社会開発協力部報告書

No. 07

THE HASHEMITE KINGDOM OF JORDAN

MINISTRY OF PLANNING

IN ASSOCIATION WITH

WATER AUTHORITY OF JORDAN

HYDROGEOLOGICAL AND WATER USE STUDY OF THE MUJIB WATERSHED

FINAL REPORT

SUMMARY

JULY 1987

JAPAN INTERNATIONAL COOPERATION AGENCY

THE HASHEMITE KINGDOM OF JORDAN

MINISTRY OF PLANNING

IN ASSOCIATION WITH

WATER AUTHORITY OF JORDAN

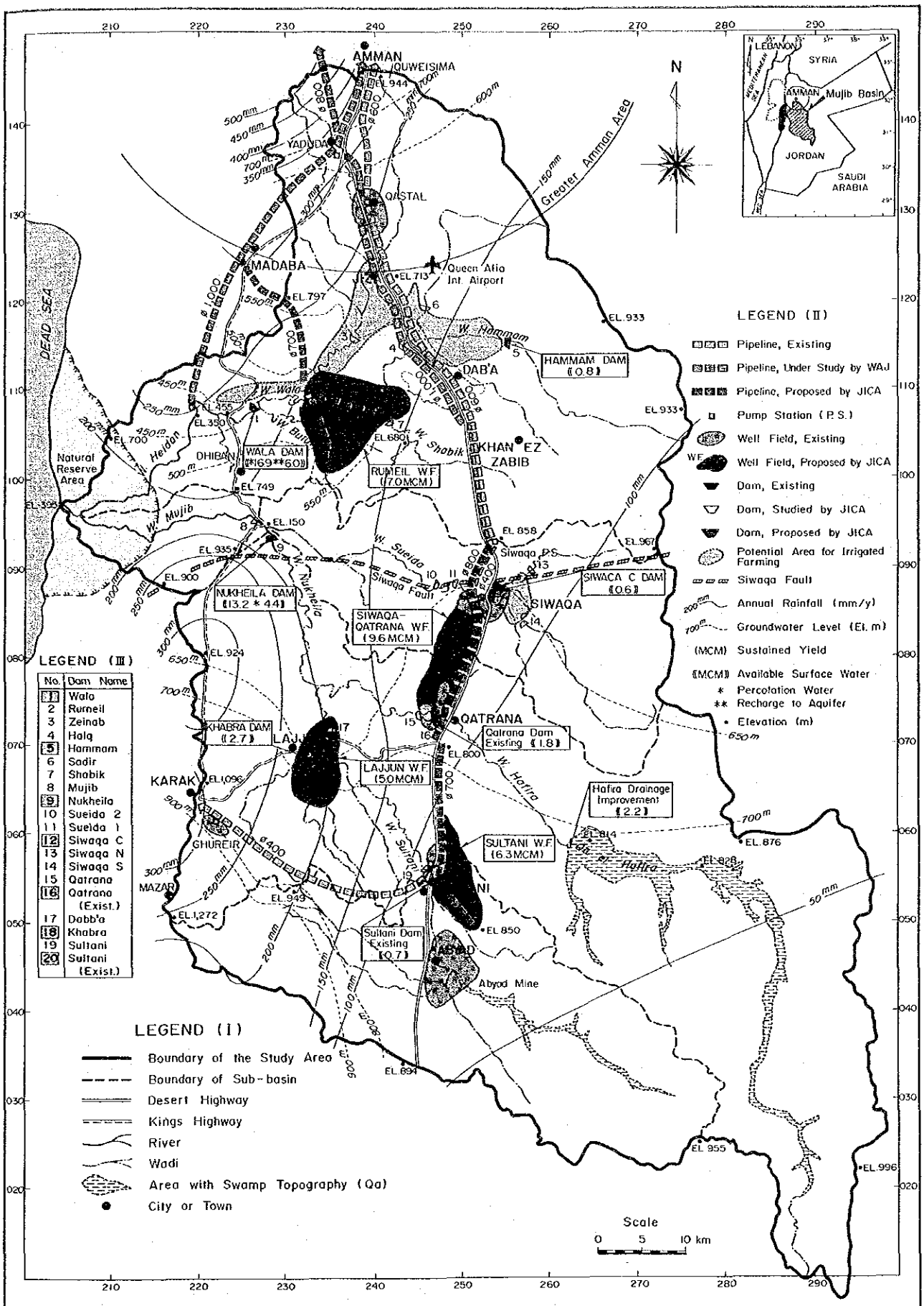
HYDROGEOLOGICAL AND WATER USE STUDY OF THE MUJIB WATERSHED

FINAL REPORT

SUMMARY

JULY 1987

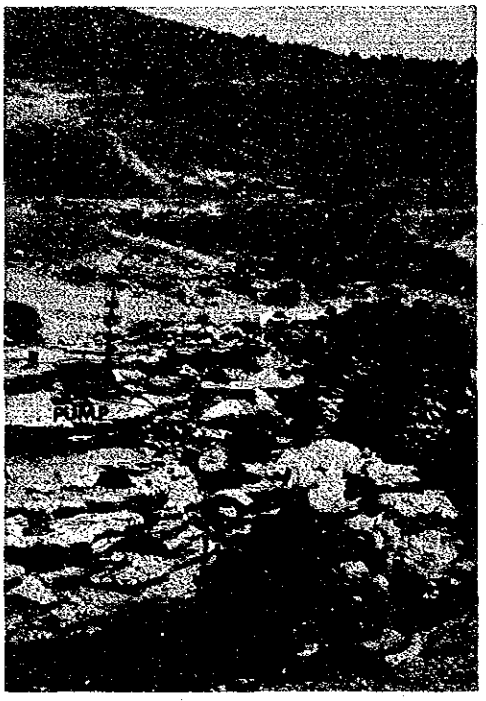
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MUJIB WATERSHED

THE HASHEMITE KINGDOM OF JORDAN
HYDROGEOLOGICAL AND WATER USE STUDY OF THE MUJIB WATERSHED
JAPAN INTERNATIONAL COOPERATION AGENCY

Wadi Mujib (View from Dhiban)



Small Spring in Wadi Heidan
(200m eastward from Wala bridge)

Flush Flood in Wadi Sueida (at Siwaqa bridge)
Date : 8 Nov. 1986

Qatrana Existing Dam

A Background

1 In the Hashemite Kingdom of Jordan, the most important and vital area is the capital area (the Greater Amman area), and the watershed of the Mujib River system is located adjacent to the south of the capital area. The water resources in the watershed has been developed to a considerable extent, but an overall study has not been made yet, and the potential of the water resources has not been evaluated. Thus, the Government of Jordan decided to implement the hydrogeological and water use study of the Mujib watershed (the Study), and requested the Government of Japan to provide a necessary technical assistance. The executive agency of the Study is the Water Authority of Jordan (WAJ).

2 In response to this request the Government of Japan organized a Study Team through Japan International Cooperation Agency (JICA). The study works were commenced in October 1985. Until July 1987, the Study Team was dispatched to Jordan for four times and carried out the field works in close cooperation with WAJ, as well as the home works in Japan. Four reports such as the Inception, Progress, Interim and Draft Final Reports were prepared, and discussions were made with WAJ and other concerning agencies of Jordan. This is a Final Report of the Study with the comments from the Jordanian side are duly incorporated in.

