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GROUNDWATER RESOURCES AND USE IN THE NORTHERN TIHAMA REGION (HAJJAH)

Final Report
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in association with
TEAM CONSULTING ENGINEERS CO. LTD
DARWISH CONSULTING ENGINEERS

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1 INTRODUCTION

Groundwater studies were undertaken in the northern Tihama as an integral component of development and management studies being executed under the auspices of the Sana'a Sa'dah Hajjah Agricultural and Rural Development Authority (SSHARDA) Northern Region Agricultural Development Project (NORADEP).

The area of study is shown in Fig. 1.1

1.1 BACKGROUND

Previous water resource studies in the Tihama under the auspices of the Tihama Development Authority (TDA) were directed toward specific wadi development programmes. These have led to construction of improved surface water irrigation systems at Wadis Zabid, Rima and Mawr. Design and construction of similar works in Wadi Siham is in progress.

The first water resource study with a whole Tihama perspective was undertaken through the period 1984-1988 - the Tihama Basin Water Resource Study (TBWRS).

Reports from this study (TDA/DHV, 1988) provide the most comprehensive data available on the hydrogeology of the northern Tihama and should be referred to for details; only an overview of the hydrogeological environment is given herein, and summary details relating to water use. Further information on the area can be found in the reports of the Master Plan Study for Hajjah Province Integrated Rural Development: Japan International Cooperation Agency, 1980 (JICA).

1.2 TIHAMA BASIN WATER RESOURCE STUDY

The TBWRS provided the first quantitative data on the water resources of the northern Tihama area. A regional geo-electric survey was undertaken to delineate the geometry of the extensive alluvial aquifer of the plain. Monitoring networks were established for measurement of groundwater levels, wadi discharges (Harad and Hayran) and rainfall; a comprehensive well inventory was undertaken to provide data on groundwater use and quality. Provisional water balances were compiled.

Results from the well inventory indicated that the rapid growth in groundwater irrigation practices experienced in the central and southern Tihama was also evident in the north. More than 800 pumped wells were imposing a total annual draft on the alluvial aquifer of 115 Mcm. With only rudimentary estimates of natural aquifer discharge and recharge possible with the limited data, an annually accumulating groundwater storage deficit of the order 90 Mcm was indicated. For the central and eastern zones, where most wells are located, this translates into an average water level decline of the order 0.4 m/year. Credence for such declines was given by the identification of several areas adjacent to the foothills, in the east, where dry or successively deepened wells were common.

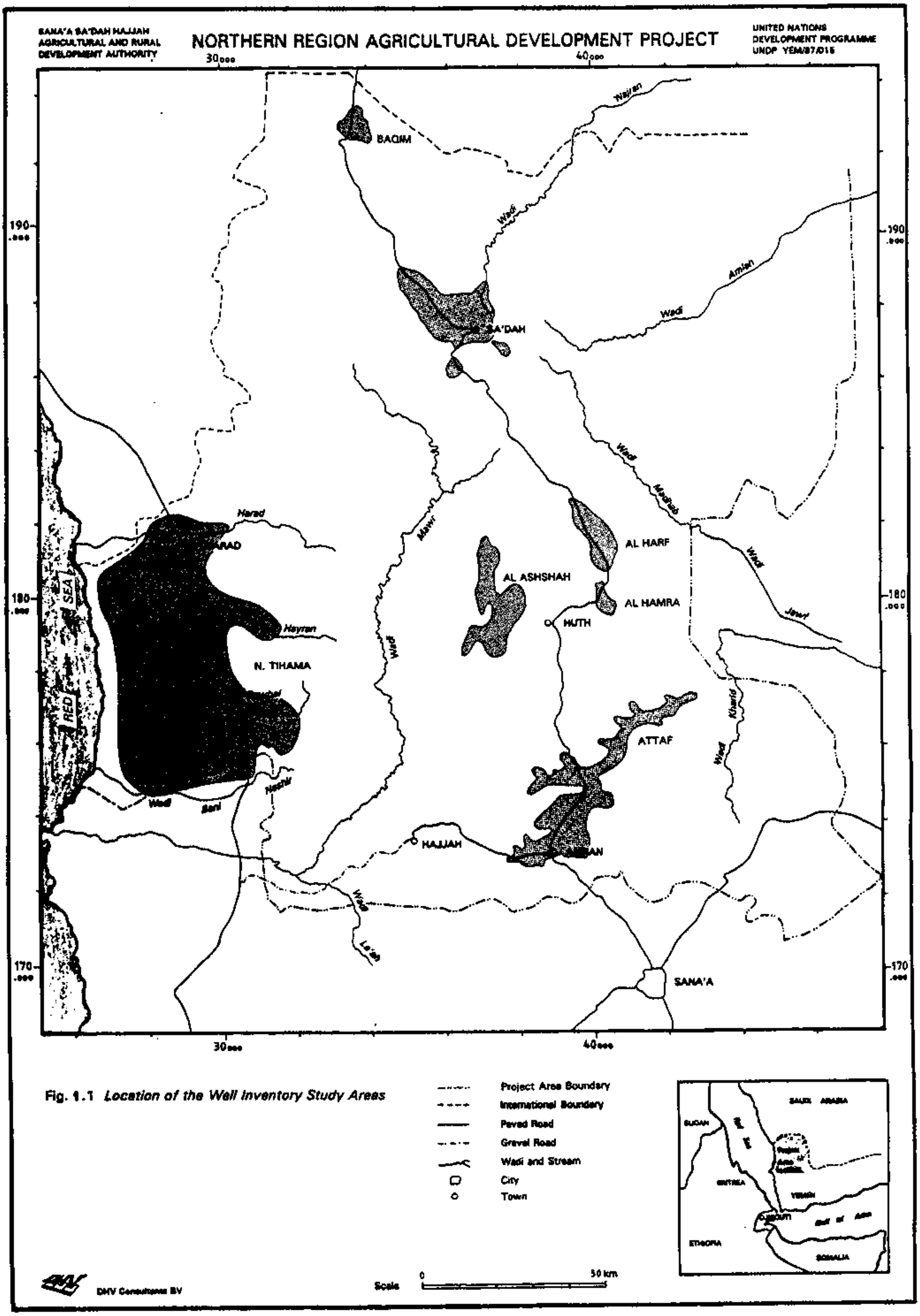


Fig. 1.1 *Location of the Well Inventory Study Areas*

While not studied for the northern Tihama, TBWRS established that recent increases in the use of surface and groundwater in upstream wadi reaches elsewhere, had modified the traditional flow regime with deleterious effects to downstream users.

1.3 SCOPE OF WORK

Against this background, the objectives of the NORADEP groundwater studies in the northern Tihama were formulated to:

- Assess current groundwater usage in the Tihama and any deviations from previous assessments.
- Acquire data on groundwater use in the inland and upstream wadi areas not covered in TBWRS.
- Assess groundwater level data and trends with a view to confirmation of the existence of an accumulating groundwater storage deficit.
- Upgrade the groundwater balance of the region where newly acquired data permits.

To meet these objectives the following primary study components were identified:

- Acquisition of TBWRS well inventory data analyses.
- Acquisition and assessment of monitoring data collected and compiled by the Tihama Development Authority (TDA).
- Execution and analysis of a selective well inventory in the Tihama and inland/upstream wadi areas.
- Evaluation of the integrated data set.

During the course of the study it was discovered that detailed analysis of the northern Tihama TBWRS well inventory data had not been undertaken by the responsible agency. Consequently, copies of the original data diskettes were obtained and analysis included as an additional component of this study.

The results of the various study components are presented herein. In Section 2 an overview of Tihama hydrogeology is given, mostly drawn from TBWRS compilations and findings, updated wherever possible with newly acquired data. Reference should be made to the respective TBWRS volumes on Climate (Technical Report 1), Surface Water (TR-2) and Groundwater (TR-3) for comprehensive data.

In Section 3 specific attention is given to groundwater use in the Tihama and in Section 4 summary findings of the inventory of the inland and upstream wadi areas are presented. Observations on groundwater level and quality changes since termination of the TBWRS in March 1988 are detailed and assessed in Section 5.

Future development and prospects for improved groundwater management are discussed in Section 7, followed by study conclusions and recommendations.

2 HYDROGEOLOGY OF THE NORTHERN TIHAMA

2.1 GEOMORPHOLOGY AND GEOLOGY

The Tihama Coastal Plain is bounded to the east by the foothills of the Yemen Mountains and to the west by the Red Sea. The Plain in the northern Tihama varies in width from 30-40 km and generally displays an even gradient to the sea; eastern Tihama elevations are typically of the order of 200 m.

The major geomorphological features in the Tihama are associated with the current drainage systems where alluvial fans emanate from the mouths of wadis and grade into gently sloping alluvial plains. The alluvial features are bordered with sand plain/dunes of aeolian origin which form extensive belts devoid of vegetation. Near the coast extensive areas of minimal relief with halophyte vegetation delineate a sabkha environment. Outcrops in the region are limited to small bedrock occurrences near the eastern foothills.

The Plain was established primarily by the accumulation of unconsolidated or slightly cemented clastic sediments which unconformably overlie a down-faulted surface of consolidated bedrock similar to that exposed in the adjacent mountains. The evolution of the plain has been controlled to varying degrees by the tectonism associated with the Red Sea rift system of which it forms the eastern part.

The alluvial sediments can be divided into an upper (Quaternary) unit and a lower (Tertiary) unit.

The Quaternary unit consists largely of the alluvial fan and plain deposits of the wadis that drain the adjacent highlands and debouch onto the Tihama plain. Additionally, in the western half of the plain, sand dunes and associated aeolian deposits frequently occur on the surface, while marine deposits occur near the coast. This unit may locally be further divided into an upper layer of several tens of metres thickness which overlies a less permeable layer below.

The underlying Tertiary unit contains relatively fine deposits of the Baid Formation comprising shales, sandstones, carbonates, and evaporates the thickness of which may range from several hundreds of metres to in excess of 3000 m.

The geology of the northern Tihama is illustrated in Fig. 2.1.

2.2 THE TIHAMA ALLUVIAL AQUIFER

The alluvial deposits which dominate the Quaternary sequence of the Tihama form an extensive unconfined aquifer system the geometry of which is determined by both lithological and water quality boundaries. Near the coast, the western aquifer boundary is delineated by a transition between fresh water and saline water, whereas in the east a distinct boundary is formed by faulted bedrock strata.

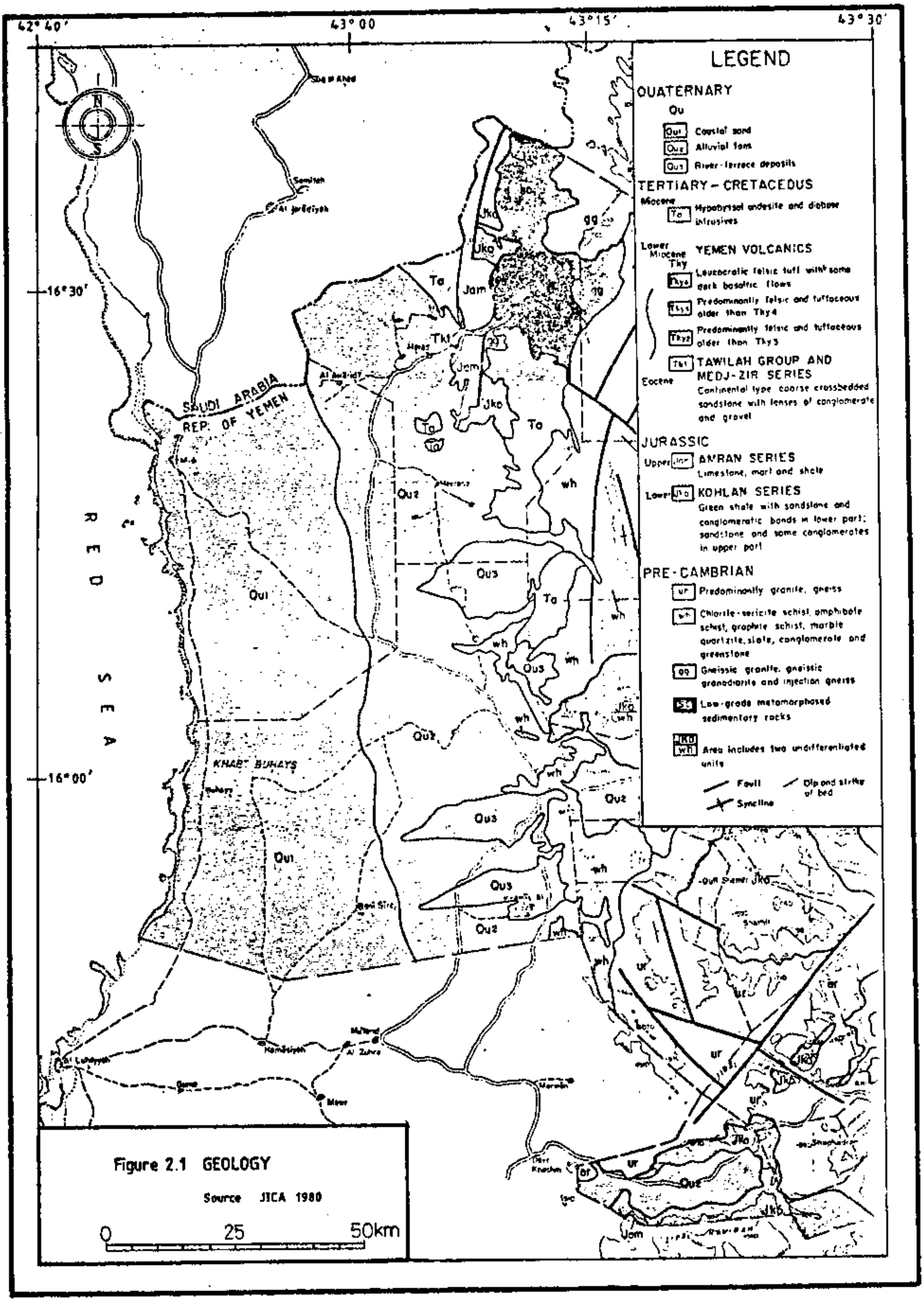


Figure 2.1 GEOLOGY

Source JICA 1980

0 25 50km

Between the eastern and western boundaries bedrock strata comprising variously volcanics, granites and consolidated alluvial and evaporite sediments, underlie the alluvial sequence. The base of the aquifer may be delineated directly by these strata, as in the east, or by the interface with saline water where this occurs within the Tertiary sediments.

Fault location and aquifer geometry as determined from a regional geo-electric survey (TBWRS) is shown in plan in Fig. 2.2 and in sections as Fig. 2.3.

The salient features of these figures are:

- Aquifer thickness is limited in the eastern Tihama on account of shallow bedrock; aquifer thicknesses of less than 50 m occur along a 2-8 km wide strip along the eastern boundary.
- Aquifer thicknesses increases to maximum depths in the range 180-250 m in the central plains area on account of bedrock faulting.
- In the extreme north of the region there are indications of an uplifted block of bedrock strata in the central plains area (refer Profile 20 of Fig. 2.3).
- Fresh groundwater does not extend to the coast. Saline groundwater occurs throughout the profile between 2-6 km distance from the coast; a transition zone of brackish-saline groundwater extends a further 3-6 km inland which locates the western extremity of the fresh groundwater aquifer about 10 km distant from the coast.

2.2.1 Lithology

The alluvial deposits display extreme heterogeneity at local scale reflecting the variety of source material, its mode of deposition and the dynamicism of the environment.

At a regional scale they have been differentiated according to lithology and mode of deposition. The upper wadi deposits are widespread and comprise typical fluvial sediments associated with a high energy environment: blocks, boulders, pebbles and sands with only rare inclusions of clayey material. These sediments become increasingly finer westward. The underlying sediments consist of sands and gravels with increased amounts of sandy clay which may be cemented and include intercalations of clay layers.

Lithological logs from three recently drilled TDA sites in the northern Tihama are summarised in Table 2.1; the locations of the boreholes are shown in Fig. 2.2.

The borehole lithological data display the general characteristics of the alluvial sequence as described. Although sample descriptions tend not to be definitive, an increase in clay content is evident below 50 m depth in both boreholes TDA-16 and TDA-17. Formation grading analysis of virtually all sand samples collected indicate poor sorting with median grain sizes typically in the range 0.5-1.0 mm. A single exception with respect to sorting is a sample from shallow sands (22-24 m) at the near coast location of TDA-17.

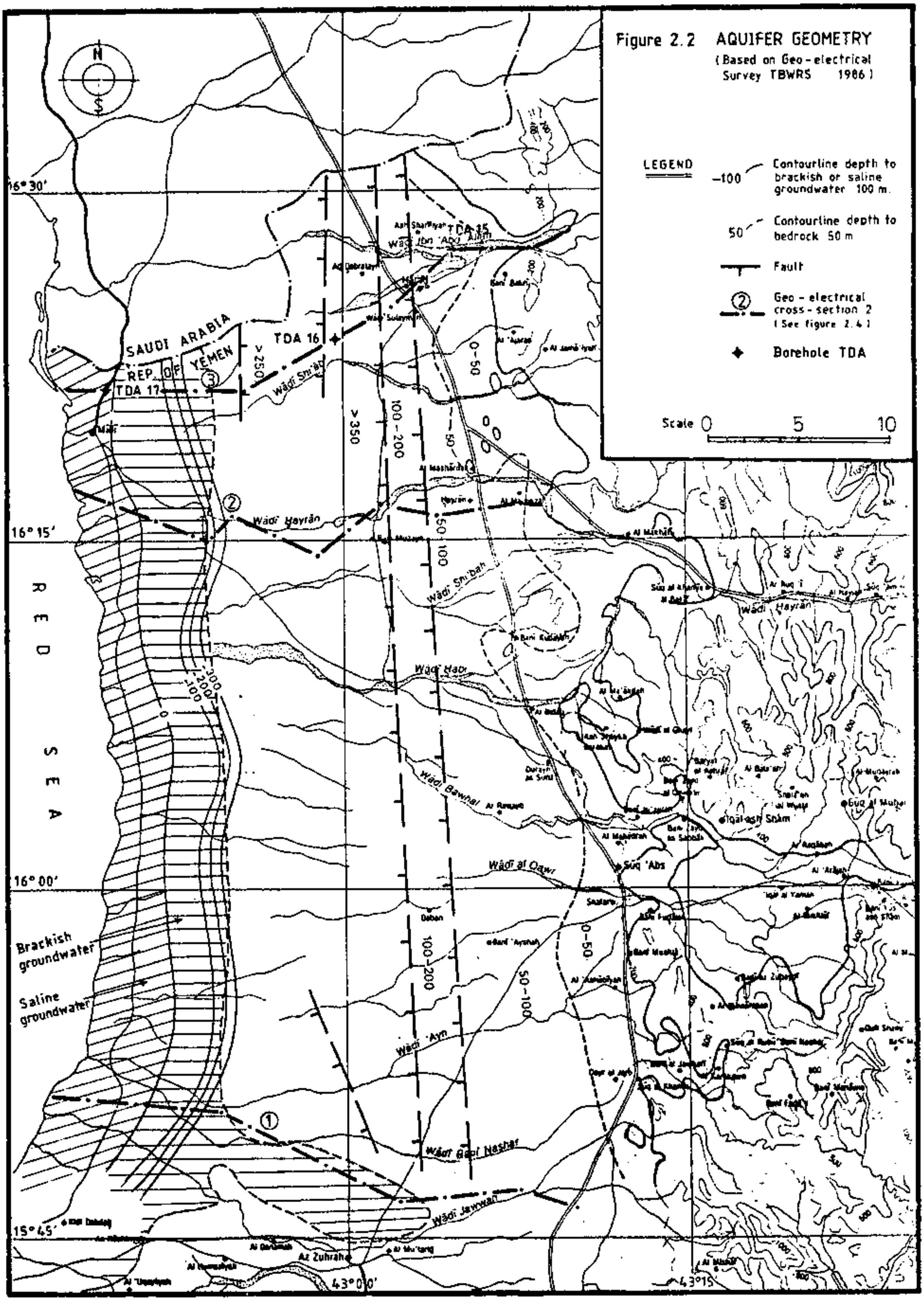


Figure 2.2 AQUIFER GEOMETRY
(Based on Geo-electrical Survey TBWRS 1986)
LEGEND
-100 Contourline depth to brackish or saline groundwater 100 m.
50 Contourline depth to bedrock 50 m
Fault
② Geo-electrical cross-section 2 (See figure 2.4)
Borehole TDA
Scale 0 5 10
SAUDI ARABIA
REP. OF YEMEN
TDA 15
TDA 16
TDA 17
RED SEA
Brackish groundwater
Saline groundwater
16°30'
16°15'
16°00'
15°45'
43°00'
43°15'
Wādī Hayrān
Wādī Shi'bah
Wādī Hajr
Wādī Bawhal
Wādī al Qawr
Wādī 'Ayn
Wādī Jawwah
Wādī Shi'ab
Wādī Sulaym
Az Zuhrah
Sūq 'Abs
>250
>350
100-200
0-50
50-100
50-100
300
200
100

Table 2.1 *Summary Lithological Logs; TDA Exploratory Drilling Programme*

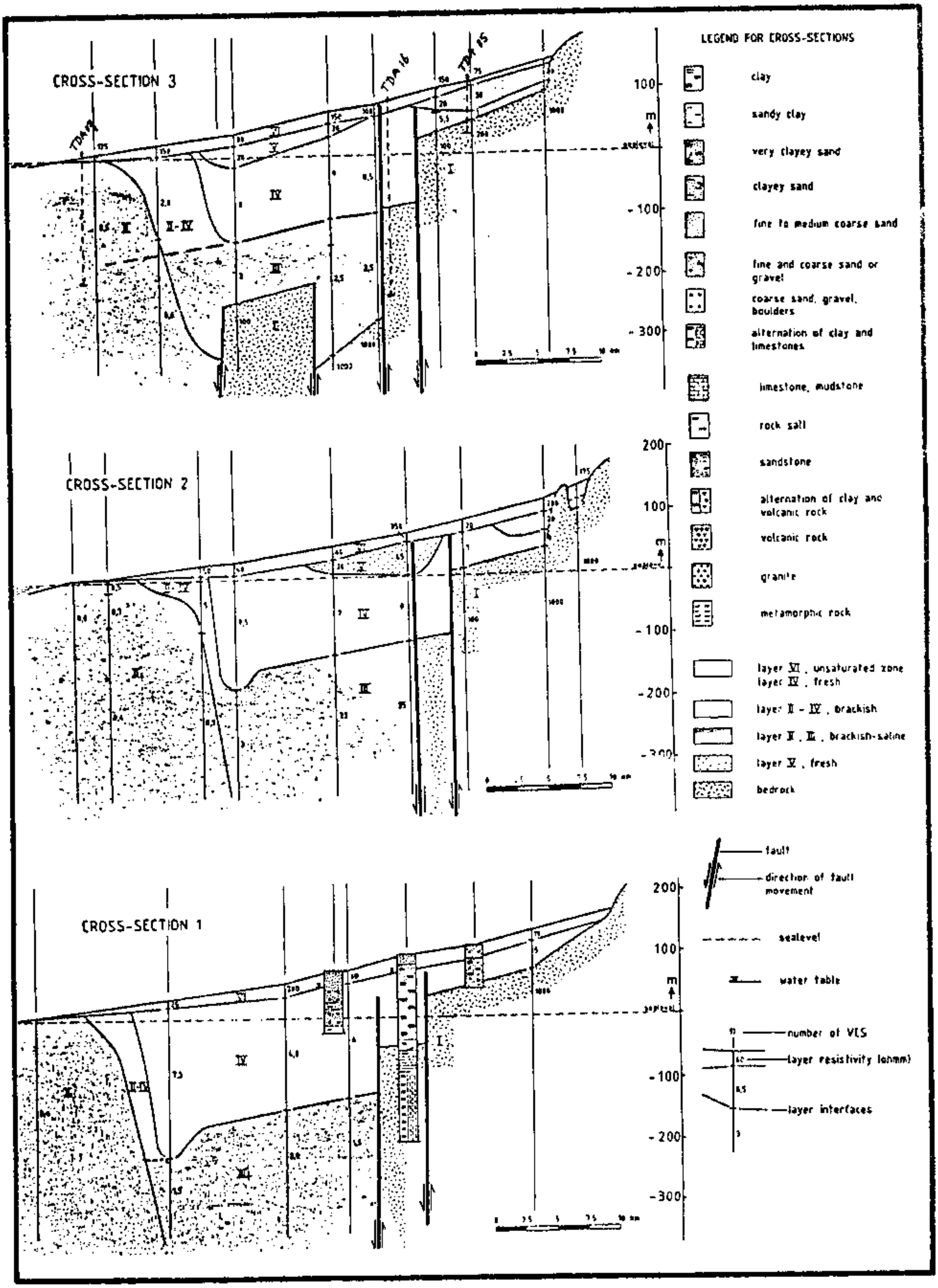
Depth Interval (m)	Lithology	Depth Interval (m)	Lithology
Borehole TDA-15A		Borehole TDA-16B	
0-2	sand/soil	0-2	sand/soil
2-13	sand,clayey	2-28	sand,m-c
13-28.5	sand	28-40	sandy clay
28.5-34	silt,sand	40-46	sand,f-m
34-36	sand,m-c	46-50	silt,sandy
36-61	TC basalt	50-52	clay
Borehole TDA-17		52-65	sand,f-m
0-34	sand	65-73	sand,gravel
34-36	clay,sandy	73-75	sand,f
36-40	gravel,sand	75-86	sand,silt,clay
40-46	sand,i-m	86-90	clay
46-50	boulders	90-94	sand,f-m
50-60	sand	94-100	silt,sandy
60-76	silt,clay	100-102	sand,clayey
76-88	sand,clay	102-110	clay
88-98	clay	110-122	sand,f-m
98-128	gravel.sand	122-140	sand,clay
128-140	gravel,silt,clay	140-155	sand,gravel
140-152	sand,m-c	155-186	sand,gravel
152-158	grave,sand,silt	186-212	clay,sand
158-166	sandstone	212-302	TC claystone with minor sandstone interbeds
166-174	clay,sandy		
174-188	sand,c		
188-198	silt	aquifer base	
198-204	TC sand,silt		

The TDA drilling results also provide general confirmation of the geo-electric survey interpretation (Cross-section 20 of Fig. 2.3) with intersection of shallow bedrock at site TDA-15 and a formation change (Quaternary to compacted Tertiary alluvium?) at 212 m in TDA-16; the depths of both intersections, however, are at some variance with the established geo-electric model. Whilst the exact location of the boreholes, relative to the geophysical sounding, is unknown it appears that the bedrock intersection in the east was shallower than anticipated whilst the converse is true in the central plain; these differences are not of sufficient magnitude to invalidate the geophysical interpretation and are too localised to justify general revision of established aquifer geometry. The possibility of reduced aquifer thickness in the east, however, may have significant impact on local groundwater availability.

2.2.2 Aquifer Parameters

The number of controlled pump tests that have been conducted in the Tihama alluvial aquifer is quite small. Results from given areas typically fail to establish definitive regional trends due to the extreme heterogeneity of the alluvial sediments.

Fig 2.3 *Geo-Electrical Profile (TBWRS) (Section Lines See Fig. 2.2)*



In general, however, relatively high mean section permeabilities tend to be associated with the wadi courses, decreasing westward and with increasing distance from the wadi.

Evidence has also been put forward (MMP, 1982) for the decrease in lateral permeability with depth. In Wadi Mawr mean section permeabilities in the upper 30 m of the alluvial sequence were found invariably to be in excess of 14 m/d whereas below this level permeability decreased markedly with depth, falling to about 1 m/d at about 130 m. In Wadi Surdud, testing of two boreholes constructed to the east (central plain) and west (coast) of a north-south trending fault/flexure, yielded lateral permeability values, for the contributing aquifer horizons, of 8 m/d and 17 m/d respectively. The higher value, near the coast, was associated with more uniform and better graded/sorted sediments indicating intercalation with aeolian or marine sediments. Flow in the well constructed to the east of the fault/flexure appeared to be restricted to discrete horizons within the uppermost 100 m of the aquifer.

Further information has become available for the Northern Tihama with completion of the TDA exploratory drilling and test production well programme. Aquifer tests have been conducted at sites TDA-15 and TDA-16.

Shallow test wells TDA-15A and TDA-16A were drilled at 387 mm diameter and equipped with a 250 mm diameter inline casing/screen assembly with a gravel envelope placed in the casing/borehole annulus. The deeper well TDA-16B, located 5 m distance from TDA-16A, comprised a 55 m deep pump housing of 250 mm diameter with a lower, inline production string of 200 mm diameter. Summary details of well depths and screen intervals are given in Table 2.2. At each test site two observation wells were constructed (75 mm dia galvanised pipe in 150 mm dia borehole).

TABLE 2.2 *Summary Construction Data: TDA Test Production Wells*

Well Nr	Depth Pilot (m)	Well (m)	Screen Interval (m)	Total Screen Length (m)
15 A	60.5	45	14 - 43	29
16 A	50	50	30.8 - 54	23.2
16 B	300	175	55.4 - 172	81.2

The pumping tests comprised:

- Initial variable rate discharge test (3 steps of 60 minutes).
- Constant discharge test (15A-62 hr; 16A-40 hr; 16B-72 hr).
- Recovery test (24 hr).
- Repeat variable rate discharge test (3 steps of 60 minutes).

The data set and plots are given in Annex 7; a summary of results is given in Table 2.3. A wide range of transmissivity values were derived for each test with conventional methods of analysis; in some cases, inadequate control of discharge during an individual test has prevented meaningful analysis.

TABLE 2.3 *TDA Test Wells: Summary Pumping Test Results*

(A) CONSTANT RATE AND RECOVERY TESTS:

Well	Time Interval (minutes)	Transmissivity[1] (m^2/d)
Test Site TDA-15A	Discharge Rate = 1253 m3/d (± 43)	
15-A pumped	5-60	1835
	90-500	158
	500-1000	1835
	1000-2000	116
15-B ob. well: 5 m	1-30	1720
	30-3500	770
15-C ob. well: 15 m	1-40	2085
	40-3500	997
Recovery ([2])		
15-A	5-200	580
	50-900	771
15-B	4-600	580
	100-1000	955
15-C	3-50	580
	150-2000	2290
Test Site TDA-16A - Discharge Rate = 587 m^3/d (highly variable)		
16-A pumped(s)	data unusable	
	2-100	977
16-B ob.well:5m(d)	200-1000	1107
	20-1000	1007
16-D ob.well:30m(s)	inadequate response	
Recovery		
16-A	100-500	64
15-B ob.well:5m	40-1000	664
	30-2000	895
Test Site TDA-16B - Discharge Rate 1814 m^3/d		
16-A ob.well: 5m(s)	20-2000	1509
16-B pumped well(d)	4-2000	1639
	15-1000	738
16-C ob.well: 10m(d)	10-2000	738
Recovery		
16-A	80-2000	791
16-B	10-400	604
	800-4000	536
16-C	40-1500	626

(B) STEP-TESTS:			
Step	Discharge (m^3/d)	Drawdown (m)	Specific Drawdown ($m/m^3/d$)
Test Site TDA-15A Initial Step-test			
1	1037	2.97	0.0029
2	1598	20.80	0.013
3	2506	20.96	0.0083
Repeat Step-test			
1	994	2.46	0.0025
2	1555	20.69	0.013
3	2506	20.85	0.0083
Test Site TDA-16A Initial Step-test			
1	216	2.05	0.0095
2	626	6.05	0.0097
3	950	12.80	0.0135
Repeat Step-test			
1	259	2.03	0.0078
2	626	6.05	0.0097
3	950	12.80	0.0135
Test Site TDA-16B Initial Step-test			
1	281	0.52	0.00185
2	2117	3.7	0.00174
3	3154	5.5	0.00174
Repeat Step-test			
1	410	0.62	0.00151
2	1944	3.55	0.00183
3	3154	5.7	0.00181

Notes

(s) shallow; (d) deep.

(1) Analysis by Jacob method; semi-log plots in Annex 7.

(2) Time interval actually t/t' - ratio of elapsed time since pumping commenced and time since pumping stopped. Mean section permeabilities were derived assuming an upper layer of thickness 30 m with mean permeability 20 m/d overlying a layer of thickness 160+ m with mean permeability 4 m/d.

The data set for estimation and derived value is given in Table 2.4. A groundwater flux of the order 90 Mcm/yr is indicated of which an estimated 10 Mcm/yr flows out of the study area into the Asir region.

