THE HASHEMITE KINGDOM OF JORDAN

MINISTRY OF PLANNING

IN ASSOCIATION WITH

WATER AUTHORITY OF JORDAN

WATER RESOURCES STUDY OF THE JAFR BASIN

FINAL REPORT

SUMMARY

MARCH 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

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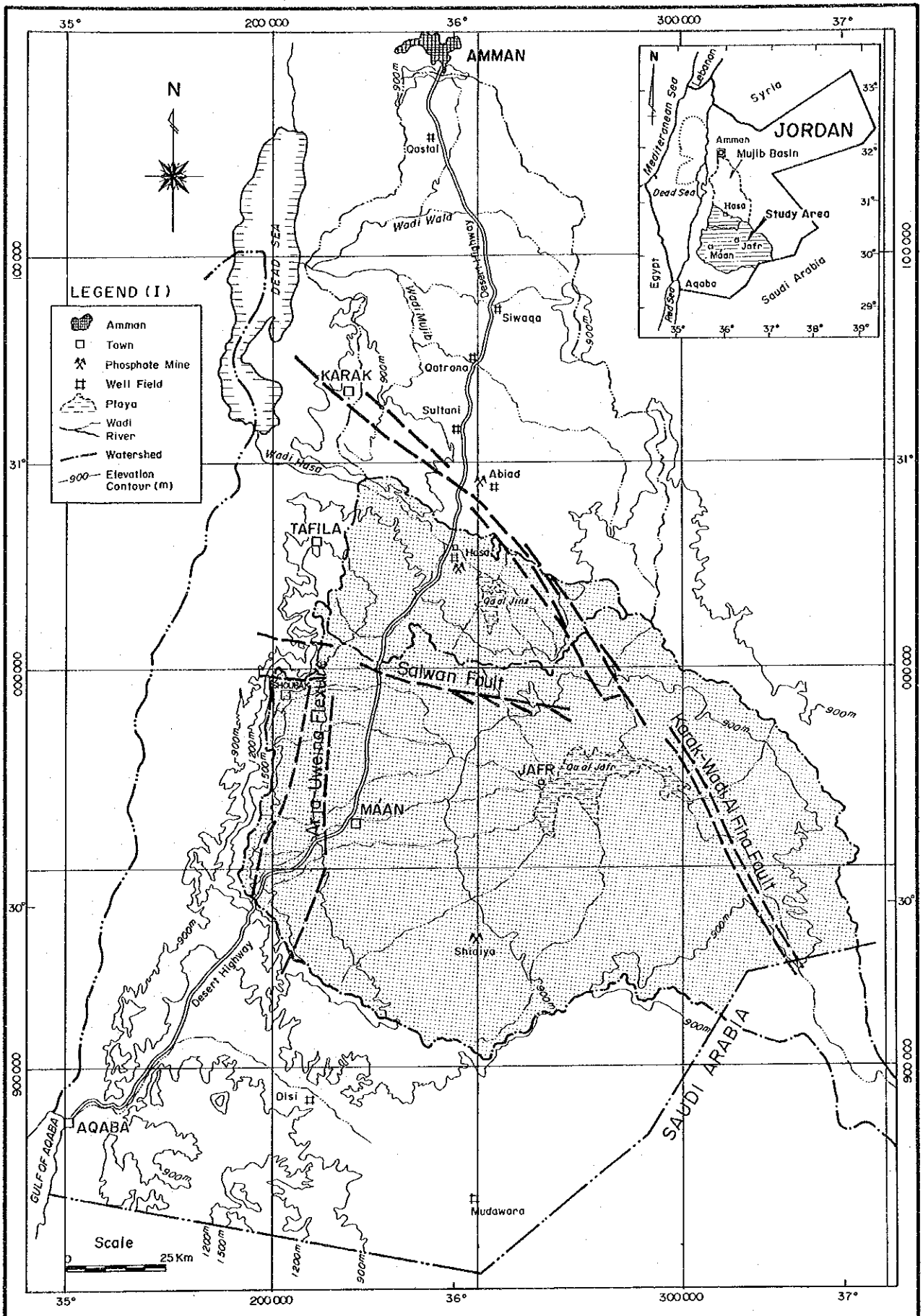

Location Map

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Water Resources Study of the Jafr Basin