B Present Condition

3 Geography: The Mujib watershed is situated adjacent to the south of Amman having a drainage area of 6,600 km^2 which occupies 7% of the territory of Jordan, 98,000 km^2. The Mujib River consists of two tributaries, the Wadi Wala (alias Heidan) and the Wadi Mujib, which join into the Wadi Mujib immediately upstream from the estuary. Many tributaries run with gentle slopes on the flat highlands, 700-900 m high above sea level, flow down in gorges with steep slopes joining neighbouring tributaries, and the main stream finally debouches to the Dead Sea of which salt content is 25%, being the highest in the world, at about 400 m below the sea level which is the lowest water level in the

world. The Desert Highway and the King's Highway run in the north-south direction crossing the tributaries on the highland and on the escarpment respectively. Northern half of the watershed belongs administratively to the governorate of Amman and southern half to the governorate of Karak. The Queen Alia airport is located in the north of the watershed. Population in the watershed is about 80,000 (1985) or 12 head/km^2 which is forecast to grow 110,000 (17 head per 1 km^2) in 2005.

4 Greater Amman area: Under the present study, an area encircled by 30 km radius from Amman is referred to as the metropolis area. Southern part of this area is included in the Mujib watershed. This area which occupies 3% of the area of the Kingdom includes such cities as Amman, Zarqa, Salt and Madaba and is populated by about 1.62 million (1985) of population (573 head/km^2). It is estimated that the population in this area will grow to 3.37 million (1,192 head/km^2) in the target year 2005 when the national population will reach 5.06 million (52 head/km^2).

