Table D-2 MONTHLY WATER SUPPLY VOLUME FOR AMMAN AND ZARQA GOVERNORATES (1985)

Unit: (m^3)

Month	Amman	Zarqa	Total
Jan	3,878,596	600,204	4,478,800
Feb	3,551,604	552,344	4,103,948
Mar	4,162,618	548,179	4,710,797
Apr	4,235,400	713,736	4,949,136
May	4,696,407	888,057	5,584,464
Jun	4,710,840	885,240	5,596,080
July	4,765,816	905,789	5,671,605
Aug	4,405,534	918,313	5,323,847
Sep	4,697,760	851,490	5,549,250
Oct	4,622,224	841,805	5,464,029
Nov	4,280,580	739,800	5,020,380
Dec	4,336,621	710,241	5,046,862
Total	52,244,000	9,155,198	61,499,198

APPENDIX E

ENGINEERING GEOLOGY

TABLE OF CONTENTS

LIST OF FIGURES

1. GENERAL GEOLOGY AND HYDROGEOLOGY

1.1 General Geology

The Study Area is underlain by Paleozoic, Mesozoic and Cainozoic sedimentary rocks with some basic and acidic intrusives. The Mesozoic system, especially Cretaceous carbonate sedimentary rocks dominate in the Study Area.

The Cretaceous to Paleogene systems are divided into three groups, i.e. Kurnub, Ajlun and Balqa in ascending order. The Wadi Sir Formation (A7) in the Ajlun group, the Wadi Rusaifa Formation (B1), the Amman Formation (B2) and the Muwaqqar Formation (B3) in the Balqa Group of the middle to upper Cretaceous age cover most of the Study Area.

The middle to lower Cretaceous and the pre-Cretaceous sedimentary rocks are found only in the lower reaches of Wadi Wala, Wadi Mujib and to the lower slopes of the rift escarpment along the Dead Sea. The Tertiary Carbonate rocks are found only along the east boundary of the Study Area. The Pleistocene basalt flows associated with plugs, cones and vents are common in the western part of the Study Area.

The Quaternary fluviatile deposits, mantle rocks and mudflat pelitic sediments have accumulated over extensive areas in the desert and obscure the older formations. These deposits are normally relatively thin. The mudflat deposits have developed over extensive areas where the drainage is restricted. These sediments are commonly saline and may contain salt layers. The regolith or mantle rocks consist mainly of cherts, and extensive pavements of this material are present on the plateau.

The Paleozoic to Cainozoic sedimentary rocks in the Study Area generally have a structure of monoclinol flexures at a low angle, faults and joints. The dominant fault direction in the area ranges from NW-SE to NNW-SSE. Siwaqa Fault, the most remarkable fault in the area, runs SW-

NE to W-E. The fault systems correlated to the rift also occur to the west of the area. Geological map of the Study Area is shown in Fig.E-1. Regional stratigrapy is compiled in Fig.E-2.

1.2 Hydrogeology

The middle to upper Mesozoic sediments form a sequence of aquifers and aquicludes. Four aquifer systems of B2/A7, A4, A2 and K have been recognized in the Study Area. Among them, the B2/A7 aquifer has regional and economic importance. The B2/A7 aquifer has been considered to be a uniform aquifer unit with hydraulic connections, which is widespread throughout the entire Study Area with a thickness of 100 to 300 m. The B1 Formation which is composed of alternating marl, marly limestone, chert and sandstone is intercalated between the B2 and the A7. The B2a/A7b formation is an excellent aquifer with the permeability varrying due to joints, fractures and karstification of the limestones.

2. FOUNDATION DRILLING

A series of exploratory drilling was carried out for geological investigation of foundation at five dam sites, which had been selected out of twenty contemplated sites on the criterion for the drilling to cover representative parts of formations of the Mujib Basin stratigraphy. The drilling was commenced on May 24, 1986 by the local contractor of Geotechnical Engineering and Material Testing Co.(GEMT) financed by WAJ. Core drilling at nine locations and the borehole permeability test at the depths of 30 m to 60 m, were performed at the selected dam sites of Wala, Rumeil, Sueida 1, Mujib and Nukheila (see Fig. E-3). Results of the borehole permeability tests are given in Fig.E-4. Interpretation of those core samples is described in the following chapter. Summary of the drilling at five dam sites is shown below;

Dam site	No.	Depth(m)	Location	Formation
Wala	BW-1	50	Left abutment	B2a
	BW-2	30	Wadi bed	B2a, B1
Rumeil	BR-1	50	Left abutment	B2a
	BR-2	30	Wadi bed	B2a
Mujib	BM-1	60	Left abutment	A3-6, Debris
Nukheila	BN-1	60	Left abutment	A3, Debris
	BN-2	30	Wadi bed	A3
Sueida 1	BS-1	50	Right abutment	B2a
	BS-2	30	Wadi bed	B2a

3. TOPOGRAPHY AND GEOLOGY OF DAMSITES

3.1 Wala Damsite

The damsite is located on the Wala river, about 4 km upstream from the Wala bridge where Kings highway crosses the lower reaches of Wadi Wala. The left abutment rises at a uniform slope of 5-10 degrees from the bottom of the wadi to the top of the hill, while the right abutment rises steeply with a uniform slope of 35 to 45 degrees. No baseflow is recorded throughout the year.

The left abutment is covered with thick unconsolidated loose sediment of debris of which thickness is estimated to be about 15m by boring at BW-1 as shown in Fig.E-5. The B2a Formation, which is composed of alternating silicified limestone, chert and chalky marl, outcrops extensively along the steep cliff of the right abutment. The bed strikes N80W and dips 10N. The chert layers are fractured with some open cracks. Alluvial river deposits of gravel and sand, widely cover the wadi with a thickness of about 13m. The B1 Formation, which is composed of marls with a low permeability of 1 to 3 Lugeon values, is located at a depth of more than 20m. The groundwater table has been measured at 15m from the surface in the borehole BW-2. The B2a Formation, which is considered to be a very pervious layer, outcrops intensively in the reservoir rims. Strong attention will have to be paid to the probable high water leakage through the B2a Formation which outcrops both at the damsite and on the reservoir rims. Estimated geological profile along the proposed dam axis is shown in Fig.E-5.

3.2 Rumeil Damsite

The damsite is located on the middle reaches of Wadi Wala, about 10 km upstream from the Wala bridge where Kings highway crosses the wadi. The left abutment shows an inclination of 35 to 40 degrees in the lower part and 5 to 10 degrees in the upper part. The slope of the right abutment is 5 to 10 degrees up to a relative height of 100 m from the wadi bed and 30 to 35 degrees above that. No baseflow is recorded throughout the year.

Successive fresh outcrops with stratified silicified limestone unit are found in and around the damsite area. The bedrock of the lower left abutment up to 20m from the wadi bed is composed of silicified limestone, chert and chalky marl of the B2a Formation. The higher left abutment above the 20m level consists of phosphate, chert and chalky marl of the B2b Formation. The bed strikes N55E and dips to 12S. The bedrock of the lower right abutment up to a 45m height is the B2a Formation. The right abutment higher than 45m is composed of the B2b Formation. The bed strikes N35E and dips 12E. These chert and silicified limestone layers are fractured and caved with very high Lugeon values of 20 to more than 100 as measured in the borehole BW-1 and BW-2 as shown in Fig.E-5. The wadi channel is covered with a thin alluvial deposit of 1 to 2m in thickness. Diluvial wadi deposit of about 10m thickness covers the toe of the right abutment. The groundwater table is located at the depth of about 80m in the private wells in the middle of the reservoir area. The B2a Formation which includes many caves, outcrops not only in and around the damsite but on the reservoir rims. Strong attention shall be paid on the water leakage through the B2a Formation. The reservoir area is covered with thick soil and is widely used for private farms which are irrigated by deep wells in the proposed reservoir. This reservoir area is a promising well field of a part of Rumeil which consists of B2/A7 aquifer and may have a groundwater potential of about 2 MCM/year or less. Estimated geological profile along the proposed dam axis is shown in Fig.E-5.

3.3 Zeinab Damsite

The damsite is located on the Wadi Zeinab, which is a tributary of Wadi Wala, and located about 15km southeast of Madaba. The left abutment rises gently with a slope of 5 to 10 degrees. The right abutment rises steeply with a slope of 30 to 35 degrees. No baseflow is recorded throughout the year.

The gentle slope of the left abutment is covered with thick top soil or debris, and no outcrops are found on the slope of the left abutment. The bed, located at the toe of the left abutment, strikes N60E and dips 15S. Successive outcrops are found at the steep slope of the right abutment. The bedrock of the lower right abutment, less than the 35m height, is composed of alternating silicified limestone, chert and chalky marl of the B2a Formation. The upper part, above 35m dam height, consists of alternating phosphate, chert and chalky marl of the B2b Formation. The bed strikes N10W and dips 10E. A part of the wadi bed is covered with alluvial river deposit 3 to 4m thick. The groundwater depth is estimated to be more than 100m deep. The B2a Formation, which includes some fractured chert, outcrops on the steep slope of the right reservoir rim. Strong attention will have to be paid to the probable high water leakage through the B2a on the right abutment and the reservoir rim. Assumed geological profile along the proposed dam axis is shown in Fig.E-5.

3.4 Halq Damsite

The damsite is located on the Wadi Halq, which is a tributary of Wadi Wala, and located 2 km downstream from the Halq bridge where Desert highway crosses the Wadi Hammam. The left abutment rises rather steeply with a slope of 25 to 30 degrees, while the right abutment rises gently with a slope of 5 to 10 degrees. No baseflow is recorded throughout the year.

The bedrock of the lower left abutment, up to 10m height above the wadi bed, is composed of alternating chert, silicified limestone, silicified phosphate and chalky marl of the B2a Formation. The middle part of the abutment, more than 35m in height, is composed of alternating phosphate, chert and chalky marl of the B2b Formation. The upper part higher than 35m consists of Coquina bed of the B2b Formation. The bed strikes N55E and dips 10S. The mild slope on the right bank is covered with thick top soil and debris, therefore no outcrops are found both at the left abutment and on the reservoir rim. A part of the wadi bed at the left bank is covered with thin diluvial wadi deposit of about

4m thickness. The bed strikes N30E and dips 10W. The B2a Formation, which is considered to be a highly pervious layer, widely covers the right abutment of the reservoir area. Strong attention shall be be paid to the water leakage through the dam foundation and the reservoir rim. The groundwater table is located at about 100m in depth. Assumed geological profile along the proposed dam axis is shown in Fig.E-6.

3.5 Shabik Damsite

The damsite is located on the Wadi Shabik, which is a tributary of Wadi Wala, and located about 6 km southwest of Dabb'a. The left abutment rises steeply with a slope of 35 to 40 degrees, while the right abutment rises gently with a slope of 5 to 10 degrees. No baseflow is recorded throughout the year.

The bedrock of the left abutment is composed of alternating phosphate, chert, silicified limestone and chalky marl of the B2b Formation. The bed strikes N55E and dips 5N. No outcrops are found at the right abutment. The B2a Formation of silicified limestone, which is intensively jointed and fractured, outcrops in the wadi bed with strike N55E degrees and dip 5N. The B2b Formation successively outcrops in the left side of the reservoir area, which is not considered to be an impervious layer. The right side of the reservoir area is covered with rather thick overburden with less permeability. Strong attention will have to be paid to the permeable zones in the foundation rock and left reservoir rim. Assumed geological profile along the proposed dam axis is shown in Fig.E-6.

3.6 Hammam Damsite

The damsite is located on the Wadi Hammam, a major tributary of Wadi Wala, and is situated about 10 km southeast from the Alia International Airport. This damsite is located in the flat wadi with a gentle slope of 5 to 10 degrees. No baseflow is recorded throughout the year.

The whole area including the damsite and the reservoir is covered with thick alluvial to diluvial deposit of 10m thickness, therefore no outcrops are found in the area. The diluvial deposit, which is composed of clay and silt including some pebbles , is considered to be impervious. Assumed geological profile along the proposed dam axis is shown in Fig.E-6.

3.7 Mujib Damsite

The damsite is located on the lower reaches of Wadi Mujib, about 1.5 km downstream from the Mujib bridge where Kings highway crosses the wadi. The left abutment rises steeply with a slope of 30 to 35 degrees, while the right abutment rises rather gently with a slope of 10 to 20 degrees. Perennial baseflow of about 100 litre per second on average has been recorded at the site.

Both damsite and reservoir area are composed of alternating marly limestone and marls of the A3-6 Formation, which is covered mostly with thick unstable debris or residues of landslides. Outcrops are found only near the bottom of the wadi within a height of 10m. The area higher than 10m is covered with thick debris or residues of landslides. The marly limestone bed at the wadi bottom strikes NS-5 and dips 7W. Thickness of the unstable deposit of debris has been estimated to be 30m in the borehole MB-1 as shown in Fig.E-6. Thick unstable sediments are widespread along the area of the rim. Careful approach will be required for the slope stability of the reservoir rim and the left abutment. Estimated geological profile along the proposed dam axis is shown in Fig.E-6.

3.8 Nukheila Damsite

The damsite is located on the Wadi Nukheila, a major tributary of Wadi Mujib, and is situated 2 km upstream from the Mujib bridge where Kings highway crosses the wadi. An almost vertical cliff, approximately 18m in height, is formed at the foot of the left bank slope which shows a general inclination of 45 degrees in the upper part. The right abutment rises with a moderate slope of 20 to 25 degrees. Perennial baseflow of about 100 litre per second or less has been measured at the site.

The bedrock of the left abutment is composed of alternating marly limestone and marl of the A3 Formation. The upper part, at a height above 10m is covered with 10m thick debris, which has been confirmed by boring NB-1 as shown in Fig.E-7. The right abutment is covered with debris except in the toe of the slope where the A-3 Formation of alternating limestone and marl outcrops. The bed in the A-3 Formation strikes N-S and dips 5W. Marly limestone and marl outcrops extensively at the left side of the wadi bed. The right side of the wadi bed is covered with thick diluvial wadi deposit of about 10m in thickness. Successive outcrops of the A-3 Formation are found in the reservoir rim. The extensive debris on the left slope is thick and unstable. From the topography, structural faults and/or active faults can be assumed beneath the debris on the left bank. Careful attention will be required to ensure the stability of the slope at the left bank, where the thick debris covers the slope with a height of more than 35m from the wadi bed. The marly limestone in the A-3 Formation is not considered to be a very pervious layer, but, high Lugeon values of 70 to 80 have been measured in the borehole NB-2 as shown in Fig.E-7. Substantial water leakage through the A-3 Formation may not be expected as a whole. However, more detailed test borings with permeability test and geophysical prospecting will be needed to examine the engineering geology of such unforeseen pervious zones, faults and unstable thick debris. Estimated geological profile along the proposed dam axis is shown in Fig.E-7.

3.9 Sueida 2 Damsite

The damsite is located on the Wadi Sueida, a major tributary of Wadi Mujib, and is situated 7km downstream from the Siwaqa bridge where Kings highway crosses the wadi. The left abutment rises rather gently with a slope of 10 to 15 degrees, while the right abutment rises steeply with a slope of 40 to 45 degrees. No baseflow is recorded throughout the year, and groundwater level is located at about 50 m or less in depth.

