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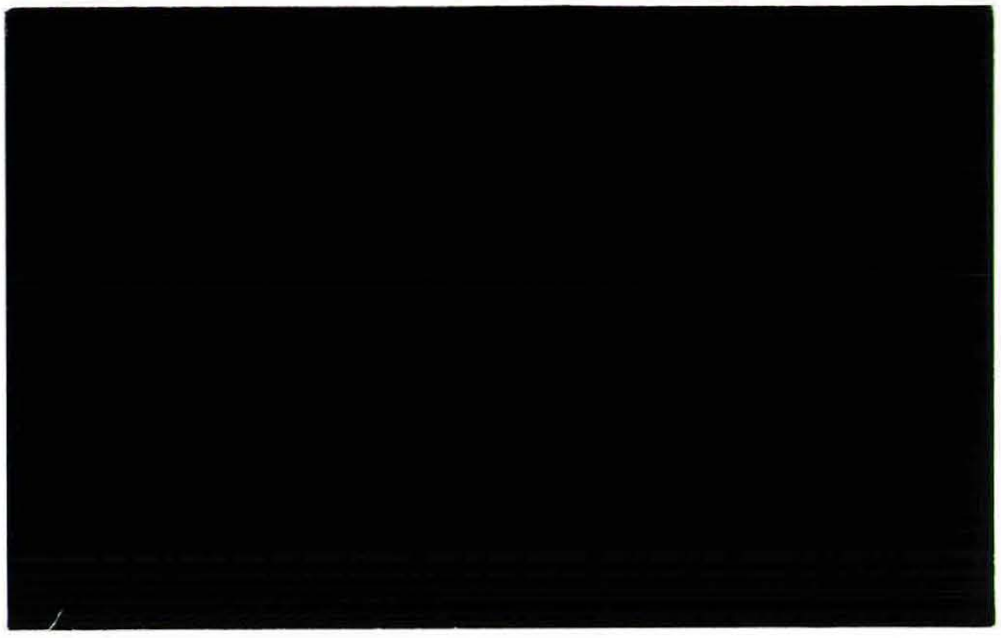

Natural Environment Research Council

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ANNEX 3

Date: 25 April 1990

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

GROUNDWATER RESOURCES

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PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

GROUNDWATER RESOURCES

I. INTRODUCTION

This annex reviews the available information on the groundwater resources of the Wadi Maadin, Wadi Timnan and Ras al Ara Delta in the Toor el Baha District of Lahej Governorate in west PDRY.

c. Cultivated areas are restricted to terraces of limited extent bordering the wadi channels in the north and to similar areas adjacent to the braided channels of the wadi alluvial fans (deltas) near the coast. Agriculture relies almost entirely on irrigation from spate flows and groundwater due to the low rainfall in the project area.

The use of groundwater for irrigation has been a relatively recent development in the Project Area. Over the past 20 years there has been a rapid increase in groundwater abstraction due to the construction of new wells and the use of diesel-driven pumps to supplement traditional

irrigation from irregular and uncertain spate flows. This development, which is still ongoing, has taken place with very limited information on the aquifer systems or their resources.

4. It was originally assumed that project benefits would be derived mainly by identifying and developing unexploited surface and groundwater supplies to expand the present area of cultivation. Estimates of the groundwater resource of the Wadi Timnan were not attempted due to insufficient information. Wadi Maadin was considered to be overexploited already and no further development was proposed for this area. A potential groundwater resource appeared to be present in the Ras al Ara delta, although the resource estimate was based on very broad assumptions. In view of the uncertainty of the groundwater resources, and their distribution, and potential for further development, the Identification Mission proposed a staged approach based on investigation prior to development. Subsequently, this was modified to a combined investigation-development programme of 30 boreholes which would enable earlier returns to the project.

5. The Preparation Mission was able to undertake a more detailed appraisal of the agricultural, socio-economic, and hydrological situation. This has revealed important constraints on further development. Firstly, the need for more information to plan further development and, secondly, whether the approach proposed by the Identification Mission was appropriate. In addition, the following changes were noted since the earlier mission:

The area now considered available for further development has been significantly reduced.

A further 21 wells have been constructed in the Wadi Maadin, perhaps in response to the reduced availability of spate flows in recent years. Two boreholes were drilled in the agricultural area at Ras al Ara in 1989.

- A groundwater reconnaissance survey of the Wadi Timnan area began in 1990. This forms part of the Soviet-Yemeni National Water Resources Survey. It includes a drilling programme in the Ras al Ara delta.

An unpublished report on a survey of the groundwater occurence in the Second Governate carried out in 1977 was made available to the Preparation Mission.

A UNDP project for the training of water resources staff from the Department of Irrigation recently began an 18-month study of the Wadi Maadin which includes the establishment of a hydrological monitoring network.

6. The further development of groundwater in this region requires a more detailed understanding of these small wadi systems and a different and more cautious approach to their development compared to the larger wadi systems that occur elsewhere in PDRY. In view of the limited resources of the wadi systems in the project area, a phased approach is now proposed which aims at optimizing agricultural production in relation to the inherent variability and scarcity of the water resources throughout the whole district. A programme of works is presented with cost estimates for the groundwater related aspects of an initial 3-year project which, whilst concentrating on the Wadi Maadin, will also include surveys in the Wadi

Timnan and at Ras al Ara. This results from the initial phase will be correlated with agricultural and socio-economic surveys to enable other similar wadi systems throughout the Toor el Baha District to benefit from a planned programme of development in a subsequent phase.

II. BACKGROUND

1. The Project Area

The proposed project is located within the Toor el Baha District of Lahej Governorate in the extreme west of PDRY. The general location is shown in Map 1. The Government of PDRY has identified the following three target areas within the Project Area:

- the lower part of the Wadi Maadin catchment(area 25 km^2), which includes the district administrative centre of Toor el Baha.

- the upper part of the Wadi Timnan catchment (area about 200 km^2), centred on the Wadi Madarba to the north of Al Shatt.

- the Timnan-Shabu delta region (area about 100 km^2), in particular the agricultural areas of Uzeifa and Gudeima.

o. The location of these areas is shown in Map 2. Other small wadis with similar characteristics occur throughout the Toor el Baha District, but were not visited by the Preparation Mission

B. Climate

9. Rainfall generally occurs from November to March and May/June to September. Measured data are not available, but the average annual rainfall is estimated to be 50 to 100 mm in the Ras al Ara delta, 150 to 200 mm in the Wadi Timnan, and 150 to 450 mm in the Wadi Maadin catchment.[5]

10. In Wadi Maadin, the maximum temperatures occur in June to August, averaging 32.5°C, and the minimum temperatures occur in December to January, averaging 23°C. The coastal area has an arid climate with a high humidity and high temperatures varying from 28°C in January to 38°C in June Annual evaporation is estimated to be 1,500 to 2,000 mm.

C. Topography

11. The elevation in the Wadi Maadin area ranges from 450 m at El Khatabiyah to 650 m at Toor el Baha. The upper mountainous part of the catchment has an elevation of 1,000 to 1,500 m, with a maximum of about 2,000 m. Deeply incised, parallel NW-SE trending valleys characterise the upper part of the Wadi Timnan. Elevations range from 500 to 1,000 m in this area.

12. The Ras al Ara delta has a low relief and an average gradient of about 1:150 from Huwayrib (elevation 150 m) at the head of the delta to the coast, a distance of some 25 km. Jebal Karaz, a volcanic caldera, rises to 850 m on the eastern edge of the delta.

). Geology

13. The Wadi Maadin catchment comprises granitic gneisses and schists of the Pre-Cambrian Basement Complex. In the lower part of the catchment these have been intruded by volcanic dykes and sills of the Aden Trap Series (Miocene to Pliocene age).

14. Quartzitic sandstones of the Tawilah Group (Cretaceous) occur in the headwaters of the Wadi Timnan (Map 3). A thick sequence of predominantly basaltic lavas with tuffs and agglomerates of the Aden Trap Series are widespread in the central part of the Wadi Timnan system.

15. The unconsolidated deposits of the wadi channels form the main aquifer in the area and are of Pleistocene to Recent age. They consist of a variable sequence of sands and gravels with cobbles and silts varying in thickness from a few metres to about 50 m and in width from about 20 m to several hundred metres. Fluvial sands, sands and gravels and clays, perhaps partly cemented, form a complex sequence of unknown thickness in the Ras al Ara Delta. Terrace deposits, comprising silty to sandy loams up to 10 m thick, overlie the wadi channel deposits and border the present wadi channels. These form the main agricultural areas.

Drainage

16. The general pattern of drainage is south towards the Gulf of Aden. The wadis are deeply incised in the areas of higher relief whilst a braided channel system with numerous poorly-defined channels occurs in the delta area.

17. The Wadi Maadin has a total catchment area of about 410 km^2 above El Khatabiyah, of which 90% lies within YAR. Both of the main tributaries, the Wadi Shaab and Wadi Maabak, have a reticulate drainage system influenced by a NE-SW structural or foliation trend. The upper part of the Wadi Maadin has a dendritic drainage pattern.

18. Wadi Timnan has two main tributaries: Wadi Shabu and Wadi Khudeimah. The total catchment area is about 755 km^2, extending from Jebel Hawab near the border with YAR to the coast at Ras al Ara. The main wadis of interest are Wadi Mardabah, Wadi Harhar (Wadi Melbia), Wadi Hagrah, and Wadi Furuqiyah.

Groundwater Abstraction

Irrigation

19. There are no reports of any significant springs in the area. A baseflow of about 15 to 25 l/s (perhaps increasing to 50 l/s after the autumn rains) occurs in the Wadi Mardaba due to constrictions in the wadi channel. This flow is reported to occur for a total of about 5 months per year. A seasonal baseflow also occurs in the Wadi Harhar.

20. Groundwater supplies are obtained mainly from dug wells. Whilst some limited information is held by the Co-operatives, up-to-date information on the groundwater sources or their current status is limited as no recent well surveys have been carried out. There are reported to be 116 wells and 12 boreholes in Wadi Maadin and 171 wells in Wadi Timnan. Agriculture in the Ras al Ara delta is supported almost entirely from spate flows and only one borehole is in operation. The cultivated area served by groundwater irrigation in conjuntion with spate flows is given in Table 1.

21. Wells in the Wadi Timnan often reach or penetrate the underlying bedrock, whereas most of those in the Wadi Maadin usually only partially penetrate the aquifer. Most of the wells are lined and the majority, perhaps 80%, are fitted with Yanmar pumps and engines. Cross-belt turbine pumps are common in the Wadi Maadin. The shallow water levels in the Wadi Timnan allow the extensive use of centrifugal pumps, although this restricts the area that can be commanded by each well Most boreholes are fitted with shaft-driven, turbine pumps of various makes.

22. Piped or lined conveyance systems are restricted to a few boreholes in Wadi Maadin. Polyethylene hose is used widely in Wadi Timnan to enable water to be conveyed to different parts of each farm.

Domestic Supplies

23. The water demands of the rural centres and villages are met entirely from groundwater. A wellfield at Toor el Baha is used to supply several piped water schemes and a tanker delivery service in Wadi Maadin. A borehole, yet to be equipped, has been drilled in the Wadi Harhar for a local piped water scheme and Al Shatt has piped water supply obtained from a well. Elsewhere, supplies are obtained from pumped irrigation wells and boreholes and by rope and bucket from open wells.