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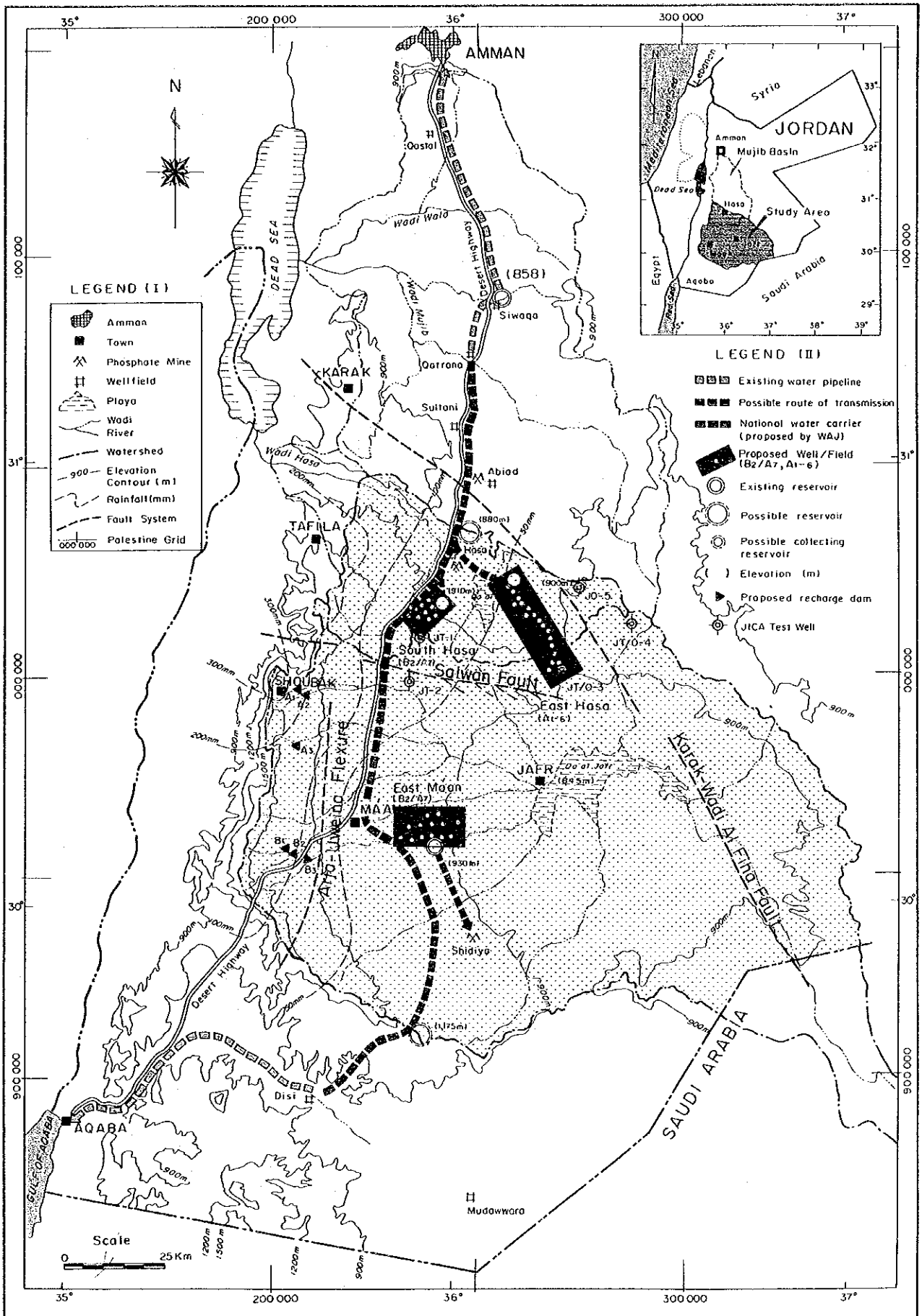

