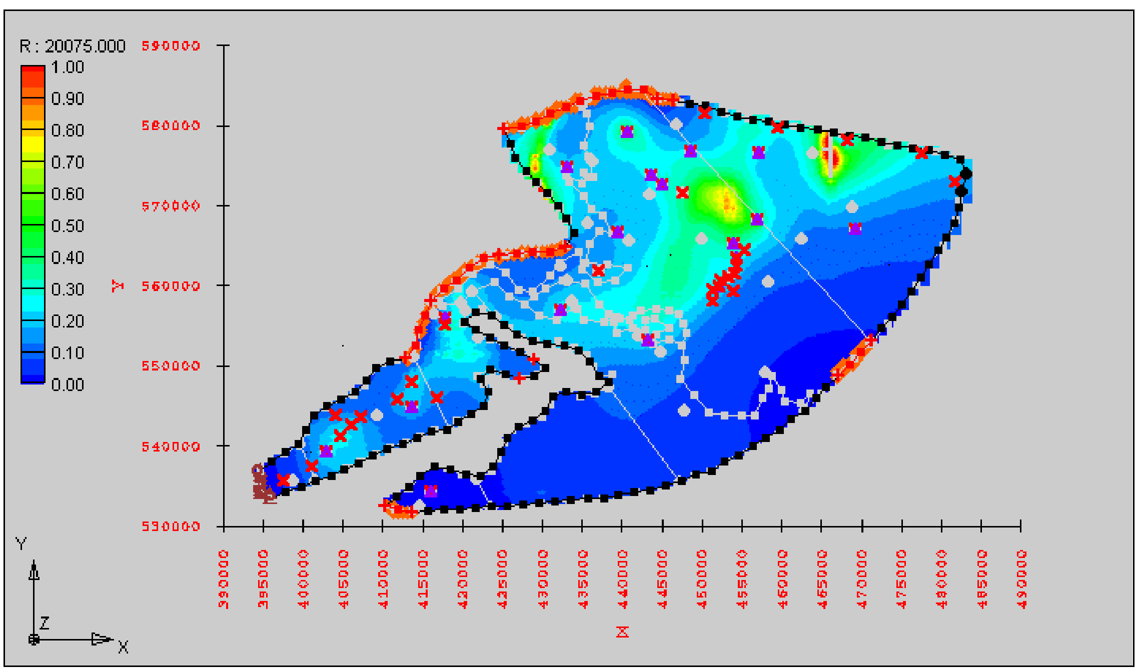
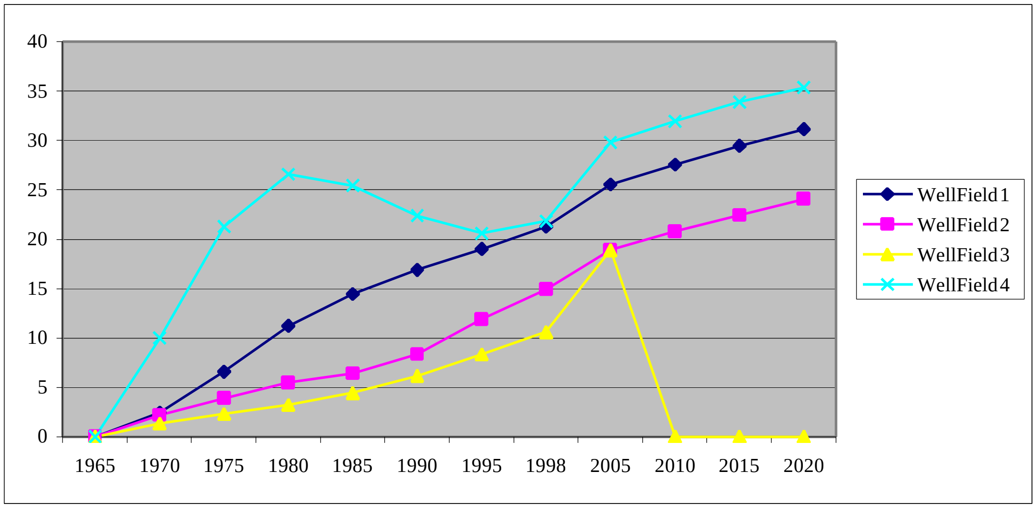
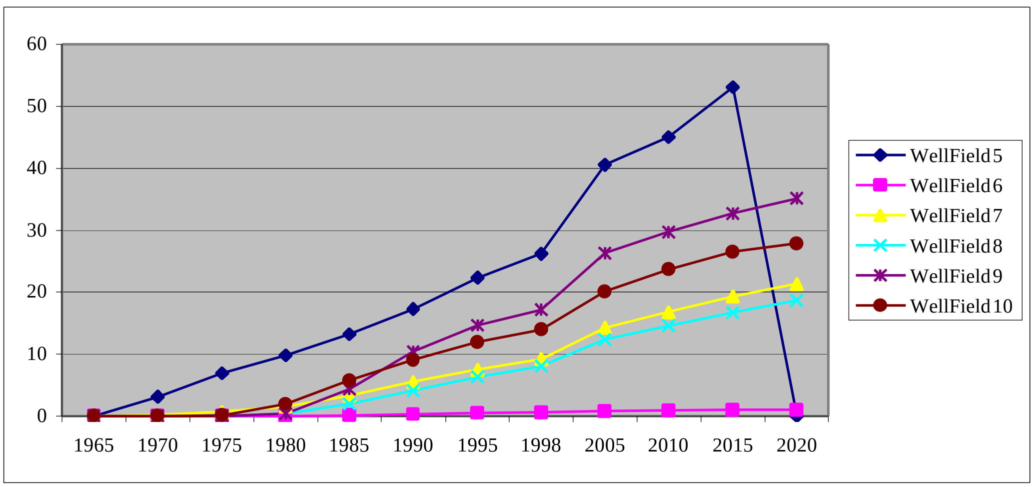
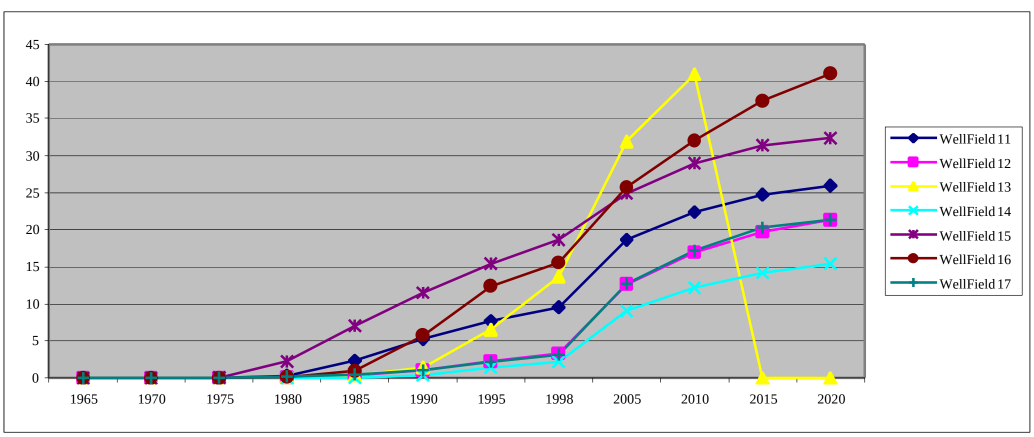


Figure 5.5: Relative drawdown map for the year 2020 based on Scenario NM2 abstraction

Figure 5.6: Scenario NM2 drawdown plot for wellfields 1-17 from 1965 – 2020







5.2 Impacts of Groundwater Use Reduction Scenarios

The following practical options for groundwater use reduction in the AZB were identified, following the Rapid Appraisal (RA) work and discussion with MWI and other stakeholders, and presented in the report of the preliminary Groundwater Management Action Plan (MWI/ARD, April 2001):

- Irrigation Advisory Service (5 MCM/year estimated reduction)
- Wells buy out (15-20 MCM/year)
- Enforcement of abstraction limit (10-15 MCM/year)
- Exchange of groundwater with treated wastewater (15 MCM/year: 10 MCM for irrigation and 5 MCM for industrial use)
- M&I reduction: 30 MCM, with10 MCM as regained Unaccounted for Water (UFW) resulting from reduction of physical losses due to rehabilitation of water conveyances and M&I water use saving by reducing water wastage by big industries, hotels, and households; and 20 MCM replaced by new water supplies from Disi, Wehda, Zara-Main, and AZB brackish water sources

These options are grouped in four scenarios. This section presents each one of the scenarios and the prediction of its impacts on the behavior of the B2-A7/Basalt aquifer.

5.2.1 Scenario 1

This scenario groups three management options including IAS (5 MCM), Minimum buy out (15 MCM), and Minimum Abstraction limit (10 MCM). Total reduction (30 MCM) comes entirely from irrigation use, as shown in Table 5.1.

The model applies this reduction to all 10 irrigation wellfields, mentioned above, proportionally to their 1998 abstraction, which is shown in Table 4.2. The reduction starts at 6 MCM in 2003, increases gradually to reach 30 MCM in 2010, and remains at the same level until 2020. This corresponds to a planned abstraction which starts at 145 MCM in 2001, increases to 155 MCM (additional 10 MCM from Corridor wells) in 2002, and begins declining from 149 MCM in 2003 to 125 MCM in 2010-2020; as illustrated in Table 5.1.

