3. PATTERNS OF WATER UTILIZATION

3.1 Water Use in Irrigation

3.1.1 Irrigated Areas

The location of irrigated lands within the Barada and Awaj Basin is illustrated on Figure C-3.1, the total area is 664 km^2. The main irrigated area is the Damascus Ghouta which occupies the alluvial fan of the Barada and is watered by it's many distributary canals. The Ghouta has an area of just over 370 km^2. The irrigation follows the course of the Sebrani and Janani rivers from there headwaters, initially confined within the narrow valleys but broadening on the alluvial fans. There are also irrigated lands occupying the intermontane valleys such as the Zabadani, Sergaya, Saboura and Sednaya areas. The area of irrigated land has not been assessed since the mid 1980's, however the senior technical staff at the MOI Barada and Awaj Center verbally informed the JICA team that there has been no change in either overall irrigated area or usage. Changes, it was said, have occurred but they have been a case of abandoning one area in exchange for a new area, and a progressive switch from surface water to groundwater sources.

3.1.2 Irrigation Volumes

The total annual volume of irrigation in the basin is about 1,000 MCM used with an annual application of 1,480 mm/y. Within the Ghouta, the rates are much higher than the average, 669 MCM are used at an application rate of 1,800 mm/y, while for the rest of the basin 1,080 mm/y are used. These totals comprise both surface and groundwater sources. The breakdown of the total volume for the Ghouta is available, with 31% groundwater, 23% surface water and the remaining 46% from both sources. A summary of the available information is found in Table C-3.1.

3.1.3 Irrigation Practice

Surface water is conveyed to agricultural land by the main canals. Where possible the off-takes are by gravity flow control and a network of minor channels. Elsewhere water is pumped from the canals and stretches of the Barada River they taken by pipeline to the crops. Groundwater is taken from tube wells generally with surface mounted vertical lift pumps powered by a separate diesel engine. Regardless of the origin of the water the method of use is similar. Water is allowed to flood along shallow furrows between ridges with the crops. There is little or no spray or drip irrigation practiced in the Barada and Awaj catchment.

3.2 Water Use in Water Supply

3.2.1 Damascus Rural Governorate

The water supply for the towns and villages in the Damascus Rural Governorate are supplied by EDWSSR. The sources used by EDWSSR are listed in Table C-3.2, and those that are within the Barada & Awaj Basin near to Damascus are located on a map, Figure C-3.2. In total the installed capacity of the establishment is 4.3 m^3/s, if the sources are used at 75% of capacity over the year then 101.4 MCM will be used. The predominant source is groundwater (97%) while springs make up the remainder, there are no surface waters used for municipal supply. The greatest concentration of population is in the ring of urbanization from Daraya in the south to Dumma in the north that surrounds the eastern side of Damascus. It is within this zone the largest abstraction and usage occurs.

3.2.2 Damascus City Governorate

The usage of water in Damascus City Governorate area is from groundwater sources and is described in section 4 of this appendix.

3.2.3 Industry

Industry and technological enterprises have been estimated to use 12 MCM/y in the 1980's Lengiprovodkhoz (1986). The responsibility for managing and licensing these abstractors lies with the Municipality within the City Governorate and with the MOI in the Rural Governorate. It has not been possible to obtain more up to date information on industrial water consumption patterns from the Municipal authority.

3.2.4 Net Water Usage

By comparison of natural and current water flows in the rivers the net effect of the all water usage is seen. The natural flows in the river system have been assessed and this may be compared to the current conditions. Data collected in the last 10 years have been of the modified flow regime and shed light upon the modified conditions for the river basin. By a comparison of the assessed natural flows and the current situation the influence of the human activities in irrigation and water supply, may be quantified in the absence of any more direct other data.

Determination of present stream flows records from the stream flow measuring stations in use on the rivers and its tributaries and canals. These are operated by the MOI. Monthly data was provided for the use in this study for the hydrologic years 1990-91 to 1993-94. The data cover a period with greater than average rainfall and so the use of the numbers in an average would give a distorted picture of the true situation. The rainfall being perhaps 125% of the long term mean rainfall as determined from DAWSSA's observation network. The year 1990-91 received just above the mean rainfall and was preceded by a dry year while 1993-94 received just below the mean rainfall and was preceded by a wet year. To represent the current conditions stream flows have been taken to be the mean of these two years. This method though crude and unsophisticated is a pragmatic approach.

The net use in the sections of the catchment were the method may be applied are tabulated in Table C-3.2. The net quantities used in the upper section of the Awaj system are small, the majority of the use occurring in the agricultural land near Saasaa. Similarly in the Barada catchment the reduction of flow on Wadi Karren is small, but the main course of the river in the Zabadani Valley is significantly effected.

4. GROUNDWATER ABSTRACTION

4.1 Abstraction from Quaternary Alluvial-Proluvial Aquifers

4.1.1 DAWSSA Sources

In the city DAWSSA operated 7 wellfields in 1995 with a combined abstraction 30 MCM plus another 4.1 MCM from the Fringe Wells. A peak output of 167,400 m^3/d (1.94 m^3/s) was achieved during September. The wellfield are used in periods when the discharge from Figeh spring is insufficient to meet the demands, Figure C-4.1. This period has been from June to February in recent years with a peak period from September to November. Figure C-4.2 shows the mean pattern of abstraction for the whole period. There has been a steady increase in the use of the city wellfields over the 10 years indicated by the monthly abstraction data. The rise, shown in Figure C-4.3 is about 50,000 m^3/d (0.58 m^3/s) every seven years for the peak month abstractions. The change is due to the use of new wellfields and the more intensive utilization of the wells at the existing stations. The output from individual wellfields on a monthly basis are provided in Data Book 3 in both tabular and graphical formats.

4.1.2 Damascus Municipality Sources

The city authority operates 55 wells for the purpose of irrigating the gardens and street cleaning. The individual wells are not metered and so there is no direct way to determine their abstraction quantity. The pumps installed in the wells are from 7.5 to 100 HP in power with 20 HP being the most common. The total power is 1,111 kW (1,490 HP) from all 55 wells. By comparison with the DAWSSA fringe wells in which a 25 kW pump provides 50 m^3/h abstraction a rough measure of the potential pumped quantities is calculated as about 0.6 m^3/s. Since the holes are operated on a 6 hours per day basis the sources could give up to 4.7 MCM in a full year. It is expected that this is an upper limit since the garden irrigation does not take place throughout the year. A more realistic total annual abstraction being 3.5 MCM/y.

The current situation may be compared with 1985 when the Municipality abstracted 10.6 MCM/y from 103 wells within the city. The total at that time included all the DAWSSA wells which then were operated by the Municipality.

4.1.3 EDWSSR Sources

The Establishment of Drinking Water Supply in the Rural Province of Damascus (EDWSSR) supplies water to the area surrounding Damascus in the Rural Governorate. The population served within the Barada and Awaj Basin was estimated to be over 990,000 in 1985, and consuming over 56 MCM/y, from groundwater and spring sources. Information provided by EDWSSR in 1996 is presented as a map of the source locations, Figure C-3.2, while Table C-3.2 itemizes each source and it's capacity. The majority of the abstraction is concentrated in the heavily populated Ghouta; the supply districts of Douma, Harasta, Erbeen, Babbila, Jaramana, Kafan Batna, Dariah and Sehnaya, with a capacity of 1.94 m^3/s, (61.10 MCM/y). Other parts of the lowlands around Damascus are much less heavily populated and have a commensurately lower water usage. The total capacity in the sources in the lowlands is 2.57 m^3/s.

4.1.4 Irrigation Sources

The main irrigated zone lies in a swath to the east and south of Damascus in the area known as the Ghouta. A further irrigated area fed by water from the Awaj River lies in a similar topographic position to the south of the Ghouta. In addition irrigation in the intermontaine basins such as the Zabadani, Sergaya and Sednaya valleys are dependent upon groundwaters. The waters from the Barada have fed the fields in the Ghouta for thousands of years, but the extent of the irrigation has increased dramatically in the second half of the twenty century. In 1947 there were just 622 wells in the Ghouta, in the early 1980's this had mushroomed to 16,200 while currently it is estimated by MOI that there may be in excess of 30,000, or about one brothel per hectare of land. The area of irrigated land and volume of groundwater withdrawals has increased in a similar manner from 74 km^2 using 53.2 MCM/y in 1947 to 371 km^2 using 293 MCM/y in the early 1980's. The extent of the irrigated land in 1985 is shown in Figure C-3.1, and a summary of the irrigated areas in Table C-3.1. It is stated by the MOI that both the area and water consumption in irrigation has remained constant in the last ten years. However the balance of water usage may have tended to switch from surface water to groundwater as the streams have become less reliable in both quality and quantity.

4.1.5 Other Groundwater Abstractions

Industry and technological enterprises have been estimated to use 12 MCM/y. The responsibility for managing and licensing these abstractors lies with the Municipality within the City Governorate and with the MOI in the Rural Governorate. Prior to the construction of a well and also prior to the abstraction of water the relevant authority must issue a license. The Municipality has issued 512 licenses in the period 1975 to 1996, 15 of which are industrial and 497 are for domestic uses. This does not reflect the true situation of actual wells or abstractors since many have been constructed and pumped without licenses.

The build up of abstractions in the city area was considered to be a problem as early as 1961 when there were 200 wells in the city. A complete ban on the construction further holes and abstractions was issued by the government at the time. This ban remained in force until 1976 when a revision was made. All new buildings that were to be over 7 floors high or would have an area of over 3000 m^2 were required to have a well prior to construction. The well was to provided water for the construction and subsequently for cleaning and garden watering. The license for the well stipulated the capacity of the pump that could be installed and normally limited the output by requiring a rising main of only 1" or 1.5". The implementation of the licensing system has been rigorously enforced with many wells constructed and operated without the necessary licenses from the Municipal authorizes. To identify the actual situation a survey was held collaboratively by the MOI and Municipality in 1990. A report prepared of the survey has been requested from the Municipality, however this could not be made available to DAWSSA. It is understood that there may be about 6000 wells inside the city identified by the report. The Municipality perceives there to be a problem with the extent of the illegal abstractions within the city. To combat the problem the Mayor of the city issued a declaration that required all unlicensed wells to be notified and a license application submitted. Wells that continued to be used would be backfilled. The text of the Mayor's declaration was given only a limited circulation to official organizations and not to the general public. By the time that the deadline for the submission of applications had been reached the response had been, by their own admission, very weak. Until the authorities take a more determined approach to illegal groundwater use there is unlikely to be any change in the situation. So for the purposes of the Master Plan, since it lies outside control of DAWSSA, abstraction in the city will be the same or will increase.

4.2 Abstraction from Jurassic - Cretaceous Limestone Aquifers

4.2.1 DAWSSA Spring Sources

The abstraction from Figeh Spring comprises the majority of all water supplied by DAWSSA. The quantity taken varies seasonally with the demand and the natural discharge. The hydrology of the spring is explained in detail in section 2.4.5 (2), in summary though. During the spring flood period of February to March there is a natural discharge greater than the demand from Damascus, and larger than the capacity of the tunnels. Water is permitted to discharge into the Barada River. After the peak discharge the flows will diminish in a predictable manner to a minimum near the end of the year. All the water from the spring may be taken, and the discharge is artificially increased by pumping and lowering the spring base level. The average quantity abstracted by DAWSSA over the last 10 years has been 5.03 m^3/s, with a seasonal average minimum of 4.0 in November and a maximum of 6.4 m^3/s in May. These figures mask a wider fluctuation, the records in the last 10 years are a peak monthly abstraction of 8.4 m^3/s in August 1992, and a minimum of 2.9 m^3/s was used in January 1990 during a low flows, Figure C-4.4.

4.2.2 DAWSSA Well Sources

The Barada Spring wellfield has been in operation since July 1995 and has been steadily increased to the operational production rate of about 100,000 m^3/d. The Dummar wellfield is no longer in use as the station is undergoing redevelopment.

4.2.3 EDWSSR Sources

The settlements in the Rural Governorate in the mountainous areas is supplied by many smaller springs and minor wellfields. There is a total capacity of 0.709 m^3/s from groundwaters, (86% from wells and only 14% from springs).

4.3 Abstraction from Minor Aquifers

The population in Rural Governorate is locally supplied from minor aquifers with a total source capacity of 0.38 m^3/s.

5. WELL INVENTORY

5.1 General

There are very large number of wells in the Damascus Basin, ten years ago it was estimated that there were over 16,000 with about 750 within the Damascus Urban area. Today it is estimated by the MOI that there may be 30,000 wells. The majority of these are private irrigation wells. Others are operated by the MOI, DAWSSA and the Damascus Municipality.

A catalogue of 402 wells is collated in the Soviet report. The catalogue provides lithological logs of the wells as well as brief construction and testing details. These wells are from all over the Barada and Awaj Basins and include some of the DAWSSA wells. Information about wells constructed since 1985 by the MOI and DAWSSA have been collated and incorporated into the data which is presented in the Data Book 1.

A well inventory has been prepared for all the known DAWSSA wells. The information has been collated from construction drawings, site plans, city maps, field reconnaissance and interviews with DAWSSA staff. All the wells are listed in the inventory, which their type is summarized in Table C-5.1. The observation wells within Damascus which are particularly important in the water resources monitoring program, are listed separately in Table C-5.2.

The numbering systems for wells in operational wellfields differs from that used in the recording of the drilling and pump testing data. In order that future confusion of well numbers may be minimized both the current operational number of the well and the drilling number are included in the inventory.

The geographic location of the wells is provided in two coordinate systems. The Universal Transverse Mercator (UTM) system and the Syrian Cadaster National Grid. The positions of wells have been taken from the best available site plan or map available for the area.

The well inventory information is held on Lotus 123 spreadsheet files and the United Nations groundwater database, "Groundwater for Windows". The GWW files and the associated database software has been provided to DAWSSA as part of the second field input. The data can be updated as further wells are constructed or tested and other hydrogeological information such as water levels and chemical analysis are collected.

5.2 Hydrogeological Monitoring Networks

A well network was established in the Damascus Basin in the late 1950's and early 1960's for the purpose of monitoring the effects of pumping on the groundwater levels. Of the 159 observation wells in the area only 17 have been monitored for a relative long period between 1975 and 1986. The most of the remainder have only a 5 year record collected as part of the hydrogeological assessment investigations, USSR(1986). The investigation wells in the vicinity of Damascus are shown on Figure C-5.1

The monitoring network used by DAWSSA is concentrated upon observing the water levels in the operational wellfields during their period of operation. The wells are either specially drilled holes with 3" casing or are larger diameter production wells with a low yield. A summary of the observation wells is given in Table C-5.2, while other details may be obtained from the well inventory in Data Book 1. There is a network of 7 new observation wells which are located throughout the city, and 3 holes in unused wellfields. Of the new observation wells, only one is currently monitored by DAWSSA (Diwania Gardens). The other observation holes are reported to be filled with sand or inaccessible, for these reasons they have not been used for their intended purpose.

6. PRESENT WATER RESOURCES OF DAWSSA

6.1 Water Resources Organization in Syria

The Ministry of Irrigation (MOI) is the governmental body within Syria that is designated the responsibility for coordinating water usage and planning future water resources development. The Ministry has the authority to issue licenses for the abstraction of water from surface and underground sources. Due to the historical development of the EPEF it was given the right to the water from Figeh and groundwater within the municipality of Damascus. These rights have been carried over to EPEF's successor establishment, DAWSSA. Within the municipality, the management of water resources, other than those utilized by DAWSSA, is under the overall control of the MOI. However the licensing of abstractions has been delegated to the Damascus Municipality. Possibly as a result of these three organizations, (MOI, Municipality and DAWSSA) all having an interest in Damascus, water resources planning and abstraction licensing is somewhat haphazard.

6.2 Potential Water Resources Available to DAWSSA

The water resources that are available for use in the vicinity of Damascus are already almost fully committed to water supply and irrigation uses. In the preparation of the Master Plan the maximum utilization of the existing sources is proposed together with limited development of new sources. The rough estimate of the resources is given in the following table.