The left abutment is covered with rather thin debris except the top of the abutment where Coquina bed of the B2b Formation outcrops with a strike of N75W and a dip of 20S. The bedrock is composed of chert, silicified limestone and chalky marl of the B2a Formation in the lower part of the valley up to a height of 15 m from the wadi bed. The higher part of the valley is composed of rock of the B2b Formation, which consists of a 20m thick alternation of phosphate and chert, a 10m thick Coquina bed, a 17m thick chert intercalated with phosphate layers and again a 16m thick Coquina bed, in ascending order. The bed strikes N55E and dips 5E. Assumed geological profile along the proposed dam axis is shown in Fig.E-7.

3.10 Sueida 1 Damsite

The damsite is located on the Wadi Siwaqa, a major tributary of Wadi Mujib, and is situated 4km downstream from the Siwaqa bridge where Desert highway crosses the wadi. The left abutment rises steeply with a slope of 35 to 40 degrees, while the right abutment rises rather gently with a slope of 10 to 20 degrees. No baseflow is recorded throughout the year and the groundwater table is located at about 50m below the surface.

The bedrock of the left abutment is composed of alternating chert, silicified limestone and chalky marl of the B2a Formation. The chert layers are fractured in some parts and include a number of open cracks. The beds strike N75E and dip 15S. The site is located just beside the Siwaqa fault showing a disturbed geological structure. The right abutment is covered with debris up to a height of 30m from the wadi bed. Very high Lugeon values of more than 100 have been measured in the borehole SB-1 which penetrated the B2a Formation as shown in Fig.E-7. The bed strikes N20E and dips 10E. The wadi bed which consists of the B2a Formation is partly covered with alluvial river deposit. The area on the left bank is covered with impervious soils and debris. Successive outcrops of the B2a Formation are seen on the steep slope near the right reservoir rim on the right bank, which is considered to be a highly permeable geological unit. Strong attention shall be paid to the probable water leakage through the B2a Formation in and around the damsite. The estimated geological profile along the proposed dam axis is shown in Fig.E-7.

3.11 Siwaqa N Damsite

The damsite is located on the Wadi Mustabtih, a tributary of far upper reaches of Wadi Sueida, and is situated 50m northeast from the Jordan National Railway. The left abutment rises very gently with a slope of 5 to 10 degrees, while the right abutment rises steeply with a slope of 20 to 25 degrees. No baseflow is recorded throughout the year and the groundwater table is located at about 100m or more in depth.

The Coquina bed of the B2b Formation outcrops on the top of the left abutment. The gentle slope on the left abutment is fully covered with debris with clayey material. The bed strikes N40W and dips 5W. The B2b Formation of chalky marl intercalating thin chert layers outcrops on the cliff of the right abutment within the height of 5m from the wadi bed. The bed strikes N30E and dips 15W. The site is located just beside the Siwaqa fault showing the disturbed geological structures in the bedrock. The reservoir area is widely covered with diluvial deposit of clay and gravel, which is considered to be virtually impervious. Strong attention shall be paid to the probable high water leakage through the foundation rock. Assumed geological profile along the proposed dam axis is shown in Fig.E-7.

3.12 Siwaqa S Damsite

The damsite is located on the Wadi El Tuwai, a tributary of Wadi Sueida, and is situated 5 km southeast from the Siwaqa bridge. The left abutment rises gently with a slope of 5 to 20 degrees. Jordan National Railway passing the middle part of the slope crosses the wadi at this point. The right abutment rises gently with a uniform slope of 5 to 10 degrees. No baseflow is recorded throughout the year and the groundwater table is located at about 100m below the surface.

The lower part of the left abutment below the railway is covered with debris. The Coquina bed and chalky marl of the B2b Formation outcrop on the top of the slope. The beds strike N25E and dip 10E. Coquina bed and phosphate of the B2b Formation outcrop on the lower right abutment less than 15m in height. The beds strike N40W and dip to 10W. The left bank side of the reservoir area is covered with diluvial deposit of clayey material with gravel. Alternating chert and silicified limestone of the B2a Formation, which seems to be pervious, outcrop in the right reservoir rim on the right bank. Assumed geological profile along the proposed dam axis is shown in Fig.E-9.

3.13 Dabb'a Damsite

The damsite is located on the Wadi Dabb'a, a tributary of upper Wadi Mujib, and is situated 2 km downstream from the Dabb'a bridge where Qatrana-Karak road crosses the wadi. The left abutment rises steeply with a slope of 35 to 40 degrees, while the right abutment rises rather steeply with a slope of 25 to 30 degrees. The site is located in a V-shaped wadi. No baseflow is recorded throughout the year, and the groundwater table is located at about 50m below the surface.

The bedrock of the slope along the dam axis is composed of alternating phosphate, chert and chalky marl of the B2b Formation. Coquina bed in the B2b Formation outcrops only at the top of the abutment. The bedding planes are nearly horizontal. The wadi bed and the reservoir area are composed of alternating silicified limestone, chert and chalky marl of the B2a Formation with continuous outcrops. Strong attention shall be paid to the probable very high water leakage through the B2a Formation. Assumed geological profile along the proposed dam axis is shown in Fig.E-9.

3.14 Qatrana Damsite

The damsite is located on the Wadi Qatrana, a major tributary of Wadi Mujib, and is situated 5 km westwards from the Qatrana Railway Station and 2 km downstream from the Qatrana's existing dam. The left abutment rises steeply with a steep slope of 35 to 40 degrees, while the right abutment rises gently with a slope of 5 to 10 degrees. No baseflow is recorded throughout the year and the groundwater table is located at about 100m or more below the ground surface.

The bedrock of the left abutment is composed of alternating chert, silicified limestone and chalky marl of the B2a Formation. The beds strike N70E and dip 30W. The chert layers are highly fractured with open cracks. The right abutment is covered with thin debris. The B2a Formation outcrops above 25m from the wadi bed. The reservoir area is covered with diluvial wadi deposit which is composed of clayey sediments with gravel. Strong attention shall be paid to the probable high water leakage through the fractured B2a Formation. Assumed geological profile along the proposed dam axis is shown in Fig.E-9.

3.15 Khabra Damsite

The damsite is located on the Wadi Arbid, a tributary of Wadi Dabb'a, and is situated about 3.5 km upstream from the Dabb'a bridge where Qatrana-Karak road crosses the wadi. Both abutments rise with a uniform slope of 10 to 15 degrees. No baseflow is recorded throughout the year, and the groundwater table is located at a depth of 100m or less.

The debris covers the whole area except the wadi bed. The wadi bed is composed of Coquina bed of the B2b Formation. The bed strikes N30E and dips 5W. The reservoir area is covered mostly with debris except in some part of the left abutment where bituminous marl or shale outcrops. Water tightness of the B2b Formation is not considered to be lesser than thepervious geological unit of the B2a Formation. Assumed geological profile along the proposed dam axis is shown in Fig.E-9.

3.16 Sultani Damsite

The damsite is located on the Wadi Sultani, a major tributary in the upper Mujib basin, and is situated about 2 km north-westwards from the existing Sultani dam. The left abutment rises steeply with a slope of 30 to 35 degrees, while the right abutment rises with a slope of 25 to 30 degrees. No baseflow is recorded throughout the year, and the groundwater table is located at about 100m below the surface.

The left abutment is composed of alternating Coquina bed, silicified phosphate, chert and chalky marl of the B2b Formation. The beds strike N55W and dip 5W. The right abutment is covered with debris or mudflow. The reservoir area is covered with thick mudflow which is considered to be an impervious layer. Assumed geological profile along the proposed dam axis is shown in Fig.E-8.

3.17 Siwaqa C Damsite

The damsite is located on the upper most reaches of Wadi Sueida, about 0.5 km upstream from the Siwaqa bridge where Desert Highway crosses the wadi. The left abutment rises gently with a slope of 5 to 10 degrees, while the right abutment rises rather steeply with a slope of 30 degrees. No baseflow is recorded throughout the year and the groundwater table is located at a depth of about 50m.

The bedrock of both left and right abutments is composed of uniform Coquina bed of the B2b Formation with thickness of 20 m. The chert layer in the B2a Formation which outcrops on the wadi bed is covered with alluvial deposit. The reservoir area is covered with thick diluvial wadi deposit which is considered to be an impervious layer. The reservoir area is located in Siwaqa well field where two excellent deep wells are being used by WAJ for water supply to Amman. Assumed geological profile along the proposed dam axis is shown in Fig.E-8.

3.18 Sadir Damsite

The damsite is located on the Wadi Halq, a tributary of upper Wadi Wala, and is situated about 5 km south-westwards from the Alia International Airport. Both left and right abutments rise with a uniform slope of 5 to 10 degrees. No baseflow is recorded throughout the year and the groundwater table depth is about 100 m or more.

The whole area is covered with diluvial wadi deposit which is composed of clayey sediments with gravel with less permeability. No outcrops are found in and around the damsite. Assumed geological profile along the proposed dam axis is shown in Fig.E-8.

3.19 Qatrana Dam, Existing

The damsite is located on the Wadi Qatrana, a major tributary of Wadi Mujib, and is situated about 1 km upstream from the Qatrana damsite. A dam was constructed in a rather flat valley with a height of 10m. Some outcrops, which are composed of B2a Formation, are found on the slopes along the dam axis. Most of the reservoir area is coverd with fluviatile which consists of gravelly sediments with clayey matrix.

3.20 Sultani Dam, Existing

The damsite is located on the Wadi Sultani, a major tributary in the upper Mujib basin, and is situated about 1 km south-eastwards from the WAJ's Qatrana pumping station. The dam was constructed in a flat valley with a height of 5m. Some outcrops, which consist of the B2b Formation, are found at the slope on the right bank. The reservoir area is covered with fluviatile which is composed of gravelly sediments with clayey matrix.

4. ENGINEERING GEOLOGY

Most of the damsites are located in the limestone terrain, where pervious stratum outcrops in the wadis. Geological investigation was carried out with emphasis on estimating the permeability of the limestone layers in Balqa and Ajlun Groups. The geotechnical circumstances of the conceivable damsites are examined on the basis of the result of field mapping. Some core borings with pressure permeability test were performed at selected damsites which include the representative geological units of B2, B1 and A3. Possibility of water leakage from the reservoir has been evaluated in view of the results of these tests and geological mapping. Fig.E-1 shows the geological map of the Study Area. Regional stratigraphy is compiled in Fig.E-2.

Pervious layers are found in the B2a Formation which consists of alternating limestone, chert and silicified limestone with frequent joints, cracks and caves. The B2a Formation is one of the most important aquifer systems in Jordan, which has been exploited in the Study Area for a long period of time. Some sections of the boreholes in the B2a Formation was too pervious to be correctly measured with the testing equipment of ordinary capacity as shown in Fig.E-4. Such high permeability is deemed due to irregular distribution of joints and karstification in the limestones. Considering the very important role of the B2a Formation for recharging groundwater to the B2/A7 aquifer system, it is probable that leakage problems may be met by the dam schemes with the reservoir on the B2a Formation, that is the schemes of Zeinab, Halq, Rumeil, Wala, Sueida 2, Sueida 1, Qatrana and Dabba'. Ordinary grouting method may not solve the seepage problems in the limestone foundation and/or the reservoir. Storage dam scheme is not recommended in this geological unit of B2a.

The B2b Formation, which consists of alternating Coquina limestones, chalky marl and chert, is considered to be a less pervious stratum than the B2a Formation, because of the massive lithology and less cracks and joints. Proposed damsites of Khabra, Sultana and Siwaqa C, Siwaqa N, Siwaqa S are located in this geological unit of B2b. Ordinary foundation grouting will be effective except a part of caved limestones.

The B1 formation, which is composed of marls, is not considered to be a pervious stratum, with low range in Lugeon values of 1 to 3 have been measured in a shallow bedrock foundation at a depth of about 15m at Wala damsite.

The A3/6 Formation, which consists of marls and marly limestones, is not expected to be a pervious stratum. Ordinary foundation grouting will be effective except a part of caved limestones.

For the purpose of reservoir operation program, the following infiltration rates are assumed to estimate the probable water leakage from the reservoirs ; (1) 0.5 $mm/day/m/km^2$ of A3/6 and B2b Formation and (2) 5.0 $mm/day/m/km^2$ of B2a Formation. Correlation between Lugeon values and geological unit of B2a, B1 and A3/6 is shown in Fig.E-4.

Unsaturated highly pervious B2a Formation, which covers most of the reservoir area at Wala dam, overlies saturated impervious bedrock of B1 Formation which spreads widely at a depth of about 15m from the wadi bed. This hydrogeological structure suggests the possibility of the scheme of groundwater recharge dam at Wala site. Groundwater potential in and around the damsite will be increased by the leakage water from the reservoir, together with the potential of springs at the lower reaches of Wadi Wala (Heidan) near the Kings highway. According to the result of reservoir operation at Wala dam, 16 MCM/y of reservoir water, which is 80 % of effective capacity of 20 MCM/y, leaks within a few months after the rainy season. A part of the leaked water, which is preliminarily estimated in the range between 5 to 8 MCM/y, will add to the existing groundwater potential and outflows downwards to the flowing springs in the Wadi Heidan. Construction scale and type of dam as well as amount of groundwater seepage will be carefully studied on the basis of the further feasibility studies on engineering geology and hydrogeology.

Unstable thick debris, which overlies the A3/6 Formations, are widespread along the toe of the left bank at the damsites of Mujib and Nukheila. These unconsolidated loose sediments are to be removed to settle the slope stability. Taking account of the probable geotechnical problems in the huge amount of debris and the faults on the slopes of the proposed two damsites, the following are concluded; (1) Lower priority is given to the Mujib dam, (2) Retention height of the Nukheila dam which is believed to be 43m from the wadi bed (Refer to the Report of "East Bank Jordan Water Resources", Vol.3, 1965) shall be carefully examined by the future geological investigations and (3) Construction scale and type of dams will be carefully studied and selected on the basis of the further feasibility study.

5. CONSTRUCTION MATERIAL

5.1 Construction Materials

Based upon the geological and topographical conditions in the Study Area, the proposed dam type is anticipated to be a rockfill dam with earth core and earthfill dam or concrete gravity dam from the engineering and economic points of view.

The rockfill type dam and earthfill type dam will be selected because the construction materials such as rocks and impervious materials are easily obtainable within economic distance around the prospective site, and also as Jordan has ample experiences in the construction of rockfill dams, such as King Talal, Wadi Arab, Kafrein and Khaldia dam.

The concrete gravity type dam, on the other hand, will be selected in the case that the dam foundation has sufficient bearing strength and if the diversion and or spillway works are costly from the topographic and geological conditions.

The construction materials of the above dam type are the impervious earth material, filter material, rock material and concrete aggregates.

The quarried rock materials from the massive limestone of Balqa group (B2) in and around each of the proposed damsites are available for these rock material or concrete aggregates requirements.

As for the filter material and concrete aggregates, the alluvial river deposit of gravel and sand which are scattered at the middle through lower reaches of Wadi Mujib and Wadi Wala, is useful. However, in case that the total quantity is not sufficient, it is expected that the additional quarried and crushed material from the limestone and/or sandstone will be required. Furthermore, for the concrete aggregates, the special attention will be required to examine alkali reactive rocks, i.e. some cherts, siliceous limestones. Also, with considerable caution, the concrete aggregates, i.e. products from alluvial river deposits and quarried rocks should be viewed for undesirable components such as chlorides, sulphates, silts, clays and undesirable rock types.