The model shows that the above irrigation water use reduction is expected to lead in the next 20 years to a moderate groundwater level recovery (Appendix 1 and Figures 5.7-5.9) of around 2 meters in Hashimiya (Wellfield 3). On the other hand, the rest of the wellfield areas are expected to register water level decline within the next 20 years reaching 16 meters in the northwest of the corridor wells (Wellfield 13), 14 meters around the corridor area (Wellfield 17), 10 meters at the outskirts of Zarqa and Amman (Wellfields 1 and 2), and between 7 and 10 meters in the Zatari area (Wellfields 10 AND 15). However, compared to the no management scenario NM1, the 30 MCM pumping reduction has positive impacts. It has avoided drying up of wells and attenuated the rate of drawdown. Figure 5.8 and Appendix 2 shows a decrease of the relative drawdown, which reflects the above moderate local recovery in Hashimiya and the drawdown attenuation in other parts of the basin.

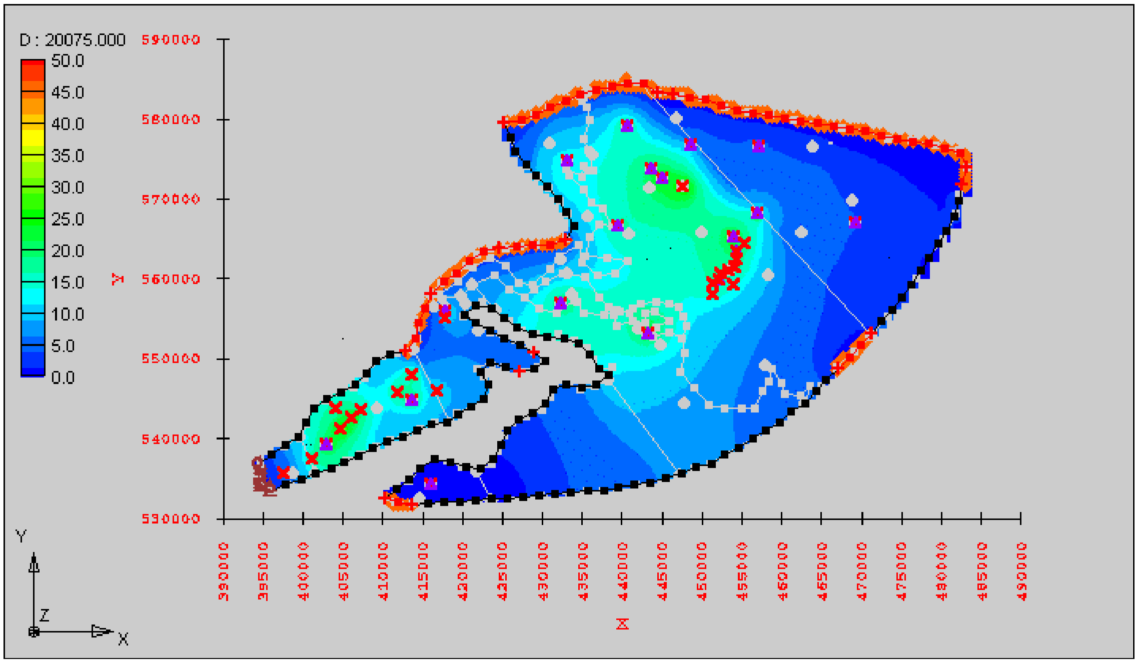


Figure 5.7: Drawdown map for the year 2020 based on Scenario 1 abstraction reduction

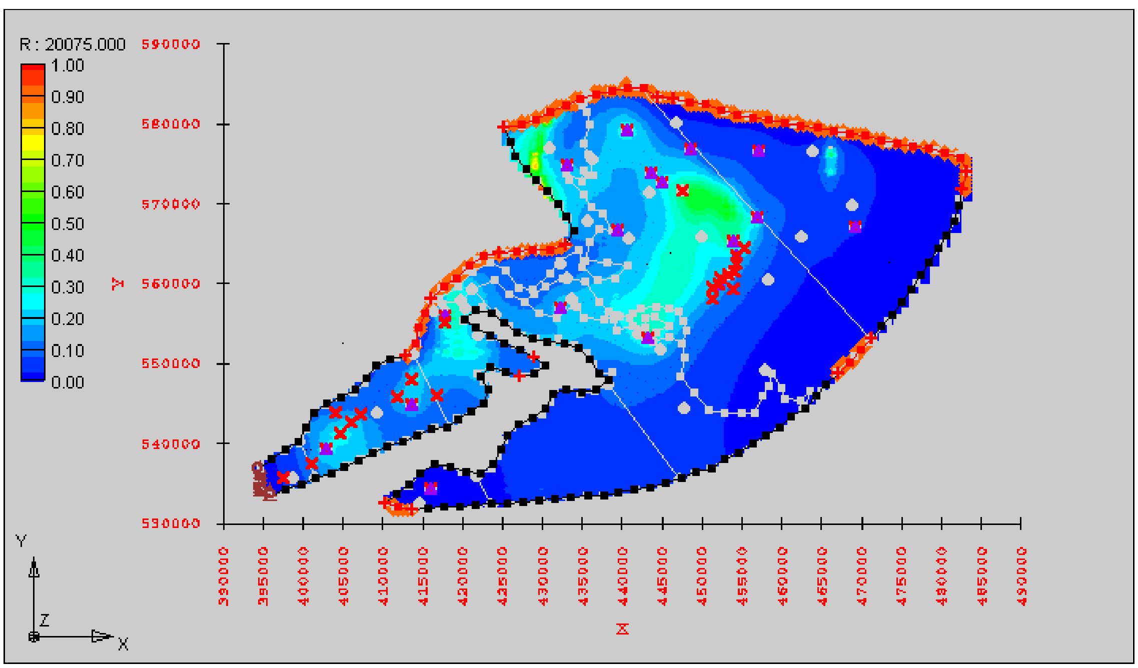
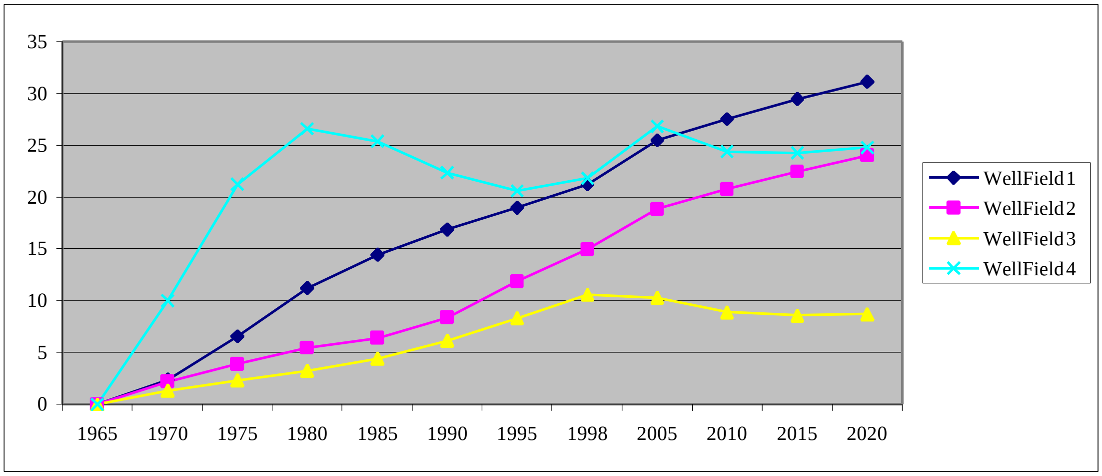
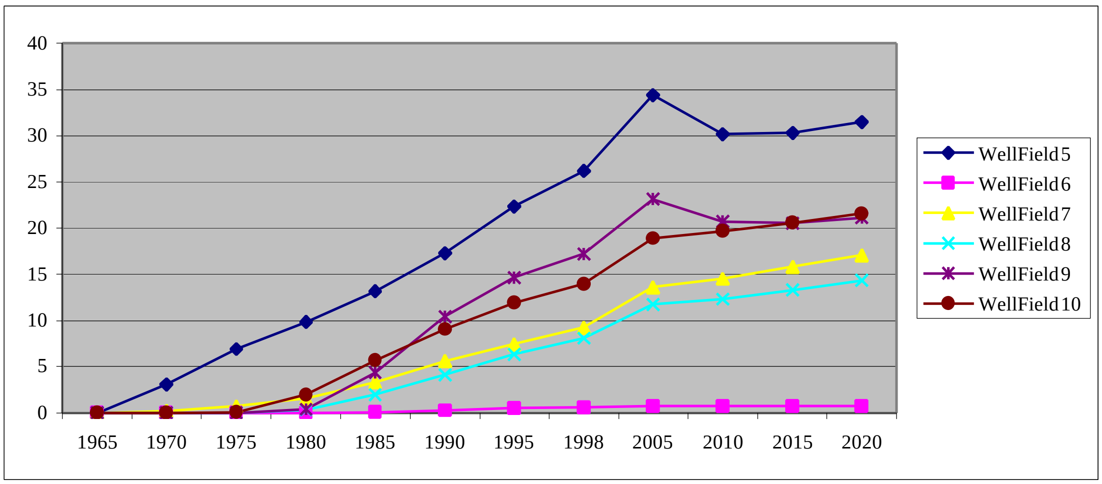
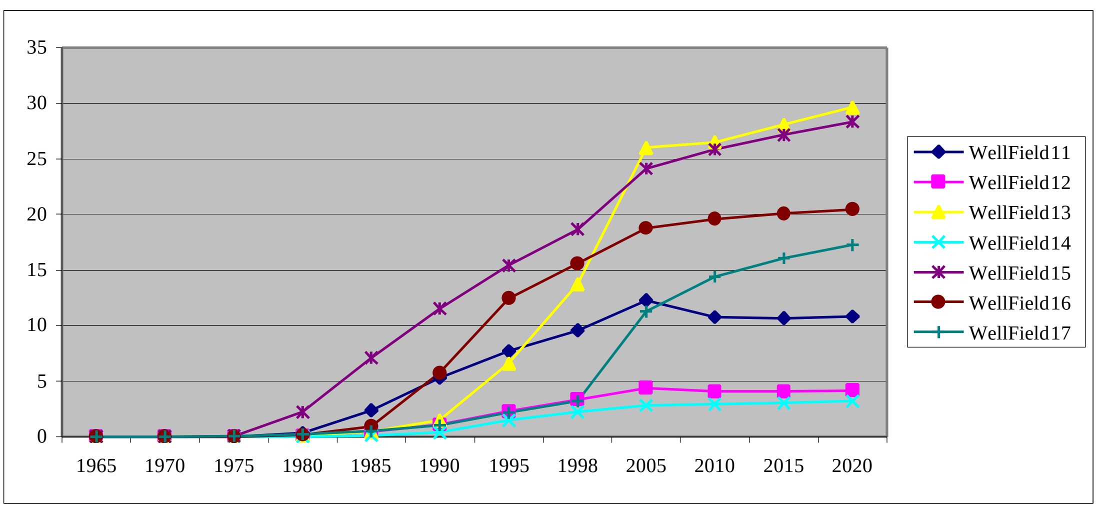