Source	Total Replenished Resource with acceptable water Quality (MCM/y)	Estimated Resource available to DAWSSA (MCM/y)
Figeh Source	220	220
Barada Source	100	34
Sergaya Area	9	3
Deir al Ashayer Area	7	3
Damascus Quaternary	50	50

At present about 130 to 185 MCM/y are used from Figeh Source and up to 35 MCM/y from Damascus. The unused portion of the Figeh source over flows into the Barada River during the flood season when the quantity of water from this single spring exceeds the requirement of Damascus. The natural flow of the Barada is about 100 MCM/y, however not all of this is available for use. The flow has reduced to about 70 MCM/y, the water probably being intercepted by irrigation wells before reaching the spring. The MOI has allocated a 34 MCM/y tranche for use by DAWSSA. The estimates of the resources in the Jurassic aquifer east of Sergaya and the Cretaceous around Deir al Ashayer is based upon water balances for the aquifer units. The water in these two areas is already used for local water supply and irrigation the amount that may be taken is therefore limited. The source of Wadi Marwan is the Cretaceous aquifer block that also supplies Figeh spring. It is anticipated that the use of Wadi Marwan will not create any new resources but will share those that naturally discharge from Figeh. For that reason it is not included in the list of water resources.

The groundwater resources under Damascus are not clearly quantified. Broadly, the resources in the mountainous areas comprise the rainfall less evapotranspiration. Whereas on the plains and foothills the quantification of resources is more complicated. The rainfall less evapotranspiration is much less or negative, and the water resources are those that enter the area either by groundwater flow, surface water streams or conveyed by public water supply distribution systems. The water balance of the whole catchment has been estimated for natural conditions and for the mid 1980's. This balance has been updated with data as is available for the mid 1990's. The zones where the water balance is most different to those pertaining to natural conditions is the city of Damascus and the Ghouta. It is this region where large and un-measured fluxes occur. The groundwater resources usable by DAWSSA have been set at about 50 MCM/y which would be derived from groundwater flow into the area from the Cretaceous, less through-flow of groundwater towards the Ghouta. To this should be added a very small contribution from infiltrated winter rainfall, and then a significant quantity due to leakage from the distribution system, canals, river bed, and, waste water systems. From the groundwater DAWSSA has taken 35 MCM/y and other abstractors an unknown amount. The maximum exploitable quantity is higher than that used at the present. The value of 50 MCM is approximately half the estimated storage in the Pebble Beds, this is assumed to be the safe limit.

Within the duration of the Master Plan schemes will be implemented may reduce recharge to the aquifer. Firstly the leakage from the distribution system is to be reduced especially in the informal areas of the city. Secondly connection to the sewerage system will become more wide spread. This will reduce seepage from soak-aways and for those settlements upstream of Damascus reduce the flow in the river and irrigation canals through the city. If these schemes are successful and there is an overall reduction in absolute amounts of water losses, groundwater recharge quantity will reduce even though the quality will be safe-guarded.

6.3 Previous Recommendations on Water Sources

A large study of the Barada and Awaj catchment undertaken by a team of Soviet experts was undertaken in the early 1980's, Lengiprovodkhoz(1986). The purpose of the work was to provide overall report on water resources and a guide for the planning for water use in the catchment for public water supply for Damascus, and predominantly, irrigation uses. The study found that there were some further water resources that could be used to serve Damascus. These new sources are listed in Table C-6.1.

6.3.1 Springs

The water resource potential to supply Damascus from Figeh was considered to be a fixed quantity. However the regulation of the spring flow might be achieved by the pumping in the recession period depleting the aquifer storage which would be replaced by recharge the following winter.

Barada spring was proposed as a source with a capacity of 81 MCM (2.56 m^3/s) over a year. This source has been adopted by DAWSSA but abstraction from a wellfield surrounding the spring and a much lower total capacity.

6.3.2 Groundwater

Cretaceous & Jurassic of Ash-Sheikh Region, 6 wellfields producing 1.366 m^3/s were proposed. The Cretaceous of Sharki-Kalamoon Region, was proposed to be used with a single wellfield producing 0.300 m^3/s. The Jurassic aquifer of the Barada spring was proposed for the use of 3 wells with a capacity of 20 MCM/y providing an average output of 0.630 m^3/s.

The use of the springs at the headwaters of the Awaj River was proposed, namely Beit Jenn, Talmasiyeh and Tabibiyeh was also considered a possible source for water resources.

The aquifer under Damascus City was considered, to have the best water quality and well yields. The construction of six wellfields at Mazraa, Oumawiyin, Jobar, Kaboon, Ibn Assaker and Kadam was proposed giving an extra 7 MCM/y, with a peak yield of 1.427 m^3/s. These wellfields have all been constructed and are in operation.

The Upper Quaternary aquifer in the central part of the Damascus Depression was identified for the installation of 6 new wellfields (Mapkara, Shifonieh, Jaramana, Bale/Deir al Assafir, Darasalama, Kasmiyeh). The total yield to increase in a stages to 39 MCM/y then to 83 MCM/y. A peak capacity of 1.018 m^3/s was anticipated. Most of these lie in the area of EDWSSR and as such were not in DAWSSA's area for exploration. Jaramana, which lies just within the city area has been drilled and awaits commissioning.

The Ghouta wellfields have not been implemented due to financial and technical problems. The main technical problem is the water quality in the aquifer south east of the city. The groundwaters are thought to be contaminated by infiltration of polluted surface waters, pesticides and salts. However, DAWSSA has not ruled out their future construction. The planned abstraction of 83 MCM/y is perhaps unrealistically high, since yields from wells in the Ghouta are about 10 l/s, so almost 300 wells would be required to meet the planned target.

6.3.3 Surface Water

The scheme was designed to take water from the Barada River and any flow in the Awaj River and store it in a large off channel reservoir 12 km south of Damascus. A barrage on the Barada near Kudsaya would divert water into a tunnel through the mountain to emerge near Daraya. From there it would be conveyed by canal and gallery and cute to the reservoir. The design for the reservoir is to hold a live storage of almost 357 MCM. Water would be pumped from the reservoir back to a treatment plant south west of the city. The scheme also required the protection of river water quality from Barada to the diversion structure at Kudsaya. The settlements along the course of the Barada should not discharge untreated waste water into the river and urban run off in Kudsaya is to be directed away from the river. The timetable was for construction to take place over a seven year period.

The plan for the construction of a dam has been shelved by the Syrian government. The decision was made by the Prime Minister because there is firstly insufficient water within the Barada River, secondly there was no economic advantage from the scheme, thirdly the work would have taken up valuable agricultural land and villages and finally water would need to be treated prior to use in the public supply network.

6.3.4 Water Conservation Measures

The Draft City Master Plan of 1994 identifies the potential for future problems in water supply and itemizes a number of ways that resources may be managed.

- Use groundwater for industrial purposes, ensuring that there is adequate treatment of water before discharge.
- Refusal of planning permission for industries that consume large quantities of water.
- Introduction of modern irrigation systems (sprinklers, drip fed) where economically and technically feasible to reduce the total volume consumed.
- Irrigation to be undertaken using treated industrial waste water.
- Introduction of a ban on the drilling of wells in the Damascus Depression.

- Construction of exploration wells in the Damascus Depression instrumented with automatic water level recorders and to use the information to manage groundwater abstractions.

6.4 Current Water Sources Capacity

The current water resources available to DAWSSA to serve the population in Damascus are summarized below, the details of individual sources are provided in a full version in Table C-6.2

Source Name and Type	Source Capacity				Seasonal Capacity
	Installed (l/s)	Minimum (l/s)	Average (l/s)	Average (m^3/d)	(MCM)
Damascus Wellfields	3,073	1,585	1,900	164,020	41.47
Figeh Sources					
Average Year	12,400	-	5,800	507,000	185.00
Dry Year	-	2,880	3,870	334,000	122.00
Barada Spring	1,100	1,100	1,100	95,000	23.27
TOTAL					
Average Year	16,573	-	8,860	771,220	249.74
Dry Year	-	5,565	6,930	598,220	186.74

6.5 Water Source Schemes in Progress

6.5.1 Figeh Side Spring.

The water intake structure at Figeh side spring consists of a sump about 8 m deep. It is equipped with 13 pumps with a theoretical total capacity of 3.25 m^3/s, however during operation they produce from a peak of 1.8 to a minimum of 1 m^3/s. A scheme to replace the existing water intake structure for Side Spring is under construction. A planned total of 20 new wells each 50 m deep and 762 mm (30") diameter are to be built. The new structure will be able to create a larger drawdown in the wells and it is anticipated that a larger yield will be available. The present operation of the wells causes a drawdown of exactly 8.8 m from 825 masl to 816.2 masl. Since the dynamic pumping water is determined by the pump depth, it does not change regardless of the pumping rate. The new wells will permit a much higher drawdown to be developed by pumping the source. It is anticipated by DAWSSA that a further 500 l/s could be added to the available resource. If this is the case the net effect will be to add another 8.6 MCM over a 200 day critical period to the total output of Figeh.

6.5.2 Ain Haroush.

The existing wells at this site are to be replaced by new deeper wells. The additional yield that will be available is expected to be about 800 l/s (69,000 m^3/d), or 13.8 MCM over a 200 day pumping period. Two wells have been drilled, each 800 mm internal diameter and 40 m deep, a third well is due to be constructed. The new wells are awaiting testing to evaluate their performance before the installation of pumps and commissioning the source.

6.5.3 Barada Group 1, 2 & 3 Wellfields

There are three wellfields north of Barada Spring that were drilled in the 1980's by the MOI. They are referred to as Groups 1,2 and 3, and are separate to Barada Spring Wellfield. The right to use these sources has been given to DAWSSA and they are in the process of commissioning the wellfields.

The wells that have been designated for inclusion in the new wellfields are itemized in Table C-6.3. The design capacities are 230, 150 and 70 l/s for the three groups with an achievable average seasonal production for the groups used for planning is 185, 120 and 60 l/s respectively.

The wells all penetrate Jurassic dolomitic limestone aquifer. Groundwater flow in the aquifer is predominantly by fissure flow, as a consequence the wells in this area display a wide range of aquifer properties, Table C-6.4. The average transmissivity is about 17,000 m^2/d and Storativty of 3%, (from analysis of Barada Spring) in the area, using these values the interference drawdowns over a 245 day period are 1.18 m, 1.62 m, and 1.85 m for wellfields 1, 2, and 3 respectively.

The equipping of the Group 2 Wellfield and the construction of the necessary pipelines and civil works is nearing completion at the time of report preparation. The source has a design capacity of 150 l/s (13,000 m^3/d). The source is to be operated in conjunction with Barada Spring wellfield, such that the total output of the two wellfields does not exceed the assigned Water Right.

6.5.4 Wellfield at Takadom

The wellfield lies in the south of the city in an area of the displaced Palestinian's housing. The wells were drilled on the perimeter of a recreational area on one side and a refuse collection center on the other. Since the wellfield was drilled in 1989 informal housing has encroached up to the edge of the site. This housing does not appear to have an effective sewage infrastructure and as such is likely to be a potential source of aquifer contamination. Out of 13 holes 11 were drilled one of which has been designated as an observation well (number 9). However to date there has been no regional water level monitoring undertaken at the site.

In 1989 the wells were performance tested with step tests and the aquifer was tested with a constant rate test. A summary of the step test results is provided in Table C-6.5. The wells divide into two groups one with small drawdown which are ideally suited for use as production wells (1,4,6,7,9,12 & 13) and the remainder which have high well losses, large drawdowns and a rapid increase in drawdown at high pumping rates (5,8,10,11). Radial flow modeling was used to obtain aquifer parameters for the site. The pumping test data from well 7, which is typical of the wells in Takadom was compared with theoretical aquifer response calculated by a radial flow model. The aquifer has a leaky confined response with a transmissivity of 800 m^2/d, a storativity of 0.0001 with a leakance of 1000 m. This information was used to calculate the steady state drawdowns at various radial distances within the wellfield, thereby enabling the estimation of the interference drawdowns that may be anticipated. The pumping water levels on the site will also experience a regional recession in water levels of perhaps 3 m during the summer season.

It is planned by DAWSSA to install 10 pumps, 3 with 120 m^3/hr capacity and 7 with 100 m^3/h capacity at this site. The three higher yield pumps are to be brought from the university wellfield and will have a head of 50 m, while the remaining 7 are new pumps awaiting installation they have a slightly lower head (40 m). The predicted drawdowns in these wells for a pumping season is given in Table C-6.5. For the Master Plan the wellfield has been rated at an average capacity of 140 l/s or 2.96 MCM in 8 months

6.5.5 Wellfield at Kadam Store

The wellfield lies in the southern area of the city about 500 m to the north west of the Kadam Railway wellfield. The wellfield is constructed in DAWWSA's general store and training center. Abutting the site is an informal housing area. The wellfield was drilled in 1983 and to date only 3 of the 10 wells on the site have been commissioned as production wells. The wells are between 72 and 86 m deep and have 9" casing. The details of the length of perforated casing are not known.

The wells in this wellfield are closer together than on other wellfields in Damascus. As a consequence the interference drawdowns will be more significant here than on the other wellfields. An estimate of the anticipated drawdowns was made using the aquifer hydraulic parameters from Takadom wellfield; transmissivity of 1000 m^2/d, storativity of 0.0001 and a leakance of 1000 m. The parameters were used in a radial flow model and the steady state drawdowns at different radial distances from a pumped well were calculated. The total drawdown at the well locations will be the sum of the individual drawdown plus the radial effects from the other 9 wells.

It is planned by DAWSSA to equip all the remaining holes on the site with pumps with a 30 m head and a 100 m^3/hr capacity. An estimate of the anticipated drawdowns is provided for each well in Table C-6.6. For the Master Plan the output from the site is estimated as an average of 170 l/s for 8 months.

6.5.6 Wellfield in Wadi Marwan

DAWSSA is working on the commissioning of a wellfield, pipeline and associated works to provide a water supply to the new development area of Kudsaya. The wellfield is located approximately 19 km west of the center of the City at UTM grid coordinates 349 km East, 3715 km North. The wadi is dry but occasionally may have a stream that would flow to the south west and south joining a broad west to east orientated wadi that discharges into the Barada River near El Hame. The wellfield comprises 16 wells, three drilled by the MOI in the 1980's and 13 constructed between May 1990 and September 1992. The wellfield has been designated to supply an the expected demand of over 250 l/s throughout the year. Most of the civil work necessary for the scheme have been completed, and those that remain are planned to be finished in 1996.

Geologically the area comprises an inlier of Cretaceous limestone in the form of a pericline with the long axis orientated north-south. The limestone being a southerly continuation of the Cretaceous that extends north east from the Barada River. Overlying and surrounding the Cretaceous is the Palaeocene-Lower Eocene that comprises chalky limestones and marls. To the north west of the site there is a major fault that is down thrown to the south, the upthrown block is the Jurassic limestone of Jabel Mezar. Neogene strata lie unconformormably above the Palaeogene in the area around the Cretaceous limestone inlier.

The aquifer underling the wellfield is Cretaceous Limestone, a southern continuation of the aquifer that feeds Figeh Spring. The Palaeocene-Lower Eocene is an aquiclude that can confine the Cretaceous limestone and separates the Cretaceous groundwater flow system from the Neogene aquifer. Groundwater levels in the Cretaceous are about 835 masl at Wadi Marwan, while in nearby holes into the Neogene the level is over 900 masl. Cretaceous groundwater has a very shallow hydraulic gradient, with either no flow or a sight gradient to the east or south, while in the Neogene flow is towards the north east along the course of the broad wadi. Water levels in the Jurassic to the west are almost 300 m higher than those at Wadi Marwan. It is considered that the fault, shown on the cross section, acts as an impermeable boundary isolating this aquifer block to the west. Water levels fluctuate within the Cretaceous limestones demonstrating that it receives annual recharge, or is hydraulically linked to such an area.

The local recharge area for the aquifer is 20 km^2 for the aquifer block up to Wadi Barada. Within this area the long term average rainfall is 350 mm/yr and the evaporation 325 mm/y. An estimate of the renewable resources may be calculated to lie from 25 mm/y (based on the local climate data) to 430 mm/y (based upon the water balance for the whole of the Figeh Catchment zone A.1.3 in which there is a surplus of rainfall exceeding evaporation of 319 MCM in an area of 732 km^2). The actual recharge into this unit may lie from about 0.5 MCM to a maximum of 8.7 MCM, since most of the Figeh catchment is higher and wetter than this area a realistic estimate for should lie closer to 0.5 MCM than 8.7 MCM. The recharge into the aquifer block could then support an average abstraction of between 15 l/s and 276 l/s. If local recharge is about 0.5 MCM, to support a major wellfield abstraction water must be induced to flow from the Figeh catchment area to the north of the Barada River. A groundwater flow under the Barada River it hydraulically feasible in this area, instead of the water discharging at Figeh spring it would be abstracted from Wadi Marwan.