24. There are three water supply development schemes in the Wadi Maadin: Al Fasha (serving about 17 communities), Toor el Baha (rural centre, including the hospital and school, and four large villages), and Wadi Shaab (also serving about 17 communities). These are operated and maintained by the Public Water Corporation (PWC), which has an office and workshop at Toor el Baha. The schemes were constructed over the past five years with financial assistance from UNICEF, and are supplied from 4 boreholes in the Toor el Baha wellfield and a borehole in Wadi Shaaba. A new borehole has been constructed recently at Toor el Baha and there are plans to drill a further one or two boreholes in the same area to expand the supply.

25. The open wells used for local domestic supplies are particularly susceptible to contamination. Nitrate levels well in excess of World Health Organisation permissable limits of 50 mg/l were recorded by Tecneco in the Wadi Maadin in 1978, as shown in Appendix 2. No information is available on

the bacteriological quality but high bacterial counts can be expected in those wells where supplies are obtained by hand.

G. Organisations

26. The collection and analysis of groundwater information is primarily the responsibility of the Water Resources Section of the Department of Irrigation and ~~Mechanical Engineering (DIME)~~ Land Reclamation under the Ministry of Agriculture and Agrarian Reform (MAAR).

27. The Water Resources Section comprises 25 engineering and technical staff. The Hydrogeology Sub-Section has only 3 staff (1 Engineer and 2 technicians). Activities of the section are constrained by low staff levels and a lack of training, equipment, ~~and~~ facilities, and recurrent funds. A training programme, which will include the provision of equipment and vehicles, is currently under way with UNDP support and should strengthen the capabilities of the section.

28. Drilling activities are undertaken by the Drilling Corporation, which also operates under MAAR. Drilling costs are especially high in PDRY but are currently under review. It is understood that a larger element of the work may be assigned to private contractors in future.

29. Urban and rural water supplies are the responsibility of the Public Water Corporation (PWC) under the Ministry of Energy and Natural Resources (MENR) Overall coordination in the water resources sector is also provided by PWC through the non-executive Water Resources Committee

30. Detailed information relating to the organisations and institutions involved with water resources are described in Project Formulation/Feasibility Report for the Rehabilitation of Rural Water Supplies (M. Mansell-Moulin and W.K. Boehmer, UNDP/PDY/87/103 December 1987).

H. Groundwater Studies

31. A groundwater study of the Wadi Maadin was undertaken as part of the Wadi Maadin Rural Development Project by Tecneco in 1977-78.[1] Since then little spatial or time-varying information has been collected.

32. A reconnaissance survey of the groundwater resources of the western part of Lahej Governorate was undertaken by Tersch for MAAR in 1977.[6] This included details of selected wells, water analyses and preliminary resource estimates.

33. A three year UNDP/MAAR Water Resources Management Training Project (RAB/86/008) began in September 1988. It consists of two phases each of 18 months, and forms part of a programme covering the less-developed Arab countries (PDRY, YAR, Sudan, Somalia and Djibouti). The programme is directed at improving the collection and analysis of water resources data and involves the engineering and technical staff of the Water Resources Section of MAAR. The first phase of this programme, training in other Arab countries, has been completed. Wadi Maadin has been selected as the training area for the second phase which began in February 1990. Equipment to be provided includes a meteorological station (installed in February 1990), two stage recorders, three water level recorders, five rain gauges, and pumping

test and geophysical equipment. Two vehicles are also to be provided. A well inventory of the Wadi Maadin is planned for May 1990.

34. The Soviet-Yemeni National Water Resources Assessment includes a reconnaissance survey of the groundwater resources of the Lahej Governorate. This began in March 1990 as part of a two-year programme to assess groundwater resources throughout PDRY. The Wadi Timnan has been selected for more detailed studies and a limited programme of drilling and testing is planned for Ras al Ara during 1990.

35. The Project Area will also be included in the Yemeni Joint Project for Natural Resources: Water Resources Monitoring Network. This is a UNDP project with Arab funding covering both PDRY and YAR. It is due to start during 1990 and is intended to identify gaps and weaknesses in the existing water resources monitoring network during the first phase lasting 12 months. The second phase will include the construction of the network itself. The Department of Irrigation and ~~Mechanical~~ Land Reclamation Engineering is involved with this project.

III. GROUNDWATER RESOURCES AND DEVELOPMENT POTENTIAL

A. Ras al Ara

Data Availablity

36. Recharge in the Ras al Ara delta is derived from floods and aquifer inflow from Wadi Timnan, Wadi Shabu, and, to a lesser extent, Wadi Khudeima (Map 4). There are no meteorological or hydrological data for this area and only very limited hydrogeological information. The Soviet-Yemen programme includes proposals for a limited programme of three exploration-test wells between Huwayid and the coast and a geophysical profile at Huwayid. It is anticipated that this programme will be undertaken during 1990.

37. Only two boreholes have been drilled in the Gudeima agricultural area. The Agricultural Support Services Project (ASSP) borehole, which was drilled in 1984 at Gennah village to a depth of about 50 m, is the only borehole operating at present. It serves an area of 12 ha and has an annual abstraction of about 0.25 Mm3. A second borehole was was drilled 300m north-east of the ASSP borehole in 1989 to a depth of 44 m to encourage bedouin resettlement but has not yet been equipped. The rest water level is 21 m bgl. It was tested at 15 l/s but has a low specific capacity of 2 l/s/m. This would indicate an approximate transmissivity of about ~~only~~ 200 m2d, although significant well losses could produce this low ~~estimate~~ value

38. A further borehole to encourage bedouin resettlement was also drilled in 1989 about 3km north of Uzeifah to a depth of 79 m. The water level was deep, about 64 m, and the yield was insufficient for testing.

39. There are 5 dug wells in the Gudeimah-Uzeifa area (Table 2). These are all used for domestic and livestock water supplies which are obtained by rope and bucket. One is situated adjacent to the ASSP borehole. In addition, irrigation supplies are drawn from pumped wells in the Huwayid area at the head of the fan. These will intercept groundwater inflow from Wadi Timnan, but their annual abstraction is not known.

40. A borehole situated about 3 km from the coast in the Wadi Tarbah delta provides Ras al Ara itself. This was drilled in 1969 to a depth of 64m and has a water level of 40 m bgl. The log reports 40 m of sands and gravels overlying a hard red clay.

41. The mean annual runoff for the whole of the Wadi Timnan-Shabu catchment has been estimated to be 12 Mm3/y and the mean annual flood as about 170 m3/s. Local reports suggest that spates occur 10 to 15 times each year. Flows are reported to reach the coast but the frequency and amount of the surface water lost at the coast is not known.

42. Whilst the groundwater quality is likely to be an important factor in the development of groundwater for irrigation in the Ras al Ara delta, the information available on groundwater quality is limited to a few samples from the dug wells which only represent the shallowest part of the aquifer. EC values in the dug wells range from about 1000 mS/cm at Huwayrib to about 1300 mS/cm at Uzeifah and Gudeimah. Available chemistry data are presented in Appendix ?. The well adjacent to the ASSP borehole has an EC of 1300

mS/cm whereas the ASSP borehole, which is 20m deeper, has an EC of 2600 mS/cm and the borehole just to the north has an EC of 1900 mS/cm. This would suggest that the water quality deteriorates with depth and pumping rate.

Groundwater Resource Estimates

43. The average annual recharge from groundwater inflow and floods was estimated by the Identification Mission to be 15 Mm3/y This was based on an estimate of flow through the aquifer assuming a transmissivity of 800 m2d, an average width of 10 km and an average hydraulic gradient of 0.005. Given the lack of information it was stressed that this should be considered as a very tentative estimate only and should be confirmed by a programme of investigations prior to any development. The width of aquifer across the existing agricultural area is about 6 km which would give a potential availability resource of about 9 Mm3/y.

44. In 1977, Tersch estimated the annual recharge in the Ras al Ara delta to be 5.6 Mm3/y. This estimate was derived by (a) assuming 5% of the rainfall in the Timnan-Shabu catchment (700 km2) recharged the delta area, or 4 Mm3/y, and (b) a recharge component from flood infiltration of 0.6 m of water over 10 distributary channels having a total area of 1.35 km2 and an average of 2 floods per year, or 1.6 Mm3/y.

45. Recharge to the wadi sediments from surface flows has been estimated in other areas of PDRY to be about 30% of the mean annual runoff, which for the Wadi Timnan-Shabu catchment has been estimated as 12 Mm3/y. This would suggest a recharge from surface flows of about 4 Mm3/y. Underflow input from the Wadi Timnan and the Wadi Shabu, assuming a gradient of 0.007, a transmissivity of 800m2/d, and with a total combined width of flow of

1000 m, would only be about 2.0 Mm3/y. The total mean annual recharge would therefore be about 6 Mm3/y, only 40% of that estimated by the Identification Mission but similar to that estimated by Tersch in 1977. The irrigation abstraction at Huwayid, which has developed over the past two decades, would reduce the amount of inflow now occuring at the head of the fan.

46. The volume of groundwater in storage was estimated by the Identification Mission to be 200 Mm3 assuming an area of 100 km2, an average thickness of 40m and a specific yield of 5%. The effective availability of storage was taken to be 25 Mm3, although the basis for this was not given.

Development Potential

47. On the basis of existing information, there is a potential groundwater resource of between 5 and 10 Mm3/y in the Ras al Ara delta which as yet is essentially unexploited. However, the development of this resource for irrigation is restricted by a number of considerations, all of which need to be studied in more depth to ensure that benefits will be achieved from such development:

The overall uncertainty of the resource estimates. These are based on very limited information on the aquifer characteristics, lithology and water quality. Only a proportion of the resource would actually be available for development, due mainly to water quality considerations.

Alluvial fan sequences often show a wide variation in permeability, which may also be reduced by the prescence of cementing materials when the overall recharge is limited. Whilst there is some doubt as to the reliability of the log of the borehole at Ras al Ara, it indicates that the unconsolidated sequence may be relatively thin in places and lie on more consolidated deposits. Further information on the aquifer characteristics and an improved estimate of aquifer throughflow should become available from the survey being undertaken by the Soviet-Yemeni Project.

The groundwater quality is not expected to be suitable for irrigation within a few kilometres of the coast. The water quality is expected to deteriorate with depth, pumping rate and away from the distributary channels. Several of the shallow wells at Gudeimah have EC values of more than 3500 mS/cm2, which would suggest that at least part of this particular area is unlikely to be suitable for groundwater irrigation (Appendix 2).

In general, the groundwater potential should be more favourable in the Uzeifah area than at Gudeimah due to water quality constraints. However, the borehole drilled recently north of Uzeifah was non-productive at a total depth of 79m. However, it is not known whether this is typical of the conditions in this area.

Boreholes are needed to obtain irrigation supplies in this area. Consequently, the cost of groundwater supplies would be high, yet mission interviews suggested that lower value fodder crops would still continue to be grown. The estimated groundwater pumping cost for a borehole of 70m depth is 20 fils/m3, excluding interest and

plant costs. Details are given in Appendix 1.

- Local interest in using groundwater for irrigation seems to be low due to the the availability of spate, which allows an average of 1.5 crops per year. Farm interviews indicate that not all of the available spate flow is used. This unused spate could be obtained at lower cost than borehole supplies and needs to be assessed.

- There are also agronomic, marketing and socio-economic factors which will need to be studied before investing in groundwater irrigation supplies. These are discussed in the other relevant Technical Annexes.

