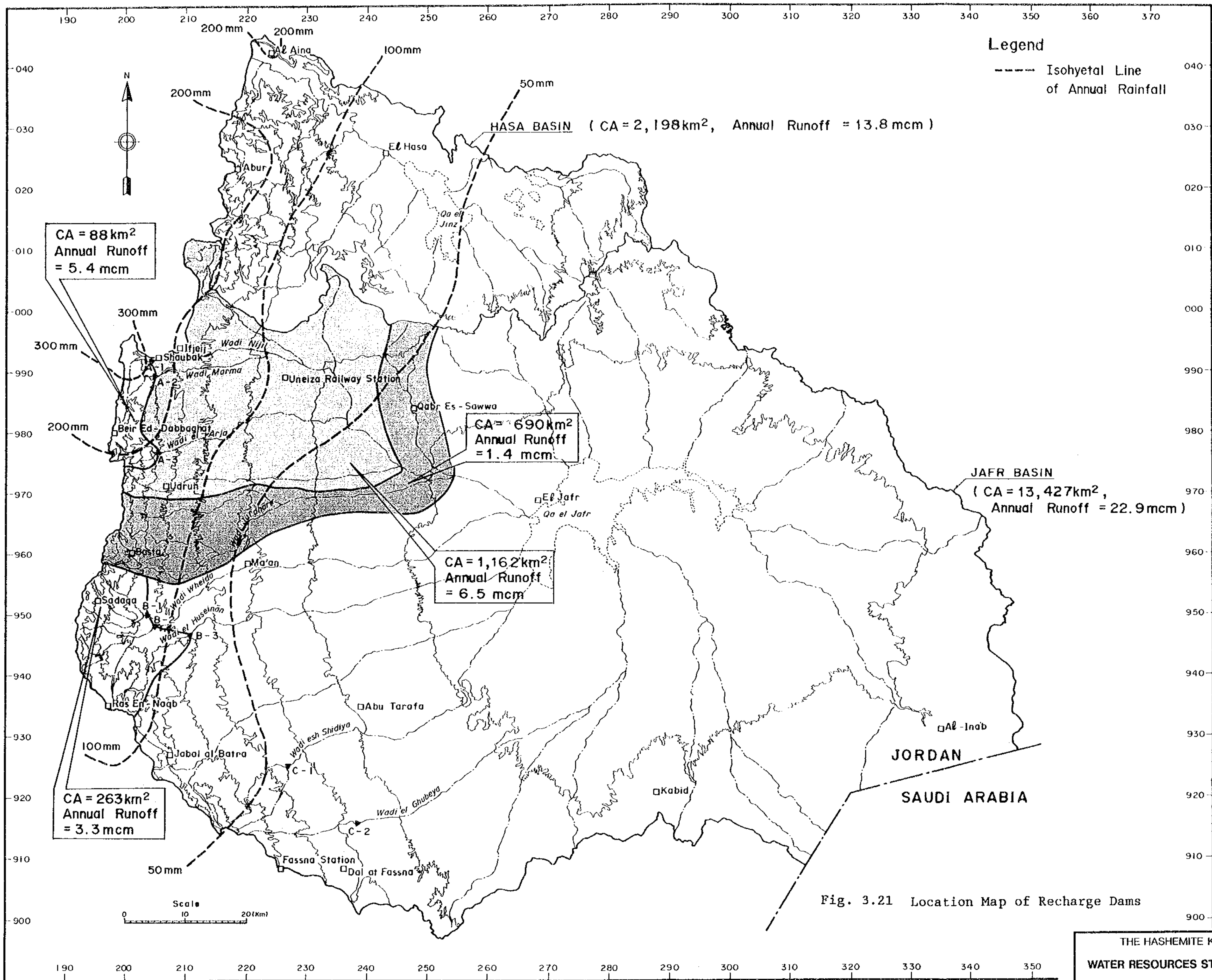

Fig. 3.21 Location Map of Recharge Dams

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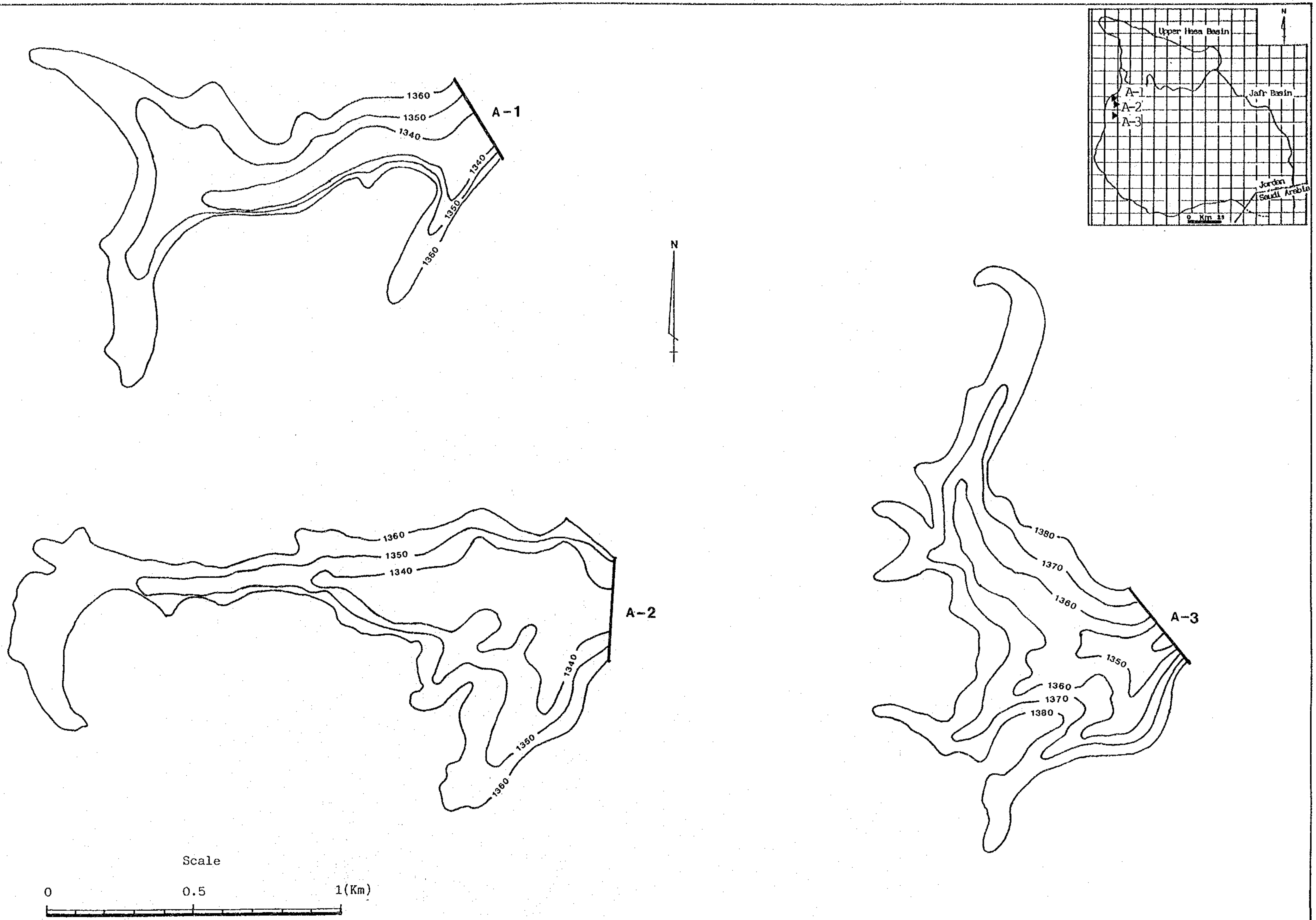