The hydraulic properties of the aquifer can only be roughly estimated for the area. Although pumping tests have been conducted on all the holes the only data available within DAWSSA is a yield and drawdown. Assuming that the test was of sufficient length for the assumption of steady state conditions the transmissivity may be determined from Equation C-15.

$$T = \frac{2.303\, Q \log_e \frac{R_0}{R_w}}{2\pi s} \qquad (C.15)$$

Where

	R_w	Radius of the well
	R_o	Radius with zero drawdown, assumed to be 1000 m
	s	Drawdown in meters
	Q	Pumping rate in m^3/d
	T	Transmissivity in m^2/d

The transmissivities are in the range 200 to 76,000 m^2/d with a median value of 5,760 m^2/d, it is therefore assumed, in the absence of better information that the transmissivity is about 6,000 m^2/d in the Cretaceous limestones or a permeability of about 0.05 cm/s (44 m/d).

Water quality is good from the wellfield a single sample from a well water analysis tabulated below. The water chemistry is similar to that from Side Spring at Figeh, but with slightly high concentrations of ions, and proportionally more magnesium and chloride. The slightly high concentrations of ions, and proportionally more magnesium and chloride. The water is better than that abstracted from DAWSSA sources in the City and is acceptable for human consumption.

Parameter	Well No 4
Turbidity (mg/l)	1.5
Conductivity (mS/cm)	575
pH (-)	7.5
Total Hardness (mg/l)	300
Calcium (mg/l)	76
Magnesium (mg/l)	27
Sodium (mg/l)	18
Potassium (mg/l)	2.5
Bicarbonate (mg/l)	329
Sulfate (mg/l)	34
Chloride (mg/l)	18
Nitrate (mg/l NO_3)	5
TDS (mg/l)	345
Date	29/6/95

The wells are all about 300 m deep with 9" or wider casing with a static water level about 180 m below the surface. The known details for each well may be found in Data Book 1. The wells have been tested revealing a very wide variation in specific yield from a minimum of 2.1 to a maximum of 685 l/s/m. Since the water level is at a depth of over 165 m the actual percentage variation in pumping lift required is marginal, there is little hydraulic advantage in using one well as apposed to any other well in the wellfield. The capacity of each hole is in excess 15 l/s and quite possibly as much as 30 l/s could be pumped from each hole. This would give an overall wellfield capacity of 450 l/s or 14.2 MCM over a full year. DAWSSA plans to install 13 pumps each with a capacity of 18 l/s, however for the Master Plan the achievable quantity is 185 l/s or 5.84 MCM over a full year if pumping.

6.5.7 New Wellfield at Kaboon

A scheme for increasing the abstraction from the area of the existing wellfield is due to start in 1996. In the first phase two deep wells will be drilled, subject to these being successful in obtaining an acceptable yield a further 8 holes are planned for a second phase. For the purpose of the Master Plan it has been assumed that the wells will all be constructed and have an overall yield of 120 l/s, or 2.54 MCM in 8 months.

6.5.8 Wellfield at Dummar

The wellfield at Dummar was drilled in 1979 and 1983, it has however not been used since 1991. The wells are due to be re-commissioned to supply the local area. Five pumps with a capacity of 30 l/s are due to be installed into the wells. For the Master Plan these wells are assumed to operate throughout the year at a rate of 100 l/s, 3.14 MCM/y.

7. ALTERNATIVE FUTURE WATER RESOURCES FOR DAWSSA

7.1 Potential Sources Described

7.1.1 Hermon Area

(1) Cretaceous groundwater source at Deir al Ashayer

(a) Location and land use.

Deir al Ashayer lies within an intermontain valley about 25 km west of Damascus and 7 km south west of Tekieh, immediately west of Jabel Mazar and adjacent to the Lebanese border, Figure C-7.1. To the south east of Mazraat Deir al Ashayer, and just over the border in Lebanon lies a dried lake bed covering almost 2 km^2. The lake bed and the bottoms of the valleys are intensively used for irrigated agriculture. The area produces apples, peaches, cherries and vegetables.

(b) Geology and hydrogeology

The geology of the area comprises limestones of Cretaceous and Jurassic age. The wells penetrate a north-south elongate trough of Cretaceous limestone which lies between higher mountains of Jurassic limestone to the west and east. The eastern side of the Cretaceous is faulted against the Jurassic. The Cretaceous is hydrogeologically isolated from the Jurassic to the west and east with a high permeability zone only about 1 km wide running south to north. The Cretaceous has been proved by investigation wells numbers 308K and 809 to be up to 330 m thick. From this thickness, the aquiferous zone is only about 60 to 70 m thick at a depth of between 75 and 135 m below ground surface.

Regionally groundwater flow is from west to east in the Jurassic and Cretaceous strata, but in the Deir al Ashayer area groundwater in the Cretaceous flows to the north towards Wadi Barada. Although the water levels in the Jurassic to west and east are respectively higher and lower than the Cretaceous, the faulted zones act as low permeability barriers. It is considered (by MOI) that very little groundwater flows between the Cretaceous and the Jurassic. The piezometric surface for 1989 determined by a survey of many private wells in the area is illustrated in Figure C-7.2.

The depth to water is about 20 to 30 m in the lower parts of the intermontain valley. The water levels in the area have been monitored by MOI at wells 849 and 809B, data for the period 1991-1995 are available, see Figure C-2.56 for the groundwater hydrographs. The period of record is one with a gradual lowering of water levels from the peak in 1992 resultant from unusually high rainfall. The trend is observed in many observation wells in the karstic aquifers and probably is not caused by local irrigation abstractions.

The aquifer properties are quite variable as is illustrated by the range of specific capacities in the tested wells, see Table C-7.1a ~ b. The transmissivity of well 308K is reported to be 5800 m^2/d from a 26 hour airlift pumping test (USSR 1986).

A water balance for the area has been determined for the water years 1987/8 and 1988/9. The average components of the two budgets presented in the table below.

Item	Flux in MCM/y		
	1987-1988	1988-89	Average
INFLOWS			
Infiltration	11.04	2.83	6.9
Surface Flows	0.95	1.26	1.1
Change in Storage	0.31	3.47	1.9
OUTFLOWS			
Spring Flows	0.63	0.00	0.3
Abstraction	3.78	4.41	4.1
GW Flow to East	4.73	1.89	3.3
GW Flow to North	2.52	0.94	1.7
GW Flow to West	-	0.31	0.2
Change in Storage	-	-	-

They are for markedly different years, the first year the rainfall was 140% of normal while in the second only 55% of the median. As a rough estimate, the water balance unit receives an average rainfall of 500 mm/year over an area of 28 km^2, assuming that rapid occurs and that 50% of the precipitation is becomes infiltration then the long term recharge is 7 MCM.

(d) Current water exploitation

A field reconnaissance of a 3 km section, east from Mazraat Deir al Ashayer in the valley bottom was undertaken to establish the current water use in the area. Along this section there are at least 16 private irrigation wells. The holes are typically 50 to 100 m deep and equipped with a vertical lift pump powered by a surface mounted engine. They are used from between 7 and 12 hours each day during the irrigation season, each one supplying 10 to 30 dunums (1 to 3 ha). The average pumping rate is estimated to be about 5 l/s per well. Over the whole of the aquifer there were recorded over 60 wells by the MOI in the late 1980's. Estimates made by the MOI for 1987/8 and 1988/9 asses the irrigation abstraction to be 3.8 and 4.4 MCM respectively, an average usage of 8 l/s for 12 hr/d over 6 months from each well.

As well as the private sources the MOI has many holes in the area, some of which are used for observation and others were for testing and exploration. None of the government wells are currently used for abstraction.

(e) Wellfield proposed by MOI

The use of groundwaters in the Deir al Ashayer region was first proposed as a potentially promising area by the team of Soviet experts. They predicted (Lengiprovodkhoz 1986) that a wellfield could have a capacity of 330 l/s from the area. Subsequently the Ministry has undertaken a major investigation of the Hermon area (MOI 1994) incorporating a study of the Deir al Ashayer area. The report concluded that a wellfield with a peak capacity of 255 l/s and a suitable yield of 4.1 MCM/y was feasible for the area. The source to be used to supply the requirements of Damascus during the summer period for 6 months from the mid May to mid November. Three wells, numbers 844, 846 and 854, were put forward to form the small wellfield with the anticipated water levels and capacities.

Well	Pumping Rate (l/s)	Water Levels (mbgl)	
		Static	Dynamic after 6 months
844	90	26.12	52.66
846	80	25.15	50.36
854	85	28.96	56.15

A group pumping test was undertaken to assess the hydrogeological conditions in the Deir al Ashayer area. The test used three wells, numbers 844, 846 and 854, pumping at a combined rate of 165.5 l/s for a 44 day period started in August 1990. Analysis of the testing indicated a transmissivity for the area of 620 to 1000 m^2/d and a storativity of between 0.007 and 0.04. These figures together with the geometry of the aquifer and positioning of the wellfield were used to calculate the theoretical drawdowns in a wellfield pumped at a higher rate and for a longer period of time than the group pumping test.

The yield of the source was base upon a pumping rate that would not cause an unacceptable drawdown. The recommended maximum drawdown would cause a 50% de-watering of the effective aquifer thickness, and in addition would not lower the levels into the productive zone. A pumping rate of 255 l/s was selected to meet these criteria.

A design report was produced by DAWSSA in 1990 based on the use of the wellfield with a scheme of civil works to build a local storage reservoir and then gravity feed pipeline to the Barada-Figeh major water conveyor. The scheme included for the drilling of a further 10 wells with an overall capacity of 500 l/s. Although DAWSSA has permission to use water from this area, to date the scheme remains at the planning stage.

(g) Wellfield proposed for Master Plan

The scheme is a modified and scaled down version of the DAWSSA design. The total scheme operational quantity is revised downwards from 500 to 200 l/s on the basis of use for 6 months in the year. The recharge into the aquifer, rather than well hydraulics, is the limiting factor on water resource utilization in this area. The yield is based on assessment of the aquifer block in which the long term recharge may be only 7 MCM/y. Construction of a large scale wellfield with a large pumping capacity would be possible, but, after the initial use of aquifer storage, would not be able to be used at an annual rate greater than the recharge. To abstract the water three of the existing MOI wells are proposed plus a further purpose drilled well. Observation wells should not be necessary since there are many unused MOI investigation wells available. The drilling of a further production well to make a wellfield of four holes is recommended, for a number of reasons; Firstly it would enable the wells to be operated at or near to the rates that are known to have been achieved during the group pumping test, secondly, high capacity operation at 80 l/s is ruled out since this would require a pump larger than can be fitted into the casing, and thirdly the overall drawdowns in each well are reduced.

The location for the new well is about 200 m north east of the existing well number 854. This would place it along a track at an elevation of about 1180 masl. The depth of 150 m is chosen to fully penetrate the productive zone of the Cretaceous limestone between 70 and 135 m depth. The hole is planned to be 17" diameter to 20 m then 12" to the total depth. These dimensions are to accommodate 20 m of 13" conductor pipe and 9" casing of which the upper 70 m are plain and the lower 80 m perforated. The existing wells are known to have extremely variable yields, as with all drilling into karstic aquifers, the yield will depend upon intersecting fractures and fissures that are well connected and will transmit water to the well. The hole when drilled may prove to have a low yield, in such a case it another hole should be drilled.

The drawdowns have been calculated based upon the hydraulic properties of the region determined by the group pumping test. The values were used in a well interference calculation. The transmissivity was taken to be uniform and 960 m^2/d while a value of 0.03 was used for storativity. To represent the elongate aquifer block image wells pumping were used. They were placed so as to create a 1 km wide high productive aquifer strip, with the pumped wells centrally located.

Well	Static Water Level (mbgl)*	Drawdown (m)**	Dynamic Water Level (mbgl)***	Pump Capacity (l/s)	Installation Depth (m)
844	16	24.2	46.2	50	65
846	15	23.0	44.0	50	65
854	19	24.2	49.2	50	65
new	20	23.0	49.0	50	65

Notes: * Typical level anticipated for beginning of pumping period, using May 1995 as the reference year, Using determined by comparison with well 809.
** After 6 months pumping
*** Lowest expected level based on drawdowns plus 6 m of regional recession from an initial static water level in May

The water quality from the area is suitable for public water supply. The chemistry of three samples are presented below. Well 308K is adjacent to the well 854 which may prove to have a similar chemistry.

A survey of the electrical conductivity of groundwaters was undertaken in August 1996. Samples of 9 pumped sites were measured in the field to provide a quick impression of the spatial variability of water chemistry. The conductivity ranges between minimum of 380 mS/cm near to MOI well 850 and a maximum of 620 μS/cm about 1.5 km to the north east. The average is 420 μS/cm in the area of the proposed wellfield.

Parameter	Well 308K 6 Aug. 1985 (mg/l)	Well 846 5 Dec. 1989 (mg/l)	Well 844 26 Sep 1990 (mg/l)
Bicarbonate	195	183	329
Chloride	71	106	57
Sulfate	5	11	10
Nitrate	20	9	9
Calcium	48	56	84
Magnesium	22	5	24
Sodium	31	69	41
Potassium	4	6	4
Total Dissolved Solids	298	354	407

(2) Jurassic groundwater source at Rimeh

(a) Location

The village of Rimeh lies about 40 km south west of Damascus at UTM grid reference 330 km east, 3696 km north. It is in the upper valley of the Sebrani River, a tributary of the Awaj, it nestles on the eastern flank of Jabel Sheikh (Mount Hermon) at an altitude of approximately 1400 m, the main summit of the mountain at 2814 m elevation, is 5 km north west of Rimeh. A single road runs up the valley side to Rimeh and on to the village of Arneh a further 3 km to the south west. The valley is a narrow gorge in the reach besides Rimeh, but up stream at Arneh the valley opens out and divides with the main valley rising to the south west and a tributary daughter valley to the south. Cultivation is confined to the wide section of the valley floor and the lower slopes of the mountains below the spring line. Fruit tree orchards are the dominant agricultural land use in this valley. Upper hill slopes are rough grazing or unused by man. The proposed wellfield lies about a kilometer to the north east of the village.

(b) Geology and hydrogeology

Jabel Sheikeh is formed by the faulting and folding of the Jurassic limestones underlies the whole of the area and dominates the hydrogeology of the area. The upper part of the mountain is of Callovian age and the lower slopes around Rimeh are older, being of Bathonian and Bajocian age. To the east of the mountain the Jurassic is unconformably overlain by Cretaceous, Palaeogene and Neogene sedimentary strata. Neogene to Quaternary basalts abut the Jurassic to the east of Rimeh. The detailed geology of the upper Sebrani valley is complex. A fault bound trough has caused the younger Cretaceous and Palaeogene strata to lie surrounded and at a lower elevation than the Jurassic. The Jurassic is the main aquifer in the area, comprising karstic limestones. Many small springs occur in the lower slopes and base of the valley to drain the area. Many are ephemeral, probably only draining perched water levels within the aquifer. (Regional groundwater flow is to the south east approximating the surface topography.) Within the Jabel Sheikh groundwater flow directions are not known by direct observation. All the observation wells are on the lower flanks of the mountain near to the base level for springs. In these areas groundwater flow is directed towards the springs. Regionally within the whole Jurassic block the lowest base level is at about 300 masl in Dan and Banias Spring, (UTM 311 km east, 3680 km north) this is some 25 km south west of the Rimeh area springs who have an elevation of about 1400 masl. The flow regime of these springs is not known in detail, but, it is thought that there is an average flow of in excess of 11 m^3/s, necessitating a large groundwater catchment to support the discharge. It may be anticipated that regional groundwater flow is towards Banayas and that Rimeh area is in the upper part of this regional catchment.

The aquifer properties of the Jurassic limestone are mainly dictated by the degree of the fracturing and fissuring within the rock. The fractures are very variable spatially, wells within as close as 25 m have been found to have quite different yield characteristics consequent on the intersection of underground fractures. Table C-7.2 with the well details show the range of transmissivities and well specific capacities encountered within Rimeh.

(c) Wellfield proposed by MOI

The MOI study of the Hermon identified an area near to Rimeh as a promising area for water resources. A series of investigation wells were drilled and tested, the most productive of which were subsequently group tested. The results of these works were used to make a recommendation for a small wellfield with a peak capacity of 279 l/s and an annual yield of 5 MCM. Details of the proposed wellfield are tabulated below.