Development Alternative

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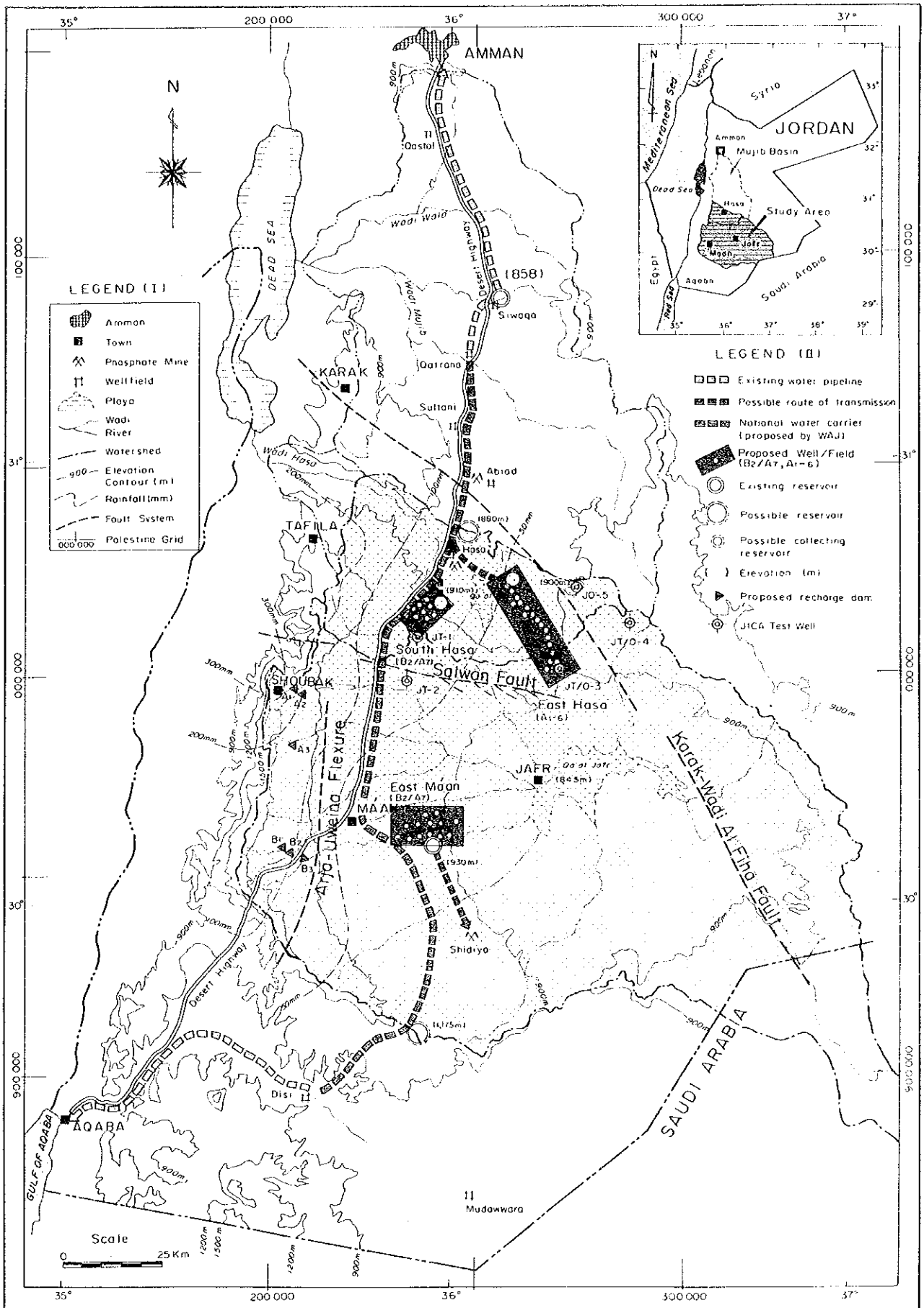

Development Alternative

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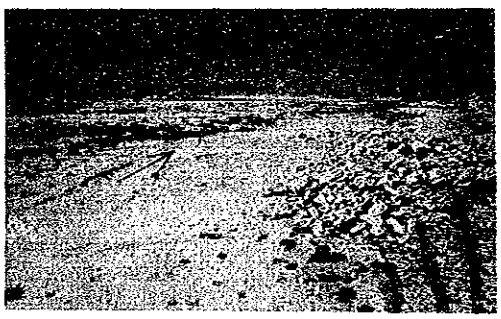
Pumping test at test well JT-3; Excellent quality of pimped water from deep aquifer of Lower Ajlun (A1-6), with T.D.S. of 330 mg/l.(December,1988)