Figure 5.8: Relative drawdown map for the year 2020 based on Scenario 1 abstraction reduction

Figure 5.9: Scenario 1 drawdown plot for wellfields 1-17 from 1965 – 2020







5.2.2 Scenario 2

Scenario 2 includes three management options including IAS (5 MCM), Maximum buy out (20 MCM), and Maximum Abstraction limit (15 MCM). Total reduction (40 MCM) comes also entirely from irrigation use.

The model reduces the 40 MCM from the abstraction of the 10 irrigation wellfields proportionally to their 1998 abstraction. The reduction starts at 7 MCM in 2003, increases gradually to reach 40 MCM in 2010, and remains at the same level until 2020. This corresponds to a planned abstraction which starts at 145 MCM in 2001, increases to 155 MCM (additional 10 MCM from Corridor wells) in 2002, and begins declining from 148 MCM in 2003 to 115 MCM in 2010-2020, as illustrated in Table 5.1.

The model shows that the 40 MCM irrigation water use reduction is projected to lead in the next 20 years to a moderate groundwater level recovery (Appendix 1 and Figures 5.10-5.12) of around 3 meters in Hashimiya (Wellfield 3) and 0.5 meter in Dulayl (Wellfield 4), respectively. On the other hand, the rest of the wellfield areas are expected to experience water level decline within the next 20 years of 12.7 meters in the northwest of the corridor wells (Wellfield 13), 14 meters around the corridor area (Wellfield 17), 10 meters at the outskirts of Zarqa and Amman (Wellfields 1 and 2), and between 6 and 8.7 meters in the Zatari area (Wellfields 10 and 15). Compared to scenario 1, overall scenario 2 has improved the groundwater situation. It has slowed down the water table decline in many parts of the basin, especially in the agricultural wellfield areas. Figures 5.11 and Appendix 2 show a further decrease of the relative drawdown, which reflects the above moderate local recovery in Dulayl-Hashimiya and the drawdown attenuation in other parts of the basin.

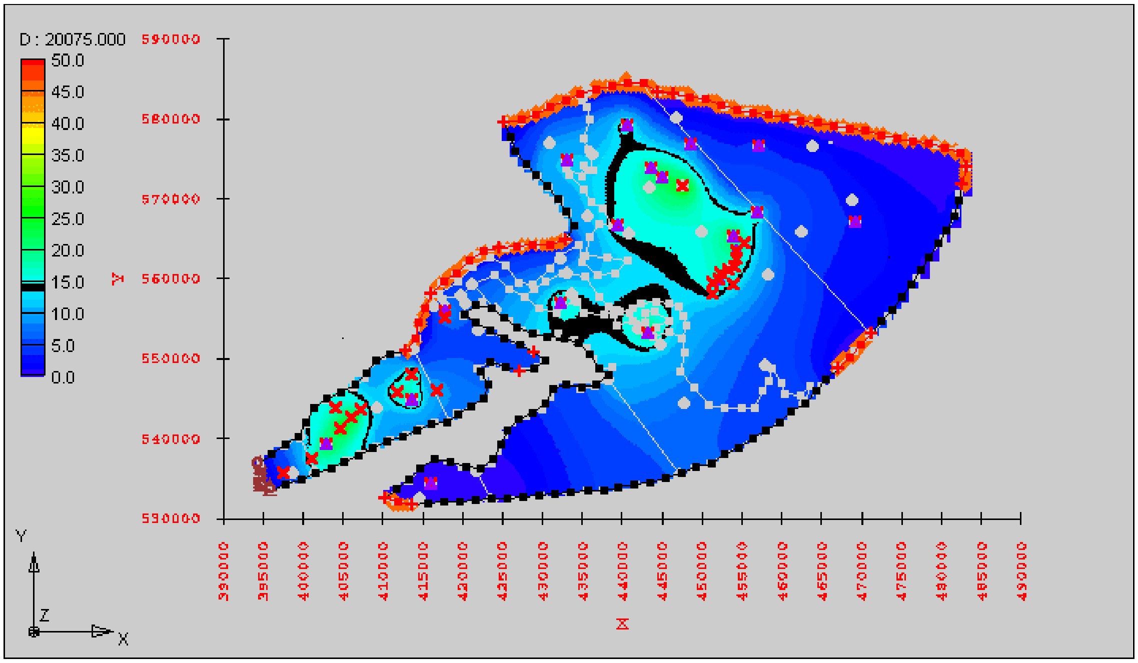


Figure 5.10: Drawdown map for the year 2020 based on Scenario 2 abstraction reduction

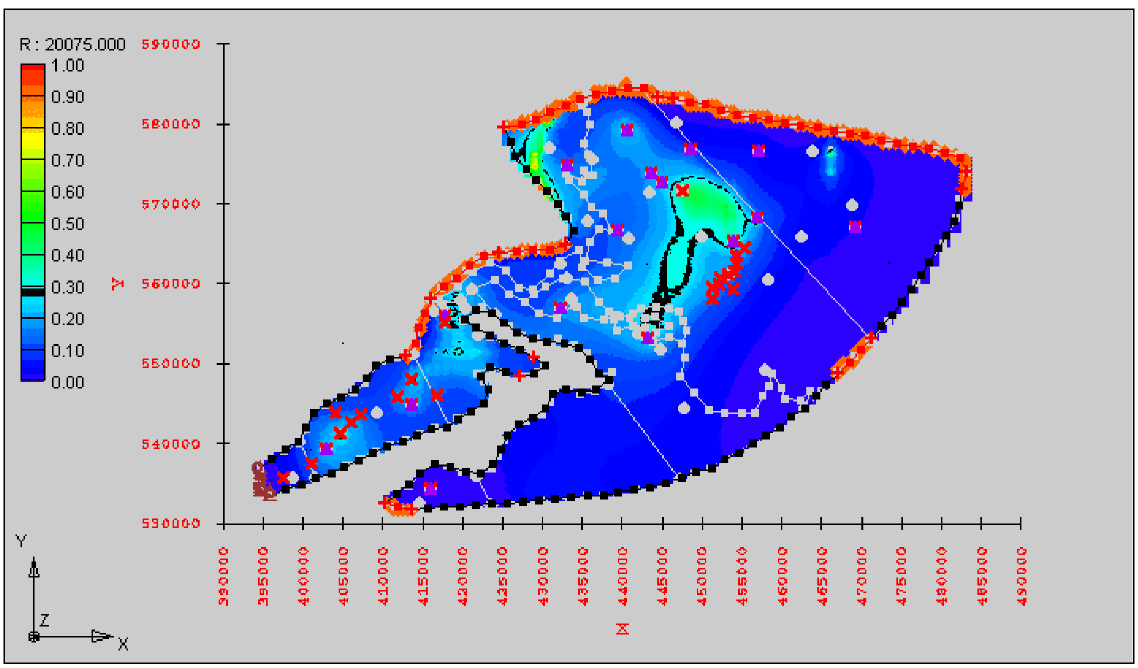
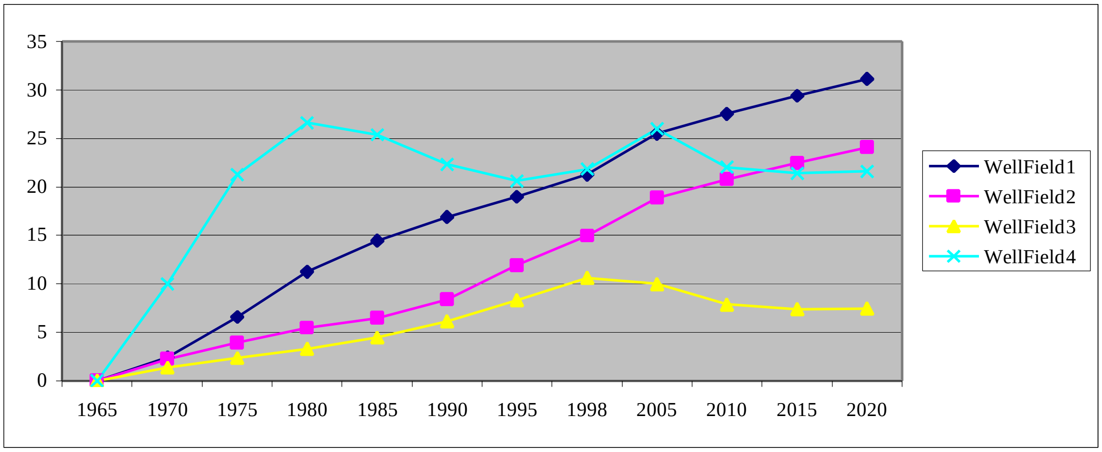
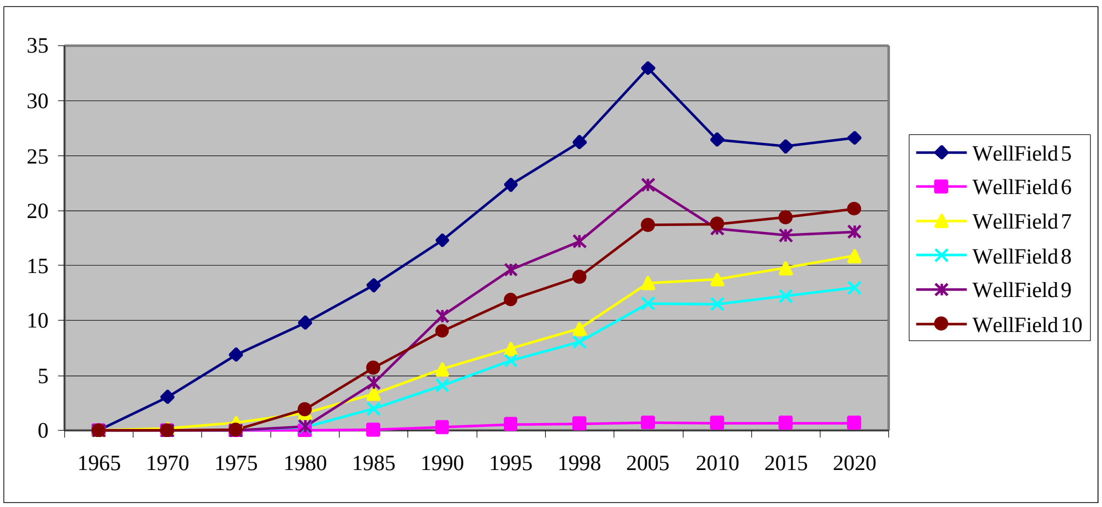
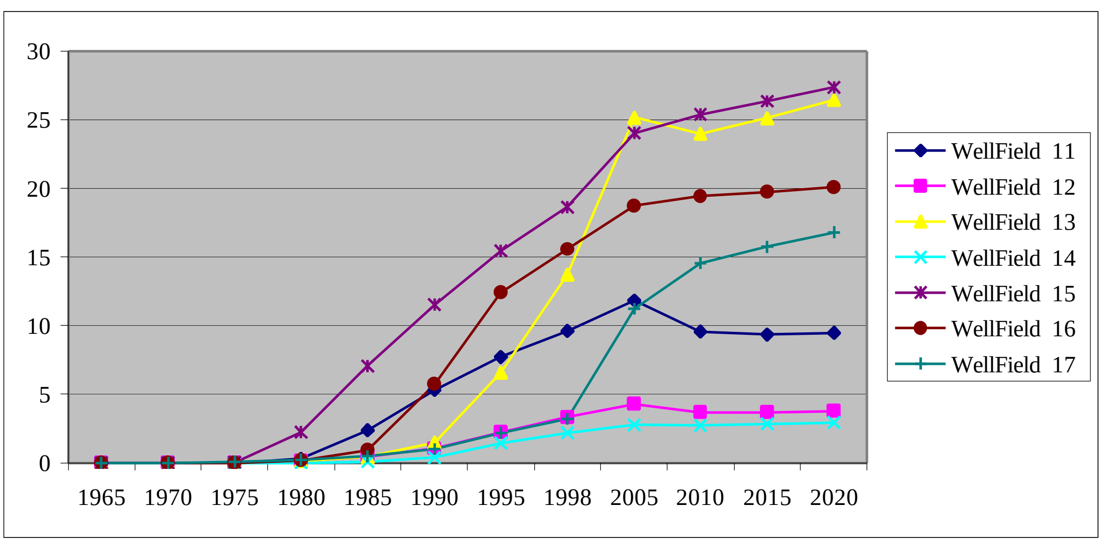