5 Geology of the Mujib watershed is not complicated. The surface of the watershed is covered by a thick horizontal layer. This layer is referred to as the Balqa/Ajlun (B/A) layer composed mainly of limestone layers of the upper to middle cretaceous periods, and is about 900 m thick. Surface of the highland is the upper surface of B/A. This B/A is underlain by the Kurnub (K) layer composed of sandstone layers of lower cretaceous period, which crops out on the riverbed below about El. 0 m. The main aquifer is the pervious layers called B2/A7 of which water is sustained by precipitation and has good quality. A long fault called the Siwaqa Fault is running in the east-west direction. The B/A is bisected by the fault, but the aquifers in the both portions are continuous.

6 Precipitation is very small. The highest precipitation is seen in the northern and western fringes being 300 m a year. The precipitation descends towards the south-east, and finally becomes 50 mm or less in the south-eastern corner. Yearly average precipitation over the Wala basin is 189 mm, over the Mujib basin 128 mm and over the whole basin 154 mm. Precipitation is concentrated in the rainy season from October to April, but quantity and timing fluctuate very much by year. In the present

study, the most frequent value (50% frequency) is used.

7 Hydrology: The tributaries (wadi) are dry except for short periods after the rainfalls. Perennial base flow is seen only on the lowest reaches downstream from the King's Highway bridges. The base flow is constant being 1.1 m^3/sec or 35 MCM a year. The outflow in the rainy season which is referred to as the flood flow is 29 MCM and 36 MCM from the Wadi Wala and the Wadi Mujib respectively, totalling 65 MCM. Coefficient of runoff is 4.2% for the base flow and 5.3% for the flood flow, totalling 9.5%. Because of high concentration of outflow, very little flood flow has been used.

8 Hydrogeology: Groundwater potential of the basin is relatively rich because of the geological characteristics. Main sustained aquifer is B2/A7. The whole basin is bisected by the Siwaqa fault. In the northern portion, the groundwater is B2/A7 flows in the similar directions to the surface flow of the Wala river system, and appears to the surface in a river stretch of 5 km downstream from the King's Highway bridge. Although the groundwater in the both portions are hydraulically continuous, the groundwater in the southern portion is dammed up by the impermeability of the fault by 50 m to 100 m. In the southern portion, there is an indistinct ridge of the groundwater contour approximately underneath the Desert Highway. The groundwater flows towards the estuary in the western part of the ridge, whereas it flows in the north-east direction towards the Azraq Oasis in the eastern part of the ridge, and hence, this flow does not join the outflow towards the estuary.

9 Soil: Because of the dry condition, the soils in the Mujib watershed are generally poor both in quantity and quality. Soils of relatively good quality for agriculture are distributed on areas with more precipitation or flood flow, particularly in the northern part, on the western escarpment, and on the spots around the crossing points of the Desert Highway and tributaries. Natural vegetation is extremely scarce especially in the poorly precipitated areas.

10 Agriculture: Non-irrigated and irrigated farms are existing in the basin. In the northern part, plastic house or drip irrigation from private wells are distributed (about 3,500 ha) mainly for vegetables. In the western part where the precipitation is more than 150 mm a year, rainfed fields are existing, but the area planted varies very much with the yearly variation of rainfall. On such rainfed area, wheat and barley are grown in the traditional method without giving much inputs. Hence, the harvest is very low, for example 0.6-0.8 tons/ha for wheat. Along the lower reaches of the Wadi Wala, there are vegetable growing area irrigated by pumped water from the base flow. It is said that almost all of the areas in the basin suited for agriculture under the present condition have been developed, remaining no room unless new water source is given.

11 Present water use: The groundwater in the Mujib watershed has been used to a considerable extent. There are 223 existing wells (1985) in the northern part and along the Desert Highway. Among them, 155 wells are privately owned by farmers for growing vegetables, and 68 wells are Government owned for supplying water to Amman, Karak and many villages in the watershed. In 1985, 15.1 MCM were sent to Amman bearing one quarter of the Amman's consumption. Besides, base flow on the lower reaches of the Wadi Wala is used for irrigated farming. The flood flow is left unused.

