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AMMAN WATER RESOURCES

MASTER PLAN

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AMMAN JORDAN

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Introduction

In January 1976 Amman Water and Sewerage Authority commissioned VBB, in association with Fawzi & Associates, to undertake a Water Resources Investigation and Feasibility Study for Amman Water Supply and Sewerage Facilities. The basic aim of the investigation was to identify potential water sources within and outside Amman to provide for the immediate and long-term needs of the city and to formulate a Water Resources Master Plan to meet Amman's water requirements by the year 2005.

The water resources study was completed at the beginning of 1977 and the Final Report was submitted some months ago. Since the city of Amman is a major consumer of water in Jordan, the planning of its future water supply is of the greatest importance from the regional and national point of view. This factor alone may justify our choice of contribution to this Symposium. We have, however, also felt it necessary to elaborate on the recycling of water since this is an important component of the Amman Water Resources Master Plan and may also play a major role in the planning of other areas.

Background information

Amman is situated within the Amman-Zerqa Basin which covers an area of about 850 km^2 in the uppermost part of the Zerqa River drainage system, see Figure 1. The population living within this basin is at present about 1.3 million, of which nearly half live in Amman. The water supply for the entire population is based on ground water drawn from two aquifers extending over the greater part of the basin.

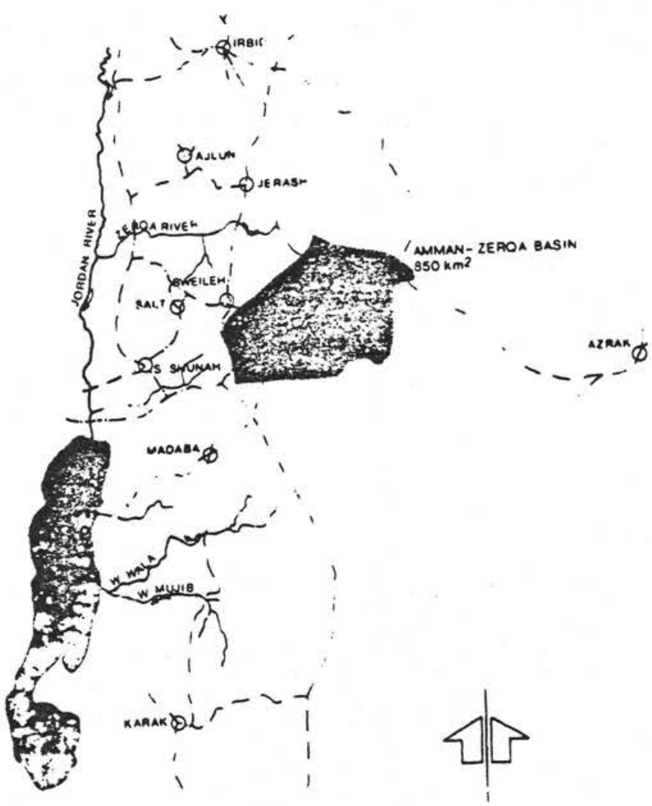


Figure 1. AMMAN-ZERQA BASIN

The total water demand within the Amman-Zerqa Basin, which corresponds to approximately the same area as the Governorate of Amman, comprises requirements for domestic, irrigation and industrial purposes. An estimate for 1974 shows that about 50 million m³ were extracted, thereof 34 for domestic, 13 for irrigation and 3 for industrial purposes. The extraction in Amman that year was about 18 million m³, which corresponds to a water production of 80 l/pd. Our own survey in 1976 showed only 24 Mm³ extracted for domestic use, while the other figures were the same as in 1974.

A certain proportion of the water consumed in Amman is conveyed via a sewer system for treatment in a sewage treatment plant and is then discharged into the upper part of the Zerqa River. However, most of the sewage is still discharged from the houses into private cesspools for infiltration. Outside Amman the cesspool system is the prevailing means of disposing of sewage. All water extracted from the basin is thus in one way or another discharged back into the basin.