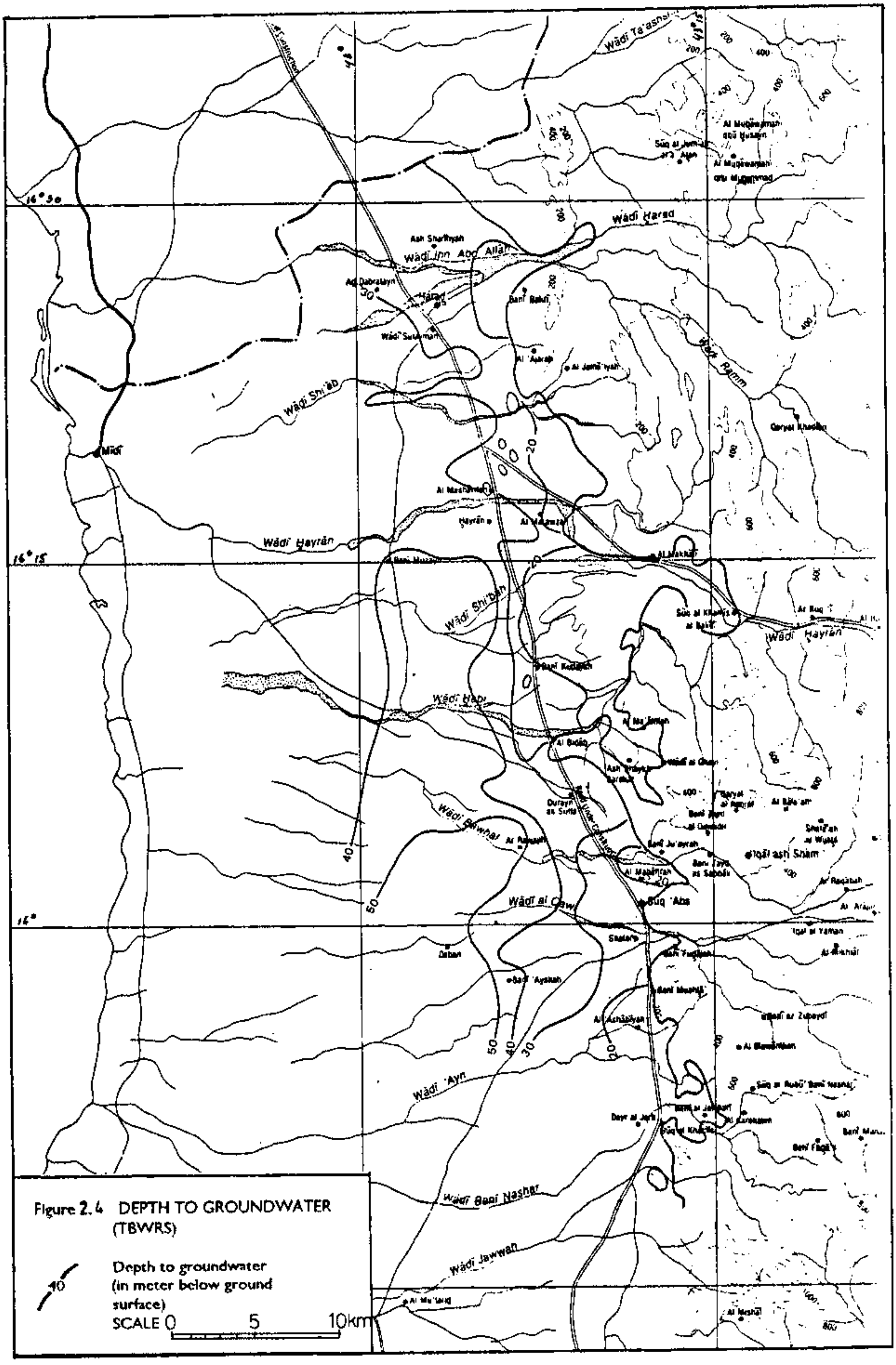


Figure 2.4 DEPTH TO GROUNDWATER (TBWRS)

At site 15, in the alluvial fan area of Wadi Harad, anomalous behaviour was recorded during the step-tests where during both the initial and repeat step-tests an increase in pumping rate from 18 to 29 l/s failed to produce an appreciable drawdown increment. The drawdown level for both discharge rates equates approximately with the top of the bedrock and probably also with the top of the pump. If the drawdown readings are accurate then the inference is that the alluvial sequence is essentially dewatered locally and that the bedrock sequence or its weathered upper section sustains flows of the order 30 l/s. Transmissivity values derived from the constant rate and recovery tests range from 116 to 2290 m^2/d; most values however tend to be in the range 600 -800 m^2/d which gives a mean section permeability of the order 20-25 m/d for the assumed 30 m saturated thickness/screen length.

Analysis of the test on the shallow well at site 16B in the central plains area is restricted by the poor control of the pumping rate during the constant rate test and the minimal response of the shallow piezometer (16-D) with the low pumping rates. The deeper piezometers display transmissivity values in the range 644 - 1107 m^2/d which probably more closely reflects the entire alluvial thickness rather than the upper tested portion. The test on the deeper well (16-B), provided more consistent data and demonstrates the leaky response of the aquifer. Transmissivity values for the deeper aquifer section tend to be in the range 600 -740 m^2/d indicating a mean section permeability of the order 4 - 5 m/d for the 140 m saturated thickness.

2.2.3 Groundwater Levels

The most complete data set for establishment of depth to water in the northern Tihama was provided by the TBWRS well inventory; contours are given in Fig. 2.4

Water depths of less than 20 m can be found in a narrow 3-10 km band along the eastern boundary with westward extensions generally coincident with wadi courses (recharge zone), and along a 12-15 km wide strip parallel to the coast (discharge zone). Groundwater depths in the intermediate central plains area where surface elevations are augmented by sand dunes, range from 20 m to 60 m.

Contours on the phreatic surface are given from the results of the TBWRS well inventory in Fig. 2.5

Groundwater flow is from east to west with hydraulic gradients changing markedly across the plain. In the eastern alluvial fan area where aquifer thickness is limited, hydraulic gradients are of the order 0.005 decreasing to 0.003 in the central plains area where aquifer thickness is at its maximum. Within the coastal discharge zone, gradients decrease further to 0.001.

It may be further discerned from Fig. 2.5 that a significant portion of the Wadi Harad groundwater flow system flows into the Asir region.

2.2.4 Groundwater Flux

An estimate of the groundwater flux in the alluvial aquifer of the northern Tihama can be obtained from aquifer geometry and hydraulic gradients with assumed mean section permeability values (Table 2.4).

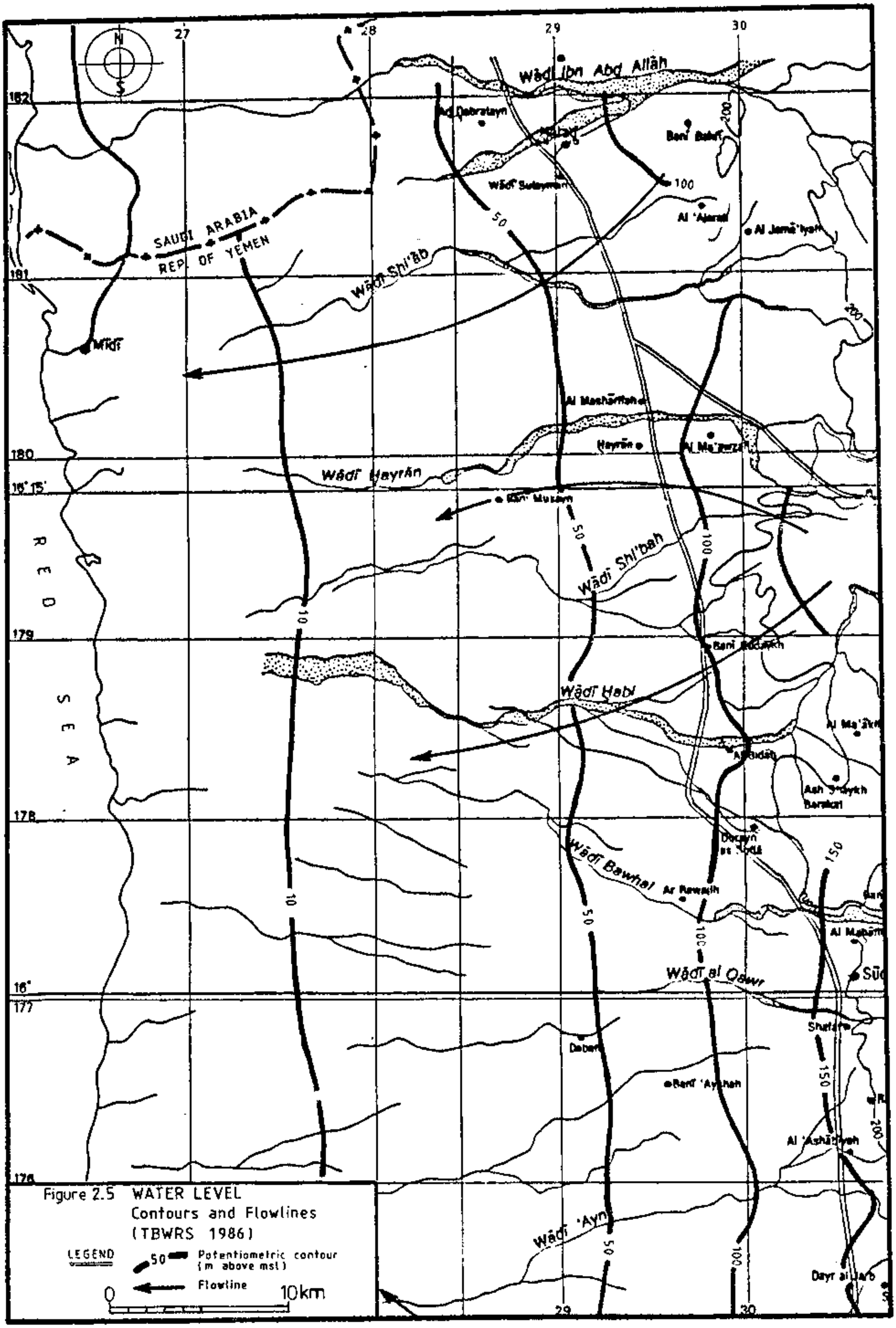


Figure 2.5 WATER LEVEL
Contours and Flowlines
(TBWRS 1986)

LEGEND
50 Potentiometric contour (m above msl)
Flowline
0 10km

Values from each of the geo-electric profiles (Fig. 2.4) were averaged to provide aquifer thickness and hydraulic gradients for locations immediately east of the north-south trending faults (fan) and at the point of maximum aquifer thickness in the central plain area.

TABLE 2.4 *Estimation of Groundwater Flux Flow Section*

Item	Unit	Flow Section	
		Fan	Central Plain
Aquifer thickness	(m)	47	190
Hydraulic gradient	($*10^{-3}$)	4.8	3.2
Assumed mean section permeability	(m/d)	14	6.5
Flow section length	(km)	70	70
Throughflow	(Mcm/yr)	82	101

2.2.5 Groundwater Quality

No chemical analyses for groundwater in the northern Tihama have been reviewed; a visit to NWASA, currently engaged in the development of public water resources in Abs, failed to provide useful data. Groundwater quality, expressed in terms of electrical conductivity (EC), is shown in Fig. 2.6 (TBWRS).

The general features of the EC distribution are as follows:

- Freshest groundwater (< 1000 micro S/cm) development extending westward from the foothills in association with wadi courses;
- Gradual deterioration in water quality towards the coast and in the inter-wadi areas;
- Saline groundwater (> 4000 micro S/cm) occurrence in a strip, of width 5-10 km at the coast.

Groundwater apparently suitable for agriculture (< 2000 micro S/cm) can be found over 65% of the total area. Brackish water (2000-4000 micro S/cm) extends coastward covering an additional 12% of the total area. The EC distribution, as determined from water sampling during the TBWRS well inventory, shows excellent agreement with the geo-electric interpretation (refer Fig. 2.2 and 2.3).

2.3 AQUIFER RECHARGE AND DISCHARGE

2.3.1 Recharge

Recharge to the Tihama alluvial aquifer would naturally be derived from:

- Rain falling directly on the Tihama plain.

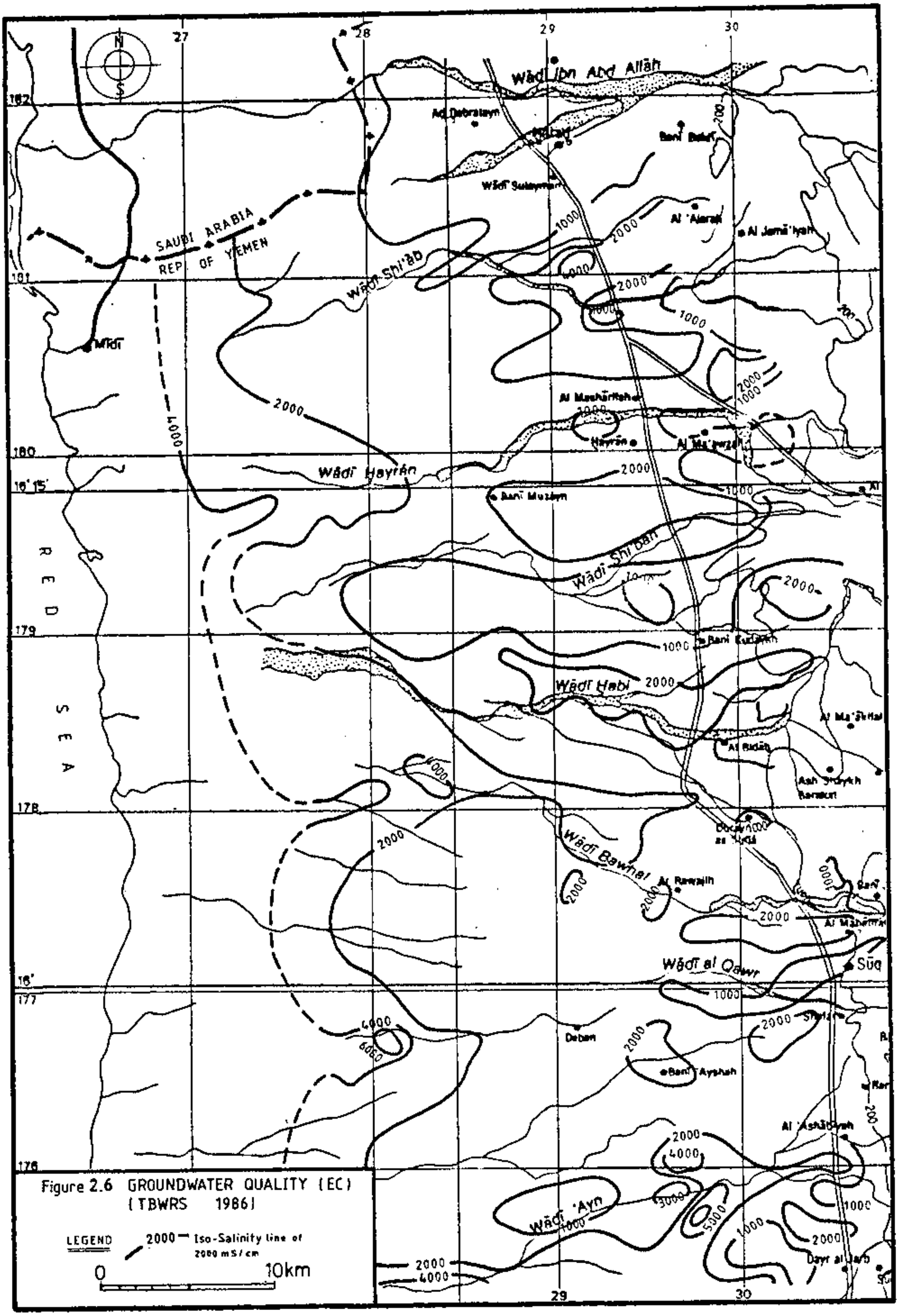


Figure 2.6 GROUNDWATER QUALITY (EC) (TBWRS 1986)

- Runoff from Tihama-facing hill slopes.
- Surface water inflows (wadis).
- Sub-surface boundary inflows (wadi bed and bedrock sections).

Within historic times the traditional diversion of wadi flows for surface water irrigation has modified the recharge processes associated with surface water flows; the introduction of conveyance and field losses being associated with a consequent reduction in wadi bed losses.

The more recent impact of groundwater abstraction is discussed in Section 3.

Tihama Rainfall

Mean annual rainfall in the Tihama increases eastward from less than 100 mm near the coast to about 400 mm at the foothills. Mean monthly rainfall data for three stations installed in 1986 (TBWRS) are given in Table 2.5; histograms for the period for which data is available are given as Fig. 2.7. Full data sets including daily totals are given in Annex 1. Rain gauge station location is shown in Fig. 1.1.

Rainfall tends to occur in occasional, localised storms. In 1989, for example, the number of rain days for Midi, Al-Khadrah and Harad Al-Kadimah were 7, 6 and 15 respectively. Individual storms typically yield 10-20 mm precipitation with occasional events in the central plains and foothills areas of 40-50 mm.

With mean daily evaporative demand in the area of about 5-6 mm/day (Al Zuhrah Meteorological Station, TBWRS) it is evident that the potential for direct recharge from rainfall is limited.

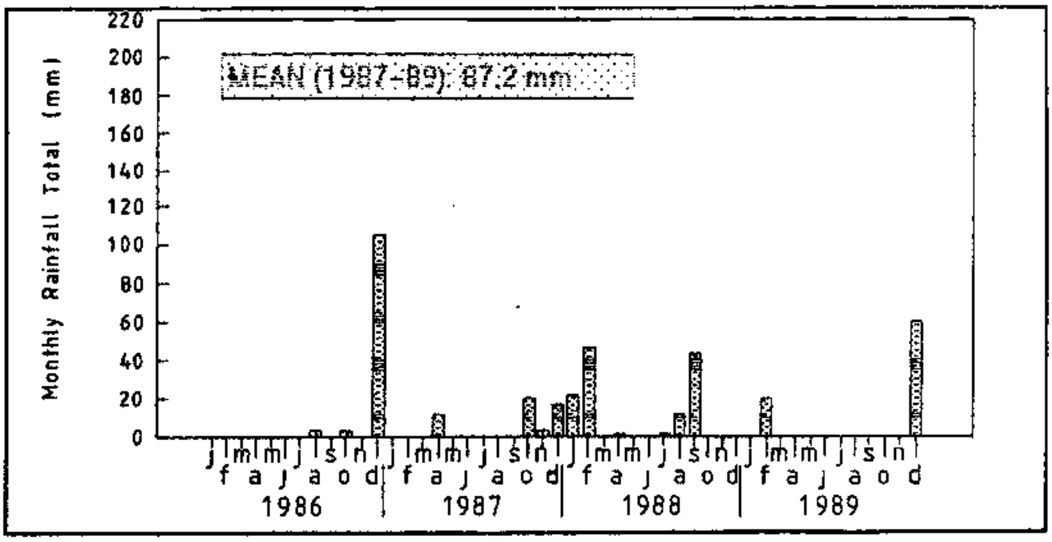
Recharge may occur, however, where intense storms fall on the predominantly sandy soils common in the central plains and coastal areas. Collectively, such soils constitute about 80% of the total area of 2500 km^2. Assuming that 50% of the mean area rainfall (240 mm, TBWRS) occurs as intense storms and adopting a recharge factor of 10%, the recharge from rainfall would be of the order of 24 Mcm.

Table 2.5 *Tihama Rainfall (Source: TDA Data Base)*

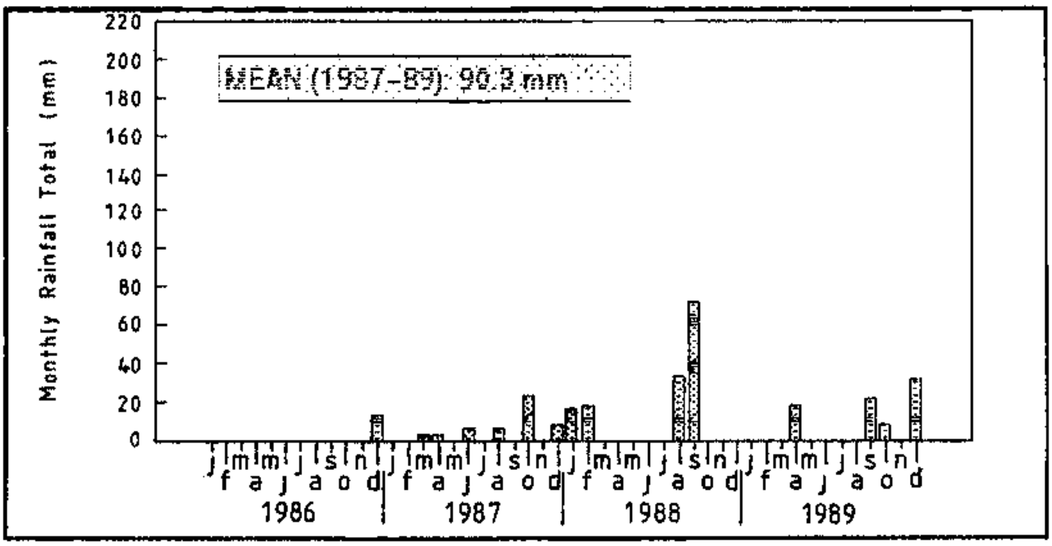
Mean Monthly Rainfall (mm) for the Period July 1986 - Dec 1989												
Station	J	F	M	A	M	J	J	A	S	O	N	D
Midi (1.04)	7.2	22.4	0.0	3.9	0.0	0.1	0.6	4.1	11.0	5.8	0.9	46.0
Al-Khadrah (1.05)	5.8	5.9	0.8	7.3	0.0	1.9	0.0	9.8	23.8	7.8	0.0	13.6
Harad Al-Kadimah (1.06)	0.6	3.6	0.5	17.4	8.8	8.1	7.0	46.3	48.5	18.3	3.0	28.4
Note: Station numbers are TDA network reference												

Fig. 2.7 *Tihama Rainfall (1986 - 1989)*

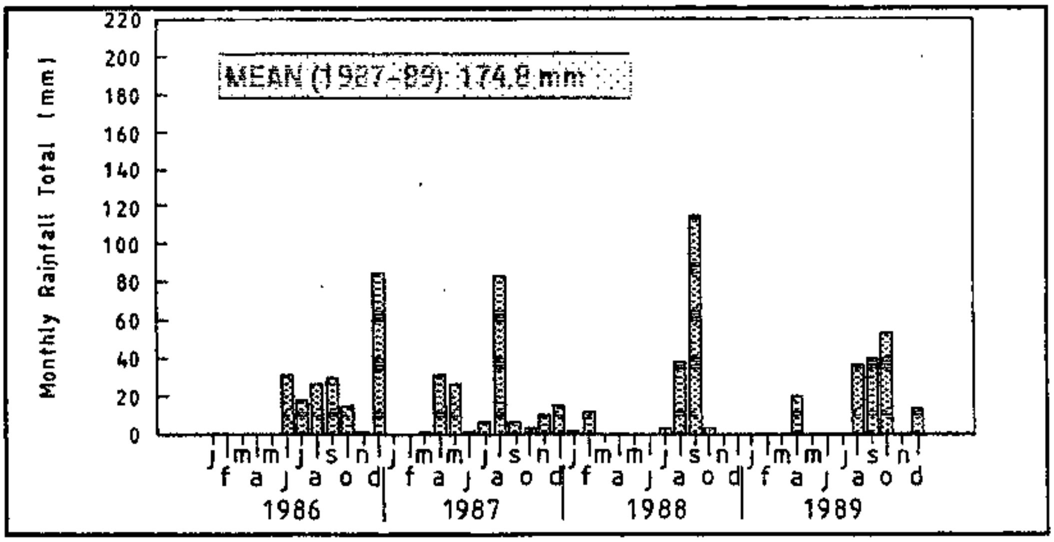
MIDI (1.04)



AL-KHADRAH (1.05)



HARAD AL-KADIMAH (1.06)



Runoff from Tihama-facing Hill Slopes
An assessment of hill slope runoff was undertaken within TBWRS based on consideration of catchment areas, physiography, hill slopes, and rainfall. The generally low slopes that occur within the catchments adjacent to the Tihama boundary in the northern region preclude recharge to the Tihama alluvial aquifer. Runoff generated in these areas develops ephemeral streams that may join local wadi courses, or infiltrates into the poorly developed soil profiles from where it is lost through evaporative processes or percolates into the shallow bedrock strata.

Surface Water Inflows
A number of wadi courses transect the northern Tihama, delineating the historic passage of surface water spate flows generated by relatively high rainfall in the mountainous catchments to the east. The association of fresh groundwater with wadi courses in the Tihama bears testament to the recharge resulting from the line sources of wadi course flows.

Wadi Harad has the largest catchment in the area (912 Km^2) followed by Wadi Hayran (426 km^2). Smaller catchments are associated with Wadis Bawhal and Al Qawr (250 km^2) and Bani Nashar (127 km^2).

Rainfall data is extremely limited in the catchments of these wadis; there is only one station in the Hayran catchment (Wah'ha, TDA station 1.01) with intermittent data available for the period 1977 to 1989.

Discharge monitoring of Wadis Harad and Hayran commenced in 1986; while baseflows have been measured regularly, total flow volumes (flood plus base flow) are only available for both wadis for the period March 1986 to April 1987.

Total flow volumes for this period are given in Table 2.6 and shown as histograms with the middle catchment rainfall data from Wash'ha in Fig. 2.8.

Table 2.6 *Measured Surface Water Inflows*

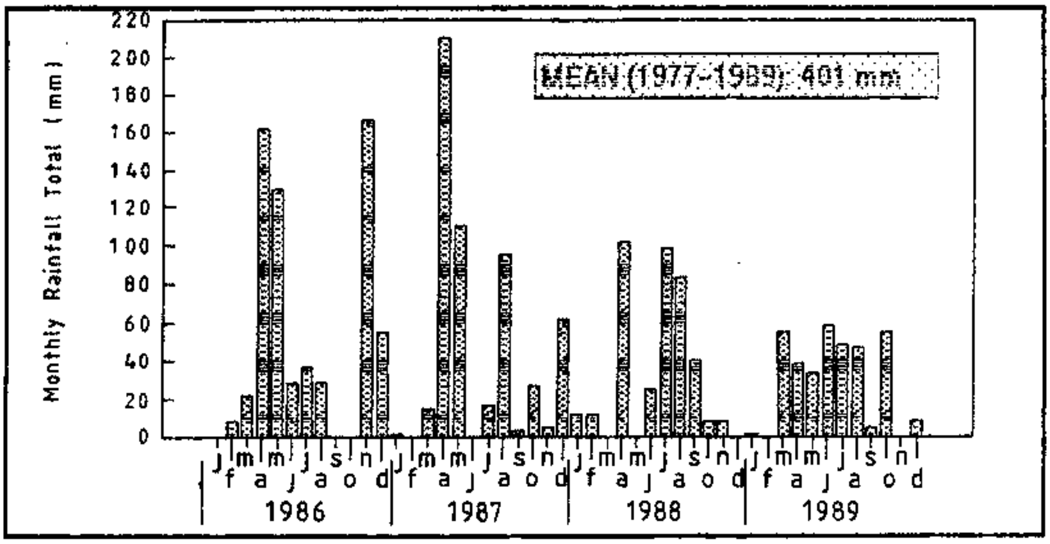
Measured Flows for the Period March 1986 - April 1987 (Mcm)														
Station	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Harad (045)	0.9	6.9	2.2	0.6	1.5	4.2	5.8	1.0	1.1	2.6	1.0	0.6	1.1	1.2
Hayran (046)	0.1	2.8	0.7	0.1	0.2	0.6	0.8	0.4	1.0	1.0	0.4	0.4	0.5	3.4
Note : Station numbers are TDA network reference														

All available discharge data are given in Annex 2; the locations of the TDA discharge measuring stations are shown in Fig. 1.1.

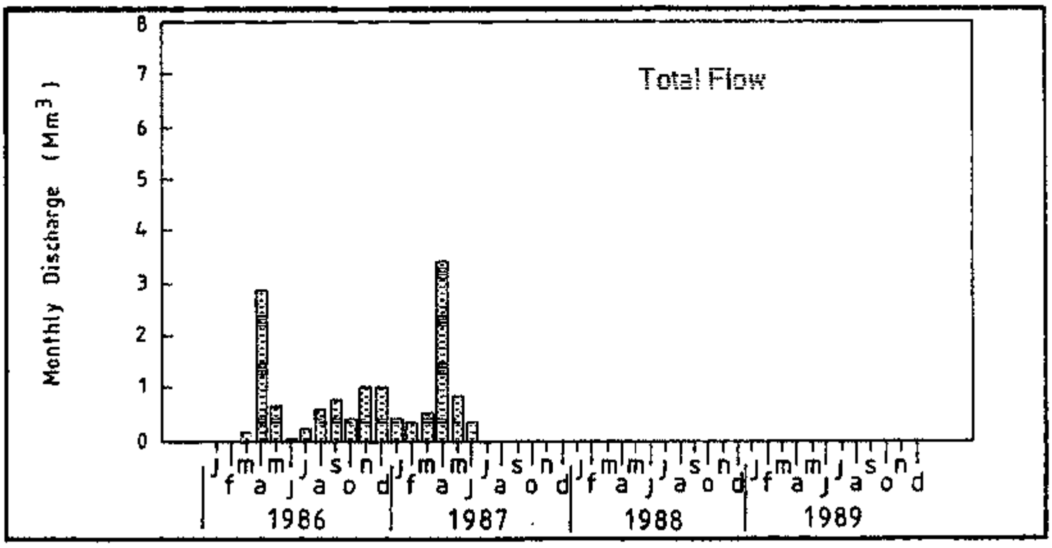
From Table 2.5 the common characteristic of April-May and July-August-September high discharges can be seen.

Fig. 2.8 *Wadi Discharge and Upper Catchment Area Rainfall (1986-1989)*

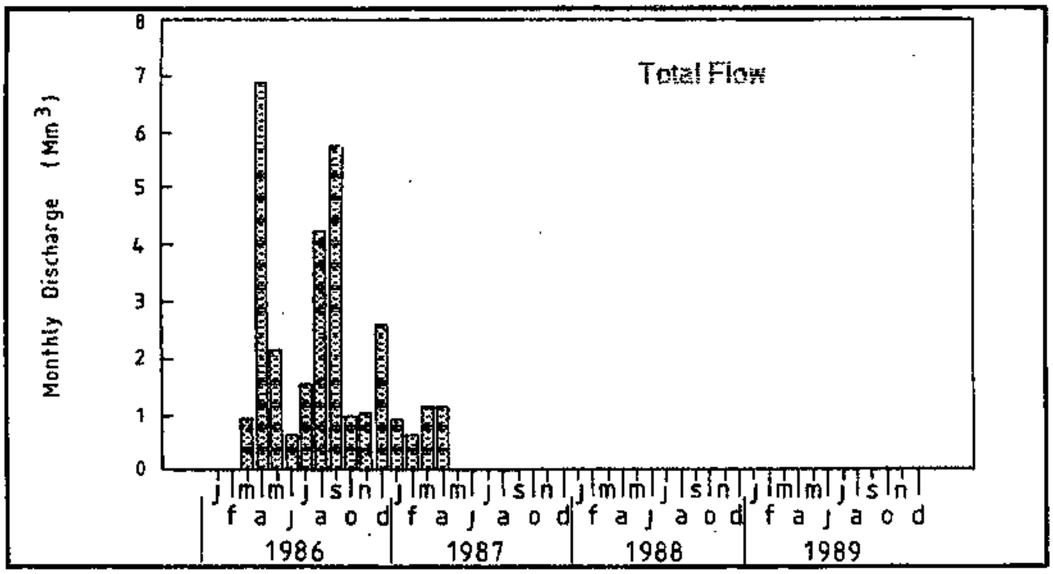
WASH'HA (1.01)



WADI HAYRAN (046)



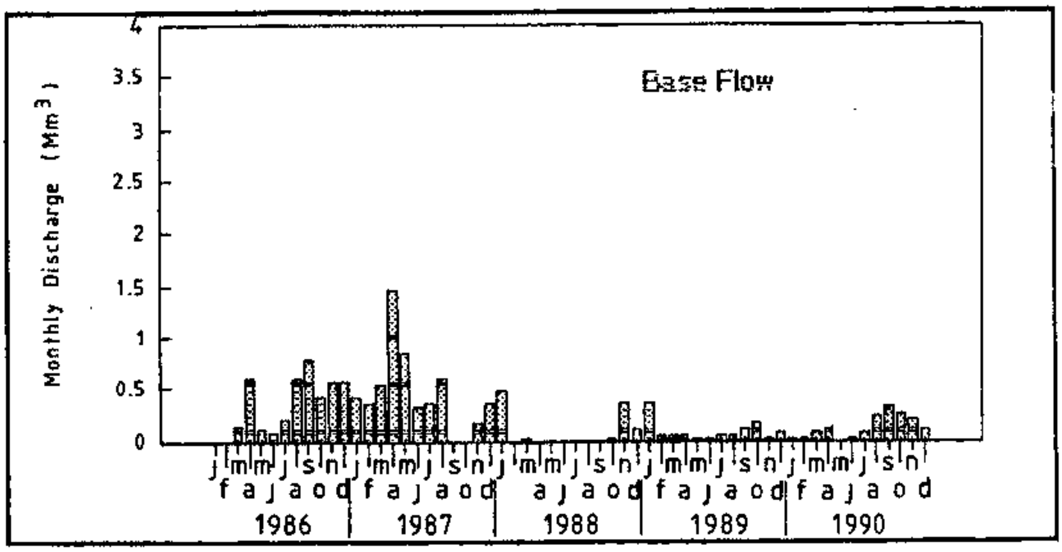
WADI HARAD (045)



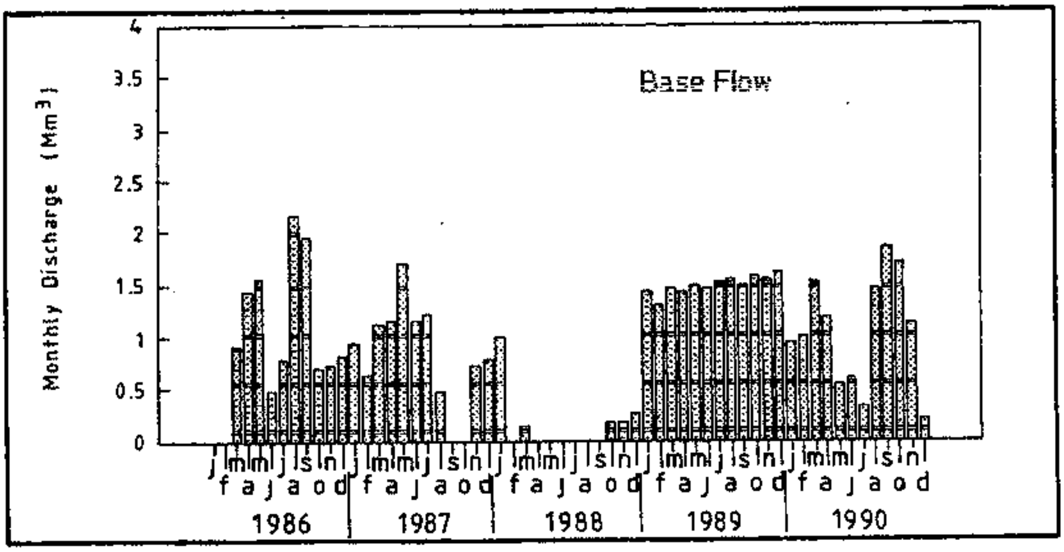
The rainfall/surface flow relationship is evident for the Harad system (Fig. 2.8). Relatively high catchment rainfall in April and, to a lesser extent, November (1986), is associated with discharge peaks. That the relationship is not so evident for Hayran confirms the irregularity in catchment rainfall distribution. This is further evidenced by the base flows shown in Fig. 2.9. Wadi Harad baseflows remain remarkably consistent throughout 1989 and 1990 whereas reduced baseflows are coincident with the generally lower catchment rainfall (1989-1990) in Wadi Hayran. Average annual baseflows for Wadis Harad and Hayran for the two year period 1989-1990, are 15.2 Mcm and 1.3 Mcm respectively (TDA Data Year Book). Assuming that baseflows constitute about 50% of the total annual discharge (TBWRS), total annual flows of the order 30 Mcm and 3 Mcm are indicated.