Well No	Pumping Rate (l/s)	Elevation (masl)	Water Level (m bgl)	
			Static	Dynamic after 6 months
825r	108	1433.6	14.30	89.3
825a	37.5	1433.2	9.14	84.2
825b	33	1433.8	11.42	76.4
825c	40.5	1437.5	13.41	88.4
867	60	-	27.00	73.2
Total	279			

The capacity proposed is 150% of the tested rates for each of the wells during the group pumping test. While the water levels have been calculated based upon the hydrogeological parameters determined for the test. These were a transmissivity of 1850 m^2/d and a storativity of 0.014. The wellfield capacity is set so that the drawdowns do not lower the levels into the productive zone. The test indicated that the productive aquifer extends for a radius of 1.055 km from the center of the wellfield. Within this area all the water to supply the yield is derived.

(d) Wellfield proposed for the Master Plan

The proposed wellfield for the Master Plan uses the existing and three new wells. The wells will not be used at the rates proposed by the MOI because firstly the holes were not tested at the higher rates and secondly the existing casing is too narrow to accommodate the pumps necessary to achieve the output. The holes will be used at approximately their test rate and the three new wells are each to be used at 40 l/s. The new wells are to be 17" diameter for the top 20 m then reducing to 12" diameter to the total depth of 150 m. The casing is proposed to be 100 m of plain and 50 m of perforated 9" diameter. The wells should be located at about 50 m spacing from the existing holes to be in the vicinity with good aquifer yields.

Well No	Pumping Rate (l/s)	Elevation (m asl)	Depth (m)	Water Level (mbgl)	
				Static	Dynamic*
825r	50	1433.6	-	14.30	89.3
825a	25	1433.2	113	9.14	84.2
825b	25	1433.8	250	11.42	76.4
825c	25	1437.5	112	13.41	88.4
867	40	-	260	27.00	73.2
1(new)	40	c.1440	150		
2(new)	40	c.1440	150		
3(new)	40	c.1440	150		
Total	285				

(3) Beit Jenn Spring source

(a) Location

Beit Jenn lies in the Janani Valley, about 45 km to the south west of Damascus. The valley which runs approximately west to east has four principal springs between the headwaters and the town of Saasaa where it is crossed by the main road from Damascus to Quaneitra. The springs are Ras el Nabei about 3 km to the north west of Beit Jenn village while Beit Jenn spring lies 2 km to the east, however, somewhat confusingly, both springs may also be called Beit Jenn. Other important springs are at Membej, 2 km east of Mazraat Beit Jenn and Talmasieh which lies a further 2.5 km down stream.

(b) Topography and drainage

The springs rise in the headwaters of the Janani, a tributary of the Awaj River. The Beit Jenn or Ras el Nabei spring rises at UTM grid reference 326.8 km E, 3689.9 km N at an elevation of 1300 m asl, the other Beit Jenn spring rises from alluvium in the valley floor at 330.4 km E, 3687.8 km N and an elevation of 1063 m asl. The Janani starts on the eastern flanks of Jabel Sheikh and flows to the east joining the Sebrani to form the Awaj River near Saasaa. The river flows in a narrow steep sided valley within the mountains which then open out onto an alluvial fan area at Mazraat Beit Jenn and then flows onto a broad plain of the El Arab Depression. Surface water flow reaches as far as Mazraat Beit Jenn in at high flows, before it has completely infiltrated into the alluvium before it reappears at Talmasieh spring. Discharge only occurs at Membej during periods of high groundwater level, the spring not representing the true base point of the hydraulic system.

(c) Geology

Jabel Sheikh is a folded massif of Jurassic limestone surrounded by younger rocks. Between Ras el Nabei spring and Beit Jenn area the Jurassic is flanked by steeply dipping Cretaceous Palaeocene sediments. East of Mazraat Beit Jenn the Cretaceous and Palaeogene is overlain by younger Neogene and Miocene rocks. Volcanic activity in the area has spread basalt over much of the land to the south of the Janani River. A local volcanic center lies 3.5 km south of Ras el Nabei from which a basaltic lava flowed to the east.

(d) Spring yield

The MOI has monitored the spring flow from Beit Jenn spring on a monthly basis. The annual and monthly yield of the spring for the period 1974/5 to 1994/5 has been made available to DAWSSA for this investigation.

The spring yield has been previously assessed as 791 l/s (24.9 MCM) by the Russian study. Analysis of the longer period flow record has re-estimated the long term yields by correlation with rainfall and predicting the yield at different rainfall probabilities. The annual yield of the spring is assessed to be to be 739 l/s (23.3 MCM/yr), with a 95% probability of annual discharge exceeding 505 l/s (15.9 MCM). For the period of record 1974 to 1994 the actual average was 19.9 MCM/y while the sum of the 95% probability for each month is only 9.6 MCM. The spring hydrograph is illustrated in Figure C-7.3 while the monthly flows with mean and 95% condition flows are to be found in Figure C-7.4. There has been no change in the catchment hydraulics as is illustrated in Figure C-7.5.

Flow (l/s)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	418	379	443	629	859	954	1001	719	681	580	457	436
95% >	228	157	188	266	427	486	434	286	366	335	190	274

The quantity that is available from the source for the critical supply period of June to January is 9.7 MCM for a 50% year or 5.3 MCM for a 95% year (peak output limited to 500 l/s).

	Minimum Discharge (MCM)	
Period	50% probability	95% Probability
Annual	13.6	9.6
June to January	9.7	5.3

(e) Water quality

The chemistry of spring waters in the Janani Valley is presented in the table below.

Parameter	Spring Sample Location				
	Ras el Nabei	Beit Jenn	Membej	Talmasieh	Tabibiyeh
Turbidity (mg/l)	2.5	1-1.5	1	1.5	1.5
Conductivity (μS/cm)	225	290	300	325	525
pH (-)	8.1	7.7	7.5	7.5	7.5
Total Hardness (mg/l)	120	150	160	170	290
Calcium (mg/l)	36	40	52	56	92
Magnesium (mg/l)	7	12	7	7	15
Sodium (mg/l)	2	4	9	9	12
Potassium (mg/l)	0	1	1	1	1.5
Bicarbonate (mg/l)	134	171	183	195	256
Sulfate (mg/l)	19	11	10	10	64
Chloride (mg/l)	2	6	8	10	20
Nitrate (mg/l NO_3)	0	2	4	4	15
TDS (mg/l)	135	165	185	195	350
Date	30/6/96	30/7/96	30/6/96	30/6/96	2/7/96

The Total dissolved solids (TDS) is low with a calcium / magnesium bicarbonate type water. As the water flows east its quality deteriorates as is indicated by the rise in the concentration of major ions. The bacteriological quality of the water at Ras el Nabei is likely to excellent since there are no settlements or cultivation in the catchment area of Jabel Sheikeh. The waste water and solids from Beit Jenn village are currently discharged or dumped into the river course. Even though the spring water of Beit Jenn is filtered by the alluvial gravels it is likely that it will be bacteriologically contaminated at the spring and all the other locations to the east.

(f) Current water utilization

Ras el Nabei spring is used by EDWSSR to provide a drinking water supply to the settlements in the Janani valley (Beit Jenn, Mazraa Beit Jenn, Harfa and Moghr el Mir). The current capacity of the system is reported to be 50 m^3/hr (14 l/s), this is only a small percentage of the total spring capacity. The rest of the water from the springs is lost to evapotranspiration and used by agriculture in the Awaj basin.

(g) Scheme proposed for the Master Plan

The scheme proposed for further water resources for Damascus involves the use of Beit Jenn Spring. A water intake structure and associated gravity fed pipelines should be designed to carry 500 l/s, but would due to seasonal fluctuations, be rated with the minimum November flow in a 1 in 20 drought year of only 160 l/s. The water could be collected by a structure partially excavated into the valley floor and sides into which the spring water would flow. Alternatively, must a slightly more costly option would be to construct a ranny well. This type of well is used to abstract water from shallow gravel aquifers. They consist of essentially a caisson sunk into the valley gravels with a series of horizontal bores in the base. These are made by jacking perforated tubes into the surrounding ground. The use of such a structure will permit the de-watering of the alluvial gravels during the summer period hence providing a small amount of flow control. The water should be chlorinate prior to passing into a gravity feed pipeline. The proposed course of the pipeline has a total length of 44 km with a fall from 1063 to 700 masl. Most of the fall is in the section from the spring to Tabibiyeh a distance of 15.5 km.

(4) Tabibiyeh Spring source

(a) Location

Tabibiyeh lies on the course of the Awaj River about 30 km south west of Damascus and 6 km from Saasaa. The site is adjacent to some military installations and a short distance from the main Damascus to Qunaitra highway.

(b) Topography and drainage

Although the land is an open plain at the foot of the mountains the river is locally constrained in a narrow valley that skirts around the northern edge of lava flows.

(c) Geology and hydrogeology

The site lies at the geological boundary between to different lithologies. To the north west and stretching to the mountain front are Neogene and Quaternary sedimentary strata while to the other side of the site are Quaternary basalts. The sedimentary rocks are conglomerates, sandstones and marls formed by the erosion of the Jabel Sheikh mountain. It is possible that these interdigitate with the basaltic lava flows, so in the vicinity there may be alternations of basalts and sedimentary rocks in a vertical section. Groundwater flow determined from a few wells in the area roughly follows the topography, towards the south east. There is no information to indicate that water flows towards the spring from the basalt, so it is assumed that the source of the spring water is the groundwater of the sedimentary strata.

(d) Spring yield

The natural spring discharge is 828 l/s (26.1 MCM) on average over a typical year, see Figure C-7.6 and 7.7. The currently the spring a has a lower yield of 653 l/s (20.6 MCM). The reasons for the reduction is probably the use of surface and groundwater for irrigation in the catchment that supplies the spring. The yield of the spring will reduce further if extra water use occurs in the Janani and Sebrani River catchments. The change in flow from this spring during 1982 to 1984 may be clearly seen in Figure C-7.8. The relationship between rainfall and flow does not seem to have changed since 1984, however the feasibility of the scheme is dependent upon the effective control and stabilization of water use in these river catchments. The monthly spring flow characteristics for the period 1984 to 1994 are tabulated below.

Flow (l/s)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	347	470	573	754	914	1007	939	809	733	551	423	326
>95%	102	234	262	449	567	607	378	293	312	205	131	99

The quantity that is available from the source for the critical supply period of June to January is 10.9 MCM for a 50% year or 4.7 MCM for a 95% year.

Period	Minimum Discharge (MCM)	
	50% probability	95% Probability
Annual	14.6	9.1
June to January	9.4	4.7

(e) Water quality

The water quality from the spring is not as good as those from springs emerging nearer to the mountain front along the Janani River. However it is better than the groundwater that underlie most of Damascus. The water quality analysis from this site is reported in the previous section.

(f) Current water usage

The spring is pumped to provide water to the military, their consumption is not known. Spring flow is passed through a fish farm also operated by the army, however it did not appear to be in use when the site was visited in June 1996. The overflow from the spring augments the Awaj River in winter and forms its origin in the summer. The river waters are used for irrigation in the Awaj basin.

(g) Scheme proposed for the Master Plan

During the winter months the spring will flow by gravity and the water may be pumped into a supply main. The summer discharge may be controlled by a wellfield in the vicinity of the spring, abstracting a similar quantity. The groundwater reservoir would be depleted during the summer, but will be replenished by the following recharge season. The feasibility of the scheme must be tested before proceeding with the major capital investment in pipelines. There are two main elements that need further study, the role of surface water recharge from the Janani River, and the groundwater flow in the area around the spring. If it is found that the majority of recharge is from the Janani River the scheme will be in completion for the same water resources as are planned to be used by the Beit Jenn spring. The detail of the groundwater flow in the spring region is important in the correct location of the wellfield.

The planned yield of the source is 500 l/s throughout the year. The water will be pumped to a reservoir at 900 m elevation, then will flow under gravity to Damascus. The spring is at an elevation of 831 m, and summer wellfield water levels may be as low as 810 m. A pumping main is required to the reservoir 2.25 km long. From the reservoir water may flow by gravity to Damascus. If the scheme is combined with that at Beit Jenn the total flow could be 1 m^3/s.

(h) Plan for Tabibiyeh and Beit Jenn (not included in the Master Plan)

Phase I. 1998. Consultation between DAWSSA, EDWSSR and MOI and local water users on water utilization in the Awaj Catchment. These discussions should concentrate upon the allocation of the available water resources to the competing uses of irrigation, local water supply and Damascus water supply. There is considered to be scope to reduce water consumption in agriculture while still maintaining the same crop production. These savings would come about by the adoption of more efficient irrigation systems to replace the flood method that is commonly used. A reduction in water use in agriculture and a switch to poorer quality shallow groundwaters would allow the water resources to be allocated to local and Damascus water supply. If all parties agree that water allocation is to change then further phases may proceed.

Phase II. 1998-2004 Changes in irrigation practice promoted by the Ministries of Irrigation and Agriculture.

Phase III. 2004	Design and Construction of spring intake structures at Tabibiyeh and Beit Jenn.
Phase IV. 2007	Design and Construction of the pipelines, one gravity feed from Beit Jenn to Tabibiyeh, and a second pump assisted from Tabibiyeh to the Mezze area of Damascus.

7.1.2 Zabadani Valley

(1) Jurassic groundwater source at Sergaya & El Irk

(a) General background

The scheme uses water resources from the mountains that form the eastern side of the valley between Sergaya and Zabadani comprise Jurassic limestones. This is the same aquifer that feeds Barada Spring, though it is not within the same catchment. The recharge to the aquifer is thought to emerge from three main springs; Sarada, Ain Hour and El Irk. This assigns an average recharge of 370 mm/y to the catchment and an average spring flow of 295 l/s (9.27 MCM). The Rural Establishment currently operates wellfields at Sergaya, Ain Hour and El Irk with a combined capacity of output of 133 l/s. These sources are probably not run at peak capacity throughout the year, and it would appear from the spring flows that an average of 80 l/s are utilized.

(b) Scheme proposed for the Master Plan (but not included)

The scheme proposes the construction of wells with the combined capacity of 180 l/s or about 650 m^3/hr. These wells could not be used throughout the year but would be limited to a 245 day period abstracting at an average rate of 140 l/s, resulting in a production of 2.94 MCM. The capacity of existing wells operated by the Rural Establishment is 60 m^3/hr. It is proposed to construct 9 wells with an average yield of 75 m^3/hr in two wellfields. The details are tabulated below.

Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	Static Level	Pumping Level	Capacity (m^3/hr)
1	354,500	3744,050	1440	120	40	60	75
2	354,320	3743,830	1430	110	30	50	75
3	353,950	3743,400	1420	100	20	40	75
4	353,800	3743,200	1450	130	50	70	75
5	353,600	3742,900	1450	130	50	70	75
6	350,830	3736,800	1375	135	55	75	75
7	350,700	3736,500	1375	135	55	75	75
8	350,550	3736,250	1360	120	40	60	75
9	350,400	3735,950	1350	110	30	50	75

The total drilling is 1090 m for all the proposed wells. Although during the construction of the wellfields it will become clear whether a smaller number and a shallower depth of hole may achieve the same overall yield. The holes may be constructed by percussion drilling at a standard diameter of 12.25" and installed with 9" plain and slotted casing. The casing of the holes may not be necessary for the full depth as the rock may be competent, it is planned that the section to 20 m below the pumped water level is cased. The quantity of casing required for the holes is 730 m.

The water may be conveyed by a new gravity pipeline to the Barada Wellfield where it can join the existing pipelines to Damascus. The pipeline may follow the contours and join the main road after 3 km, it runs beside the road for 2 km until reaching the railway line. It is proposed to run a pipeline adjacent to the railway as far as Zabadani, within this section of the pipeline a break pressure reservoir is planned with the short pipeline from the El Irk wellfield joining. The route from Zabadani to Barada follows the course of the old road by way of the group 3 and group 1 Barada wellfields. The total length of the pipe lines is estimated at 22 km.

There are two organizations competing for the same water resources. An integrated plan for the local consumers and those in to Damascus would appear necessary to efficiently and equitably use the limited water in the area. It may be possible to have a shared wellfields.

(c) Plan of work

It is proposed that the scheme be divided into four phases to ensure that the investment is wisely used on a scheme that will be operationally plausible. The most expensive items of the scheme are only constructed once the source has been proven by the preceding phases of work. The scheme does not include the timings for the preparation of detailed designs, contract documents and other items.

Phase I - Investigations

The aim of the first phase is to collect information that will indicate whether further work is likely to be successful. The existing wells which belong to the Rural Water Establishment would be tested to determine the yield characteristics of the wells and the interference effects in the aquifer. This information will be used to decide upon well separations and the depth of drilling that may be required.