Upper Hasa basin; Southwards view from Hasa town. (July,1988)

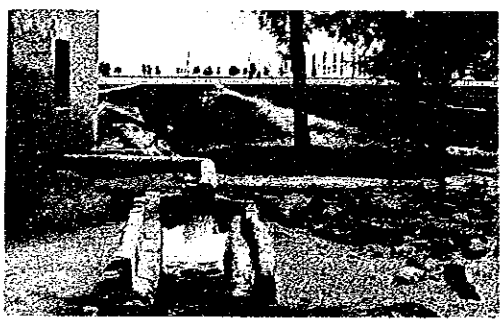
Outcrop of Amman (B2) formation in the Western Highlands; Alternating silicified limestone and chert, with frequent joints, cracks and fissures. (December,1988)

A-2 groundwater recharge damsite; Northwestern part of the Western Highlands in the Jafr basin, where pervious Amman (B2) formation outcrops in and around the damsite. (July,1989)

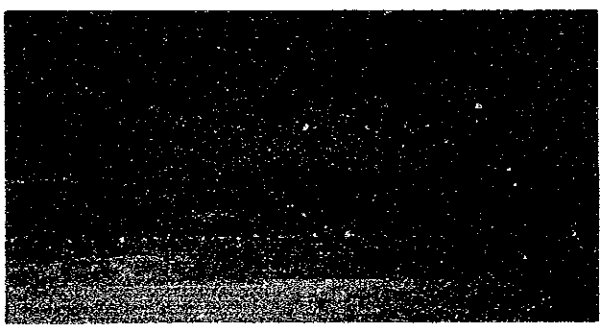


Wadi Jurdhan at middle reaches; Eastwards and/or downstream view from Desert Highway bridge. (July,1988)

Groundwater recharge area of the Western Highlands, which is covered with snow in December,25,1988. (December,1988)



Groundwater irrigation at Al Jafr; Abstracting from shallow water table aquifer of Rijam (B4), of which water salinity was increased by excessive irrigation return flow and/or deep percolation. (June,1989)



Qa' Al Jafr, end of the wadi course at the center of the playa, : 10 km northeastwards from Al Jafr town. (October,1988)

SUMMARY

A. Background

1. The Hashemite Kingdom of Jordan is making steady progress in the economic development of the country, but is handicapped by the limited availability of water. Great efforts have been made in the water resources development sector with the allocation of JD 250 million in the 1981-1985 five-year plan or about one sixth of the national budget. Such efforts will be continued also in the future.

2. The Government of the Hashemite Kingdom of Jordan (hereinafter referred to as "the Government of Jordan") decided to make a study of the water resources of the Jafr basin and the upper Hasa basin, which are adjacent with each other, and requested the Government of Japan to provide the required technical assistance. In response to this request the Government of Japan through the Japan International Cooperation Agency (hereinafter referred to as "JICA") the sole official agency for the implementation of the technical cooperation programs of the Government of Japan commenced the Study in close cooperation with the Government of Jordan through Water Authority of Jordan (hereinafter referred to as WAJ) as the executive agency of the Study. In a short period of time, JICA organized a Preliminary Study Team and dispatched it to Jordan in February 1988. The Scope of Work for the Water Resources Study of the Jafr Basin (hereinafter referred to as "the Study") was agreed upon on 25 February,1988. JICA further organized a team for the Study (the Study Team) and dispatched it to Jordan on 6 July 1988.

B. Present Situation

3. Geography : The Jafr basin is located in the southern part of the central Jordan plain and lies to the east of the western highlands. The basin has an area of 13,500 km^2, most of which may be classified as an arid desert. The basin displays a classic centripetal drainage pattern

with all wadis draining from the encircling highlands to the central El Jafr Playa, the largest concave surface in Jordan. The catchment lies at an elevation of between 850 m in the El Jafr Playa and 1,750 m in the Western Highlands. The Upper Hasa basin is situated adjacent to the northern Jafr Basin by watershed. The catchment area is about 2,200 km^2, and lies at an elevation of between 400 m at the basin outlet near Tannour and 1,250 m in the eastern highlands. The wadis in the southern-western highlands are characteristically narrow and moderately incised, while the wadis are gentle in the eastern part of the basin where the elevation is about 900 m. All the wadis in the upstream reaches drain flashing floods to the central playa named Qa El Jinz.