Fig. 3.22
Contour Lines of Reservoir Area of Recharge Dams (1/3)

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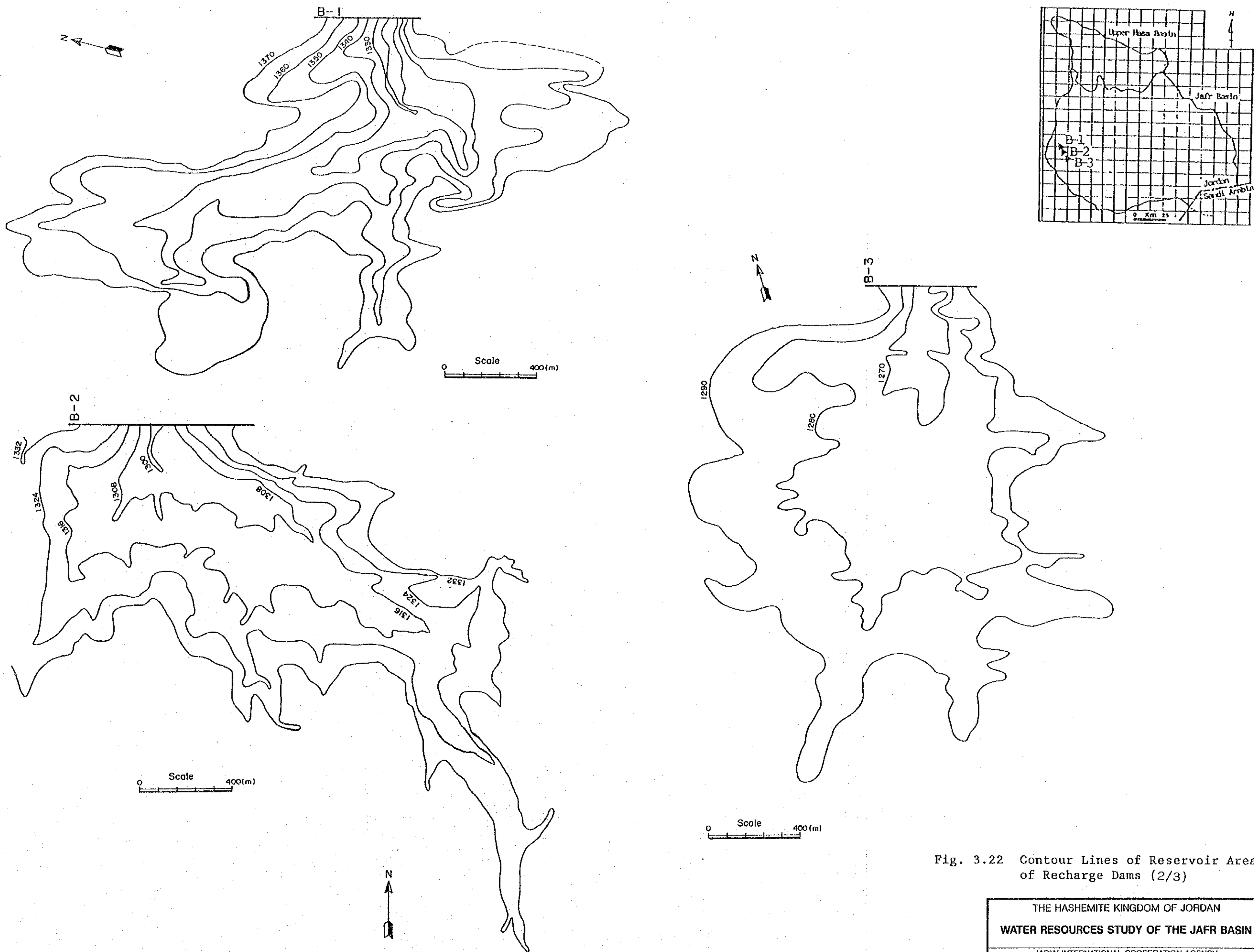

Fig. 3.22 Contour Lines of Reservoir Area of Recharge Dams (2/3)

THE HASHEMITE KINGDOM OF JORDAN

WATER RESOURCES STUDY OF THE JAFR BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

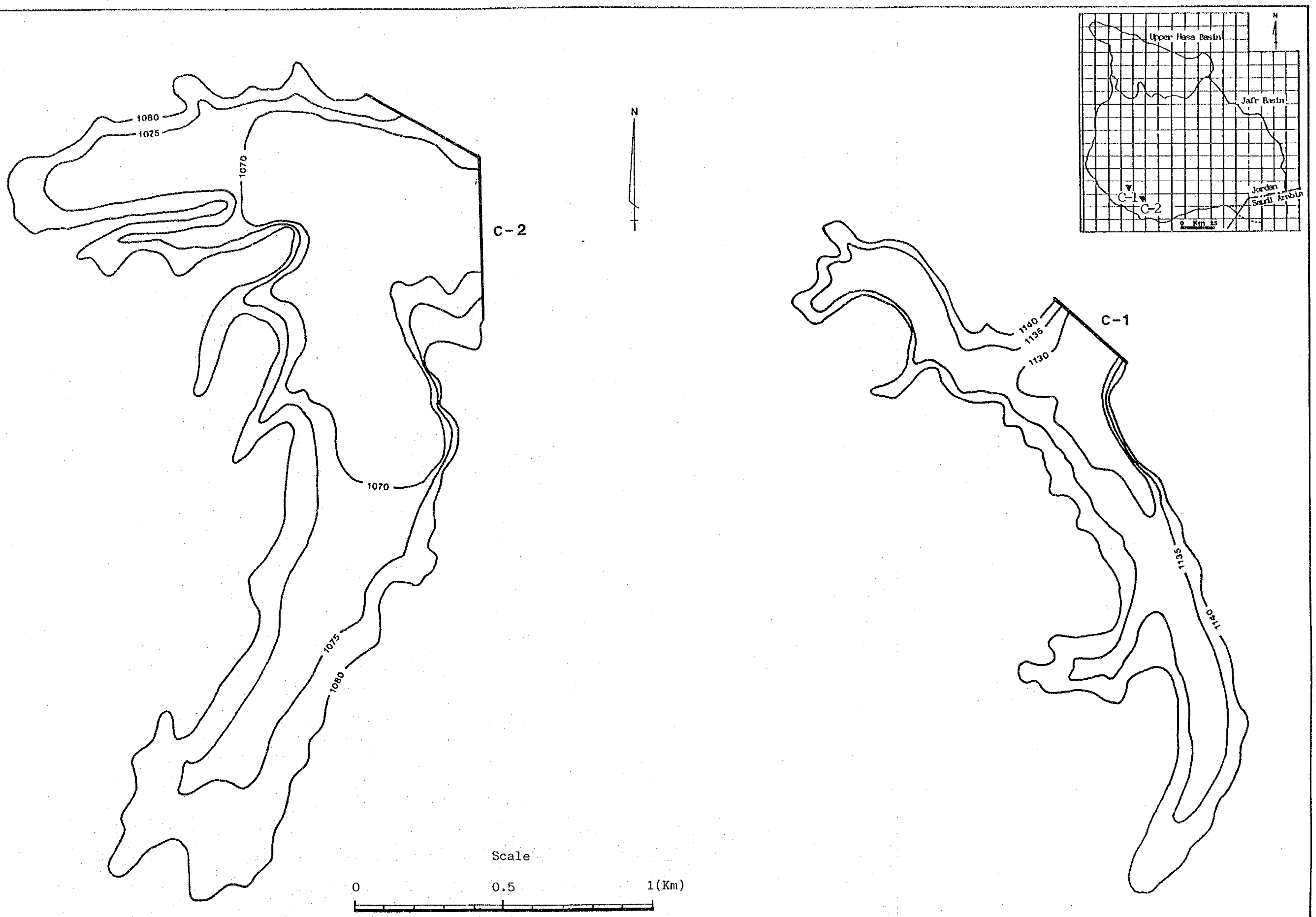

Fig. 3.22
Contour Lines of Reservoir Area of Recharge Dams (3/3)