48. It will not be possible in any case to intercept all of the flow moving towards the coast in order to prevent upconing of poor quality water or excessive saline intrusion. The relatively high EC at Gudeimah (2600 ms/cm at the ASSP borehole) would suggest that the area would be sensitive to a slight deterioration in water quality, particularly if high value crops were introduced. Pumping water levels will need to be kept above sea level to avoid the risk of upconing and this reduces the amount of storage that can be commanded.

B. Wadi Timnan

Data Availability

49. There are no hydrological or meteorological data for the upper Wadi Timnan catchment and only very limited hydrogeological information. No well inventories have yet been undertaken.

50. The Soviet-Yemeni Project began their reconnaissance groundwater survey of Wadi Timnan in March 1990. Three pumping tests had been completed in the Wadi Mardarba, each of of only 2 hours duration. These were performed on selected dug wells penetrating bedrock. Whilst the data had not been interpreted at the time of the mission, preliminary estimates of transmissivity based on specific capacities are given in Table 3. Other work planned includes a well survey, some 50 water samples, and a geophysical profile at Al Shatt. It is also proposed to install two gauging stations, one at Al Shatt and the other in the Wadi Harhar.

51. Sub-catchment areas (Map 4) and estimates of run-off are given in Table 4. Both the Wadi Marbar and Wadi Harhar (Melbia) extend into YAR and have a slightly higher rainfall and larger catchments than Wadi Hagrah and Wadi Furaiqiyah to the west. The mean annual runoff from the Wadi Timnan catchment above Al Shatt is estimated to be only 4 Mm3 and the mean annual flood as 130 m3/s.

Groundwater Resource Estimates

52. Each wadi comprises a series of small groundwater sub-basins limited by rock bar constrictions (at least 10 such rock bars were observed along the Wadi Mardarba above Al Shatt). The average thickness of the wadi deposits is about 10m, varying from 5 to 15m, although some wells are 30m deep. Water levels are shallow ranging from bed level in the Wadi Mardaba to about 5 to 10m in the Wadi Harhar, where the width of the wadi is much greater, or in the Wadi Furuqiyah, where less recharge is likely to occur. The effective width of the wadi deposits is taken to be 300m based on the width of the area under cultivation, although the width reduces to about 20m at some rock bars.

53. Water levels are very low in the Wadi Harhar at present and pumping rates and durations have been reduced. The District Officer reported that wells tend to go dry following periods of reduced runoff, such as in 1988, and that the intensity of agriculture varies as a result.

54. A tentative estimate of the average annual throughflow is 1.75 Mm3. This is based on an aquifer width of 300m, a hydraulic gradient of 0.016 and a transmissivity of 1000 m2d.

55. Preliminary estimates of the available aquifer storage within the agricultural area of each sub-catchment are given in Table 5. These indicate a total storage of 22 Mm3. A water level rise of 2m which is reported to occur during the flood season, ~~which~~ would represent an annual recharge of about 6.5 Mm3.

56. The average area irrigated by each well in this area is about 2.5 ha. Information from Wadi Beihan [4], suggests that this area would require a pumping rate of 3.5 l/s. The annual abstraction required from each well to produce two crops requiring 3000 hours of pumping would therefore be 0.039 Mm3 and the total annual abstraction from the 171 dug wells in the area would be 6.5 Mm3/y. This is the same as the estimated recharge, although the actual abstraction may vary each year due to reduced water levels, exceptional spates, or the number of pumps in use.

57. Groundwater quality within the Wadi Timnan catchment is generally suitable for irrigation, although water chemistry data are very limited (Appendix 2). EC values of 1000 mS/cm are typical in most areas, although higher values up to about 2300 mS/cm are reported in the Wadi Furuqiyah. The poorer water quality is thought to be associated with the western sub-catchments (which receive less recharge) and to the underlying bedrock.

Groundwater Potential

58. Preliminary groundwater resource estimates suggest that the pumping capacity is similar to the annual average recharge. Overexploition could even be occuring in the western part of the catchment. Local factors, such as the size of individual sub-basins, rock bars, or cemented beds, are particularly important in these small wadis but cannot be taken into account in either the recharge or storage estimates with the existing information available. Consequently, the sub-basins will need to be surveyed prior to any further development. In addition, given the rapid development of groundwater in this area and the shallow depth to water level, very likely that farmers will continue to dig new wells without assistance from

the project.

59. Although the baseflow in the Wadi Mardaba suggests that the available groundwater is not fully utilised in this particular sub-catchment, the development of this resource is limited by the lack of land suitable for cultivation.

60. Most of the existing wells are dug to bedrock. The upper part of the bedrock may offer some limited potential where fractured and this is being investigated by the Soviet-Yemeni project. However, since the fractures are localised and merely draw upon storage in the overlying alluvium, they should not be considered as an additional resource.

61. Wells rather than boreholes are more appropriate for these shallow aquifers as they can be constructed, operated and maintained at lower cost, have a longer life (when lined), and are operated at a lower rate thereby allowing greater use of the available storage. Buried pipe systems, which were proposed for trials in the project, are not considered to be a practical option to dug wells as their shallow depth (2 to 3m) makes them susceptible to seasonal and longer term variations in water level

C. Wadi Maadin

Data Availability

62. Except for some additional lithological and pumping test data from two boreholes drilled in 1984 in the Toor el Baha wellfield, the Tecneco study undertaken in 1978/9 still remains the major source of hydrogeological information. The collection of time-varying data effectively ceased on completion of the Tecneco study. The lack of such data is a constraint on defining the variation in groundwater resources availability and the aquifer response to abstraction.

63. The geometry of the aquifer system has been reasonably well defined by the Tecneco study. Map 8 shows the saturated aquifer thickness based on water level data and 81 vertical electrical soundings (VES), although the calibration of the geophysical data was based on only two borehole logs and the broad lithological variations have not been investigated.

64. Twelve pumping test were undertaken to estimate aquifer characteristics, although data interpretations were only possible for seven sites. Only one borehole was tested: the other tests were carried out on partially penetrating, large diameter wells at rates of 8 to 20 l/s for 8 to 10 hours. The results of these tests are included in Appendix 2. No tests were undertaken in the lowest part of the catchment nor to examine the hydraulic characteristics of the weathered zone or fractures in the underlying bedrock.

65. At two sites a nearby well was used as an observation well from which specific yield values of about 2 to 3% were derived. These values are exceptionally low for this type of sequence and are considered to reflect the short duration of the test (or perhaps an analytical error since the sites also have the highest transmissivity values). Pumping tests, particularly of short duration, tend to underestimate the true specific yield and studies in the other wadi systems[2] suggest that specific yields of 15 to 20% would be more representative of the wadi channel deposits.

66. An inventory of wells and boreholes carried out in 1978 from the YAR border just above the gorge to Khatabiyah identified 50 dug wells and 8 boreholes (Map 7.). Information was collected on depths, water levels, electrical conductivity (EC), pump type, status and elevation. Estimates were made of the pumping rate, daily duration of pumping and the monthly and annual abstraction from each well and borehole.

67. Water level surveys were made on each well and borehole in August 1977, February and October 1978, and January/February 1979. An automatic water level recorder was fitted to a borehole (W51) situated in the lower part of the study area for which data were obtained for March 1978 to February 1979.

68. Nine water samples were obtained (mainly at the pumping test sites) in May 1978 for chemical analysis of the major cations and anions. These results are given in Appendix 2. Two tritium analyses were also carried out but no bacteriological analyses were undertaken.

69. A meteorological station was established at the Wadi Maadin State Farm (elevation 530 m) but data are only available for 1977/8 and 1982. A new station was established at the same location in February 1990. There are no rainfall data for the upper part of the catchment.

70. Two gauging stations were set up at Toor el Baha and 5km downstream but only provided some limited stage information. These are to be rehabilitated by the UNDP programme. The only flow estimates available are of two floods in September 1973 of 314 m3/s and 3.4 m3/s. The catchment area is shown in Map 6.

71. The hydrogeological information was presented as a series of maps at 1:20,000 scale showing the location of wells and boreholes, depth to water level, transmissivity, saturated aquifer thicknesss, and electricity conductivity (EC). A water level map was prepared during the Identification Mission (Map 7). The distribution of data collection points is shown in Map 8.

72. The total annual abstraction in 1978 was estimated to be 5.77 Mm3/y, as shown in Table 6. This comprised 5.59 Mm3/y from 31 wells (62% were operational) and 6 boreholes in operation for irrigation supplies and 0.18 Mm3/y for municipal supplies. The net abstraction for irrigation (assuming 25% conveyance losses) was 4.2 Mm3/y. Table-7 shows that 70% of the irrigation abstraction took place along a 7km length of the wadi below Toor el Baha.

Groundwater Resource Estimates

73. Tentative groundwater balances were prepared by Tecneco in 1979 and by the Identification Mission in 1989. These indicated deficits of 0.1 and 0.5 Mm3/y respectively. Values adopted for these estimates are summarized in Table 8.

74. A revised average year groundwater balance is given in Table 9, which is based in part on ~~includes~~ information given in ~~from~~ Annex 2. This indicates an average annual recharge of 7.8 Mm3/y compared to 8.8 Mm3/y derived by the GIM from throughflow estimates. The balance indicates a loss of 0.6 Mm3/y in 1978/9. The increase in abstraction since that time would be derived from throughflow and storage.

75. The total saturated aquifer volume was estimated by Tecneco to be 254 Mm3 but this took no account of the porosity. Their adopted value for specific yield would suggest an available storage of only 5 Mm3. A more realistic estimate based on a specific yield of 20% is 50 Mm3, as given in Table 7 for each sub-basin.

76. Estimates of the actual situation in 1978/9 can be estimated from the water level hydrograph from borehole W51, assuming this to be representative of the whole aquifer area of 12.67 km2. These are as follows: recharge 1.0 Mm3; outflow 3.2 Mm3 with a ~~and the~~ net loss in storage 2.2 Mm3. The total decline in water level during the year was 0.85m.

77. The number of wells had increased from 50 to 95 by 1988 and there is now reported to be 116 wells and 12 boreholes. The present abstraction is uncertain due to the effects of the decline in water levels. Assuming that 60% of the wells are in use, the annual abstraction from wells for irrigation would be about 9.75 Mm3. Monitoring of the output from the Toor el Baha wellfield began in February 1990 and it is estimated that the annual abstraction is about 0.6 Mm3/y. The eight boreholes used for irrigation are estimated to have an annual output of 1.3 Mm3. The present total abstraction is therefore estimated as 11.6 Mm3/y. The net abstraction is about 8.25 Mm3/y (assuming 25% of the irrigation abstraction returns to the aquifer), an increase of about 4 Mm3/y since 1978.

Development Potential

Wadi Maadin

78. Abstraction is exceeding recharge in the Wadi Maadin. Water levels have declined by about 10 m over the past 10 years and wells are now going dry or suffering a cutback in abstraction. There are also reports that the salinity has increased over the past 5 years. The main agricultural area south of Toor el Baha will be affected by any development of the water resources upstream.

79. Whilst the undeveloped southern part of the Wadi Maadin has a large available storage (Table 7), this area receives very infrequent recharge and has a poor water quality (EC 3000 to 4000 mS/cm) which is generally unsuitable for irrigation.

80. Any further development of groundwater in the Wadi Maadin would be inadvisable. The situation will be updated by the UNDP/MAAR training project over the next 12 months but, even so, additional monitoring data will be required to ensure better management of the resources.