4. Geology: The geologic groups comprise "Disi", "Khreim", "Kurnub", "Ajlun" and "Belqa", which are of sedimentary origin, ranging in age from Cambrian to Cenozoic. The lower part of the sedimentary sequence consists mainly of sandstones of the Paleozoic and the lower Mesozoic, while the upper part comprises alternating limestone, sandstone, chert, marl and shale of the upper Mesozoic and Cenozoic. The Ajlun group is composed of two formations of "lower Ajlun (A1-6)" and "Wadi Sir (A7), while the Belqa group comprises three formations of "Ruseifa-Amman (B1/2)", "Muwaqqar (B3)" and "Rijam (B4)". These thick sequences are bisected by the fault structures such as "Karak - Wadi Al Fiha", "Salwan" and "Arja-Uweina flexure", which are not continuous system but consists of a series of the discrete faults.

5. Climate: Annual minimum temperature is recorded in January, ranging from 3.9°C at Hasa to -2.6°C at Udruh on average, and annual maximum temperature is recorded in July or August, ranging from 35.5°C at Jafr to 27.4°C at Shoubak on average. Annual total evaporation measured by a class-A pan ranges from 1,800 mm at Shaubak to 4,200 mm at Jafr.

6. Rainfall : The hydrological year is divided into two distinct seasons, namely, the rainy season from October to May and the dry season from June to September. In the rainy season, more than 95% of precipitation is observed,including snow. The annual rainfall decreases from 300 mm in the western highland to less than 50 mm in the eastern

part. Long-term average annual rainfall of the Upper Hasa basin and the Jafr basin is 92 mm and 51 mm, respectively. In these, precipitation is limited to a small area. Taking for example the historical flood recorded at the Wadi Jurdhan on March 11, 1966,the rainfall gauging station at Ma'an had a record rainfall of 50 mm for 15 minutes while the rainfall gauging station at Udruh and Basta in western watershed areas recorded rainfall of 10 mm in 24 hours. These three rainfall stations are only about 20 km apart.

7. Runoff: Runoff usually takes place for a few days during floods. There is no perennial stream flow. A typical local floods was that of March 11,1966 flood which had a peak discharge of 120 m^3/sec at Wadi Jurdhan, north of Ma'an. This flood is nearly equivalent to the 10-year probable flood in terms of peak discharge and had a duration of about 10 hours. There also seem to be different runoff patterns in the study area. In the rainy western, in watershed areas which are covered by less pervious material, runoff seems to appear at wadis immediately after rain. This is in stark contrast to the central and eastern part of the study area which are covered by relatively thick layer of silty material. In these areas where the moisture retention capacity of soils is considered greater, it is understood that wadis are likely to have no stream flow if rainfall is less than 8 mm per day. The long-term average annual runoff is estimated at 13.8 MCM for the Upper Hasa basin with a runoff coefficient of 6.8 %, and 22.9 MCM for the Jafr basin with runoff coefficient of 3.3 %.

8. Hydrogeology: Aquifers have been recognized in argillaceous, arenaceous and/or carbonate rocks of the Cambrian to Paleogene age such as "Disi" (D), "Kurnub" (K), "lower Ajlun" (A1-6), "Amman - Wadi Sir" (B2/A7) and "Rijam" (B4). In the course of the present Study, attention was focused on the aquifers in the Ajlun and the Belqa such as A1-6, B2/A7 and B4. The regional groundwater flows in the aquifers of both B2/A7 and A1-6 are confined by three major faulting structures such as "Karak - Wadi Al Fiha" fault, "Salwan" fault and "Arja - Uweina" flexure. The main sustained aquifer is the B2/A7, which is intersected by two major faulting structures, the east-west "Salwan" fault and

north-south "Arja-Uweina" flexure. While the regional groundwater flow in the A1-6 is confined to the area between the north of the "Salwan" fault and the west of the "Karak - Wadi Al Fiha" fault. The shallow unconfined aquifer of B4 is found in the central part of the Jafr basin, which receives a limited amount of groundwater recharge through the outcrops in the wadi course during the occasional floods.