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WATER RESOURCES STUDY OF THE JAFR BASIN
JAPAN INTERNATIONAL COOPERATION AGENCY

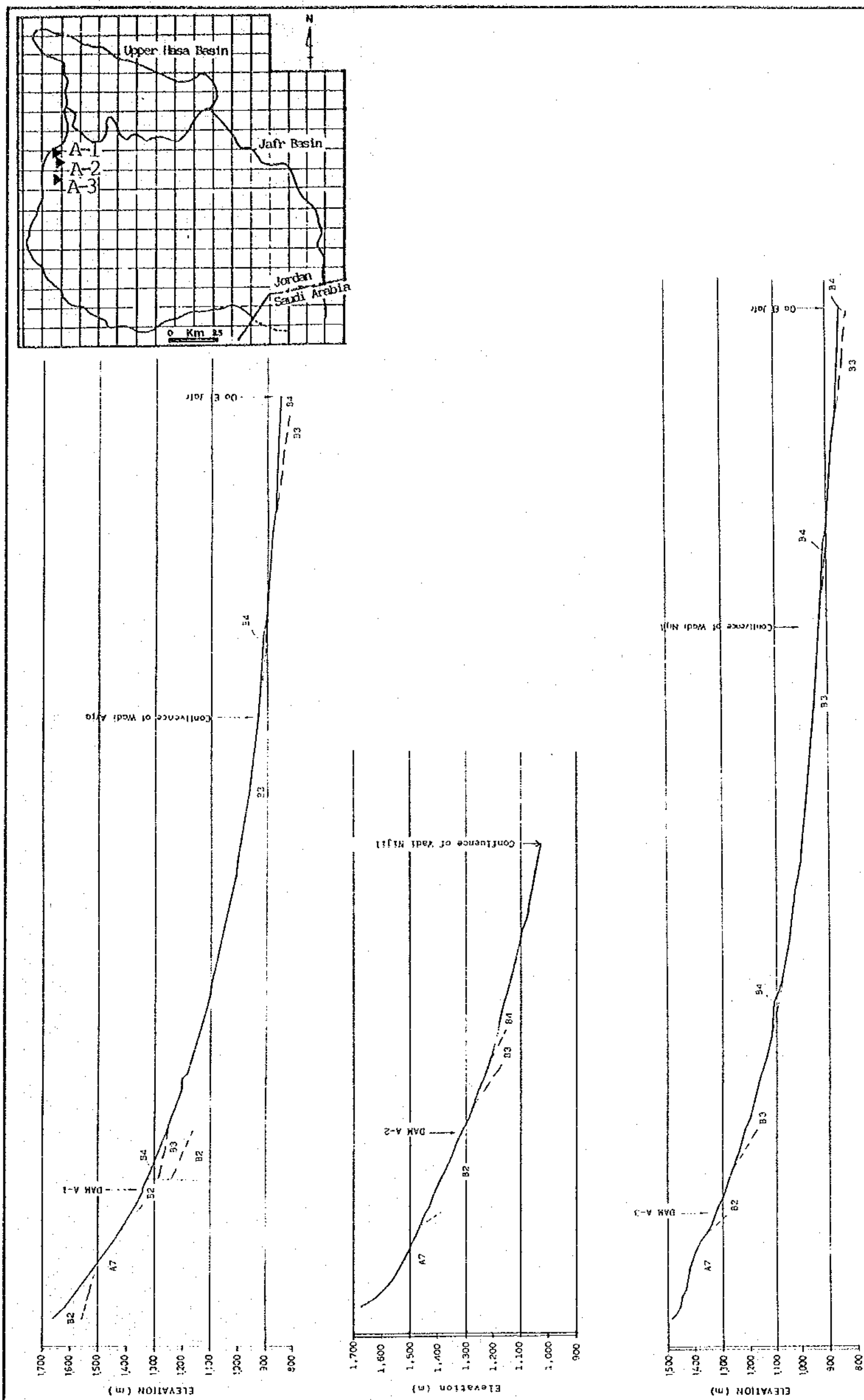


Fig. 3.23
Distribution of Geological Formation along Longitudinal
Cross-Section of Streams around Recharge Dam Sites (1/3)

THE HASHEMITE KINGDOM OF JORDAN

WATER RESOURCES STUDY OF THE JAFR BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