Phase II - Exploration Well Drilling

Two new wells will be constructed and tested in the second phase of the work. These holes may become part of the wellfield if they prove to productive. A hole will be drilled in both the wellfield positions. The second phase will roll on into the third phase if the holes are successful. Otherwise two further exploration holes will be drilled at a lower elevation into the Pliocene conglomerates, sandstones, marls and limestones to investigate if they contain usable groundwater fed by the adjacent Jurassic limestones.

Phase III - Wellfield Drilling and Testing

The remaining wells of the wellfield will be drilled in this phase. The number and exact location to be determined based upon experience gained in the earlier phases of the project. The testing of the new wells should evaluate the capacity of the wellfield and in addition the effect upon the springs of the region. The testing should be carried out during the summer, at some time between June and September.

Phase IV - Pipeline Construction and Wellfield Commissioning

(2) Barada Spring wellfield

The hydrology and hydrogeology of the site is described in section (on hydrology of springs).

Capacity of the wellfield is about 100,000 m^3/d (1.16 m^3/s). The effect of this abstraction will be to reduce the flow in the Barada by up to this quantity. The table below illustrates the anticipated flow into Barada from the spring at two probabilities of rainfall.

Flow (l/s)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	1895	1930	1920	2124	2292	2660	3120	2660	2350	2195	1930	1880
95%	1260	1490	1645	1780	1690	1840	2110	1840	1665	1560	1490	1420

Although DAWSSA does not have a legally enshrined obligation to maintain flow into the river it may consider it good practice to maintain some flow in the river. The flow is required for the use by legitimate riparians, to dilute effluent discharges and for aesthetic environmental reasons. Should the spring discharge fall below a pre-set flow is could be possible to open slightly the washout valve from the reservoir to maintain the flow at the desired rate. An alternative management strategy would be to reduce pumping to enable water to flow from the spring.

The maintenance of the stream flow, although desirable for many reasons, may, in future years be incompatible with the provision of water to Damascus. Should this be the case then the wellfield may be operated at a higher capacity. The resources of the catchment of the spring are assessed to be 70.8 MCM/y, an average of 2.23 m^3/s. The operation of the Barada Wellfield and the three future Al Sahl wellfields should have a limit of this amount in the long term. Over-pumping this capacity in drought years will be possible, subject to a reduction in abstraction in subsequent years when resources from other sources can be used.

7.1.3 Damascus City

(1). Increased abstraction from the existing wellfields

(a) General

The capacity of the existing wellfields is limited by the storage in the aquifer, the ability of the water to move towards the well and the hydraulic properties of the well. It is considered by DAWSSA that there is still available capacity in the aquifer that may be abstracted by the wellfields and that the limiting factor is the ability of the wells to remove the water from the ground. The wells can be used to pump water from the aquifer so long as the water level within the structure does not fall too far. For the purposes of the evaluation it is considered that the annual maximum abstraction rate should be set so that the water level does not decline below a critical limit. The selection of the critical limit is a somewhat arbitrary. For example within the UK water industry a guideline of lowering the water level to 50% of the saturated aquifer thickness has been quoted, Water Research Council (1996). For the critical limit in Damascus since the exact detail of the aquifer configuration at the wellfields is unknown a more conservative approach is recommended in which the water level should not be permitted to decline to below 75 % of the perforated length of the casing.

DAWSSA have noted that a number of their existing wellfields have experienced a decline in yield in recent years particularly towards the end of the pumping season. This is particularly apparent at the Mazraa and Oumawiyin wellfields. The drawdown in the wells increases through the operational period thus increasing the head on the submersible pumps. The pumps may not be able to produced the same discharge rate at higher heads and as a consequence the overall output of the wellfield is reduced. If there is a genuine decline in output it may be due to either overall de-watering of the aquifer or the deterioration of individual well performances. DAWSSA has very little control of the levels within the aquifer, but should be able to identify if holes are not performing as well as they have done in the past. Rehabilitation, or re-drilling should be considered for such holes. It is recommended that investigations are undertaken at the critical sites to attempt to find particular problem holes. Firstly the wells must be installed with a dip-tube so that the pumped and static water levels may be measured. By the comparison of the ratio of drawdown to pumping rate, the well behavior can be compared with the anticipated ratios measured when the hole was first tested.

Divergence in well behavior would point out those wells that require redemption works.

(b) Methodology

To determine the capacity of wells in a wellfield a pumping rate is chosen that will result in the water level falling to the critical level during the pumping season. There is no data on water levels in pumped wells for the Damascus wellfields. None of the wells have a dip tube and so it has not been possible to measure pumped water levels during the field study work. To combat the data deficiency a methodology has been used to calculate the anticipated pumped water levels. The information that is available for the wellfields comprises; a yield and drawdown for pumped holes measured the original step testing of the site; observation well water levels and pumping rates. The water level in the pumped well is the sum of four components; original water level before pumping started, the regional water level recession, the aquifer losses and the well losses. By making assumptions and applying some simple well hydraulics equations a reasonable estimate of the various components can be made.

Original or static water level. The typical water level in May or June prior to the pumping of wellfields was taken from the observation well level. During the spring water levels rise from recharge and recovery so that in May the aquifer has a natural piezometric surface. This surface has a gradient of 0.01 to near Mazraa to 0.005 near Ibn Assaker. Within the wellfields the water level will possibly range in elevation by up to 2 m due to the piezometric gradient. This variation is ignored and a single water level from the observation well for May is assigned to the wellfield.

Regional Recession. There is a natural decline in water levels from about May to November each year. DAWSSA does not have any observation wells that are sufficient distance from the wellfields to record the regional recession and long term changes within aquifer storage. However, the MOI has two observation wells (numbers 170 and 191) which are away from the main wellfields. These holes themselves may be influenced by other local abstractors, but it is assumed that there typical decline of about 3 m is due to the regional recession effect only.

Water level in the observation well is known and therefore is a useful benchmark to compare with the level in the production well. The observation well is assumed to be in the center of the wellfield and to typify the levels in the arc of the wellfield. A knowledge of the aquifer transmissivity and water level response in the first 20 days of pumping permits a crude estimate of future water levels. A rough estimate of the transmissivity of the wellfields was taken from the map illustrating its spatial variation across Damascus. The change in water level per log cycle of time may be calculated from equation C.16.

$$\Delta s = \frac{2.3\ Q_t}{4\pi T} \quad \text{(C.16)}$$

Where	Ds	Change in water level per log cycle of time in meters
	T	Aquifer transmissivity in m^2/d
	Q_t	Pumping rate for whole wellfield in m^3/d

The time from which the drawdowns become effective at the observation well may be calculate from equation C.17. This equation applies to a single well pumping, however it gives a reasonable agreement to observed water levels if the average radius to all the pumped wells is used and an unconfined storativity of 0.05 is used. A typical t_o of 10 days has been applied to all the wellfields based upon the observed aquifer response in previous years. To determine the drawdown in the observation well at any time equation C.18 is used. The pumping period during which there are continually declining water levels is about 200 days from mid May to the end of November. Recharge to the aquifer reverses the declining levels at about this time, so this 6.5 month season is used as the time.

$$t_o = \frac{S\ r_o^2}{2.25T} \quad \text{(C.17)}$$

Where	t_o	Time from which drawdowns are determined in days
	r_o	Radius from pumped to observation well in meters
	S	Storativity of the aquifer, dimensionless.

$$s_o = \Delta s\,(\log t - \log t_o) \quad \text{(C.18)}$$

Where	s_o	Drawdown at time t in meters in the observation well
	t	Time in days since start of pumping

The water level in the individual production wells will be lower than in the observation well dependent upon the radial distance between the two wells and the transmissivity. The radius to the production well is taken as the distance to the nearest pumped well. The equation is valid if the wellfield is uniform and infinitely large, to give a single and uniform interference drawdown. As this assumption in not met the water levels will be slightly less than those predicted by the equation and will vary from hole to hole.

$$s_p = s_o + (\log r_o - \log r_p)\,\frac{2.3\ Q_i}{4\pi T} \quad \text{(C.19)}$$

Where	s_p	Drawdown in the pumped well in meters less the well loss component
	r_o	Distance of the observation well from the production well in meters
	r_p	Radius of the production well in meters
	Q_i	Pumping rate of the individual production well in meters

The final component of drawdown is the well losses. These are normally determined by analysis step tests, however since such information does not exist for all the wellfields a single specific capacity is used. It is assumed that the variation in the specific capacity between the wells that comprise a wellfield is solely a consequence of differing well losses. Furthermore, it is assumed that the highest specific capacity is from a well with negligible well losses and that well losses are in the quadratic form. Equation C.20 is merely a rearrangement and substitution into the standard well performance equation of Bierschenk and Wilson.

$$s_l = Q_a^2 \frac{(s_t - \frac{Q_t s_i}{Q_i})}{Q_t^2} \qquad \text{(C.20)}$$

Where	s_l	Well Loss drawdown in meters
	s_t	Drawdown from yield test in meters
	s_i	Drawdown for well with no well losses
	Q_a	Pumping rate of well m^3/hr
	Q_i	Pumping rate in well with nor well losses in m^3/hr
	Q_t	Pumping rate from yield test in m^3/hr

The water levels in wellfields have be calculated using the composite method previously described using a spreadsheet table permitting the easy adjustment of the many parameters involved, see Table C-7.3. Most of the wellfields are near to the critical limit of drawdown set for the site at one or more of the wells by the end of 200 days pumping. However it should be noted that since a worst realistic case assumption has been made at many stages in the calculations the results will tend to underestimate the hydraulic capabilities of the sites.

(c) Mazraa

There is a theoretical scope to increase the pumping by a small quantity from this site up to about 31,700 m^3/d (367 l/s). This could be achieved by increasing the existing overall pumping capacity by 10%. The most favorable wells for the use of larger capacity pumps are operational numbers 8, 10, 12, 13 and 15. Increase in available resources of 33.3 l/s or 0.58 MCM/y. Due to the existing difficulties in maintaining flow from this site near to the end of the pumping season and the water turbidity difficulty known at this wellfield an increase in pumping is not recommended.

(d) Ibn Assaker

The abstraction from the site may be increased to 40,000 m^3/d (463 l/s). The lift pumps in the reservoir may be have an increased capacity so as to enable the well pumps to be utilized more efficiently. The wells on the site are used typically 65 % of the time, by increasing this utilization to about 90% the site can increase the output by 10,000 m^3/d.

(e) Kaboon

The hydraulics of the site do not permit the abstraction of a greater quality from the five existing wells that are currently used. On the contrary it would appear that the water level in the wells may be lowered more than 25 % of the screen length in some instances.

(f) Jobar

The well hydraulics indicate that no more may be taken from this site without de-watering the aquifer below the critical limit.

(g) Kadam Railway

The site could yield more water, though there may be long term water quality problems in this area. It is proposed to increase the average capacity of the pumps from 100 to 135 m^3/hr. With the current utilization rate this would result in an increase of about 115 l/s or 2.3 MCM/y.

(h) Oumawiyin

The capacity of the Oumawiyin pumping station will be increased with the supply from Tishreen and Kywan wellfields amounting to sum 5 to 7 wells with a combined output of up to 195 l/s (17,000 m^3/d). It is not proposed to further increase the abstraction from the aquifer in this area.

(i) University

The university wellfield lies on the interface between good water quality that is actively recharged from the Barada and a poor water area lying to the west towards Mezze. As a consequence the wells on the west of the site have elevated chlorides, sulfates, lead and other determinands compared to the east side of the wellfield. In view of the water quality constraints at this site and the laudable desire from DAWSSA to not induce the migration of poor water quality from the west, the site should be considered the last to be utilized. No change to the capacity of the site is recommended.

(j) Fringe wells

There are 23 Fringe Wells operate by DAWSSA on the perimeter of the city. The wells are equipped with pumps with 50 m^3/h (13.9 l/s) capacity. The wells are used at a typical total output of 9,000 m^3/d in the winter months and 12,500 m^3/d in the summer. This equates to an average use of 8 and 11 hours per day for each well in the winter and summer respectively. Certain of the wells could produce more water by equipping them with more powerful pumps and possibly increasing the capacity of the distribution system in the vicinity of the source. Wells that have a specific yield of greater than 2 l/s/m and do not have records of high nitrates or total dissolved solids are selected for re-equipping. The wells with the revised capacities are listed in Table C-7.4. An interference plus seasonal regional recession of groundwater levels is assumed to be 5 m.

The estimated net effect of the change would be an overall increase in production of 1.76 MCM in a year. The estimate is based on the newly equipped sources operating 18 hours per day for a six month period each year. During the rest of the year when demand is lower they will operate for fewer hours to produce a similar amount to that produced in the other wells. The unchanged fringe wells are assumed to operate at the existing rates.

(2) Wellfield at Jaramana.

The wellfield consists of one observation and 10 production wells. The holes were mainly drilled in 1990 but were not equipped. The testing shows that the aquifer is highly productive in this area, with a transmissivity of 3800 m^2/d causing individual well drawdowns of about 1 m at the tested pumping rate of 30 l/s. The well performance equations determined from the step tests are summarized in the Table C-7.5. It is proposed that 9 of the wells may be pumped at up to 40 l/s in this wellfield. This would provide a peak site capacity of 360 l/s, if an allowance is made for one of the wells to be undergoing maintenance over a 245 day pumping season a yield of 290 l/s or 6.12 MCM is available.

The water quality is typical of the Damascus wellfields. In operation the wellfield may tap poorer water which lies to the east, it is therefore possible that in the medium to long term water quality of the site will deteriorate. To continue using the site it may be necessary to blend water from Figeh to obtain a satisfactory water quality for consumers.

The static water level at the beginning of the pumping season in May is about 12 m below ground. By November the level will be around 24 m below ground, the drawdown caused by 1.4 m in the well plus 7.6 m of interference effects plus about 3 m of regional recession.

(3) Wellfield in Tishreen and Kywan

This wellfield lies to the west of the current operational source at Oumawiyin. It comprises two parts, the wells in Kywan Gardens to the south of the old road to Dummar and beside the course of the Barada River, and the second part within Tishreen Gardens occupying higher ground north of the road, Figure C-7.9.

The five wells in Kywan were drilled in 1989 and tested in April 1990. The investigations mainly comprised a 3 day constant rate test and a one hour period of pumping at a similar rate. The results are not amenable to conventional pumping test analysis, however radial flow modeling of wells 2 and 3 give transmissivities of 3900 and 2300 m^2/d respectively. These hydraulic properties would indicate that high yields might be obtainable from the area. However the wells have high drawdowns due to head losses in the immediate vicinity of the hole, thereby reducing the quantities of water that may be produced from the wellfield, Table C-7.6. Only wells numbers 2 and 3 are really suitable for use as production wells, the remaining holes have a very low yields. The two holes can each reliably produce 30 l/s without excessive drawdowns.

The Tishreen part of the wellfield consists of ten wells drilled in 1993 but as yet they also have not been equipped. Only three of the holes at the site are hydraulically efficient and possibly suitable for use as production holes, (nos 3,4 & 8). Both well losses and aquifer losses are high in the other wells, table below. The testing of wells 3 and 4 used steps of between 7 and 14 minutes, with such short steps it is not possible to reliably confirm their behavior.

The water quality from this wellfield is the best in Damascus, and it is not expected to change or cause a limitation on the use of the source.

To use the wellfield it is proposed that a phased approach be adopted. Initially the best wells should be equipped secondly the lower capacity wells may used and lastly two new wells may be constructed. The production from the wellfield should be piped to Oumawiyin pumping station for chlorination and addition to the distribution system. The planned capacity of the wells to be equipped in the first phase is 135 l/s. If used operationally for 80% of the time during an 8 month season the production would be 110 l/s and 2.33 MCM. In the second phase smaller capacity and higher head pumps are to be installed. The extra capacity is 120 l/s or a further 100 l/s and 2.03 MCM. The final phase the capacity could be increased by the addition of two wells which could produce a total of 50 l/s. The final potential total installed capacity would be 260 l/s from 16 wells, an average of 210 l/s or 4.44 MCM in an 8 month year.

(4) New wellfield at Kanawat Gardens

The potential location for a new wellfield is within the triangle of land at the junction between Abou Baker as Swddik Street and 17th April Street, UTM grid reference 365.8 km E, 3709.4 km N, see Figure C-7.10. The land is now used for small farms in the center of the plot, but the wellfield is planned to be constructed on the perimeter of the area to minimize the effects on the existing land users.