IV. PROPOSALS FOR FUTURE DEVELOPMENT

A. Strategy

General

81. The availability of irrigation supplies in this part of PDRY is limited by a combination of low rainfall, small catchment areas, and the occurence of thin aquifers of limited extent and storage capacity that are sensitive to natural or induced changes in the hydrological regime. Hence, in contrast to the much larger primary wadi systems in other parts of PDRY, the opportunity for agricultural development and expansion based on improved spate diversion and the intensive and widespread use of groundwater is much more limited. There is a strong risk that investment will not be appropriately targeted and only limited benefits achieved or sustained if development proceeds on the limited information available regarding these small wadi systems.

82. The rapid development of groundwater for irrigation in the Project Area has been due to several factors: groundwater occurs at shallow depth enabling supplies to be obtained from dug wells; benefits in crop production from the better security of groundwater supplies; and income from expatriate

earnings to construct wells and purchase pumps. The benefits of groundwater irrigation may, however, be low at present because traditional farming practices have not altered accordingly.

83. Preliminary estimates of the groundwater resources within each priority area are summarised in Table 10. Despite the uncertainty of these estimates, the groundwater resources of the small wadis are limited and the aquifers are already extensively exploited by the local farmers such that the pumping capacity is similar to or exceeds the average recharge. The present decline in water levels must raise concern for the long term stability of these secondary wadi systems and therefore the potential for further development: only the Ras al Ara delta can be considered on the basis of existing information as still having potential groundwater resources to be developed.

84. Due to the variability of rainfall-runoff each year, the concept of average annual recharge can be misleading and aquifer storage plays an important role in maintaining supplies during periods of reduced recharge. The available storage in the small wadi systems is limited. Well deepening or the increased use of boreholes in order to command more of the storage would increase the overall absraction capacity. This would then be more likely to lead to a long term depletion in storage and to a more rapid seasonal decline in water levels.

Outline Strategy

85. The need for more hydrogeological investigations to determine how additional pump irrigation would affect the water balance of small catchment systems was identified by IFAD in their special programming mission to PDRY in 1985/. Although this referred to the mountain areas, it can equally applied to the wadi systems in the Toor el Baha District. Normally, a phased investigation and monitoring programme would be required to assess the groundwater resources more accurately and to update the current level of abstraction and pumping capacity in relation to these resources prior to further irrigation development.

86. A phased approach, whereby investigation preceded development, was proposed in Annex 2 (Water Resources) of the General Identification Report due to the uncertainty of the resource estimates. However, this approach was modified subsequently so that investigation and development could proceed at the same time thereby reducing costs and producing earlier benefits to the project. Each successful exploration site yielding more than 10 l/s would be brought into supply. A success rate of 60% was adopted to give 30 new boreholes abstracting a total of about 5 Mm3/y. This would enable an area of some 360 ha to be developed. No further development was proposed in Wadi Maadin as this area was considered to already be over-exploited and the new boreholes would be drilled in Wadi Timnan and Ras al Ara.

87. A "rolling programme" has a major limitation in that it takes into account only the local aquifer conditions and not the ability of the aquifer system as a whole to sustain such development in the long term or during periods of reduced recharge. In effect, the resources become developed before they have been quantified. Given the uncertainty in the available

resources a more cautious, phased development based on a more thorough understanding of the spatial distribution and annual variation in the availablity of the water resources will be more likely to produce greater and more sustained benefits in the longer term and ~~should~~ be the ~~proffered~~ recommended approach.

88. The other wadis within the Toor el Baha district are expected to have similar conditions to those of Wadi Maadin or Wadi Timnan and to have the same resource constraints. Future development of these areas must ensure that abstraction does not permanently deplete aquifer storage by relating agricultural improvements to the resources available.

89. The revised strategy now proposed would involve adapting existing irrigation and agricultural practices to make better use of the scarce water resources throughout the whole district. The first phase would develop a data base of information that can be applied to the other wadi systems in the Toor el Baha District to allow more effective use of these resources. The main objective would be to gain a greater understanding of these small wadi systems and how the water resources can be used in conjunction without long term adverse effects on the aquifer. Subsequent development would take place during a second phase.

90. Phase 1 of the programme would focus on the Wadi Maadin, where the aquifer geometry is fairly well known. It would continue the collection of monitoring data and other studies being undertaken by the UNDP Water Resources Management Training Programme due to be completed at the end of 1991. Data collection in the upper part of the catchment would be coordinated with the YAR authorities through the YJPNR Water Resources Monitoring Network programme due to start in 1990. The hydrogeological data

would be integrated with the water resources, irrigation, agricultural and socio-economic surveys to enable the results to be applied to other wadi systems between Toor el Baha and Al Shatt in particular.

91. The programme would also extend to the Wadi Timnan above Al Shatt to expand the results of the Soviet-Yemeni reconnaissance survey, mainly by providing time-varying data. The results would be applicable to the minor wadis west of Al Shatt.

92. A resistivity geophysical survey would be undertaken in the Ras al Ara delta to extend the drilling programme results and resource estimates being undertaken by the Soviet-Yemeni Project. This survey would help to define areas of poor quality water and the aquifer thickness and would be integrated with the results of associated surveys relating to agriculture, spate use and socio-economic factors. Should these surveys show a favourable development potential, then a drilling programme would be undertaken in a second phase of the project.

B. Data Networks

Wadi Maadin

93. Water level changes and trends would be related to wadi flows and patterns of abstraction in each sub-basin. Five automatic recorders would be fitted to disused wells and boreholes: 3 at locations along the wadi and 2 at peripheral locations away from the channel. These would supplement the two recorders to be installed by UNDP/MAAR. Additional information would be obtained from repeat water level surveys of existing wells at appropriate

intervals, with increased frequency during the flood seasons.

94. A representative sample of ten dug wells and boreholes would be selected covering the area to monitor abstraction rates and duration of pumping. Discharge meters and operation recorders would be installed for this purpose.

95. Thirty water samples would be collected. These would be used in particular to examine the suitability of groundwater in the lower sub-basin for irrigation. EC would be monitored at quarterly intervals at selected wells to establish seasonal or longer term trends in water quality.

96. An assessment would be made as to whether the existing wells could be replaced by boreholes to draw upon the deeper part of the aquifer in order to utilise storage to maintain irrigation during years of reduced recharge, or whether a programme of well deepening would be more appropriate for the same purpose. This would involve comparing well depths to information on the depth to the base of the aquifer obtained during the Tecneco study.

97. In cooperation with the YAR authorities two rain gauges would be installed in the upper catchment.

98. Specific yield would be estimated by monitoring water levels in three disused boreholes or wells in the wellfield area and relating these to the metered abstraction.

99. An appropriate groundwater data base would be provided for the Water Resources Section of ~~DIME~~ the Department of Irrigation in Aden capable of storing and presenting the spatial and time varying information as tables, figures and maps. This would also be used to undertake a more rigorous appraisal of the Tecneco data and provide additional training for the staff of the Water Resources Section.

Wadi Timnan

100. An electro-magnetic (EM) geophysical survey would be undertaken in selected areas of the Wadi Mardaba and Wadi Harhar for ~~the~~ a rapid appraisal of the thickness of the wadi deposits.

101. A meteorological station would be established at Al Shatt. Three raingauges would be installed in the upper catchments and read by local observers.

102. By arrangement with local farmers, pumping tests of at least 24 hours duration would be made ~~on~~ at 10 ~~selected,~~ sites with closely spaced wells to provide information on transmissivity and specific yield.

103. Water levels would be monitored on three selected disused wells using automatic recorders to establish seasonal and long term trends.

Ras al Ara

104. An electrical resistivity survey will be undertaken using vertical electrical soundings over an area of about 25 km2 extending north of Gudeima-Uzeifah to investigate the aquifer. The information obtained would be integrated with the Soviet-Yemeni survey information to provide a better understanding of the areal variation in aquifer conditions.

C. Staffing

105. It is assumed that support staff (engineer, technician and observer) would be provided from the Water Resources Section of the Department of Irrigation and Land Reclamation. The experience gained by this section from the UNDP training programme in the Wadi Maadin would be a particular advantage.

106. A UN volunteer would be recruited for the duration of the study to supervise the collection of data and analyse the results. Technical support would be provided by a hydrologist and a hydrogeologist who would both visit the area twice per year. A geophysicist would supervise the geophysical survey and interpret the results.

). Costs

107. Costs for the proposed programme of works relating to the groundwater aspects of the First Phase are given in Annex The total investment cost is 0.45 M$US.

Issues

108. It should be recognised that the groundwater resource estimates and development potential are based on various assumptions due to the limited availability of data, notably on the aquifer characteristics and time-varying parameters. A water balance approach has limitations when applied to semi-arid zones due to the uncertainty in each measured parameter and may require 10 to 15 years of data collection to provide a representative sample of the hydrological variations. An approach based on water level data and specific yield can produce more reliable results but also requires a monitoring programme and representative values of specific yield.

109. Conflicting information was received from the MAAR and Ministry of Planning as to whether the information being collected by the Soviet -Yemeni project would be available for Phase 1. The level of detail that this survey will be able to provide is also uncertain.

110. It is assumed that the results from Phase 1 would be applicable and capable of being replicated in the other wadis in Toor el Baha District, in a second phase of the project.

111. Follow up issues include:

The plans of the UNDP-MAAR study for Wadi Maadin were still being finalised at the time of the mission and need to be examined.

The area of cultivation throughout the district could be assessed by the digital interpretation of satellite imagery. It was not possible to undertake this during the Preparation Mission and this should be carried out before the appraisal stage. A listing obtained from the Remote Sensing Unit of FAO indicated that TM scenes for 18 October 1987 and SPOT scenes for 29 August 1986 are likely to be the most cloud free. The images for these dates should be inspected prior to obtaining the tapes.

- A new Water Act is understood to be in preparation which could have a bearing on the future groundwater development and management in the Project Area.

ANNEX 3

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

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ANNEX 3
Table 1

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Areas Commanded by Wells

	Wells only (ha)	Wells and Spate (ha)	Total (ha)	Average area/well (ha)
Ras al Ara		12	12	
Wadi Timnan	20	430	450	2.5
Wadi Maadin	30	620	650	5.0

format as other tables

ANNEX 3
Table 2

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Ras el Ara Delta
Dug wells

Village	Depth (m)	Rest Water Level Depth (m)	Rest Water Level Estimated Elevation (m. asl)	Distance from Coast (km)
Huwayrib	20	10	140	25
Uzeifah	38	31	20	6
Gudeimah:				3
Sabil	22	20	5	
Gennah	18	20		
Hagah	12			
Al Barodh		12		

ANNEX 3

Table 3

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Wadi Timnan: Pumping Tests

Location	Total Depth (m)	Depth to Bedrock (m)	Saturated alluvial thickness (m)	Rest Water Level (m)	Q (l/s)	Q/s (l/s/m)	T_2. (m^2/d)
Upper Mardaba	13.7	6.8	3.5	3.3	8	2.3	250
Lower Mardaba	15.5	6.5	3.5	3.0	8		1,800
Am Shatt	11.0		>6.3	4.7	7	10	1,075

Source: Soviet-Yemeni Project. Test data not yet analysed. Transmissivity (T) is based on Logan's approximation method.
Q/s Specific capacity.