C Study Works

12 Fieldworks: Since the start of the present study in October 1985, works of many items are carried out. These works are made through four batches of fieldworks in Jordan and four batches of homeworks in Japan. Main items of fieldworks achieved are;

- Hydrologic observation and analysis.
- Excavation of four test wells with two observation wells; as existing 223 wells are not distributed uniformly, positions of these wells are selected to supplement the distibution so that uniform

constants for simulation can be obtained, 260 to 305 m deep totalling 1,684 m with 4 inches to 13 inches diameter.

- Mapping of twenty sites of dam and reservoir from air-photo, 1/7,500 or 1/15,000 in scale with 5 m contour intervals.
- Engineering boring at five damsites and soil mechanical tests.
- Soil and land use survey.
- Topographic survey mainly for preliminary design of pipelines.
- Preparation of Inception, Progress and Interim Reports.

13 Homeworks: Of many items of the homeworks achieved, the main items are;

- Simulation of groundwater potential on natural condition, using the finite element method (FEM) on two dimensional groundwater model simulation.
- Dam study on each of 20 topographically selected sites putting use of all the results of fieldworks. Finally, several promising dam plans are selected out.
- Simulation of groundwater on condition that flood flow is caught by dams and added into aquifers.
- Master planning works. Using all the results of aforementioned studies, some plans worthy of future development are selected.
- Study on two pipeline (P/L) plans (projects) on a feasibility study level. Projects studied are the Sultani-Siwaqa P/L project and the Rumeil-Madaba P/L project.

14 Simulation of groundwater potential: After careful study on the hydrogeological structure and characteristics of the Mujib basin, three well fields such as the Sultani, Siwaqa-Qatrana and Rumeil well fields are selected. The future development plans of these well fields are obtained by means of two dimensional model simulation applying the finite element method (FEM). Total potential is estimated at 23 MCM/y. This value can be obstructed safely without giving much influence to the base flow of the lower reaches for a long period of time.

15 Water Quality Quality of groundwater in the main aquifer, B2/A7, is good to fair with salinity (TDS) in a range between 500 and 1,500 ppm. Both existing and proposed well fields are located in the area with TDS less than 1,200 ppm. The hydrochemical structure of the B2/A7 aquifer is non-uniform. By a long term pumping up to 20 to 100 years, the TDS will be increased by 50 to 80% respectively at the maximum. The TDS of the base flow in the Wadi Wala (Heidan) is in a range between 400 and 900 ppm, while the TDS is 1,000 to 1,300 ppm in the base flow in the Wadi Mujib. The TDS at the confluence of Wadi Wala and Wadi Mujib is measured at 1,056 ppm, but the TDS at the confluence will be increased by 40% at the maximum, if the base flow is withdrawn at the upper Wadi Heidan. However, the provision of the proposed Wala Dam will mitigate such increase.

16 Dam planning: As the flood flow occurs only for a short time after rain in the rainy season, dams are indispensable to put the flood flows into use. By thorough study on the general topographic map (1/50,000 scale with 25 m contour intervals), all of the possible sites for dam and reservoir are selected. Reservoir capacity of each site is measured and the elevation-capacity (H-V) curves are drawn. From the results of the engineering borings, preliminary geological profiles of each dam site are drawn. On the other hand, the values of inflow and flood discharges with different probabilities to each dam site are estimated on the basis of all of the past precipitation data as well as on the hydrologic data. All of these works are made on 20 sites which are selected preliminarily.

17 Putting use of the said materials, the simulation of the reservoir operation are made taking into account the seepage from the reservoir, evaporation from the reservoir water surface, and the decrease in the reservoir capacity owing to sedimentation. As the results, the available flow of each dam is estimated. (These works are made on each site except those which are obviously unfavourable in view of geology or in case of comparison in group of similar nature.) Then, provisional design of dam is made in consideration of the type and optimum scale of dam, and the usable flow and cost are estimated. Finally, seven sites which are considered worthy of further study are selected out; they are, Qatrana

(existing), Sultani (existing), Siwaqa C, Wala, Hammam, Khabra and Nukheila sites.

18 Irrigation planning: Firstly, the soil distribution is mapped considering the relative location to the water source. Next, several cropping patterns for the basin are designed in consideration of the present status of agriculture in the whole country and new Governmental policy on agriculture. Then, irrigation schemes are planned taking into account the land and water source. In general, precipitation over the basin is extremely poor, and the soil distribution is limited for the irrigation schemes. Therefore, it is hardly possible to formulate the irrigated agriculture schemes of large scale but only a few schemes of small sizes scattered in the basin are planned.