The site is chosen to be in an area where the aquifer is good, the highly productive pebble beds are about 30 m thick under the site and the static water level about 10 m below the surface. The location is also a balance between poor water quality to the west in Mezze with elevated sulfates and chlorides and higher nitrate water towards Kadam.

The proposed wellfield will have 5 production and one observation hole. Each will be 70 m deep to fully penetrate the aquifer. The design should allow for 20 m of plain and 50 m of perforated 9" diameter casing to be installed into a 12.25" hole, and 10 to 20 m of 13" casing for the conductor pipe. The anticipated capacity of the wells will permit the installation of a 25 l/s pump, giving an average site production of 80 l/s or 1.69 MCM over an eight month period.

(5) New wellfield at Kafar Sousch

The wellfield, proposed by DAWSSA is of a very similar type to the Kanawat Gardens wells. The location is beside the Municipality offices at grid reference, UTM 365.9 km East, 3609.1 km North, Figure C-7.11. The wellfield is to the south east of the proposed Kanawat Gardens wellfield, as such the hydrogeology and the hydrochemistry is expected to be similar. The well design and capacity is the same as the Kanawat Gardens site for the planning in the Master Plan.

(6) New wellfield at Shoukry al Qouwatly Street

The potential location is within the parks adjacent to the Barada River opposite the International Fair and the National Museum, UTM grid reference 366.2 km E, 3710.7 km N, see Figure C-7.12. There are existing wells along the river bank that are used for garden irrigation and fountains, these are operated by the Municipality.

The zone along the river is anticipated to have hydraulic properties suitable for the construction of high yield wells for a wellfield. In this area the pebble beds better developed than the rest of Damascus being over 40 m thick. A transmissivity of over 1000 m^2/d can be expected in this area, therefore individual well drawdowns may be less than 5 m at a pumping rate of 100 m^3/hr. In addition the water chemical quality is likely to be good with the total dissolved solid less than 400 mg/l. The static water level is likely to be about 10 m lower in elevation than at Oumawiyin in May or June, that is an absolute elevation of 685 m in 1994 or about 5 m below ground level.

The natural groundwater flow direction is from the north west, whereas the Barada is aligned east to west. The abstracted water will be derived from a radius around the wellfield and may in addition induce leakage from the Barada River. River water quality is an important consideration in the viability of this scheme. However, the effective 'filtering' of river water through the aquifer will improve some of the river water quality determinands. The fountains in the Barada are supplied by wells along the walkways adjacent to the river, a sample of this water has an electrical conductivity of 620 mS/cm and does not have any problems with the major ions chemistry.

To utilize the groundwater at the site a exportation cum observation well and five high yield wells are proposed. The first hole to be drilled will be the observation well which can be drilled and constructed to the standard DAWSSA method modified by this study's recommendations. It is anticipated that the hole will need to be 75 to 80 m deep to fully penetrate the highly productive sediments. The hole should be tested to check the aquifer properties and water quality prior to the establishment committing it's self to the location. Subject to the exploration hole having a transmissivity of greater than 1500 m^2/d and water of a drinking water standard the five production wells may be drilled. These holes will have the same depth as the exploration well but may be drilled at a diameter of 20" (508 mm) to permit the installation of 17" casing and slotted casing. A large diameter is recommended to enable the well to have a specific yield of more than 10 l/s/m, this could permit each hole to abstract 150 m^3/h with a drawdown of less than 4.3 m. An additional drawdown of 7 m can be anticipated from other wellfields plus an interference between the wells of up to 17 m through a typical pumping season from May to the beginning of the natural recharge in November or December. A pumped water level of up to 33 m below ground level is expected at this new wellfield. The details of the proposed wells and the pumping equipment required are given in Tables C-7.7 and C-7.8.

(7) New wellfield at Yalbuga

The Yalbuga Center is located within the center of Damascus, occupying the block stretching from the north side of Al Shouhada Square (also known as Martyrs Square) to Al Ittihad Street. Upon the site is being constructed a mosque and conference center for the Ministry of Religion. Work began upon the site in the late 1970's, and as yet all the foundations have not been completed, while the eventual end of the construction work is not known. The reason for the slow progress has been stated to be due to groundwater. The groundwater level under the site is naturally about 5.5 mbgl, a level higher than the basements of the building. To enable construction to proceed 19 shallow de-watering wells encircle the site and are pumped throughout the year to lower the water table. Water is discharged via a special channel into the Barada River in Martyrs Square. From March to May all the pumps are required to depress the water table to an acceptable level whereas later in the year as few as three are used.

Groundwater is contained within the alluvial pebble beds that are highly productive in the zone along the course of the river. The natural direction of groundwater water flow is from the north west and under the course of the Barada. The pumping at the site will have modified the levels slightly though the overall drawdown must be less than 5 m (the de-watering holes are only 10 m deep). Water physicochemical properties are excellent and similar to the water from Oumawiyin wellfield, see the table below. The water is however contaminated by bacterial pollution, which, considering the water is pumped from less than 10 m depth is not too surprising.

Parameter	Well 1	Well 2	Well 3
Turbidity (mg/l)	1.5	1	1
Conductivity (μS/cm)	575	600	600
pH (-)	7.5	7.3	7.3
Total Hardness (mg/l)	290	300	300
Calcium (mg/l)	88	92	92
Magnesium (mg/l)	-	-	-
Sodium (mg/l)	18	21	21
Potassium (mg/l)	2.5	3	3
Bicarbonate (mg/l)	329	332	332
Sulfate (mg/l)	25	23	23
Chloride (mg/l)	22	26	26
Nitrate (mg/l NO_3)	15	15	15
TDS (mg/l)	355	370	370
Total Colonies (/ 100ml)	300	400	155
Coliform (/100 ml)	10	25	20
Date	15/8/96	15/8/96	15/8/96

The water that is currently pumped from the site is immediately run to waste. In total it is estimated that in excess of 2 MCM are abstracted each year (over 40 MCM since construction started). It is proposed that the groundwater under the Yalbuga site be considered a water source. Three options for the use are detailed;

- Use by the Municipality for street washing, garden watering and similar purposes. The water is of suitable quality for all these functions without any treatment. Only a slight modification to the pumping system would be required, so that water may be switched to a tanker hose. A temporary roadway to the east side of the site could allow tankers to fill-up. This option would only be possible subject to the construction progress on the site and could only use a very small percentage of the available water pumped.

- Use by DAWSSA from the existing wells. A scheme to directly use the water would require; headworks modifications, pipelines, submersible pumps, control room, chlorination facility and contact tank (reservoir). The headworks of the wells would need to be modified to incorporate a subsurface headworks chamber. The pipelines would need to include for a washout facility to the Barada. The washout would be used to pump extra water not required by DAWSSA into the river to maintain depressed water levels while the construction of the Yalbuga Center continues. The control room, reservoir and chlorination facilities may be either located on an adjacent plot acquired by DAWSSA for the purpose, probably near the vegetable market, or if an suitable local site can not be used, the raw water must be pumped to a location where it is possible to build the required facilities. Subject to the civil works being possible at the surface, the major drawbacks with the scheme are that; superchlorination will be necessary to provide safe drinking water, the wells will be especially susceptible to contamination, the available drawdown at each well is small so a large number of them will be required, and, pumping will have to continue throughout the year with a large volume lost to the river.
- Use by DAWSSA from new wells. The construction of a ten hole wellfield in approximately the same location as the de-watering wells is proposed. The holes should be 70 to 100 m deep to fully penetrate the pebble beds of the alluvial aquifer. The holes to be constructed according to the proposed design which minimizes the risk of surface and near surface water contamination. The capacity of each wells is anticipated to be about 30 l/s, providing a total peak site output of 300 l/s, or, with 80% utilization, a daily volume of over 20,700 m^3/d, and over a 250 day pumping season, 5.18 MCM each. The location of the surface facilities that comprise a wellfield has the same constraints has have been described in the previous option. The scheme has advantages over the previous options, the bacteriological quality of the water will be better, the drawdowns can be larger so that higher pumping rates are possible. However, because the aquifer is layered and the abstraction will be from lower layers than the shallow gravel beds, the de-watering effect on the shallow groundwater may be minimal. It is probable that to control shallow groundwater in the spring period the existing de-watering wells may need to be retained.

7.1.4 Deep Groundwaters

A potential source for extra groundwater resources may lie in deep or fossil groundwaters in the area. A brief review of the previous work has indicated that there are no suitable sources of deep groundwaters.

Exploration of the Barada and Awaj with deep wells has been undertaken by the Russian study in the 1980's. There are 13 holes greater than 500 m deep distributed over the area, from which geological and hydrogeological information is available. These wells together with geophysical and other information build up the picture of the geological structure.

El Arab Trough. The deep wells within the El Arab Trough penetrate to a maximum depth of 886 m (252 m below sea level). The basin is infilled with lacustrine deposits, clays, marls, limestones and basalts all of which have poor aquifer characteristics. For example the well at Adra 19K passes through almost 500 m of Neogene strata which only yielded 1.5 l/s during testing. The Cretaceous limestones of Cenomanian and Turonian age that from a good aquifer in the Anti-Lebanon mountains is at a greater depth than any of the exploration wells. The limestone forms Kassioun Mountain to the north west of Damascus, under the city the top of this same formation dips steeply and is anticipated to be up to 1700 m below ground level. A section though the Al Arab Trough compiled with information from these deep borings is illustrated in Figure C-2.4.

The suitability of the Cenomanian and Turonian limestone in the El Arab Trough for use as a water source can only be surmised. On the positive side the water resources stored in these formations is not currently exploited by any user and is beyond the means of the local population to exploit in the future. However there probably is not a useable resource present in the ground for anyone. The hydraulic properties are unknown, but perhaps may be surmised from well 41K drilled into Kassioun. Here almost 300 m thickness of limestone was tested and yielded 14.5 l/s with a drawdown of over 30 m, yields greater than this can not be expected for the formation buried at depth. Secondly the water physicochemical properties are likely to be unfavourable, the temperature of water from a depth of 1700 to 2000 m below ground level will be greater than 75℃ and the water is likely to have a high total dissolved solids.

Deep groundwaters in the Zabadani Valley has been investigated with the construction of well 21K. This well penetrated 1020 m of Cretaceous and Jurassic limestones and is the deepest well in the area. The well is productive, a yield of 73 l/s is derived from the uppermost part of the Jurassic (117 to 250 mbgl). A temperature log run on this hole showed no variation from 17℃ throughout the full length, indicative that surface groundwaters were moving vertically down the hole. The Jurassic limestones from 250 to 1020 mbgl were not tested and it is assumed that they were non-productive. It is concluded from the information that the karstic aquifer development is associated with the upper part or near surface portion of the Jurassic limestones. Deep groundwaters are not exploitable in Jurassic.

Well Number	Total Depth	Geology	s/Q (m/l/s)	Tested Interval (mbgl)
1A	886	-	-	-
19K	833	Quaternary	31.6	198 to 263
"		Neogene	34.6	335 to 833
20K	610	Quaternary	-	-
"		Neogene	16.8	248 to 326
"		Paleocene	793	326 to 610
21K	1020	Jurassic	0.08	117 to 250
41K	860	Cretaceous	2.2	450 to 749
85K	557	Basalt	214	89 to 102
118aK	641	Quaternary	6.7	256 to 350
177K	525	Cretaceous	-	-
203K	607	Neogene	-	-
226K	530	Paleocene	10.7	312 to 355
235K	775	Quaternary	0.5	3 to 35
246K	830	Quaternary	0.04	8 to 46
"		Quaternary	16.6	84 to 119
"		Quaternary	-	338 to 355

7.2 Options for Future Water Sources

The future water sources that may be used by DAWSSA are located on Figure C-7.13. The anticipated capacities are summarized in Table C-7.10. Included within the future water resources are the existing and on-going schemes of the Barada and Figeh Spring reinforcement within DAWSSA's current five year plan (1996-2000).

7.2.1 Option 1

The first option proposed comprises developing sources to which DAWSSA has been assigned Water Rights. The Rights exist for all the groundwater sources within the Municipality plus Figeh Spring, Wadi Marwan, Deir al Ashayer, Rimeh and the Al Sahl wellfields near Barada Spring. The quantity that may be taken from Damascus wellfields and from Figeh spring is limited only by the physical availability of water. Whereas from Barada & Al Sahl the Prime Minister has granted a Right to abstract up to 34 MCM per year from the combined wellfields near Barada Lake. DAWSSA intends to utilize the Barada source up to the maximum permitted by the Water Right. To this end, if in a wet year it is not necessary to use the full license limit the quantity of water that was not abstracted is planned to be 'carried over' to future years when other sources are less productive. Such a practice may be acceptable to

DAWSSA and MOI, however, the planning options are formulated using just the annual quantity since this is the safest option. The MOI has reported on the available water and assigned a quantities of 4.1 MCM at Deir al Ashayer and 4.5 MCM at Rimeh for use by DAWSSA. The use of the Yalbuga wellfield is excluded from the development of wellfields in Damascus due to anticipated land acquisition problems and the shallow depth of the groundwater being particularly vulnerable to pollution.

The schemes that are thus included in option 1 are; new, equipped and upgraded wellfields in Damascus, a completion of the ongoing schemes near Barada Spring, Wadi Marwan, Figeh and Damascus, and, the development of the Deir al Ashayer wellfield. The use of Rimeh is excluded on economic and financial grounds from the first option.

7.2.2 Option 2

This option includes all the schemes that are in option 1 plus the promotion of schemes in areas for which DAWSSA has not been assigned Water Rights. These areas are the springs on the Awaj River at Beit Jenn and Tabibiyeh, and also the Rimeh wellfield, all which lie south west of Damascus. In the option is also the use of new wellfields at Sergaya and El Irk north east of Zabadani.

7.2.3 Option 3

Like option 2 this option envisages the use of all the schemes proposed in option 1. In addition a greater exploitation of the Barada Wellfields in excess of the assigned water Right of 34 MCM. An extension of the wellfield around Barada Lake and Spring is considered the best means to increase the abstraction.

7.2.4 Option 4

The fourth option comprises the combination of all the is the previous options and involves the development of all the water resources identified.

7.3 Master Plan Projects

7.3.1 Selection Criteria

The choice of an option of use in the Master Plan is a balance between what will provide sufficient water to the city and yet will not adversely affect the environment, the economic livelihoods of the local population and be a politically acceptable solution. The selection must also be economically and financially attractive to both DAWSSA and to lending agencies. All the schemes proposed are thought to be technically feasible so this is not a consideration for the screening process.

At the time of the Master Plan formulation only option 1 is politically acceptable. The other options have to be approved and accepted by government, something that can not be guaranteed and used for planning purposes. The economic analysis has shown that the scheme at Rimeh has a very low viability and therefore has been excluded. All the options will affect the local availability of water for other uses. In option 1 this will be confined to the farmers in the Deir al Ashayer area who use groundwater for irrigation. Water levels will be lowered by the proposed wellfield and some of the irrigation wells will be de-watered while in others the pumps will need to be lowered. The scheme at Sergaya and El Irk will intercept water that otherwise would discharge through springs from where it is channeled and used in irrigation. The use of water by EDWSSR from the adjacent areas has already had this effect. The farmers have started to look for other means to irrigate their lands, the drilling of private wells seams to be the most common solution. The social effect of the Hermon area schemes is likely to be large plus there will be an environmental impact on the upper reaches of the Janani River. The spring water is now used in flood irrigation of the land. If all this water is piped to Damascus there will be no viable source of irrigation water in some areas. Within the Awaj basin there is a switch to groundwater for irrigation, this is not always technically feasible for all farmers. Option 3, the further exploitation of the Barada Spring source, will have an effect upon farming in the Zabadani Valley. The Barada River, whose headwaters are Barada Spring, is used as a source of irrigation water, albeit illegally. The existing quantity taken from Zabadani Valley wellfields reduces the stream flow, as also do private irrigation wells within the spring catchment. The further development of DAWSSA's water use will need to take these factors into account. The substitution of the river as a source of irrigation with another source is one possible solution, but this lies outside the jurisdiction of DAWSSA.

The use of options 2,3 and also 4 are ruled out on socio-economic and/or political grounds, even though they may be able to satisfy the demand in the year 2015. The choice of option 1 permits the reduction and at times elimination of the season deficit of water currently suffered by the inhabitants of Damascus. The option will achieve these improvements up to the year 2005, by which time all the schemes will have been commissioned and there is a forecast deficit which grows to 46.7 MCM by the year 2015. The deficit in option 2 is 20.8 MCM and for option 3 it is 16.9 MCM at the end of the Master Plan period. Option 4 removes the deficit completely. For the Master Plan, option 1 is the most desirable option and so it is adopted for use. The water production plan and the water sources development plan are base upon this option.