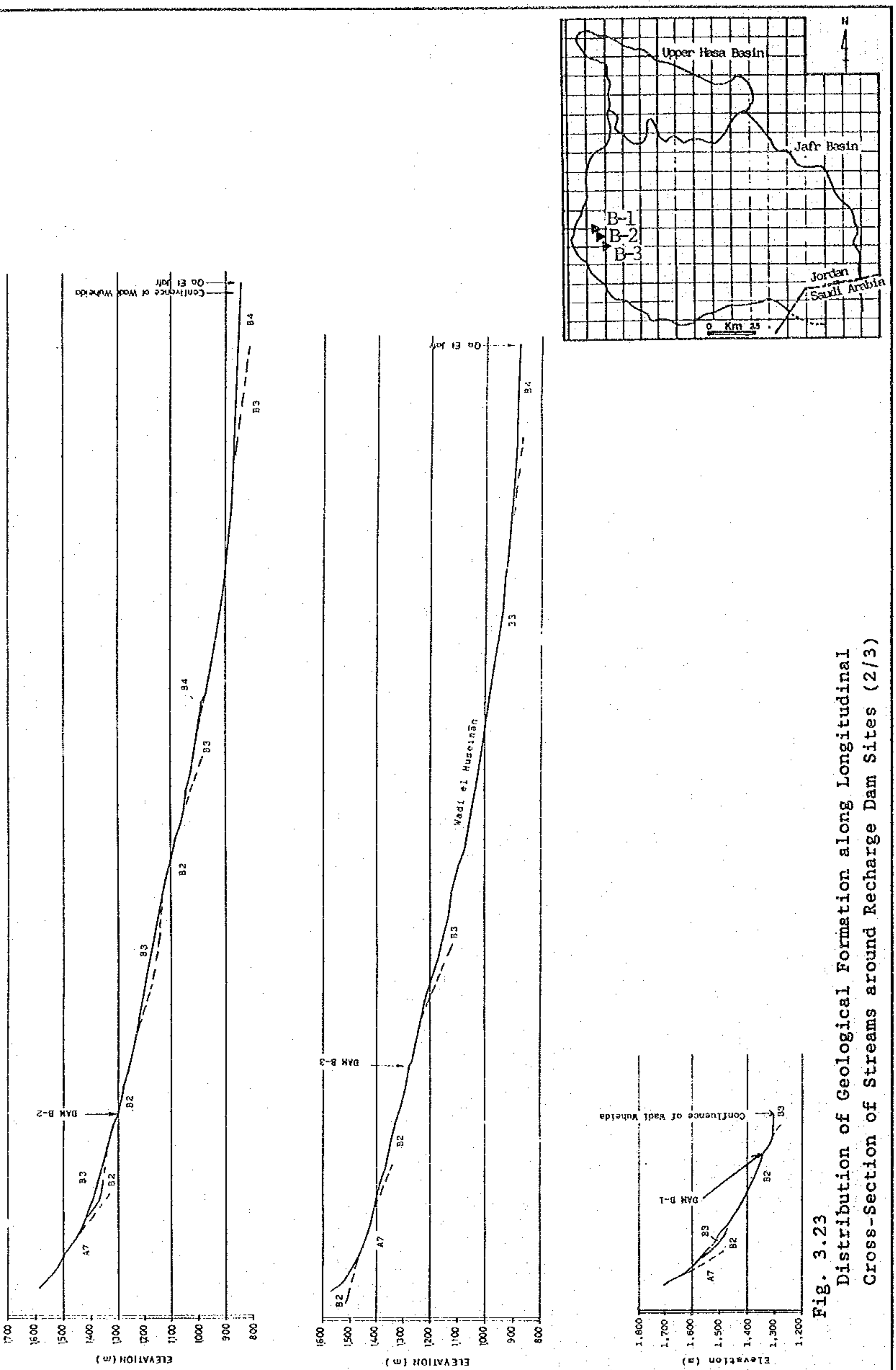


Fig. 3.23
Distribution of Geological Formation along Longitudinal
Cross-Section of Streams around Recharge Dam Sites (2/3)

THE HASHEMITE KINGDOM OF JORDAN

WATER RESOURCES STUDY OF THE JAFR BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

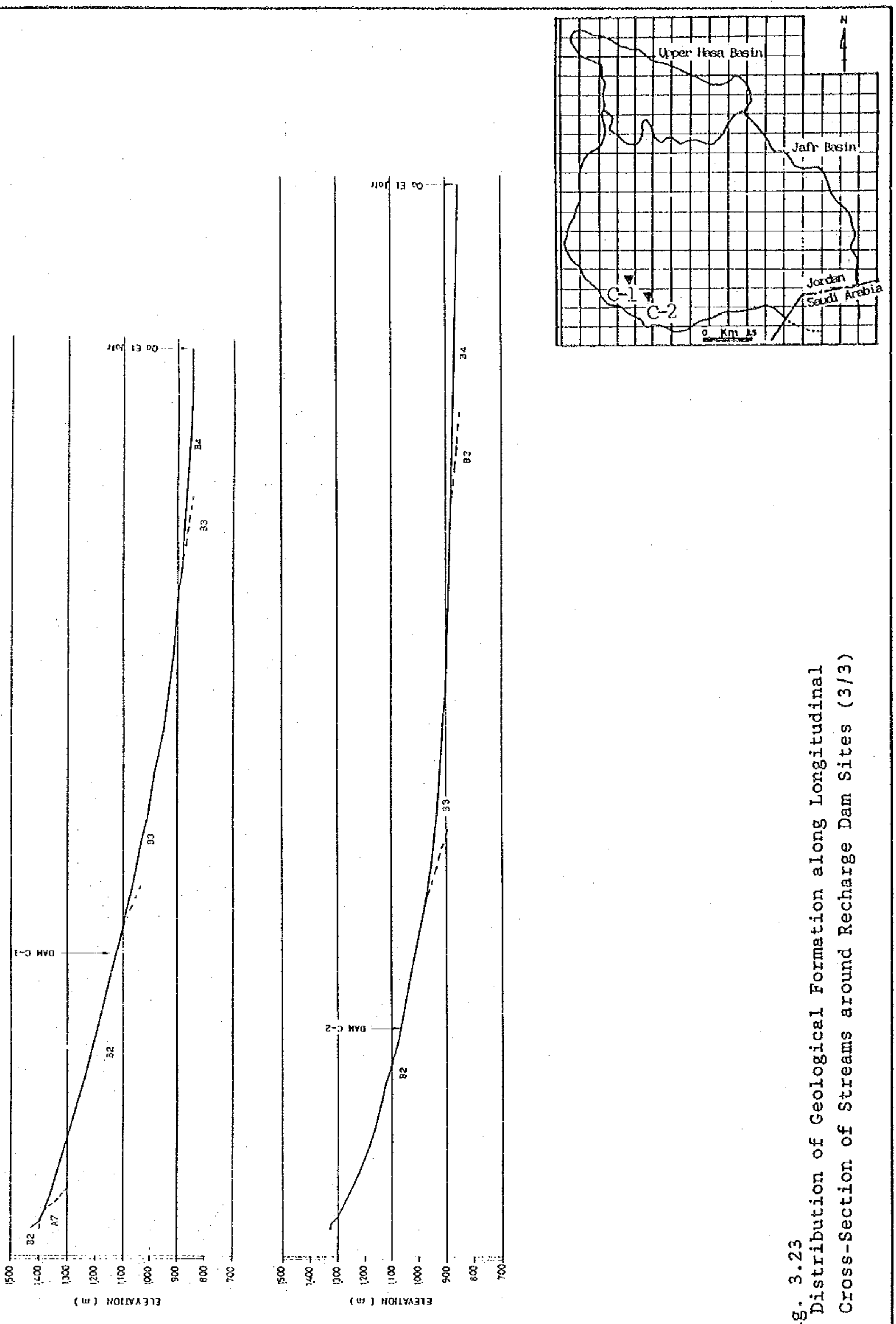


Fig. 3.23 Distribution of Geological Formation along Longitudinal Cross-Section of Streams around Recharge Dam Sites (3/3)

THE HASHEMITE KINGDOM OF JORDAN

WATER RESOURCES STUDY OF THE JAFR BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