Fig. 2.9 *Baseflows (1986-1990)*

WADI HAYRAN (046)



WADI HARAD (045)



Mean annual flows estimated by (a) application of runoff coefficients to individual catchment areas (JICA, 1980), and regression analysis of Tihama catchment characteristics (hydro-environmental units) and measured flows (TBWRS, 1988) are given in Table 2.6. The TBWRS did not recognise the smaller wadis Al Qawr and Bani Nashar as significant contributors to the Tihama groundwater balance.

There is currently insufficient data with which to quantify the mean annual flows of the wadis entering the northern Tihama with a reasonable degree of accuracy. Historic annual discharges of the order 25 Mcm, 10 Mcm and 4 Mcm are indicated for Wadis Harad, Hayran and Bawhal; total surface water inflow to the region is of the order of 50 Mcm/year.

Recharge from surface flows, including percolation from wadi beds, the canals and fields of associated traditional irrigation systems, is assumed to be of the order 60% of the mean annual wadi flow. Historic total annual recharge from surface water inflows into the region is estimated to be of the order of 30 Mcm.

Table 2.7 Estimated Surface Water Inflows

Wadi	Historic (Mcm/yr)		Recent (Mcm/yr)(3)
	(1)	(2)	
Harad	24.2	18.5	12.4
Hayran	12.3	10.7	6.8
Bawhal	8.1	4.3	2.3
Al Qawr	8.5		
Bani Nashar	4.4		

Notes

(1) JICA 1980: application of 5.4% runoff coefficient to catchment areas and average annual rainfall.

(2) TBWRS 1988: regression analysis of Tihama catchment characteristics (hydro-environmental units) and measured flows.

(3) TBWRS 1988: flows reduced in accordance with measured reductions in other Tihama wadis over period 1983-1988 due variously to reduced catchment rainfall and increased upstream use of water.

Sub-surface Boundary Inflows

Sub-surface groundwater inflow to the Tihama can occur through saturated alluvial/colluvial fill wadi bed sections, and possibly also from adjacent bedrock sections.

The magnitude of bedrock inflow has been considered negligible in previous studies on account of the general lack of primary permeability of the boundary strata and the lack of evidence from groundwater level monitoring of any recharge process. Localised sub-surface inflows of hot, mineralised groundwater have been recorded at near-foothills locations throughout the Tihama, however, which testify to the transmitting capacity of fractures/faults under certain hydrogeological/thermal regimes. Whether such inflow can occur in the absence of a thermal gradient is a matter of conjecture and unlikely to be resolved without detailed hydrogeological mapping and groundwater/ hydrochemical monitoring.

In the northern Tihama alluvial sediments locally abut and overlie Tertiary acid intrusions and sandstones of the Tawilah Group, Mesozoic limestones, marls and shale (Amran Series); shales, sandstones and conglomeratic bands (Kohlan Series); and Pre-Cambrian schists. With the local exception of Tawilah Group sediments, none of these formations have been exploited as a major aquifer elsewhere in Yemen. Any contribution from bedrock sources to the Tihama alluvial aquifer is likely to be minimal in the context of the major water balance components. Evidence of rapid water level declines in areas of shallow bedrock adjacent to the foothills, presented in Section 3 hereunder, tend to confirm this hypothesis although the pump test results from TDA-15 (reported in Section 2.2.2) leave open the possibility of significant local inflows from weathered bedrock sections. In the absence of quantitative data, the arbitrarily established annual inflow of 0.1 Mcm/km section length (TBWRS) is retained, which yields a total bedrock inflow to the region of the order of 7 Mcm.

Wadi courses on entry to the Tihama tend to be narrow with incised alluvial/colluvial fill channels that remain saturated throughout the year. Geo-electric sounding at the Tihama boundary of Wadis Harad and Hayran indicated bedrock depths of 50 and 10 m respectively. With estimated through flow sectional areas, hydraulic gradients equivalent to wadi bed slopes and assumed mean section lateral permeabilities of 50 m/d, the annual sub-surface inflow is estimated to be about 3-4 Mcm for each wadi section. A similar quantity can be anticipated for the sub-surface inflow section associated with Wadi Bawhal with lesser amounts for Wadis Shi'ab, Habl and Ayn. The total sub-surface inflow from saturated wadi bed sections abutting the Tihama is estimated to be of the order 15 Mcm/yr.

2.3.2 Discharge

Discharge from the alluvial aquifer is effected primarily by direct evaporation of shallow groundwater and evapotranspiration. Both processes can occur where depth to the phreatic surface is less than about 5 m and the unsaturated hydraulic conductivity in the unsaturated zone is of sufficient magnitude to permit upward flow under evaporative demand. Such areas in the region are confined to a coastal strip of less than 2 km width and, seasonally, narrow zones immediately adjacent to and sub-parallel with upper wadi courses.

At the coast where direct evaporation is sustained under an evaporative demand of the order 2000 mm/year, a sabkha environment occurs with development of saline soils through precipitation of salts from the groundwater during the evaporative process.

TBWRS estimates for the cumulative loss of groundwater via direct evaporation were made utilising an equation relating evaporation rate to groundwater depth which was found to adequately describe losses in the Wadi Mawr coastal environment (MMP, 1982). In the absence of any new data or improved technique the TBWRS estimate

3 GROUNDWATER USE IN THE TIHAMA

The TBWRS inventory in the northern Tihama, undertaken through the period September 1985 to July 1986, provides the most comprehensive data set on well distribution and groundwater use in the region. The NORADEP study area in the northern Tihama is almost coincident with the TBWRS geohydrological provinces of Harad and Abs which incorporates the TBWRS well inventory areas Harad, Hayran, Habl, Qawr and most of Ayn.

Summary data for the TBWRS well inventory, presented herein, is derived from the above-mentioned well inventory areas and may show some minor deviations from the geohydrological province data given in TBWRS reports. These differences are insignificant with respect to the general characteristics of groundwater development and use.

The NORADEP well inventory in the Tihama was designed to review the groundwater use situation and provide information on recent, post-TBWRS, developments in the area. For this purpose, it was intended that approximately 10% of the estimated total number of wells, evenly distributed throughout the region, would be re-visited and become the focus of investigations into newly constructed wells. This survey was undertaken through the period April-May 1991. NORADEP well inventory data has been processed to provide three data sets:

- NORADEP 1 - Tihama plain, all wells
- NORADEP 2 - Tihama plain, new wells (> 1985)
- NORADEP 3 - Inland and upstream wadi areas.

The locations of wells inventoried in the Tihama during the NORADEP inventory are shown in Fig. 3.1.

In the following sections aspects of groundwater development are discussed from the findings of all Tihama data sets with specific attention being given to the establishment of the general characteristics of groundwater use and identification of any recent changes. Details relating to the inland and upstream wadi areas are discussed separately in Section 4.

3.1 GENERAL CHARACTERISTICS

3.1.1 Well Distribution

Pumped well distribution is shown in Fig. 3.2, which includes a soil underlay from which it may readily be discerned that well location is related to soil types, depth to water and groundwater quality (refer Fig. 2.4 and 2.6). Distribution is also dependent upon access to surface water supplies and aquifer development; thus, few wells occur in the spate irrigated area of Wadi Harad and over extended distances adjacent to some foothill areas where shallow bedrock occurs. In downstream wadi areas, where optimal soil, water depth and quality conditions prevail, there are many wells; these appear as the westward extending "arms" in Fig. 3.2.

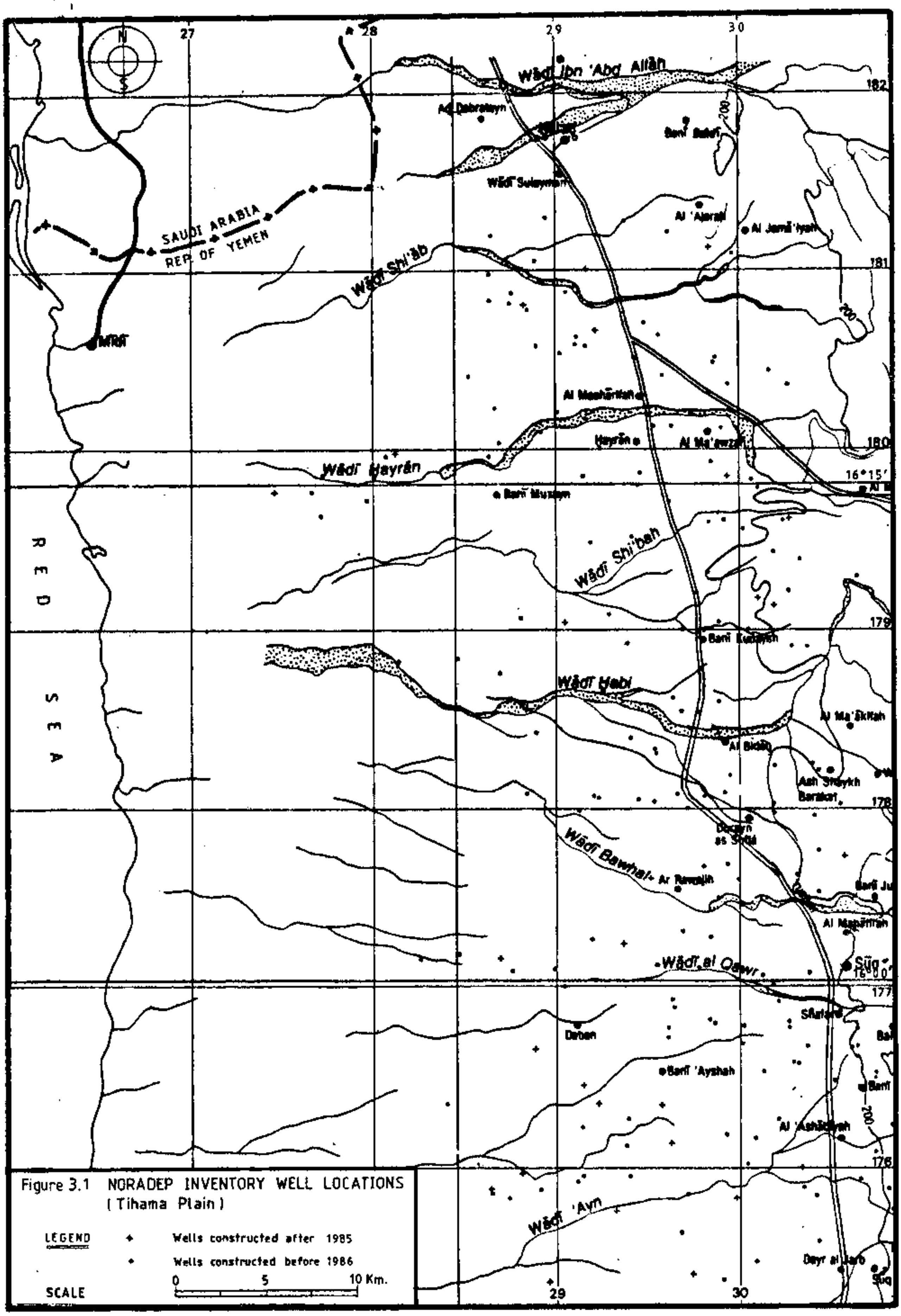


Figure 3.1 NORADEP INVENTORY WELL LOCATIONS (Tihama Plain)

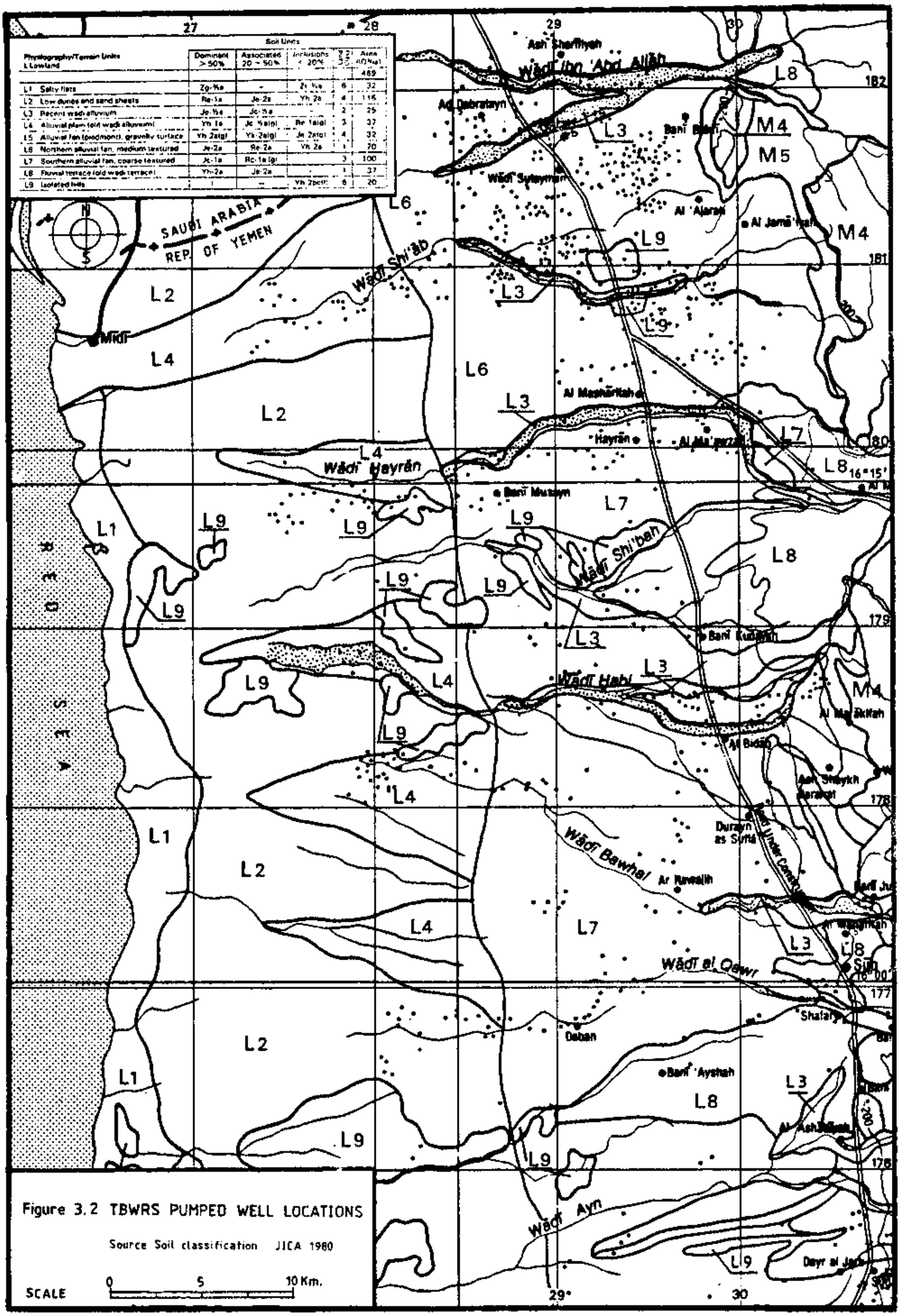


Figure 3.2 TBWRS PUMPED WELL LOCATIONS

Source Soil classification JICA 1980

Table 3.1 *Comparison of TBWRS (1985) and NORADEP (1991) Well Inventory Data*

	Survey	TBWRS	NORADEP 1	NORADEP 2	NORADEP 3
(a)	WELL TYPE (%)				
	sample nr	830	222	42	182
	dug	41	78	74	98
	drilled	36	10	14	2
	combination	23	12	12	0
(b)	DEPTH TO WATER (m)				
	sample nr	508	229	42	192
	minimum	6.0	3.5	3.5	0.6
	maximum	62.8	70.0	65.0	33.0
	mean	24.7	27.8	29.2	6.8
(c)	WELL DEPTH (m)				
	sample nr	1259	241	44	202
	minimum	0.0	1.0	5.8	0.4
	maximum	100.0	140.0	126.0	60.0
	mean	34.6	43.5	49.1	9.6
(d)	DISCHARGE RATE (l/s)				
	sample nr	508	94	13	104
	minimum	1.0	0.3	2.4	0.1
	maximum	25.0	25.0	18.8	11.4
	mean	9.5	8.9	8.4	3.2
(e)	PUMP TYPE (%)				
	sample nr	828	157	34	157
	lineshaft	92	93	88	3
	centrifugal	8	7	12	97

NOTE:
- TBWRS — Tihama Basin Water Resource Study 1985–1986
- NORADEP1 — Noradep Well Inventory 1991; Tihama plain, all wells
- NORADEP2 — Noradep Well Inventory 1991; Tihama plain, new (1985) wells
- NORADEP3 — Noradep Well Inventory 1991; inland/upstream wadis area

3.1.2 Pumped Well Numbers and Use

1259 wells were located in the TBWRS well inventory of which 830 were equipped with a pump. The expansion in groundwater exploitation in the northern Tihama has been rapid. In the early to mid-1970s, from a base level of less than 300 wells, expansion occurred at the rate of about 20 wells/year increasing to about 60 wells/year through the late 1970s early 1980s. A further increase in expansion rate became evident in the mid-1980s at which time more than 100 new wells were installed annually.

Of the total of 830 pumping wells located in 1985-1986, 760 (92%) were utilised for irrigation purposes. The intensification of groundwater development in the region is illustrated by the annual and cumulative irrigation pump deployment in Fig. 3.3.

3.1.3 Well Types, Depths and Discharge Rates

Dug, drilled and combined (dug well deepened by drilling) well types occur. Statistics showing the proportions of each type are given in Table 3.1 (a). There are no indications that drilling activity has increased in recent years; new wells are predominantly constructed by manual excavation techniques.

Well depths vary locally in accordance with the primary control-depth to water. Dug wells typically only extend a few metres beneath the water table whereas 10-20 m of aquifer penetration is commonly effected in drilled wells as indicated by comparison of summary data given in Tables 3.1 (b) and (c). The maximum irrigation well depth recorded is 140 m; mean well depths show an increase from 35 m (TBWRS) to 49 m (NORADEP 2). Depth to water as determined by the NORADEP inventory is shown in Fig. 3.4.

Well discharge rates range from 1-2 l/s to maximum values of 25 l/s with a mean of about 9 l/s as shown in Table 3.1 (d). The NORADEP inventory confirmed TBWRS findings with respect to the general tendency of well yields to increase westward. Relatively low well yields (< 10 l/s) occurred near the inter-wadi foothills zones and higher yields in the central plains area (Fig. 3.5).

This variation was considered to reflect, in part, variable depth to water and pumping equipment, but may also signify reduced aquifer transmissivity in the near-foothills inter-wadi areas. Insufficient specific capacity data (well discharge/drawdown) are available to confirm this hypothesis.

3.1.4 Pumping Equipment

Discharge is typically effected by vertical turbine (lineshaft) pumps coupled via crossed webbing belts to 20-25 HP diesel motors - Table 3.1 (e). There is a fairly high degree of standardisation in pumping equipment with Caprari models accounting for more than 50% of pump types and Yanmar about 80% of engine types.

Lower capacity centrifugal pumps were only found in the wadi environs and in areas of shallow bedrock near the foothills where depths to water were minimal.

3.1.5 Farm Irrigated Areas

Average individual well irrigated farm area, as determined by TBWRS was 9.3 ha (assumed local measure 1 ma'ad = 0.006 ha). NORADEP data indicate that farm sizes associated with newly constructed wells were somewhat larger with mean value 13.5 ha - Table 3.2 (a).

The smallest farm sizes (less than 5 ha) were typically found in the east, adjacent to the foothills in the traditional rainfed agricultural areas, and at isolated locations in the central plain area.

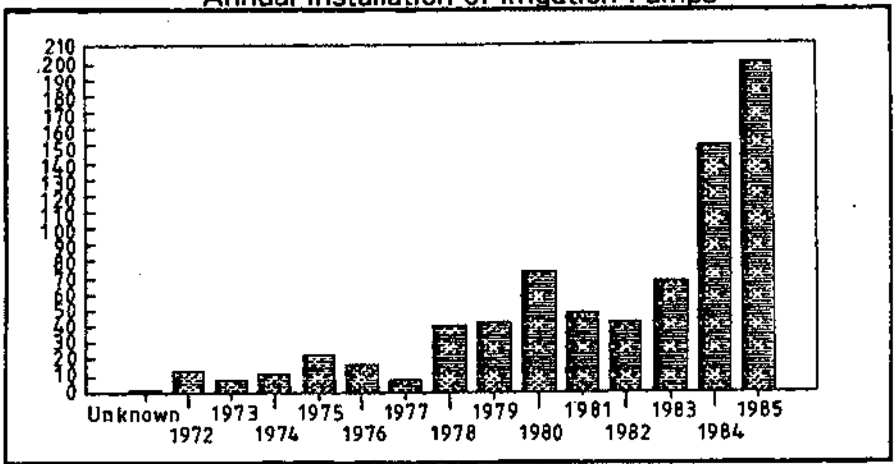
The total groundwater irrigated area in the northern Tihama was estimated at about 7100 ha (TBWRS) of which almost 60% occurs in the environs of Harad.

Fig. 3.3 *Irrigation Pump Equipment (TBWRS)*

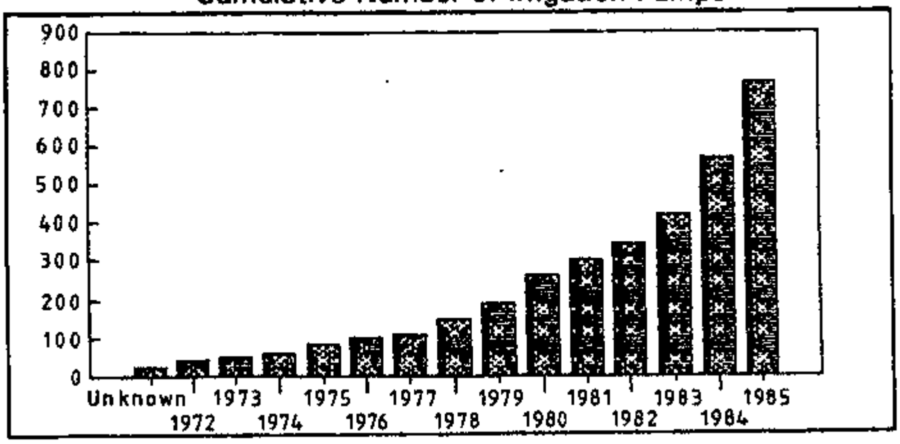
TBWRS Well Inventory / Irrigation Pump Installation

	TBWRS Well Inventory Area					Total Nr Wells/year	Cumulative Total
Year	Harad	Hayran	Habl	Qawr	Ayn		
Unknown	2	0	0	0	0	2	2
1973	9	1	2	0	1	13	15
1973	4	0	4	0	0	8	23
1974	8	3	0	0	0	11	34
1975	14	2	5	0	1	22	56
1976	16	1	0	0	0	17	73
1977	6	0	1	0	0	7	80
1978	35	0	4	0	2	41	121
1979	27	8	8	0	0	43	164
1980	54	6	8	2	4	74	238
1981	31	4	7	3	2	47	285
1982	23	7	7	4	1	42	327
1983	25	7	20	9	6	67	394
1984	41	22	40	18	28	149	543
1985	70	41	37	20	31	199	742
Totals	365	102	143	56	76	742	

Annual Installation of Irrigation Pumps



Cumulative Number of Irrigation Pumps



3.1.6 Crops

Information on crop choices is given in Table 3.3. Sorghum remains the dominant crop in all seasons for about 95% of farms. In only 3% of cases were vegetables identified as a primary crop and 2% for fruits.

Sorghum may be sown once or twice and allowed, after individual harvests for grain and fodder, to also yield one or more ratoon crops solely for fodder. During maturation of the ratoon crops part of the farm area may be given over to cultivation of secondary crops. Areas allocated to the respective crops were not established during the well inventories. In many cases it is believed that the primary sorghum crops would occupy most if not all of the irrigable area and that cultivation of secondary crops would be limited to less than an estimated 20% of the total area. Secondary crops included vegetables (including okra, melokhia, tomatoes, peppers), fruits (mangoes, papaya, banana, guava, melons) and industrial crops (sesame).

The data given in Table 3.3 indicate recent increased development of fruit crops at the expense of vegetables and sesame. Such a change in cropping pattern was confirmed locally in the field. In the traditional rainfed Daban area, north of Wadi Al Qawr, extensive mango cultivation has been initiated. A large scale operation covering > 300 ha and utilising modern, irrigation techniques (drip, centre pivot) has stimulated local interest to the extent that most neighbouring farmers were now cultivating the same or similar fruits.

3.1.7 Groundwater Abstraction

Data relating to seasonal and annual abstraction volumes are summarised in Table 3.2 (b) and (c). The data presented are raw data as given by measured discharges and the respondents' estimate of hours/day and days/month pump operation. Actual abstraction volumes are likely to be less, given farmers' common underestimate of stoppages for maintenance and repair; a reduction factor, adopted in TBWRS, of 0.8 is used for the quantification of actual abstraction.

Little variation in seasonal volumes appeared on comparison of mean values. TBWRS data indicated seasonal abstraction volumes of about 38 000 m^3 whereas NORADEP data provided a lower value of about 30 000 m^3. Annual volumes averaged 0.14 Mcm/well (TBWRS) and 0.12 Mcm/well (NORADEP).

The significance of this variation is uncertain. Field inspection of the area shows that irrigation canal lining and occasional use of flexible pipe conveyances are more common than during the TBWRS inventory. However, the proportion of wells with such improvements remained quite low, thus the impact on reduced water abstraction associated with reduced losses is likely to be minimal. A mean abstraction volume of 0.14 Mcm/well is retained for the purposes of this study.

3.1.8 Water Application

Water application as shown by uncorrected data in Table 3.2 (d) shows extremely wide variation and significant contrast also between mean TBWRS and NORADEP data.

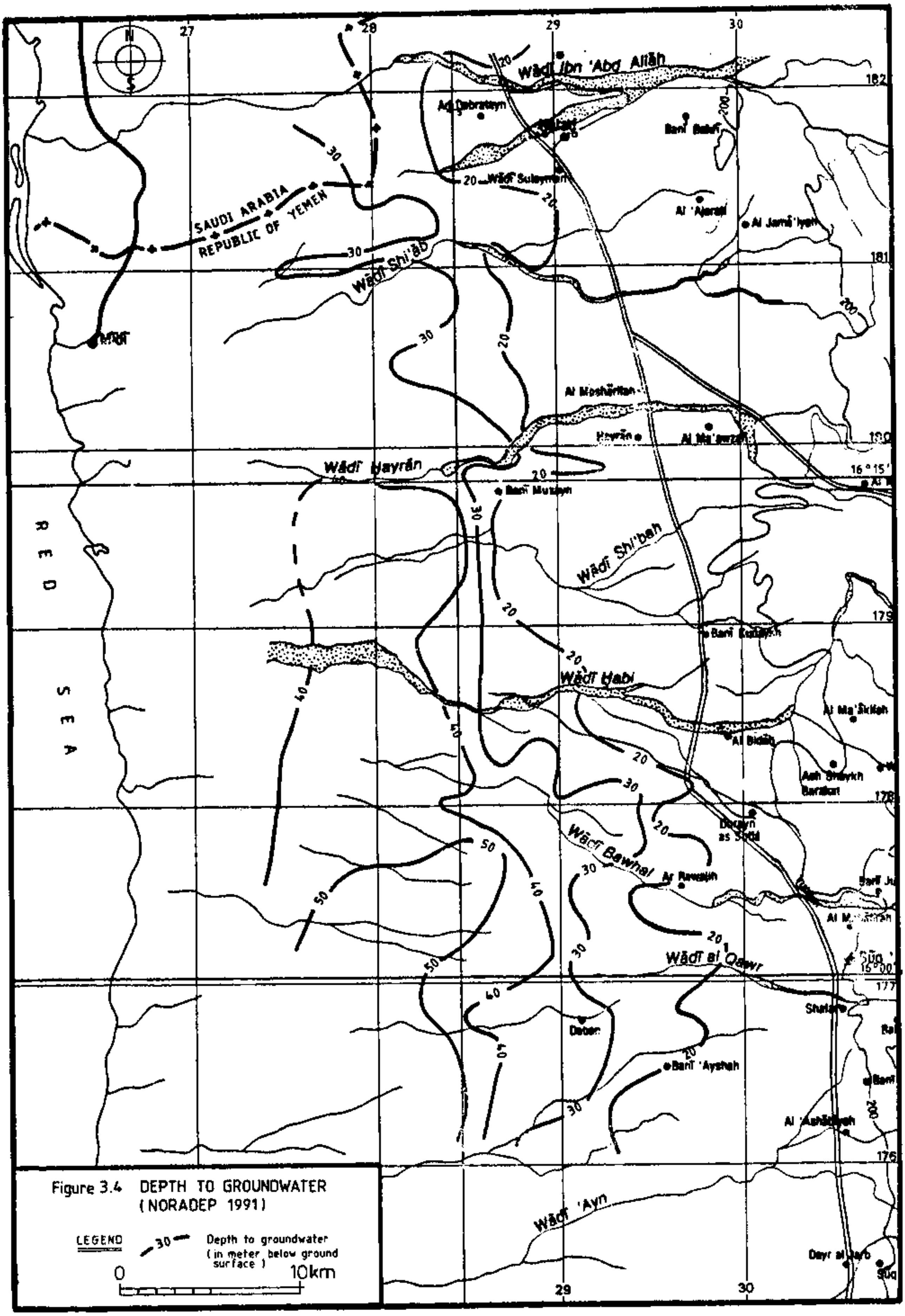


Figure 3.4 DEPTH TO GROUNDWATER (NORADEP 1991)

Mean values, expressing water volume/irrigated area without losses, ranged from 2700 mm (TBWRS) to 1700 mm (NORADEP) which reduced, respectively, to about 2200 mm and 1400 mm when farmers' over-estimate of pump operation was taken into account. Experience on the Tihama suggests that the NORADEP figure is too low unless it were assumed that significant crop under-watering was occurring; field observations do not support this thesis.

Table 3.2 *Comparison of TBWRS (1985) and NORADEP (1991) Well Inventory Data*

	Survey	TBWRS	NORADEP 1	NORADEP 2	NORADEP 3
(a)	IRRIGATED AREA (ha)	+	+	+	*
	sample nr	732	74	18	69
	minimum	0.2	0.4	4.0	0.0
	maximum	800.0	45.0	45.0	9.2
	mean	9.3	10.6	13.5	0.7
	(+) assumed 1 ma'ad = 60 m2 = 0.006 ha (*) assumed libna = 48 m2 = 0.005 ha				
(b)	MEAN SEASONAL ABSTRACTION (Mm3)				
	Rabia	0.0477	0.0381	0.0392	0.0072
	Sayf	0.0444	0.0370	0.0344	0.0071
	Kharif	0.0493	0.0376	0.0390	0.0068
	Shita	0.0500	0.0379	0.0393	0.0072
	(+) (uncorrected values)				
(c)	ANNUAL ABSTRACTION (Mm3) +				
	sample nr	638	132	13	103
	minimum	0.00	0.00	0.00	0.00
	maximum	0.69	0.49	0.46	0.19
	mean	0.18	0.15	0.15	0.03
	(+) (uncorrected values)				
(d)	WATER APPLICATION (mm) +				
	sample nr	590	89	7	68*
	minimum	1000	5	8	19
	maximum	125800	18000	3180	11758
	mean	2738	1704	790	1545
	(+) (assumes no losses; Annual Abstraction/Irrigated Area) (*) (uncorrected values)				

NOTE
TBWRS Tihama Basin Water Resources Study 1985 – 1986
NORADEP1 Noradep Well Inventory 1991; Tihama plain, all wells
NORADEP2 Noradep Well Inventory 1991; new (1985) wells
NORADEP3 Noradep Well Inventory 1991; inland upstream wadis area

Further detail on water applications was sought from a study of NORADEP data on groundwater irrigation farms that receive no supplemental water from wadi flows.

Summary findings are given in Table 3.4; the complete data set (with corrected abstraction volumes) are given in Annex 3. Further complications, however, arose from this data set.