7.3.2 Reinforcement of Existing Water Resources

The sources at Figeh; Side Spring and Ain Haroush are both under re-development. New wells have been drilled near to the existing sources that allow for much greater drawdowns than are currently available. The up-graded sources are hoped to increase the total Figeh output during peak demand months. There are no changes planned for the Main spring and the Deir Moukaren wellfield.

Barada wellfields groups 1,2 and 3 are ongoing projects, the group 2 wellfield is nearing completion, the other groups have yet to be developed. The sources together have a capacity of 450 l/s which will be pumped via a pipeline to Damascus via Figeh. the Jurassic that feeds Barada spring is estimated to have a long term natural recharge of about 100 MCM/y. DAWSSA has been permitted to use 34 MCM/y the resource. It is considered that with careful water abstraction management an additional 20 MCM/y may be available from the aquifer without deleterious effects on local water users and the Barada River, if the water is to be allocated for use in Damascus.

The study of the sources operated by DAWSSA has shown that there are three wellfields that have undeveloped potential for further water abstraction, (Ibn Assaker, Kadam Railway and the Fringe Wells). Ibn Assaker wellfield is under utilized, and an additional 120 l/s may be pumped from the wells. The limiting factor constraining usage is the ability of the reservoir pumps to get the water into the distribution system. By up-grading the capacities of these pumps the quantity that may be produced from the site as a whole can be increased. Kadam Railway may also produced more, the limiting factor being the capacity of the submersible pumps. By upgrading these it should be possible to obtain an average of 115 l/s extra from the whole site.

The other existing wellfields in the City; Mazraa, Jobar, Kaboon, Oumawiyin are used at near optimal rates, no changes in the operation of these sites are made in the Master Plan. The university wellfield is on the interface between good and poor water quality. The continued operation of the site is liable to result in the water quality not meeting the Syrian drinking water standards. It is therefore proposed that this site is not used in the future. The Kadam Store wellfield is to be fully equipped with submersible pumps, this will add water to the distribution network in south Damascus.

An existing wellfield at Dummar is to be re-equipped after period of idleness while new reservoirs and pumping station were built. It is intended that the water will be used for the local distribution network in Dummar, releasing the supply that currently comes from Figeh to other parts of the network. The fringe wells have different specific capacities, however they are all equipped with the same pumps. Those wells that are in higher yielding parts of the aquifer could be used at a higher rate. The re-equipping of just 8 sites could give an extra 1.76 MCM in a typical year. The emergency wells continue to be a back-up source for DAWSSA in times of unprecedented water shortage if the main sources can not be used. No change in the use of these sources are planned.

7.3.3 On Going and Planned Water Supply Improvements

(1) New well centers for informal areas

New wellfield sites are identified in DAWSSA's plan to supply existing informal areas. The capacity of the existing Kaboon wellfield will be expanded with new and deeper wells. In the first phase two wells are planned. If these prove to be successful than another eight will be constructed. Jaramana wellfield is located in a highly productive area. This wellfield will be equipped to serve the distribution network in the area of South Damascus. The water supply in the informal area of Takadom, south of Damascus will be enhanced by the Takadom wellfield. The site has 10 production wells that were drilled in 1989 but not immediately equipped for production. DAWSSA plans to commission the Takadom wellfield in the next couple of years.

(2) New well centers for formal area

DAWSSA's development plan identifies several projects to increase the capacity of water sources supplying the city. A new wellfield is planned for Afar Souse, this will be a small source with approximately 5 wells. The wellfield at the Faculty of Agriculture between Mazraa and Kaboon is not viable since DAWSSA has not been able to acquire any suitable land to locate the wellfield. The Tishreen and Kywan wellfield have been drilled but not equipped with pumps. It is planned to develop this source is a phased sequence by first equipping the high yield wells, followed by the lower yield wells and finally by drilling another two wells. The wellfield will be controlled from the neighboring and existing Oumawiyin center.

(3) New water resources schemes in the Hermon area

DAWSSA's five year plan identified a number of potential water resources development schemes described as follows:

A wellfield near Rimeh in the southern part of the Hermon area. The site consists of various wells including some drilled by the MOI for hydrogeological studies in the area. The limited capacity of the source (285 l/s for 6 months of the year) and the long distance to Damascus have made the scheme economically unattractive.

The Kudsaya residential development located north west of Damascus will be supplied by a wellfield in Wadi Marwan. The wellfield, pipeline and associated works are designed for a capacity of 20,000 m^3/d.

An existing wellfield in the Cretaceous limestone at the northern end of Hermon near the village of Deir al Ashayer is identified as a potential new water source. Three existing MOI wells and a fourth to be drilled for DAWSSA, make up a small wellfield. The water would be supplied to Damascus via a new pipeline to Huseiniyeh, where it joins existing pipelines.

7.3.4 Proposed New Water Supply Schemes

(1) New proposed water resources schemes in Damascus (New Stations)

Three new wellfields are proposed; one in the center of the city on Shokry al Qouwatly street, another in Kanawat Gardens and a final one in Kafar Souseh. A wellfield is planned to be located in gardens along Shokry al Qouwatly street and opposite the National Museum. The water quality and yields from the ground are both anticipated to be good in this part of the City. A potential water source that is not put forward for the Mater Plan is the area north of Al Shouhada Square near the Yalbuga Center. The groundwater is known to be shallow depth and the pebble beds known to be highly productive. Although for quality reasons it may not be suitable as potable water, but may be a substitute source for the Municipality.

A third phase of the development of the Tishreen wellfield comprises the construction of two new wells in that part of the site where existing holes have already demonstrated the potential for high well yields. The Kanawat Gardens wellfield is planned for an area of small market gardens between Kanawat and Kafar Souseh. The area was selected to be distant from existing wellfields yet still have reasonable well yields and good water quality. A small wellfield of 5 holes is anticipated for this site.

(2) New proposed water resources schemes in Hermon and Zabadani areas

Three sources identified in the Hermon area would all require long pipelines if the water is to be allocated for use in Damascus. In the Awaj basin a spring source at Beit Jenn and Tabibiyeh could provide a supply, although it would be very seasonally variable. The Jurassic aquifer east of Sergaya and north east of Zabadani has only limited recharge, but may have a small development potential. A pair of wellfields at Ain el Irk and Sergaya could have a potential yield of about 3 MCM/y.

8. WATER RESOURCES DEVELOPMENT PLANNING

8.1 General

8.1.1 Design Proposed for New City Wells

(1) Existing design

The wells constructed for DAWSSA since 1979 in Damascus all have a similar construction. The method of construction adopted has been found to be relatively easy, inexpensive and suited to the local geology and technology.

(a) Drilling

Drilling is undertaken by the percussion method. The technique is favored since it is easy to drill a vertical hole. The exact details of diameters and depths drilled will reflect the anticipated site conditions, but generally well designs are fairly similar. Firstly a 17" to 20" diameter hole is drilled to a depth of 6 to 20 m. Into this hole a 13" to 17" diameter length of protective casing is installed and the annular space between the casing and the hole grouted with ordinary Portland cement. In practice 30 kg of cement per meter of annulus is specified to make the grout. The main hole is usually drilled at 12" diameter to a depth of 60 to 100 m. The aquifer is stable and temporary casing may not be necessary for the full length of the drilled hole.

(b) Casing and screen

The casing string consists of perforated and blank casing which is installed to the bottom of the hole. There is a 5 to 10 m blank sump section at the base of the hole above which a section of perforated casing with a second blank casing section from the top of the perforated casing to the surface. The casing does not have an end cap to seal the end of the pipe. The string rests on the bottom of the hole and is centralized at the surface by cutting and folding the top of the conductor pipe.

The casing is usually 9" diameter with a wall thickness of 4 mm (approx. 1/6"). It is manufactured locally by a press formed method with welded seams, coated with a metal primer paint both inside and out and then given an outer coating of bitumen. The perforated casing is fabricated by either punching or flame cutting vertical slots. These slots are 10 mm by 100 mm arranged around the pipe with about 20 slots per linear metre. The slotting produces an open area of 2.7%. In practice the slots may be smaller and less frequent, the casing used in the

Oumawiyin wellfield has been observed to have 10 mm by 80 mm slots with 22 slots in a 5 m length, equating to an open area of 0.5 %.

(c) Well development

Following drilling temporary casing is partially withdrawn to expose the aquifer. A vertically mounted spindle pump is used for clearance pumping. Experience has shown that after pumping the well at 100 m^3/hr for three hours most of the fine particles, sand and loose small pebbles are removed. Typically the clearance pumping lasts for 6 hours. Following the pumping it is decided whether to install casing, deepen or to abandon hole.

(e) Testing and analysis

The testing of the wells that is usually undertaken in one series of tests for a completed wellfield, not when an individual well is finished. Testing consists of a three step yield drawdown test. The length of the steps may be as short as 10 minutes, or may extend to over 24 hours. The steps are usually sequential, but sometimes there is a period of recovery between the steps. After the third step the recovery of the water levels is measured in the tested well. The holes are tested at discharge rates of up to 100 m^3/hr (28 l/s). During the pump testing a water sample is taken for a bacteriological and physicochemical water quality analysis. The pumping rate is measured by the volumetric method, measuring the time that it takes for the pumped water to fill a container of known volume.

The well design, lithological log, results of the yield testing and water quality testing are collated onto a single A0 sized drawing. These drawings permit the easy appraisal of all the aspects of a well hydrogeology. A graphical analysis of the yield drawdown information is presented but no analysis of the test pumping data for aquifer hydraulic properties is undertaken.

(2) Potential problems with existing well design

(a) Cementation.

The quantity of cement used to grout the conductor pipe is insufficient to fully seal the annular volume. This may result in voids in the annulus which reduce the bonding to the surrounding ground and could allow the passage of contamination to reach the well. The effective grouting of the conductor pipe is particularly important since the main casing in the hole is not grouted in position.

(b) Casing alignment

The main casing rests on the base of the hole and will therefore tend to bend to the orientation of the hole and rest against the formation on one side. The alignment problem will be most sever if the well it's self is non vertical or crooked. Possible problems could range from difficulties in installing and removing pumps, clogging of perforated casing and sand pumping.

(c) Casing material

The casing is usually of 4 mm wall thickness. The strength of this casing is less than is normally recommended for water wells. Problems may arise with the splitting or collapsing of the casing. The metal primer paints and bitumen applied to prevent steel corrosion may have a detrimental effect upon water quality.

(3) Recommended well design

(a) Drilling method

The percussion drilling is recommended for pragmatic reasons since it is cheap, technically simple and a proven method for the strata underlying Damascus and the Ghouta.

(b) Well dimensions

The well should be drilled in two stages. An upper hole to about 15 m and a lower hole to a depth of about 100 m. The upper hole shall be to the depth of the first impervious formation or to a minimum depth of 15 meters. The diameter of the hole should be such as to allow for a minimum of 2" annulus between the conductor pipe and the well wall, and be of sufficient size that the method of cementation may be effectively accomplished. A diameter of 17" is satisfactory for use with a 13" conductor pipe. The lower hole should be drilled at a minimum diameter of 12". This diameter is satisfactory for the typical well yields anticipated in the city area.

(c) Conductor pipe installation and cementation

The conductor casing should be installed to the depth of the upper hole. The casing prevents contamination from the near surface, stabilizes the ground around the well to permit drilling to greater depth and provides a foundation onto which well casing and screen may be suspended. The effective cementation of the conductor pipe is very important in providing the desired sanitary seal for the well. The grout used should be with fully hydrolyzed cement for maximum strength. Up to 5% bentonite clay as a powder should be added to the grout to prevent cracking of the grout. Calcium chloride up to 1 % may be added to reduced the curing time of the grout from 72 hours to 24 hours. A cement grout with a density of 1.75 g/cm^2 is recommended this should be made with 29.6 litters of water per 50 kg sack of cement, each sack of cement producing 45.5 litters of grout. To grout the annulus between the 17_" hole and 13" casing with an allowance of 10% extra a volume of 69.5 litters of grout per linear metro are required made from 1.52 sacks of cement per meter.

To ensure that the annulus is effectively sealed the grout should be emplaced from the bottom of the hole. This may be done by the use of a tremie pipe in the annulus or by pumping through a cement shoe on the conductor pipe.

(d) Sampling

Rock and water sampling should be undertaken during the construction of the wells. The following comments could act as a guide to an effective sampling plan. Bulk disturbed rock samples, mass 1 kg, should be collected every 2 m of depth from the surface or when then formation changes. Samples should be stored in sealed containers and clearly marked with the well number, date, and depth interval. The hydrogeologist may select rock samples for sieve (grain size) analysis. Normally these samples will be chosen from the aquifer horizons and will provide information to assist in selection of the screen. Water samples should be taken when the water is initially encountered and at every major influx, or every 10 m interval. The electrical conductivity of the water should be measured and recorded on the drillers records. Water samples are to be stored in sealed containers. If there are significant water quality changes with depth as indicated by conductivity changes the hydrogeologist may decide to have the different waters analyzed.

(e) Geophysical logging

Following the drilling it is recommended that the hole be geophysically logged to provide information on lithology and water quality. The logs should be run on the full saturated length of the open hole. If temporary casing has been used this should be partially withdrawn to expose the aquifer. It is understood that The Ministry of Irrigation will undertake logging operations on behalf of DAWSSA. The following logs should be run as a minimum requirement; gamma ray, spontaneous potential (most effective if the hole has drilled with a mud drilling fluid) and electrical resistivity (short and long normal, or their equivalents), in addition calliper, temperature and electrical conductivity logs may provide useful information.

(f) Blank and perforated casing

The locally manufactured casing is considered to be appropriate for the wells to the shallow depths used in Damascus. A wall thickness of 1/4" (6.35 mm) is recommended by AWWA Standard A 100-84 for 10" or 8" casing installed to a depth of 300 m, this is thicker than the currently adopted practice of using 4 mm wall thickness casing. However for holes over about 300 m depth API H40 grade steel pipe should be considered.

The well casing should be designed so that the screen entrance velocities and the critical radius are satisfactory. The critical well radius is defined as the distance measured from the center of the well to a point where the flow changes from predominantly turbulent to laminar. The critical radius should be larger than the effective diameter of the well which is the diameter of the hole (12.25"). The critical radius may be determined from graphs produced by the AWWA. For a critical radius of greater then 6" the required flows per meter of casing should be less than those listed here;

Large pebble gravel	0.25 l/s per m of screen
Small pebble gravel	0.57 l/s per m of screen
Very course sand	1.26 l/s per m of screen
Coarse sand	3.15 l/s per m of screen

The wells in Damascus normally have design capacity of about 30 l/s so should have over 52 m of perforated casing if turbulent flow is to be avoided in a small pebble gravel aquifer or 24 m of screen if the aquifer is a very course sand.

Water enters the perforated section of a well only passes through some of the slots cut into the casing in a naturally gravel pack since they will be partially blocked by particles. The effective open area will therefore always be smaller than the measured open area. To maximize well efficiency an effective open area of 3 to 5 % is desirable. Reduction of the open area from 5 % to .5 % changes the theoretical well efficiency from 90 to 70 %, increasing the effective open area above 5% has been shown in tests to not significantly increase the well efficiency. Screen entrance velocities are recommended to be less than 0.03 m/s. The equation C.21 may be used to calculate the entrance velocities. A tabulation and graphical presentation of screen lengths and percentage open area required to maintain recommended screen entrance velocities are to be found in Table C-8.1 and Figure C-8.1.

$$V = 1.253\frac{Q}{dlp} \qquad (C.21)$$

Where	V	Entrance velocity in m/s
	Q	Discharge rate in l/s
	d	Casing diameter in inches
	l	Length of perforated casing in meters
	p	Effective percentage open area in %

For a typical well designed with a yield of 30 l/s from 9" casing with 40 m of 2.5% open area the entrance velocity would be 0.04 m/s, this is just above the recommended limit and consequently sand pumping may occur. To mitigate against this problem the open area should be higher and or the length of perforated casing longer.

A steel end plate should be fixed to the bottom of the casing string. To keep the casing from the well wall, centralisers should be placed along the pipe a 25 m intervals. The casing should also be hung from the surface and not allowed to rest on the base of the hole. A cement basket (tampon) should be deployed at a depth of not less than 20 m and then the annulus above the basket grouted with cement of the same specification used to fixed the conductor pipe.