D Water Use Plans

19 Strategy: Basing upon the results of the aforementioned studies and the elemental schemes, the overall water use plan of the Mujib watershed on master planning level is elaborated. As to the water source, the groundwater of B2/A7 which is dependable and sustained by precipitation is to be used in the main. As to the surface flow, the dams are to be used. However, the main function of the dam is for the recharge of the B2/A7 groundwater and sub-function is for the surface storage in view of the nature of the surface geology which consists mainly of limestone. As for the use of the water, main use is for the city water supply which is the most important water demand in the country, but the supply thereto is chronically deficient. Especially the water supply to the metropolitan area is attached by the highest importance. Irrigation water is considered next to the city water supply. Dam schemes by which storage or supply to the groundwater is possible, but of which present demand is not yet definite at present, are raised with conceivable uses of water.

20 In line with the abovementioned strategy, the water use plan of the Mujib watershed is made. Firstly, the development of well fields and pipelines are planned with due consideration of the on-going projects by WAJ. Next, dams are planned which have main function to catch flood flow and turn the caught flow into the groundwater or base flow. Irrigated agriculture schemes are planned as far as the given condition allows. Possible available flow by other dams are estimated for the water use in the future when such water becomes required. Pipeline (P/L) projects are studied on the feasibility study (F/S) level, and other schemes are studied on the master plan level.

21 Planned schemes: As the results of planning works, the following schemes are planned. (Refer to the location map on flyleaf).

	Purpose and name of scheme	Priority
1.	City water supply	
	Sultani-Siwaqa P/L project	A
	Rumeil-Madaba P/L project	A
2.	Reinforcement of base flow or groundwater	
	Wala dam scheme	A'
	Qatrana dam scheme	B
	Sultani dam scheme	B
	Siwaqa C dam scheme	C
3.	Irrigated agriculture	
	Hammam irrigation scheme	C
	Qatrana irrigation scheme	C
4.	Storage	
	Nukheila dam scheme	C
	Khabra dam scheme	C
5.	Others	
	Green belt	C

Note; A : scheme on which F/S level study is already made
A' : scheme of which F/S study is to be made urgently
B : scheme of which F/S study is to be made soon
C : schemes of which F/S study is to be made when needed

E Water Supply Projects

22 Water demand to the Greater Amman area: In 1985, the supply of water to the municipal area and the Mujib watershed was 61.5 MCM against the demand of 70 MCM. This value is a sum of the supply for domestic, public and small industrial uses, but the supply for large industries are not included because the demand is supplied from the wells owned by respective factories. This water demand is projected to grow in the target year 2005 to 198 MCM/y with the mean annual growing rate of 5.2%. This value consists of 190 MCM/y of the Greater Amman area, 2 MCM/y of the Mujib basin and 6 MCM/y of a part of Karak which is already connected with the Sultani wells by pipeline. WAJ is undertaking the implementation of some other projects to increase the supply capacity. However, with all these capacities of such projects added, the total capacity will become 114 MCM/y leaving a deficiency of 84 MCM. Then, the groundwater source left in the Mujib basin is raised to fill the deficiency. The Mujib groundwater source is located nearer to the municipal area than any other water sources. Water quality is good and suited for water supply without being purified. Thus, the available groundwater in the Mujib watershed is to be developed for the municipal area as much as possible.

23 Allotment of Groundwater: It is clarified under the Study that the sustained yields of the well fields are 6.3 MCM of Sultani, 9.6 MCM of Siwaqa-Qatrana, 7.0 MCM of Rumeil and 5.0 MCM of Lajjun. Of them, the Lajjun well field is to be preserved for the future development of the oil shale by the Government policy. Total of the remainder makes about 23 MCM. This amount corresponds to 27% of the aforementioned deficiency of 84 MCM and to reduce the deficiency down to 61 MCM. Moreover, the

extraction of the full amount does not give essential influence on the amount of the base flow on the lower reaches. Hence, it is planned to take this amount for the water supply of the municipal area.