Figure 5.11: Relative drawdown map for the year 2020 based on Scenario 2 abstraction reduction

Figure 5.12: Scenario 2 drawdown plot for wellfields 1-17 from 1965 – 2020







5.2.3 Scenario 3

Scenario covers four management options including the three (3) options of scenario 2 and the reuse option for Hashimiya-Dulayl-Hallabat, which starts in 2005 with10 MCM followed by an additional 5 MCM in 2010. Part of the total reduction of 55 MCM comes from irrigation use (40 MCM) and the rest from reuse (15 MCM).

The 15 MCM wastewater reuse is targeted to exchange groundwater use in the Hashimiya-Dulayl area with treated wastewater from As Samra Wastewater Treatment Plant, with 5 MCM for industrial use in Hashmiya, and 10 MCM for irrigation in both Hashmiya and Dulayl agricultural sector. Therefore, the 5 MCM are reduced from the 1998 abstraction of wellfield 3 in Hashmiya and the 10 MCM is subtracted from the groundwater use of wellfields 3 and 4 (Dulayl), proportionally to their 1998 abstraction. On the other hand, the 40 MCM irrigation water use reduction is applied to the remaining irrigation area in the AZB highlands, specifically wellfields 3, 4, 5, 7, 8, 9, 10, 11, 12, and 14. The annual distribution of scenario 3 groundwater use reductions is detailed in Table 5.1, which indicates that the total planned abstraction will decrease gradually from 155 MCM in 2003 to 100 MCM in 2020.

Appendix 1 and Figures 5.13, 5.15 show that a groundwater mound is expected to form under the Hashimiya-Dulayl as a direct result of significant groundwater use reduction due to the exchange of groundwater with treated wastewater. This mound is reflected by a groundwater level rise of around 14 and 9 meters at wellfields 3 and 4, which are located respectively in Dulayl and Hashmiya areas.

The model also indicates that the water table in the remaining parts of the basin has almost the same behavior as that portrayed by scenario 2. Appendix 2 and Figure 5.14 show a significant decrease of the relative drawdown at wellfield 3 and 4, which reflects the formation of the groundwater mound in Hashmiya-Dulayl area.

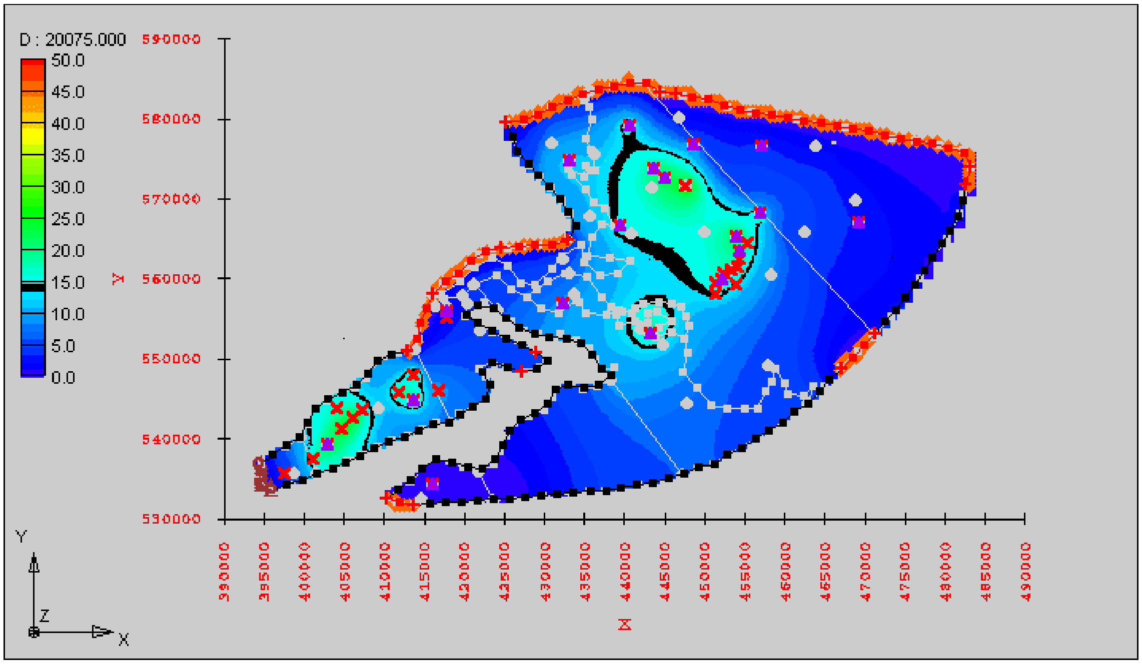


Figure 5.13: Drawdown map for the year 2020 based on Scenario 3 abstraction reduction