Water demand forecast

Water demand forecasts have been made for Amman as well as for the Governorate of Amman, see Figure 2. The domestic demand, which constitutes the major part of the total demand, has been calculated on the basis of population forecasts and per capita production, the latter including unaccounted for water. The rate of increase in population has been calculated to be 5 % per year in 1975

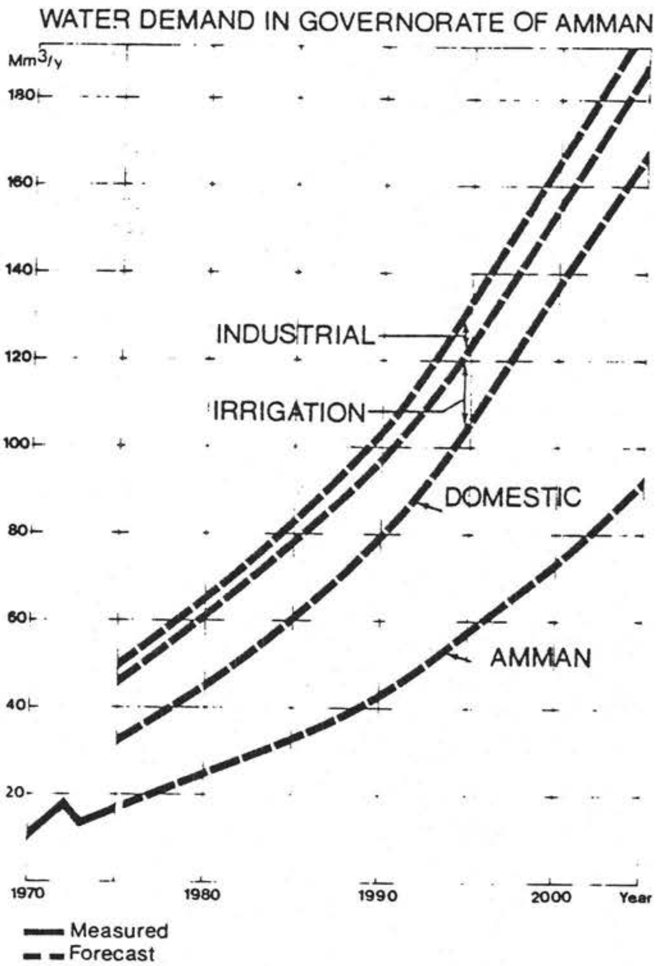


Figure 2. WATER DEMAND

which will gradually decrease to 3 % by the year 2005. It is estimated that the per capita production of water will increase from about 80 l/pd in 1975 to 145 l/pd by the year 2005. It is evident from the curve in Figure 2 that the present rate of water production in Amman, about 18 million m³ per year, is constrained by lack of water.

Existing ground-water resources

The existing ground-water resources within the Amman-Zerqa Basin have been calculated by means of mathematical models, one for each aquifer. Input data have been extracted from previous studies and investigations and collected during field investigations carried out in 1976.

The conclusions of the models study are that the potential recharge into the upper aquifer is in the order of 20 million m³/year for the whole basin of which only 10 million m³/year are re-charged within the area now commanded by Amman. The potential recharge into the lower aquifer is in the order of 5 million m³/year of which 2-3 million m³/year can be extracted within Amman.

At present the total quantity of ground water recharged within the area commanded by Amman is only 12-13 million m³/year while the total extraction is about 18.5 million m³/year. This means there is an overdraft from the upper and lower aquifer of about 6 million m³/year, which is only possible as long as the cesspool system exists in Amman. An uncontrolled recycling of water is in fact taking place via cesspools and to some extent also from leaking water pipelines. Infiltration from cesspools has caused deterioration of the ground-water quality, mainly in the upper aquifer, and must be eliminated as soon as possible.