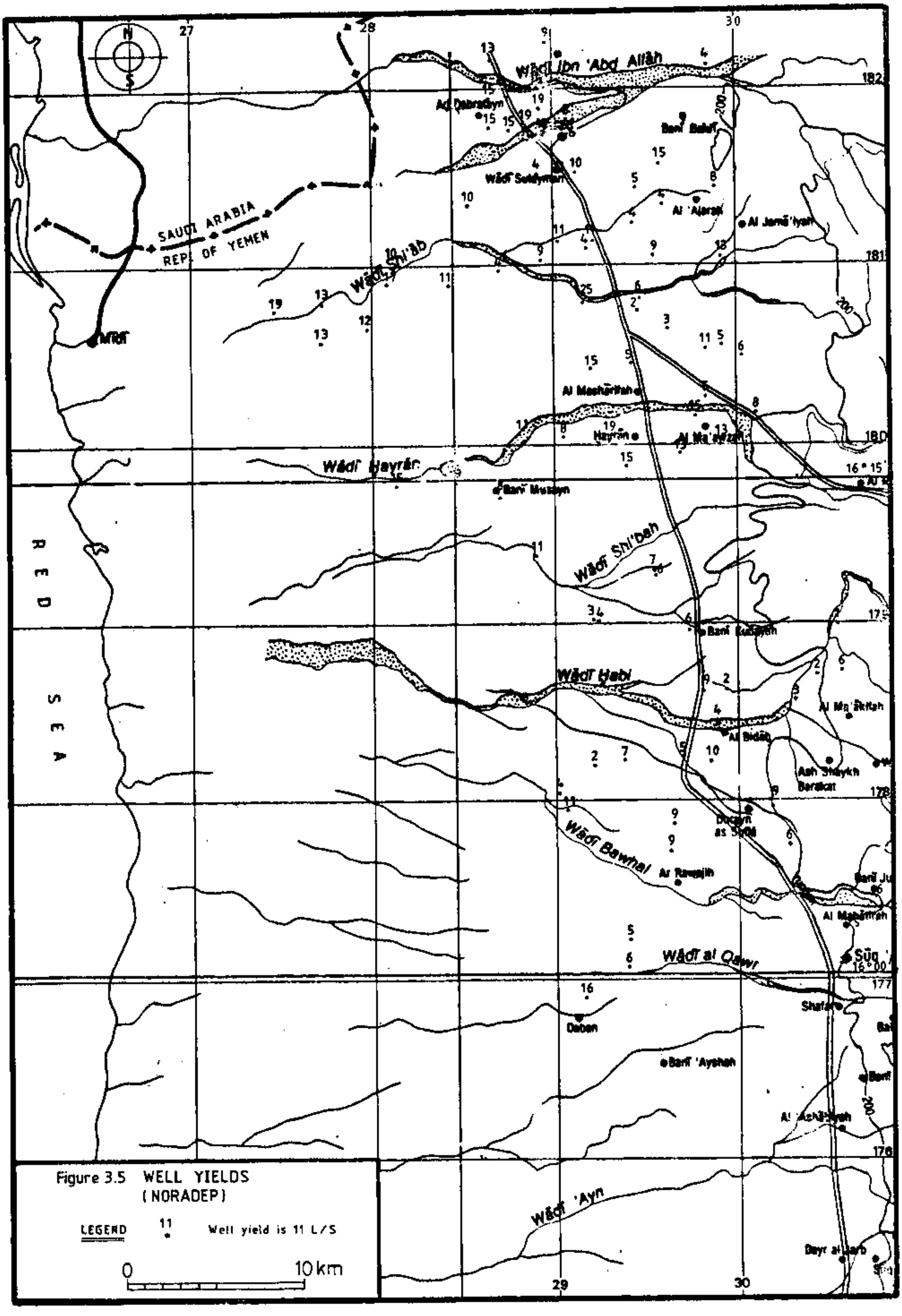


Figure 3.5 WELL YIELDS (NORADEP)

LEGEND 11 • Well yield is 11 L/S

Table 3.3 *Crop Choice Data as Collected During TBWRS (1985) and NORADEP (1991) Well Inventories*

CROP CHOICE (percentage of respondent sample)							
Season	Crops	Survey	Sample	Grains	Fruits	Vegetables	Industrial
RABIA	Primary	TBWRS	734	94	2	3	0
		NORADEP 1	114	95	3	3	0
		NORADEP 2	24	92	4	4	0
		NORADEP 3	73	68	18	14	0
	Secondary	TBWRS	568	4	10	12	26
		NORADEP 1	114	7	12	3	20
		NORADEP 2	24	17	17	8	17
		NORADEP 3	73	14	26	27	0
SAYF	Primary	TBWRS	731	93	2	3	0
		NORADEP 1	103	94	3	3	0
		NORADEP 2	20	95	0	5	0
		NORADEP 3	148	90	8	2	0
	Secondary	TBWRS	564	4	10	12	26
		NORADEP 1	103	4	14	5	18
		NORADEP 2	20	20	20	20	15
		NORADEP 3	148	6	20	10	0
KHARIF	Primary	TBWRS	733	92	2	3	2
		NORADEP 1	105	95	4	1	0
		NORADEP 2	19	100	0	0	0
		NORADEP 3	75	61	20	17	0
	Secondary	TBWRS	635	6	10	13	26
		NORADEP 1	105	7	11	2	18
		NORADEP 2	19	11	21	5	15
		NORADEP 3	75	21	24	19	0
SHITA	Primary	TBWRS	723	92	2	3	2
		NORADEP 1	100	97	2	1	0
		NORADEP 2	18	94	6	0	0
		NORADEP 3	117	76	12	10	0
	Secondary	TBWRS	637	6	10	13	34
		NORADEP 1	100	6	11	2	19
		NORADEP 2	16	11	17	6	17
		NORADEP 3	117	16	10	12	0

NOTE:
TBWRS Tihama Basin Water Resource Study 1985–1986
NORADEP1 Noradep Well Inventory 1991; Tihama plain, all wells
NORADEP2 Noradep Well Inventory 1991; Tihama plain, new (.1985) wells
NORADEP3 Noradep Well Inventory 1991; inland upstream wadi areas

Mean water applications for the sample of 60+ sites was 1650 mm, again apparently low, whereas mean values for sites located in wadi alluvium (Soil Type L4) were 2800 mm. The variation in alluvial fan soils was also anomalous with 1700 mm on the medium textured (Type L6) soil and 1000 mm on the coarser soil (Type L7).

Table 3.4 *Water Application on Various Soil Types*

NORADEP WELL INVENTORY	IRR. AREA (ha)	PUMP RATE (l/s)	GROSS ANNUAL ABSTR.(i) (mm3)	WATER APPLIC. (mm)
ALL GROUNDWATER IRRIGATED WELLS (NO SPATE)				
Minimum	0.4	1.7	0.000	27
Maximum	28.8	18.8	0.390	6858
Mean	10.3	9.5	0.130	1651
SOIL TYPE L4				
Minimum	4.3	9.7	0.141	817
Maximum	21.6	18.8	0.389	6840
Mean	12.3	14.9	0.253	2804
SOIL TYPE L6				
Minimum	2.2	2.1	0.012	59
Maximum	25.2	18.8	0.390	4800
Mean	10.2	10.4	0.137	1694
SOIL TYPE L7				
Minimum	0.4	1.7	0.004	27
Maximum	28.8	11.0	0.248	3214
Mean	11.0	6.0	0.080	1027

NOTE:
(i) annual gross abstraction =
(0.8 * well discharge rate * respondents' estimates of pump operation)
SOIL TYPES:
L4: old wadi alluvium
L6: northern alluvial fan (medium textured)
L7: southern alluvial fan (coarse sand)

There were no obvious differences in cropping pattern to explain these variations. Whilst detailed examination of the data set showed a number of obvious errors with respect to irrigated area (in many cases it is believed that the actual farm area was recorded as opposed to the irrigated portion and thus water application is under-estimated), the differences in derived water applications appeared to be related largely to well yield and pumped operation. It could be argued that the farmers on the alluvial fan pumped less because they benefit from higher rainfall; if this was the case it is difficult to reconcile the differences between sites on soil types L6 and L7 which are, with respect to rainfall, in the same position, also the consistency of cropping patterns in each of the three zones.The wide range of values obtained from the respective inventories and the anomalies within data sub-sets prevent establishment of a meaningful estimate of water application for the typical cropping patterns.

3.1.9 Well and Pumping Equipment Costs

Data relating to well and pumping equipment costs, as provided by the inventory respondents (cost at time of construction or purchase) are given in Table 3.5 (a) and (b). Irrigation well costs ranged from YR 3000 (shallow hand-dug) to about YR 200 000 (deep, drilled). The mean well cost is currently of the order YR 57 500, an increase of about 40% since 1985. Mean pumping equipment costs appear, from comparison of survey data, to have more than doubled over the same time period from YR 42 000 to YR 93000.

Table 3.5 *Costs of Well Construction and Pumping Equipment*

	Survey	TBWRS	NORADEP 1	NORADEP 2	NORADEP 3
(a)	WELL CONSTRUCTION COSTS (YR)				
	sample nr	728	187	38	169
	minimum	2000	3000	3000	150
	maximum	200000	45.0	45.0	9.2
	mean	41700	57800	57400	20700
(b)	PUMPING EQUIPMENT COSTS (YR)				
	sample nr	782	136	32	138
	minimum	1000	4000	4000	10
	maximum	105000	340000	340000	200000
	mean	42200	93200	137700	9700

NOTE:
TBWRS Tihama Basin Water Resources Study 1985–1986
NORADEP1 Noradep Well Inventory 1991; Tihama plain, all wells
NORADEP2 Noradep Well Inventory 1991; Tihama plain, new (1985) wells
NORADEP3 Noradep Well Inventory 1991; inland upstream wadi areas

3.2 INCREASE IN NUMBER OF WELLS

The NORADEP survey identified 44 new well sites; their location is shown in Fig. 3.2. Recent intensification of groundwater development appeared to be occurring in the central plains area.

TBWRS data for 1985 indicated that new wells were being installed at a rate of 100/year. Had this rate been maintained, an additional total (post-TBWRS) of about 500 wells could be anticipated. While recognising that only a small proportion of new wells had been located during the NORADEP survey, the general impressions of field crews was that it was unlikely that such expansion had indeed taken place. For estimating purposes it was assumed that expansion rates had declined since 1985 and that the total number of irrigation wells in the area has increased from 760 (1985) to 1100 (1991).

3.3 NET GROUNDWATER ABSTRACTION IN THE NORTHERN TIHAMA

Gross abstraction for irrigation purposes in the northern Tihama (GAi) was estimated, assuming 1100 irrigation wells with mean individual annual abstraction of 0.14 Mcm, at about 150 Mcm.

Given the variation and anomalies in water application assessment it was not possible to control estimates of irrigation returns; for estimating purposes it was assumed that under-watering is not practised and that the efficiency of the irrigation system is 40%, with 60% of the abstracted volume returning via percolation to the groundwater reservoir.

Thus, net groundwater abstraction (NAi) was estimated at 40% of gross abstraction; an annual discharge of about 60 Mcm. Cumulative annual discharge from the 70 or more domestic utilities in the region (GAd) is of the order 3 Mcm.

The total net groundwater abstraction in the area was estimated to be about 63 Mcm.

3.4 CURRENT GROUNDWATER BALANCE

The natural groundwater balance of the region has been significantly modified by the successive increments in abstraction over the past 20 years. The increased abstraction, while locally modifying flow paths, has probably not yet had significant impact on regional (central plains and coast) hydraulic gradients and so natural coastal discharge is likely to remain at historic levels.

A current annual groundwater balance can thus be established as:

Recharge = Natural Discharge + Net Abstraction - Storage Change

Where recharge and natural discharge are as given in Section 2.3.3 and net abstraction is determined above in Section 3.3.

Hence, the aquifer storage change can be estimated:

Storage Change = Recharge - Natural Discharge - Net Abstraction

= (76 - 76 - 63)

= 63 Mcm/yr

Note: For estimating purposes it was assumed that the accuracy of volume of recharge/discharge is ± 20% (Section 2.3.3).

This storage change represents the volume of water that is withdrawn annually from aquifer storage to meet abstraction demand. Such withdrawal is naturally accompanied by a decrease in aquifer storage volume and thus a decline in water level. The magnitude of water level decline will vary according to the hydrogeological environment; in particular, the degree of local abstraction and the specific yield of the sediments being drained.

The occurrence, distribution and magnitude of water level declines in the region are evaluated in Section 5.

4 GROUNDWATER USE IN THE INLAND AND UPSTREAM WADI AREAS

The NORADEP well inventory was extended into several inland and upstream wadi areas, not previously assessed, to gain general insight into water use and developments. The location of areas visited is shown in Fig. 4.1; in total about 220 sites were visited.

Significant groundwater development has occurred east of Abs in the upper reaches of Wadis Al Qawr and Bawhal. Here 271 wells were located (121 inventoried) in the narrow valley sections incised into a predominantly rocky, undulating terrain.

Development was also evident in the upper reaches of Wadi Bani Nashar (59 wells) and Wadi Hayran (27 wells). Little development was observed in the upstream sections of Wadi Habl and even less in Wadi Harad.

Statistics describing groundwater development in these areas can be found with the other NORADEP data sets in Tables 3.1 (a)-(e), 3.2 (a)-(d), 3.3 and 3.5 (a)-(b) under the headings NORADEP 3.

In contrast to the Tihama plains, agricultural development in the inland and upstream wadi areas was typically restricted to narrow stream beds or wadi bed margins; extensive development was limited by topography and absence of suitable soil profiles. Farm sizes consequently tended to be small, of the order of 0.5 ha.

Well depths were typically <10 m with depths to water averaging 6-7m; such shallow depths to water enable the almost invariable use of centrifugal pumps (97% of sample). Well yields ranged from <1 l/s to 11 l/s with a mean of about 3 l/s.

Sorghum remained dominant in cropping patterns although at a lower proportion of the sample than found for the plains; maize was also cultivated on a small scale locally. Fruit (banana, papaya, mango, oranges) and vegetable (potatoes, tomatoes, carrots, peppers) cultivation was significantly more developed in the inland and upstream wadi regions.

The seasonal variation in cropping pattern was more marked than in the plains with virtually only grain (sorghum) production in the dry Sayf season. Almost 40% of respondents claimed that their wells went dry during this season.

Despite this phenomenon, no significant seasonal variation in abstraction volumes was evident from measured discharges and respondents' estimate of pump operation. Mean annual abstraction volumes for individual wells was of the order 24000 m^3 (corrected value). Data for water application suffered from the same difficulties experienced on the plain; the mean value, discounting highly irregular values, is of the order 1500 mm.

Mean costs for predominantly shallow, dug wells were about YR 20 000 with pumping equipment at about YR 10 000.

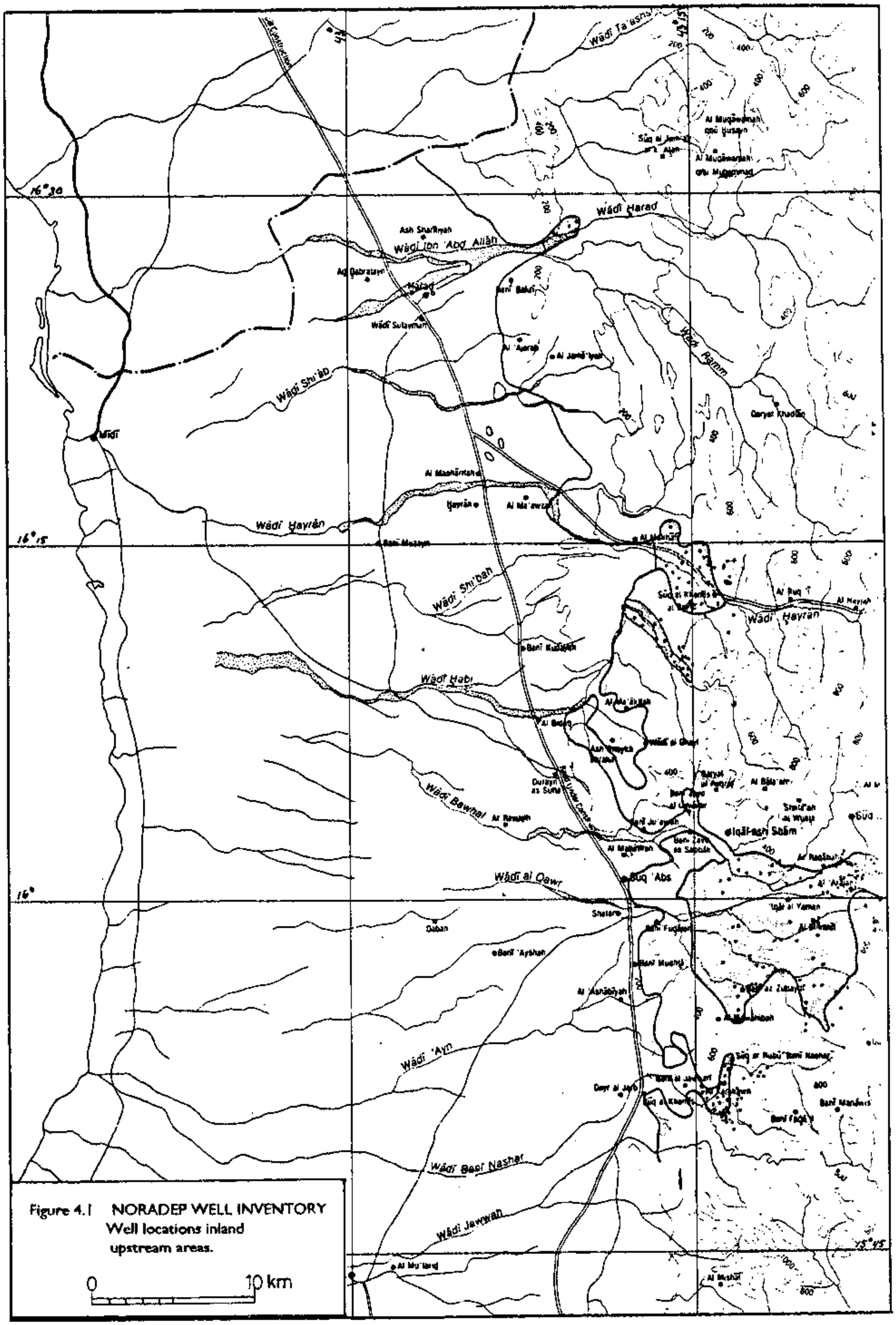


Figure 4.1 NORADEP WELL INVENTORY
Well locations inland
upstream areas.

0 10 km

5 GROUNDWATER LEVEL AND QUALITY CHANGES

5.1 DATA

5.1.1 TDA Monitoring Network

The monitoring network established in the northern Tihama during the TBWRS comprised 41 wells; the locations are shown in Fig. 5.1. Information relating to location, well type, depth and use are given in Table 5.1.

Initial data sets were compiled from the TBWRS well inventory through the period September 1985 to July 1986; monthly monitoring of groundwater levels and groundwater quality (EC) commenced February 1988. Regular monitoring was continued by TDA since November 1988.

In mid-1991 only 28 sites were operable; 13 sites where water levels had fallen below the base of the well have been abandoned. The number of observations made since initiation of the monitoring programme is shown graphically in Annex 4.

The monitoring wells were visited by the NORADEP well inventory crews in June 1991. One well, HAR-293, could not be located and some minor discrepancies were noted with respect to the location of other sites. Well head elevations were also found to be at variance with those established during the TBWRS well inventory. The differences, within the range ± 20 m but typically less than 10 m, however, fall within the anticipated error range of the altimeters used. The TBWRS elevations, given in Table 5.1, have been retained; any elevation errors are unimportant with respect to trend analysis but may introduce appreciable error potential with respect to establishment of hydraulic gradients/flow analysis (as undertaken in Section 2.2.5).

5.1.2 NORADEP Well Inventory

Additional information was sought on groundwater level and quality variations with time from a comparison of TBWRS and NORADEP well inventory data in selected areas.

5.2 GROUNDWATER LEVELS

The full data set of groundwater level monitoring is given in Annex 4.

5.2.1 Groundwater Level Trends

The time series of groundwater levels (1988-1991) were assessed with a view to identification of trends. In the assessment, difficulties were experienced, with the incomplete data set and the spatial variability of groundwater level minima and maxima, in meeting the requirement for a suitable time frame for comparison.

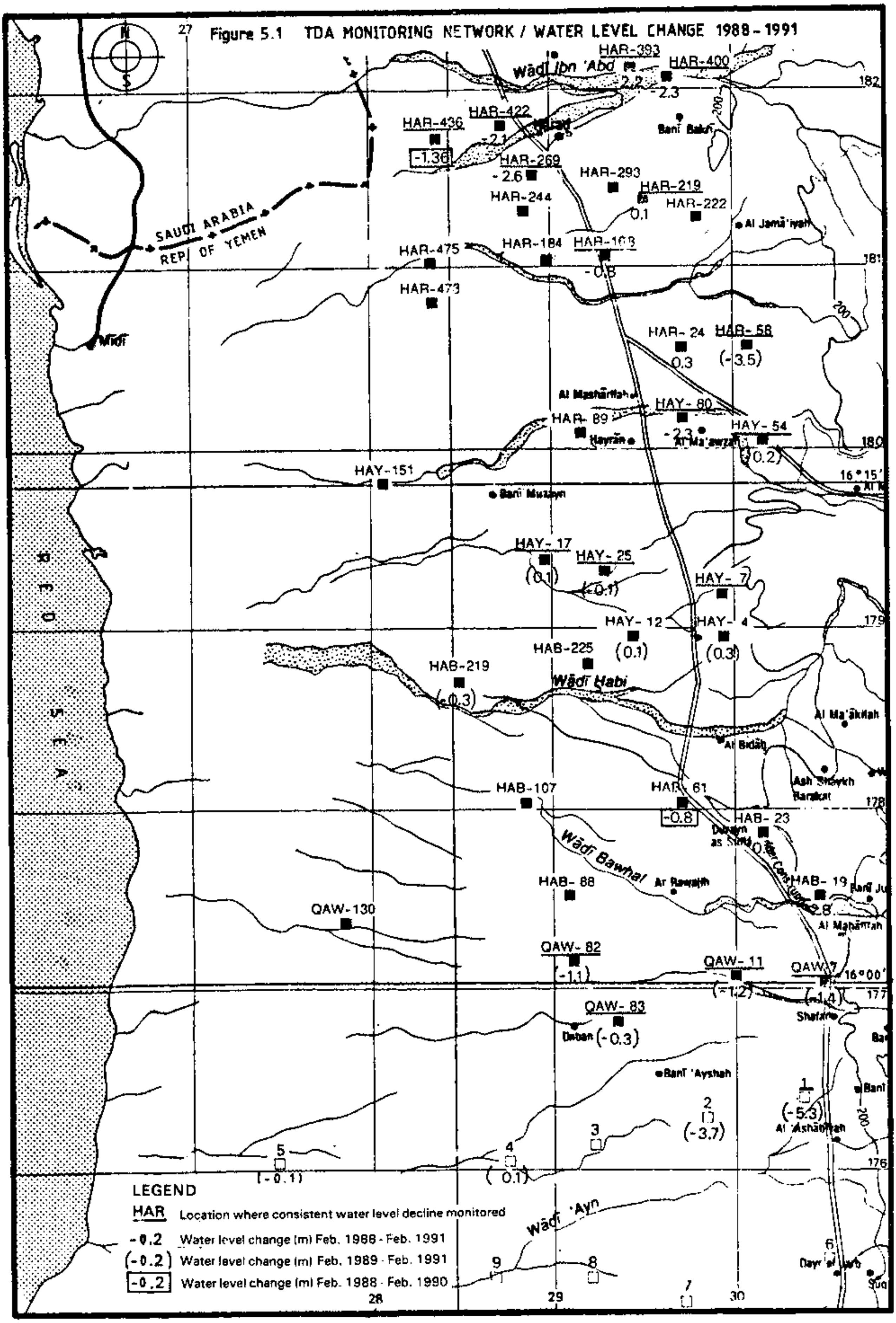


Figure 5.1 TDA MONITORING NETWORK / WATER LEVEL CHANGE 1988 - 1991

In the first instance graphs for all wells with a reasonable time series of data, were prepared and sites differentiated with respect to the occurrence of an obvious consistent trend. The only consistent trend observed was one of water level decline; examples are given in Fig. 5.2. Sites at which such trends of water level decline were identified are shown in Fig. 5.1.

Absolute water level depths were then compared for the month of February in 1988, 1989, 1990 and 1991. This month was selected as a compromise between data availability and coincidence with the minima of the groundwater recession curve. Differences between the values for Feb 1988 and Feb 1991 or, where data were absent, between Feb 1989 and Feb 1991 were then computed; these are given with the annual values in Table 5.2 and shown in Fig. 5.1. In two cases, where Feb 1991 data were missing, the difference between Feb 1988 and Feb 1990 was adopted.

Whilst a groundwater level rise, typically less than 0.3 m, was indicated at six sites and no change observed at one site, the vast majority of sites (21 out of 28 for which a two or more year comparison could be made) displayed a groundwater level decline. Declines over the 3 (2) year period 1988 (1989)-1991 ranged from 0.1 to 5.3 m and showed considerable areal variation. The most significant declines were associated with the areas of debouchment of Wadis Ayn/Al Qawr and Bawhal, along the courses of Wadis Harad and Hayran and at an inter-wadi site located near the foothills.

Rates of water level change at the various sites, over their respective monitored periods, are given in Table 5.2 and shown in Fig. 5.3. An average rate of about 0.75 m/yr is evident for the Wadis Harad and Hayran areas whilst higher rates of 0.9 m/yr and about 2.0 m/yr are indicated at locations in Wadis Bawhal and Al Qawr/Ayn. Water level declines are observed up to 20 km from the foothills.

Confirmation of these findings was given by matching wells inventoried by both the TBWRS and NORADEP surveys. Data and maps for the Wadis Hayran, Al Qawr and Bawhal areas are given in Annex 5. This data indicates annual water level declines of 1.0m around Wadi Hayran and 0.6m around Wadi Bawhal.

Further demonstration of water level declines is given by maps showing the distribution of TBWRS survey disused and dry wells (Fig. 5.4) and NORADEP survey deepened wells (Fig. 5.5).

Occurrences of repeated deepening of wells was typically limited to the shallow bedrock, near-foothills and inter-wadi regions where aquifer development and throughflow is limited; in the Abs area, instances where wells have had to be deepened more than three times are common.

Enquiries of farmers in such areas show that seasonal water shortages regularly occur with consequent demand for the vehicular transport of water for domestic purposes. For a number of wells deepened into bedrock strata there were reports of deteriorating water quality.

Table 5.1 *TDA Monitoring Network*

Area		Coordinates		Elev.	TBWRS Original Data Set		NORADEP Variations				
Well Nr	Ref	E	N		Well Type	Well Depth	Well Use	Well Type	Well Depth	Well Use	Comments
HARAD											
HAR – 58	1	30250	180550	130 dug		15.4 Dis			17.0		deepened
HAR – 24	2	29850	180590	109 dug		33.5 Dis				Irr	
HAR – 186	3	29050	161070	79 drill		30.0 Irr			44+		deepened
HAR – 473	4	28360	180840	55 drill		30.0 Irr			35+		
HAR – 475	5	28340	181020	57 dug		32.6 Dis		comb			deepened
HAR – 241	6	28940	181330	82 dug		24.0 Dis					
HAR – 134	7	29660	181110	100 dug		17.6 Dis					dry
HAR – 222	8	29850	181260	115 drill		100.0 Dis					dry
HAR – 219	9	29600	181370	105 dug		42.8 Dis	drill			Irr	
HAR – 293	10	29450	181460	105 dug		53.0 Dis					not located
HAR – 269	11	29000	181540	91 drill		55.0 Dis					
HAR – 436	12	28430	181750	69 drill		56.0 Dis					
HAR – 422	13	28770	181820	84 comb		32.0 Dis				Irr	
HAR – 393	14	29530	182110	121 comb		29.0 Dis					
HAR – 400	15	29750	182100	134 dug		14.2 Dom					
HAR – 54	16	30280	180080	135 dug		10.8 Dom					
HAY – 80	17	29820	180170	112 dug		16.6 Dis					
HAY – 89	18	29250	180100	88 comb		57.0 Dis					
HAY – 151	19	28020	179810	42 dug		32.0 Dis					dry
HAY – 25	20	29340	179320	95 dug		48.4 Dom					
HAY – 17	21	29030	179360	70 dug		45.5 Dis					
HAY – 11	22	29710	178940	109 dug		29.0 Dom					
HAY – 4	23	30080	178950	129 dug		13.9 Dom					
HAY – 7	24	30080	179220	132 dug		13.2 Dom					
ABS											
HAB – 225	1 25	29270	178820	89 dug		35.0 Dis					dry
HAB – 219	2 26	28570	178730	56 dug		45.0 Dis					dry
HAB – 107	3 27	28950	178040	75 dug		65.0 Dis					dry
HAB – 23	4 28	30250	177930	141 dug		27.7 Dom					
HAB – 19	5 29	30670	177550	177 dug		34.4 Dom			37.5		
HAB – 61	6 30	29790	178040	119 dug		36.0 Dom					
HAB – 88	7 31	29160	177560	96 dug		52.6 Dis					dry
QAW – 130	8 32	27900	177360	39 dug		29.0 Dom				Dis	dry
QAW – 82	9 33	29170	177210	95 dug		58.6 Dis					dry
QAW – 7	10 34	30590	177030	180 dug		25.0 Dom					
QAW – 11	11 35	30090	177120	148 dug		28.9 Dom					
QAW – 83	12 36	29480	176850	110 dug		64.8 Dis					
QAW – 1	13 37	30380	176040								
QAW – 2	14 38	29630	176050								
QAW – 3	15 39	26220	176130								
QAW – 4	16 40	28740	176280								
QAW – 5	17 41	27640	176400								

LEGEND
- Dis = Disused
- Dom = Domestic
- Irr = Irrigation
- Com = dug+drilled
- drill = drilled

5.2.2 Aquifer Storage Depletion

The widespread occurrence of groundwater level declines provide confirmation of the imbalance that has been created within the groundwater flow system.

The rates of decline were, as might be expected, quite variable but tended to be of the order 0.75 m/yr for much of the monitored alluvial fan near-foothills area.

If it were assumed that this 0.75 m/yr rate of decline provided a mean value representative of the entire area extending up to 15 km from the foothills, the annual aquifer storage change can be estimated, assuming a specific yield of 0.13 (TBWRS), and an areal reduction factor (ARF) of 0.5 because abstraction is not distributed evenly over the entire area, from:

Storage Change = Water Column (m) * Area (m^2) * ARF
= (0.75 * 0.13) * (70 000 * 15 000)*0.5
= 51 Mcm/yr.

This value, of the same order as that derived from the groundwater balance of Section 3.4, confirms the magnitude of the annual aquifer storage depletion.

5.3 GROUNDWATER QUALITY

The full data set of groundwater quality (EC) monitoring is given in Annex 6. As for groundwater level monitoring data, graphs were made of all monitoring sites and trends assessed. Example EC graphs are shown in Fig. 5.6. From these graphs, seasonal variations in EC, reflecting recharge processes can be observed; these are typically less than 500 micro S/cm.

Sites were differentiated according to whether they displayed relatively consistent values throughout the monitoring period (eg. HAR-400, HAY- 80) or a trend of water quality deterioration (eg. HAR-219, HAY- 4, HAR-222, QAW- 5). Sites at which a trend of water quality deterioration was evident are shown in Fig. 5.7. Also shown in this figure are areas of varying EC range as displayed by the time series of monitoring data. Wadi areas were characterised by minimal EC variation (< 1500 micro S/cm) whereas generally higher absolute base values and significant variation occurred in inter-wadi and downstream wadi areas. The sites at which water quality deterioration was indicated lie within these areas with the sole exception of site QAW- 1.