24 Formulation of pipeline projects: Currently, WAJ is undertaking the implementation of many pipeline (P/L) projects. The outcomes of these projects are to be used fully for the development of water source under the present study. Water from the proposed Sultani and Siwaqa- Qatrana well fields located to the south of Siwaqa is to be sent through P/L to Siwaqa from which place the Yadudah-Siwaqa P/L is to be constructed by WAJ. This P/L with the Sultani and Siwaqa-Qatrana well fields is to formulate a P/L project referred tentatively to as the Sultani-Siwaqa P/L Project. While, the water from the Rumeil well field is to be sent through P/L to Madaba from which place the Yadudah-Madaba P/L is being constructed by WAJ. This P/L with the Rumeil well field is to formulate a P/L project referred tentatively to as the Rumeil-Madaba P/L Project. For these two P/L projects, studies on the feasibility study level are made.

25 Sultani-Siwaqa pipeline project: Scope of this project is to develop the Sultani well field, 6.3 MCM/y in sustained yield, and the Siwaqa-Qatrana well field, 9.6 MCM/y, and to transmit the total amount of water 15.9 MCM up to Siwaqa. WAJ is planning the construction of the Yadudah-Siwaqa P/L. Hence, the water transmission from Siwaqa to the Amman area is to be made through this pipeline.

26 The project consists of such components as, 18 production wells in the Sultani well field, 21 production wells in the Siwaqa-Qatrana well field, two reservoirs and P/L. This pipeline consists of a portion from Sultani well field to Sultani reservoir (500-600 mm in diameter, 11.7 km long), a portion from Sultani reservoir to Siwaqa reservoir (66-700 mm in diameter, 23.1 km long), and a portion from Siwaqa reservoir to Siwaqa pumping station to be constructed by WAJ (600-800 mm in diameter, 5.9 km long). Total length of the pipe is 40.7 km. No purification plant is required.

27 Four years will be necessary for construction. The cost is estimated at JD million 19.26 (equivalent to US$ million 6.7 at 1 JD = 2.92 US$ rate). Of the amount, JD million 14.43 or 74% is for foreign exchange and JD million 4.84 or 26% for domestic currency. Economic benefit is estimated at JD million 2.1 a year, and financial benefit at JD million 1.5 a year. Then, the economic internal rate of return (EIRR) is calculated at 11% and the financial internal rate of return (FIRR) at 7%.

28 Rumeil-Madaba pipeline project: Scope of this project is to develop the Rumeil well field, 7.0 MCM in sustained yield, and to transmit the produced water to Madaba. WAJ is undertaking the construction of the Yadudah-Madaba pipeline (1,000 mm in diameter). Hence, the water transmission from Madaba to the Amman area is to be made through this pipeline.

29 The project consists of such components as 20 production wells, two reservoirs, one booster pump station, a main P/L and a branch pipeline. The main pipeline collects water from 9 wells and the branch pipeline 11 wells. The main pipe is 300-700 mm in diameter and 27.4 km long. The branch pipe is 300-500 mm in diameter and 13.9 km. Total length of the pipes is 41.3 km. The booster pump station is for pumping head of 160 m of maximum discharge of 1.04 m^3/s for a distance of 17.9 km. Purification plant is not required.

30 Four years will be necessary for construction. The cost is estimated at JD million 14.62 (equivalent to US$ million 42.7 at 1 JD = 2.92 US$ rate). Of the amount, JD million 11.14 or 76% is for foreign exchange and JD million 3.48 or 24% is for domestic currency. Economic benefit is estimated at JD million 1.1 a year, and financial benefit at JD million 0.7. Then, EIRR is calculated at 7% and FIRR at 1%.

31 Combined consideration: As mentioned above, two pipeline projects are formulated because of the intention to utilize fully the on-going and planned pipeline projects undertaken by WAJ. However, these two projects are to be considered to be the integral parts of the comprehensive plan

to develop the groundwater potential of the whole Mujib watershed. In this context, the fund procurement of two projects can be made in a package. Combined EIRR is calculated at 10%, and FIRR at 7%.

32 Recommendation for pipeline projects: Both projects are technically feasible and economically viable. In view of the necessity of urgent reinforcement of city water supply to the Greater Amman area, it is recommended to commence to take necessary steps for implementation of the both projects at the earliest possible time.

F Recharging of Groundwater or Base Flow

33 General: It is studied to retain the flood flow by dam and thereby recharge the groundwater or base flow. This principle is applicable in two parts of the whole basin. One is the lower reaches of Wadi Wala and the other is the upper reaches of the tributaries of Wadi Mujib. Former is to retain flood flow by the proposed Wala dam for recharging the base flow and groundwater. The latter is to retain flood flow by the Qatrana dam, the Sultani dam (both existing) and the Siwaqa C dam (newly proposed) for recharging the groundwater along the Desert Highway of both existing and proposed well fields.