ANNEX 3
Table 4

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Wadi Timnan: Catchment Areas

Sub-Catchment	Area within YAR (km^2)	Area within PDRY (km^2)	Total (km^2)	MAR (Mm^3/y)	MAF (m^3/s)
Wadi Mardaba (up)	32	28	60	1.4	28
Wadi Mardaba (down)	13	15	28	0.4	17
Wadi Harhar	65	43	108	1.6	44
Wadi Hagrah		24	24	0.33	15
Wadi Furugiyah		53	53	0.75	25
			273	4.5	129

Areas within YAR 200 mm rainfall
" " PDRY 180 mm rainfall
Runoff co-efficient 0.075
Areas based on graphical estimation
MAR: Mean Annual Runoff
MAF: Mean Annual Flood (based on ~~Binnies~~ 1988)

ANNEX 3
Table 5

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Wadi Timnan: Estimates of Aquifer Storage

Sub-catchment	Agricultural Area km^2	Number of wells	Annual Abstraction Mm^3	Storage Mm^3	Porosity Mm^3	Storage change/m Mm^3
Wadi Mardaba (up)	0.35	29	1.13	0.5	0.75	0.11
Wadi Mardaba (down)	1.0	56	2.18	1.5	2.0	0.29
Wadi Harhar	8.1	19	0.74	11.5	17.0	2.4
Wadi Hagrah	0.6	15	0.58	1.0	1.25	0.18
Wadi Furuiyah	1.0	52	2.03	1.5	2.0	0.29
	11.05	171	6.66	16	23	3.27

Abstraction: Average/well 0.39 Mm^3/y
Storage: (Sy) 20%; average saturated thickness 7m; ~~in~~ agricultural areas only.
Porosity: 30%

Specific yield

ANNEX 3
Table 6

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Wadi Maadin: Groundwater Abstraction for Irrigation 1977/78

Number of wells	50
Number of boreholes	8 (2 not in use)
Wells used for irrigation	31 (62% total)
Number of wells not pumping abandoned or dry, or for local drinking water	19
Average pumping rate all sources	14.6 l/s
wells	13.5 l/s ~~(range 6 to 20 l/s)~~
Annual abstraction: wells	4.3 Mm^3
boreholes	1.3 Mm^3
Total annual abstraction	5.6 Mm^3
Average pumping rate boreholes (6)	20 l/s ~~(r 5-20 l/s)~~
Average depth dug wells	20.0 m (r 4.3 ~~31.5m~~)
boreholes	47.m (r ~~31-69m~~)

ANNEX 3
Table 7

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

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Estimates of Abstraction (1978/79) and Available Groundwater Storage by Sub-basin in the Wadi Maadin

Sub-basin	Abstraction Mm^3/y	Available Storage 1/ Mm^3
1. Above gorge	0.38	(no estimate)
2. Toor el Baha Well field	0.72	11.7
3. El Khazaga	1.13	1.0
4. Maridiah	2.83	13.7)
		) EC 2500-4000 $\mu S/cm^2$
5 Khatabiyah	0.52	24.4)
	5.58	(50.8)

1/ Specific yield 20%
Area of aquifer 12.67 km^2
Based on Tecneco 1979

ANNEX 3
Table 8

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Summary of Parameter Estimates used for Groundwater

Resource Estimates

	Tecneco (1979)	Identification (1989)	Preparation
Irrigation return (%)	40	30	25
Rainfall recharge (Mm^3/y)	0.5	Nil	Nil
Rainfall (mm)	500	400	375
Runoff co-efficient	0.16	0.12	0.10
Mean Annual run-off	32	19	15
Borehole abstraction - total Mm^3/y	6.0	12.3	11.3
Specific yield (%)		2 - 4	20
Transmissivity (m^2d)	864	700	700
Aquifer width (m)	900	1,300	900
Resource availability (Mm^3/y	-0.1 (-1.5)	0.5	-3

ANNEX 3
Table 9

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Groundwater Balance for Wadi Maadin (Mm^3)

Mean Annual Runoff		15	
Irrigation Diversion		9	
Field return			1.8
Wadi channel recharge and subsurface inflow			6
Rainfall recharge			Nil
Total annual average recharge			7.8
Abstraction:			
1978/79	Total	5.9	
	Net (25% return)	4.4	
1988/89	Total	12.3	
	Net (25% return)	9.4	
Underflow output 1978/79		4.0	
Balance 1978/79	7.8 - (4.4 + 4.0) =	0.6 Mm^3 (-0.24 m) 1/	

1/ Aquifer area 12.67 km^2, specific yield 20%.

ANNEX 3
Table 10

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Summary of Groundwater Resource Estimate

Potential Availability

Area	Mean Annual Run-off Mm^3	~~Annual Average Recharge~~ 1/ Mm^3	Aquifer Storage Sy %	Aquifer Storage Total Mm^3	Aquifer Storage Exploitable Mm^3	Annual Abstraction Total Mm^3	Annual Abstraction Net Mm^3
Ras al Ara	12	5-10 ~~6~~ 4/	5	200	25	0.25	0.2
Upper Wadi Timnan	4.5	6.4 ~~6.4~~ 3/	20	16	10	6.5	4.9
Wadi Maadin	15	7.8	20	50	25	11.7	8.8

1/ Aquifer throughflow. Actual availability will be less than average recharge.

2/ Tersch (1979) estimate 5.6 Mm^3/y.

3/ Based on seasonal charge in water level of 2m.

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Estimates of Groundwater Pumping Costs

A. RAS AL ARA

Borehole Depth 75 m, at YD 175/m	13,125
Casing 10-inch, 50m, at YD 25/m	1,250
Screen 10-inch, bridge slot, 25m, at YD 40/m	1,000
	15,375

Pumping Rate (Q) 15 l/s 54 m^3/h
Head (H) 40 m

WHP $15/\frac{1,000 \times 1,000 \times 40}{75 \times 0.75}$ 10.67 hp

Diesel level consumption (l/h) = 10.67 x 0.30 = 3.20 l/h
Annual consumption 3,000 hrs x 3.20 = 9,600 l/y
Fuel cost 0.10 YD/l x 9,600 = 960 YD/y

Borehole	15,375
Pump, shaft driven NP 23	1,250
Engine, NP 23	1,430
Spares at 20%	536
Pump shed, tank and pipes	4,500
Well head	30
	23,121

Annual Fixed Costs:	Borehole depreciation (4%)	615
	Pump and engine depreciation (8%)	214
	Pump shed depreciation (4%)	180
		1,009

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Estimates of Groundwater Pumping Costs

Operating Costs:	Fuel		960
	Maintenance, servicing, oil (30% fuel)		288
	Pump attendant 365 d at 2.5 YD/d		912
			2,160
Cost per m^3 water:	(1,009 + 2,160)YD / 54 m^3/h x 3,000 h	3,169 / 162,000	0.0196 YD/m^3

20 fils/m^3 (excluding plant costs and interest charges)

Crop hectarage: Assume crop water requirement 7500 m^3/ha/crop

$\frac{54 m^3/ha \times 3,000 h}{7500}$ = 21.6 ha single crop, 10.8 ha double crop

Water costs: 7,500 m^3 x 0.0196 YD = 147 YD/crop ha x 21.6 ha = 3,175 YD

Interest charges at 10% on capital investment:

(a) Borehole and Pump/engine.

Interest on Plant costs YD 23121 = YD 2,312

Operation 3,000 h

Pumping rate 54 m^3/h

Interest on Plant costs	YD 2,312
Operation 3,000 h	0.77 YD/h
Pumping rate 54 m^3/h	0.014 YD/m^3
Total cost = 20 + 14	34 fils/m^3

(b) Pump and engine only

~~Pump and engine only~~ Interest on Plant costs	YD 2,680
Operation 3000 h	YD 268
Pumping rate 54 m^3/h	0.089 YD/h
Total cost = 20 + 1.6	0.0016 YD/m^3
	= 21 6 fils/m^3

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Estimates of Groundwater Pumping Costs

B. DUG WELLS

Cost of plant:	Dug well, assume YD 4,500			4,500
	Pump and Engine NP 16			2,250
	Spares at 20%			450
	Pump shed			200
				7,400
Annual Fixed Costs:	Well depreciation			-
	Pump and Engine depreciation (8%)			180
Operation Costs:				
	Well Depth (m)	10	30	30
	Head (m)	6	28	28
	Pumping Rate (m^3/h)	9	21.6	47
	Water Horse Power (hp)	0.96	10.75	23
	Diesel (l/h)	0.075	0.81	1.75
	Fuel 2,400 hours	180	1,935	4,211
	Fuel cost	18	193	421
	Maintenance, oil at 30% fuel cost	6	58	126
	Pump attendant			-
Cost per m^3 (YD)	$\frac{180 + 18}{9 \times 2,400}$ = 0.009		$\frac{180 + 251}{21.6 \times 2,400}$ = 0.008	$\frac{180 + 547}{47 \times 2,400}$ = 0.006
		9 fils	8 fils	6 fils
Interest:	Plant at YD 0.208/h	23 fils	10 fils	4 fils
Total cost/m^3, including interest		32 fils	18 fils	10 fils

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Pumping Tests Results, Wadi Maadin

		Tp m^2/d	TR m^2/d	D m	Q/s m^2d	S%
(a)	Dug Wells					
	W25	1,770	1,770	2.0	1,435	
	W33	630	690	6.9	420	
	W34 (observation)	525	2,505		-	2.75
	W36	630	595	n/r	660	
	W37	200	530	4.6	430	
	W38	390	390	6.9	245	
	W45	475	440	2.4	595	
	W47	670	1,440	4.9	390	
	Av	661	1,045		596	
(b)	Boreholes					
	WS2					
	TB Wellfield No. 2	865	1,235	40	520	
	TB Wellfield No. 3	630	645	n/r	800	
		690	725	26	1,055	

Source: Dug wells and borehole WS2 Tecnico 1978
Boreholes 2, 3 MAAR 1984

Tp Transmissivity, drawdown phase
TR Transmissivity, recovery phase
D Aquifer thickness penetrated
Q/s Specific capacity
S Storage co-efficient

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

Groundwater Analyses (mg/l)

Wadi Maadin

Well No.	W19	W25	W33	W37	W38	W42	W45	W47	WW52	TB3 1/
pH	7.7	7.7	7.55	7.6	7.55	7.5	7.55	7.5	7.5	8.1
EC mS/cm	970	1,135	1,465	2,072	3,581	2,590	2,755	2,645	3,140	1,483
TH ($CaCO_3$)	390	457	573	928	1,325	1,055	1,121	1,175	1,425	
Na	125	145	180	330	560	400	430	380	415	207
K	10.8	11.6	12.6	19.6	28	22.4	22.8	25.6	30	14.1
Ca	80	94	114	164	224	182	172	210	228	112
Mg	47	54	70	126	186	146	168	158	208	22
Cl	113	146	216	430	744	541	585	575	665	202
SO_4	138	188	2.607	530	900	680	660	680	950	208
HCO_3	433	411	417	473	421	426	482	405	387	325
Tot. Alk ($CaCO_3$)	355	337	342	388	345	349	395	332	317	
SiO_2	25.5	28	28	31	34.5	31.5	30	29	30.5	
NO_3	26.6	51	67.6	8.38	157	120	177	138	123	
TDS	805	951	1,200	2,025	3,150	2,420	2,582	2,496	2,960	1,097
SAR	2.73	2.95	3.27	4.69	6.67	5.35	5.58	4.81	4.76	