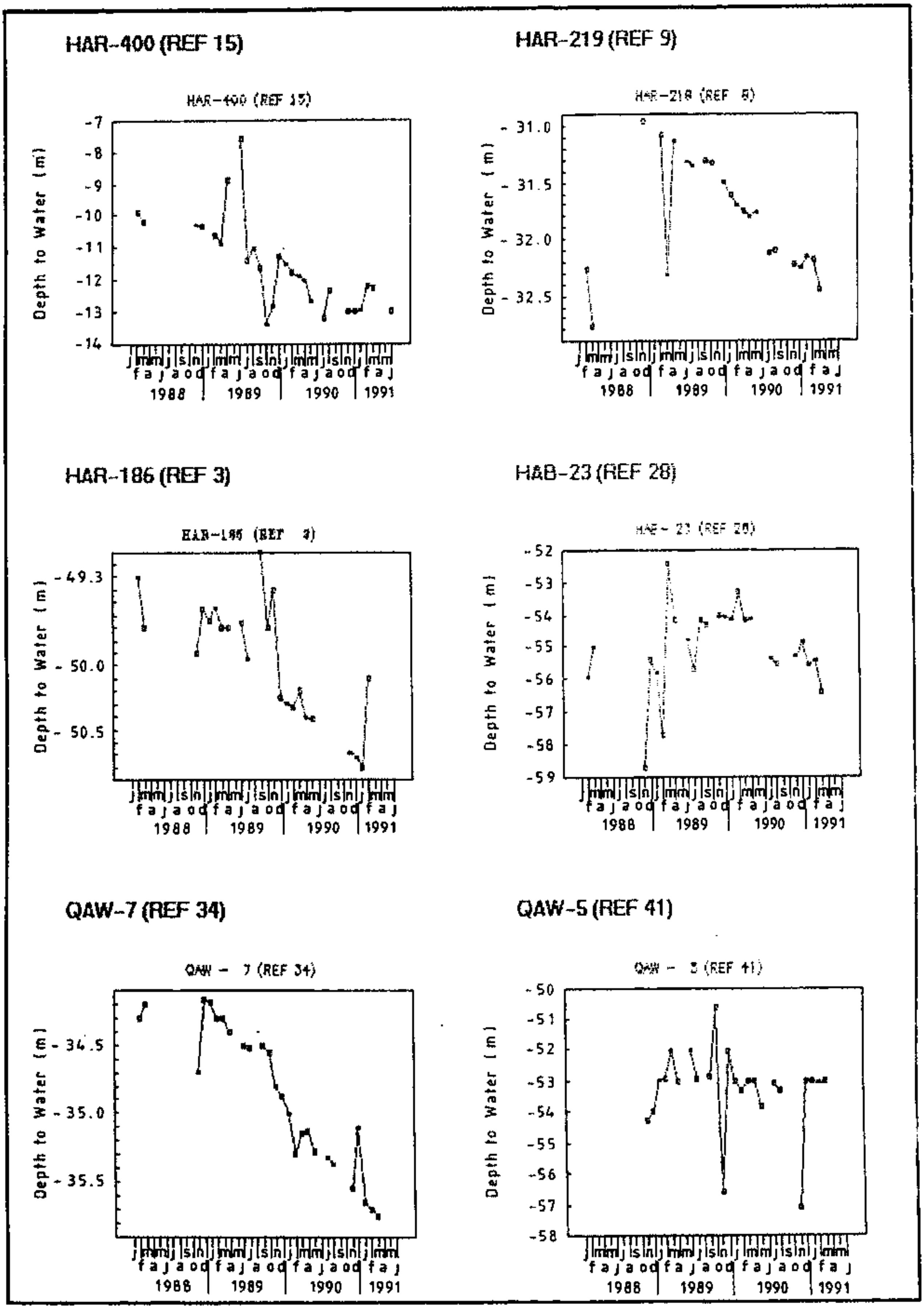
Water quality deterioration in the inter-wadi and near-foothills locations is an intensification of existing conditions (refer Fig. 2.6 and Section 2.2.5) which may be attributed to modification of the local flow regime by pumping and/or a reduction in fresh water recharge.

Table 5.2 *TDA Monitoring Network; Depth to Groundwater, 1988 - 1991 (February)*

TDA MONITORING NETWORK
Depth to Groundwater, 1988 – 1991 (February)

Well Ref	Ser Nr	1988	1989	1990	1991	Variation (2.3 Year)	Rate (m/yr)
HAR – 58	1		16.4	16.6	19.9	–3.5	–1.75
HAR – 24	2	15.1	14.8	14.5	14.9	0.3	0.10
HAR – 186	3	24.3	24.5	25.3	25.1	–0.8	–0.27
HAR – 473	4						
HAR – 475	5				30.7		
HAR – 241	6		26.3				
HAR – 134	7						
HAR – 222	8		24.0	24.1	24.0	0.0	0.00
HAR – 219	9	22.3	21.1	21.7	22.2	0.1	0.03
HAR – 293	10		20.4				
HAR – 269	11	19.8	19.9	21.1	22.3	–2.6	–0.87
HAR – 436	12	28.3	28.9	29.8		–1.6	–0.80
HAR – 422	13	21.2	21.3		23.3	–2.1	–0.70
HAR – 393	14	12.3	13.1	22.5	14.5	–2.2	–0.73
HAR – 400	15	9.9	10.6	11.8	12.2	–2.3	–0.77
HAR – 54	16		6.7	7.3	6.9	–0.2	–0.10
HAY – 80	17	12.6	12.9	13.9	14.8	–2.3	–0.77
HAY – 89	18						
HAY – 151	19						
HAY – 25	20		45.5	47.2	46.5	–1.0	–0.50
HAY – 17	21		44.5	44.4	44.4	0.1	0.05
HAY – 11	22		11.1	9.7	11.0	0.1	0.05
HAY – 4	23		11.8	9.8	11.4	0.3	0.15
HAY – 7	24		29.7	29.8			
HAB – 225	25		28.1	28.1			
HAB – 219	26		38.7	45.1	39.0	–0.3	–0.15
HAB – 107	27		47.7				
HAB – 23	28	36.0	37.7	33.3	35.4	–0.5	–0.17
HAB – 19	29	34.2	35.2	37.4	37.0	–2.8	–0.93
HAB – 61	30	36.3	36.2	37.1		–0.8	–0.40
HAB – 88	31						
QAW – 130	32						
QAW – 82	33		57.3	57.9	58.3	–1.1	–0.55
QAW – 7	34	24.3	24.3	25.3	25.7	–1.4	–0.47
QAW – 11	35		27.8	28.3	29.0	–1.2	–0.60
QAW – 83	36		62.8	63.1	63.2	–0.3	–0.15
QAW – 1	37		19.6	20.3	25.0	–5.3	–2.65
QAW – 2	38		40.3	36.9	44.0	–3.7	–1.85
QAW – 3	39				60.8		
QAW – 4	40		50.4	50.6	50.5	–0.1	–0.05
QAW – 5	41		33.0	33.3	33.1	–0.1	–0.05

Fig. 5.2 *Example Hydrographs (1988 - 1991)*



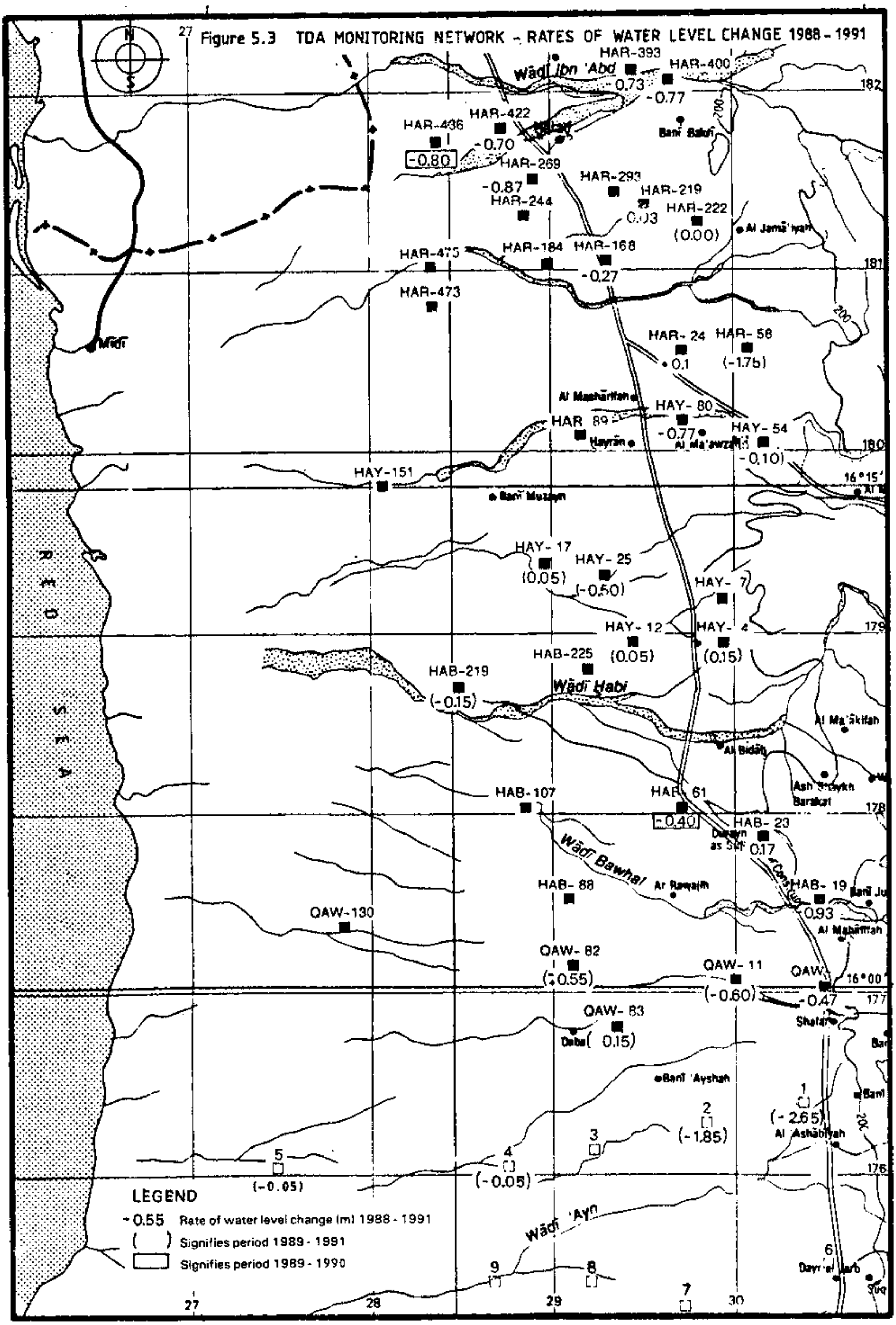


Figure 5.3 TDA MONITORING NETWORK - RATES OF WATER LEVEL CHANGE 1988 - 1991

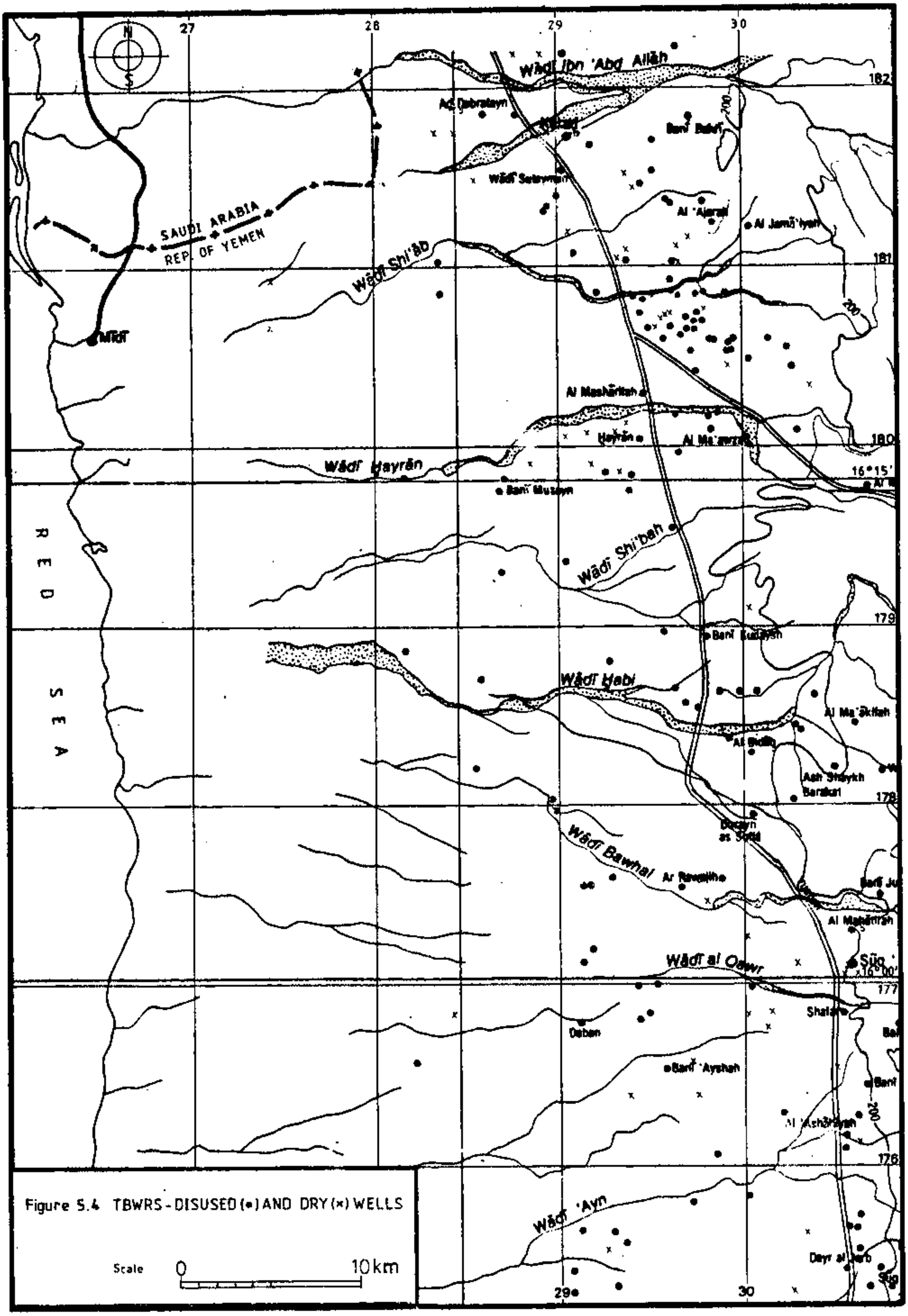


Figure 5.4 TBWRS - DISUSED (•) AND DRY (×) WELLS

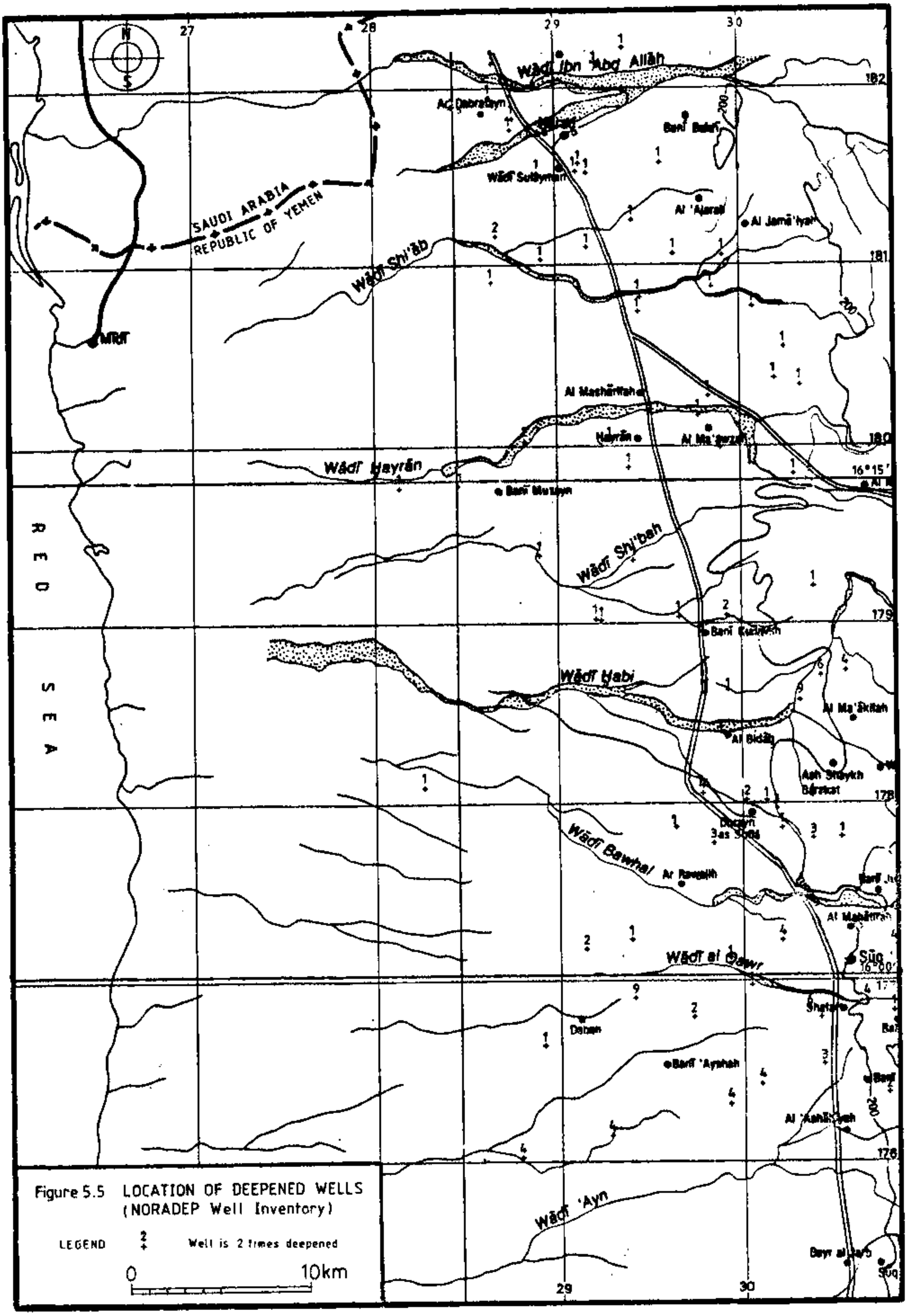
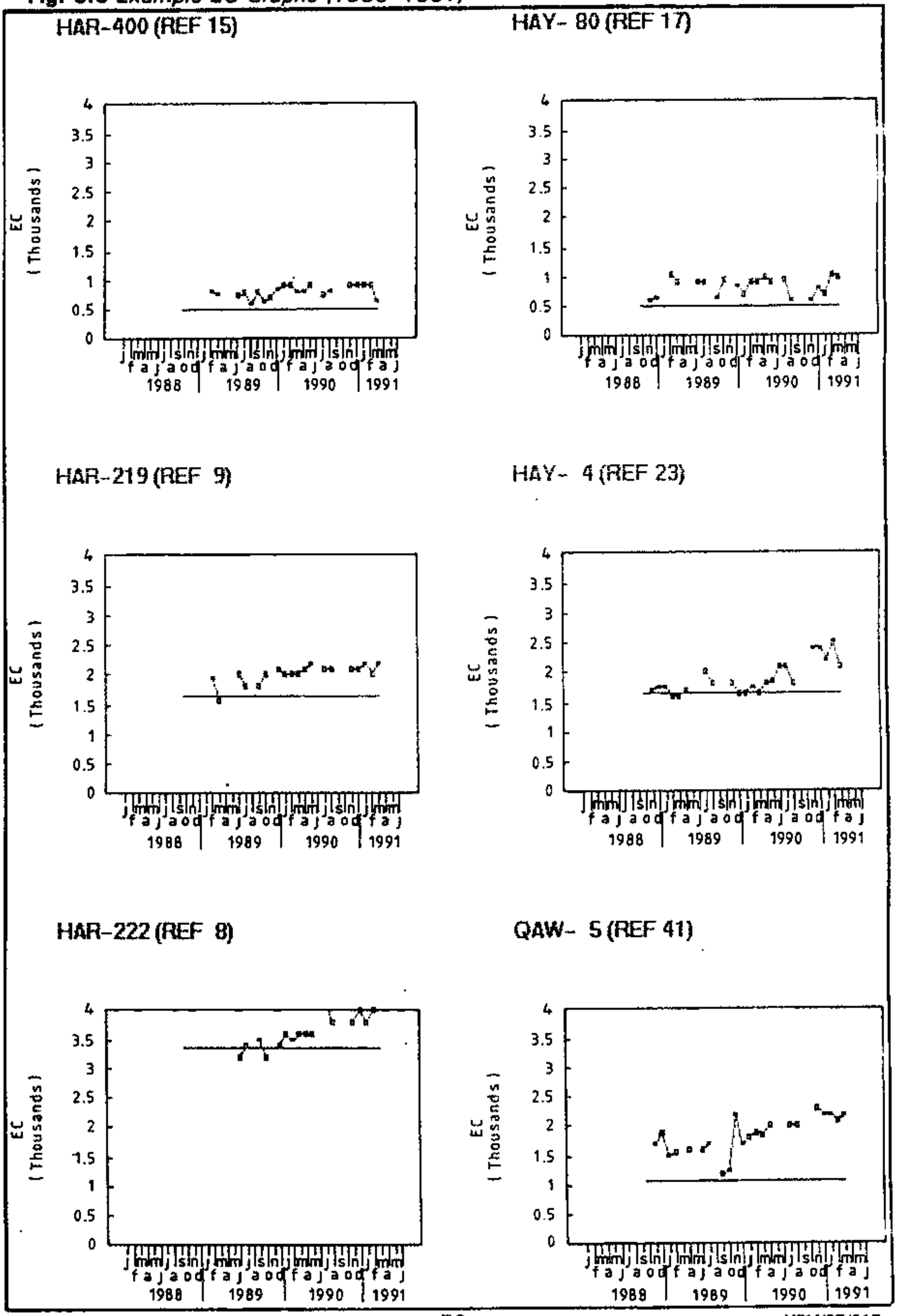


Figure 5.5 LOCATION OF DEEPENED WELLS (NORADEP Well Inventory)

Fig. 5.6 *Example EC Graphs (1988 -1991)*



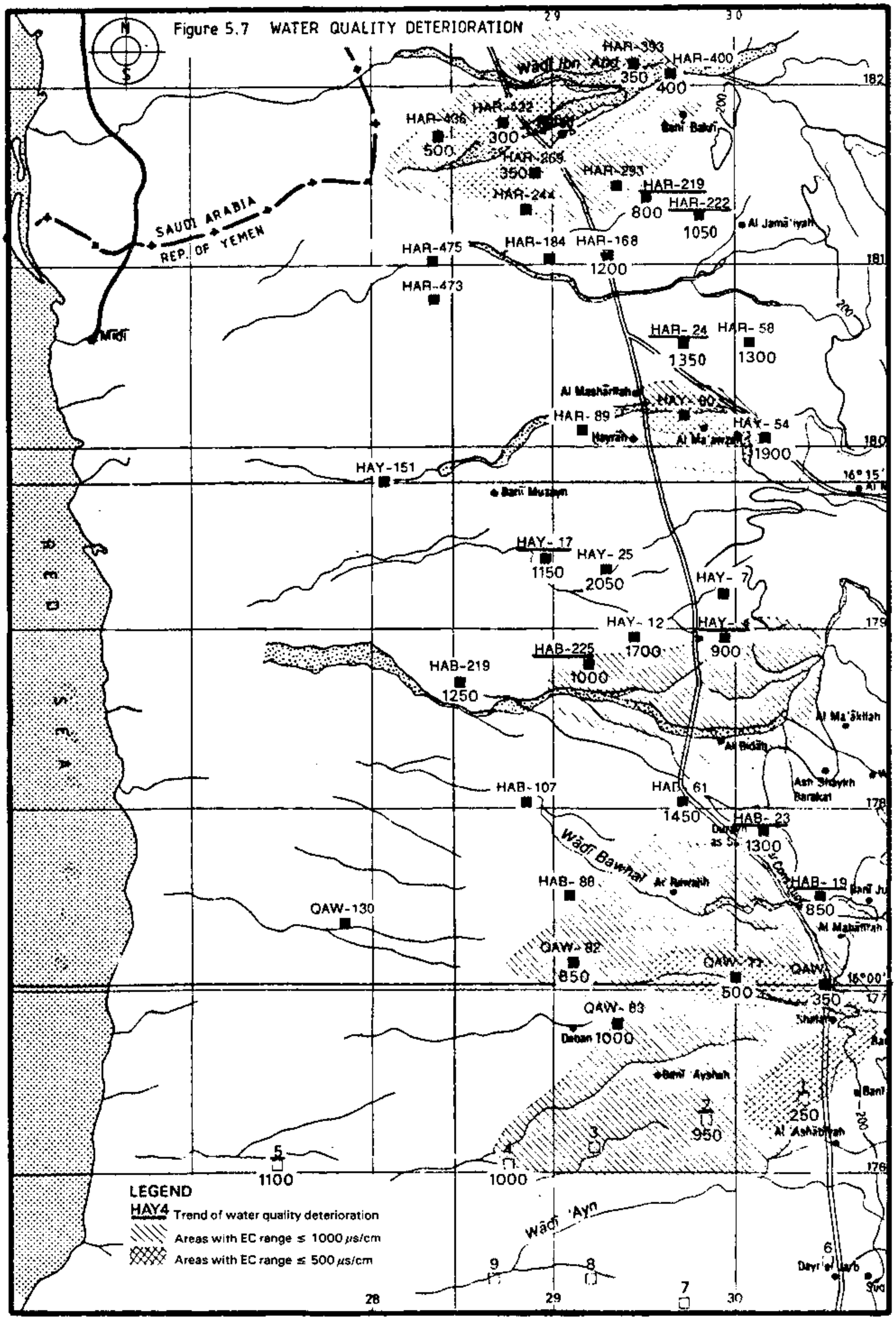


Figure 5.7 WATER QUALITY DETERIORATION
SAUDI ARABIA
REP. OF YEMEN
HAR-393
HAR-400
350
400
HAR-436
HAR-432
300
500
HAR-269
350
HAR-293
HAR-219
HAR-244
800
HAR-222
1050
Al Jama'iyah
HAR-475
HAR-184
HAR-168
1200
HAR-473
Midi
HAR-24
1350
HAR-58
1300
Al Masharifah
HAR-89
HAY-54
1900
HAY-151
Bani Musayn
HAY-17
1150
HAY-25
2050
HAY-7
HAY-12
1700
900
HAB-225
1000
HAB-219
1250
Al Ma'akilah
HAB-107
1450
HAB-23
1300
Wadi Bawhal
HAB-88
HAB-19
850
QAW-130
QAW-82
850
500
350
QAW-83
1000
Bani Ayshah
250
950
1100
1000
Wadi 'Ayn
LEGEND
HAY4 Trend of water quality deterioration
Areas with EC range ≤ 1000 µs/cm
Areas with EC range ≤ 500 µs/cm
28
29
30

Further detail is offered by the comparison of TBWRS and NORADEP inventoried wells; data and maps for the Wadis Hayran, Al Qawr and Bawhal areas are given in Annex 5. From a limited sample of 15 sites where direct comparisons could be made between 1985/86 and 1991 data, 12 fell within the range ± 500 micro S/cm while at three sites a significant deterioration in water quality (900 to 2300 micro S/cm) was noted. Two of these sites lie on the margins of the fresh water bodies associated with the wadi courses adjacent to brackish water, inter-wadi areas.

6 GROUNDWATER DEVELOPMENT IN THE FUTURE

Groundwater development in the Tihama will in all probability intensify in the future under the demand of a rapidly increasing rural population.

The rate of groundwater development, however, is conjectural; a rapid upsurge in development might be expected to accompany the large scale return and resettlement of emigrant workers. Conversely, a number of pumping/farm operations which were previously subsidised by such workers may become redundant in the absence of regular, assured incomes.

Left uncontrolled, groundwater development will tend to be concentrated in the central and western plains areas; well construction in the alluvial fan areas is likely to be limited, as a result of limited aquifer development (shallow bedrock), brackish water occurrences (inter-wadi zones), low yields, known water level declines and land shortages in and near wadi courses.

Under the draft of existing and increased future abstraction, groundwater levels will continue to fall as water is taken from aquifer storage. Prospects exist, as upper more permeable aquifer sections become dewatered, for the rate of water level decline to increase. The impact of water level declines will have most effect in the shallow bedrock areas that may extend up to 10 km from the foothills. Here, local aquifer sections will become dewatered.

There is also the prospect in the region of local water quality deterioration as the command of well fields extends into brackish water inter-wadi zones and deepened wells penetrate poor water quality horizons that may exist locally at depth.

Westward expansion of tubewell construction for irrigation will increase the risks of water quality deterioration through upconing. Increased well densities along the wadi courses in the central and western plains area will augment prospects for lateral inflow of brackish water from inter-wadi areas.

The anticipated intensification of groundwater development in the plains area may be accelerated by relocation of farmers whose wells go dry in the alluvial fan areas. The mobility of these farmers, who occupy traditional rainfed lands is uncertain.

While fruit production under groundwater irrigation is likely to increase locally, sorghum will remain the dominant crop for pump operators under an anticipated sustained (domestic and livestock) market demand for both grains and fodder. Significant changes in cropping pattern from low risk crops with high local demand to high risk crops with often uncertain marketing conditions are unlikely to occur naturally in the near future.

The cost of water will naturally increase with falling water levels and progressively lower returns from abstraction will be realised. The change in groundwater irrigated farm economics will doubtless lead to some degree of self-correction as an increasing number of wells become abandoned. No degree of such correction resulting in a reduced draft on the aquifer is evident to date. The increased cost of water will naturally tend to result in more efficient irrigation systems; this is already evident locally and is likely to develop with availability of appropriate materials and increased farmers' awareness.

7 PROSPECTS FOR IMPROVED GROUNDWATER MANAGEMENT

7.1 INTRODUCTION

Rudimentary estimates of the major water balance components and assessment of widespread groundwater level declines indicate that annual net abstraction in the northern Tihama is currently of the same order as recharge. With natural discharge at the coast remaining probably at or near historic (pre-pumping) levels under the regional hydraulic gradient, an aquifer storage deficit of the order 63 Mcm accumulates annually.

Further groundwater development, as will inevitably occur, will lead to aquifer loss through dewatering and water quality deterioration.

The current level of groundwater use is not sustainable. Efforts must be made to reduce abstraction drastically in order to ensure long-term viability of the groundwater resource. Establishment of the reduction factor required demands further detailed study but is likely to be of the order of 50%.

7.2 GROUNDWATER MANAGEMENT OPTIONS

7.2.1 Improved Irrigation Techniques

Closed water conveyance at farm level was introduced in the Tihama by the UNDP-FAO extension project YEM/84/002 which was followed by project TCP/YEM/4406/T under drought relief emergency assistance (1985-1986). The system to be provided included head control works and 400 m of buried PVC (or surface galvanised) 110 mm diameter pipe. It was intended that 50 farms be so equipped in the Tihama of which 5 were to be in the Harad environs. No technical data could be found with which to evaluate this initiative; the Terminal Report (FAO, 1986) describes institutional and logistical problems with recommendations for project extension. It is believed that the Project was terminated at, or shortly after, this time; it is not known whether this action reflects the magnitude of problems encountered or failure of the system proposed. The introduction of low pressure irrigation systems is being effected, more recently, with reported success in Rada'a (Euroconsult, 1988).

Improved irrigation techniques do offer potential for more efficient use of groundwater through reduction in losses that result from extreme evaporative demand. While promotion of such techniques should be pursued, it must be acknowledged that their widespread introduction offers little scope for redressing the accumulating aquifer storage deficit.

Agricultural extension could usefully be employed to improve the generally poor irrigation layouts, quantity and timing of water application, inappropriate basin and furrow dimensions.

7.2.2 Spatial Distribution of Abstraction

Prospects for improved groundwater management through modification of abstraction patterns to reduce the potential and scale of saline intrusion or upconing are constrained by non-uniform aquifer conditions; aquifer development is limited in the alluvial fan areas and inter-wadi areas are characterised by brackish water occurrences. Management of groundwater abstraction in the Tihama would, in an ideal case, involve controls to reduce abstraction in the alluvial fan areas where aquifer sections will become dewatered. This reduction will occur naturally and consequent impact should be accommodated in any management option scenarios.

7.3 DISCUSSION

Groundwater development has dual objectives - agricultural production and sustainability of water resource. Recent works (TBWRS, 1988 and MOMR/TNO, 1991) have identified constraints on production imposed by farm practices, and increased awareness of the increasing complexity of the water resource system and the relations and conflicts between the different categories of water use.

The groundwater resource cannot be viewed in isolation. An integrated approach is required for determination of the optimal use of water involving assessment of the costs of water and the value of agriculture-derived benefits throughout the catchment. The pilot study undertaken for Wadi Surdud provides excellent insight into the inter-relationships of the various components.

Water resources management objectives established during this study (MOMR/TNO, 1991) include :

- Economic efficiency of water use.
- Sustainability of water use.
- Fair distribution of water-related benefits.

The decision variables considered were:

- Rate of groundwater pumping as a function of time.
- Spatial pattern of groundwater pumping.
- Introduction of conjunctive use in spate irrigated zones.
- Wadi improvement works.
- Modification of cropping patterns.

The water resource management issues were identified as:

- Interference of upstream development with downstream water use.
- Risks to sustainability such as sea water intrusion and excessive declines in groundwater level.
- Low economic returns in some of the water use zones as a result of conditions of unfavourable water resources or inefficient water use.

These objectives, decision variables and management issues are wholly applicable to the northern Tihama. Thus, the concept of "wadi development" previously associated only with improved surface water irrigation systems where the wadis debouch onto the Tihama Plain, is outdated.

Spate irrigation areas in the northern Tihama tend to be small and unlikely to be able to produce the benefits necessary to justify the investments required for structural improvement unless undertaken within a conjunctive use scheme and adoption of a more beneficial water use pattern. The impact of such works, which will reduce wadi bed percolation losses, on downstream groundwater users must be taken into account.

With increased agricultural production and water conservation - management in mind there are two development prospects in the northern Tihama worthy of further consideration. These involve:

- Conjunctive use of ground and surface water resources
- Modified cropping patterns.

It is beyond the scope of this report to expand on the increases in agricultural production deemed possible through improved agricultural practices (current production at about 30% of potential rate: TBWRS, 1988) but water and agricultural management clearly warrant simultaneous attention.

7.3.1 Conjunctive Use of Ground and Surface Water Resources

Conjunctive use of groundwater is already, in essence, being practised in the smaller streams associated with many of the inland/upstream wadi courses. Groundwater is mined during the extended dry season and the aquifer seasonally replenished.

Such upstream water use, however, reduces the amount of water available to downstream users. Surface water flow is reduced by the amount necessary to fill the dewatered profile; sub-surface throughflow is reduced by interception and lower hydraulic gradients. Despite these "losses", low pumping heads and mining opportunities make inland/upstream operations both cost and technically efficient. However, agricultural benefits should be increased by the adoption of more lucrative crops.

Conjunctive use of groundwater and surface water resources in the areas of spate irrigation is not considered feasible for the wadis of the northern Tihama due to the generally limited aquifer development in the near foothills locations. A possible exception is Wadi Harad. An alternative development scenario may, however, be available for this wadi due to the unique occurrence of an upstream area extending several kilometres inland from the Tihama that is virtually devoid of agricultural development, and forms an extensive, flat valley-wash plain much of which is covered by natural vegetation including small trees.