Requircd water resources

The water demand in Amman already exceeds existing ground-water resources. The forecast shown in Figure 3 clearly proves that there is a critical need for other, new resources. By the year 2005 the demand will be 94 million m³/year or about 80 million m³/year in excess of existing ground-water resources. It is obvious that Amman needs new resources with capacities in the order of tens of million m³/year in order to overcome the present shortages and keep ahead of the growing demand. Development of such large sources takes some time and we have assumed that 1980 will be the earliest possible time by which any new major resource can be in production. By that time Amman will need

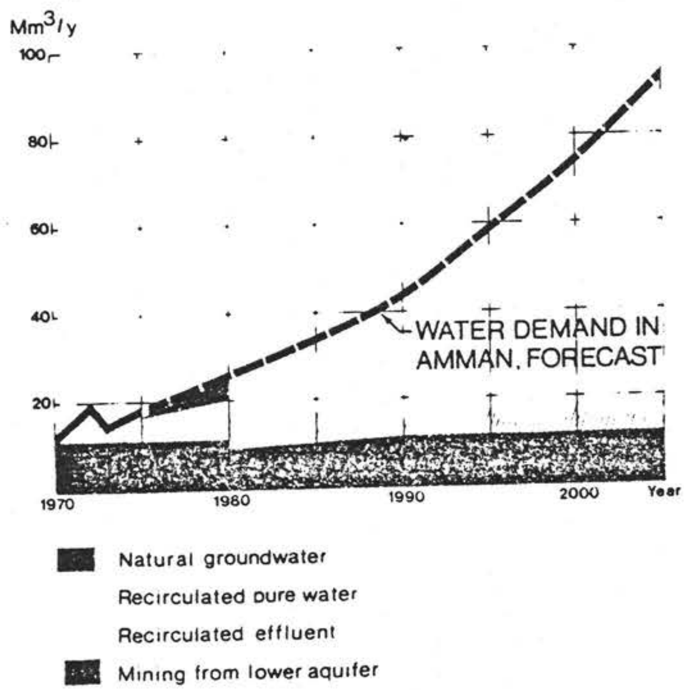


Figure 3. REQUIRED WATER RESOURCES

about 25 million m³/year which will have to be extracted from the aquifers in Amman thereby necessitating continued dependency on the recycling of water. In order to avoid further pollution we have proposed a temporary mining of water from the lower aquifer as illustrated in Figure 3. This mining will have to stop as soon as a new resource becomes productive in 1980 in order to allow time for the lower aquifer to recover.

The maximum utilization of the two aquifers in Amman is shown in Figure 3 up to the year 2005. In addition to the natural ground water we have also relied upon 10 % recycling of water from the water supply network. Recycling of water from cesspools is estimated to cease by about 1990 as a result of the gradual eradication of the cesspool system.

The minimum demand for new water resources will increase from about 12 million m³/year in 1980 to just below 75 million m³/year in the year 2005.

Outside water resources

In all, 10 potential outside water resources have been studied. The sources are all located within a radius of not more than 85 km from the centre of Amman, see Figure 4. Each source was first studied with regard to water quantity, availability, magnitude and water quality. The minimum capacity requirement of about 12 million m³/year, reduced the number of potential sources to 3, namely the King Talal Dam, Azrak ground water and the upper Wala Dam.