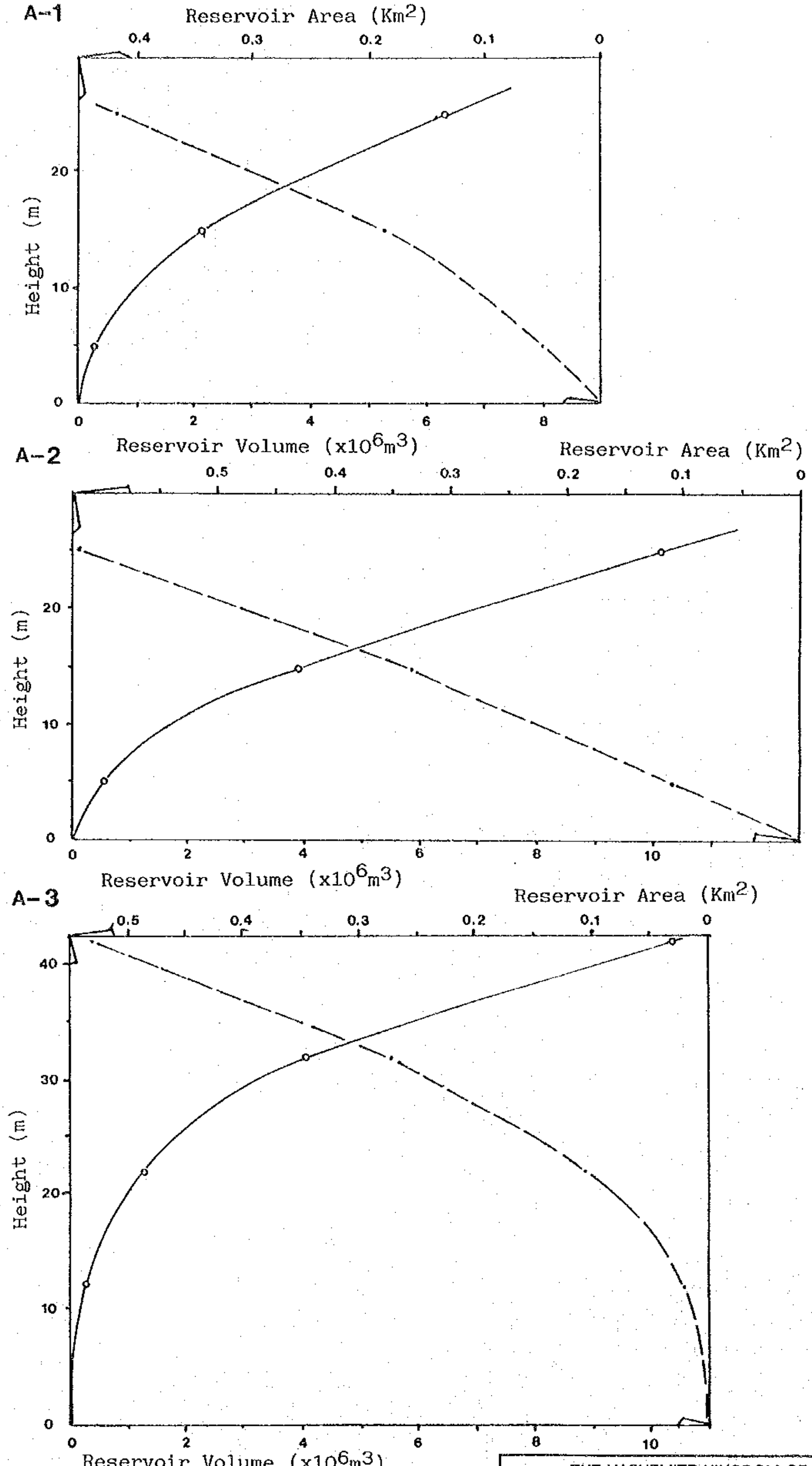


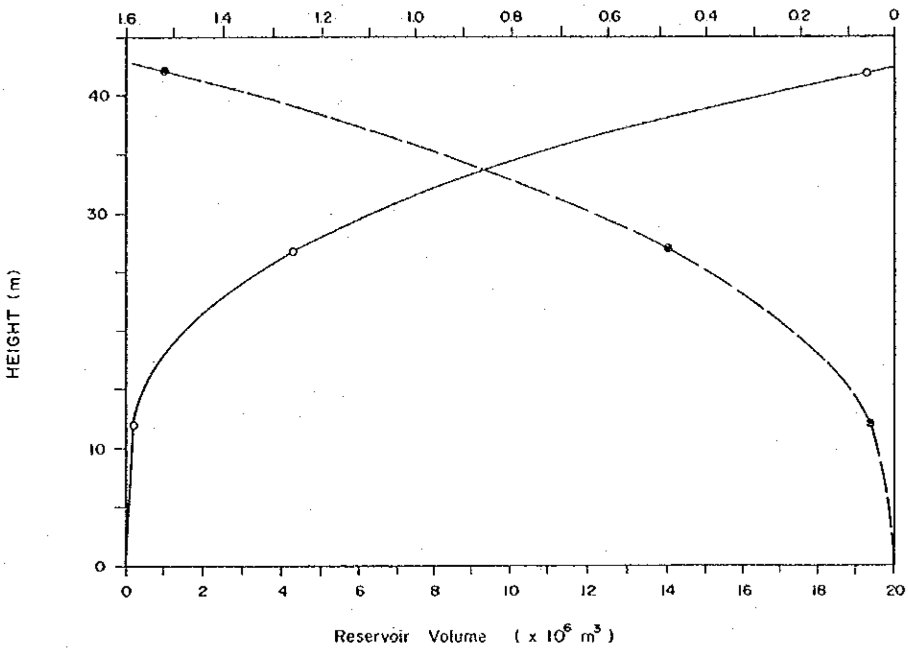
Fig. 3.24
Reservoir Volume Curves of
Recharge Dams (1/4)

THE HASHEMITE KINGDOM OF JORDAN

WATER RESOURCES STUDY OF THE JAFR BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

B - 1



B - 2

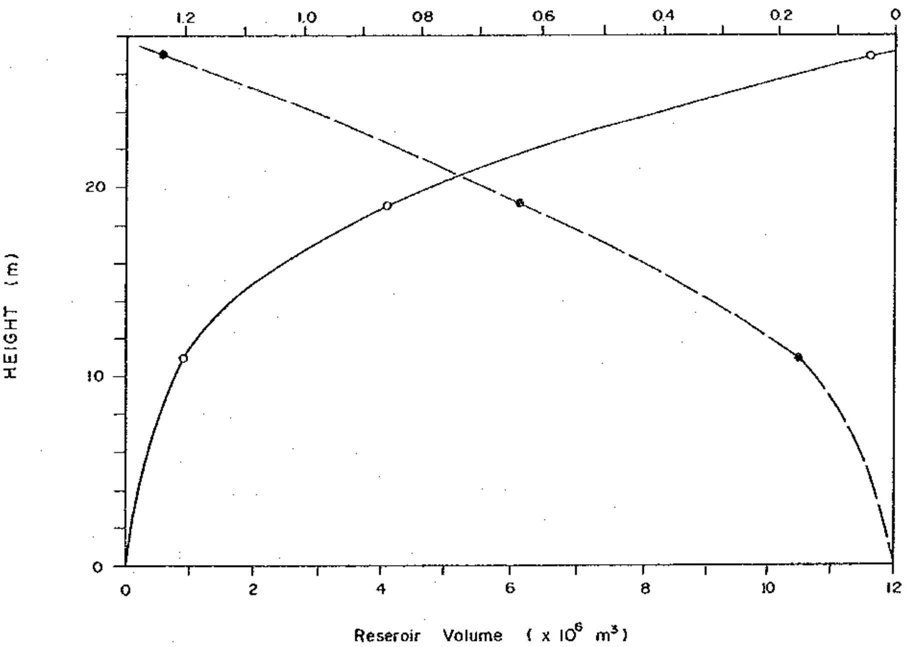


Fig. 3.24 Reservoir Volume Curves of Recharge Dams (2/4)

THE HASHEMITE KINGDOM OF JORDAN

WATER RESOURCES STUDY OF THE JAFR BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