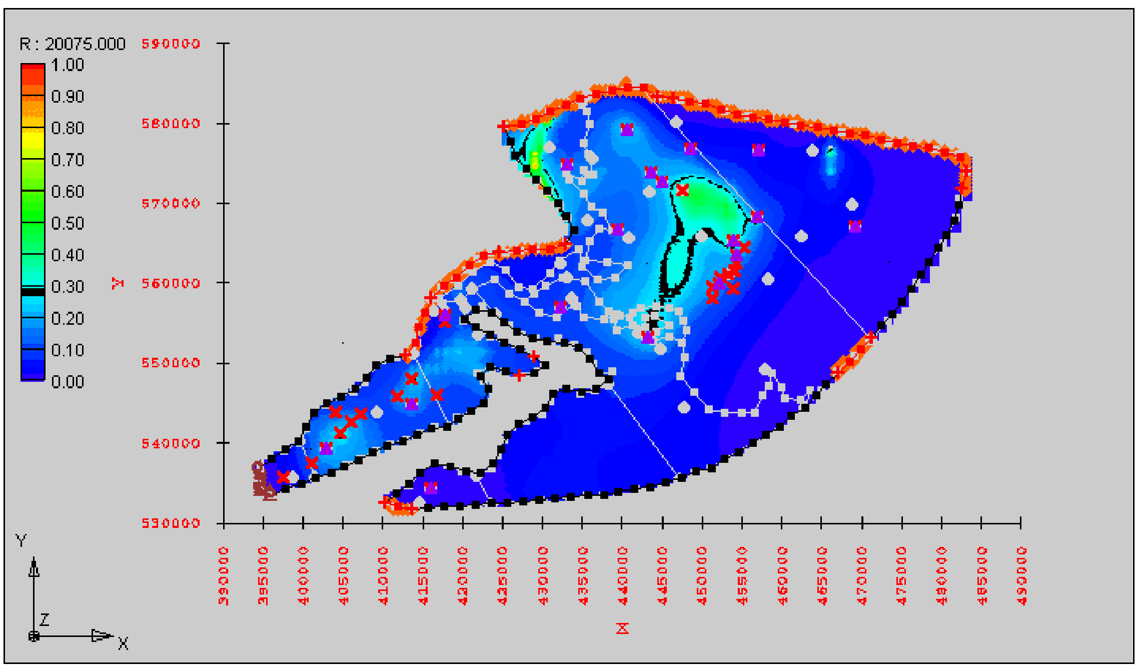
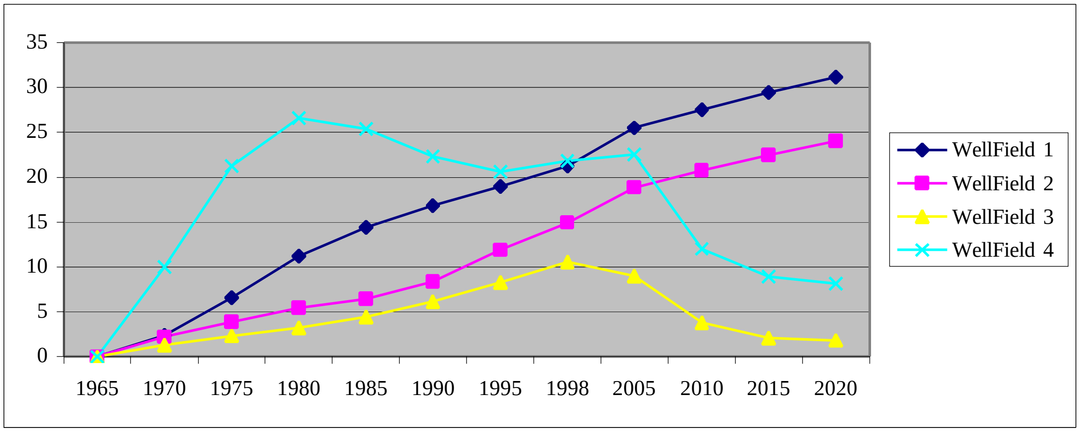
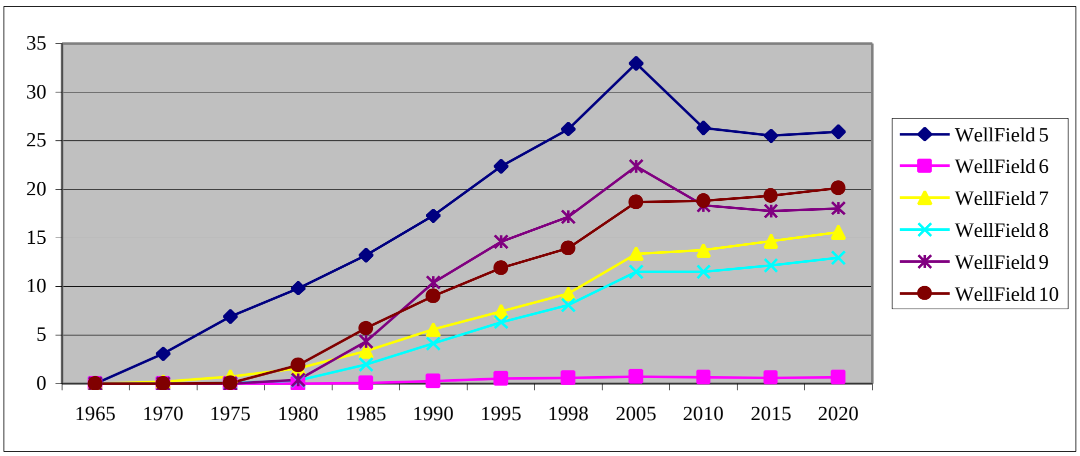
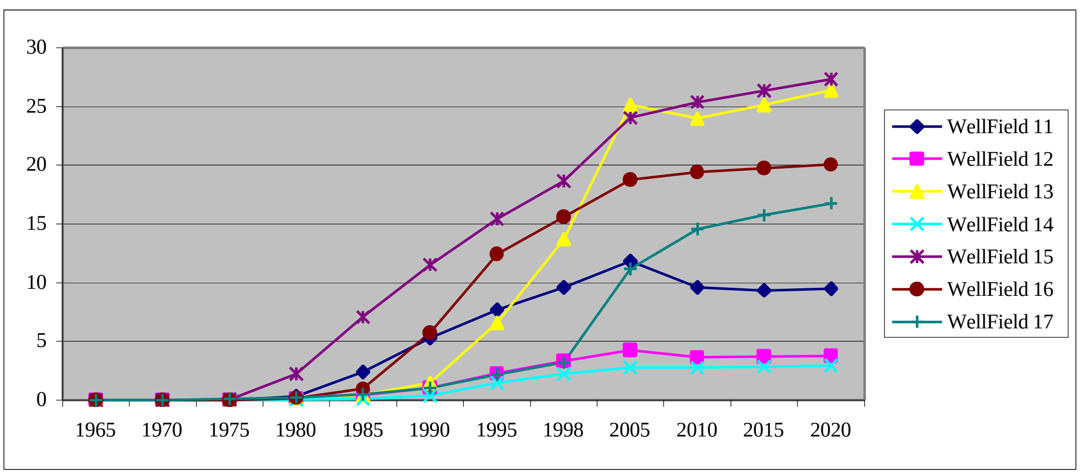


Figure 5.14: Relative drawdown map for the year 2020 based on Scenario 3 abstraction

Figure 5.15: Scenario 6 drawdown plot for wellfields 1-17 from 1965 – 2020







5.2.4 Scenario 4

This scenario includes all the five management options including the four (4) options of scenario 3 in addition to the M&I option. Scenario 4 corresponds to a total groundwater use reduction of 85 MCM (Table 5.1); with 40 MCM from irrigation, 15 MCM exchange of groundwater with treated wastewater, and 30 MCM from M&I sector (option 4). This balances the planned abstraction in 2020 with the safe yield (70 MCM) of groundwater in the AZB highlands.

The model used the same distribution applied in scenario 3 to the irrigation wellfields to accommodate the 40 MCM and 15 MCM reductions. The 30 MCM M&I abstraction reduction was applied to all the M&I wellfields, indicated in section 4.3.2, proportionally to their 1998 abstraction. The model assumed no reduction for the corridor wells (Wellfield 17).

By applying the latter reductions, the irrigation wellfields reflected similar behavior to that expected in scenario 3 in addition to further attenuation of water level decline in the north Badia (Wellfields 8, 9, 10, and 12) and Khaldiya (Wellfield 7) and a water table rise in Sabha area (Wellfield 11), as illustrated in Appendix 1 and Figures 5.16, 5.18. Appendix 1 also illustrated a positive impact on all M&I wellfields. This was not apparent in the previous scenarios (1 to 3) since the proposed reductions apply only to the irrigation wells. The impact of scenario 4 on the M&I wellfields is especially reflected in the moderate water level rise in the outskirts of Amman (Wellfield 1) and the 5 meters water table rise at Baghdad road wellfield 16, south of Addafyaneh.

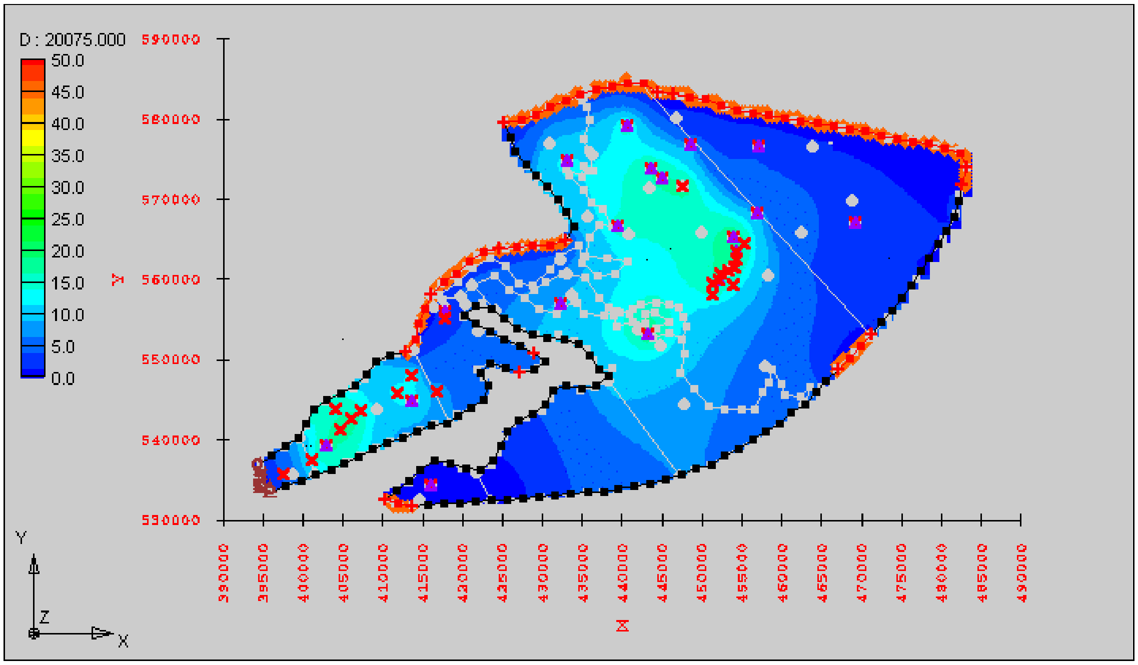


Figure 5.16: Drawdown map for the year 2020 based on Scenario 4 abstraction Reduction