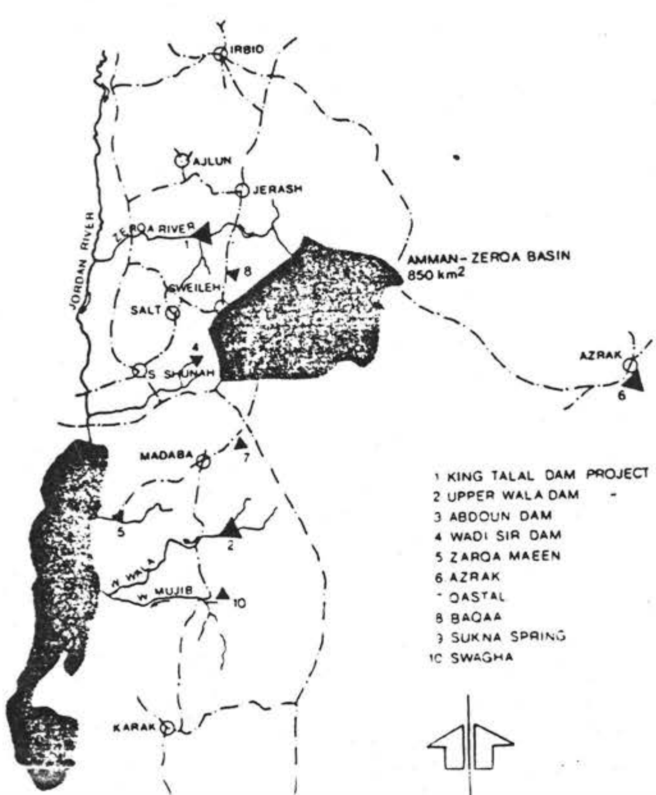


Figure 4. LOCATION OF POTENTIAL OUTSIDE WATER RESOURCES

The other seven sources were found to be too small to fit into a water resources master plan although some of them could be developed as supplementary sources in connection with development of main sources.

As regards availability, the only outside resource that can definitely be put into operation as early as 1980 is the King Talal Dam. This is also the only source which has magnitude to secure a reliable water supply to Amman during dry years and allow further development in several stages. The King Talal Dam is therefore the source which has to be developed first.

The Azrak and Upper Wala Dam sources have sufficient capacity for a maximum development of 10-12 million m³/year. In economic terms the Azrak source has been found to be significantly more expensive than the King Talal Dam and Upper Wala sources. The availability of the Azrak source is highly uncertain due to conflicting interests. Furthermore, the ground water from Azrak is of lower quality than the waters from the King Talal and Upper Wala dams.

The conclusions from the study of the three main sources are illustrated in Figure 5 which clearly shows that the King Talal is to be ranked number one from all points of view with the Upper Wala Dam as second choice and Azrak as third. The size of the dots indicates comparative preference.

WATER RESOURCE	QUANTITY	AVAILABILITY	MAGNITUDE	QUALITY	ECONOMY	RATING
KING TALAL DAM	⬤	⬤	⬤	•	⬤	1
UPPER WALA DAM	⬤	•	–	⬤	⬤	2
AZRAK	⬤	•	–	•	•	3

Figure 5. COMPARISON OF MAIN WATER RESOURCES

Master Plan alternatives

After final evaluation of all potential outside water resources only two, the King Talal Dam and the Upper Wala Dam, remained as possible alternatives. It is, however, essential to develop the King Talal Dam as a first stage while keeping the Upper Wala Dam for a second or later stage.

Extensive cost estimates and comparisons have been made regarding the optimum size of development stages. It has been found that the minimum quantity to be developed is 10-12 million m^3/year since this involves almost continuous construction. The next most suitable stage sizes are 20 and 32 million m^3/year, which only applies to the King Talal Dam and would require 500 mm and 800 mm diameter transmission pipelines.

The three Master Plan alternatives shown in Figure 6 have been studied. It should be noted that Alternative A goes beyond the year 2005 but that this has been duly considered when comparing the costs of the various alternatives.

Before going any further into the final choice of alternative there are two very important matters to be discussed, namely the effect on the King Talal Dam as regards water quantity and water quality.

	DEVELOPED QUANTITY IN MM^3/Y		
ALTERNATIVE	STAGE 1	STAGE 2	STAGE 3
A	KTD 32 1981-91	KTD 32 1991-2002	KTD 20 2002->05
B	KTD 32 1981-91	KTD 32 1991-2002	UWD 12 2002-05
C	KTD 32 1981-91	UWD 12 1991-96	KTD 32 1996-05

KTD-KING TALAL DAM
UWD-UPPER WALA DAM

Figure 6 MASTER PLAN ALTERNATIVES

Water from the King Talal Dam is intended mainly for irrigation in the Jordan Valley. The live storage is 48 million m^3 and the average inflow 97 million m^3/year, half of which as base flow and half as storm inflow. An existing agreement allows Amman to draw 10 million m^3/year from the dam which is far less than the Master Plan alternatives require. There is, however, no contradiction between the alternatives and reality since recycling is involved. Figure 7 below shows the recycling process in principle. Amman is situated within the catchment area of the King Talal Dam. Most of the water pumped to Amman will be returned to the Zerqa River through the ground or as surface flow.