B - 3

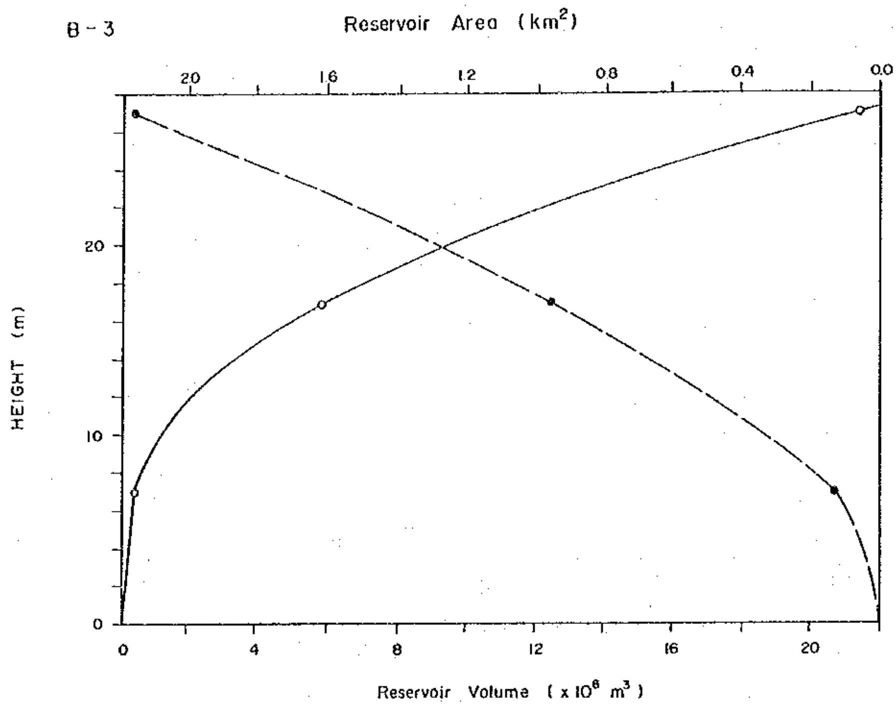


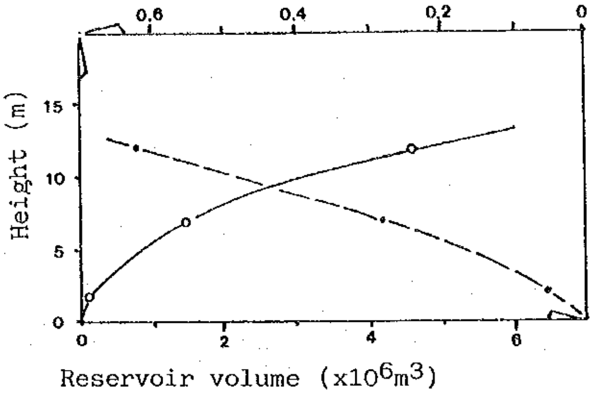
Fig. 3.24 Reservoir Volume Curves of Recharge Dams (3/4)

THE HASHEMITE KINGDOM OF JORDAN

WATER RESOURCES STUDY OF THE JAFR BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

C-1



C-2

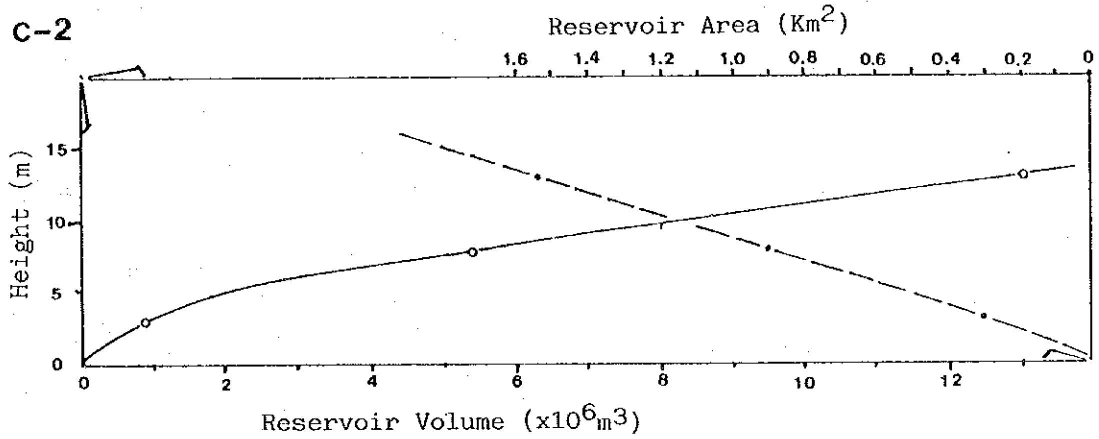


Fig. 3.24 Reservoir Volume Curves of Recharge Dams (4/4)

THE HASHEMITE KINGDOM OF JORDAN

WATER RESOURCES STUDY OF THE JAFR BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

IV. TOPOGRAPHY AND GEOLOGY

IV. TOPOGRAPHY AND GEOLOGY

4.1 Topography

The Hashemite Kingdom of Jordan covers an area of approximately 89,206 km^2 in the northwestern part of the Arabian Peninsula. It has been divided into physiographic provinces, which coincide with the seven geologic provinces: "Southern mountain desert", "Mountain ridge and northern highlands east of the rift", "Central plateau (includes Al Jafr and Al Azraq-Wadi as Sirhan basin)", "Northern plateau basalt", "Northeastern plateau","Wadi Al Araba-Jordan rift" and "Highlands west of the rift".(Ref.4.1, see Fig.4.1)

The Study area, which covers the two watersheds of "Jafr basin" and "upper Hasa basin", is located in the southern part of the Central Plateau. The Jafr basin, which is about 150 km long NW-SE and about 100 km wide, displays a typical centripetal drainage pattern with all wadis draining from the encircling highlands to a central playa. The drainage system has a catchment area of 13,450 km^2 Km with an extensive mudflat (240 km^2). The upper Hasa basin with a catchment area of 2,198 km^2 shows topography like a centripetal drainage pattern with a playa "Qa El Jinz", but it is drained by wadi Hasa to the northeast into the Dead Sea. (See Location Map)

The highest altitudes in the Study area (1,733 m) is in the western mountain ridge of the Jafr watershed, while the lowest (845 m) is in the center of the playa "Qa El Jafr".

4.2 Geology

4.2.1 Geologic history

In the study area, the geology is of sedimentary origin, ranging in age from Cambrian to Recent except in the north-western areas, where volcanics of the Quarternary age occur. The sedimentary succession which is between 2,000 and 3,000 m thick is mainly due to a series of regional regressions and transgressions of the Tethys Sea. The lower part of the sedimentary sequence comprises mainly sandstones of Paleozoic and lower Mesozoic age, while the upper part is mainly composed of limestones, marls and cherts of upper Mesozoic and Cenozoic age.

Lithologic Composition

The Disi group, which is the oldest succession unconformably overlying the basement complex, was exclusively continental in the Cambrian but became mixed marine and deltatic and finally fully marine in the early Ordovician when the first major transgression of the Tethys across Jordan occurred. The Khreim group, which comprises mainly fine-grained sandy and argillaceous materials, were deposited in an unstable shallow marine environment at the unstable shelf edge of the Tethys during the middle and late Ordovician and the early Silurian. These sedimentary basins were centers of subsidence throughout the Paleozoic.

From the Silurian through the late Jurassic, the Tethys sea underwent a series of discontinued transgressions and regressions, however, regional crustal epeirogenic movements uplifted and tilted the southern Transjordan block to the east, by following the erosion of the Disi and Khreim.

The Kurnub group, which is composed of sandstones with shales, shows the marine to brackish influence of the major Tethys transgression after the Silurian.