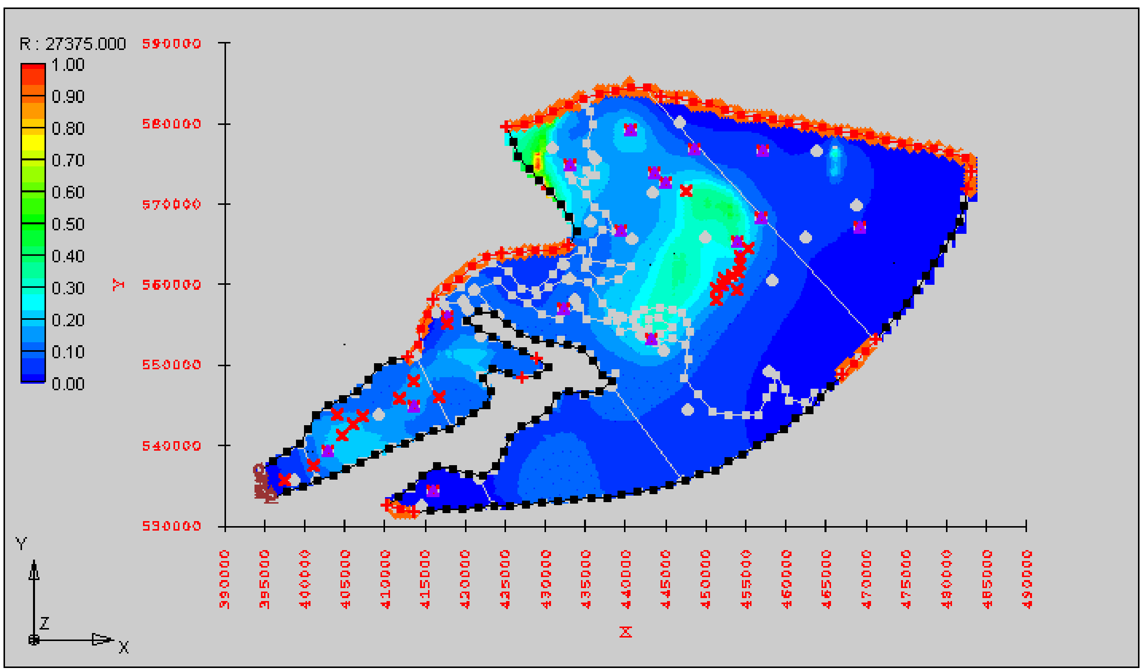
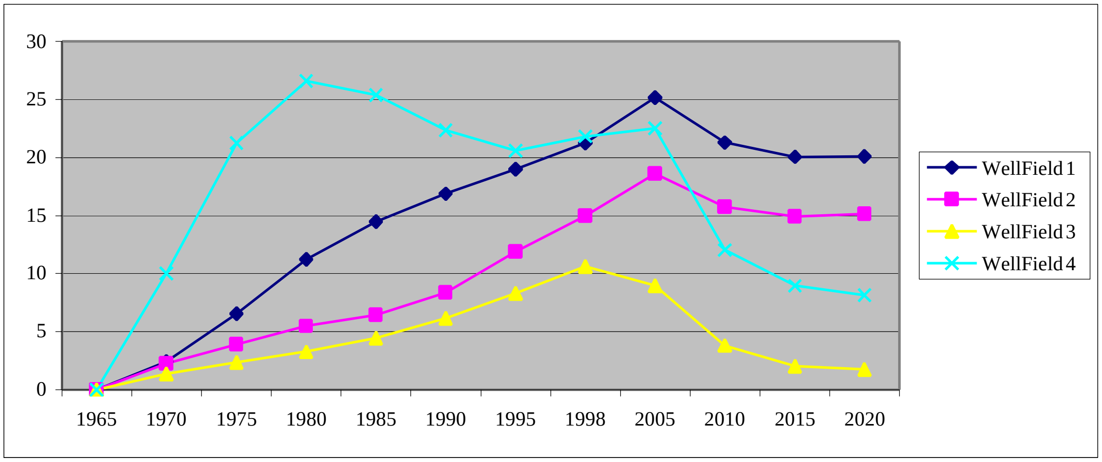
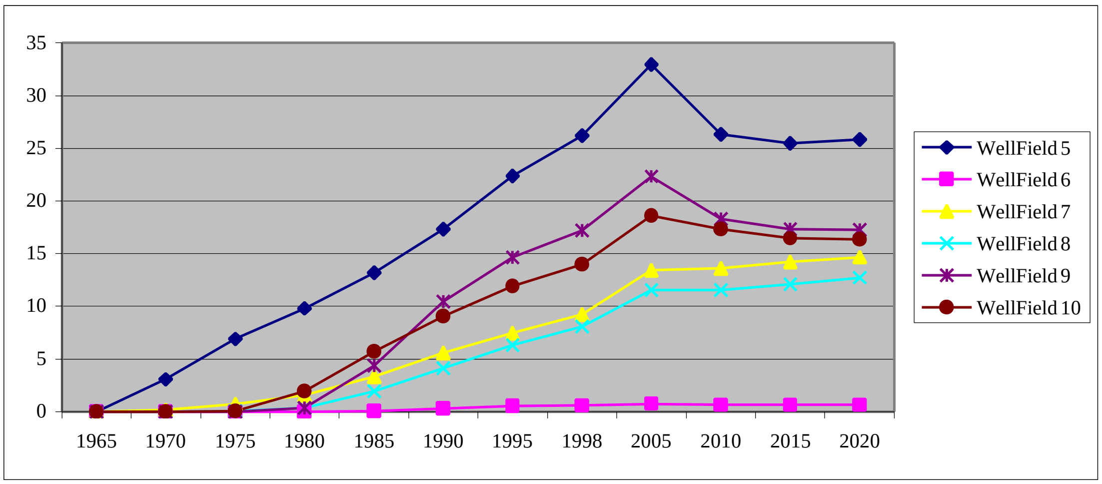


Figure 5.17: Relative drawdown map for the year 2020 based on Scenario 4 abstraction reduction

Figure 5.18: Scenario 7 drawdown plot for wellfields 1-17 from 1965 – 2020





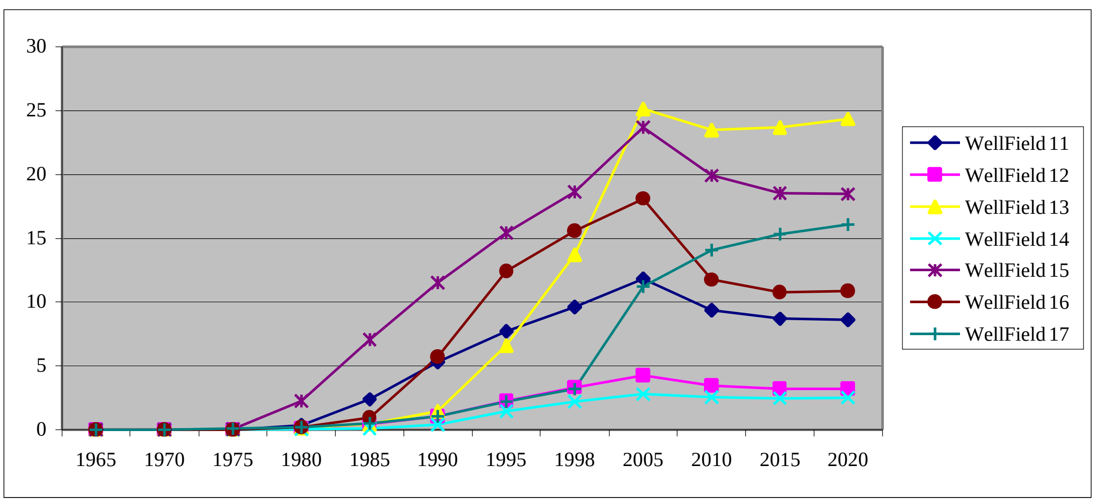


Table 5.1: Groundwater Use Reduction Scenarios, B2-A7/Basalt in Amman-Zarqa Basin

Scenarios	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010-2020	Comments
Scenario NM1											Adjusted 1998 (Add 20 MCM To irrigation)
Planned Abstraction	**145**	**155**	**155**	**155**	**155**	**155**	**155**	**155**	**155**	**155**	**& Corridor Project Starting 2002**
Scenario NM2											Adjusted 1998, Corridor
Planned Abstraction	**145**	**155**	**155**	**155**	**155**	**155**	**155**	**155**	**155**	**155**	& 50% recharge from Sirya
Scenario 1											1. IAS, Min Buy-out, Min Abstraction limit
IAS	0	0	1	2	3	4	5	5	5	5	
Buy-out	0	0	3	6	9	12	15	15	15	15	
Abst/Crop	0	0	2	3	4	5	6	6	6	10	
Total Reduction: Irrigation	0	0	6	11	16	21	26	26	26	30	
Planned Abstraction	145	155	149	144	139	134	129	129	129	125	
Scenario 2											1. IAS, Max Buy-out, Max Abstraction limit
IAS	0	0	1	2	3	4	5	5	5	5	
Buy-out	0	0	4	8	12	16	20	20	20	20	
Abst/Crop	0	0	2	4	6	8	10	10	10	15	
Total Reduction: Irrigation	0	0	7	14	21	28	35	35	35	40	
Planned Abstraction	145	155	148	141	134	127	120	120	120	115	