Provided that irrigation is not increased between Amman and the King Talal Dam the return flow is estimated to amount to 80 % of the water supplied to Amman. This means that the 10 million m^3/year allowed to be drawn from the King Talal Dam will be sufficient for 50 million m^3/year pumped to Amman and recycled. A slight increase in the net withdrawal from the dam would secure the water supply of Amman until the year 2005 and even longer. Due consideration has been given to water pollution and purification which automatically follows when recycling takes place. The water pumped through Amman returns to the Zerqa River as sewage effluent after passing through a sewage treatment plant or through the ground. It then flows as surface water along the river or as ground water which emerges as springs along the river course. In both cases a natural purification process takes place. When the water reaches the dam it mixes with water in the reservoir and remains there for some time during which a natural process of purification again takes place. The mixed water is then pumped to Amman via a water treatment plant where it undergoes final purification to the required degree.

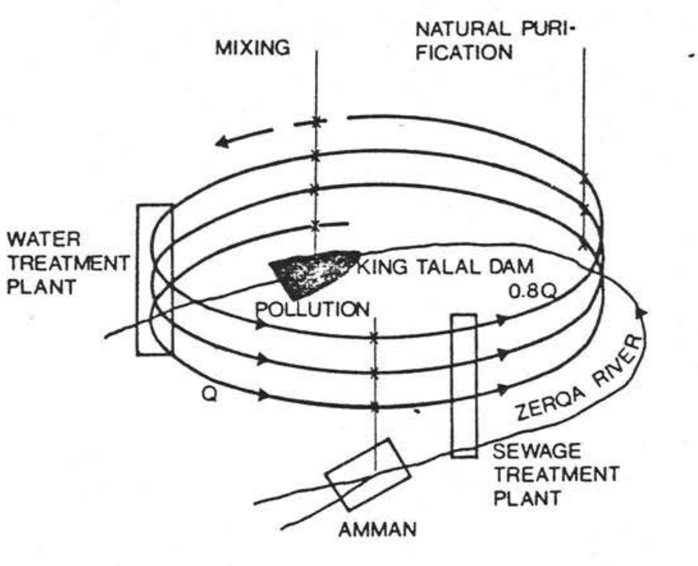
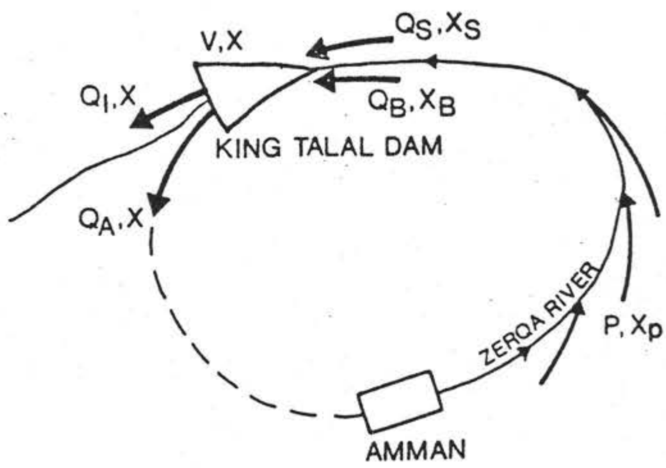


Figure 7. RECYCLING PRINCIPLE

It is obvious that the water stored in the King Talal Dam will become contaminated and this should be allowed up to reasonable limits. There will be a seasonal variation in chemical properties with peak concentrations when the water in the reservoir is at its lowest level. These peaks will also increase over a period of years in proportion to the increase in recycling.

In order to assess the effects which recycling has on quality the total dissolved solids (TDS) and nitrate (NO_3) concentration have been studied by means of a mathematical model. The principle of the model and the continuity equations used are shown in Figure 8.