The diluvial terrace deposits around the damsites which contain much fine materials with gravels and rock fragments hold promise for the impervious earth core material and the homogeneous embankment of the rolled earthfill type dams. There is some fear of saline and alkali soils in the arid area having piping action owing to the colloidal erosion. Such "dispersive" characteristics of the above impervious earth material shall be examined carefully in the future study stage.

5.2 Impervious Earth Material Survey

The representative borrows of the diluvial terrace deposits around the conceived damsites such as Wala, Rumeil, Sueida No.1, Nukheila and Mujib damsite are examined by pitting with 5m depth for the availability as the impervious embankment material by WAJ.

The location of test pits are shown in Fig.E-10. Physical/classification tests, i.e., natural moisture content, specific gravity, particle size distribution, consistency test on about 35 samples from the above 11 test pits are carried out at the laboratory of Geotechnical Engineering & Materials Testing Co. in Amman.

The results of all test pits logs and soil tests are summarized in Figs.E-11 to E-16. These test results indicate that these materials are mostly classified into GC, SC, SM, CL and ML in the Unified Soil Classification System.

Three important engineering properties of the impervious earth material are (1) permeability when compacted (2) shear strength when compacted and saturated, and (3) compressibility when compacted and saturated. In addition, (4) workability as a construction material has been rated.

Above classification results indicate the impervious or semipervious to impervious as for (1) permeability, fair to good as for (2) shear strength and (4) workability and medium to very low as for (3) compressibility, from which it is obvious that the soils from the above borrows are suited as material for rolled earth dams.

However, the natural moisture content of soils from these borrows ranges from 3% to 20%, which are lower than the plastic limit that ranges from 17% to 34%. Therefore, strong wetting operation will be required for embankment of core so that it will be stable and at maximum density when compacted.

Furthermore, "Dispersive" characteristics shall be checked by physico-chemical test and or pine hole test in a future study.

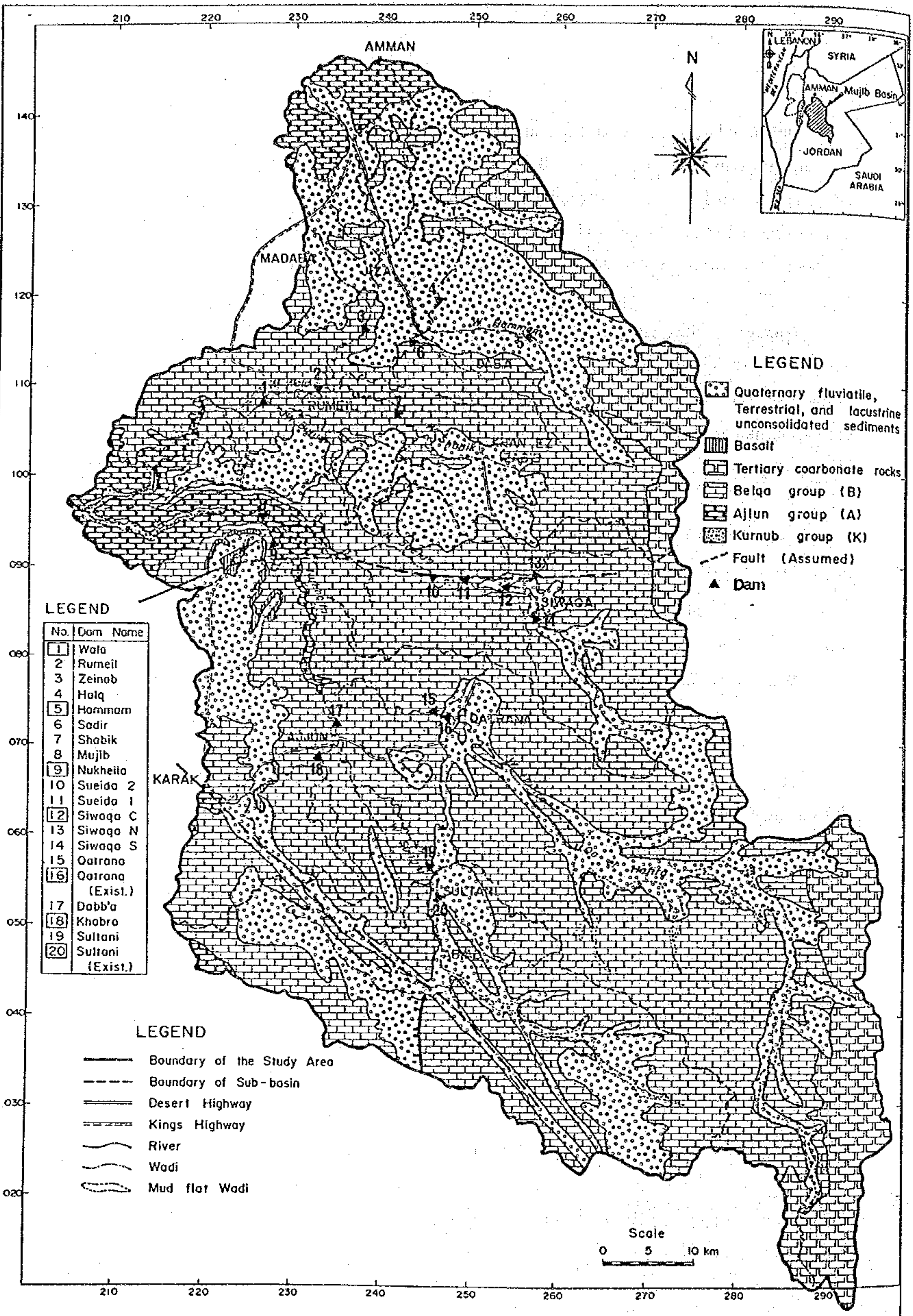


Fig.E-1 Geological Map of Study Area

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

Period		Group	Formation	Sub-Unit		Colmn	Description
QUATERNARY			Al (Alluvial)				Top soil, talus deposits, river deposits
QUATERNARY			Dl (Diluvial)				Unconsolidated clayey silt with gravels Old debris or old wadi deposits
TERTIARY		BELQA	B3	B3b			Chalky marl with some thin beded chalky limestone and chert beds
CRETACEOUS	Upper	BELQA	B3	B3a			Oil shale with thin beded limestone
CRETACEOUS	Upper	BELQA	B2	B2b	U		Phosphoritic thin chert, chalky marl, limestone
CRETACEOUS	Upper	BELQA	B2	B2b	M		Coquina limestone (oyster bed) with some chert, chalky marl in the middle
CRETACEOUS	Upper	BELQA	B2	B2b	L		Phosphorite, chert, silicified limestone and chalky marl, Localy nodular silicified limestone
CRETACEOUS	Upper	BELQA	B2	B2a			Silicified limestone unit. Alternation of silicified limestone, chert, marl or calcareous shale. Silicified limestone and chert are phosphatic in local. Intensively joint-developed and fractured
CRETACEOUS	Upper	BELQA	Bl				Calcareous sandy shale, sandy limestone, marl, with sandstone
CRETACEOUS	Middle	AJLUN	A7				Limestone, marly limestone, marl
CRETACEOUS	Middle	AJLUN	A5/6				Marl and marly limestone unit with gypsiferous shales
CRETACEOUS	Middle	AJLUN	A4				Dolomitic limestone unit, with few chert and some gypsum
CRETACEOUS	Middle	AJLUN	A3				Marly nodular limestone unit, with shale and shaly limestone
CRETACEOUS	Middle	AJLUN	A2				Massive limestone unit. Concretionary towards base, thin bedded slightly marly limestone
CRETACEOUS	Middle	AJLUN	Al				Marly limestone, marlstone
CRETACEOUS	Lower		KURNUB				Sandstone with shales, some friable

Fig.E-2 Geological Column of Study Area

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

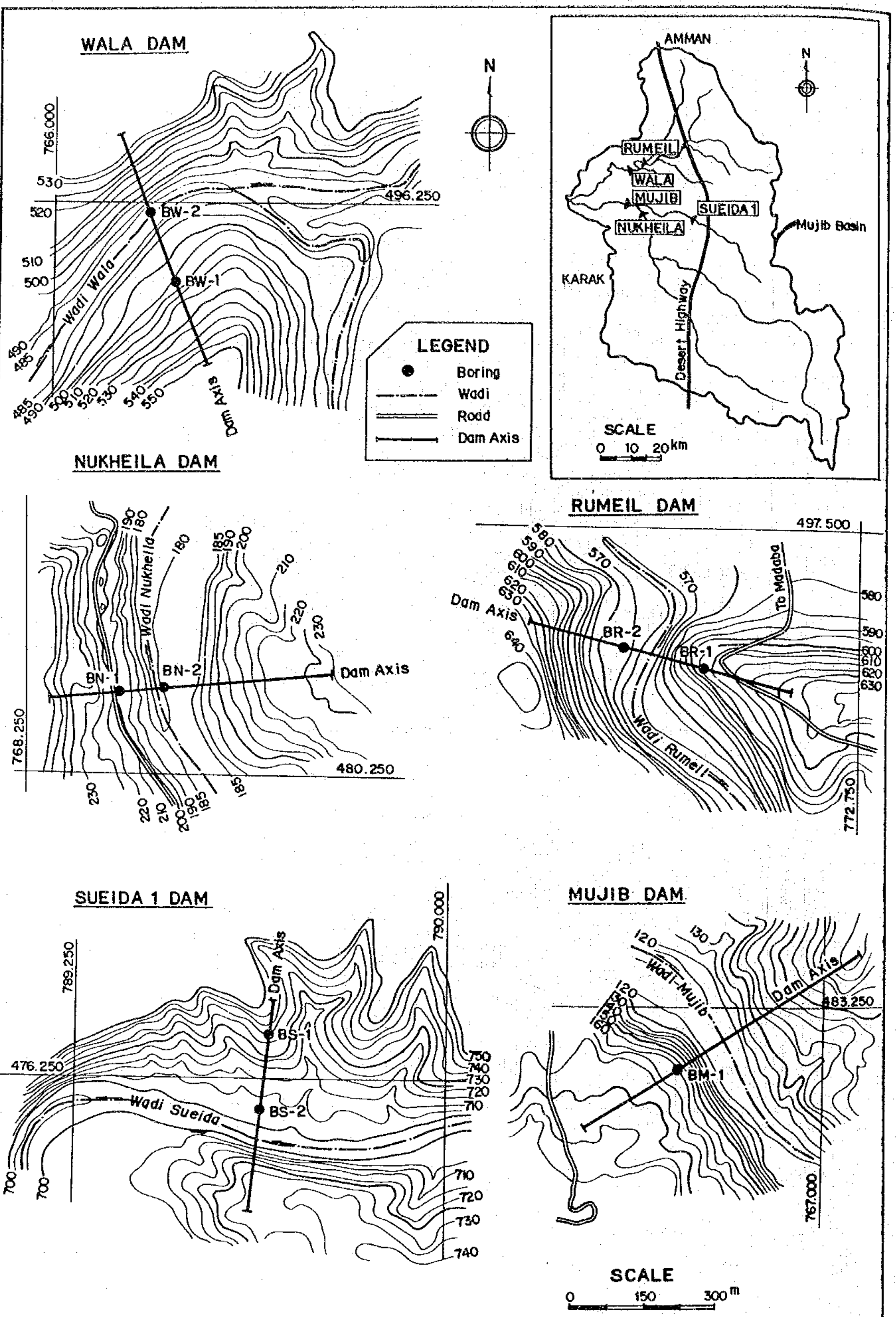


Fig.E-3 LOcationMap of Test Boring

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

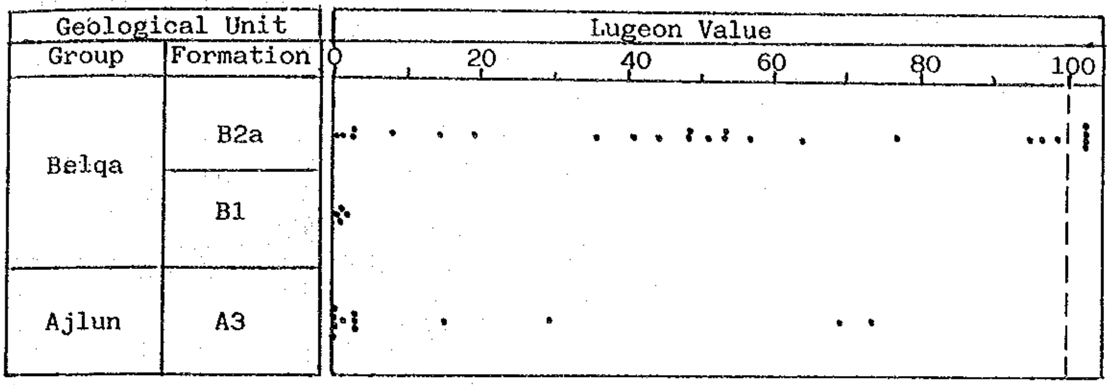


Fig.E-4 Geological Unit and Lugeon Value

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

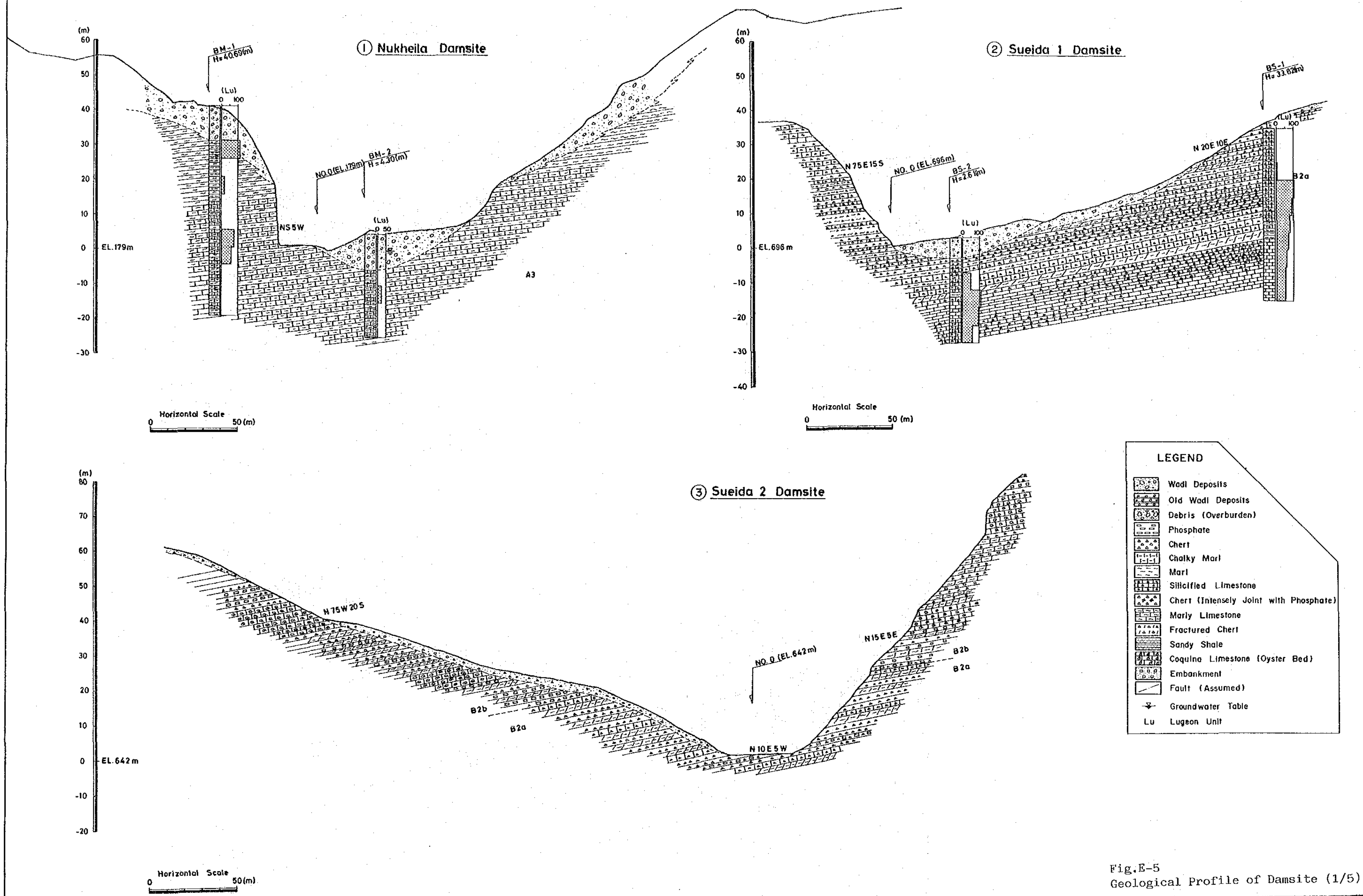


Fig.E-5
Geological Profile of Damsite (1/5)