The water resources of this plain should be investigated with a view to determining ability to supplement spate irrigation downstream. The primary factors of interest are aquifer geometry/thickness (water storage volume) and possible losses resulting from direct evaporation and evapotranspiration.

As the valley section at the Tihama boundary is narrow it is conceivable that throughflow is impeded causing high water levels throughout the inland plain with high resultant system losses through evapotranspiration. Such losses could be significant where phreatophytic vegetation is supported. Reducing losses by abstraction (water table lowering) and transfer to irrigable lands would produce a net benefit for the system. Mining of groundwater in this area, which is subject to seasonal replenishment, is a further option to consider.

7.3.2 Modified Cropping Patterns

Sorghum remains the single most important crop in all land use categories within the Tihama plain and in inland/upstream wadi areas. The quest for maximisation of returns on water use will necessitate conversion to crops more lucrative both for individual farmers and the national economy. Farmers in the groundwater and spate irrigated areas, however, are unlikely, generally, to modify their cropping pattern unless either market forces dictate or a viable alternative is apparent. Increased local fruit production is a healthy response to Government intervention but remains, regionally, at relatively low levels of production. Fruit production levels can be expected to increase further naturally but cannot be expected to overshadow sorghum cultivation in the short or medium-term. It is postulated that improvements in rainfed agriculture could be instrumental in bringing about the required modifications in cropping patterns and by so doing create conditions whereby groundwater (and in part spate) users would become more amenable to water control. The concept, in summary, looks to research and development of rainfed agriculture with the objective of increasing production and significantly increasing the market share for rainfed grain and fodder products. This has particular import also as it is the rainfed area that overlies that part of the aquifer that is gradually being dewatered.

Where increased production can be achieved and supplemented by investment/subsidies for an associated dry stockfood processing industry to meet seasonal deficiencies, any sorghum cultivated under different conditions will be at an economic disadvantage. For groundwater users this disadvantage will increase as pumping costs rise.

Market forces can thus be expected to direct groundwater users to alternative crops. Their ultimate selection can be guided and stimulated by actions taken earlier during the development programme in the rainfed areas, such as improvement of marketing conditions and introduction of vegetable and fruit packing and processing industry. Where such modifications to cropping patterns can be effected, farm incomes should increase and conditions more favourable to acceptance of water use control created.

The concept as described remains simplistic and requires further inputs with respect to agronomic, economic and sociological feasibility.

8 CONCLUSIONS

8.1 TIHAMA PLAIN

The northern Tihama is underlain by an extensive unconfined alluvial aquifer the thickness of which is largely structurally controlled ranging from <50 m near the foothills to maximum thicknesses of the order 200 m west of major north-south trending block faults, in the central and western plains area.

The aquifer is recharged in the alluvial fan areas by percolation of surface water flows, rainfall, and sub-surface inflows. Natural discharge is effected at the coast via direct evaporation. Knowledge of water balance components remains at a rudimentary level; little is known of wadi flow volumes. Annual recharge is estimated to be of the order 76 Mcm.

Fresh to brackish groundwater occurs throughout the area except in a 5-10 km wide strip along the coast where a transition from fresh to brackish to saline water is evident. Fresh groundwater is commonly associated with wadi courses, brackish water occurring in the inter-wadi zones.

Groundwater use for irrigation continues to intensify. There are an estimated 1100 pumped wells in the northern Tihama plain that collectively impose an annual draft on the alluvial aquifer of the order 63 Mcm.

Well distribution on the plain is controlled by depth to water, water quality, soil type and availability of surface water resources, with consequent primary concentration along the downstream reaches of wadi beds and, where soil profiles permit, along the traditionally rainfed areas in the inter-wadi areas.

Groundwater irrigated farm sizes are typically of the order of 10 ha. Sorghum remains the dominant crop for almost all farmers with production of fruit, vegetables and sesame relatively minor on a regional scale. Locally, fruit production is increasing.

There is an absence of quantitative data on crop water applications and the efficiency of groundwater irrigation systems.

Under the imposed groundwater draft, water levels are falling in the region. These declines are most evident in the alluvial fan and near-foothills zones where aquifer development is limited by shallow bedrock occurrences; here rates of water level decline in the range 0.5-1.0 m/year are common. Such rates have created a demand for frequent deepening of wells. There is some evidence also that water quality deterioration occurs locally at the margins of the fresh water bodies associated with some wadis, as the command area of well-fields presumably induces flow from the adjacent inter-wadi zones.

8.2 INLAND/UPSTREAM WADI AREAS

There is significant groundwater use locally along many of the wadis and inland areas adjacent to the Tihama plain. Farm sizes in such areas, however, tend to be limited by topography and absence of suitable soil profiles. Abstraction is almost invariably effected by centrifugal pumps as depths to water are minimal. Sorghum remains dominant within cropping patterns and tends to be used primarily to sustain livestock which is the major income source. Fruit production in the inland areas is at a significantly higher level than on the plains.

Mining of groundwater is practised in many of these areas; where aquifer development is limited by shallow bedrock, well water supplies diminish in dry seasons but are replenished in the ensuing wet period. The large scale development of almost 300 wells in the upper reaches of Wadis Bawhal and Al Qawr have doubtless contributed to the high rates of water level decline in the areas of debouchment on the plain as greater proportions of the natural wadi flow are utilised for upstream profile filling.

There is virtually no agricultural development in the reach of Wadi Harad immediately east of the Tihama. Here a wide naturally vegetated valley wash plain occurs at the confluence of the wadis Harad and Ramm. Significant water losses may be occurring in this area through direct evaporation and evapotranspiration; given appropriate aquifer geometry, such losses could be reduced by abstraction, making further benefit potential available with seasonal groundwater transfer to downstream spate irrigated areas.

Elsewhere, there appears to be limited scope for further development. The existing water usage and any possible future development will to a large extent be self-regulating by the finite volume open to mining.

8.3 GROUNDWATER MANAGEMENT

The present degree of groundwater exploitation on the Tihama plain is not sustainable. Groundwater is being removed from aquifer storage to meet irrigation demands; with natural discharge probably remaining near historic levels, the annual aquifer storage deficit is of the order 63 Mcm.

Continued over-exploitation will lead to dewatering of the upper most permeable strata, local water quality deterioration and ultimately intrusion of saline water in the west. The rate of water level declines in the east will result in complete aquifer dewatering of most of the 5-10 km wide strip adjacent to the foothills where shallow bedrock occurs.

Abstraction on the plain must be reduced significantly if the groundwater resource is to be protected; such a reduction which must eventually be implemented through legislation will be of the order of 50%. Groundwater resource management must be an integral component of catchment water management; consequently, derived agricultural benefits per unit of water for each water use zone (groundwater, spate, rainfed) must be optimised.

In this respect it is evident that modifications must be made to irrigated cropping patterns with the objective of replacing the areas of sorghum with more lucrative crops. Such modifications are unlikely to occur naturally in the short term whilst the demand for low risk grain/fodder crops remains high and marketing conditions for alternative crops are deficient.

Market forces could be employed to promote a change in groundwater irrigation cropping patterns if the production of grain/fodder from the traditional rainfed areas could be increased to a level where local and regional demands could be met solely from this land use category.

Prospects for conjunctive use of ground and surface waters in the relatively small spate irrigated areas of the region are limited by poor aquifer development.

8.4 MONITORING

There is currently insufficient data on water resources in the area with which to meaningfully consider any detailed wadi development option. Measurements of wadi flows are restricted to intermittent base flows with only one year of spate flows recorded. Time series of rainfall and groundwater level data are incomplete and extend over only three years.

9 RECOMMENDATIONS

Water Resources Management
There is a growing awareness and rising tide of informed opinion in Yemen in favour of integrated water resources management. SSHARDA should support and participate in such evolution and possibly take a lead in some aspects under the auspices of the NORADEP Project. The primary issue to be addressed is reduction in groundwater abstraction. In the absence of effective legislation, attention should be focused on:

Research and Development in Traditional Rainfed Areas
The agro-socio-economic aspects of rainfed area development as outlined should be studied within the proposed rapid rural appraisal (RRA) programme.

Industrial Development
The prospects/potential for development of agro-industries including dry stockfoods, vegetable and fruit packaging and processing, and (sesame) oil refineries in the area should be studied.

Water and Agricultural Management in Wadi Harad
The aquifer potential of the inland/upstream Wadi Harad area should be evaluated with respect to its possible contribution to a conjunctive use scheme directed at the downstream spate irrigation area. The adaptability of spate irrigation farmers to crop change and controlled water use under a possible conjunctive use scheme should be studied within the proposed RRA programme in the area.

Institutional Relationships
Close relationships should be established with the Technical Secretariat of the High Water Council who are intimately involved in similar water/agricultural management issues and are currently in the process of formulating water law codes which may provide the necessary degree of control on abstraction that is demanded in the northern Tihama.

Water Resource Monitoring
SSHARDA should hold discussions with TDA with respect to continued, and in some cases expanded, water resource monitoring. Of particular import are groundwater levels and quality, wadi discharges (base flows and spate) and rainfall.

Expansion of the rain gauge network should be considered. Where doubts exist with respect to TDA's ability to continue and upgrade this work, SSHARDA should allocate adequate manpower and equipment resources to take over completely all networks. Groundwater monitoring points should be surveyed and levelled.

Protection of Potable Water Supplies
The locations of all major potable water utilities for urban domestic use should be determined and risk assessment undertaken for projected water level declines and/or water quality deterioration.

Groundwater Irrigation Efficiencies
Further investigations are required with respect to improvement of groundwater irrigation efficiencies. The investigations should comprise field studies which could most readily be executed within the demonstration farm programmes, and review of systems under trial in Rada'a with regard to applicability in the Tihama environment.

REFERENCES

FAO	1986	Drought Relief Assistance Through Improved Irrigation System: Terminal Report (FAO/TCP/YEM/4406/T), May 1986.
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MOMR/TNO	1991	Water Resources of the Wadi Surdud Area: Pilot Study on Water Resources Management (Report WRAY-22, Feb 1991), Ministry of Oil and Mineral Resources, General Department of Water Resource Studies, TNO Institute of Applied Geoscience and Delft Hydraulics
TDA/DHV	1988	Tihama Basin Water Resources Study; Reports Nrs 1-8; Tihama Development Authority, DHV Consulting Engineers, April 1988.

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Mr Said Al-Nammari (Chief Technical Advisor, UNDTCD, High Water Council Project) for describing current water resources policy initiatives in Yemen,

The members of the NORADEP team (Dutch students, counterparts and drivers) who executed the well inventory under arduous conditions.

ANNEX 1

Rainfall Data

Table 1 Daily rainfall data of Midi (1989)

TIHAMA BASIN RAINFALL

Area : 01 — Area name : WADI HARAD/HAYRAN
Station number: 04 — Station name: Midi
Elevation : 10 m.
Geogr. coord. : N
UTM coord. : 2670 E 18050 N
Location :
Name observer : Bahib Ibrahim Bhib
Type of gauge :
Installed on : - 07 - 1986 — YEAR : 1989
Operated by : TDA
Comments :

Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	20.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.8
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.3
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0		0.0		0.0		0.0	0.0		0.0		0.0
Total	0.5	20.6	0.0	0.0	0.0	0.3	0.0	0.2	0.0	0.0	0.0	61.1
No. of rainy days	1	2	0	0	0	1	0	1	0	0	0	2

TOTAL ANNUAL PRECIPITATION : 82.7 mm
MAXIMUM MONTHLY PRECIPITATION : 61.1 mm in December
MAXIMUM DAILY PRECIPITATION : 40.8 mm on December 15

\+ = No observation available or data not complete
# = Data not reliable
) = Daily precipitation not known
$ = Data estimated

Table 2 Daily rainfall data of Harad Al-Kadimah (1989)

TIHAMA BASIN RAINFALL

Area : 01
Station number: 06
Elevation : 90 m
Geogr. coord. : E N
UTM coord. : 29200 E 151800 N
Location : Roof obs. house
Name observer : AHMAD HASAN BODAIRI
Type of gauge : Hellmann (ordinary)
Installed on : -06-1986
Operated by : T.D.A.
Comments :

Area name : WADI HARAD/HAYRAN
Station name: HARAD AL-KADIMAH

YEAR : 1989

Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	13.4	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.1	0.0	0.0
9	0.0	0.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.2	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.3	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.1	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0		0.0		0.0		0.0	0.0		0.0		0.0
Total	0.0	0.0	0.0	20.1	0.0	0.0	0.0	36.7	40.8	53.7	0.0	13.5
No. of rainy days	0	0	0	4	0	0	0	4	3	3	0	1

TOTAL ANNUAL PRECIPITATION : 164.8 mm
MAXIMUM MONTHLY PRECIPITATION : 53.7 mm in October
MAXIMUM DAILY PRECIPITATION : 23.0 mm on August 13

* = No observation available or data not complete
\# = Data not reliable
) = Daily precipitation not known
% = Data estimated

Table 3 Daily rainfall data of Al-Khadrah (1989)

TIHAMA BASIN RAINFALL

Area : 01
Station number: 05
Elevation : 50 m
Geogr. coord. : E N
UTM coord. : 28300 E 161300 N
Location : 81360
Name observer : AI_HAJ ABSO IBRAHEM
Type of gauge : HELLMAN (ORDINARY)
Installed on : -07-1986
Operated by : T-D-A
Comments :

Area name : WADI HARAD/HAYRAN
Station name: Al-Khadrah

YEAR : 1989

Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	18.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.4
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5	0.0	0.0	6.4
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.7	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0		0.0		0.0		0.0	0.0		0.0		0.0
Total	0.0	0.0	0.0	18.6	0.0	0.0	0.0	0.0	22.2	7.4	0.0	31.8
No. of rainy days	0	0	0	1	0	0	0	0	2	1	0	2

TOTAL ANNUAL PRECIPITATION : 80.0 mm
MAXIMUM MONTHLY PRECIPITATION : 31.8 mm in December
MAXIMUM DAILY PRECIPITATION : 25.4 mm on December 15

* = No observation available or data not complete
# = Data not reliable
) = Daily precipitation not known
R = Data estimated

Table 4 Daily rainfall data of Wash'ha (1989)

TIHAMA BASIN RAINFALL

Area : 01
Station number: 01
Elevation : 700 m
Geogr. coord. : 43.12. E 16.46. N
UTM coord. : E N
Location : Roof house Al Misyal
Name observer : Hadi Mohammed Dawa
Type of gauge : PS61
Installed on : -08-75
Operated by : TDA
Comments : Useful

Area name : WADI HARAD/HAYRAN
Station name: WASH'HA (AHIM)

YEAR : 1989

Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	5.0	0.0	46.7	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	11.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	17.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	17.0	0.0	0.0	0.0	11.2	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	3.0	0.0	13.5	5.0	0.0	0.0	1.9
18	0.0	0.0	3.0	0.0	22.0	0.0	0.0	12.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.3	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	18.5	0.0	0.0	25.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0		18.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0
30	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0	0.0	0.0
31	0.0		18.0		0.0		0.0	0.0		0.0		0.0
Total	1.0	0.0	56.0	39.0	33.0	58.7	48.1	47.7	5.0	55.3	0.0	8.9
No. of rainy days	1	0	4	5	2	3	4	5	1	4	0	2

TOTAL ANNUAL PRECIPITATION : 352.7 mm
MAXIMUM MONTHLY PRECIPITATION : 58.7 mm in June
MAXIMUM DAILY PRECIPITATION : 46.7 mm on June 07

* = No observation available or data not complete
# = Data not reliable
) = Daily precipitation not known
E = Data estimated

Table 5 Monthly rainfall data of stations Wash'ha, Midi and Al-Khadrah (1975/1986-1989)

1.01 Wash'ha

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
1975							84.4	67.2	24.0	2.0	4.3	.0	
1976	46.3	5.2	11.6	212.1	64.7	6.5	13.3	2.4	38.3				
1977	30.0	1.0	.0	45.8	150.0	14.0	9.0	45.0	7.0	29.0	87.0	13.0	430.8
1978	66.0	20.0											
1979	16.0	.0	24.0	150.0	10.0	5.0	7.0	.0	.0	.0	122.0	20.0	354.0
1980	9.0	19.0	49.0	32.0	50.0								
1981				139.0	63.0	11.0	62.9	101.0	39.0	67.0	.0	.0	
1982	54.0	.0	44.0	41.0	83.0	5.0	17.0	56.0	20.0	83.0	2.0	94.0	499.0
1983	4.0	87.0	51.0	3.0	99.0	27.0	10.0	.0	79.0	26.0	.0	.0	386.0
1984	7.0	.0	.0	.0	.0	.0	106.0	19.0	51.0	5.0	.0	23.2	211.2
1985	.0	8.0	13.0	144.0	120.0	13.0	.0	107.0	20.0	2.2	15.2	.0	442.4
1986	.0	8.0	22.0	161.0	129.1	26.0	37.5	27.5		.0	166.0	54.5	
1987	2.0	.0	15.0	210.0	110.5	.0	15.9	95.6	4.0	27.2	5.5	61.6	547.3
1988	11.0	11.0	.0	103.0	.0	24.6	98.3	84.1	40.4	9.0	8.0	.0	389.4
1989	1.0	.0	55.0	39.0	33.0	58.7	48.1	47.7	5.0	55.3	.0	8.9	352.7
MEAN	20.8	12.2	23.8	98.5	70.2	16.2	40.7	50.2	27.3	25.5	34.2	22.9	401.4

1.04 Midi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
1986							.0	4.0	.0	3.0	.0	105.4	
1987	.0	.0	.0	10.8	.0	.0	.0	.0	.0	20.3	3.5	17.4	52.0
1988	21.0	46.7	.0	.9	.0	.0	2.2	12.2	44.0	.0	.0	.0	127.0
1989	.5	20.5	.0	.0	.0	.3	.0	.2	.0	.0	.0	61.1	82.7
MEAN	7.2	22.4	.0	3.9	.0	.1	.6	4.1	11.0	5.8	.9	46.0	87.2

1.05 Al-Khadrah

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
1986							.0	.0	.0	.0	.0	14.0	
1987	.0	.0	2.5	3.4	.0	5.7	.0	6.2	.0	23.7	.0	8.7	50.2
1988	17.3	17.7	.0	.0	.0	.0	.0	32.8	72.8	.0	.0	.0	140.6
1989	.0	.0	.0	16.6	.0	.0	.0	.0	22.2	7.4	.0	31.8	80.0
MEAN	5.8	5.9	.6	7.3	.0	1.9	.0	9.8	23.8	7.8	.0	13.6	90.3

Table 6 Monthly rainfall data of Harad Al-Kamidah

1.06 Harad Al-Kadimah

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
1986						31.1	18.2	25.9	30.3	14.2	1.5	85.5	
1987	.0	.0	1.6	32.1	26.5	1.2	6.8	83.5	6.5	2.8	10.5	14.4	185.9
1988	1.8	10.9	0	0	0	0	3.0	39.2	116.4	2.4	0	0	173.7
1989	.0	.0	.0	20.1	.0	.0	.0	36.7	40.6	53.7	.0	13.5	164.8
MEAN	.6	3.6	.5	17.4	8.8	8.1	7.0	46.3	48.5	18.3	3.0	28.4	174.8

ANNEX 2

Wadi Discharge Data

Table 1 Wadi Harad

Table Wadi Harad
Station 045 (base flow-Mm^3)

Year	JAN	FEB	MAR	ABR	MAY	JUN	JUL	AUG	SEB	OCT	NOV	DEC	Totl
1985	*	*	*	*	*	*	*	*	*	*	*	*	
1986	*	*	*	1.434	1.554	.474	.786	2.169	1.962	.696	.717	.818	
1987	.950	.648	1.127	1.158	1.707	1.170	1.224	.478	*	*	.740	.800	
1988	1.002	.007	.159	*	*	*	*	*	*	.190	.170	.271	
1989	1.419	1.297	1.452	1.422	1.486	1.455	1.520	1.538	1.504	1.572	1.537	1.606	17.8
1990	.952	.994	1.526	1.179	.533	.619	.329	1.452	1.855	1.708	1.114	.201	12.5

Table 2 Wadi Hayran
Station 046 (base flow-Mm^3)

Year	JAN	FEB	MAR	ABR	MAY	JUN	JUL	AUG	SEB	OCT	NOV	DEC	Total
1985					*	*	*	.030	.116	.035	.076	.039	
1986	*	*	*	.605	.125	.073	.218	.608	.792	.430	.576	.566	
1987	.422	.375	.546	1.456	.856	.409	.363	.601	*	*	.178	.363	
1988	.48	.001	.021	*	*	*	*	*	*	.031	.363	.113	
1989	.353	.062	.055	.047	.021	.034	.068	.064	.107	.168	.029	.086	1.094
1990	.025	.033	.096	.104	.007	.027	.089	.247	.317	.267	.199	.108	1.519

Table 3 Wadi Nazr
42.01 Shat al Arg (total flow Mm^3)

Year	JAN	FEB	MAR	ABR	MAY	JUN	JUL	AUG	SEB	OCT	NOV	DEC	Total
1980	3.40	$1.14	$0.19	7.94	13.34	5.54	7.09	$65.65	19.53	$.98	3.43	2.11	62.38
1981	$1.34		$5.68	$44.98	$26.26	$12.62	18.65	$14.76	.08	4.09	3.25		
1982		.14	6.05	35.40	26.11	8.45	12.10	31.14	$3.87				
1983	3.43	6.90	5.12	13.99	12.06	14.95	6.44	7.21	7.30	3.55	2.29	1.35	84.58
1984	1.49	1.62	$.8	$5.4	$20.16	$2.86	7.54	10.13	5.40	2.09	1.63	1.30	31.20
1985	3.28	1.13	16.17	40.65	16.32	8.39	14.08	18.38	10.68	4.65	2.07	2.37	138.17
1986	1.71	.2	11.85	34.98	23.50	8.16	18.13	30.40	23.62	7.45	5.94	6.81	172.75
1987	1.986	3.058	11.665	23.823	13.400	4.884	5.205	24.060	6.156	2.088	1.424	1.476	99.23
1988	1.812	2.420	2.548	6.934	2.145	7.326	15.918	19.068	13.3053	4.223	2.784	2.295	80.78
1989	1.779	1.567	13.714	40.882	9.999	23.779	8.163	33.055	13.156	3.240	.978	1.418	151.73
1990	1.176	7.853	11.634	28.267	4.734	10.498	11.803	12.808	5.928	2.103	1.111	.836	98.75

ANNEX 3

Water Application

Table 1 Summary of water application

	IRR. AREA (ha)	PUMP RATE (l/s)	SEASONAL DISCHARGE VOLUME				GROSS ANNUAL ABST. (Mm3)	WATER APPLIC. (mm)
			RABIA	SAYF (m3)	KHARIF	SHITA		
Minimum	0.4	1.7	881	881	0	881	0.00	27
Maximum	26.6	16.6	97459	97459	97459	97459	0.39	6858
Mean	10.3	9.5	33326	32070	32669	33280	0.13	1651

Table 2 Water application data of NORADEP Well Inventory (1)

NORADEP WELL INVENTORY

WELL REF NR	IRR. AREA (ha)	PUMP RATE (l/s)	SEASONAL DISCHARGE VOLUME (m3) RABIA	SAYF	KHARIF	SHITA	GROSS ANNUAL ABST. (Mm3)	WATER APPLIC. (mm)
43C1/91	18.0	9.4	43717	43717	43717	43717	0.17	971
43C1/07	10.8	15.0	62209	62208	62208	62208	0.25	2304
43C1/05	5.4	15.0	38880	38880	0	38880	0.12	2160
43C1/16	20.2	3.8	2916	2916	2916	2916	0.01	58
43C3/101	7.2	6.3	34546	34546	34546	34546	0.14	1919
43C1/02	7.2	15.0	62208	62208	62208	62208	0.25	3456
43C1/04	10.8	16.6	77760	29160	77760	77760	0.26	2450
43C1/08	18.0	15.0	54432	54432	54432	54432	0.22	1210
43C1/100	9.0	10.7	41602	41602	41602	41602	0.17	1849
43C1/06	4.3	18.8	48600	48600	48600	48600	0.19	4521
43C1/79	5.4	9.4	36547	36547	36547	36547	0.15	2707
43C3/24	10.8	4.4	22810	22810	22810	22810	0.09	845
43C3/87	8.3	7.5	34992	34992	34992	34992	0.14	1686
43C3/25	18.0	11.0	62697	62697	62697	60038	0.25	1362
43C1/52	5.4	7.5	23328	23328	23328	23328	0.09	1728
43C1/10	7.2	9.8	30462	30462	30462	30462	0.12	1693
43C3/64	14.4	9.7	30171	30171	30171	30171	0.12	838
43A1/63	21.6	6.3	24300	24300	24300	24300	0.10	450
43C1/85	21.6	15.0	23328	23328	23328	23328	0.09	432
43C3/22	7.2	1.9	9590	9590	9590	9590	0.04	533
43C1/66	18.0	18.8	97200	97200	97200	97200	0.39	2160
43C3/23	7.2	7.4	45785	45785	45785	45785	0.18	2544
43C3/62	28.8	5.9	15293	15293	15293	15293	0.06	212
43C1/89	7.2	15.0	69984	69984	69984	69984	0.28	3888
43C3/70	10.8	5.0	15552	15552	15552	15552	0.06	576
43C1/64	8.8	5.0	16848	16848	16848	16848	0.07	764
43C1/36	1.8	4.0	10238	10238	10238	10238	0.04	2275
43C1/40	9.0	5.0	15552	15552	15552	15552	0.06	691
43C1/83	10.8	2.1	5547	5547	5547	5547	0.02	205
43C1/61	14.4	6.3	19596	19596	19596	19596	0.08	544
43C1/19	9.0	9.0	41990	16330	41990	41990	0.14	1581
43C1/44	2.2	15.0	4147	4147	4147	4147	0.02	754
43C1/18	7.2	3.6	11197	11197	11197	11197	0.04	622
43C3/50	9.0	9.4	24365	24365	24365	24365	0.10	1083
43C3/49	8.3	9.4	29238	29238	29238	29238	0.12	1409
43C1/90	5.4	12.5	64800	64800	64800	64800	0.26	4800
43C3/21	10.8	4.7	27029	27029	27029	27029	0.11	1001
43C1/19	4.3	15.0	11664	11664	11664	11664	0.05	1085
43C3/7	7.2	9.1	7068	7068	7068	7068	0.03	393
43C1/26	2.9	10.7	27734	27734	27734	27734	0.11	3825
43C1/20	7.2	5.4	20801	20801	20801	20801	0.08	1156
43C1/13	25.2	13.0	40435	40435	40435	40435	0.16	642
43C1/30	5.4	5.2	10845	10845	10845	10845	0.04	803
43C3/42	3.6	9.3	28927	28927	28927	28927	0.12	3214
43C3/53	3.6	6.3	9720	9720	9720	9720	0.04	1080
43C3/6	21.6	2.8	1457	1457	1457	1457	0.01	27
43C3/5	15.0	1.9	12006	12006	12006	12006	0.05	320
43C3/25	4.3	3.3	5179	5179	5179	5179	0.02	482
43C3/27	0.4	5.8	3007	3007	3007	3007	0.01	3007
43C3/1	14.4	3.3	1690	1690	1690	1690	0.01	47
43C3/28	2.5	1.7	881	881	881	881	0.00	141
42D2/76	10.8	11.5	59616	59616	59616	59616	0.24	2208
42D2/73	5.4	18.8	92586	92586	92586	92586	0.37	6858
42D4/104	14.4	18.8	68221	68221	68221	68221	0.27	1895
42D4/105	6.5	18.8	58476	58476	58476	58476	0.23	3598
42D2/64	21.6	10.7	52695	52695	52695	52695	0.21	976
42D2/75	4.3	12.5	42120	42120	42120	42120	0.17	3918
42D2/95	18	18.8	97459	97459	97459	97459	0.39	2166
42D2/102	10.8	9.4	34111	34111	34111	34111	0.14	1263

Table 3 Water application data of NORADEP Well Inventory (2)

NORADEP WELL INVENTORY

WELL REF NR	SOIL TYPE	IRR. AREA (ha)	PUMP RATE (l/s)	GROSS ANNUAL ABST. (Mm3)	WATER APPLIC. (mm)
43C3/1	L7	14.4	3.3	0.007	46
43C3/101	L7	7.2	3.3	0.055	760
43C3/21	L7	10.8	4.7	0.107	993
43C3/22	L7	7.2	1.9	0.039	547
43C3/23	L7	7.2	7.4	0.184	2557
43C3/24	L7	10.8	4.4	0.091	845
43C3/25	L7	18.0	11.0	0.248	1378
43C3/27	L7	0.4	5.8	0.012	3007
43C3/28	L7	2.5	1.7	0.004	141
43C3/42	L7	3.6	9.3	0.116	3214
43C3/49	L7	8.3	9.4	0.117	1409
43C3/5	L7	15.0	1.9	0.047	315
43C3/50	L7	9.0	9.4	0.097	1083
43C3/53	L7	3.6	6.3	0.039	1085
43C3/6	L7	21.6	2.8	0.006	27
43C3/62	L7	28.8	5.9	0.061	212
43C3/64	L7	14.4	9.7	0.121	835
43C3/7	L7	7.2	9.1	0.028	393
43C3/70	L7	10.8	5.0	0.062	578
43C3/87	L7	8.3	7.5	0.140	1688
43A1/63	L7	21.6	6.3	0.098	454
Minimum		0.4	1.7	0.004	27
Maximum		28.8	11.0	0.248	3214
Mean		11.0	6.0	0.080	1027

42D2/102	L4	17.3	9.7	0.141	817
42D2/64	L4	21.6	10.7	0.211	978
42D2/73	L4	5.4	18.8	0.369	6840
42D2/75	L4	4.3	12.5	0.168	3918
42D2/76	L4	10.8	11.5	0.238	2208
42D2/95	L4	17.8	18.8	0.389	2182
42D4/104	L4	14.4	18.8	0.272	1890
42D4/105	L4	6.5	18.8	0.233	3600
Minimum		4.3	9.7	0.141	817
Maximum		21.6	18.8	0.389	6840
Mean		12.3	14.9	0.253	2504

(*) SOIL TYPES: L4 - Old wadi alluvium
L6 - Northern alluvial fan (medium textured)
L7 - Southern alluvial fan (coarse sand)

Table 4 Water application data of NORADEP Well Inventory (3)

NORADEP WELL INVENTORY

WELL REF NR	SOIL TYPE	IRR. AREA (ha)	PUMP RATE (l/s)	GROSS ANNUAL ABST. (Mm3)	WATER APPLIC. (mm)
43C1/02	L6	7.2	5.4	0.084	1166
43C1/04	L6	10.8	18.8	0.263	2436
43C1/05	L6	5.4	15.0	0.117	2160
43C1/06	L6	4.3	18.8	0.195	4533
43C1/07	L6	10.8	15.0	0.249	2304
43C1/08	L6	18.0	15.0	0.218	1210
43C1/10	L6	7.2	9.8	0.122	1693
43C1/100	L6	9.0	10.7	0.166	1849
43C1/13	L6	25.2	13.0	0.162	642
43C1/16	L6	20.2	3.8	0.012	59
43C1/18	L6	7.2	3.6	0.045	622
43C1/19	L6	9.0	10.7	0.144	1602
43C1/20	L6	7.2	5.4	0.084	1166
43C1/26	L6	2.9	10.7	0.111	3825
43C1/30	L6	5.4	5.2	0.043	799
43C1/40	L6	9.0	5.0	0.062	691
43C1/44	L6	2.2	15.0	0.017	754
43C1/52	L6	5.4	7.5	0.093	1728
43C1/79	L6	5.4	9.4	0.146	2707
43C1/81	L6	14.4	6.3	0.078	544
43C1/83	L6	10.8	2.1	0.022	202
43C1/84	L6	8.6	5.0	0.067	784
43C1/85	L6	21.6	15.0	0.093	432
43C1/86	L6	18.0	18.8	0.390	2166
43C1/89	L6	7.2	15.0	0.280	3888
43C1/90	L6	5.4	12.5	0.259	4800
43C1/91	L6	18.0	9.4	0.175	975
Minimum		2.2	2.1	0.012	59
Maximum		25.2	18.8	0.390	4800
Mean		10.2	10.4	0.137	1694