9. Water Quality: The quality of groundwater in the B2/A7 is excellent to good with water salinity (T.D.S.) in the range of 300 to 700 mg/l, which meets drinking water standards, and is suitable for most uses. While the T.D.S. increases to more than 1,000 to 3,000 mg/l in the south-eastern part of the Jafr basin. The quality of groundwater in the A1-6 aquifer is excellent with T.D.S. at 330 mg/l in the area of the north of the "Salwan" fault. A part of the B4 aquifer such as limited area in the western part of the Jafr town is contaminated by excessive irrigation returns, of which T.D.S increased from 350 to 3,500 mg/l.

10. Present Water Use: The present use of water resources in the Study area is dependent on the groundwater resources in the B2/A7 aquifer. A very small amount of 1.1 MCM/y, however, is being pumped from the shallow unconfined aquifer of the B4 to irrigate some pilot farms. Abstractions are preliminary estimated by WAJ at 18.4 MCM/y in total, which includes the biggest consumer of the Hasa phosphate mine of 7.4 MCM/y, and Shoubak irrigation of 3.3 MCM/y. No surface water is used, whereas 0.75 MCM/y of spring water is being used for the local villages and farms in the Western Highlands.

C. Study Tasks

11. Work Stage: The Study has comprised four stages of the investigations as follow:

12. The 1st stage investigation: The 1st stage was used for preparing the Inception Report in August 1988. Investigations and analysis to follow were carried out during the period from July 1988 through March 1989 as shown below;

- Data collection of topographical maps (1/50,000), aerial photos (1/50,000) and Landsat imagery (1/750,000), geological maps (1/50,000 1/1,000,000), hydrogeological maps, land use map, population, meteorology, soil moisture, stream flow, suspended solids in the flash flood, well inventory, well drillings, pumping test and water quality test.
- Geological and hydrogeological mappings
- Geophysical prospecting by VLF (Very Low Frequency)
- Test well drillings 7 in number with a total depth of 2,940 m.
- Groundwater monitoring
- Hydrogeological analysis
- Topographic mapping for recharge dams
- Runoff analysis by using tank model method
- Flood frequency analysis
- Sedimentation analysis
- Seminar on surface hydrology; data base
- Submitting Progress Report (March 1989)

13. The 2nd stage investigation: The 2nd stage was initiated by discussing the Progress Report. An hydrogeological analysis was carried out to construct the groundwater simulation models of both B2/A7 and A1-6. The computer program of UNISSF, which was designed for the FEM (Finite Element Method) simulation model, was transferred to WAJ's VAX-8200 computer system. Investigations and analysis to follow were performed during the period from May 1989 through September 1989 as shown below;

- Transfer of the computer simulation program of UNISSF to WAJ computer VAX-8200
- Hydrogeological analysis
- Groundwater modeling
- The first seminar on the groundwater model simulation
- Steady state calibration of the groundwater simulation models (B2/A7, A1-6)
- Non-steady calibration of the groundwater simulation model (B2/A7)

- Simulations for alternative groundwater development plans
- Salt-water balance simulation by using tank model
- Submitting Interim Report (October 1989).

14. The 3rd stage investigation: The 3rd stage was initiated by discussing the Interim Report. Alternatives of the water resources development plans, groundwater monitoring and groundwater modeling were studied during the period from October 1989 to January 1990, including the following;

- The second seminar on the groundwater model simulation
- Installation of computer plotter CALCOMP-1043
- Conceptional design of the water source facility and preliminary cost estimate thereof for the selected alternatives
- Water demand and model predictions
- Alternative development plan
- Groundwater monitoring plan
- Submitting Draft Final Report (January 1990)

15. The 4th stage investigation: A Draft Final Report was explained to and discussed with the Government. The 3rd computer simulation seminar was held to transfer the technology of operating the simulation models. A final report is herewith prepared, incorporating the Government's comments.

D. Water Resources Development Plan

16. Storage Dam : A prefeasibility study of storage dams in western wadis of the study area were conducted by WAJ, which was finalized in October 1988. This study aimed at identifying the best construction sites of dams with purposes of water supply for irrigation use and livestock husbandry, water supply to local people and a phosphate mine in Shidiya etc..