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

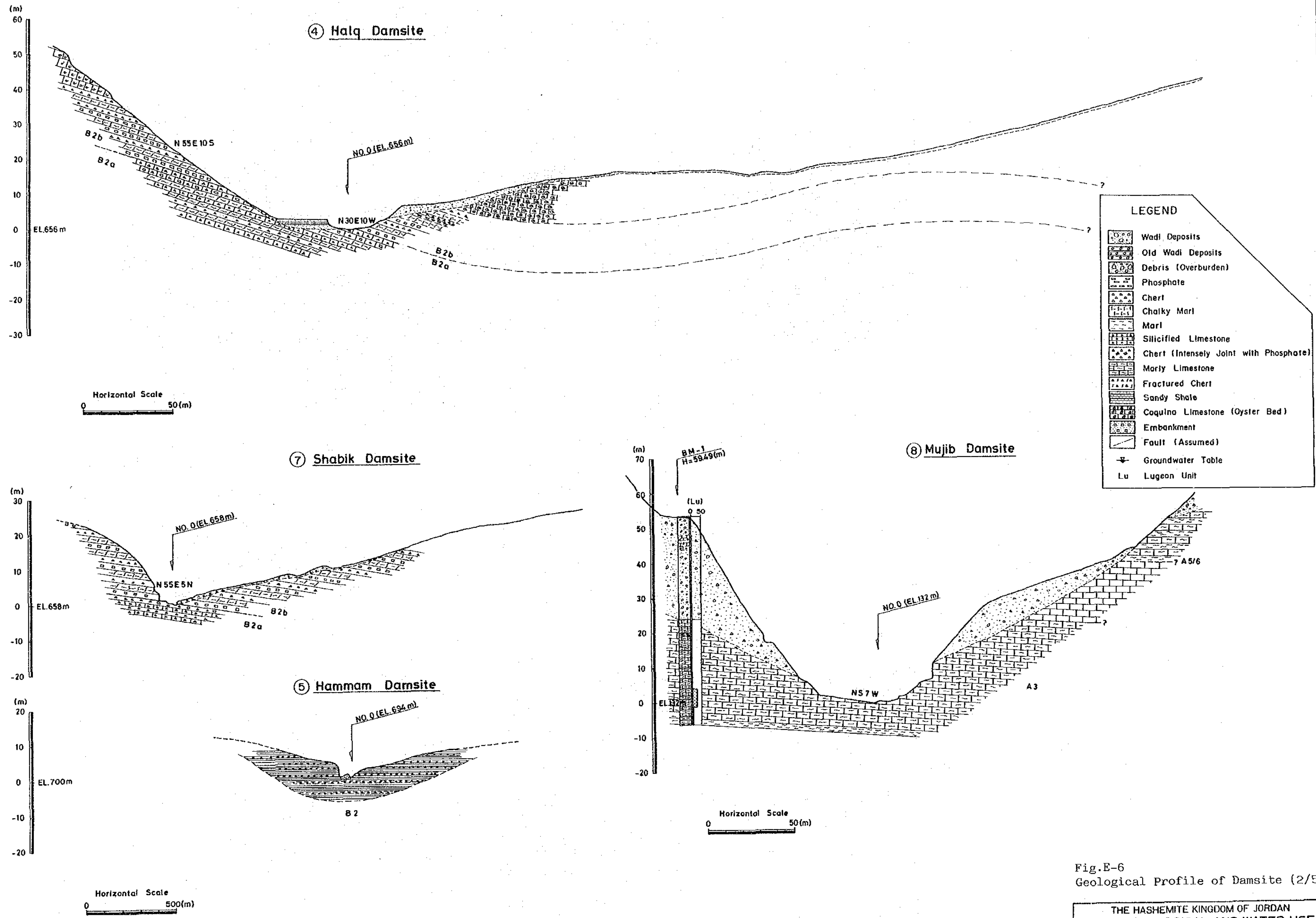
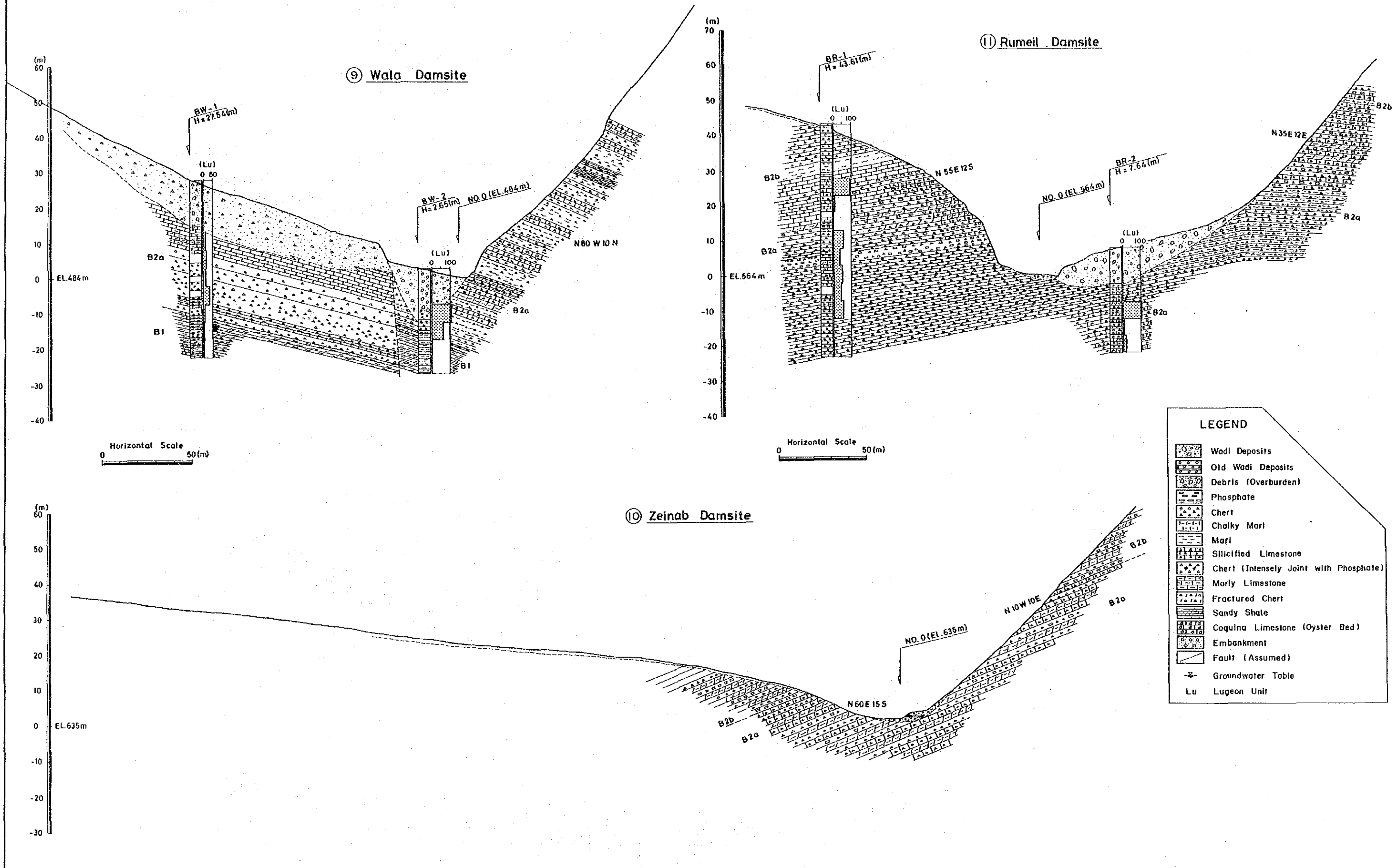


Fig.E-6
Geological Profile of Damsite (2/5)

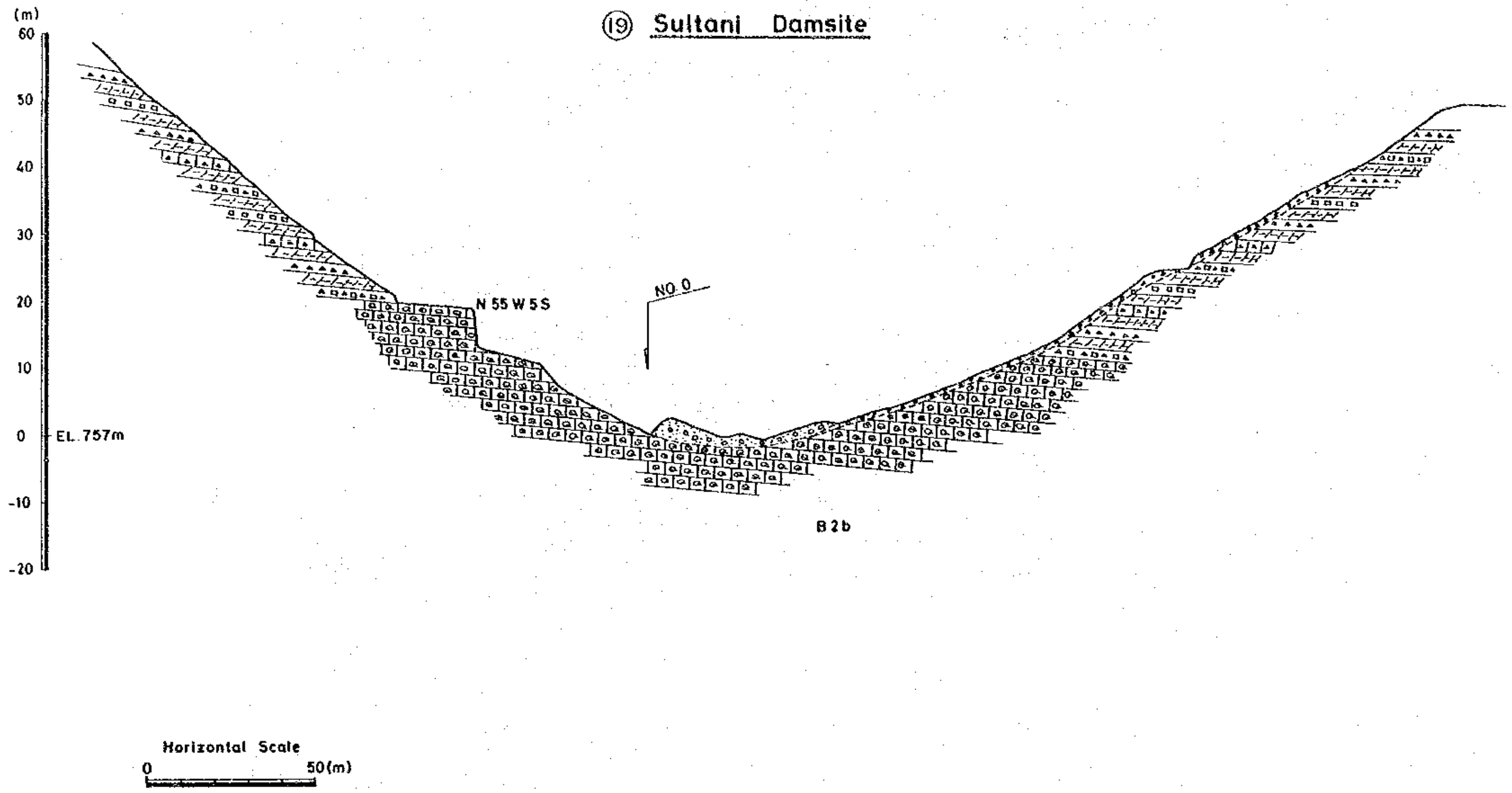
THE HASHEMITE KINGDOM OF JORDAN
HYDROGEOLOGICAL AND WATER USE STUDY OF THE MUJIB WATERSHED
JAPAN INTERNATIONAL COOPERATION AGENCY

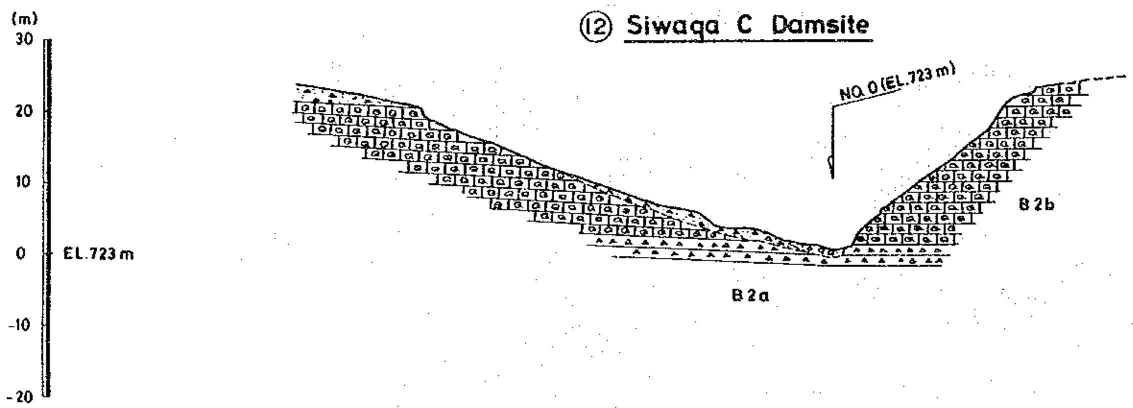


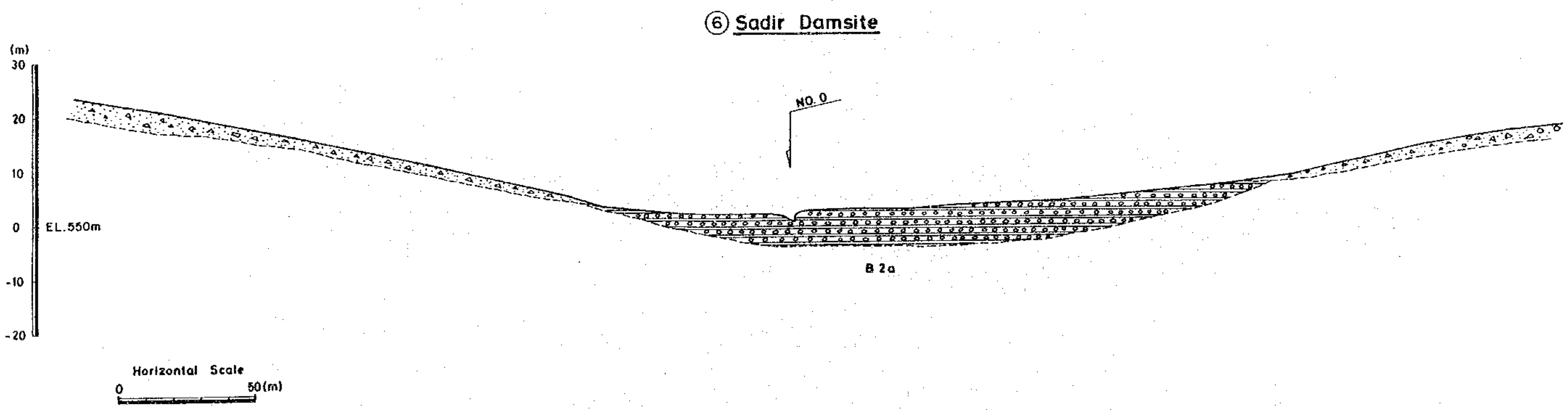
Horizontal Scale 0 50(m)