Scenarios	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010-2020**	**Comments**
Scenario 3											1. IAS, Max Buy-out, Max Abstraction limit, Reuse
IAS	0	0	1	2	3	4	5	5	5	5	
Buy-out	0	0	4	8	12	16	20	20	20	20	
Abst/Crop	0	0	2	4	6	8	10	10	10	15	
Total Reduction: Irrigation	0	0	7	14	21	28	35	35	35	40	
Reuse	0	0	0	0	10	10	10	10	10	15	Starting 2005 in Dulayl-Hashimiyah (wellfields 3&4)
Total Reduction	0	0	7	14	31	38	45	45	45	55	
Planned Abstraction	**145**	**155**	**148**	**141**	**124**	**117**	**110**	**110**	**110**	**100**	
Scenario 4											1. IAS, Max Buy-out, Max Abstraction limit, Reuse
IAS	0	0	1	2	3	4	5	5	5	5	
Buy-out	0	0	4	8	12	16	20	20	20	20	
Abst/Crop	0	0	2	4	6	8	10	10	10	15	
Total Reduction: Irrigation	0	0	7	14	21	28	35	35	35	40	
Reuse	0	0	0	0	10	10	10	10	10	15	Starting 2005 in Dulayl-Hashimiyah (wellfields 3&4)
M&I (rehab)	0	0	0	0	2	4	6	8	10	10	
M&I (Disi and others)	0	0	0	0	3	6	9	12	16	20	
Total Reduction: M&I	0	0	0	0	5	10	15	20	26	30	
Planned Abstraction	**145**	**155**	**148**	**141**	**119**	**107**	**95**	**90**	**84**	**70**	

5.3 Impacts of Over-pumping on Salinity

A three-dimensional finite difference solute transport model was used to track the salinity concentration and assess the build up based on existing and future abstraction activities. Based on the objectives of this study, MT3D solute transport model was selected, MT3D runs under GMS-**G**roundwater **M**odeling **S**oftware interface. MT3D is a 3D finite difference solute transport model that includes multiple modules to model advection, dispersion, sources and sinks, and chemical reactions. For the purpose of this project only the solute transport by advection was modeled. The flow model was run for Scenario NM2, no-management-two scenario. Then the solute transport model was run with the flow results as one of the inputs. Porosity and the initial salinity distribution were also inputted. A porosity of 0.3 was used while the salinity measured in the monitoring wells before 1970 was used as the initial condition. The 1998 measured concentrations were used as continuous spatial sources. The results are shown in Figures 5.19, indicate that by 2015 the water salinity is expected to be between 1000 and 1500 ppm in North Badia; 1500 to 2500 ppm at the corridor wells; 3,000 to 3500 ppm in Hallabat and Hashmiya areas (Wellfields 3 and 5); and reaches 5000 ppm in Zarqa and Dulayl areas (Wellfields 2 and 4).

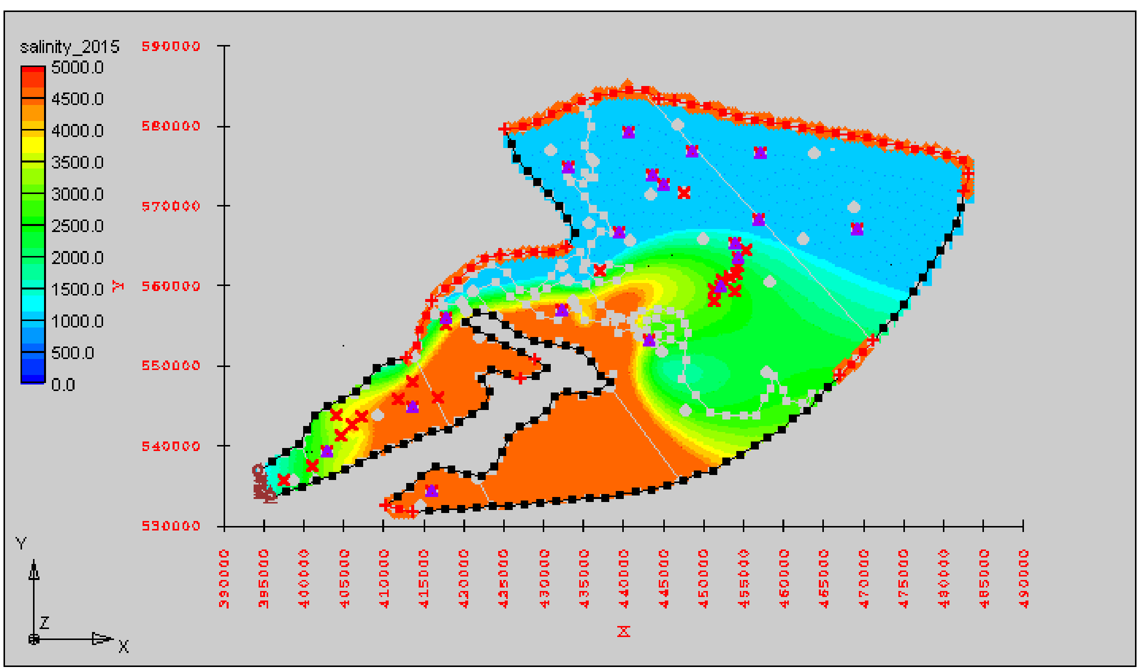


Figure 5.19 Salinity concentration map for the year 2015 based on Scenario NM2

6. CONCLUSION

A three-dimensional finite difference flow model was developed, using the Groundwater Modeling System (GMS), to predict the effects of over pumping and analyze the impacts of the above groundwater management options on the behavior of the B2-A7/Bsalt aquifer system.

This report presents the development and results of the AZB highlands groundwater model for six water use scenarios. The first two scenarios are designed to predict the impacts of over-pumping by assuming no management action for the next 20 years. The other four scenarios represent alternatives for combining the above five groundwater use curtailment options.

The first no management scenario assumes a continuation of over-abstraction without being controlled. The model shows that scenario is expected to lead to a drying up of 70% of the wells (74 wells) in the Hashimiya-Dulayl-Hallabat area within the next 15 years, and a water table drop by an additional 10 to 30 meters in many parts of the aquifer, including the corridor wellfield with 16 meters drawdown.

The second no management scenario assumes a continuation of over-abstraction without being controlled at the Jordanian side, in addition to a decrease of 50% of indirect recharge from Mountain Arab area, as a result of a possible increase of abstraction in the Syrian side of the basin by 23.5 MCM.

The model indicates that this scenario would result, within the next 15 years, in a drying up of 70% of the wells (74 wells) in the Hashimiya-Dulayl-Hallabat area and all the wells in Wellfield 13 located in the northwest of the corridor wells. In addition to a significant water table drop in Khaldiya, North Badia, and the corridor area.

The identified groundwater use reduction options were also grouped in four (4) scenarios, starting with a minimum reduction for scenario 1 and progressing to a maximum reduction for scenario 4. Scenarios 1 and 2 include three irrigation water use reduction options namely Irrigation Advisory Service (IAS), wells buy out, and enforcing abstraction limits. They correspond to a reduction of 30 MCM and 40 MCM for scenarios 1 and 2, respectively. Scenario 3 leads to a 55 MCM reduction, which encompasses the options of scenario 2 in addition to the 15 MCM of reuse option. Scenario 4 has a total reduction of 85 MCM including all options in scenario 3 in addition to 30 MCM M&I reduction. This scenario would result in a sustainable abstraction from the highland aquifers equivalent to of 70 MCM/year.

The model shows that scenario 1 is expected to lead; in the next 20 years; to a moderate groundwater level recovery of around 2 meters in Hashimiya (Wellfield 3), and It would attenuate the rate of drawdown in the other basin areas, thus avoiding drying up of wells. Scenario 2 has further improved the groundwater situation, and slowed down the water table decline in many parts of the basin, especially in the agricultural wellfield areas. The model also demonstrates that a groundwater mound is expected to form under the Hashimiya-Dulayl as a direct result of significant groundwater use reduction due to the exchange of groundwater with treated wastewater, however, the water table in the remaining parts of the basin would almost the same behavior as that portrayed by scenario 2. And scenario 4 would improve significantly the water table in most parts of AZB highlands. The impact of scenario 4 is especially reflected in the moderate water level rise in Sabha area (Wellfield 11) and in the M&I wellfields at the outskirts of Amman (Wellfield 1) and south of Addafyaneh (wellfield 16), in addition to the formation of groundwater mound under Hashimiya-Dulayl and the attenuation of water level decline in the north Badia (Wellfields 8, 9, 10, and 12), and Khaldiya (Wellfield 7).

The impacts of over-pumping on the groundwater salinity were also analyzed by applying the solute transport model of the Groundwater Modeling Software interface to the first no management scenario, described above. The model indicates that by 2015 the water salinity is expected to be between 1000 and 1500 ppm in North Badia; 1500 to 2500 ppm at the corridor wells; 3,000 to 3500 ppm in Hallabat and Hashmiya areas (Wellfields 3 and 5); and reaches 5000 ppm in Zarqa and Dulayl areas (Wellfields 2 and 4).