17. Recharge Dam : In the beginning, total eight recharge dams were planned to recharge B2/A7 aquifers by infiltration along wadis in the

Western Highlands. Among them, two dams of group-C, which are located in the southern part of the Western Highlands, were canceled owing to unsaturated and/or poor inflow characteristics. For this study, recharge dams which are located on the upstream part of wadis from the storage dams proposed by WAJ, were intended to divert the spilt water into these storage dams. From 23 years hydrological records, catchment area, annual average runoff, gross storage capacity,effective storage capacity and dam height of each recharge dams are estimated as follows:

Dam No.	Catchment Area (km)	Average Annual Inflow (MCM)/1	Maximum Annual Inflow (MCM)/2	Gross Storage Capacity (MCM)/3	Effective Storage Capacity (MCM)	Dam Height (m)	Priority /4
A1	34.3	1.5	5.6	3.7	3.2	19	C
A2	32.2	1.9	9.1	6.0	5.3	18	A
A3	31.1	2.0	12.0	8.5	7.8	39	B
B1	55.7	0.8	3.6	2.4	2.1	20	A
B2	135.9	1.6	8.9	4.2	3.7	19	C
B3	71.7	0.9	4.8	2.0	1.7	10	A
	Total	(8.7)					

Remarks; /1 ; Average of 23 years between 1963/64 and 1985/86

/2 ; Maximum in 23 years between 1963/64 and 1985/86

/3 ; Gross storage capacity is equal to effective storage capacity plus dead storage due to 50-year sedimentation

/4 ; Priority ranking is based on the environmental aspect (compensation) and dam cost; A: No restricting factor, B: Cost effectiveness will be checked for high dam, C: Problem in compensation

18. Groundwater Development in the lower Ajlun (A1-6) Aquifer: The highly confined groundwater in the lower Ajlun (A1-6) remains untapped. The aquifer will be promising in the area to the north of the Salwan fault. The quality of groundwater is good, as water salinity in T.D.S. less than 350 mg/l. The "East Hasa" wellfield, which is located 40 km

to the southeast of Hasa town on the Desert Highway, is proposed for examination of the aquifer potential in the simulation model. From the model simulation study, the potential yield is preliminarily estimated at 5 to 10 MCM/y.

19. Groundwater Development in the Amman - Wadi Sir (B2/A7) Aquifer: Groundwater in the B2/A7 aquifer is being exploited in the areas of the Western Highlands and Hasa mine. In the area to the east of the Desert Highway, the aquifer is confined and untapped. From the model simulation study two potential wellfields, tentatively named "East Ma'an" and "South Hasa", are proposed for coordination with the increase in water demands in the regions and/or the entire Kingdom of Jordan. The "East Ma'an" wellfield, which is located about 20 km to the north of the Shidiya mine, is estimated to produce 5 to 10 MCM/y with installation of 10 to 20 production wells with a depth of 250 m each. The "South Hasa" wellfield, which is situated 10 km to the south of Hasa town, is also estimated to produce 5 to 10 MCM/y by installing production wells 10 to 20 in number with a depth of 350 m each. These two experimental wellfields are located about 1 to 15 km distant from the possible route of WAJ's national water carrier (Disi - Mudawwara - Amman route).

20. Groundwater Development in the Rijam (B4) Aquifer: At Al Jafr town in the central Jafr basin, irrigation has been practiced since 1965 by pumping groundwater from a shallow unconfined aquifer in the Rijam (B4) formation since 1965. Since around 1971, salinity of the Rijam (B4) aquifer has increased and its yield has become unsuitable for irrigation use. The sustained yield of the Rijam (B4) aquifer is evaluated to be less than 2 MCM per annum, due to the limited groundwater recharge through the wadi beds during the occasional floods. It is assumed that the salinity accumulation of the Rijam (B4) aquifer is caused by leaching water which transports (i) salt accumulated at the root zone by irrigation water together with (ii) salt contained in leaching water itself, while the salinity-accumulated aquifer is continually diluted by adjacent salinity-less aquifer. As long as present conditions continues, the salinity accumulation of the irrigation area is

anticipated to decline to T.D.S. of about 1,000 ppm in year 2000, which is considered acceptable for irrigation use. No extensive exploitation will be recommended without any counter-measures to protect the salt accumulation in both surfacial soils and the underlying aquifer of the B4. Groundwater use for irrigation is not promising without counter-measures for desalination of groundwater and/or replacing the irrigation method from the existing gravity flow to the drip method.