Toor el Baha Wellfield

PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

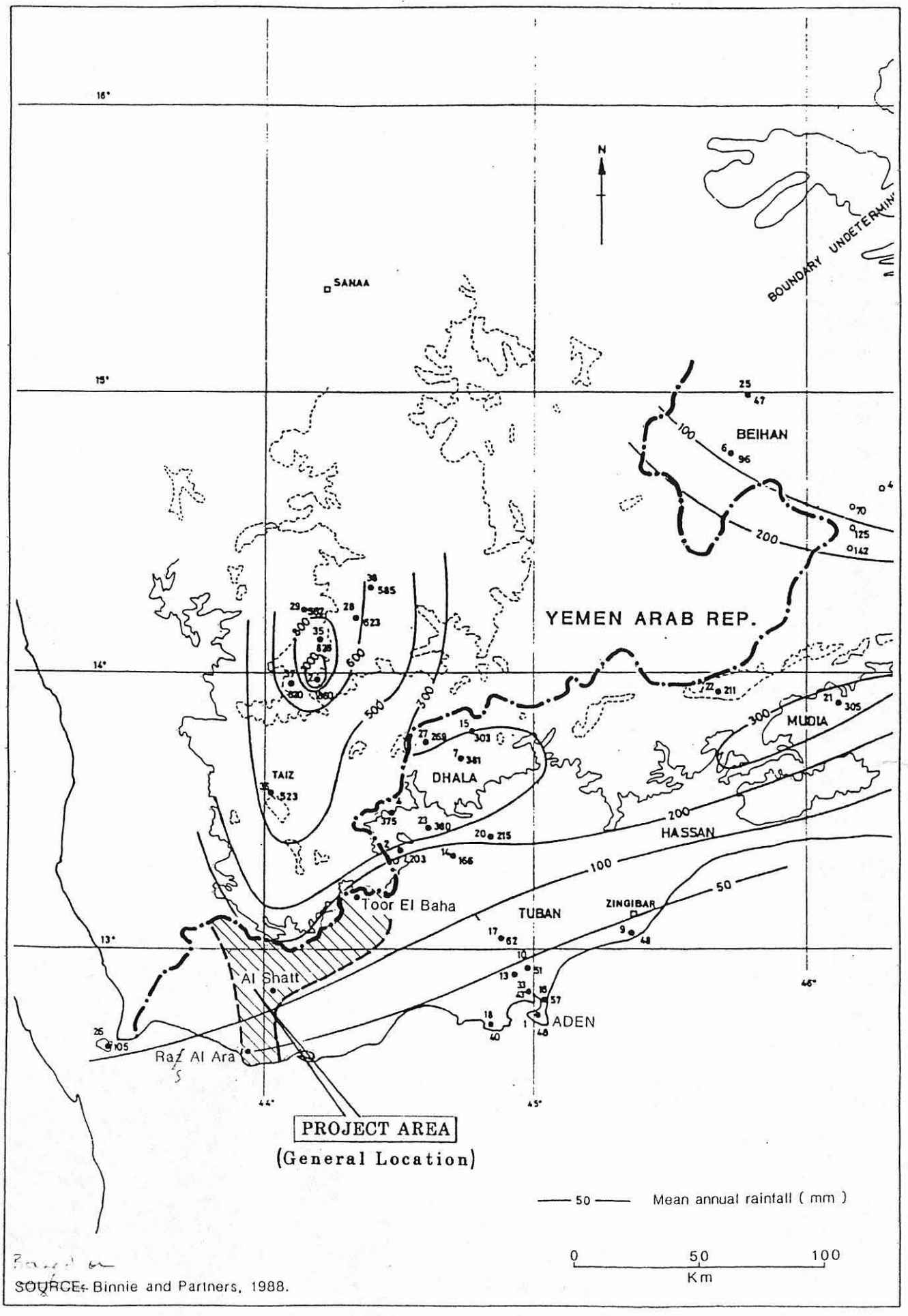
Groundwater Analyses (mg/l)

	Upper Wadi Timnan		Ras al Ara			
	Wadi Mudariba	Am Shatt	Bir Sahala (Huwayid)	Ali Abdulla well (Nuwayid)	Gudeimah well	Ras al Ara borehole
pH	8.5	8.3	8.5	8.5	8.2	8.5
EC mS/cm	923	2,982	1,420	1,562	4,970	2,556
Na	92	483	250	235	828	368
K	15.6	7.8	6.9	3.9	3.9	7.8
Ca	60	86	50	66	156	106
Mg	29	57	24	34	70	46
Cl	82	493	209	224	1,171	554
SO_4	120	504	269	232	662	288
HCO_3	281	317	171	207	152	195
TDS	622	1,967	972	1,091	3,044	1,577
SAR				5.8	13.8	7.5

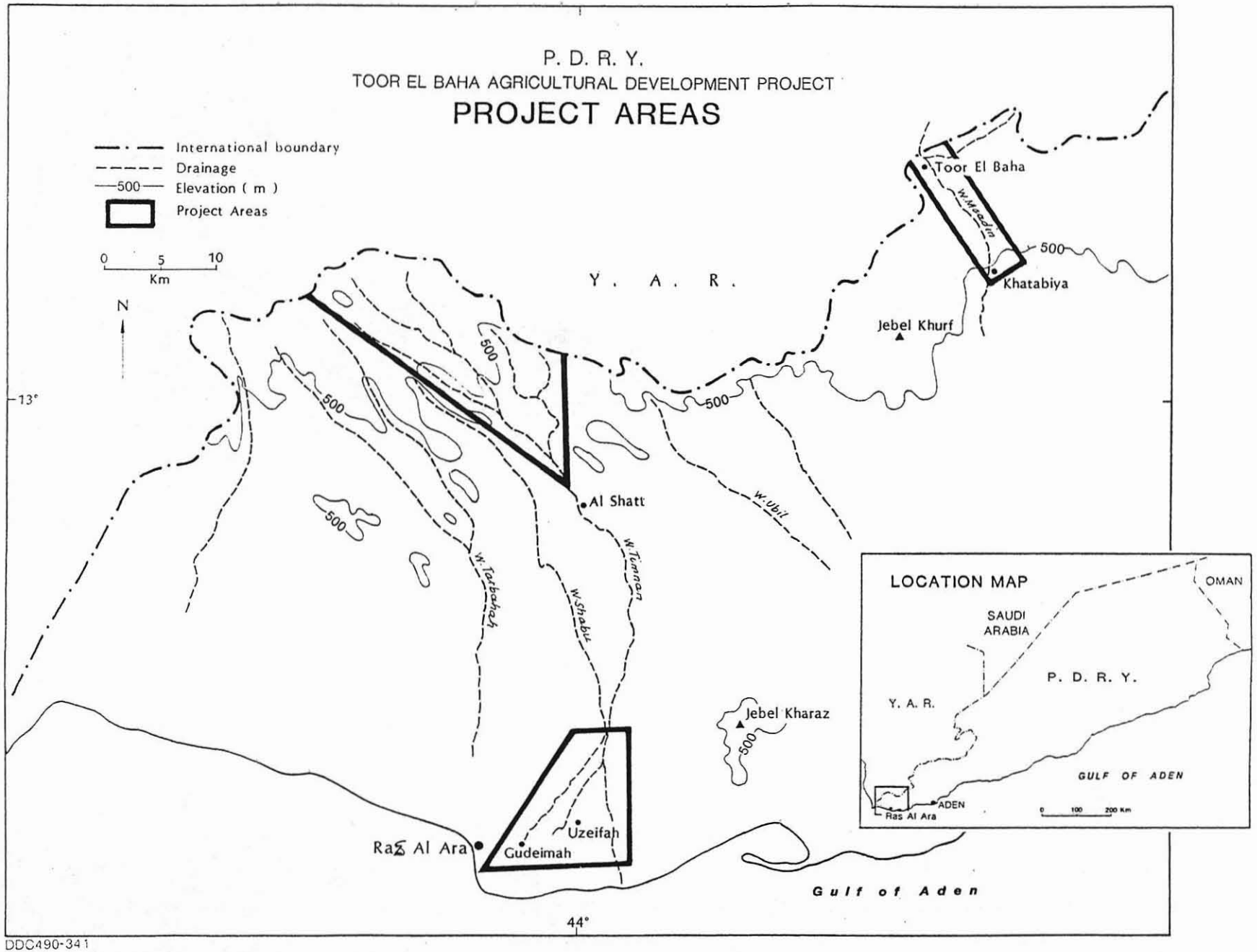
P.D.R.Y.

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

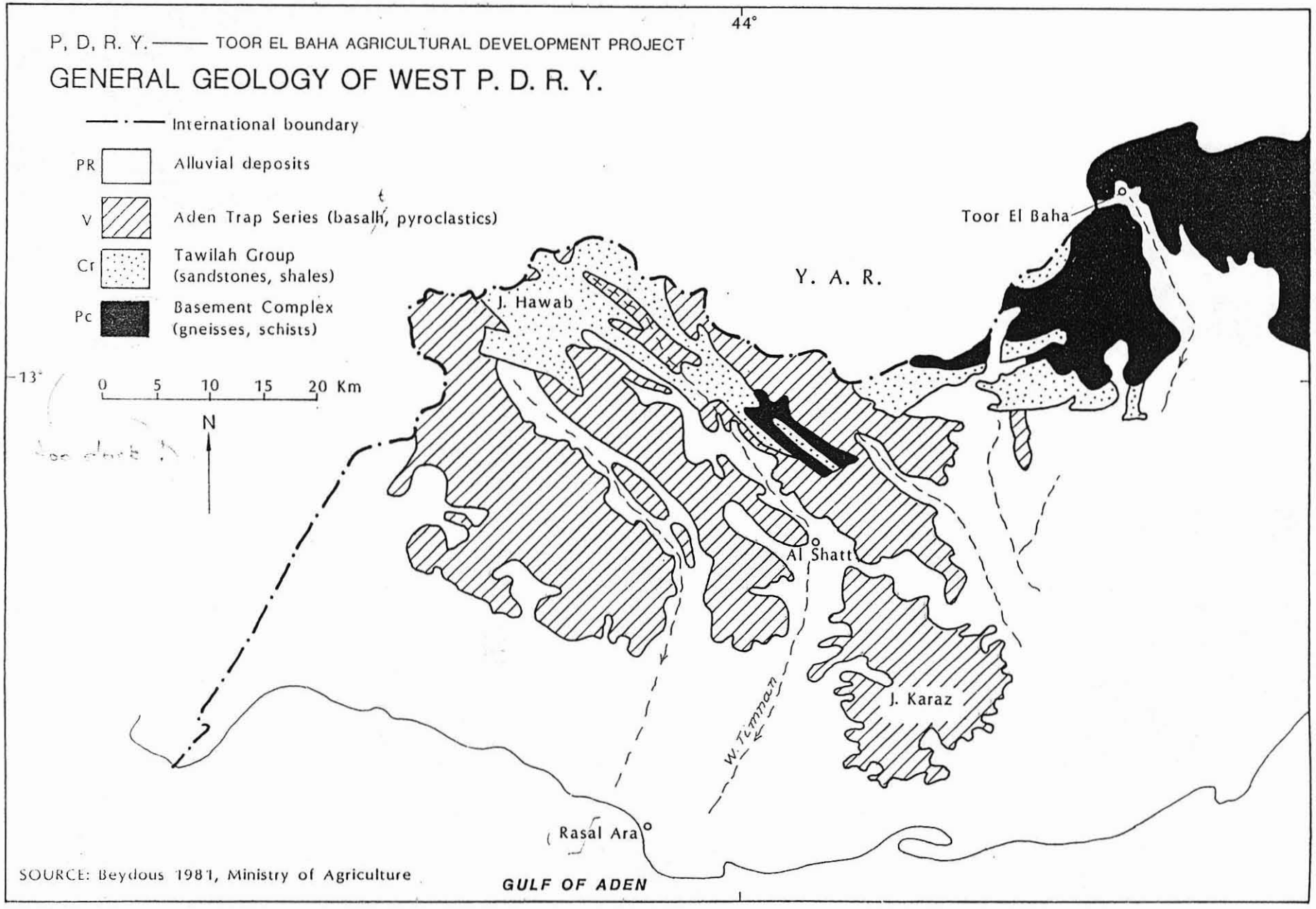
LOCATION OF PROJECT AREA



SOURCE: Binnie and Partners, 1988.