34 Wala dam scheme: There exists a group of farms on the lower reaches of the Wadi Wala downstream from the King's Highway bridge. These farms depend on the base flow of the Wadi Wala for irrigation. Area measures 350 ha of existing and 250 ha of registered farms totalling 600 ha. This group is the largest irrigated area in the Mujib basin. While, WAJ has a plan (Wala P/L project) to take 15 MCM of base flow for the water supply of highland, and the survey has been started. If this plan is put to commission, such farms will lose the irrigation water source. Hence, a compensating water for irrigation by some 6 MCM is needed.

35 The Wala dam scheme is proposed first for the compensation purpose. The damsite and reservoir areas are composed of pervious B2a layer, about 15 m thick, and an impervious B1 layer underlay. When a dam, of central core rockfill type, 65 m high, 350 m long and 0.92 MCM of fill volume is constructed, then 19.3 MCM of effective reservoir capacity is available. Water stored in the reservoir will leak into B2a layer by 16.9 MCM, and 2/3 of the same or 11 MCM/y will reappear on the downstream river channel. Of this flow, 5 MCM/y will be injected from 11 injection wells, 200 m deep each, into A7 layer so that the potential of the WAJ's Heidan well field will be increased. The remainder 1/3 or 6 MCM/y will join the base flow from the points about 3 km downstream from the dam. This flow can be used for compensation of irrigation water for the said 600 ha. Unified irrigation facilities will not be necessary because most of the existing farms are already equipped with pumps and pipes. On the other hand, the proposed Rumeil well field will be benefited because the seepage from the Wala reservoir will raise the groundwater level of the Rumeil well field by about 10 m.

36 Recharge of groundwater on upstream part: The most important area of groundwater source is the belt along the Desert Highway to the south of Siwaqa. In this belt, there are three existing well fields (Siwaqa, Qatrana and Sultani) and two proposed well fields (Siwaqa-Qatrana and Sultani). In 1986, excessive abstraction of water which might lead to a devastation of aquifer was made from the existing wells. Hence, it is better to recharge positively the existing well fields as well as to increase the potential of the proposed well fields. There are tributaries of the Mujib river nearby each of these well fields and also two existing retention dams. Such existing beings are to be utilized for the recharging purposes.

37 Qatrana dam scheme: Near the existing Qatrana well field, there exists the Qatrana retention dam on the tributary Wadi Hafira. Flood flow retained in the reservoir is to be used for reinforcement of the existing well field and a part of the proposed well field. By providing a desilting basin and three wells for injection and production, 1.8 MCM a year can be injected in the rainy season and 1.4 MCM can be pumped up

again in the dry season. Such injection is also good for curing the existing wells from which over-extraction was sometimes made.

38 On the upper reaches of the Wadi Hafira, there is a vast area where the topography is very flat. This area turns to a swamp after the rainfall. This phenomenon incurs less inflow to the Qatrana dam, more evaporation loss and more seepage which joins the groundwater flow towards Azraq. It is estimated that the outflow of the Wadi will increase by 2.2 MCM by the full drainage improvement. By adding four wells, 1.8 MCM will be pumped up again in the dry season. By combining the natural inflow and the increased outflow by the drainage improvement, 3.2 MCM by seven additional wells will become available in the dry season.

39 Sedimentation took place to some extent in the existing reservoir, and present storage capacity is 4 MCM. Hence, some additional works on the dam are required. The crest of the dam is to be heightened by 3 m to increase the capacity. Existing spillway is to be extended to 136 m and the spillway crest is to be heightened by 1.25 m high at maximum, and the dykes of 2 km are required to protect the Desert Highway from occasional floodings.

40 Near the existing Sultani well field, there exists the Sultani retention dam. Same idea as the Qatrana dam is applicable in smaller scale. The Sultani reservoir has been almost filled up by the residue from the Abyad Phosphate Mine located upstream. Hence, it is necessary to excavate the filled materials and to take countermeasures to prevent the residue to flow into the upstream part of the Wadi. Removal of 0.9 MCM is required to obtain the storage capacity of 1.1 MCM. Also, future precaution not to allow the sedimentation inflow is necessary. Then 0.6 MCM by two additional wells will become available in the dry season. This scheme as a whole will be rather costly.