21. Conjunctive Development Plan: The average annual runoff at the proposed recharge dam sites is estimated at 8.7 MCM/y in total, consisting of 5.4 MCM/y of group-A and 3.3 MCM/y of group-B. The recharge dams are located in the outcrop area of the B2/A7 which are highly pervious with fissures, open cracks and caves. Volume of infiltration through the reservoir is estimated to be equal to the average annual inflow minus annual evaporation from the reservoir surface. The group-A dams, of which infiltration capacity is estimated at 5.2 MCM/y, will be a significant source of the groundwater recharge in the northwestern part of the Western Highlands where intensive agricultural development is being practiced. The group-B dams, of which infiltration capacity is estimated at 3.2 MCM/y, are located in the southwestern part of the Western Highlands where water is taken both for irrigation and for water supply to Ma'an city from the wells dug into the B2/A7 aquifer. These recharge dams may act as a significant source of increasing the potential of groundwater in the B2/A7. The recharge dam development scheme will be incorporated in the future groundwater development in the Western Highlands.

E. Conclusions and Recommendations

22. Conclusions: As the result of the Master plan level study, the distribution, location and potential of the water resources which consists of the groundwater and surface water in the upper Hasa and Jafr watershed have been clarified. Of the potential clarified, the sustained yield of groundwater in the B2/A7 aquifer is worthy of future development. From the steady-state model simulation study, the deep aquifer of the lower Ajlun (A1-6) is preliminarily evaluated to be

promising. The salt accumulation problems in the Rijam (B4) aquifer are critical and require the counter-measures. The groundwater recharge dams are worthy of future development in the Western Highlands.

23. Recommendations:

Amman - Wadi Sir (B2/A7) Aquifer

- Of the schemes formulated under the present study, the most promising ones are for development of groundwater in the B2/A7 aquifer. After confirming the water use plan of these watersheds, it is recommended that test well drillings be made on the respective wellfields namely "South Hasa" and "East Ma'an" whenever such schemes become needed.

- To re-confirm the quantity and quality of the groundwater in each wellfield, production wells in the wellfields of "South Hasa" and "East Ma'an" will be constructed in two stages. Each wellfield will be developed for 5 MCM/y by installing 10 wells in the first stage, and adding thereafter 5 MCM/y in the 2nd stage.

- For the purpose of optimal groundwater management of the proposed wellfields of "South Hasa" and "East Ma'an", management model simulation will have to be performed by using the data from the constructed wells mentioned above.

Lower Ajlun (A1-6) Aquifer

- The deep aquifer of the lower Ajlun (A1-6) will be promising in the area of the confined upper Hasa groundwater basin. It is recommended that a series of test well drillings and model simulations be carried out to evaluate the feasibility.

Groundwater Recharge Dam in the Western Highlands

- Intensive groundwater irrigation in the Shoubak area, where thickness of the saturated aquifer is not thick with complicated geological

structures, lowers the piezometric surface in the northwestern part of the Jafr basin. Of the schemes formulated for the conjunctive water development, groundwater recharge dams are deemed to be effective for the area of the Western Highlands. It is recommended that further studies be made on the particular dam schemes whenever such irrigation development become needed.

- Domestic sewerage and/or irrigation return flow in the outcrop area of the B2/A7 in the Western Highlands shall be controlled to protect the quality of groundwater in the B2/A7 aquifer from the contamination.

Groundwater Monitoring

- WAJ's efforts in groundwater monitoring need to be continued. It is recommended that the amount of pumping discharge of each production well be monitored not only in respect of the government owned wells but also of the private owned ones.

- As to groundwater monitoring in the lower Ajlun (A1-6) aquifer, it is recommended that the water quality monitoring and isotope dating in the test well of JT-3 be carried out by using the depth water sampler.

- Prior to development of any potential wellfields, it is recommended that a monitoring well be constructed in the center of the group of wells.

Salt Accumulation Problem in Rijam (B4) Aquifer

- Salt accumulation problems in the Rijam (B4) aquifer are still critical. It is recommended that the monitoring work which comprises the measurement of both soil salinities and water salinities be continued. Counter-measure such as replacing the irrigation method from the existing gravity flow to the drip method, will be useful in reducing the salt accumulation in the Rijam (B4) aquifer.