Beginning in the late Cretaceous (Cenomanian), a regional transgression started to spread, however, the continental depositional environment of sandy sedimentation, which formed in the early Cretaceous, continued in the late Cretaceous, including the Santonian. The marine calcareous, marly and siliceous rock units of the Cenomanian, Turonian, Santonian, Campanian and Maestrichtian overlay these continental sandstones with onlap toward the southeast. Great thicknesses of sediments which accumulated in the areas occupied by the Tethys sea such as along the

Jafr basin. In the west, the Ajlun formation is a calcareous marine facies, but southeast of the oscillating Tethys sea, east of the Jafr basin becomes a continental sandy facies. In the late upper Cretaceous (Campanian and Maestrichtian) when the Mesozoic extent of the Tethys sea was at its greatest, the shallow marine marls and limestones of the lower Belqa (the Amman formation and parts of the Muwaqqar) were laid down. These sediments transgressively overlap the lower parts of the upper Cretaceous sequence to the southeast. A thick pile of bituminous shales, which belong to the Muwaqqar of the middle Belqa continued into the early Eocene, was accumulated in the El Jafr basin in particular. The shallow marine limestones of the Rijam series, which are the last sediments of the Belqa, were deposited in the late Eocene.

4.2.2 Stratigraphy and micro-paleontology

A series of successions of sedimentary origin, ranging in age from Cambrian through Recent, underlies the Study area, except the minor areas in the northeastern part of the Jafr basin where volcanic rocks of Neogene and Pleistocene age occur. The sedimentary succession is so thick as 2,000 to 3,000 m, which unconformably underlies the Pre-Cambrian basement rocks. The sedimentary rocks underlying this area are mainly of sandstones of Paleozoic and lower Mesozoic age in the lower part of the sedimentary sequence, while it is mainly limestones, cherts and marls of the upper Mesozoic and Cenozoic age in the upper part. Table 4.1 shows the summary of the geological succession. Previous study reports such as "Investigation of sandstone aquifers of east Jordan, UNDP/FAO, 1970" (Ref.4.2), "National water master plan of Jordan, German agency for technical cooperation, 1977" (Ref.4.3) and "Groundwater resources study in the Shidiya area, NRA, 1986" (Ref.4.4) formed the basis of this geological investigations and interpretation. The geological map of the Study area, which is based on the geological map sheets "Aqaba-Ma'an" and "Bayir" at a scale of 1:250,000, is shown in Fig.4.2. (Refs.4.5 and 4.6)

Geologic groups comprise "Disi", Khreim", "Kurnub", "Ajlun" and "Belqa". None of the deep test wells which were drilled in the Study area penetrated the groups of "Disi", "Khreim" and "Kurnub". The Ajlun group is composed of two formations of "Lower Ajlun (A1-6)" and "Wadi Sir (A7)", while the Belqa group includes three formations of "Amman (B1/2)", Muwaqqar (B3)" and "Rijam (B4)". The Ajlun group is collectively referred to as the "A(1-7)" and the Belqa as the "B(1-4)".

In the southern area of the central plateau, a formation name of the "Fassua" for the entire Ajlun was proposed by Weisman in 1966, because of the difficulties of distinguishing the formation units in the Ajlun group. The "Fassua" formation which has its type section on the escarpment near Batn el Ghul in fact represents only the lower A1 to A6 formations of the Ajlun group. Since the Wadi Sir (A7) formation is of importance to the Study and can be identified over most of the area, the multiple formation name "Fassua" was abandoned in favor of more descriptive terminology of lower Ajlun referred to as A1-6 formations, and the Wadi Sir (A7) for the uppermost Ajlun group.(See Table 4-1)

Correlations of stratigraphic groups and formations were made by inspecting the borehole samples of the test wells, however, it was not easy because of the complex nature of the lithological variations. Micro-fossil analysis was performed by WAJ stratigraphic section by using the representative samples from the test wells such as JT-1, JT-2, JT-3 and JO-5. (See Figs.4.3 to 4.6)

<u>Lower Ajlun (A1-6) Group</u>

The earliest late Cretaceous sedimentation in west, north, and central Jordan is marked by a marine calcareous facies, whereas in the southeast of Jordan, deposition of sandy sediment continued in a continental environment. Alternating limestone, dolomite, sandstone, marl, shale and very few cherts were deposited on top of the Kurnub group of the lower Cretaceous. A deposition from the lower to middle Cretaceous is interpreted to transgress the time boundary between the two groups.

In the Study area, the lower Ajlun (A1-6) has littoral sandy facies almost entirely, which contains some limestones in the southeast and become more shaly and marly in the east. In the east of the Study area, the lower Ajlun sequence thins out and becomes diachronous with the Subeihi formation of the upper Kurnub. In general, the formation is up to about 400 m thick in the Jafr trough but becomes thinner to the south. The thickness is about 300 m in the northeast of the Jafr basin, whereas it is about 200 m in the southern area such as in Shidiya.

The elevation of the top of the Kurnub (equivalent to the bottom of the Lower Ajlun) formation is shown in the structure contour map of Fig.4.7. Fig.4.8 shows the isopach map of the lower Ajlun formation. From the map, the lower Ajlun (A1-6) appears deepest at elevation 100 to 400 m in the Jafr trough. The formation thickness is about 250 m in the Jafr trough but less than 150 m in the Shidiya. South of Shidiya, the formation decreases in thickness to the south and finally disappears at the boundary of Jafr watershed.

<u>Wadi Sir (A7) Formation</u>

The Wadi Sir (A7) formation comprises the uppermost part of the Ajlun group. It outcrops in the Western Highlands but disappears in the southern escarpment. In the Study area, the sequences of A7 are almost entirely littoral facies, which are mainly composed of sandstone, calcareous sandstone, sandy limestone, marly limestone and limestone. In the Western Highlands, the formation is mainly limestones with chert bands but becomes sandy to the south and to the east. In the northern Study area, lithological face is calcareous sandstones and/or sandy limestones, whereas it changes predominantly sandy nature in the southern Jafr basin.

The elevation of the top of the lower Ajlun (A1-6) formation is shown in the structure contour form in Fig.4.9, and the isopach map of Wadi Sir (A7) formation in Fig.4.10. From the maps, the A7 formation appears deepest at elevation 400 to 750 m in the Jafr trough. The formation thickness is about 50 to 100 m in the Study area, but less than 50 m in the southern Jafr such as in Shidiya area. South of Shidiya, the formation decreases in thickness to the south and finally disappears at the boundary of Jafr watershed.

Amman (B2) Formation

The lowest part of the Belqa group is composed of two formations such as Ruseifa (B1) and Amman (B2). The Amman (B2) formation is a lithostratigraphically continuous unit, and has been found to occur over the study area, while the Ruseifa (B1) formation is thin and not a continuous unit in the sedimentary sequence. Because of the difficulties in distinguishing the formation unit of the Ruseifa (B1), a formation name of Amman (B2 and/or B1/2) is used to synthesize the geological unit of B1 and B2.

The Amman (B2) formation comprises two members of upper (B2b) and lower (B2a). The upper (B2b) is composed of phosphorite member of Campanian Age, while the lower (B2a) consists of silicified limestone member of Santonian to Campanian Age. The silicified limestone member intercalates alternating this bedded silicified limestone with chert, marly limestone, marl and limestone, while the phosphorite member consists of alternating thin-bedded limestone, more-or-less silicified or calcified phosphorite layers and coquina beds.

The formation outcrops in western and southern part of the Study area forming a hard, erosion resistant cap-rock to the underlying Ajlun group.

The elevation of the top of the Wadi Sir (A7) formation is shown in the structure contour map of Fig.4.11, and isopach map of Amman-Ruseifa (B1/2) formation in Fig.4.12. From the maps, the B2 formation appears deepest at elevation 450 to 850 m in the Jafr trough. The formation is up to 50 to 100 m or more thick in the Jafr trough, while it is less than 50 m thick in the central area such as in Al Jafr playa and southern part of the Jafr basin.