41 <u>Siwaqa C dam scheme</u>: Near the existing Siwaqa well field, the Wadi Siwaqa flows. By constructing a dam on the Siwaqa-C site, 0.6 MCM by one or two additional wells will become available in the dry season. The dam

will be of central core rockfill type, 16.5 m high, 124 m long, and 28,000 m^3 in fill to obtain 1.1 MCM of effective capacity. This scheme will be rather costly.

G Other Schemes

42 Irrigated agriculture: Study is made covering the entire basin to find the possibilities of developing the irrigated agriculture. However, the distribution of soils suited for agriculture are limited, and water source is scanty. Hence, it is found difficult to formulate the irrigated agriculture schemes of large to middle sizes. Only two small schemes are planned. They are Hamman scheme and Qatrana scheme.

43 Hammam irrigation scheme: This scheme is to store the flow of the Wadi Hammam by a dam and to irrigate the downstream areas. The irrigation area consists of two blocks. One is 100 ha composed of 50 ha for plastic house and 50 ha for normal upland field both of which are covered by existing farms. The other area is 75 ha, which is uncultivated at present, only for the winter irrigation. Three existing wells in the area will be kept in use. Hence, this area receives the conjunctive use of well water and stored water in the Hammam reservoir. Crops will be vegetables such as strawberry, cucumber, tomato, carrot and potato which are suited for the highland agriculture. Governmental management of the scheme is desirable. IRR is estimated at 0.5%.

44 The Hammam dam is of center core rockfill type, 16 m high, 2,670 m long (very long) and 0.6 MCM in fill volume. Effective storage capacity is 1.5 MCM. As the dam site and reservoir area are located on the clay sediment layer, there is no leakage problem, but the evaporation loss is considerable. In view of the loss and length of the dam, the storage efficiency is not favourable and the irrigation water becomes costly.

45 Qatrana irrigation scheme: There is an area of 75 ha which is suitable for the irrigated farming on the downstream area from the Qatrana existing dam. Crops will be potato, carrot and onion to be grown

in the winter season. Irrigation water can be taken from the Qatrana dam. Required irrigation water is 0.6 MCM which corresponds to one well. Governmental management is desirable.

46 Storage of flood flow: There are possibilities of flood water storage on the Nukheila site and the Khabra site. At present, it is difficult to confine the use of stored water, but these schemes will be useful when such water is demanded.

47 Nukheila dam scheme: The Nukheila dam site is located on the middle reaches of the Wala River at about El. 180 m. Many tributaries join on the upstream points from the reservoir. The dam will be of center core rockfill type, 61 m high, 350 m long and 0.94 MCM in fill volume to obtain an effective storage capacity of 20.8 MCM. The left bank is covered by thick layer of uncemented alluvial material, and it is necessary to make further geological investigation in future. Available water will be 8.8 MCM/y of storage and 4.4 MCM/y of seepage which increase the downstream base flow, totalling 13.2 MCM/y. Conceivable use of water would be, the city water supply and irrigation water on highlands, or industrial and irrigation uses on the downstream areas.

48 Khabra dam scheme: Damsite is found on the Albit river which drains the eastern escarpment of Karak. Precipitation is relatively rich in the whole Mujib basin, but the catchment area is rather small. The damsite is located at El. 690 m adjacent to the Lajjun oilshale deposit. The dam will be of center core rockfill type, 29.5 m high, 455 m long, and 0.29 MCM in fill volume. Available storage capacity will be 6.1 MCM from which 2.7 MCM/y of water can be used. As aforementioned, the groundwater potential of 5 MCM/y is reserved for the future development of the oilshale by the Government policy. The Khabra water can replace part of this requirement, and it will be possible to use the saved groundwater for the city water supply for Amman or Karak. Also the irrigation use in the Karak region or on the low lands are conceivable.

49 Combination of two dams: As mentioned above, the available water from storage reservoir will be 8.8 and 2.7 MCM/y from the Nukheila and Khabra reservoirs respectively if one of them is constructed. However, in case of two of them are constructed, the total availability of water from the storages will become 10.0 MCM/y which is some 10% less than the simple sum of two.

50 Green belt: Realization of green belt along the Desert Highway from Jiza to the south onward and from Qatrana to Karak, totalling some 100 km, will be possible. Required water for three rows of trees on both sides of the road is estimated provisionally at some 0.1 MCM. Irrigation can be made with tank lorry, and water can be taken from the nearest reservoirs. In case of the driest time, some amount of well water will be required.

JICA