Fig.E-7
Geological Profile of Damsite (3/5)

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







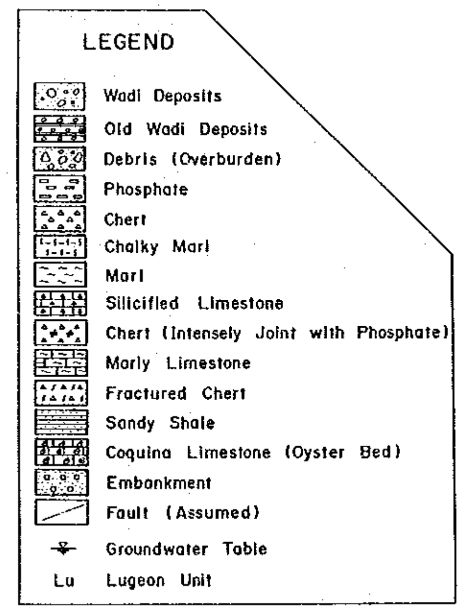


Fig.E-8

Geological Profile of Damsite (4/5)

THE HASHEMITE KINGDOM OF JORDAN

HYDROGEOLOGICAL AND WATER USE STUDY OF THE MUJIB WATERSHED

JAPAN INTERNATIONAL COOPERATION AGENCY

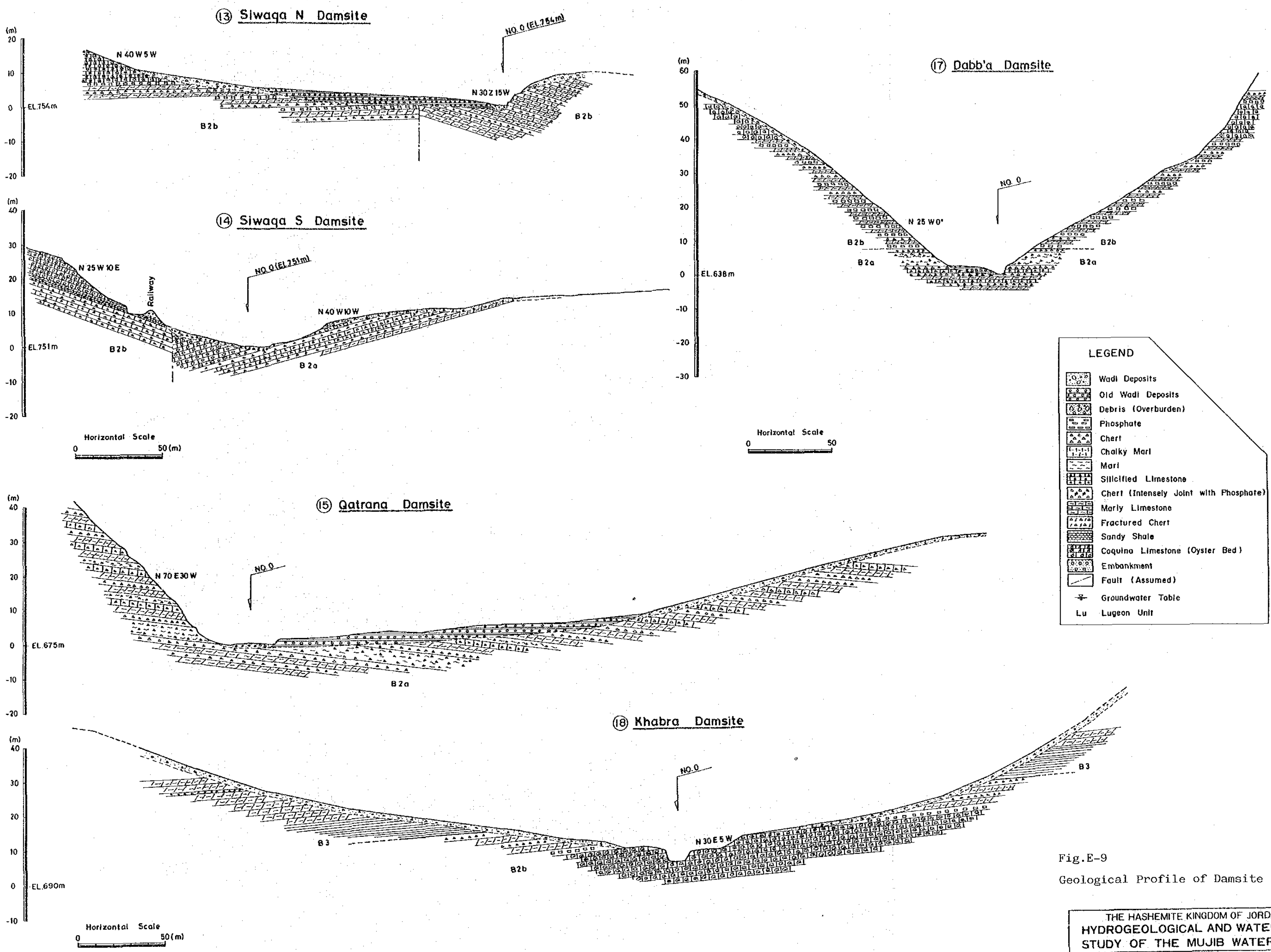


Fig.E-9

Geological Profile of Damsite (5/5)

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

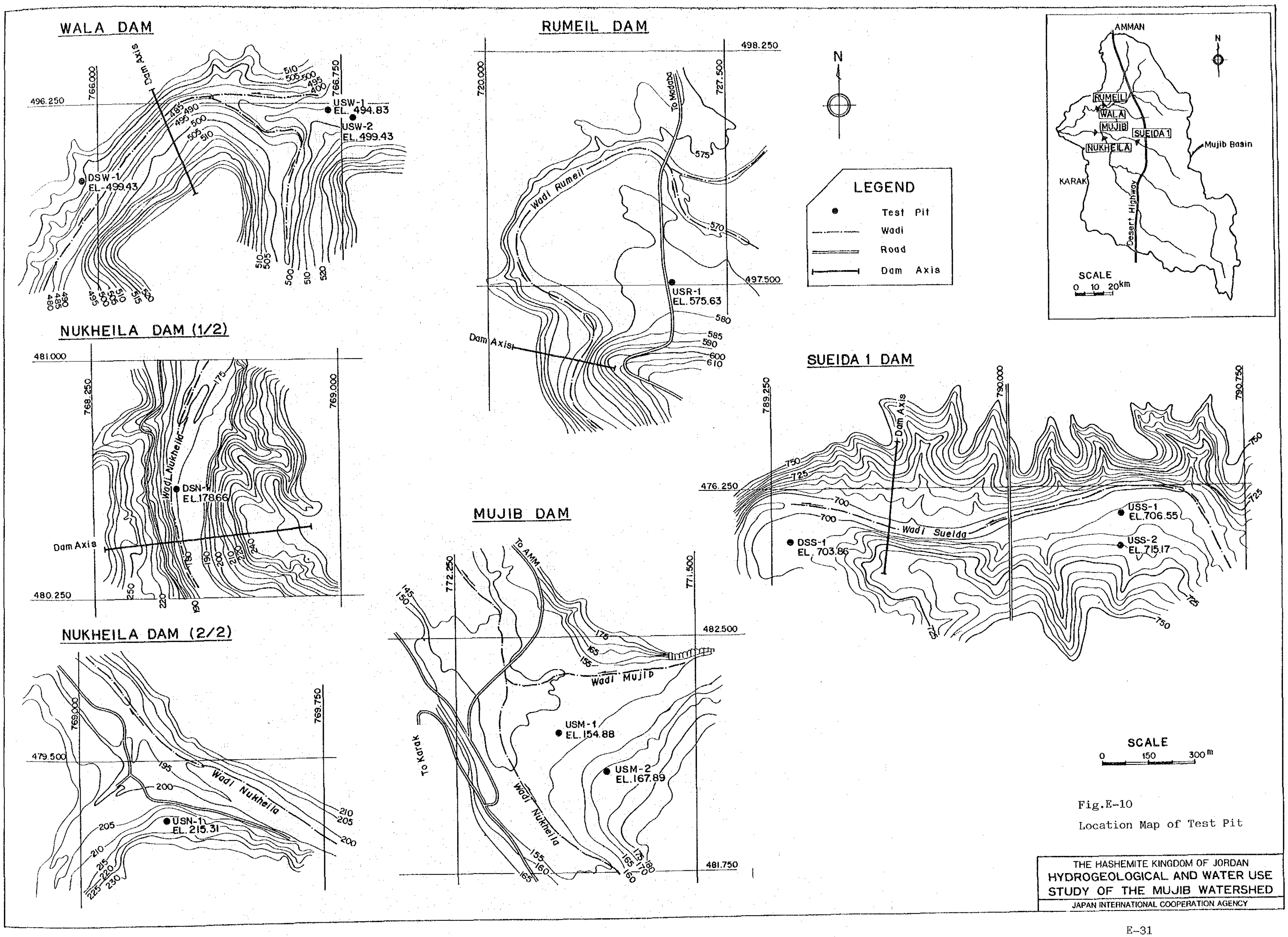


Fig.E-10

Location Map of Test Pit

TEST PIT No. 1

USW-1

Depth : 3 m

Date : From July 4 to July 5, 1986

Location : Upstream (US)

WALA DAM SITE

DEPTH (m)	SYMBOL	SAMPLES	DESCRIPTION OF MATERIAL	WATER CONTENT (%)	liquid limit (%)	Plastic Limit (%)	Plasticity Index(%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification
1			Brownish soil, very stiff to hard with gravels of limestone and chert	11	44.9	22.4	22.5	2.68		95	CL
2			- below 2.9m boulders of grey chert highly weathered CHERT, to of bedrock	6	33.0	22.2	10.8	2.73	2.39	38	SC
3				6	50.0	25.3	24.7	2.67	2.43	18	GC

TEST PIT No. 2

USW-2

Depth : 1.8 m

Date : July 8, 1986

Location : Upstream (US)

WALA DAM SITE

DEPTH (m)	SYMBOL	SAMPLE	DESCRIPTION OF MATERIAL	WATER CONTENT	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification
1			Brown soil, very stiff with gravels and cobbles of limestone	12	39.2	24.4	14.8	2.64	2.46	64	CL
2			Whitish CHALKY LIMESTONE								

Fig.E-11 Summary of Test Pit (1/6)

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

T E S T   P I T   No. 3

DSW-1

Depth : 5 m

Date : From July 6 to July 8, 1986

Location : Downstream (DS)

WALA DAM SITE

DEPTH (m)	SYMBOL	SAMPLES	DESCRIPTION OF MATERIAL	WATER CONTENT (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index(%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification
1			Brown soil, very stiff to hard with gravels and cobbles of chert and limestone	8.1	38.8	24.1	14.7	2.72	2.45	27	GC
2				9.8	36.8	20.9	15.9	2.72	2.38	39	CL
3				14.4	38.5	22.2	16.3	2.72	2.45	68	CL
4				10.1	40.4	19.9	20.5	2.73	2.38	37	SC
5				9.8	42.0	20.6	21.4	2.68	2.48	41	SC

T E S T   P I T   No. 4

USR-1

Depth : 5 m

Date : From July 14 to July 17, 1986

Location : Upstream (US)

RUMEIL DAM SITE

DEPTH (m)	SYMBOL	SAMPLE	DESCRIPTION OF MATERIAL	WATER CONTENT	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification
1			Brown to yellow soil of silty clay stiff to very stiff with white inclusions of chalky marl	14.2	37.5	22.5	15.0	2.71		97	CL
2				13.6	38.4	21.6	16.8	2.73		97	CL
3				16.4	34.3	19.4	14.9	2.73		94	CL
4				18.0	32.7	20.6	12.1	2.73		98	CL
5				12.8	37.3	20.3	17.0	2.72		96	CL

Fig.E-12 Summary of Test Pit (2/6)

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

TEST PIT No. 5

Depth : 5 m USM-1

Location : Upstream (US)

Date : From June 17, 1986 to June 19, 1986

MUJIB DAM SITE

DEPTH (m)	SYMBOL	SAMPLES	DESCRIPTION OF MATERIAL	WATER CONTENT (%)	liquid limit (%)	Plastic Limit (%)	Plasticity Index(%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification
1			Light brown soil of SILTY CLAY, very stiff with gravels	10.9	27.3	21.1	6.2	2.72		79	CL.ML
2			Cobbles, pebbles and gravels of limestone, chert and basalt	12.4	32.8	22.1	10.7	2.72	24.8	18	GC
3			Brownish soil of SILTY CLAY, stiff to medium stiff	18.1	30.8	21.4	9.4	2.74		96	CL
4				11.1	36.5	21.1	15.4	2.73		96	CL
5				19.9	35.3	22.1	13.2	2.73		79	CL

TEST PIT No. 6

Depth : 2.3 m USM-2

Location : Upstream (US)

Date : From June 21, 1986 to June 23, 1986

MUJIB DAM SITE

DEPTH (m)	SYMBOL	SAMPLE	DESCRIPTION OF MATERIAL	WATER CONTENT	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification
1			Gravels and boulders of limestone and chert with brown soil	9.0	23.2	20.8	2.4	2.7	2.5	5	GC
2			- boulders size increase with depth	7.6	22.5	N.P.		2.7	2.4	1	GP

Fig.E-13 Summary of Test Pit (3/6)

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

TEST PIT No. 7

USN-1

Depth : 5 m — Location : Upstream (US)