ANNEX 4

Groundwater Level Monitoring Data

Figure 1 TDA-Monitoring Network

Number of observations from 1988-1991

TDA MONITORING NETWORK

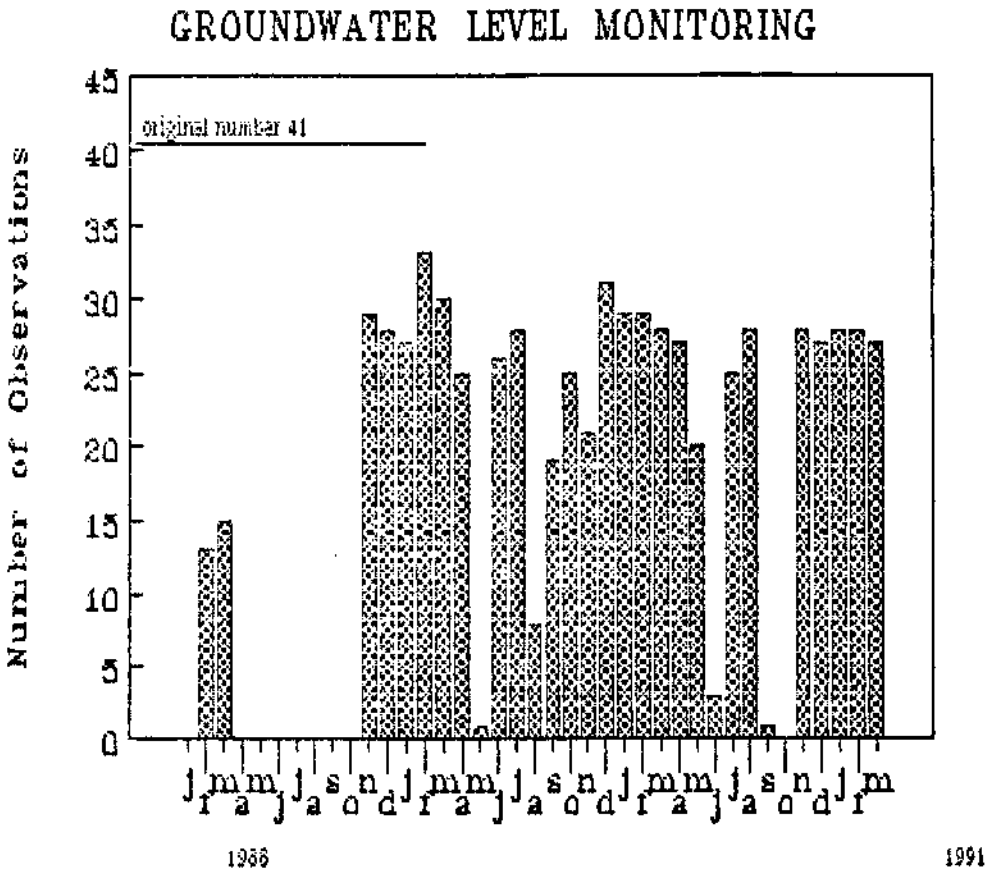


Table 1 TDA - Monitoring Network

Depths to water in 1988

TIHAMA DEVELOPMENT AUTHORITY - MONITORING NETWORK

DEPTH TO WATER (metres)

Well Nr	Ref Nr	1988 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HAR - 58	1											16.6	16.2
HAR - 24	2		15.1	15.2								15.2	14.9
HAR - 186	3		24.3	24.7								24.9	24.6
HAR - 473	4											29.9	29.6
HAR - 475	5												
HAR - 241	6											17.0	17.0
HAR - 134	7												
HAR - 222	8												
HAR - 219	9		22.3	22.8								21.0	
HAR - 293	10											20.2	22.1
HAR - 269	11		19.8									19.4	19.6
HAR - 436	12		28.3	28.7								29.8	28.8
HAR - 422	13		21.2	21.7								21.3	21.4
HAR - 393	14		12.3	12.6								12.7	12.8
HAR - 400	15		9.9	10.2								10.3	10.3
HAR - 54	16											6.6	6.8
HAY - 80	17		12.6	12.2								12.6	12.7
HAY - 89	18												
HAY - 151	19												
HAY - 25	20												
HAY - 17	21												
HAY - 11	22												
HAY - 4	23												
HAY - 7	24												
HAB - 225	25											27.5	27.9
HAB - 219	26			45.5								38.2	38.5
HAB - 107	27			44.0								44.0	44.6
HAB - 23	28		36.0	35.0								38.7	35.4
HAB - 19	29		34.2	34.7								34.9	35.0
HAB - 61	30		36.3	34.7								32.4	36.6
HAB - 88	31												
QAW - 130	32												
QAW - 82	33											57.6	57.6
QAW - 7	34		24.3	24.2								24.7	24.2
QAW - 11	35			27.6								27.7	27.5
QAW - 83	36												
QAW - 1	37												
QAW - 2	38												
QAW - 3	39												
QAW - 4	40												
QAW - 5	41											62.3	62.5

Table 2 TDA - Monitoring Network

Depths to water in 1989

TIHAMA DEVELOPMENT AUTHORITY – MONITORING NETWORK

DEPTH TO WATER (metres)

Well Nr	Ref Nr	1989 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HAR - 58	1	16.4	16.4	16.4			16.5	16.2		16.8		16.4	16.6
HAR - 24	2	14.6	14.8	14.8			14.8	14.3			14.9	14.6	14.5
HAR - 186	3	24.6	24.5	24.7	24.7		24.7	25.0		24.1	24.7	24.4	25.3
HAR - 473	4												
HAR - 475	5												
HAR - 241	6		26.3	26.6			26.4	26.4		26.5			26.6
HAR - 134	7												
HAR - 222	8		24.0	24.0	24.4		24.2	24.4		24.5	24.2		23.3
HAR - 219	9		21.1	22.3	21.1		21.3	21.4		21.3	21.3		21.5
HAR - 293	10		20.4	20.4									
HAR - 269	11	19.8	19.9	20.1	20.0					21.6	22.3		20.9
HAR - 436	12	28.9	28.9	28.8	28.7		29.0	29.1	29.1	29.5	29.2		29.3
HAR - 422	13	20.9	21.3		21.1		21.7	21.8	21.0	21.8	22.1	21.5	20.4
HAR - 393	14		13.1	12.9	13.1		13.1	13.3	13.2	12.8	13.3	13.2	13.6
HAR - 400	15		10.6	10.9	8.9		7.6	11.4	11.0	11.6	13.4	12.8	11.2
HAR - 54	16	6.7	6.7	6.7	6.8		6.7	7.0			6.6		5.8
HAY - 80	17		12.9	13.9			12.9	13.5		13.5	12.9		13.7
HAY - 89	18												
HAY - 151	19												
HAY - 25	20	45.5	45.5	45.5	45.8		45.6	44.7			45.6	45.2	45.6
HAY - 17	21	45.2	44.5	44.2	44.0		44.2	44.3			45.0	45.5	44.4
HAY - 11	22	10.7	11.1	11.6	12.0			11.6	12.0			8.8	8.6
HAY - 4	23	11.1	11.8	11.6	12.0			12.4	12.0			9.6	9.7
HAY - 7	24	29.3	29.7	29.4	29.5		29.6	29.6			29.7	29.7	29.8
HAB - 225	25	28.0	28.1	28.7	27.6		27.8	27.8		27.8	27.3	27.9	28.0
HAB - 219	26	38.7	38.7	38.6	44.9		44.9				45.2		38.8
HAB - 107	27	47.1	47.7	47.8									
HAB - 23	28	35.8	37.7	32.5	34.2		34.8	35.7	34.2	34.3		34.1	34.1
HAB - 19	29	34.0	35.2	34.5				37.2				37.3	37.3
HAB - 61	30	36.4	36.2	36.7	36.7			36.9	36.8	36.6	37.5	38.1	38.1
HAB - 88	31												
QAW - 130	32												
QAW - 82	33	57.6	57.3	57.7	55.7		57.7	57.7		57.7	57.7	57.8	57.8
QAW - 7	34	24.2	24.3	24.3	24.4		24.5	24.5		24.5	24.6	24.8	24.9
QAW - 11	35	27.7	27.8	27.8		28.8	28.1			28.1	28.8	28.3	28.3
QAW - 83	36	62.8	62.8	62.8	62.8		62.9	63.9			63.0	63.9	63.0
QAW - 1	37	20.7	19.6		19.7		21.9	21.7			20.8		19.3
QAW - 2	38	43.9	40.3		39.5		39.9	39.7			39.6		39.8
QAW - 3	39	60.5											
QAW - 4	40	50.7	50.4	50.4	50.3		50.4	50.4		50.3	50.4	50.6	51.0
QAW - 5	41	33.0	33.0	32.0	33.0		32.0	32.9		32.9	30.6	36.6	32.0

Table 4 TDA-Monitoring Network

Depth to water in 1991

TIHAMA DEVELOPMENT AUTHORITY – MONITORING NETWORK

DEPTH TO WATER (metres)

Well Nr	Ref Nr	1991 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HAR - 58	1	17.4	19.9	17.2									
HAR - 24	2	14.6	14.9										
HAR - 186	3	25.8	25.1										
HAR - 473	4												
HAR - 475	5	30.7	30.7	30.7			32.4						
HAR - 241	6												
HAR - 134	7												
HAR - 222	8	24.1	24.0	24.3									
HAR - 219	9	22.2	22.2	22.5			23.0						
HAR - 293	10												
HAR - 269	11		22.3	22.4			24.0						
HAR - 436	12						32.0						
HAR - 422	13	23.2	23.3	26.1			23.5						
HAR - 393	14	14.6	14.5	14.7			15.0						
HAR - 400	15	12.9	12.2	12.3			13.0						
HAR - 54	16	7.1	6.9	7.1			7.7						
HAY - 80	17	14.1	14.8	15.6									
HAY - 89	18						33.4						
HAY - 151	19												
HAY - 25	20	43.0	46.5	47.1			47.2						
HAY - 17	21	44.5	44.4	44.4			44.5						
HAY - 11	22	11.3	11.0	11.4									
HAY - 4	23	10.9	11.4	11.3			12.9						
HAY - 7	24	28.5		30.5									
HAB - 225	25												
HAB - 219	26	38.2	39.0	39.9									
HAB - 107	27												
HAB - 23	28	35.6	35.4	36.4			36.3						
HAB - 19	29	36.9	37.0	37.1			37.2						
HAB - 61	30						36.3						
HAB - 88	31												
QAW - 130	32												
QAW - 82	33	58.5	58.3	57.8									
QAW - 7	34	25.7	25.7	25.8			25.9						
QAW - 11	35	29.2	29.0	29.0			29.0						
QAW - 83	36	63.0	63.2	67.2									
QAW - 1	37	25.1	25.0	25.4									
QAW - 2	38	43.9	44.0	43.9									
QAW - 3	39	60.8	60.8	60.7									
QAW - 4	40	50.5	50.5	50.7									
QAW - 5	41	33.0	33.1	33.0									

ANNEX 5

Groundwater Level and Quality Changes (TBWRS 1985-NORADEP 1991)

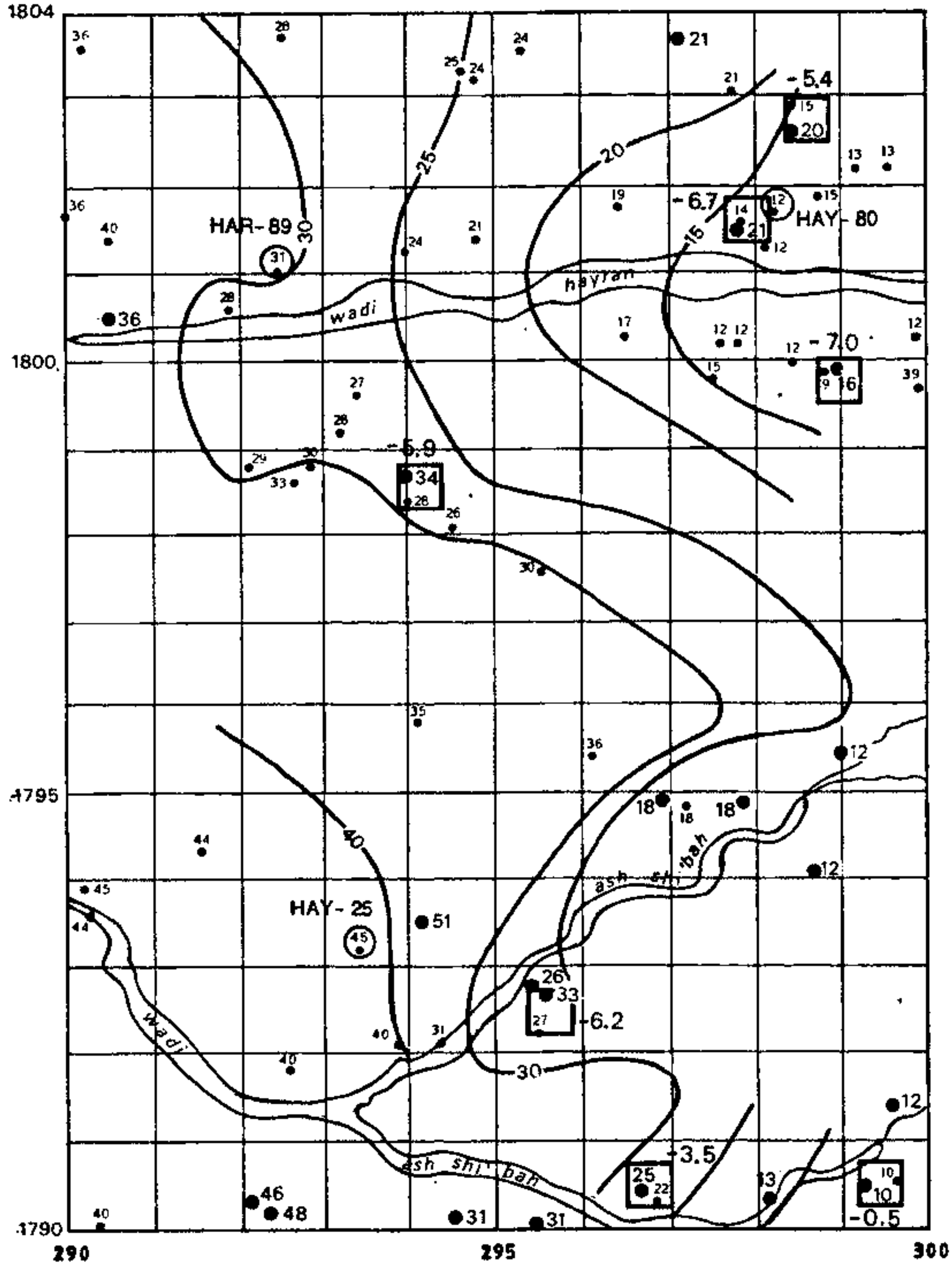


Figure 1. CHANGE IN STATIC WATERLEVEL IN THE WADI HAYRAN AREA (1985-1991)

LEGEND

- 40 — TBWRS depth to water (m)
- 20 — TBWRS depth to water contour
- (16) — TDA monitor well
- -6.7 [12] — Well inventorised by TBWRS and NORADEP with water level change (m) (1985 - 1991)
- ● 20 — NORADEP depth to water (m)

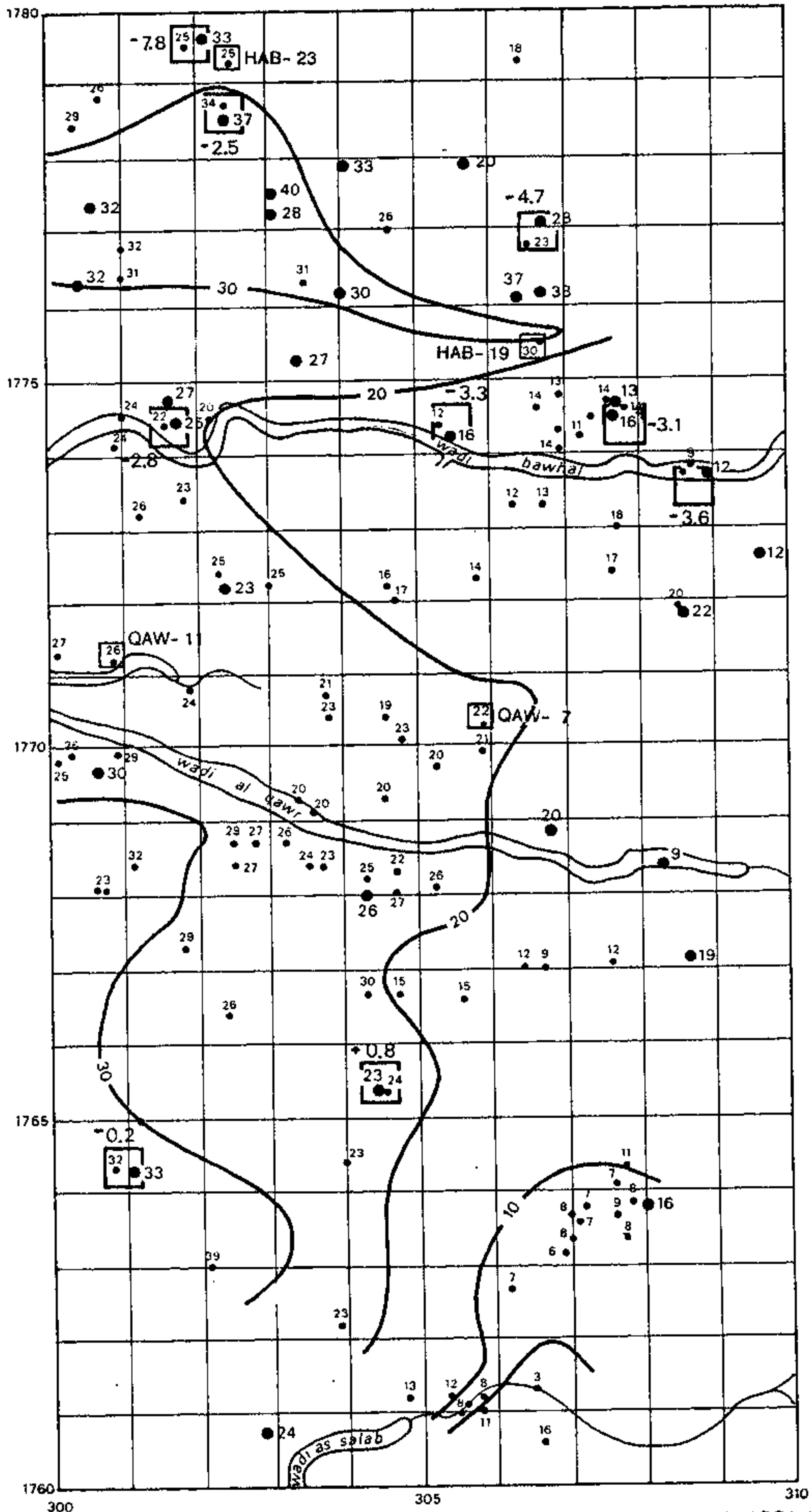


Figure 2. CHANGE IN STATIC WATER LEVEL IN THE WADIS BAWHAL / AL QAWR AREA (1985 - 1991)

LEGEND

25 TBWRS depth to water (m)

15 TBWRS depth to water contour

(16) TDA monitor well

-6.7 [12] Well inventorised by TBWRS and NORADEP with water level change (m) (1985 - 1991)

● 20 NORADEP depth to water (m)

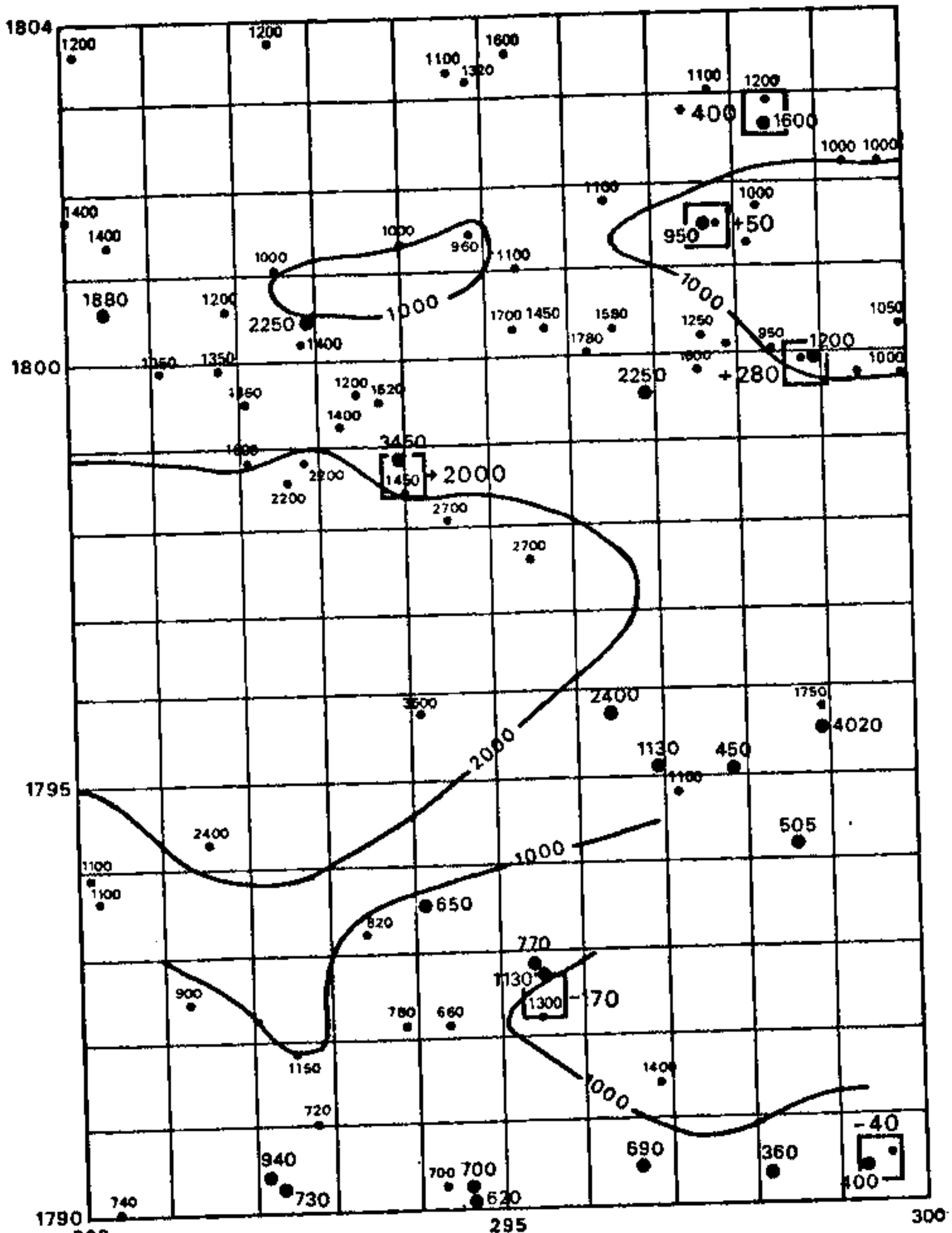


Figure 3. CHANGE IN ELECTRICAL CONDUCTIVITY IN THE WADI HAYRAN AREA (1985-1991)

LEGEND

1550 : TBWRS EC (μs/cm)

100 : TBWRS EC contour

+200 □ . Well inventorised by TBWRS and NORADEP with EC change (μs/cm) (1985 - 1991)

720 ● NORADEP EC (μs/cm)

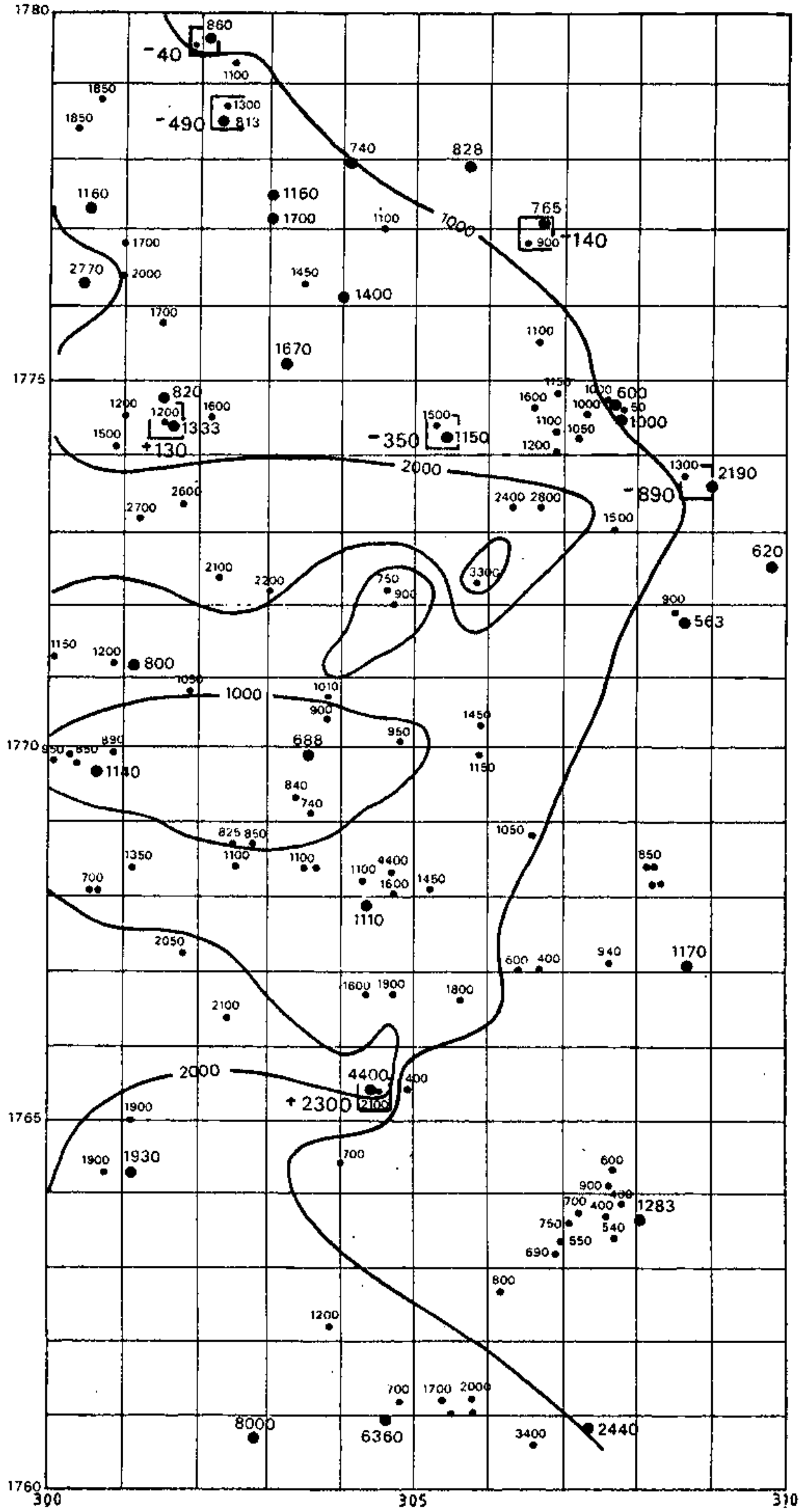


Figure 4. CHANGE IN ELECTRICAL CONDUCTIVITY IN THE WADIS BAWHAL / AL QAWR AREA (1985-1991)

LEGEND

1650 • TBWRS EC (μs/cm)

—100— TBWRS EC contour

+200 □ Well inventorised by TBWRS and NORADEP with EC change (μs/cm) (1985 - 1991)

720 ● NORADEP EC (μs/cm)

Table 1 Comparison of TBWRS (1985) and NORADEP(1991) data in wadi Hayran area

EASTING 29000-30000: NORTHING 179000-180400.

TBWRS				
Well Ref Nr	Well Depth (m)	Depth to Water (m)	EC (uS/cm)	Pump Rate (l/s)
6	10.3	9.7	440	
20	21.5	21.5		
22	62.0	27.1	1300	8.3
66	41.0	9.0	920	14.3
73	16.6	14.3	900	12.5
74	29.0	14.6	1200	
114	32.3	28.1	1450	

NORADEP				
Well Ref Nr	Well Depth (m)	Depth to Water (m)	EC (uS/cm)	Pump Rate (l/s)
33	11.0	10.2	400	
66	31.0	25.0	690	
107	45.0	33.3	1130	5.8
13	34.0	16.0	1200	13.0
19	30.0	21.0	950	15.0
20	45.0	20.0	1600	5.4
89	53.0	34.0	3450	15.0

TBWRS Well Ref Nr	NORADEP Well Ref Nr	CHANGES			
		Well Depth (m)	Depth to Water (m)	EC (uS/cm)	Pump Rate (l/s)
6	33	-0.7	-0.5	-40	
20	66	-9.5	-3.5		
22	107	37.0	-6.2	-170	-2.5
66	13	7.0	-7.0	280	-1.3
73	19	-13.4	-6.7	50	2.5
74	20	-16.0	-5.4	400	
114	89	-20.7	-5.9	2000	

NOTES: negative signs for depths indicate increase in depth
negative sign for EC indicates decrease in groundwater salinity

Table 2 Comparison of TBWRS (1985) and NORADEP (1991) data in the wadi Bawhal / Al Qawr area

EASTING 30000-31000: NORTHING 176000-178000.

TBWRS

Well Ref Nr	Well Depth (m)	Depth to Water (m)	EC (uS/cm)	Pump Rate (l/s)
60	34.6	32.4	1900	
36	22.4	22.2	1200	
22	26.3	25.2	900	8.0
24	37.5	34.0	1300	
17	23.8	23.5	2100	
9	12.7	12.5	1500	
20	23.3	22.8	900	
13	15.4	12.9	1150	8.0
4	9.2	6.0	1300	5.6

NORADEP

Well Ref Nr	Well Depth (m)	Depth to Water (m)	EC (uS/cm)	Pump Rate (l/s)
74	34.0	32.6	1937	
46	26.0	25.0	1333	
42	60.0	33.0	860	9.3
41	36.0	36.5	814	
73	23.0	22.7	4400	
55	16.0	15.6	1150	
53	28.0	27.5	765	
27	20.0	16.0	1000	5.8
61	15.0	11.6	2190	

TEWRS Well Ref Nr	NORADEP Well Ref Nr	CHANGES Well Depth (m)	Depth to Water (m)	EC (uS/cm)	Pump Rate (l/s)
60	74	0.6	-0.2	37	
36	46	-5.6	-2.6	133	
22	42	-33.7	-7.8	-40	1.3
24	41	-0.5	-2.5	-486	
17	73	0.8	0.8	2300	
9	55	-3.3	-3.3	-350	
20	53	-4.7	-4.7	-135	
13	27	-4.6	-3.1	-150	-2.2
4	61	-5.8	-3.6	890	

NOTES: negative signs for depths indicate increase in depth

: negative sign for EC indicates decrease in groundwater salinity

ANNEX 6

Groundwater Quality Monitoring Data

TABLE 1. TIHAMA DEVELOPMENT AUTHORITY - MONITORING NETWORK
GROUNDWATER ELECTRICAL CONDUCTIVITY (mS/cm) 1988

Well Ref. Nr	Serial	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
HAR- 58	1												
HAR- 24	2												
HAR-185	3												
HAR-473	4												
HAR-475	5												
HAR-241	6												
HAR-134	7												
HAR-222	8												
HAR-219	9												
HAR-293	10												
HAR-269	11												
HAR-436	12												
HAR-422	13												
HAR-393	14												
HAR-400	15												
HAR- 54	16											2680	2780
HAY- 82	17											600	650
HAY- 89	18											dry	dry
HAY-151	19											dry	dry
HAY- 25	20											2800	3000
HAY- 17	21											1100	1200
HAY- 11	22											700	780
HAY- 4	23											1700	1750
HAY- 7	24											290	250
HAB-225	25											1900	1750
HAB-219	26											1350	1500
HAB-107	27											4000	4100
HAB- 23	28											1500	1100
HAB- 19	29											1150	1100
HAB- 61	30											3200	2800
HAB- 88	31											dry	dry
W-130	32											dry	dry
QAW- 82	33											1500	1800
QAW- 7	34											1600	1650
QAW- 11	35											1220	1200
QAW- 83	36											1800	1750
QAW- 1	37											850	900
QAW- 2	38											1550	1700
QAW- 3	39												
QAW- 4	40												
QAW- 5	41											1700	1900

TABLE 2. TIHAMA DEVELOPMENT AUTHORITY - MONITORING NETWORK
GROUNDWATER ELECTRICAL CONDUCTIVITY (mS/cm) 1989

Well Ref. Nr	Serial	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
HAR- 58	1	2300	2250	2400			2500	1900		1900		1950	2000
HAR- 24	2	2800	2500	2500			2500	2750		2800	2500	2700	3000
HAR-186	3	1200	1200	1100			1000	1400		1400	1000	1400	1500
HAR-473	4												
HAR-475	5	dry	dry	dry			dry	dry	dry	dry	dry	dry	dry
HAR-241	6		3400	3600			1100	3400		3500			1100
HAR-134	7	dry	dry	dry			dry	dry	dry	dry	dry	dry	dry
HAR-222	8						3200	3400		3500	3200		3400
HAR-219	9		1950	1550			2000	1800		1800	2000		2100
HAR-293	10		1150	1100			dry	dry	dry	dry	dry	dry	dry
HAR-269	11	550	570	580						500	506		600
HAR-436	12	950	530	520			1000	800	800	800	900		900
HAR-422	13	500	520	520			440	500	500	500	500	490	500
HAR-393	14		700	600			600	650	500	700	800	750	700
HAR-400	15		800	760			750	780	600	800	650	700	850
HAR- 54	16	2500	2700	2550	2500		2500	2500			2262		2700
HAY- 80	17		1020	900			900	900		650	950		850
HAY- 89	18	dry	dry	dry	dry		dry	dry	dry	dry	dry	dry	dry
HAY-151	19	dry	dry	dry	dry		dry	dry	dry	dry	dry	dry	dry
HAY- 25	20	1280	1100	1000	1600		1600	920			1100	1200	1230
HAY- 17	21	1300	1250	1200	1250		1400	1320			1500	1550	1550
HAY- 11	22	780	800	800	800			700	700			800	700
HAY- 4	23	1750	1600	1600	1700			2000	1800			1800	1650
HAY- 7	24	400	400	400	500		400	400			400	500	600
HAB-225	25	2000	2200	2600	2000		2800	2100		2200	2800	2200	2400
HAB-219	26	1500	1450	1500			2300	1250			1300		2300
HAB-107	27				4100		4100	dry					
HAB- 23	28	1500	1400	1300	1300		1400	1300	1300	1300	1600	1650	
HAB- 19	29		1000	800	900			900	950		1400	1600	1600
HAB- 61	30	3200	2800	2100	2800			2700	2900	2800	2200	3400	3500
HAB- 88	31	dry											
QAW-130	32	dry											
QAW- 82	33		1800	1800	2300		1650	1500		1550	1800	1450	1480
QAW- 7	34	1550	1500	1500	1500		1500	1350		1400	1550	1500	1400
QAW- 11	35	1350	1600		1605		1100	1050			1200	1200	1100
QAW- 83	36	1850	1900	1800	2050		1900	1800			2000	1900	1740
QAW- 1	37	800	800	800	850		800	800			850		1000
QAW- 2	38	1400	1500	1500	1800		1700	1500			1500		1550
QAW- 3	39	dry											
QAW- 4	40	2200	1500	1500	1500		1500	1500		1500	1550	1200	1500
QAW- 5	41	1500	1550		1600		1600	1700		1200	1250	2200	1700