CONTINUITY EQUATIONS

$$\frac{dV}{dt} = Q_B + Q_S - Q_I - Q_A$$

$$\frac{d(V \cdot X)}{dt} = Q_B \cdot X_B + Q_S \cdot X_S + P \cdot X_p - Q_I \cdot X$$

LEGEND

V = actual storage in King Talal Dam
t = time
Q_B = base inflow to KTD
Q_S = storm " " "
Q_I = disharge for irrigation from KTD
Q_A = net abstraction from Amman (20% of act. abstr.)
X = pollutant concentration in dam storage
X_B = " " in base inflow
X_S = " " in storm inflow
P = population within Amman – Zerqa basin
X_p = specific pollutant from population

Figure 8. WATER QUALITY MODEL

	TDS	NO_3
X_B	600 mg/l	10 mg/l
X_S	300 mg/l	10 mg/l
X_P	40 g/pd	5-20* mg/l

*20mg/l is the theoretical maximum value if no sewage treatment or natural purification takes place

Figure 9. POLLUTANT CONCENTRATION

Since a great number of parameters are involved the calculations have been made on a computer. The pollutant concentrations employed are shown in Figure 9.

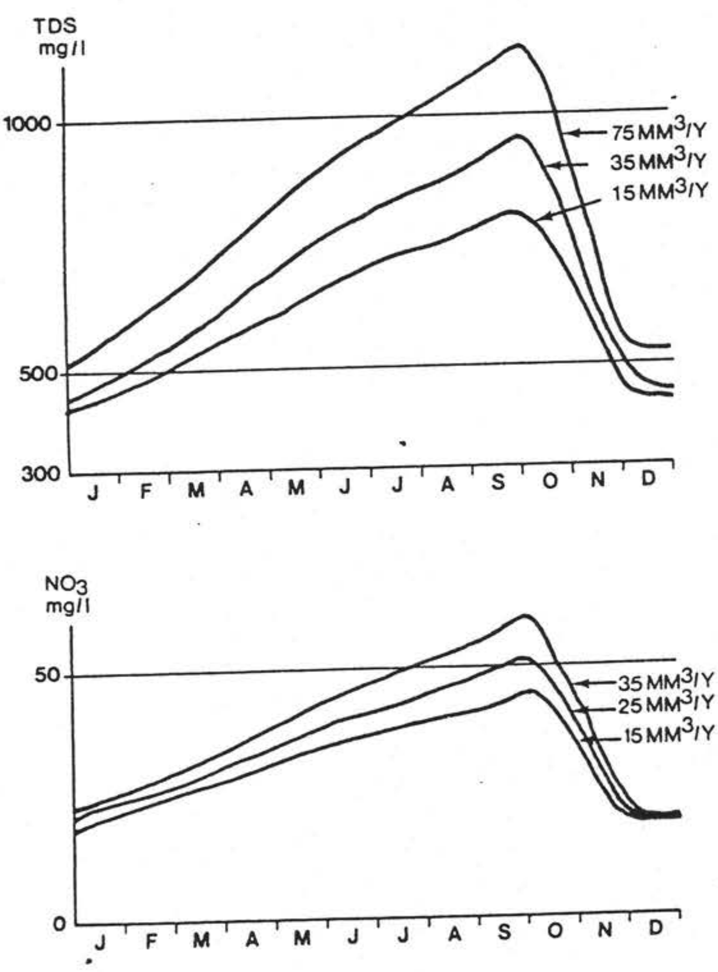


Figure 10. CALCULATED TDS AND NO_3 CONCENTRATIONS IN KING TALAL DAM

The calculated peak concentration as well as the long-term changes are shown in Figure 10. The conclusions drawn from these calculations are that denitrification is necessary when the extraction for Amman reaches about 30 million m³/year. The TDS concentration in the dam storage becomes too high for domestic supply when more than 75 million m³ per year are abstracted for Amman.

Denitrification has to be introduced in stage 2 of Master Plan Alternatives A and B but in stage 3 of Alternative C to a somewhat lesser extent. Alternatives A, B and C are shown in Figure 11, below, where the denitrification is also indicated.

The cost comparison has been made on the basis of present values of investment, operation and maintenance costs and with rates of interest of 6, 10 and 15 %. The results show that the cost differences are too small, less than 1 %, to be a deciding factor in the choice of alternative, which thus has to be based on other criteria.