Muwaqqar (B3) Formation

The Muwaqqar (B3) formation comprises the upper part of the Belqa group of Maestrichtian Age. The formation consists of marl-chalk members such as soft chalk, marl, bituminous marl and shale.

The Muwaqqar was deposited mostly in the late Mesozoic, but its deep portion in the northwest Jafr trough continued being deposited into the uppermost Cretaceous.

The formation outcrops extensively throughout the Study area except in the Western Highlands and southern part of the Jafr basin. In the south, the Muwaqqar consists mainly of marls and chalky limestones. While in the central and northwestern area, the formation thickens rapidly with a distinctive sequence of bituminous marls and shales. These thick argillaceous atrata are the sediments in the deep-sea environment.

The elevation of the top of the Amman (B2) formation is shown in the structure contour map of Fig.4.13, and isopach map of Muwaqqar (B3) formation in Fig.4.14. From the maps, the B3 formation appears deepest at elevation 500 m in the northwestern Jafr basin, where the thick sequence, is restricted to the Jafr trough that strikes northwest, with a maximum thickness of 450 m in the deepest trough.

Rijam (B4) Formation

The Rijam (B4) formation comprises the upper most Belqa group of upper most Cretaceous to lower Eocene. The formation consists of massive limestone intercalating with crystalline chert limestone and marly limestone.

The formation outcrops extensively in the northern part of the Jafr basin. The deposit is restricted to the area from the center (Al Jafr) to northwestern Jafr basin mainly along the Jafr trough.

The elevation of the top of the Muwaqqar (B3) formation is shown in the structure contour map of Fig.4.15, and isopach map of Rijam (B4) formation in Fig.4.16. From the maps, the B4 formation appears deepest at elevation 800 m in the central Jafr basin (at Al Jafr air port), where the thickness is approximately 50 m. The sequence is restricted to the Jafr through, and thickens to the northeast from 50 to 100 m or more.

4.2.3 Geological structure

In the Study area, four major structural provinces may be distinguished according to their structural evolution, types of deformation, and pattern; namely i) north-west striking normal faults, ii) west-east fault, iii) north-south striking fault zone (frexure) and iv) Jafr trough.

North-West Striking Normal Faults

The most prominent fault of this area is the "Karak - Wadi Al Fiha" fault, which extends to more than 300 km from Karak in the northwest to Saudi Arabia in the southeast. The fault is not a continuous system, but consists of a series of the discrete faults.

The fault intersects the eastern boundary of the Study area from northwest to southeast, which is composed of a series of graben-horst structures with vertical displacement. The displacement is estimated to be about 100 m such as at the northeastern part of the Jafr basin as seen in Fig.4.17. The fault appears to be diminishing southeastward, and it may die out in that direction.

West-east Faults

These occur in the northwestern part of the Jafr basin. Of significance is the "Salwan" fault zone which intersects the northern part of the Jafr basin from west to east. The Salwan fault zone is extensive, but it is not a continuous structure which is frequently cut by a series of north-south trending discrete faulting systems. It is well defined to the north of Shoubak, but disappears north of Husseiniya. To the northeast of the Jafr basin, the faulting system can be traced as "horse tail" faults aligned WNW-ESE, which parallel the long axis of the Jafr trough. The lineaments seem to continue into the Bayir Block by crossing the "Karak - Wadi Al Fiha" fault zone. The maximum vertical displacement is estimated to be about 200 m at where the adjacent Jafr trough deepens the depth up to 500 m. (See Figs.4.18 to 4.21)

North-South / North-West Striking Faults

These are sub-parallel to the Wadi Araba-Jordan Garden and form small graben and horst structures. Of significance is the "Arja-Uweina flexure/fault zone which extends from Jabal El Batra in the south to a few kilometers west of Jebel Uneiza in the north. At its northern end it appears that this tensional fault system has allowed the intrusion of a basaltic dyke which follows the alignment of the fault but becomes truncated by the east-west trending "Salwan" fault.

Jafr Trough

The most prominent geological feature in the Jafr basin is the Jafr Trough, which is bounded by the two parallel faulting zones with approximate WNW-ESE strike. The formations in the trough are controlled by the post Paleozoic sedimentations, of which the geological development can be traced by a series of increasing in the thickness of the progressively younger strata. The sediments thicken at the center of the trough where the Muwaqqar (B3) formation in the Maestrichtian epoch exceeds a thickness of 450 m.

Geological profiles to estimate the stratigraphy and structures are shown in Figs 4.22 to 4.58.

4.3 Geophysical Prospecting

4.3.1 Objective

The VLF (Very Low Frequency) survey is carried out to provide the point resistivity (apparent resistivity in the two layered system) in the shallow foundation. The survey was performed in the northwest (JT1-JT2) and northeast (JT3-JT4) Jafr basin, where major two faults of "Salwan" and "Karak - Wadi Al Fiha" intersect the groundwater basin. In the central Jafr basin at Al Jafr town, local irrigation has been carried out by using groundwater from shallow unconfined aquifer in the Rijam (B4) formation which consists of uniform limestone. The groundwater in the west of the Al Jafr town has been contaminated by irrigation return flow, increasing the T.D.S from 580 to 3,500 mg/l at Jafr No.17 well. The survey is designed to delineate the extent of the contaminated area in and around the irrigated land, taking account of the sharp response of the apparent resistivity on the electric conductivity of the groundwater in the homogeneous Rijam (B4) formation.

4.3.2 Method

The EM16/EM16R of VLF electromagnetic instrument is used to sound the subsurface resistivity. Two VLF source stations such as Moscow in USSR (UMS; 17.1 kHz, 1,000kW) and Rugby in England (GBR; 16 kHz, 750 kW) were used to receive the signals with very low frequency. The sounding was performed on the lines with measurement intervals at 500 m.

4.3.3 Interpretation

Salwan fault zone (JT-1, JT-2 area)

The resistivity is high in the area of north of the Salwan fault, while there are two different resistivities such as high and low are mapped in the area of the south. The resistivities in and around the Salwan fault are too complicated to estimated the faulting structures as seen in Fig.4.59.

Karak - Wadi Al Fiha fault zone (JT-3, JT-4 area)

The resistivity in the mountain area which consists of the B4 formation (JT-4, F-Line) is in the range of moderate to high, while the foot of mountain area which is composed of the B3 formation and/or unconsolidated loose sediment is low. Exact zone of the faulting structure could not be distinguished. Fig.4.60 shows the VLF profile along JT-3 and JT-4.

Al Jafr area

The resistivity is as low as less than 10 ohm-m in the center of the sounding grid, that explains very high water salinity in the homogeneous B4. (See Fig.4.61)

Highest resistivity such as more than 300 ohm-m is mapped on the northwestern part of the grid, that explains the low water salinity in the homogeneous B4.

The resistivity is rather high as 100 to 300 ohm-m in the southern part of the grid.

Fig.4.61 shows the apparent resistivity contour map.

4.4 Engineering Geology

4.4.1 Objective

Geological investigation is carried out to assess the geological environment of the proposed recharge damsites in the Western Highlands. The surface water, of which source is mainly dependent on the storms on the Western Highlands, is drained down to the central playa without being used. Some of the flood flows are percolated into the pervious B2/A7 and B4 formations through the wadi beds, but others more than 10 MCM/y of surface runoff are flushed out into the central playa, and finally evaporate within a few months after the rainy season. The purpose of the recharge dam is to retain the flood flows in the dam reservoir where pervious B2/A7 formation outcrops. The percolated water through the reservoir will be an important source of the groundwater recharge of the underlying B2/A7 aquifer.