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APPENDICES

Appendix 1: Summary of drawdown results for the different scenarios

Drawdown (m)	Transient	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	1965	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1970	2.41	2.22	1.35	10.00	3.06	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	1975	6.56	3.88	2.33	21.27	6.90	0.00	0.71	0.02	0.00	0.05	0.00	0.00	0.03	0.00	0.05	0.00	0.07
	1980	11.24	5.47	3.26	26.61	9.82	0.00	1.58	0.35	0.36	1.93	0.32	0.12	0.13	0.02	2.23	0.18	0.22
	1985	14.46	6.43	4.45	25.40	13.19	0.05	3.34	1.95	4.35	5.70	2.38	0.43	0.42	0.10	7.07	0.94	0.49
	1990	16.87	8.37	6.17	22.37	17.29	0.28	5.58	4.12	10.43	9.03	5.29	1.06	1.47	0.38	11.52	5.73	1.03
	1995	19.01	11.90	8.33	20.61	22.35	0.53	7.45	6.33	14.63	11.90	7.70	2.25	6.60	1.46	15.43	12.43	2.19
	1998	21.27	14.95	10.60	21.83	26.21	0.58	9.25	8.07	17.20	13.94	9.60	3.33	13.72	2.21	18.64	15.59	3.19

Drawdown (m)	Scenario# NM1	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	25.52	18.89	18.96	29.90	40.82	0.81	14.57	12.59	26.18	19.85	13.96	5.01	30.02	3.62	24.53	19.59	11.99
	2010	27.57	20.77	Dry	32.06	45.94	0.89	16.91	14.75	28.78	22.40	14.54	5.24	35.92	3.84	27.34	20.77	15.33
	2015	29.44	22.47	Dry	33.98	Dry	0.95	19.10	16.72	30.80	24.49	14.94	5.38	40.06	3.97	29.69	21.48	17.66
	2020	31.18	24.06	Dry	35.42	Dry	1.00	21.08	18.53	32.55	26.27	15.26	5.47	43.47	4.06	31.72	21.95	19.12
Drawdown (m)	Scenario# NM2	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	25.52	18.89	18.89	29.79	40.55	0.81	14.32	12.36	26.32	20.14	18.62	12.61	31.93	9.09	24.90	25.69	12.69
	2010	27.57	20.77	Dry	31.94	45.05	0.89	16.84	14.59	29.72	23.73	22.35	16.94	40.95	12.19	28.93	32.01	17.17
	2015	29.44	22.46	Dry	33.88	53.09	0.95	19.28	16.68	32.67	26.49	24.73	19.72	Dry	14.21	31.37	37.41	20.24
	2020	31.18	24.06	Dry	35.37	Dry	1.00	21.34	18.65	35.18	27.89	25.94	21.36	Dry	15.44	32.32	41.04	21.30

Drawdown (m)	Scenario#1	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	25.52	18.89	10.31	26.84	34.42	0.74	13.63	11.75	23.14	18.90	12.30	4.40	26.00	2.83	24.11	18.77	11.23
	2010	27.57	20.77	8.89	24.38	30.15	0.70	14.51	12.31	20.69	19.66	10.78	4.05	26.51	2.91	25.85	19.58	14.37
	2015	29.44	22.46	8.61	24.30	30.27	0.71	15.83	13.28	20.55	20.60	10.67	4.06	28.07	3.05	27.15	20.06	16.07
	2020	31.18	24.06	8.76	24.81	31.45	0.73	17.10	14.31	21.08	21.59	10.84	4.14	29.65	3.18	28.35	20.44	17.25

Drawdown (m)	Scenario#2	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	25.52	18.89	10.00	26.02	32.97	0.72	13.40	11.53	22.34	18.67	11.85	4.30	25.17	2.78	24.05	18.74	11.21
	2010	27.57	20.77	7.86	22.03	26.43	0.64	13.76	11.52	18.37	18.80	9.58	3.69	23.98	2.74	25.41	19.45	14.57
	2015	29.44	22.46	7.39	21.42	25.87	0.63	14.81	12.19	17.77	19.38	9.35	3.70	25.15	2.84	26.38	19.75	15.74
	2020	31.18	24.06	7.46	21.58	26.62	0.64	15.88	12.98	18.06	20.16	9.48	3.77	26.44	2.95	27.37	20.07	16.79

Drawdown (m)	Scenario#3	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	25.52	18.89	8.97	22.52	32.97	0.73	13.40	11.53	22.34	18.67	11.85	4.27	25.17	2.78	24.05	18.74	11.21
	2010	27.57	20.77	3.80	12.04	26.33	0.64	13.74	11.52	18.37	18.80	9.58	3.62	23.98	2.74	25.41	19.44	14.57
	2015	29.44	22.46	2.07	8.94	25.50	0.63	14.69	12.19	17.76	19.37	9.35	3.70	25.15	2.84	26.37	19.74	15.74
	2020	31.18	24.06	1.84	8.16	25.91	0.64	15.61	12.96	18.06	20.13	9.48	3.77	26.43	2.95	27.34	20.07	16.77

Drawdown (m)	Scenario#4	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	25.15	18.60	8.97	22.52	32.97	0.73	13.40	11.53	22.34	18.62	11.84	4.26	25.16	2.78	23.70	18.12	11.21
	2010	21.29	15.73	3.80	12.04	26.32	0.64	13.62	11.51	18.28	17.34	9.34	3.43	23.51	2.55	19.92	11.75	14.09
	2015	20.08	14.90	2.03	8.94	25.49	0.63	14.20	12.10	17.34	16.43	8.70	3.20	23.69	2.47	18.54	10.77	15.32
	2020	20.10	15.13	1.73	8.14	25.84	0.64	14.68	12.72	17.27	16.34	8.63	3.20	24.38	2.52	18.45	10.86	16.08

Appendix 2: Summary of relative drawdown results for the different scenarios

Drawdown (m)	Scenario#NM1	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	0.25	0.20	0.44	0.25	0.31	0.01	0.13	0.11	0.21	0.19	0.12	0.04	0.25	0.03	0.24	0.20	0.12
	2010	0.27	0.22	0.46	0.26	0.33	0.01	0.15	0.13	0.22	0.20	0.12	0.05	0.30	0.04	0.27	0.21	0.15
	2015	0.29	0.23	0.48	0.27	0.36	0.01	0.17	0.14	0.24	0.22	0.12	0.05	0.32	0.04	0.28	0.21	0.17
	2020	0.30	0.25	0.49	0.28	0.37	0.01	0.19	0.16	0.25	0.23	0.13	0.05	0.34	0.04	0.30	0.22	0.19

Drawdown (m)	Scenario#NM2	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	0.25	0.20	0.65	0.31	0.42	0.01	0.15	0.13	0.27	0.21	0.14	0.05	0.31	0.04	0.25	0.20	0.12
	2010	0.27	0.22	Dry	0.33	0.47	0.01	0.18	0.15	0.30	0.23	0.15	0.05	0.37	0.04	0.28	0.22	0.16
	2015	0.29	0.23	Dry	0.35	Dry	0.01	0.20	0.17	0.32	0.25	0.15	0.06	0.41	0.04	0.31	0.22	0.18
	2020	0.30	0.25	Dry	0.37	Dry	0.01	0.22	0.19	0.34	0.27	0.16	0.06	0.45	0.04	0.33	0.23	0.20

Drawdown (m)	Scenario#1	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	0.25	0.20	0.65	0.31	dry	0.01	0.15	0.13	0.27	0.21	0.19	0.13	0.33	0.09	0.26	0.27	0.13
	2010	0.27	0.22	Dry	0.33	dry	0.01	0.17	0.15	0.31	0.25	0.23	0.18	0.42	0.13	0.30	0.33	0.18
	2015	0.29	0.23	Dry	0.35	dry	0.01	0.20	0.17	0.34	0.27	0.26	0.20	dry	0.15	0.32	0.39	0.21
	2020	0.30	0.25	Dry	0.37	dry	0.01	0.22	0.19	0.36	0.29	0.27	0.22	dry	0.16	0.33	0.42	0.22

Drawdown (m)	Scenario#2	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	0.25	0.20	0.35	0.29	0.49	0.01	0.12	0.15	0.38	0.18	0.15	0.05	0.40	0.02	0.24	0.27	0.10
	2010	0.27	0.22	0.30	0.26	0.43	0.01	0.13	0.16	0.34	0.19	0.13	0.05	0.40	0.02	0.25	0.28	0.13
	2015	0.29	0.23	0.29	0.26	0.43	0.01	0.14	0.17	0.33	0.20	0.13	0.05	0.43	0.02	0.27	0.29	0.15
	2020	0.30	0.25	0.30	0.27	0.45	0.01	0.16	0.18	0.34	0.21	0.13	0.05	0.45	0.02	0.28	0.30	0.16

Appendix 2: Summary of relative drawdown results for the different scenarios

Drawdown (m)	Scenario#3	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	0.25	0.20	0.31	0.24	0.47	0.01	0.12	0.15	0.36	0.18	0.14	0.05	0.38	0.02	0.24	0.27	0.10
	2010	0.27	0.22	0.13	0.13	0.37	0.01	0.13	0.15	0.30	0.18	0.12	0.04	0.37	0.02	0.25	0.28	0.13
	2015	0.29	0.23	0.08	0.10	0.36	0.01	0.13	0.15	0.29	0.18	0.11	0.04	0.38	0.02	0.26	0.29	0.14
	2020	0.30	0.25	0.06	0.09	0.37	0.01	0.14	0.16	0.29	0.19	0.11	0.04	0.40	0.02	0.27	0.29	0.15

Drawdown (m)	Scenario#4	Well Field #1B	2A	3B	4	5	6	7	8	9	10	11	12	13	14	15A	16	17E
	2005	0.24	0.19	0.31	0.24	0.47	0.01	0.12	0.15	0.36	0.18	0.14	0.05	0.38	0.02	0.23	0.26	0.10
	2010	0.21	0.16	0.13	0.13	0.37	0.01	0.12	0.15	0.30	0.17	0.11	0.04	0.36	0.02	0.20	0.17	0.13
	2015	0.20	0.15	0.07	0.10	0.36	0.01	0.13	0.15	0.28	0.16	0.11	0.04	0.36	0.02	0.18	0.16	0.14
	2020	0.20	0.16	0.06	0.09	0.37	0.01	0.13	0.16	0.28	0.16	0.10	0.04	0.37	0.02	0.18	0.16	0.15