P. D. R. Y.
TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT
PROJECT AREAS
International boundary
Drainage
500 Elevation (m)
Project Areas
0 5 10
Km
N
Y. A. R.
Toor El Baha
W. Maadin
500
Khatabiya
Jebel Khurf
13°
500
500
500
Al Shatt
W. Ubil
W. Tarbahah
W. Shabit
W. Tamnan
Jebel Kharaz
500
Uzeifah
Gudeimah
Ras Al Ara
Gulf of Aden
44°
LOCATION MAP
OMAN
SAUDI ARABIA
P. D. R. Y.
Y. A. R.
GULF OF ADEN
ADEN
Ras Al Ara
0 100 200 Km

DDC490-341


P, D, R. Y. —— TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT
GENERAL GEOLOGY OF WEST P. D. R. Y.
44°
International boundary
PR
Alluvial deposits
V
Aden Trap Series (basalt, pyroclastics)
Cr
Tawilah Group
(sandstones, shales)
Pc
Basement Complex
(gneisses, schists)
13°
0 5 10 15 20 Km
N
Toor El Baha
Y. A. R.
J. Hawab
Al Shatt
J. Karaz
W. Tuban
Rasal Ara
GULF OF ADEN
SOURCE: Beydous 1981, Ministry of Agriculture