Date : From June 1, 1986 to June 11, 1986 — NUKHEILA DAM SITE

DEPTH (m)	SYMBOL	SAMPLES	DESCRIPTION OF MATERIAL	WATER CONTENT (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index(%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification
1			Brownish soil of SILTY CLAY, hard with gravels of limestone, chert and basalt	8.9	40.1	26.4	13.7	2.72	2.49	60	ML
2			Brownish to yellow soil of CLAY, hard with inclusions of chalky marl	10.9	35.9	20.6	15.3	2.72		92	CL
3				7.8	25.6	22.4	3.2	2.72		60	ML
4			Brownish to grey soil of CLAY, hard	12.5	30.8	19.8	11.0	2.72		84	CL
5				8.6	26.7	18.1	8.6	2.69		50	SC.SM

TEST PIT No. 8

DSN-1

Depth : 2.8 m — Location : Downstream (DS)

Date : From June 11, 1986 to June 16, 1986 — NUKHEILA DAM SITE

DEPTH (m)	SYMBOL	SAMPLE	DESCRIPTION OF MATERIAL	WATER CONTENT	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification
1			Gravels of basalt, limestone and chert with brown silty clay	11.0	41.3	20.6	20.7	2.72	2.50	63	CL
2			Brownish soil of CILTY CLAY, hard with gravels of basalt, limestone and chert	12.3	37.4	19.9	17.5	2.69		75	CL
3			Gravels and boulders of basalt, limestone and chert with silty clay	8.6	35.8	23.5	12.3	2.69	2.53	22	GC

Fig.E-14 Summary of Test Pit (4/6)

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

T E S T P I T No. 9

USS-1

Depth : 1 m

Location : Upstream (US)

Date : August 5, 1986

SUEIDA DAM SITE

DEPTH (m)	SYMBOL	SAMPLES	DESCRIPTION OF MATERIAL	WATER CONTENT (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index(%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification
1			Brownish SILTY CLAY, with gravels and cobbles of chert and crust	9.4	52.5	34.3	18.2	2.59	2.42	33	SM
			Rock (CHERT) depth from surface between 0.7m to 1m								

T E S T P I T No. 10

USS-2

Depth : 4 m

Location : Upstream (US)

Date : From August 5 to August 7, 1986

SUEIDA DAM SITE

DEPTH (m)	SYMBOL	SAMPLE	DESCRIPTION OF MATERIAL	WATER CONTENT	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification
			Light brown SILTY CLAY, stiff								
1			Gravels and cobbles of chert	4.6	25.3	18.6	6.7	2.64	2.51	20	SC.SM
2			(boulders of light fossiliferous limestone at 2.15m to 2.5m)	2.7	21.0	17.4	3.6	2.61	2.46	4	GC.GM
3			Light brown SILTY CLAY, stiff	6.5	24.2	19.9	4.3	2.65	2.44	24	SC.SM
4			Gravels and cobbles of chert	3.5	23.6	17.6	6.0	2.65	2.48	12	SC.SM
			Rock (depth varies from 3.7m to 4m)								

Fig.E-15 Summary of Test Pit (5/6)

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

TEST PIT No. 11

Depth : 2.1 m DSS-1 Location : Downstream (DS)
Date : From August 21 to August 23, 1986 SUEIDA DAM SITE

DEPTH (m)	SYMBOL	SAMPLES	DESCRIPTION OF MATERIAL	WATER CONTENT (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index(%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification
1			Light brown clayey silt, very stiff with inclusions of chalky marl	14	55.4	35.3	20.1	2.73	2.50	46	SM
2			As above, with gravels of chert and boulders below 1.6m depth	14	49.0	27.2	21.8	2.76	2.50	67	CL
			Rock / or big boulders								

TEST PIT No.___

Depth : _____m Location :

Date :

DEPTH (m)	SYMBOL	SAMPLE	DESCRIPTION OF MATERIAL	WATER CONTENT	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Specific Gravity(1)	Specific Gravity(2)	No. 200%	Unified Classification

Fig.E-16 Summary of Test Pit (6/6)

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

APPENDIX F

DAM PLANNING

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

The surface water resources of the basin of Wadi Mujib consist of the base flow and the flood flow. The base flow is perennial flow which is mostly dependent on the shallow aquifers seen only on the lower most reaches in the basin, and the discharge, approximately $1.1m^3/s$ is small but it is almost constant.

The flood flow which is only observed in the rainy season from November through April has a total discharge of 65 MCM/y on average. It is extremely small compared with the size of the basin ($6,750km^2$). Majority of surface flow, both base and flood flow, are discharged to the Dead Sea without being used. Considering the limited availability of water in the Hashemite Kingdom of Jordan, together with a viewpoint that water resources are essential to attain national socio-economical goals, the potential of the surface water resources development of the Mujib basin is examined and the maximum available development plan by dams is studied in the master plan level in this Study.

The Study Area, the Mujib watershed shown in Fig. F-1 includes Wadi Wala (catchment area: $2,050km^2$) and Wadi Mujib river system (catchment area: $4,700km^2$) which join at a point approximately 2.5km from the Dead Sea. There are many tributaries of Wadi Wala and Wadi Mujib originating on highland, ranging from 700m to 800m in elevation, and various conceivable dam sites. Although various dam planning to meet the full utilization of available and reliable surface flow by means of direct storing and recharging the ground water or the base flow can be imagined, the most desirable dam planning, including the site, scale, type, design of the dams, should be established from the technical and economical point of view.

For the above purpose, an examination is made for selection of the most effective and advantageous dam sites, preliminary design and cost evaluation of the selected dam plan, etc. This Appendix F presents the datails of the above examination.

2. POSSIBLE DAM SITES

2.1 General

For the purpose of the selection of advantageous dam sites for the maximum use of the surface water, the evaluation of all conceivable dam sites in the Study Area was carried out.

The basic purpose of the planning works of the dams is to contribute in meeting water demands such as;

- recharging of groundwater or base flow to reinforce the water source of the municipal water supply, and

- storage for irrigation water or any purpose

which include the compensation of the reduction of baseflow due to the future plans such as the water supply by pumping up of base flows at the lower reaches in Wadi Heidan and ground water development in all the Study Area.

Based on the evaluation for the above purpose, the dam sites, which are possible to make maximum use of the valuable surface flow and also advantageous economically and engineering technically, are tried to be selected.

The examination of conceivable dam sites in the Study Area, i.e. screening them through a rough evaluation of the topographic, geological and hydrologic conditions, detailed evaluation and final selection of dam sites, etc. are detailed in the succeeding sections.

2.2 Conceivable Dam Sites in the Study Area

The basin of Wadi Mujib, the Study Area, is located to the south of the capital city Amman. Wadi Mujib river system consists of Wadi Wala (catchment area: 2,050km^2) and Wadi Mujib (catchment area: 4,700km^2) which join at a point approximately 2.5km from the Dead Sea. All the tributaries of Wadi Mujib originate on highland, ranging from 700m to 800m in elevation. These tributaries flow down, joining one after another with comparatively gentle slopes on the highland, and with steep slopes in the middle and lower reaches through canyons and gorges. Elevation of the estuary is 399m below sea level as of 1985.

The basin belongs to the semi-arid area. Yearly precipitation varies from 350mm in the north western corner to 50mm or less in the south-eastern corner, and about one half of the basin receives only less than 150mm. Upper and middle reaches of most of the tributaries are dry in the dry season, but carry flood discharge in the rainy season from November through April.

Estimated averages for annual flood run-off are 29 MCM and 36 MCM at Wadi Wala and Wadi Mujib respectively.

Perennial base flow which is mainly dependent on the aquifer systems of B2/A7 (Ajlun and Balqa group) and K (Kurnub group), is seen only on the lower most reaches, ranging from 350m (B2/A7) to 0m (K) in elevation. The annual discharge from each aquifer system is comparatively constant and estimated at approximately 25 MCM (Wadi Wala), 10 MCM (Wadi Mujib) respectively, and giving a total 35 MCM at downstream of the confluence.

Firstly, all of the conceivable proposed dam sites are selected solely in view of the relatively favourable topographic condition for dam construction and reasonable storage capacity to be obtained from there on the general topographic maps on 1/50,000 scale, as shown in Fig. F-1.

These conceivable sites amount finally to 20 which include the dam sites proposed before, such as, the Rumeil, Nukheila and Sadir sites, as well as the existing Qatrana and Sultani dam sites as follows:

Wadi Wala basin	1.	Wala dam
	2.	Rumeil dam
	3.	Zeinab dam
	4.	Halq dam
	5.	Hammam dam
	6.	Sadir dam
	7.	Shabik dam
Wadi Mujib basin	8.	Mujib dam
	9.	Nukheila dam
	10.	Sueida 2 dam
	11.	Sueida 1 dam
	12.	Siwaqa C dam
	13.	Siwaqa N dam
	14.	Siwaqa S dam
Siwaqa S dam		
	15.	Qatrana dam
	16.	Qatrana (Exist.) dam
	17.	Dabb'a dam
	18.	Khabra dam
	19.	Sultani dam
	20.	Sultani (Exist.) dam

Appropriate dam sites are not available along the lower reaches of Wadi Mujib in the area wastwards of Kings Highway.

2.3 Screening of Dam Sites

Following the above selection of the conceivable dam sites in the Study Area, screening of these dam sites is made on the following considerations;

(1) Geological and Hydrogeological Condition

As mentioned in Appendix E in detail, most of the above conceivable dam sites are located in the limestone terrain.

In general, the reservoirs in limestone terrain are classified by function as;

- storage reservoirs
- flood-control reservoirs
- infiltration reservoirs (percolation ponds)

A storage reservoir holds water for future use and the loss of water must be kept within acceptable limits.

A flood-control reservoir temporarily stores flood water, and reservoir water losses are not important if the reservoir parts are not endangered and if the increased flow of formation of seeps and springs is tolerable.

An infiltration reservoir leaks the stored water to the ground-water system and seepage is encouraged up to the point of not endangering the reservoir parts.

Furthermore, reservoirs may be classified hydrologically into three major categories as shown in Fig. F-2, which are;

- perched reservoir
- semi-perched reservoir
- confined reservoir

This classification is very basic, and any given reservoir may incorporate more than one type and grade from one to another because of the geology, hydrology and topography of the reservoir area. The floor of a perched reservoir is located at some distance above the original groundwater table. The water-holding capability of the reservoir depends upon the reservoir floor and rim being impervious or the permeability of the bed rock and surficial deposits beneath the reservoir being low enough to enable a groundwater mound to build up beneath the reservoir.

The amount of seepage from the reservoir necessary to build and maintain the groundwater mound must be evaluated as a water loss. This reservoir condition is common in Karstic area, and all selected conceivable reservoirs except Nukheila and Mujib in the Study Area seem to belong to this classification.

The floor of a semi-perched reservoir is located adjacent to the original groundwater table. The groundwater table may slope gently away from or toward the valley. Again like the perched reservoir the water-holding capability of this type of reservoir depends upon the reservoir floor and rim to impede the flow of water away from the reservoir. Nukheila and Mujib reservoirs may belong to this type.

A confined reservoir is a reservoir located entirely within a depression of the groundwater table, except in the vicinity of the valley barrier. The original groundwater table rises above the reservoir rim and provides a natural hydrologic barrier to the movement of the impounded water away from the reservoir. This type of reservoir is the most suitable type to store water, but in the Study Area, it is limited to the lowest reaches of Wadi Mujib where no suitable dam sites are found due to the topographic condition.

The groundwater level and the river bed level at each dam site is shown in Table F-1.

The conceivable 20 dam sites in the Study Area are located in the limestone terrain where the representative geological unit are such as B2, B1 and A3 formation. Among them, large Lugeon unit, 40 to 100 or more of silicified limestone sub-unit (B2a formation) and the phosphorite limestone sub-unit (B2b formation) is due to rich and irregular distribution of joints and kartification in the limestones and not favourable for the year-round storage by the normal treatment of dam foundation and reservoirs.

From the view-point of above geologic and hydrologic conditions in consideration of functions, 20 conceivable dam sites are ranked as follows;

Rank	Dam Name	Gological condi- tionoffoundation & reservoir	Estimated infiltration (mm/day/m/km^2)	Remarks
A	Hammam, Sadir Qatrana (Exist.)	covered by thick impervious strata	Negligible	Perched Reservoir
B	Mujib, Nukheila	A3 formation	0.5	Semi-perched Reservoir
C	Khabra Siwaqa C, Siwaqa N, Siwaqa S, Sultani, Sultani (Exist.)	B2b formation	1.0	Perched Reservoir
D	*Wala, Rumeil, Zeinab, Halq, Shabik, *Sueida 2, Sueida 1, Qatrana, Dabb'a	B2a formation	>5.0	Perched Reservoir *Shallow ground-water table

Among the above ranks, D rank dam sites except Wala and Sueida 2 are sieved out because that the infiltration (percolation) is too big and the infiltrated water seem to be of little advantageous to the aquifer systems or the base flow because the ground water table is very deep, at 100m. Also in case of D rank dam construction, the special treatment of dam foundation and reservoir will be necessary and costly to store the flood flow effectively.

However, only Wala and Sueida 2 dam sites are located in the condition of shallow groundwater table such as 10m and the leaked water from both reservoirs will join the groundwater system resulting in increasing the base flow at the lower reaches of Wadi Mujib. Hence, Wala and Sueida 2 dam sites are reconsidered.

From the view of the stability of dam and reservoir, unstable thick debris, which overlies the A3-6 formation are widespread along the toe of both banks at the dam site of Mujib and at the left bank of Nukheila. These unconsolidated loose sediments are to be removed to settle the slope stability. Especially the rim and abutment portions of Mujib dam site are covered by huge amount of this unstable debris and show some traces of land sliding.

From the above geological conditions, the dam site of Mujib is screened out and the height of Nukheila dam shall be examined carefully for the future study.

(2) Hydrological Condition (flood runoff)

The Study Area is located in the semi-arid area where yearly precipitation varies from only 350mm in the north-western corner to 50mm or less in the south-eastern corner, and about one half of the basin receives only less than 150mm. Only flood run-off are discharged to all the conceivable reservoirs, and no base flow discharg occurs. As shown in Table F-1, the most frequent flood runoff of Sadir, Shabik, Siwaqa N, Siwaqa S, Siwaqa C, Sueida 2, and Sueida 1 are each less than 1.5 MCM/y due to the limited precipitation and limited catchment area, and it seems that the available potential water by the construction of the above dams is estimated to be less than 0.7 MCM/y respectively due to the high evaporation and percolation losses. So the above 6 dam sites except Siwaqa C are sieved out by the reason of the above hydrological conditions.

Siwaqa C dam site, out of the above dam sites which were classified as small flood runoff reservoirs, still remains because this reservoir is located on the most favourable situation for recharging of Siwaqa well field even though the annual inflow and effective water for recharge are comparatively small, about 1.3 MCM and 0.6 MCM respectively. Further study is required.

(3) Socio-economic Problems to Submergence

Once a dam is constructed, the land in the prospective reservoir area is submerged and the existing and future land use and social activities will be affected accordingly. Anticipated issues of the prospective reservoir are as follows;

Rumeil reservoir:	Private farm land (1.7km^2) and private wells (3 Nos.)
Halq reservoir:	Desert Highway and bridge (retention level: El. 670.5m)
Siwaqa C reservoir:	Wells of WAJ (2 Nos.)
Dabb'a reservoir:	Highway (Qatrana-Karak) and bridge (retention level: El. 657.1m)
Sueida 1 reservoir:	Wells of WAJ (2 Nos.)
Siwaqa S reservoir:	Railway (retention level: El. 761.5m)
Qatrana reservoir:	Desert Highway and bridge (retention level: El. 768.6m)
Sultani reservoir:	Factory and houses

(4) Utilization of Surface Water

From the view point of the purpose and functions of dam construction in the Study Area, all the conceivable reservoirs have common purposes of flood-control, storage water for the municipal use and irrigation, and recharging the existing and proposed well field for the municipal water supply and irrigation.