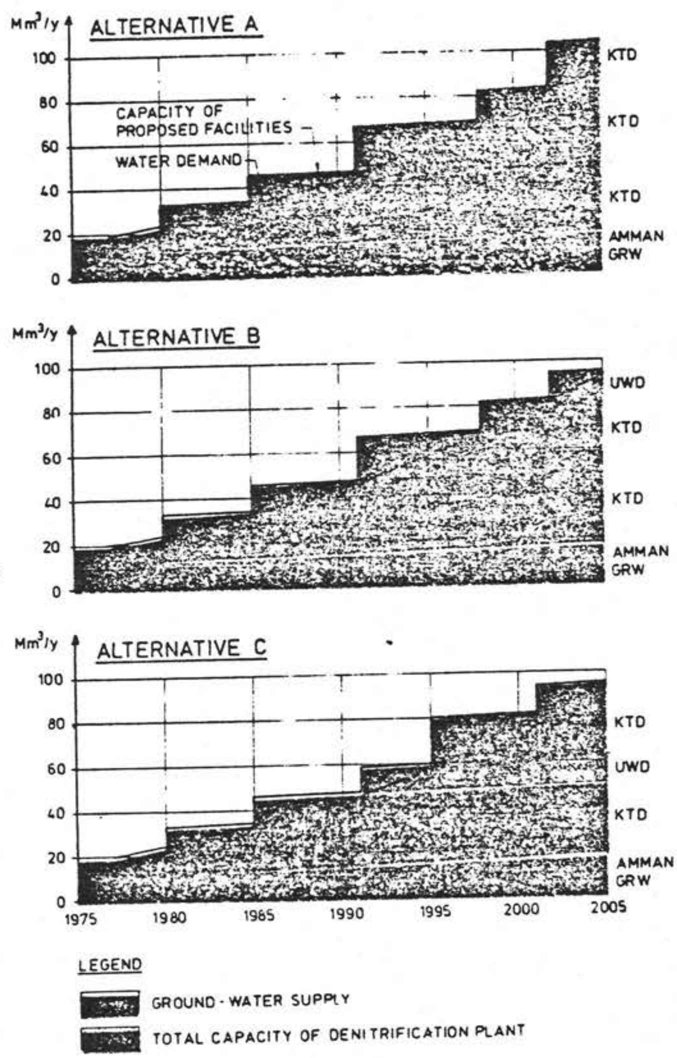


Figure 11. MASTER PLAN ALTERNATIVES

The main question is whether the Upper Wala Dam project should be implemented or not and in this respect Alternatives B and C are similar. In view of this and also because Alternatives A and B are identical up to stage 2 (1991), the choice is between Alternatives A and C only.

We have proposed Alternative C, which means implementation of the Upper Wala Dam project as the second stage, for the following reasons.

- More reliable water supply to Amman since the water will be transmitted from two independent sources.
- Lower operation cost since the static lifting head is lower and the water treatment required will be less extensive.
- The addition of 12 million m^3/year of low salinity water from the Upper Wala Dam to the Amman-Zerqa Basin will improve the water quality in the King Talal Dam and compensate for previous and future net withdrawal.

Water Resources Master Plan

On the basis of the study we recommend that the following Master Plan be implemented, see also Figures 12 and 13.

1978-80	Increase in the extraction of natural and recirculated ground water in Amman to 25 Mm^3/year
1980-91	Develop the King Talal Dam transmission of water up to 32 Mm^3/year in two steps of 20 and 12 Mm^3/year.
1991-96	Develop the Upper Wala Dam transmission of water up to 12 Mm^3/year in one step.
1996-2005	Increase the King Talal Dam transmission of water by an additional 32 Mm^3/year in two steps of 20 and 12 Mm^2/year.
2005-	Additional increase in transmission from the King Talal Dam