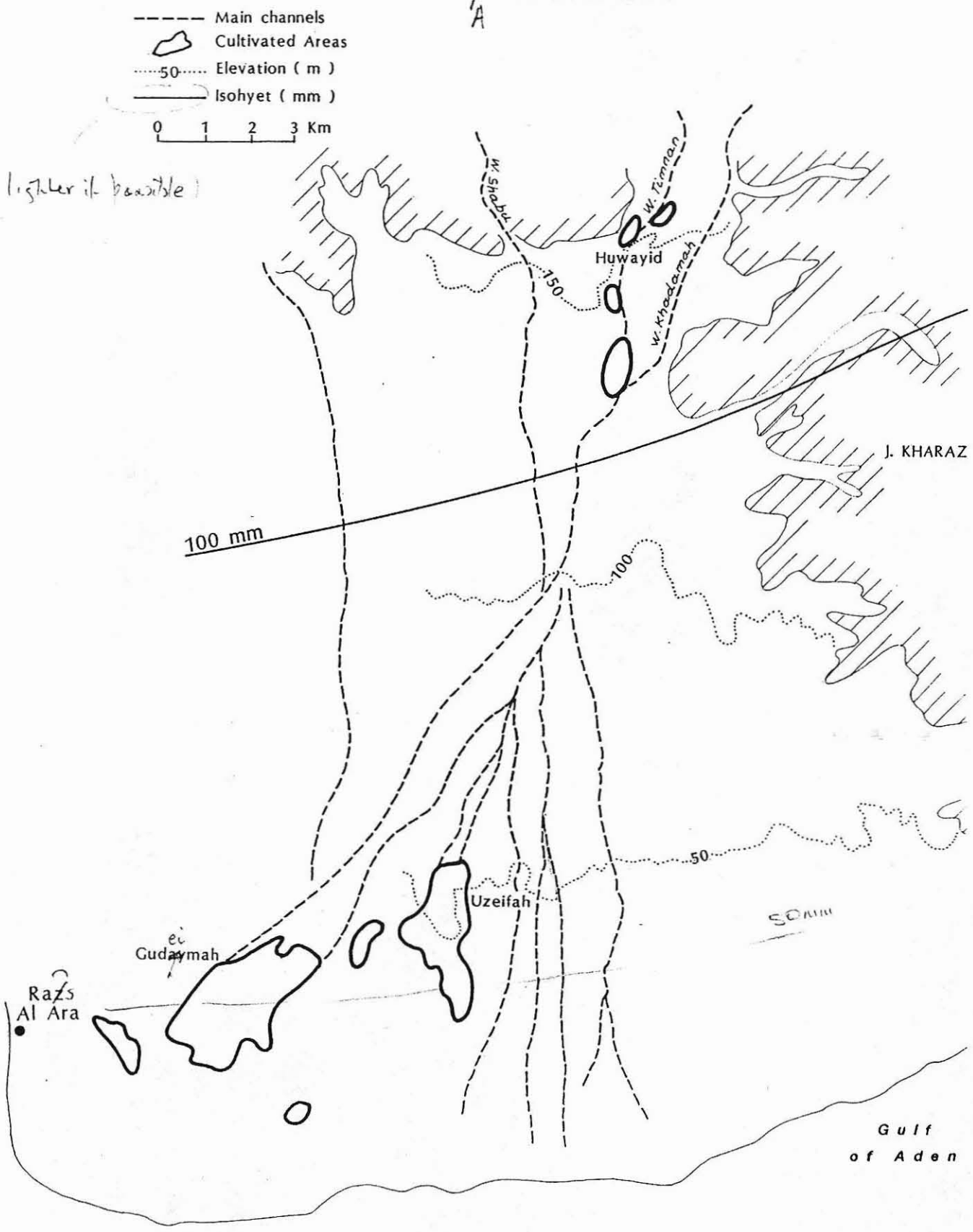
Map 4

BAHA

P. D. R. Y.

TOOR EL ARA AGRICULTURAL DEVELOPMENT PROJECT

RAS EL ARA DELTA



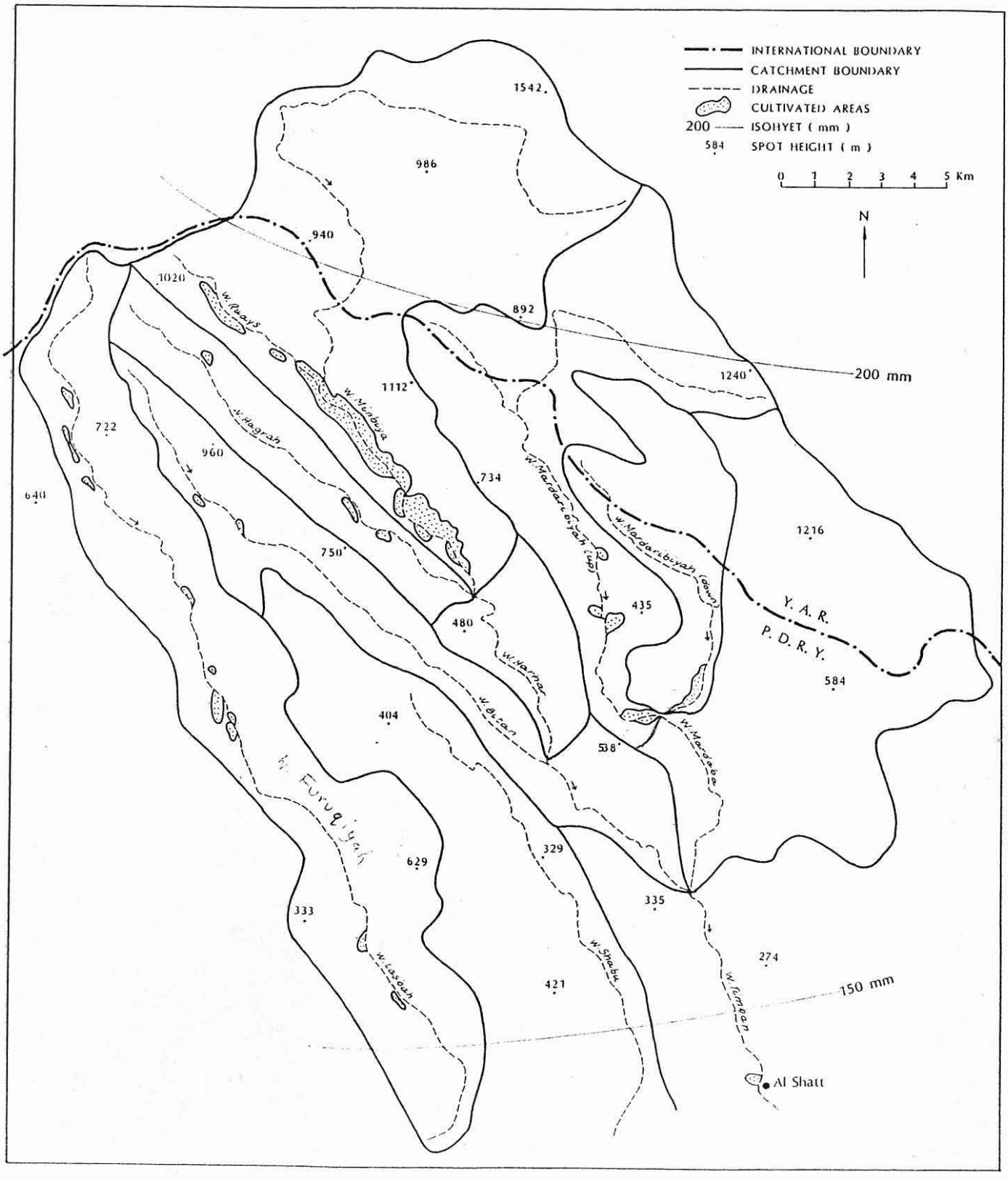
DDC490-345

Map 5

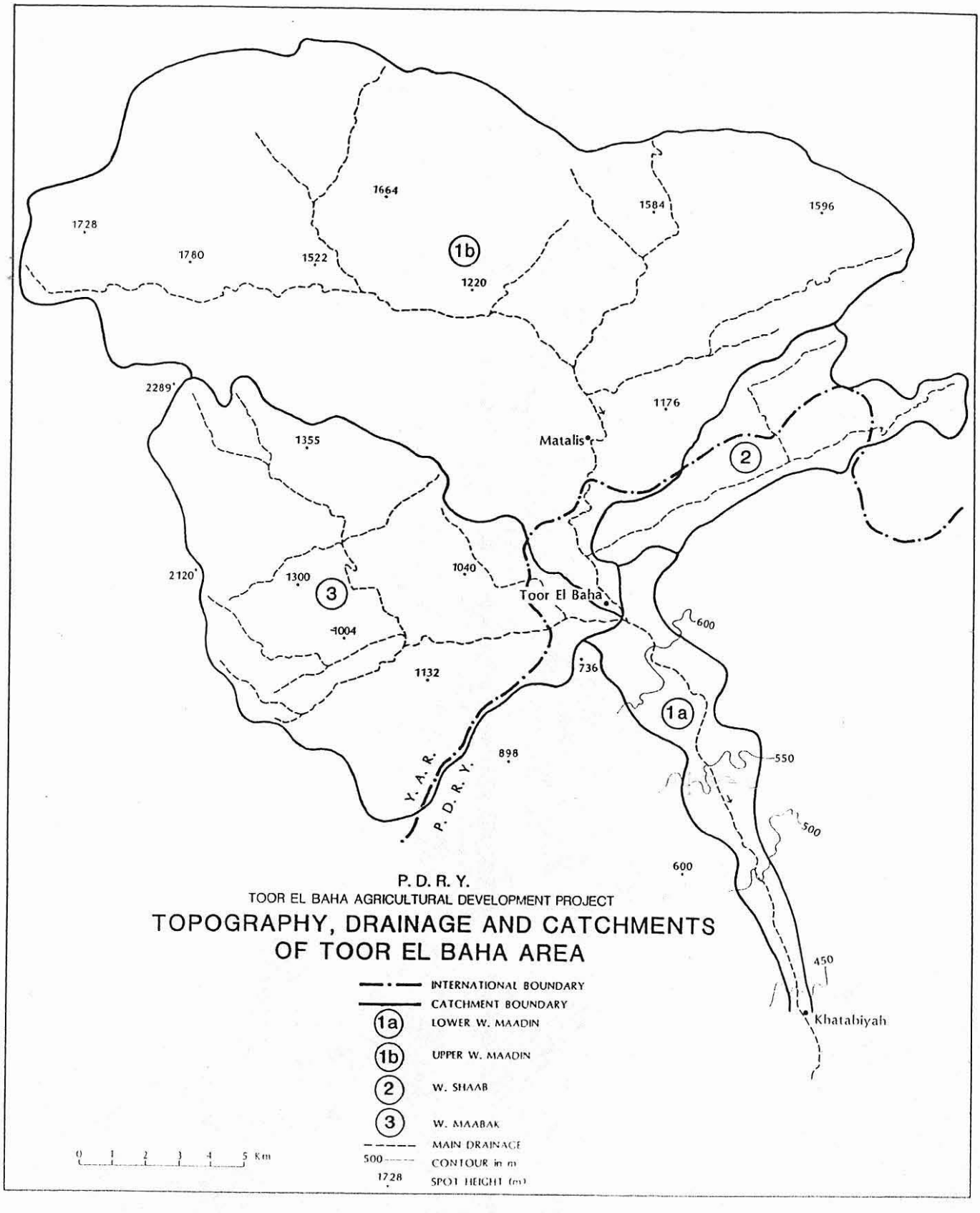
P. D. R. Y.

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

WADI TIMNAN
CATCHMENTS AND CULTIVATED AREAS



Map 6

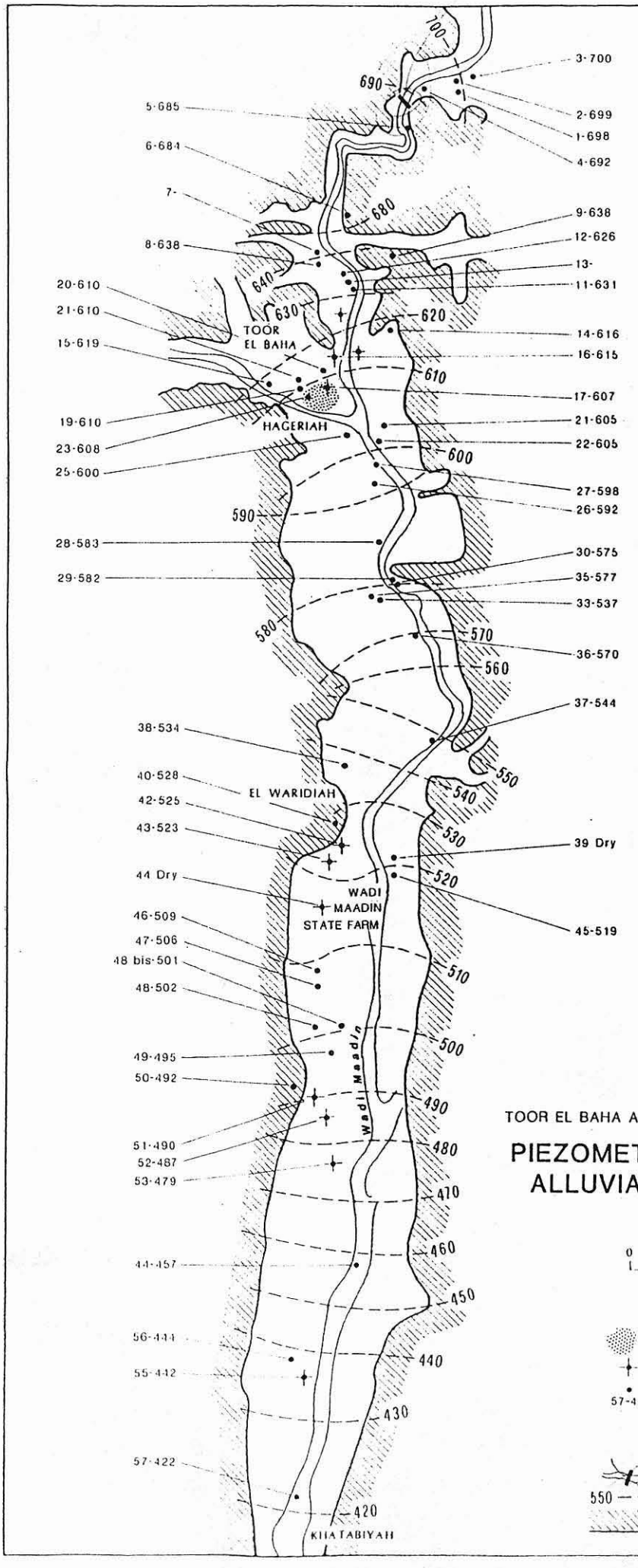


P. D. R. Y.

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

TOPOGRAPHY, DRAINAGE AND CATCHMENTS OF TOOR EL BAHA AREA

- INTERNATIONAL BOUNDARY
- CATCHMENT BOUNDARY
- (1a) LOWER W. MAADIN
- (1b) UPPER W. MAADIN
- (2) W. SHAAB
- (3) W. MAABAK
- MAIN DRAINAGE
- 500 CONTOUR in m
- 1728 SPOT HEIGHT (m)



NOTES:

- Not all wells boreholes are shown
- Some well location may not be entirely accurate
- Base map from TECNECO, 1979

P. D. R. Y.

TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT

PIEZOMETRY OF WADI MAADIN ALLUVIAL AQUIFER (1978)

0 1000 2000 m

WELLFIELD

BOREHOLE

DUG WELL

57-422

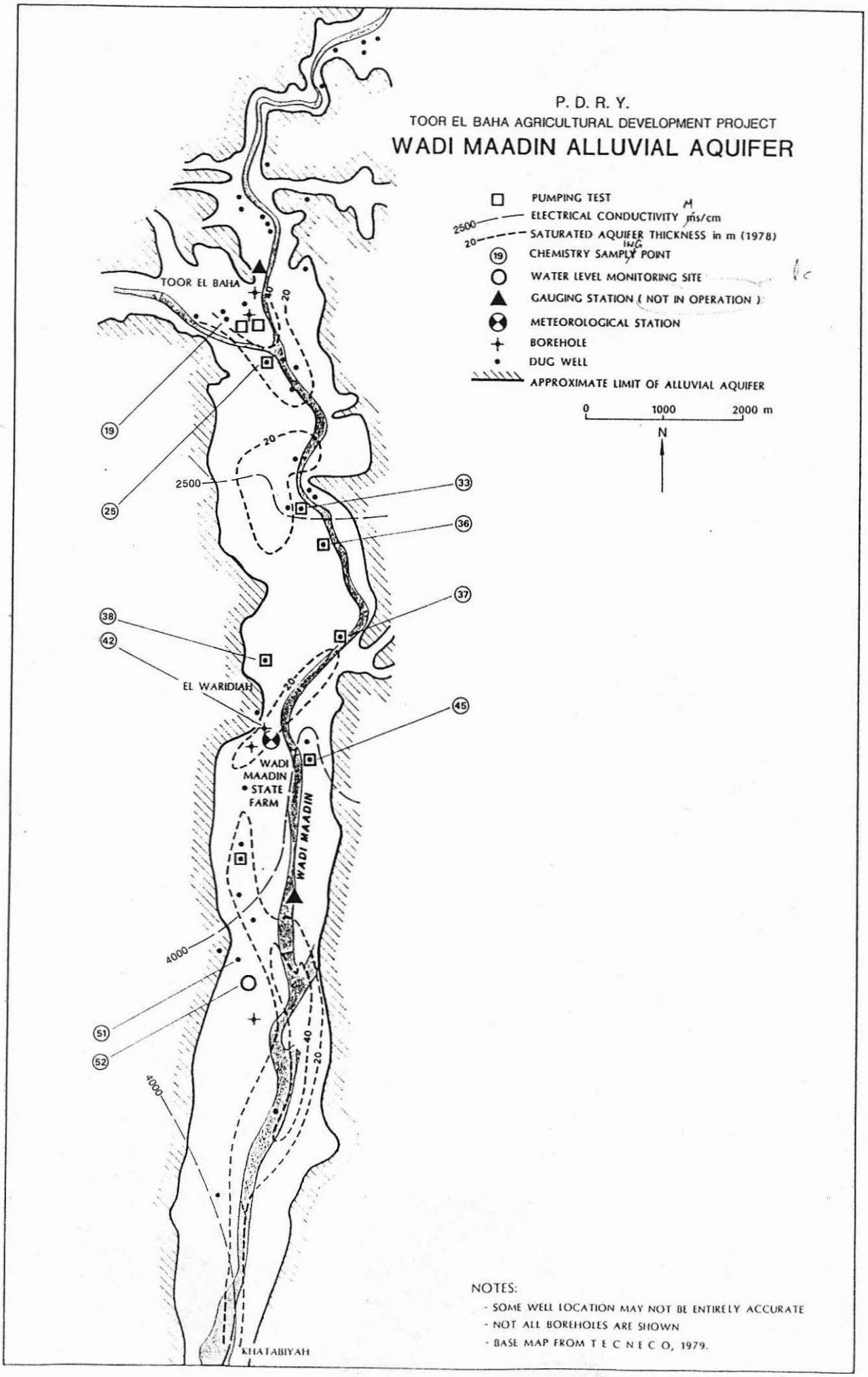
57 REFERS TO WELL/BOREHOLE INDEX No. GIVEN BY TECNECO, 1979

422 REFERS TO WATER LEVEL IN m. a. s. l.

SITE OF PROPOSED DAM BY TECNECO

550 GROUNWATER CONTOURS IN m. a. s. l. (1978)

APPROXIMATE LIMIT OF ALLUVIAL AQUIFER


P. D. R. Y.
TOOR EL BAHA AGRICULTURAL DEVELOPMENT PROJECT
WADI MAADIN ALLUVIAL AQUIFER
PUMPING TEST
ELECTRICAL CONDUCTIVITY mS/cm
SATURATED AQUIFER THICKNESS in m (1978)
CHEMISTRY SAMPLE POINT
WATER LEVEL MONITORING SITE
GAUGING STATION (NOT IN OPERATION)
METEOROLOGICAL STATION
BOREHOLE
DUG WELL
APPROXIMATE LIMIT OF ALLUVIAL AQUIFER
0 1000 2000 m
N
TOOR EL BAHA
EL WARIDIAH
WADI MAADIN STATE FARM
WADI MAADIN
KHATABIYAH
2500
4000
19
25
33
36
37
38
42
45
51
52
NOTES:
- SOME WELL LOCATION MAY NOT BE ENTIRELY ACCURATE
- NOT ALL BOREHOLES ARE SHOWN
- BASE MAP FROM T E C N E C O, 1979.