The favourable reservoir sites for the above purpose and functions are picked up in accordance with the study results of hydrogeology, location and land conditions as follows;

For the irrigation purpose	:	Zeinab, Sadir Wala, Rumeil Hammam, Qatrana (Exist.)
For the recharging of well field and base flow	:	Siwaqa C, Sueida 1 Qatrana (Exist.) Sultani (Exist.) Rumeil, Wala Nukheila, Sultani
For the municipal and industrial water supply	:	Khabra, Nukheila Wala, Rumeil

Finally, based on the above all synthetic studies, 13 dams are seived out and the following 7 dams are picked up as the promising surface water development schemes;

1. Wala dam
2. Hammam dam
3. Siwaqa C dam
4. Khabra dam
5. Nukheila dam
6. Qatrana (Exist.) dam
7. Sultani (Exist.) dam

Among the seived out dams, the Zeinab site will be the most favourable and attractive plan for the highland irrigation in view of the hydrologic and land conditions. However, the geology of the B2a formation composed of alternating silicified limestone, chert and chalky marl with frequent joints, cracks and caves, is too highly pervious to store the flood flow effectively by the ordinary foundation and reservoir treatment, so this site is screened out in this stage.

If the relationship between the percolated water and the groundwater system or the base flow could be clearer, this scheme has a chance to be reconsidered because this scheme will be very attractive with the combination of Wala dam scheme so that the flood flow could be used more effectively.

3. CONSIDERATION FOR PRELIMINARY PLANNING OF DAMS

In the preceding Chapter of "Possible Dam Sites," it is found that the seven dam sites of Wala, Hammam, Siwaqa C, Nukheila, Khabra, Qatrana existing and Sultani existing sites have the possibility to be developed with the suitable and beneficial combination for the maximum use of flood flow in the Study Area.

In order to evaluate a definite development plan of the dams at the above dam sites, the study of the available water and the possible scale of each dam is made.

The study is based on the topographic maps in the proposed reservoir area with 1/7,500 and 1/15,000 scale using areal photographs, which are used for measuring reservoir area and water storage capacity as shown in Fig. F-3 to Fig. F-5 and Table F-3 to F-5.

The site topographic and geological conditions as well as percolation parameters of the proposed dam sites and reservoirs are examined by the site geological reconnaissance, dam boring and the profile survey, which are summarized in Fig. E-4 to Fig. E-9 of Appendix E "Engineering Geology".

The monthly flood inflow to the proposed dam sites is estimated by using the rainfall and discharge records observed in the Study Area for 26 years from 1960 to 1985. The evaporation loss from the reservoirs and sediment are also examined in detail in Appendix B "Hydrology".

For the planning of dams, the definition of the reservoir water level and storage capacity applied to the study is shown in Fig. F-6 and as follows;

Normal high water level: To determine the scale of each dam, the most frequent annual flood runoff (annual runoff of 2 year return period) is selected as the effective storage capacity tentatively to use the flood runoff more favourably.

The spillway with a non-gated overflow weir is adopted due to the safety and easiness of flood control, and the normal high water level (NHWL El.) corresponds to the crest elevation of a spillway overflow weir.

Low water level: The low water level is determined on the basis that the dead storage capacity corresponds to the horizontal sedimentation within 50 years. The annual average sediment in the project area is assumed to be as much as 1.0% of the trapped water.

Maximum water level and dam crest elevation: Dam crest elevation corresponds to the crest elevation of the impervious zone tentatively. Furthermore, the dam crest elevation is designed as 3m and 5m above NHWL in case of the flood peak discharge of less and more than 1,000 m^3/sec (200 year return period) respectively. The spillway design is made so that the flood flow is discharged within the maximum water level (MWL), about 1m below the crest elevation.

As for the type of dam, the following filltype and concrete dams are considered;

Type A: Rockfill with thin center core
Type B: Zoned rolled-fill (with thick center core)
Type C: Homogeneous earthfill
Type D: Rockfill with surface membrane
Type E: Concrete gravity

Typical sections for the above 5 types of dams are shown in Fig. F-7. The Type A with dam height over 30m and Type B with dam height less than 30m are adopted tentatively for this planning study because the topographic and geological conditions are technically better suited, and other types would be more costly than these two types. Furthermore, the construction materials such as rocks and the impervious materials can easily be obtained within the economic distance around the prospective sites. The concrete dam type, i.e., the normal concrete gravity dam and the rolled concrete dam are considered. However, the total construction cost is higher than that of the filltype dam because the huge excavation works for the dam foundation is required even if considering the spillway and diversion works to be easy and not costly. Also the fly ash which is needed for the rolled concrete dam is not produced in Jordan, so the rolled conrete dam is not preferable.

Jordan has ample experiences in the construction of rockfill dams from the 1960's as shown in Table F-2, and Fig. F-8. These existing dams, especially such dams constructed recently and relatively in large scale, i.e., the King Talal dam, Wadi Arab and Kaldia dam will indicate the advantage of the filltype dam in the condition of the limestone terrain in Jordan. Furthermore, these existing dams suggest the many design parameters of the filltype dam such as the slope of dam, the foundation treatment and the availability of construction materials in the master plan level.

The water operation trial studies of 7 picked up dam schemes including existing dams of Qatrana and Sultani are carried out to determine the direction and strategy of surface water use over the whole Mujib basin as well as to estimate the available surface water resources, using the hydrology data. i.e., the flood runoff, evaporation and percolation, which are detailed in the Appendix B "Hydrology".

In order to design the spillway roughly, the peak discharge of 200-year return flood is adopted, which is very large in comparison with the annual average flood runoff, as shown below;

Dam site	Catchment area (km^2)	Average of annual runoff (MCM)	200-year flood peak discharge (m^3/s)
Hammam	340	2.15	620
Wala	1,770	21.52	1,550
Siwaqa C	440	1.32	525
Khabra	290	9.01	490
Nukheila	3,560	26.15	2,250
Qatrana	1,490	4.96	630

All above examination results are presented in the next Chapter and summarized in Table F-6.

4. PROPOSED DAMS

4.1 Wala Dam

4.1.1 Topography and geology

The damsite is located on the Wadi Wala, about 4km upstream from the Wala bridge where Kings highway cross the lower reaches of Wadi Wala. The left abutment rises at a uniform slope of 5-10 degrees from the bottom of the wadi to the top of the hill, while the right abutment rises steeply with a uniform slope of 35 to 45 degrees. No base flow is recorded throughout the year.

The left abutment is covered with thick unconsolidated loose sediment of debris of which thickness is estimated at about 15m. The B2a formation, which is composed of alternating silicified limestone, chert and chalky marl, outcrops extensively along the steep cliff of the right abutment. The bed strikes N80W and dips 10N. The chert layers are fractured with some open cracks. Alluvial river deposit of gravel and sand, widely covers the wadi with a thickness of about 13m. The B1 formation, which is composed of marls with less permeability of 1 to 3 Lugeon values, is located at the depth of 15m in the borehole BW-2. The B2a formation, which is considered to be a very pervious layer, outcrops intensively in the reservoir rims. Close attention will have to be paid to the probable high water leakage through the B2a formation which outcrops both at the damsite and on the reservoir rims.

Impounded water behind the dam will mostly leak from the reservoir area and the dam foundation through the lower part of the A and B2a formation, of which the percolation estimated roughly 5 $mm/day/m/km_2$ or more. However, there is the impervious B2 formation lying underneath the B2a formation. The upper portion of the base flow of the Wadi Wala is fed by the groundwater which flows on this B2 formation. Hence, the leaked water from the proposed Wala reservoir will join this groundwater flow exactly resulting in increasing the base flow.

4.1.2 Selection of dam type

The foundation rock consists of mainly silicified limestone of which shearing strength is favorable and under such condition of the foundation, both a concrete dam and a filltype dam of considerable size will be technically possible. However, alluvial river deposits and loose sediment of debris on the left bank reaches to 15m in depth which requires the huge excavation works for the fresh rocks. The necessary materials of the filltype dam are available from the quarry rock of the massive limestone and from the borrow of the diluvial terrace deposits around the dam site. The total construction cost is compared roughly for a filltype dam and a concrete gravity dam by estimating the dam volume in the typical type respectively, which are 92.0 x $10^4 m^3$ and 27.5 x $10^4 m^3$, so it is obvious that a concrete gravity dam is more costly than a filltype dam. Therefore, a standard zoned rockfill dam with the center core which was adopted for the King Talal and Wadi Arab dams is selected as a type of the dam to be constructed at the Wala dam site.

4.1.3 Preliminary design of the dam

The preliminary design established is given in Fig. F-9. The principal features of the proposed Wala dam are as follows,

A. Reservoir

Catchment area:	1,770 km^2
Annual average inflow:	21.52MCM
Most frequent annual inflow (2-year return):	19.31MCM
Normal high water level:	El. 534.0m
Low water level:	El. 519.0m
Reservoir area:	2.25 km^2

B. Dam

Dam type:	Zoned rockfill type with center core
Crest level:	El. 539.0m
Dam height:	55m from river bed level (El.484.0m)

Dam slope:	upstream 1:2.5
	downstream 1:2.3
Dam volume:	$920 \times 10^3 m^3$
Effective storage:	19.3 MCM excluding flood control volume.
Dead storage (Sediment volume):	9.65 MCM
Core trench depth:	15m maximum

C. Spillway

Design flood:	$1,550 m^3/sec$
Type:	Non-gated side overflow type
Overflow crest length:	120m
Overflow crest level:	El. 534.0m

Furthermore, the diversion tunnel which is considered also as a water supply tunnel is designed roughly.

In accordance with the sumilation of reservoir operation, the volume of percolated water is estimated to be 16.9 MCM/y. As considered in the preceding Chapter and Appendix C "Hydrogeology", this percolated water will increase the groundwater potential in Heidan basin by 11 MCM/y, which is composed of recharging to the shallow aquirifer of B2a and to the deep aquifer of A7, and remaining water will increase the surface water during the rainy season. Therefore, this Wala dam scheme is proposed for the municipal water supply purpose by pumping up of the groundwater or the base flow, and for the irrigation purpose.

For the purpose of developing the flood flow at the middle reaches of the Wadi Wala, two dam sites are envisaged; one is the Rumeil site which had been proposed before and the other the Wala site which is proposed in this Study. Of them, the latter is preferable to the former for the reasons that;

(i) Available storage capacity is much the same,

(ii) Storage efficiency of the Rumeil site is much better. But there are existing three wells and 170ha of vegetable farms irrigated by the well water which could be inundated by the dam, whereas, there is none of such existing facilities in the Wala reservoir area.

(iii) Available regulated flow of the Wala site is a little larger than that of the Rumeil site because of the size of catchment area.

(iv) Percolated water capacity from the reservoir is much the same, but percolated water from Wala site seem to be exactly and easily used to the demand than Rumeil site, because the former is located near to the demand area. Further detailed studies on feasibility study level will be recommended to this Wala dam scheme as soon as possible.

4.2 Hammam Dam

4.2.1 Topography and geology

The damsite is located on the Wadi Hammam, which is a major tributary of Wadi Wala, and located about 10 km south-east from the Alia International Airport. This damsite is located in the flat wadi with a gentle slope of 5 to 10 degrees. No baseflow is recorded throughout the year.

The whole area including the damsite and the reservoir is covered with thick alluvial to diluvial deposits of about 10m thickness, therefore, no outcrops are found in the area. The diluvial deposit, which is composed of clay and silt including some gravels and pebbles, is considered to be impervious.

4.2.2 Selection of dam type

From the topographic condition, the dam will be very long along the crest being about 2.7km and the embankment volume becomes huge at about 0.7 MCM. The dam height from the river bed level will be only 13m or more. The impervious to semi-pervious materials of alluvial to diluvial deposits are available just near the dam site. As stated in the geological condition, a concrete dam will be technically and economically unsuitable due to insufficient foundation strength or huge excavation volume. Therefore, a filltype dam, especially a homogeneous earthfill type or a zoned rolled-fill with thick center core will have to be selected.

4.2.3 Preliminary design of the dam

The preliminary design established is given in Fig.F-10. The principal features of the proposed Hammam dam are as follows;

A. Reservoir

Catchment area:	$340km^2$
Annual average inflow:	2.15MCM
Most frequent annual inflow (2-year return):	1.91MCM
Normal high water level:	El. 710.0m
Low water level:	El. 707.5m
Reservoir area:	$1.45km^2$

B. Dam

Dam type:	Zoned rolled-fill with thick center core
Crest level:	El. 713.0m
Dam height:	13.0m from river bed level (El. 700.0m)
Dam slope:	upstream ....1:2.8 downstream 1:2.5
Dam volume:	$680 \times 10^3 m^3$

Effective storage:	1.5MCM excluding flood control volume
Dead storage (Sediment volume):	0.75MCM
Core trench depth:	3m maximum

C. Spillway

Design flood:	620 m^3/sec
Type:	Non-gated side overflow type
Overflow crest length:	120m
Overflow crest level:	EL. 710.0m

The diversion works in the construction stage will be possible without the diversion tunnel. The impervious alluvial deposits of about 5m or more in the whole reservoir area will have the sufficient function of the blanket to protect the leakage of the storage water, therefore, no foundation treatment such as grouting work will be required.

The available storage water with 80% reliability is estimated small as only 0.8 MCM/y. By the agricultural study under the present study, efforts were made to find out the areas suited for the highland irrigation farming mainly in view of the topography, soil, land classification and water quality. As a result, the largest block of possible area is found in the northern part of the Mujib watershed centering about Dabah. Selected conceivable dam sites around this area are Zainab, Sadir, Halq, Shabik and Hammam sites. However, every site except Hammam are located on very permeable geology both for dams and reservoirs and they do not suit for the storing purpose of flood inflow, and also the percolated water does not increase groundwater or base flow due to the perched reservoirs where the groundwater level is as deep as 100m or more and due to the large distance from well fields. Only the possibility is left for the Hammam site. By the reason that the available flood flow by the dam construction is very low compared with the construction cost, a carefull study for the irrigation project will be required in future.

4.3 Siwaqa C Dam

4.3.1 Topography and geology

The damsite is located on the upper most reaches of Wadi Sueida, about 0.5km upstream from the Siwaqa bridge where Desert Highway crosses the wadi. The left abutment rises gently with a slope of 5 to 10 degrees, while the right abutment rises rather steeply with a slope of 30 degrees. No baseflow is recorded throughout the year and the groundwater table is located at about 50m below the surface.

The bedrock of both left and right abutments is composed of uniform Coquina bed of the B2b formation with thickness of 20m. The chert layer in the B2a formation which outcrops on the wadi bed is covered with alluvial deposit. The reservoir area is covered with thick diluvial wadi deposit which is considered to be an impervious layer. The reservoir area is located in Siwaqa well field where two excellent deep wells are being used for the water supply to Amman.