(g) Well development

The purpose of development is to clear the well of debris, remove the fine material from the formation, assist in the creation of a natural gravel pack and remove drilling fluid and mud from the hole. Development will enhance the performance of the well. The development that is required for a particular well should be tailored to meet the drilling method and local conditions. Generally it should consist of development with air and clearance pumping. Chemical dispersants should be used if the drilling fluid was not water. Air lift pumping and surging with air at depths along the length of the perforated casing is an effective method to remove drilling debris. Alternating the airlift with short periods of recovery will assist in creating agitation in the aquifer matrix to remove fine material. To simplify the pipe assembly needed for the operation the well casing may be used as the adductor pipe and 3.5" or 5" drill pipe as the air line. For high yield wells control of the discharged waters and channeling to a suitable disposal site must be considered. A period of 24 to 48 hours may be required to effectively develop a well and produce clean sediment free water. A preliminary idea of the likely well performance will be gained during the development of the hole.

(h) Well testing

Well testing should be aimed a providing information on the performance of the well and the behavior of the aquifer in the wellfield. Up to three sets of tests are ideally required. Firstly a step drawdown test should be undertaken. The details of the test will be adapted to meet the individual circumstances, but should consist of three, preferably four steps of a minimum of 2 hours in duration. The pumping rates should be designed to be 25%, 50%, 75% and 125% of the anticipated design yield of the hole. In between each pumping period the well should be allowed to recover for a minimum of 2 hours. After the final step a 12 hour period of recovery is desirable before the constant rate test is undertaken. The constant rate test should be of 24 hours duration. Observation of the neighboring wells should be undertaken during this test. Adoption of a pumping rate, 100% of the design yield will give a total of five steps for inclusion in the step test analysis of the hole. The third test is a long duration test, it is not necessary to carry out this test at every well in a compact wellfield such as are drilled in Damascus. The testing of neighboring wells will probably give the same or very similar results. The number and location of the wells for long duration tests should be selected by a hydrogeologist. The duration of the pump testing will depend upon individual circumstances, however a duration of 4,300 minutes or about 3 days will usually be adequate to identify leakage effects and boundary conditions and perhaps water table conditions. Prior to a long duration test daily measurements in all observation wells in a 3 km radius should be gathered. These are used to clarify any background changes in aquifer water level that may be superimposed upon the test pumping effect. Measurements of water levels should be recorded in the tested and the neighbouring holes which act as observation wells for the purpose of the testing. The logarithmic distribution of measurement intervals through time as already practiced by DAWSSA should be continued. Particular attention should be paid to the accurate measurement of water levels in the observation wells during the initial ten minute period. The initial time data from the production well is of less importance.

(i) Analysis

The results of the well testing should be analyzed and collated with other aspects of the well design into a drawing and a factual report for future reference and planning. Specialized computer software programs may be used to do the analysis of step tests and constant rate tests.

(j) Leveling

It is recommended that all new wells are leveled upon completion. This applies to both wells that are primarily intended as observation holes and also that may not be commissioned as production wells

(k) Well completion

A concrete plinth should be built around the conductor pipe and the top of the hole effectively sealed until the well is commissioned. Those wells that are to make up the wellfield should have a well head chamber constructed to allow access for maintenance and staff. The chamber should be designed to remain a clean and sanitary location. A sump in the base of the chamber should run away and drain the chamber. In areas where there is groundwater within 3 m of the ground surface a chamber wellhead is inappropriate and a small well head building is recommended. The covers to the chambers should be secure yet moveable by DAWSSA staff. They should always be in position when work is not being undertaken in chamber.

Sampling taps should be installed on each well. Ideally these would be finished at the surface in a small lockable kiosk.

8.1.2 Observation Well Network Rehabilitation

DAWSSA has a network of 19 observation wells within the City. They are mainly located within the existing wellfields. Recently 7 new observation wells have been drilled in locations remote from DAWSSA wellfields. These holes can provide information on the citywide changes in water levels away from the direct influence of the main centers of pumping. However it has been reported by the water resources directorate that all but one of these holes can not be used for its intended purpose because they are 'full of sand'. It is proposed to rehabilitate the new observation wells to make them suitable for inclusion in a citywide groundwater monitoring scheme.

The rehabilitation program should comprise two parts. In the first instance the nature of the problem should be identified, each hole should be plumbed to measure the total depth. Secondly any material in the holes should be removed by airlift pumping, if unsuccessful by redrilling the collapse material. It is recommended that slotted casing should be installed into the holes to guard against further collapse. Should it not be possible to rehabilitate the hole then the drilling of a replacement hole in the same area should be undertaken.

The Master Plan proposes to increase the groundwater abstraction from under Damascus. The extra abstraction will be introduced progressively, during this period it is imperative that the behavior of the groundwaters are studied to ascertain whether the extra pumping exceeds the capacity of the aquifer. This knowledge will be used in the planning of latter stages of the Master Plan.

8.1.3 Hydrological/hydrogeological Study and Modeling of the City

The objective of this study should be a better understanding of the water fluxes within the city, the relationship between surface water and groundwater, the relationship between waste water and both surface and groundwater. This understanding is important in the formulation of plans for the use of the City groundwaters and to establish the likely influence of the future waste water schemes. The changes in flow along the many surface canals should be investigated from El Hame to the eastern boundary of the City urban area. The understanding of the hydraulic systems may be assisted by the construction of a mathematical model of the groundwater system. Such a model is a useful way of focusing on difficult areas that deserve further investigations. The final model can become a powerful predictive and managerial instrument that would enable the future response of the aquifer system to different pumping scenarios to be determined.

8.1.4 Water Resources Information and Analysis Systems

The data collected by DAWSSA from its various monitoring networks and on the operational details of the sources is stored on the main establishment technical computer system. Although a useful tool for the day to day management of water extraction and supply it is less adaptable to the diverse requirements and analytical capabilities needed for water resources studies. The data that may be called upon for water resources work is various and will include meteorological, hydrological, geological, hydrogeological sources. A more flexible approach is desirable to cope with data on time scales from minute to minute during aquifer testing to decades when looking for long term groundwater and meteorological trends. The capacity of the system to be able to represent information graphically and cartographically would be employed extensively in water resources studies.

Information and analytical systems are widely available for the disciplines that constitute water resources. Most of such software is directed towards the personal computer or network of personal computers, either working under DOS or a Windows environment. Systems may be either standard packages, or customized versions. A need is perceived for software systems to cover the following areas:

- Pumping Test Analysis
- Hydrological / Hydrogeological Database
- Groundwater Modeling software

Work undertaken on water resources in the preparation of the master plan used 'Ground Water for Windows' (GWW) for storage and reporting purposes. The inventory of almost a thousand wells from DAWSSA, the Municipality and the Ministry of Irrigation has been collated. A copy of the files has been provided to the Water Resources Directorate.

The use of a water resources information system is considered to be a priority project for supporting and planning the schemes proposed within the Master Plan. To this end the reinforcement of the existing systems is incorporated in the Master Plan

8.1.5 Long Term Study of Barada Spring Behavior

Apart from Figeh the sources in the Zabadani Valley, (Barada and Al Sahl) represent the largest resource that DAWSSA uses. The understanding of the behavior of the spring-aquifer system to pumping is critical in the future planning of possible schemes. It is opportune to gather data that will help with the through study of the source. Currently one on site observation well is monitored every two weeks and the Barada River at Tekieh is flow gauged. It is proposed that this monitoring is intensified and broadened. The level in the lake and the observation well should both be monitored on a continuous basis with autographic float recorders. The water level in the aquifer at a distance could be monitored in the three wellfields that belong to DAWSSA. The measurement of the actual discharge from the lake should be given the highest priority. Until such time as a proper rated channel section is available at Ramleh attempts should be made to measure the flow over the penstock and into the irrigation channels.

8.2 Water Resources Plan

8.2.1 Water Sources Development

The water resources plan uses those schemes that comprise option 1. This option is the one preferred by DAWSSA. The plan is able to increase the capacity of sources from Damascus and Deir al Ashayer to meet the anticipated water requirements until the year 2005 for normal or wet conditions.

The water resources projects can be divided into four types;

- Equipping existing, tested, but unused wellfields. This comprises the installation of pumps, well headworks, reservoir, chlorination and control equipment and site pipework. The wellfields to be equipped are at Takadom, Tishreen, Jaramana, Kadam Store, Wadi Marwan, Dummar, Barada Group 1,2 & 3.
- Re-equipping existing wells to increase their production. At these sites the wells are able to produce more water the limiting factor is the capacity of either the submersible pumps or the booster pumps. The schemes are at Ibn Assaker, Kadam Railway and the Fringe Wells

– Construction of new wellfields in Damascus. Three of these are at totally new sites, Kafar Souseh, Shokry al Qouwatly and Kanawat Gardens, the third, Kaboon, involves the drilling of more holes at an existing wellfield.

– Construction of new wellfields outside the city. The wellfield at Deir al Ashayer is proposed to use some existing Ministry of Irrigation some new holes.

8.2.2 Water Production Plan

The key objectives in water production planning for DAWSSA is firstly to be able to satisfy a demand that peaks in August while the sources have their maximum capacity in March-April, and secondly, to meet the demands when the main source is very variable year to year. To meet these two objectives production plans must be constructed on a monthly basis and also for three hydro-meteorological conditions. A schedule of production is devised for each source for each year of the Master Plan for three hydro-meteorological scenarios. For these three conditions a month by month plan is produced for the years 2000, 2005, 2010 and 2015. The four options for water resources development are compared. The option prefered by DAWSSA and the option selected for the Master Plan is option 1. The production plans for this option are illustrated in Figures C-8.2, C-8.3 and C-8.4 and the annual and monthly plans provided in full in Tables C-8.2a-e, C-8.3a-e, and C-8.4a-e. The production plans for options 2, 3, and 4 for the average and dry conditions are given in Figures C-8.5 to C-8.10 and Tables C-8.5a-e, to C-8.10a-e. The wet condition production plans are almost identical to the average conditions for options 2, 3 and 4 since the water demand is almost completely met throughout the year.

To represent different hydro-meteorological conditions three reference years have been chosen for comparison. These reference years represent average wet and dry conditions. The average conditions are conveniently similar to those experienced in 1995. Dry conditions in 1990 (water year 1989-90) produced a total flow of 141 MCM a flow that is exceeded 90% of years. For the wet conditions the year 1992 is selected (water year 1991-92) during which an annual flow of 334 MCM occurred, an event that is exceeded less than 5% of years. The reference years were selected to be in the recent past when the measurements are the most reliable and the source was modified by pumping. The total flow from Figeh in future years, is taken to be the same as the total flow in the comparison year, either that by gravity discharge or by pumping. The ongoing schemes at Figeh are assumed for the purpose of the plan to have no effect upon the discharge regime. This is in fact a worst case scenario, since the effect can only be to increase the low flows and reduce the flood of the spring. Making this assumption is therefore a conservative measure, the actual situation achievable being possibly slightly better than that assumed in the production plan. The monthly production from Figeh is either all the flow or that part of the flow that is needed to satisfy the requirements of Damascus. Within the formulation of the different scenarios the antecedent hydrological conditions have always been assumed to be a normal year. A sequence of dry years, even though they might not be as dry as a *1 in 20 year drought, may result in a equivalent hydrological condition as such a drought.* For example three successive years with 85% probability rainfall is equivalent to two normal years followed by a 95% probability rainfall. For this reason the three scenarios of wet, normal and dry must be considered to include the effects of the previous years.

The total flow from Figeh under the three scenarios does not change for the duration of the Master Plan. It may however be noted that it becomes possible to take a larger proportion of the flow each year in the wet and average scenarios. This is not due to any increase in resources, but a result of higher demand during the flood period when more of the flow can be used. The ceiling on the capacity is however reached in the low rainfall scenario when all the water from Figeh is required to meet the demand and there is no overflow to the river even during the normal flood.

A theoretical limitation on the use of the Figeh plus Barada plus Deir al Ashayer sources is imposed by the carrying capacity of the two tunnels from Figeh to Damascus. They have a rated maximum flow of 14.8 m^3/s. The production plan in the year 2015 for the average and wet conditions do not exceed this infra-structure limitation. In the years after 2015 it is probable that the size of the aqueduct rather than the water sources will be a limitation on the production.

The water production plan is able to almost satisfy the forecast demand for the period 1997 to 2006 and to fully satisfy the demand from 2001 to 2004. After the year 2008 the difference between requirements and source output is greater than that expected for the year 1996 and becomes progressively more acute up to the end of the Master Plan period. However DAWSSA should be aware that during a dry year or sequence of years there will be a deficit almost as large the shortfalls currently experienced. The most sensitive period for shortfalls in a range of lower rainfall from the 50% case to the 95% case will be the months of July and August. These two months will continue to have a water deficit in all cases when the rainfall is less than average. The month by month production plans detail the size of the deficit for the years 2000, 2005, 2010, and 2015.

At certain times during the Master Plan period there is surplus capacity. When this has arisen preference is made to use Jurassic and Cretaceous sources to permit the groundwater under Damascus to recover. The use of the Quaternary aquifer under Damascus is limited by the area that has acceptable water quality and by the anticipated total resource assessment of 50 MCM/y. The plan anticipates being able to exceed this amount due to the additional, but un-quantifiable recharge from leaking distribution system, waste water system and canals. At the end of the period during an average year 69 MCM are abstracted from Damascus. However during a dry year water use is much more intensive with wellfields operated for 11 months. Storage in the aquifer will be heavily drawn upon during these years which should be offset against years with lower abstraction when recharge will replace the used resource. It is stressed that the volume of storage of good water in the aquifer is comparatively small. The ability of the aquifer to buffer a long period of abstraction with low recharge is small. Therefore, with the build-up of abstraction in the lifetime of the plan studies are recommended to monitor the groundwater and hydrological conditions in Damascus.

Water quality is generally good under the city, however there is a slug of poor water quality that lies roughly north west of the Mezze autostrada. The known poor water quality at the University wellfield has led to its planned abandonment.

8.5 Implementation Program

The schemes are scheduled to meet the requirements of the production plan. To this end those schemes that are quick and will give a proven source of water will be implemented first while the more costly and longer term schemes are programmed to start latter. Those schemes will have a longer preparation period necessary for preceding hydrogeological and hydrological investigations, preparation of detailed designs and obtaining of the necessary permits and agreements prior to any construction works. The year when each source will be finished and the extra capacity available is listed below.

Source	Year	Source	Year
Wadi Marwan	1997	Tishreen & Kywan Phase II	2000
Barada Spring Group 2	1997	Deir al Ashayer	2000
Kadam Store	1997	Barada Group 3	2001
New Kaboon Phase I	1998	Shokry al Qouwatly	2001
Takadom	1998	Ibn Assaker	2002
Tishreen & Kywan Phase I	1998	Fringe Wells	2002
Dummar	1999	Tishreen & Kywan Phase III	2002
Jaramana	1999	Kanawat Gardens	2003
Barada Group 1	2000	Kadam Railway	2003
New Kaboon Phase II	2000		

REFERENCES

Bashir (1987) Final Report on the Pump Testing of Barada Spring. Damascus, SAR. (Arabic Language)

BRGM (1991) *Protection des Ressources en Eau de la Ville de Damas (Syria)*. Orleans, France.

Damascus Municipality (1994) General Structure Plan for Damascus City. Progress Report for Phase I, 1994. Damascus, SAR. (Arabic)

DAWSSA (1994) Water Supply Production Report, Damascus, SAR

DAWSSA (1996) Report to the Ministry of Housing on Water Resources. Dated 27/1/96, (Arabic Language)

Gilbert & LaMoreaux (1982) Assessment Report of Hydrologic System at Figeh with Implementation and action plan December 1982 EPDEF. Damascus, SAR

Lengiprovodkhoz (1986) Water Resources use in Barada and Auverge Basins for Irrigation of Crops, Syrian Arab Republic. USSR Ministry of Land Reclamination and Water Management, Moscow, USSR. (English Language, translated from Russian)

Ministry of Irrigation (1994) Final Report on the Hermon Project. Damascus, SAR. (Arabic Language, translated from Russian)

SOGREAH (1973) *Etude hydrogique et hydrogeologique de la Source Figeh. Rapport Final.* R 11442. Grenoble, France. (French Language)

SOGREAH (1975) *Source Figeh. Interpretation des measures de 1972 a 1974 et mise a jour des conculsion du rapport R11442.* Vol 1 Texte. R 12318. Grenoble, France. (French Language)