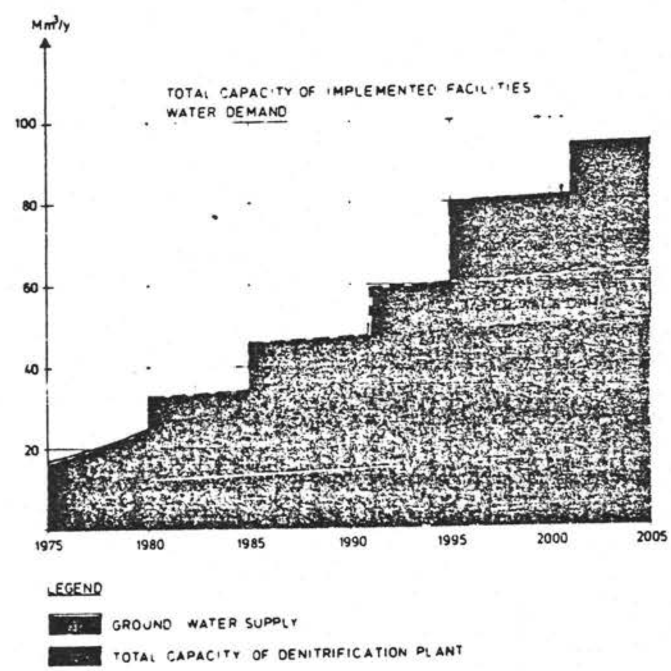


Figure 12. AMMAN WATER RESOURCES MASTER PLAN

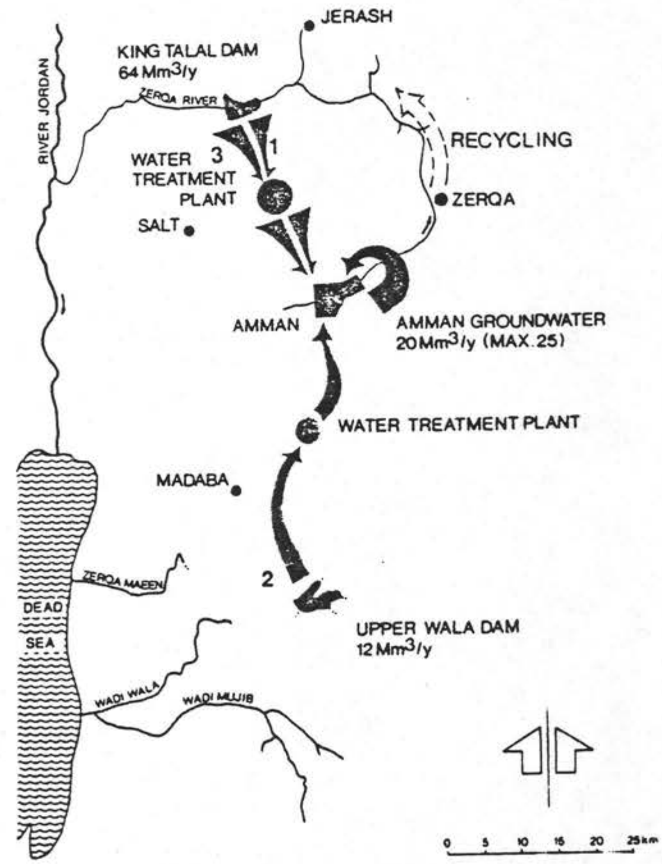


Figure 13 AMMAN WATER RESOURCES MASTER PLAN

Concluding remarks

The proposed Master Plan secures the water supply to Amman to beyond the year 2005 and since it is based on the recycling of water, no serious conflicts with other interests will develop. Other areas outside Amman will suffer less than if recycling were not applied and limitations to the Master Plan as regards water quantity will only occur in the distant future.

Recycling of water is always accompanied by pollution and requirements for purification. Natural purification processes will remove some of the pollutants but those that remain will have to be dealt with in a water treatment plant. In order not to put too heavy a burden on Nature and the water treatment plant, sewage treatment facilities should also be provided. Environmental protection in the Amman-Zerqa Basin is necessary in order to safeguard the water supply of the area both now and in the future. Sanitation of the cities of Amman, Zerqa, Jerash and Ruseifa as well as all industries must be given the same priority as the water supply schemes. Regional planning for the whole Amman-Zerqa Basin is to be given the highest priority since potable water is dependent on the whole environment and is a fundamental necessity without which we cannot