4.3.2 Selection of dam type

Both a concrete gravity dam and a filltype dam will technically be possible to be constructed under the condition of the foundation and the following reasons;

i) The foundation base rock consist of hard and strong limestone which have sufficient bearing capacity for construction of a low concrete gravity dam of 15m or more in height.

ii) Alluvial and diluvial soft deposits on the fresh rocks in the dam site are of very minor scale, and therefore, the excavation cost necessary for a concrete dam can be greatly saved.

iii) In the case of a concrete dam, overtopping of dam during construction can be allowed. The spillway structure can be provided in the dam body, making it unnecessary to excavate in the bank for the spillway structure like the fill type dam. Therefore the cost necessary for the river diversion system and the spillway structure can be greatly saved.

On the other hand, the construction materials for a filltype dam such as the rocks and the impervious soils are available from the quarry and the borrow very near to the dam site and the available quantity of them is also sufficient.

In this study, the dam type at the Siwaqa C site is selected conveniently to a standard zoned rockfill dam with the center core, because in addition to the above reason Jordan very ample experiences of the rockfill type dams. Further studies of the dam type will be necessary in the future.

4.3.3 Preliminary design of the dam

The preliminary design established is given in Fig. F-11. The principal features of the proposed Siwaqa C dam are as follows;

A. Reservoir

Catchment area:	440 km^2
Annual average inflow:	1.32 MCM
Most frequent annual inflow (2-year return):	1.10 MCM
Normal high water level:	El.733.5m
Low water level:	El.731.0m
Reservoir area:	0.6 km^2

B. Dam

Dam type:	Zoned rockfill type with center core
Crest level:	El 736.5m
Dam height:	13.5m from river bed level (El.723.0m)
Dam slope:	upstream 1:2.5
	downstream 1:2.3
Dam volume:	28 x 10^3m^3

Effective storage:	1.10 MCM excluding flood control volume
Dead storage (Sediment volume):	0.55 MCM
Core trench depth:	3m maximum

C. Spillway

Design flood:	525 m^3/sec
Type:	Non-gated side overflow type
Overflow crest length:	100m
Overflow crest level:	El.733.5m

As the excavation and embankment volumes are very small, the construction works will be completed during the dry season, therefore no diversion facilities during the construction will be needed.

The leakage from the reservoir floor will be protected by the thick alluvial deposits to a certain degree but the leakage from the reservoir rim and the dam abutment shall be protected by the normal grouting works, etc. The available storage water is estimated only as 0.6 MCM/y with an 80% reliability. This site is located closely to the existing Siwaqa well field from which 7 MCM are extracted for the water supply to Amman.

Therefore, this site is preferable to four alternatives, Siwaqa N and Siwaqa S sites which are having small catchment areas and Sueida 2 and Sueida 1 sites in which the available regulated flows are much the same and geological conditions are not favorable.

4.4 Khabra Dam

4.4.1 Topography and geology

The damsite is located on the Wadi Arbid, which is a tributary of Wadi Dabb'a, and located about 3.5km upstream from the Dabb'a bridge where Qatrana-Karak road crosses the wadi. Both abutments rise with a uniform slope of 10 to 15 degrees. No baseflow is recorded throughout the year and the groundwater table is located at about 100m or less in depth.

The debris cover the whole area except the wadi bed. The wadi bed is composed of Coquina bed of the B2b Formation. The bed strikes N30E and dips 5W. The reservoir area is covered mostly with debris except in some parts of the left abutment where bituminous marl or shale outcrops. Water tightness of the B2b Formation is considered to be rather fair compared with pervious geological unit of the B2a formation.

4.4.2 Selection of dam type

For the same reasons of geologic and topographic conditions and availability of construction materials as the Wala and Siwaqa C dams, a standard zoned rockfill dam with the center core is selected as the dam type at the Khabra site.

4.4.3 Preliminary design of the dam

The preliminary design established is given in Fig. F-12. The principal features of the proposed Khabra are dam as follows;

A. Reservoir

Catchment area:	290 km^2
Annual average inflow:	9.0 MCM
Most frequent annual inflow (2-year return):	6.12 MCM
Normal high water level:	El.713.5m
Low water level:	El.706.0m
Reservoir area:	1.36 km^2

B. Dam

Dam type:	Zoned rockfill type with center core
Crest level:	El. 716.5m
Dam height:	26.5m from river bed level (El.690.0m)

Dam slope:	upstream 1:2.5
	downstream 1:2.3
Dam volume:	290 x $10^3 m^3$
Effective storage:	6.12 MCM excluding flood control volume
Dead storage (Sediment volume):	3.06 MCM
Core trench depth:	3m maximum

C. Spillway

Design flood:	490 m^3/sec
Type:	Non-gated side overflow type
Overflow crest length:	100m
Overflow crest level:	El.713.5m

No diversion facilities during construction will be required because the excavation and embankment volume are comparatively small and the dry season is long.

Because of the covering of the impervious debris on the whole reservoir, this dam site is favorable for the storage purpose. This site is preferable to the Dabb'a site located on the Wadi Dabb'a because the wadi bed and the reservoir area of Dabb'a site are composed of the B2a formation with continuous outcrops which has very pervious layers and not suitable for the storage purpose.

Furthermore, the Dabb'a reservoir is restrained by the existing bridge where Qatrana-Karak road crosses the wadi. The restrained gross reservoir capacity is estimated as only 4 MCM which is smaller than that of Khabra reservoir of about 9 MCM.

Water from the Khabra dam which is estimated by the simulation of reservoir operation as 2.7 MCM/y could supplement a part of the future water requirement of oil shale mining and oil refinery. Otherwise, this water can be used for any purposes like the M & I water on the highlands including Karak, or uses in the further for lower reaches.

4.5 Nukheila Dam

4.5.1 Topography and geology

The damsite is located on the Wadi Nukheila, which is a major tributary of Wadi Mujib, and located 2km upstream from the Mujib bridge where Kings highway crosses the wadi. An almost vertical cliff, approximately 18m in height, is formed at the foot of the left bank slope which shows general inclination of 45 degrees in the upper part. The right abutment rises with a moderate slope of 20 to 25 degrees. Perennial baseflow of about 100 litre per second or less has been measured at the site.

The bedrock of the left abutment is composed of alternating marly limestone and marl of the A3 formation. The upper part of more than 10m of height is covered with 10m thick debris. The right abutment is covered with debris except in the toe of the slope where the A3 formation of alternating limestone and marl outcrops. The bed in the A3 formation strikes N-S and dips 5W. Marly limestone and marl outcrops extensively at the left side of the wadi bed. The right side of the wadi bed is covered with thick diluvial wadi deposit of about 10m in thickness. Successive outcrops of the A3 formation are found in the reservoir rim. The extensive debris on the left slope is thick and unstable. Careful attention will be required to the slope stability on the slope at the left bank where the height from the wadi bed exceeds 40m or more. The marly limestones in the A3 formation is not considered to be a pervious layer, but, high Lugeon values of 70 to 80 have been measured spotly. Substantial water leakage through the A3 formation may not be expected as a whole.

4.5.2 Selection of dam type

In this site it is necessary to consider carefully the water retention height and protection in view of the geology, i.e., the unstable slope on the left bank. Even considering this limit, either a concrete dam or a rockfill dam can be constructed, but the former is preferable to the latter in view of the capacities of the diversion and spillway facilities considering the huge flood peak discharge as 2,250 m^3/sec. On the other hand, for a concrete dam of considerable size such as 60m class in height, the huge excavation works at the river bed and both abutments will be required also in view of geology. In this study, a rockfill type is selected conveniently because Jordan has ample experience of the rockfill dams recently as well as the cost will be on safe side and the cost estimation is easy. Further detailed comparison will be needed to select the dam type in the next feasibility study.

4.5.3 Preliminary design of the dam

The preliminary design established is given in Fig. F-13. The principal features of the proposed Nukheila dam are as follows;

A. Reservoir

Catchment area:	3,560 km^2
Annual average inflow:	26.15 MCM
Most frequent annual inflow: (2-year return period)	20.75 MCM
Normal high water level:	El.235.0m
Low water level:	El.215.0m
Reservoir area:	1.35 km^2

B. Dam

Dam type:	Zoned rockfill type with center core
Crest level:	El.240.0m
Dam height:	61m from river bed level (El.179.0m)
Dam slope:	upstream .... 1:2.5 downstream 1:2.3
Dam volume:	940 x $10^3 m^3$
Effective storage:	20.8 MCM excluding flood control volume

Dead storage (Sediment volume):	10.4 MCM
Core trench depth:	6m maximum

C. Spillway

Design flood:	2,250 m^3/sec
Type:	Non-gated side overflow type
Overflow crest length:	160m
Overflow crest level:	El.235.0m

This reservoir is suited on the rather impervious A3 formation for the storage purpose in the Study Area. By the simulation of reservoir operation, it is estimated that a total of 13.2 MCM/y of which 8.8 MCM/y is the stored water and 4.4 MCM/y is the percolated water is available to increase the base flow in the lower reaches of the Wadi Mujib. For the purpose of developing the flood flow at the middle reaches of the Wadi Mujib, this site is the most favourable site especially for the downstrream irrigation purpose. However, further detailed investigation and study will be needed to select the dam height in view of the unstable slope on the left bank in the next feasibility study.

4.6 Qatrana Existing and Sultani Existing Dams

The conceivable four dams of Qatrana and Sultana area including two existing dams are located on the highland along the Desert Highway. Rivers on which these dams are located drain the desert area where the precipitation is scarce being 100mm a year or less, and the outflow are not rich as compared with the size of catchment areas. However, these sites are located close to the existing well fields which are supplying water for Amman and Karak and extractions of water are made sometimes over the sustained yield. Hence, these dams are proposed to recharge the existing well fields.

4.6.1 Qatrana existing dam

Qatrana existing dam is located on the Wadi Hafira near the Desert Highway draining 1,490 km^2 of catchment area where the precipitation is less than 100mm a year. The dam was constructed in a rather flat valley with a height of 10m for the purpose of the irrigation for forage production, livestock water, and groundwater recharge in 1964, but not used effectively.

The gross capacity of the existing reservoir is about 2 MCM and current silting is not notable. Average inflow is 2.28 MCM/y and the most frequent flood inflow is 1.78 MCM/y.

It is possible to increase the flood outflow by means of drainage improvement works. There is an area with swamp-shaped topography on the upper reaches of the Wadi Hafira. When it rains, water is stagnant over this area, and water which overflows this area only enters the Qatrana (Existing) dam. Such stagnant water causes considerable amount of evaporation losses and partial seepage into the ground which flows towards Azraq.

By the drainage improvement on this swamp-like area, such stagnant water will turn to the direct outflow, and the inflow to the Qatrana (Exist.) reservoir will increase. The increment is estimated provisionally at more than 2 MCM/y. Besides, the dam is located closely to the existing Qatrana well field from which 3.5 MCM/y are extracted for the water supply to Amman.

Then, it is proposed to use this existing dam positively for recharging the existing Qatrana well field. Existing reservoir capacity is not sufficient for the storing purpose of total about 4 MCM/y including the above stagnant water by means of drainage improvement works.

When the most frequent flood runoff of 4.0 MCM/y is injected, then 3.2 MCM/y will become available for extraction in the dry season on an assumption that the recovery factor is 80%. Then seven or more injection wells to cope with increment are required.

Considering the estimated design flood ($630m^3$/sec) and the conditions of reservoir area including the Desert Highway, the principal works of the proposed Qatrana existing dam improvement for the above purpose are as follows;

(1) Dam raising of 3 m in height (From El.770.5m to El.773.5m)
(2) Spillway crest widening of 36 m in length (From 100m to 136m)
(3) Spillway crest raising of 1.25 m in height (From El.767.5m to El.768.75m)
(4) Dike raising works of 2.5 m in height (From El.771.0m to El.773.5m)

Furthermore, at the downstream of the existing filldam body, some leakage phenomena are found, which may be caused by the little animal burrowing or the insufficient embankment work and foundation treatment. Careful examination and protection from burrowing will be required in case of the construction of earthfill type dam in this Study Area.

The new Qatrana dam scheme which is located on the Wadi Qatrana and 2km downstream from the Qatrana existing dam, is an alternative to the above Qatrana existing dam improvement scheme when the storage capacity is not enough to store the additional flood runoff. Therefore this alternative is sieved out because the Qatrana existing dam has the sufficient reservoir capacity by some extention works for this planning.

4.6.2 Sultani existisng dam

Sultani existing dam is located on the Wadi Sultani draining 950 km^2 of catchment area where the precipitation is mostly 100mm or less. The dam was constructed for the same purpose as the Qatrana existing dam in 1964, with a height of about 8m or more. Some outcrops, which consists of the B2b formation, are found at the slope on the right bank and the reservoir area is covered with fluviatile which is composed of silt and clay sediments produced mainly by the mine tail residue by the Abyad phosphate mine located on the upper reaches.

Total storage capacity when the dam was constructed was 1.1 MCM but more than one half of this capacity was filled up by the above residue. The average inflow is 3.12 MCM/y and the most frequent runoff is 2.07 MCM/y. The dam is also located closely to the existing Sultani well field from which 4 MCM/y are extracted and sent to Karak.

It is examined to use the Sultani existing dam as well as the new Sultani dam as an alternative which located about 2km downstream from the Sultani existing dam, for the purpose to recharge the existing well fields.

The new Sultani reservoir has the sufficient storage capacity of 3 MCM or more even though in the condition of the retention dam height for the Desert Highway and the dam site has favorable storage efficiency in view of the topography. However, the proposed reservoir area is occupied by the Sultani village and the industrial factory.

Besides, in the case of Sultani existing dam, for the storing and regulating the flood flow, it is required to restore the original capacity of the reservoir. Then, it is needed to remove the silted material from the reservoir which reaches 0.9 MCM and also to make necessary countermeasures by which the mine tail of the Abyad phosphate mine will not enter the river channel which flows into the reservoir.

When the most frequent flood runoff of some 2 MCM/y is injected in case of new Qatrana dam scheme, some 1.4 MCM/y will become available for extraction in the dry season with an assumed recovery factor of 70%. Besides, in case of Sultani existing dam, when an amount of 1.1 MCM/y after restoring works is injected, only an amount of 0.7 MCM/y will become available with same assumed recovery factor.

Comparing two alternatives, i.e., the Qatrana dam and Sultani existing dam schemes, the former is preferable to the latter if not considering the above socio-economic problems due to submergence. However, it is proposed to use the Qatrana existing dam for recharging purpose to avoid such problems tentatively and conveniently in this stage of the Study. More detailed land use and land acquisition studies will be required for this scheme in the future stage.

4.7 Combination of Dam Plan

Combinations of recommended dam plans such as Hammam-Wala and Khabra-Nukheila are considered for the effective use of water resources. The Hammam plan does not affect the downstream Wala plan because the catchment area and flood flow at the Hammam damsite are quite small compared with those at Wala dam. On the other hand, existence of Khabra dam affect the function of Nukheila Dam because the catchment area of Kabra dam includes mountainous area of western ridge which has a high rainfall. According to the dam operation study, the effective surface water potential of Nukheila Dam with and without Khabra plan are 10.8 MCM/y and 13.2 MCM/y respectively. Of them, about 34% is water infiltrated from dam reservoir which is assumed to reappear along the downstream reaches.