TABLE 3. TIHAMA DEVELOPMENT AUTHORITY - MONITORING NETWORK
GROUNDWATER ELECTRICAL CONDUCTIVITY (mS/cm) 1990

Well Ref. Nr	Serial	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
HAR- 58	1	2600	2100	2200	1600			2100	2100			2500	2500
HAR- 24	2	2.50	3000	3300	3200	3200		3400	3200			2400	2800
HAR-186	3	1450	1600	1600	1800	1800		1800	1700			2000	1600
HAR-473	4	dry											
HAR-475	5											1800	2000
HAR-241	6	full	with	sand									
HAR-134	7	dry											
HAR-222	8	3600	3500	3600	3600	3600		4200	3800			3800	4000
HAR-219	9	2000	2000	2000	2100	2200		2100	2100			2100	2100
HAR-293	10	dry											
HAR-269	11	700	800	600	600	600		600	600				600
HAR-436	12	900	500	900	1000	950		950	900			800	sand
HAR-422	13	700	700	600	650	600		600	600			600	cov'ed
HAR-393	14	700	750	650	800	700		700	600			800	800
HAR-400	15	900	900	800	800	900		750	800			900	900
HAR- 54	16	1900	2200	2500	2500	2300		2700	2500			3000	3000
HAY- 80	17	700	900	900	1000	900		950	600			600	800
HAY- 89	18	dry											
HAY-151	19	dry											
HAY- 25	20	1100	1000	1100	1000			1100	1100			2200	1200
HAY- 17	21	1550	1500	1500	1550			1900	1900			2300	2000
HAY- 11	22	700	800	600	700	700	750	750	650			2400	2400
HAY- 4	23	1650	1750	1650	1800	1850	2100	2100	1800			2400	2400
HAY- 7	24	500	550	450		750		500	500			600	1200
HAB-225	25	2000	2300	2400	2200			2600	2300			2700	dry
HAB-219	26	1350	2350	2400	1750			1250				2300	1500
HAB-107	27	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
HAB- 23	28	1900	1450	1400	1400			2450	1440			2000	1700
HAB- 19	29	1700	1100	1100	1000	1000		1000	1000			1400	1200
HAB- 61	30	3500	2700		dry	dry		dry	dry			dry	dry
HAB- 88	31	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
QAW-130	32	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
QAW- 82	33	1400	1500	1500	1450	1750		2300				2000	1800
QAW- 7	34	1400	1500	1500	1500	1650		1500	1600				1700
QAW- 11	35	1150	1150	1190	1200	1250	1300	1250	1250			1600	1300
QAW- 83	36	1750	1700	1900				1900	1700			1600	2200
QAW- 1	37	900		900	900	1100			1000			1100	1000
QAW- 2	38	1450	1550	1600	1550	1650		1750	1900			2400	2100
QAW- 3	39	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
QAW- 4	40	1700	1600	1600	1600	dry		1800	1700			1500	1800
QAW- 5	41	1800	1900	1850	2000	dry		2000	2000			2300	2200

TABLE 4. TIHAMA DEVELOPMENT AUTHORITY - MONITORING NETWORK GROUNDWATER ELECTRICAL CONDUCTIVITY (mS/cm) 1991

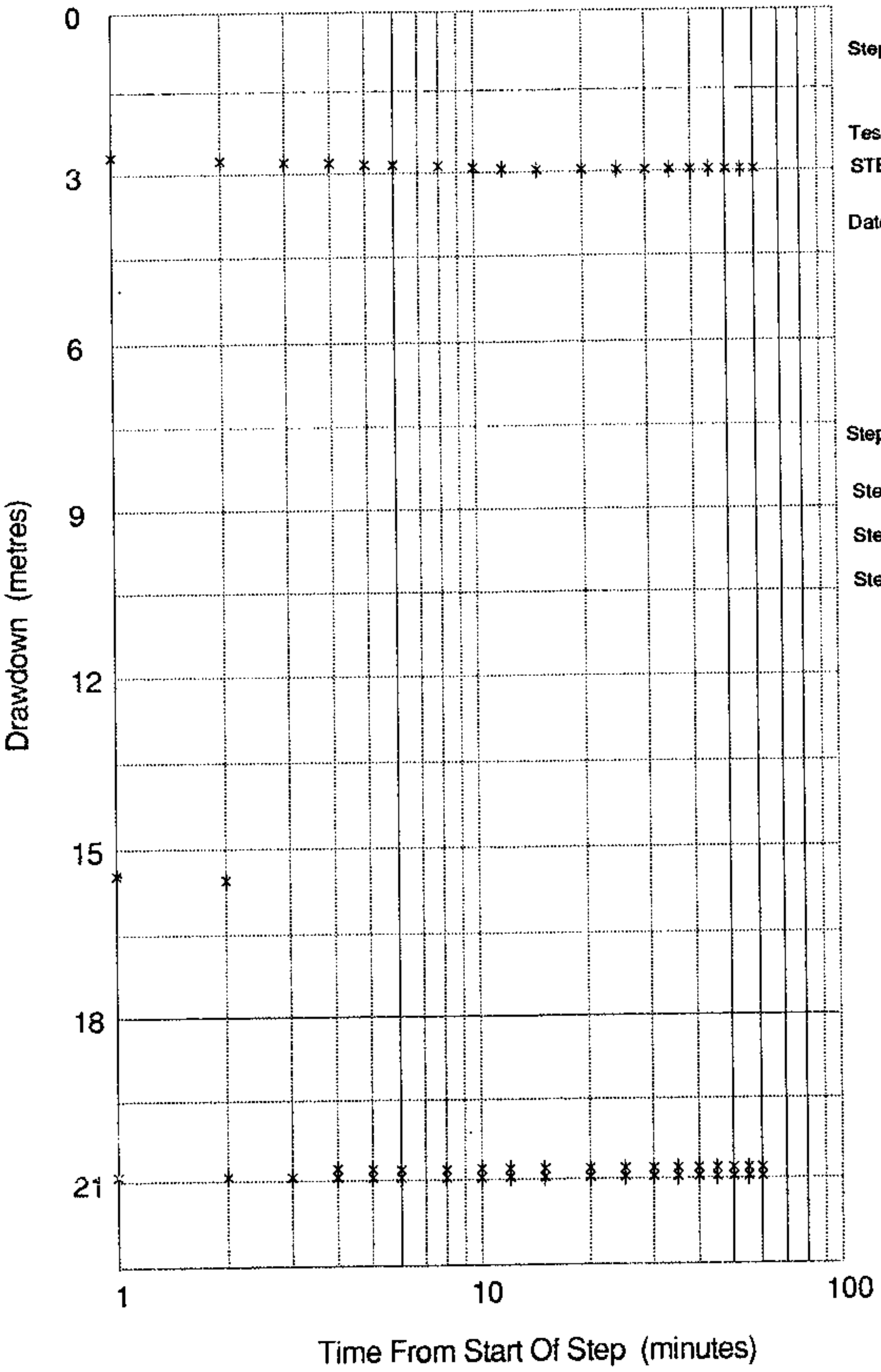
Well Ref. Nr	Serial	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
HAR- 58	1	2500	2420	2100									
HAR- 24	2	2900	2900	dry									
HAR-186	3	1500	1500	dry									
HAR-473	4	dry											
HAR-475	5	2000	1900	2000									
HAR-241	6	dry											
HAR-134	7	dry											
HAR-222	8	3800	4000	4100									
HAR-219	9	2200	2000	2200									
HAR-293	10	dry											
HAR-259	11	650	550	620									
HAR-436	12	dry											
HAR-422	13	600	550	650									
HAR-392	14	700	700	800									
HAR-400	15	900	900	640									
HAR- 54	16	3000	3780	3000									
HAY- 80	17	700	1040	1000									
HAY- 89	18	dry											
HAY-151	19	dry		1500									
HAY- 25	20	1200	1150	1150									
HAY- 17	21	2100	2000	1750									
HAY- 11	22	700	690	2200									
HAY- 4	23	2200	2520	2100									
HAY- 7	24	500	500	450									
HAB-225	25	dry											
HAB-219	26	2350	1500	1030									
HAB-107	27	dry											
HAB- 23	28	1500	1550	1550									
HAB- 19	29	1100	1080	1100									
HAB- 61	30	dry											
HAB- 88	31												
QAW-130	32												
QAW- 82	33	1600	1600	1700									
QAW- 7	34	1700	1720	1450									
QAW- 11	35	1250	1250	1100									
QAW- 83	36	1700	2160	2000									
QAW- 1	37	1100	1030	1050									
QAW- 2	38	2100	1960	2000									
QAW- 3	39	4600	4700	4600									
QAW- 4	40	1700	1700	1850									
QAW- 5	41	2200	2100	2200									

ANNEX 7

Aquifer Test Plots and Data

Figure 1

Step-Drawdown Test, Testwell STEP TEST1



Step-Drawdown Test

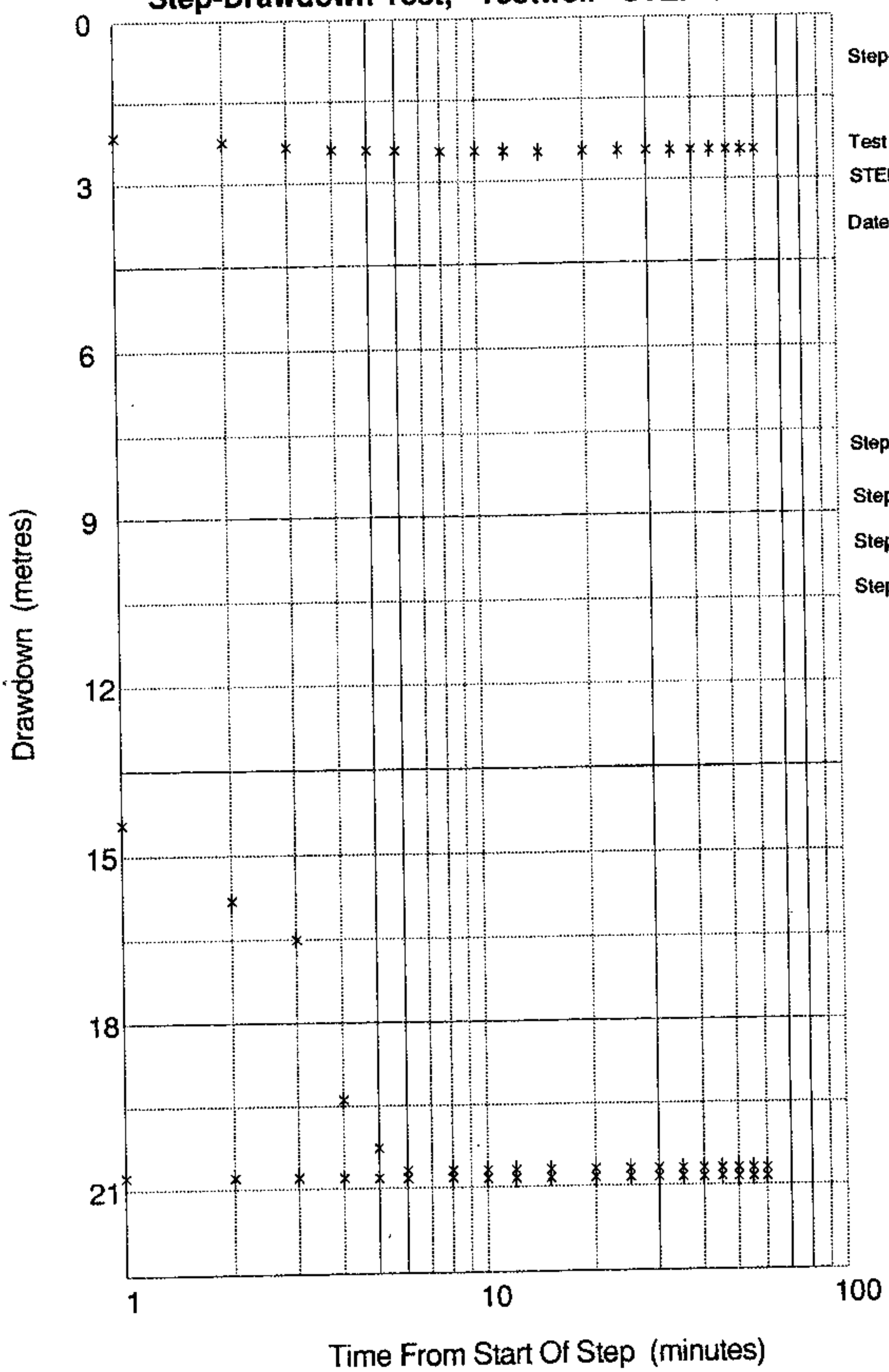
Test Reference : STEP TEST1

Date : 16/11/90

Step No.	Discharge
Step 1	12 l/s
Step 2	18.5 l/s
Step 3	29 l/s

Figure 2

Step-Drawdown Test, Testwell STEP TEST2



Step-Drawdown Test

Test Reference : STEP TEST2

Date : 20/11/90

Step No.	Discharge
Step 1	11.5 l/s
Step 2	18 l/s
Step 3	29 l/s

Figure 3
Pumping Test Results , Testwell LONG

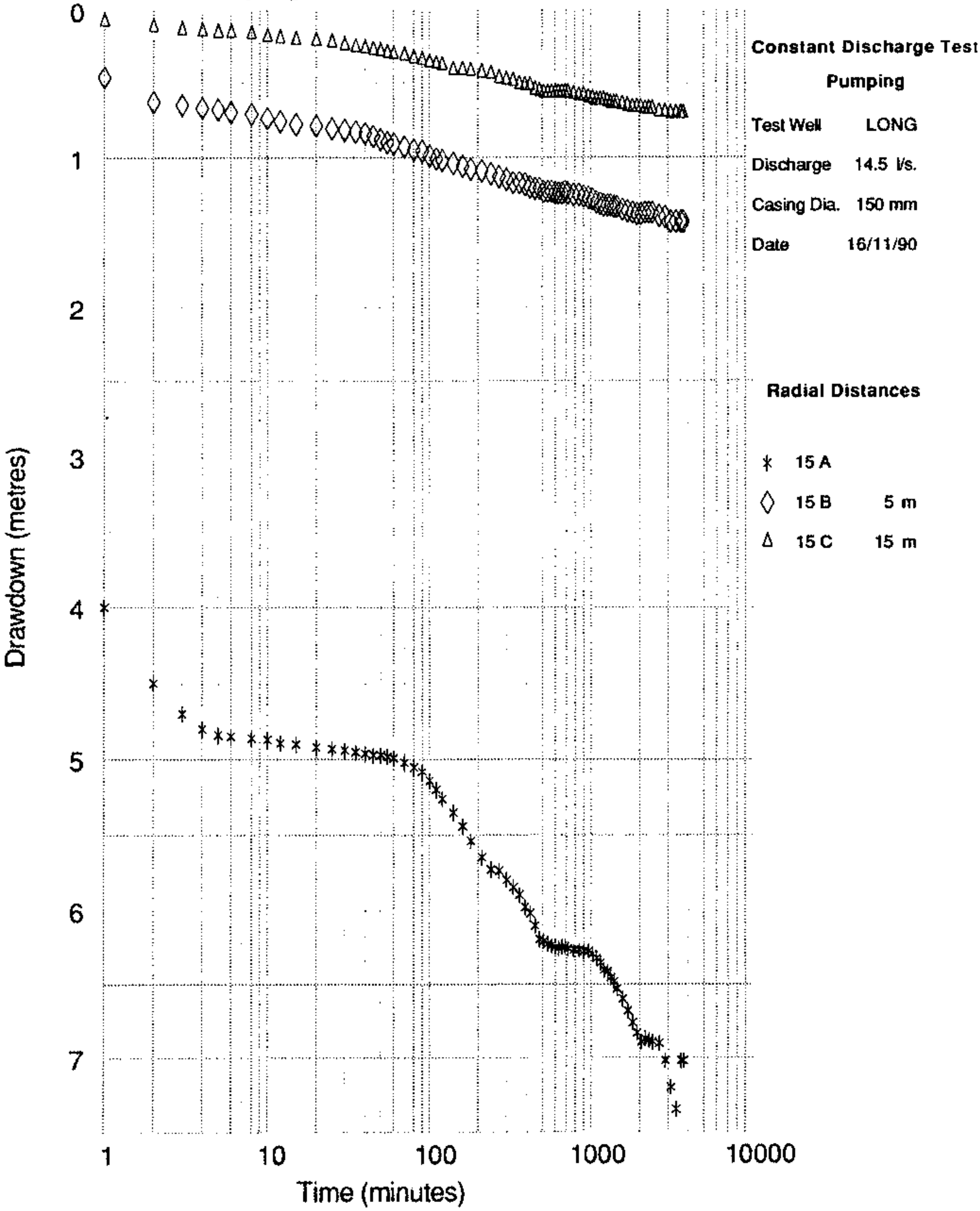


Figure 4

Pumping Test Results , Testwell LONG

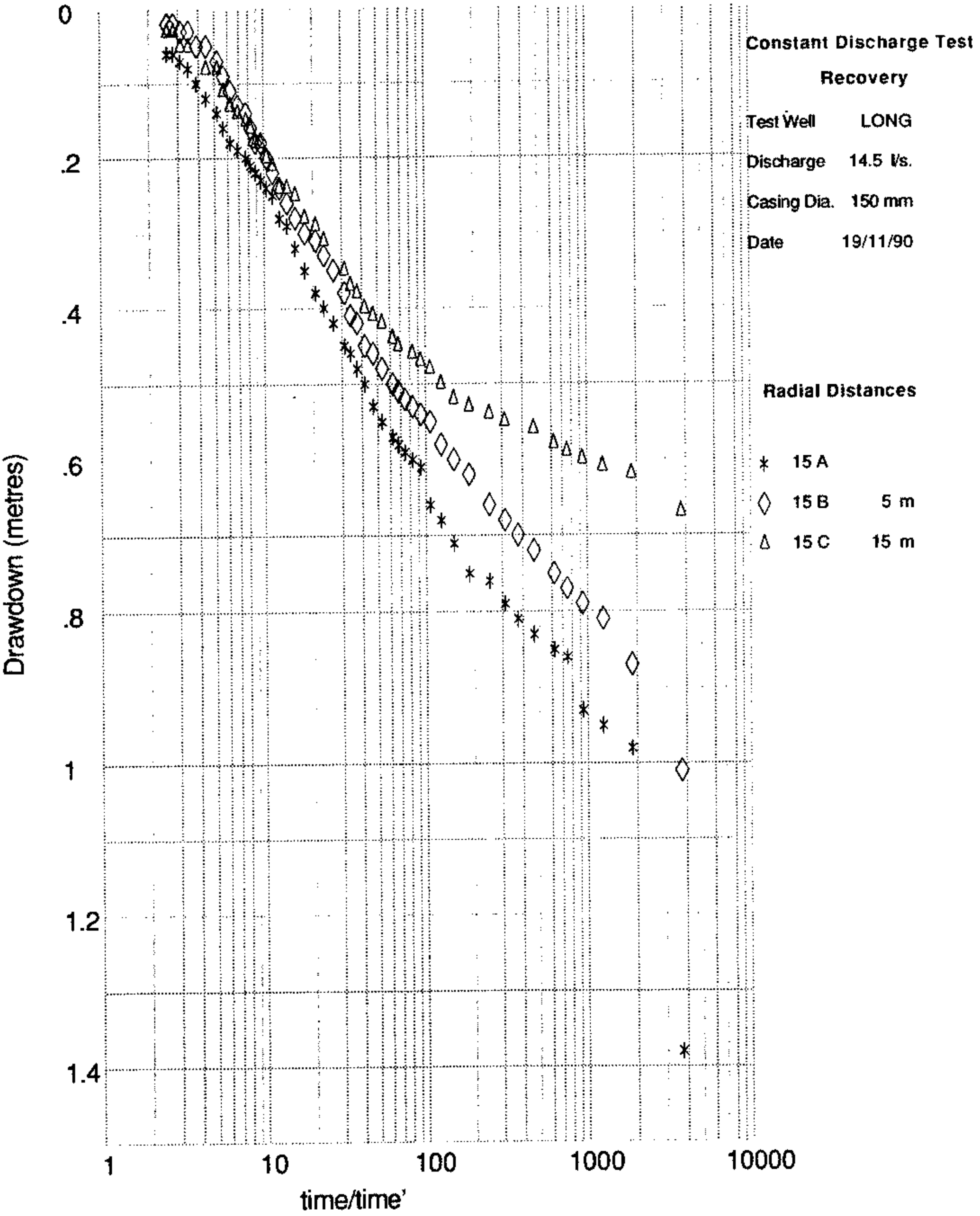
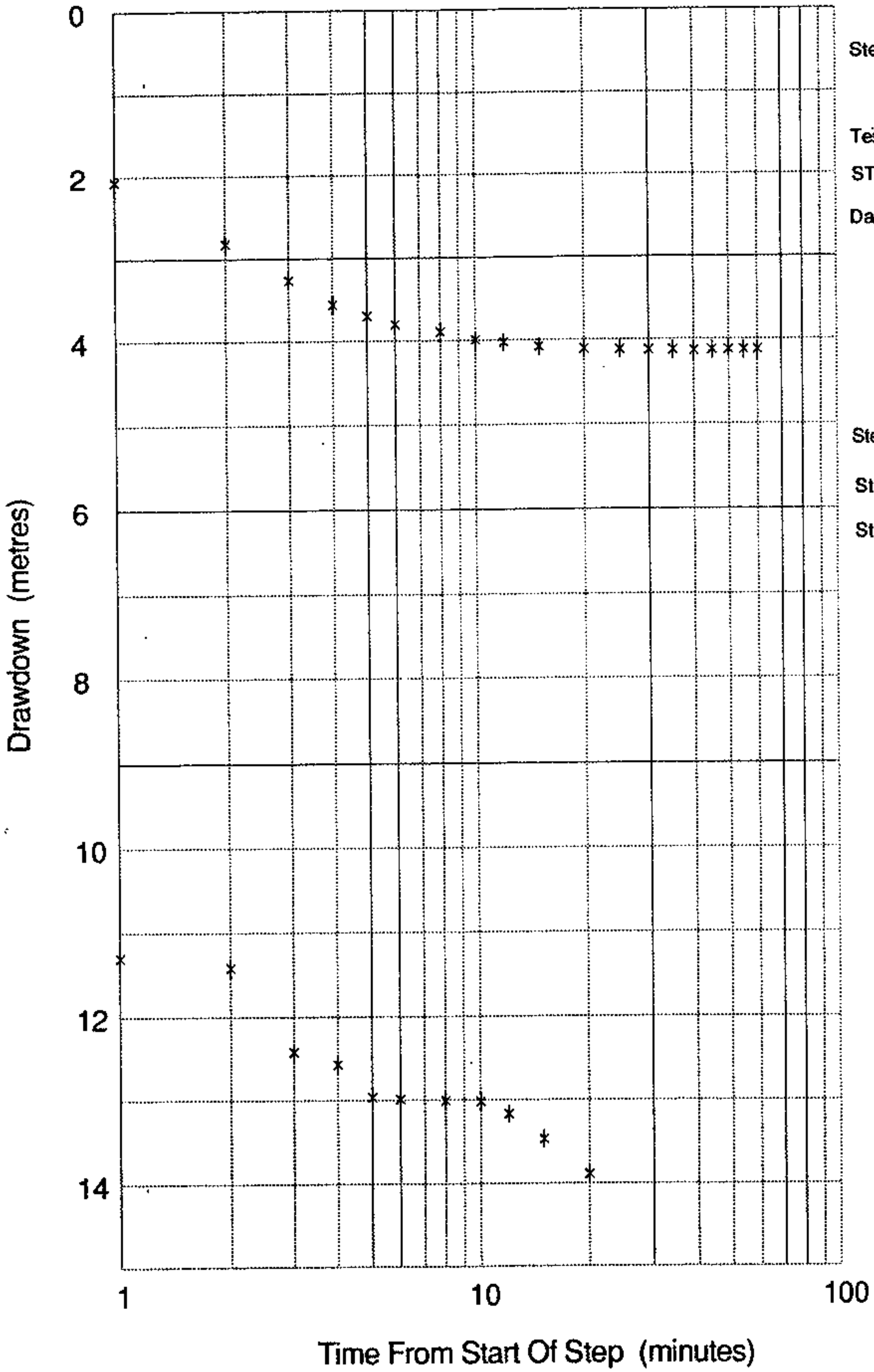


Figure 5

Step-Drawdown Test, Testwell STEP TEST3



Step-Drawdown Test

Test Reference :

STEP TEST3

Date : 5/12/90

Step No.	Discharge
Step 1	5.75 l/s
Step 2	18.5 l/s

Figure 6

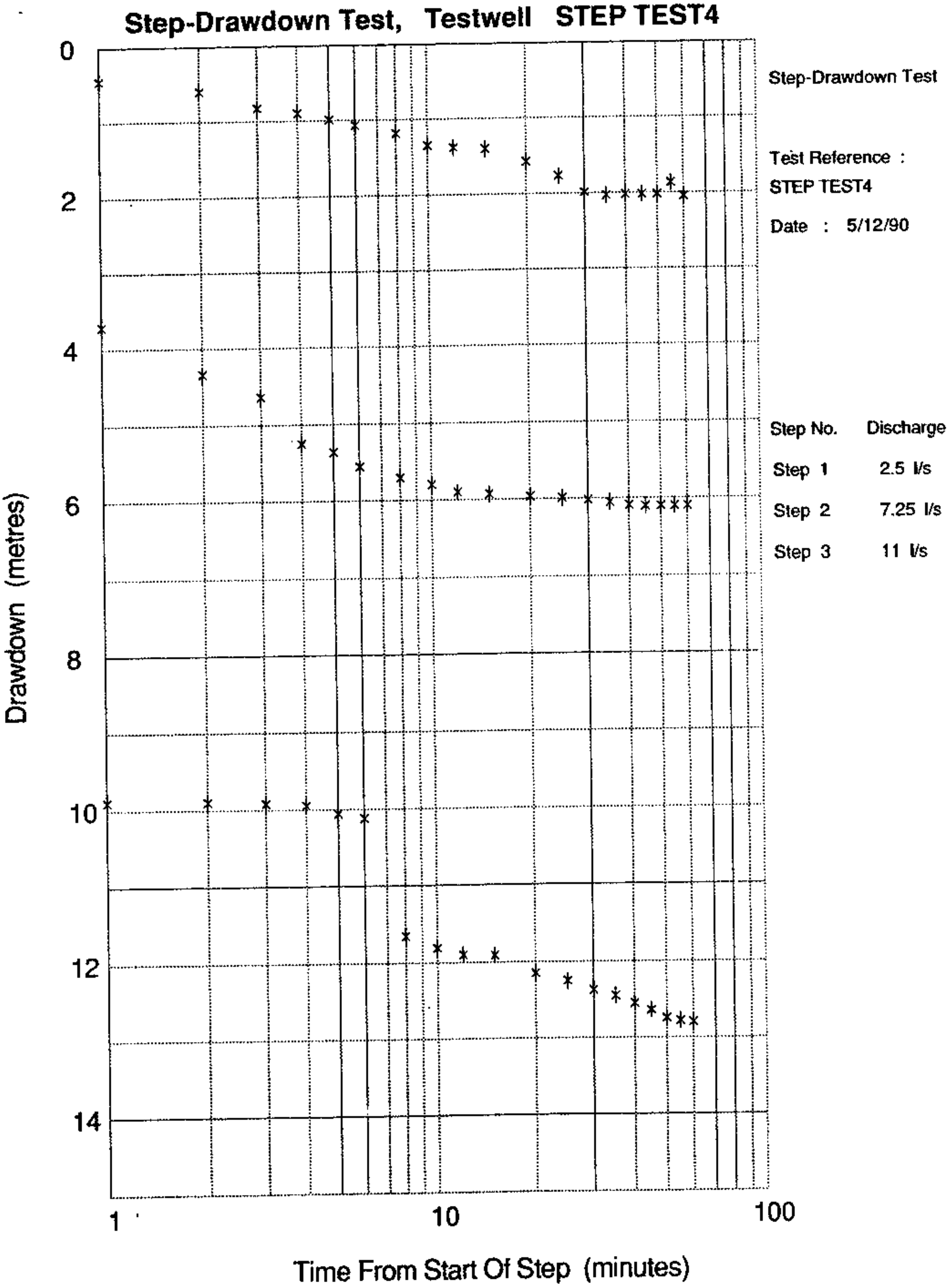

Step-Drawdown Test, Testwell STEP TEST4
0
2
4
6
8
10
12
14
Drawdown (metres)
1
10
100
Time From Start Of Step (minutes)
Step-Drawdown Test
Test Reference :
STEP TEST4
Date : 5/12/90
Step No. Discharge
Step 1 2.5 l/s
Step 2 7.25 l/s
Step 3 11 l/s

Figure 7

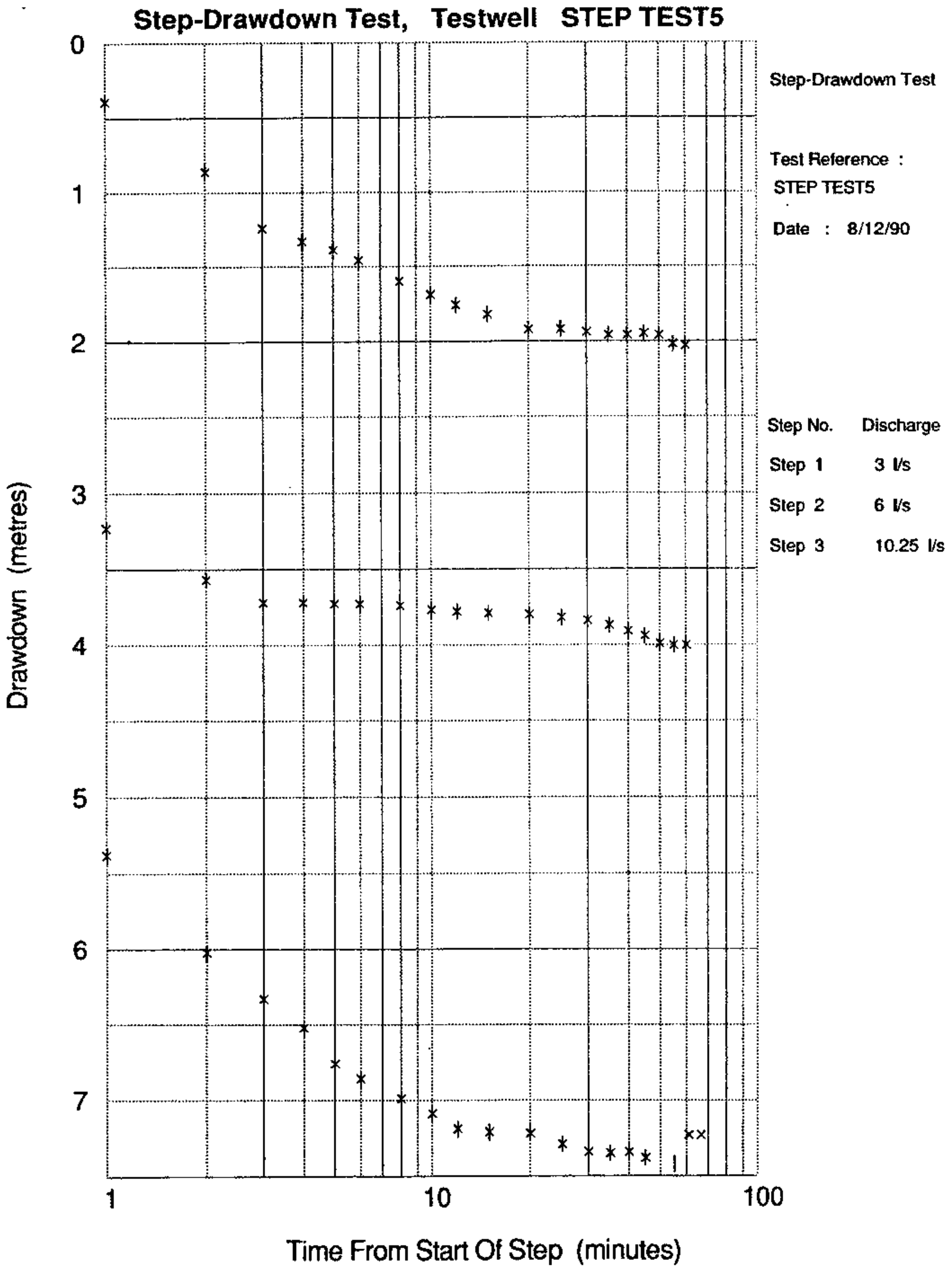

Step-Drawdown Test, Testwell STEP TEST5
0
1
2
3
4
5
6
7
Drawdown (metres)
1
10
100
Time From Start Of Step (minutes)
Step-Drawdown Test
Test Reference :
STEP TEST5
Date : 8/12/90
Step No. Discharge
Step 1 3 l/s
Step 2 6 l/s
Step 3 10.25 l/s

Figure 8

Pumping Test Results , Testwell LONG 1

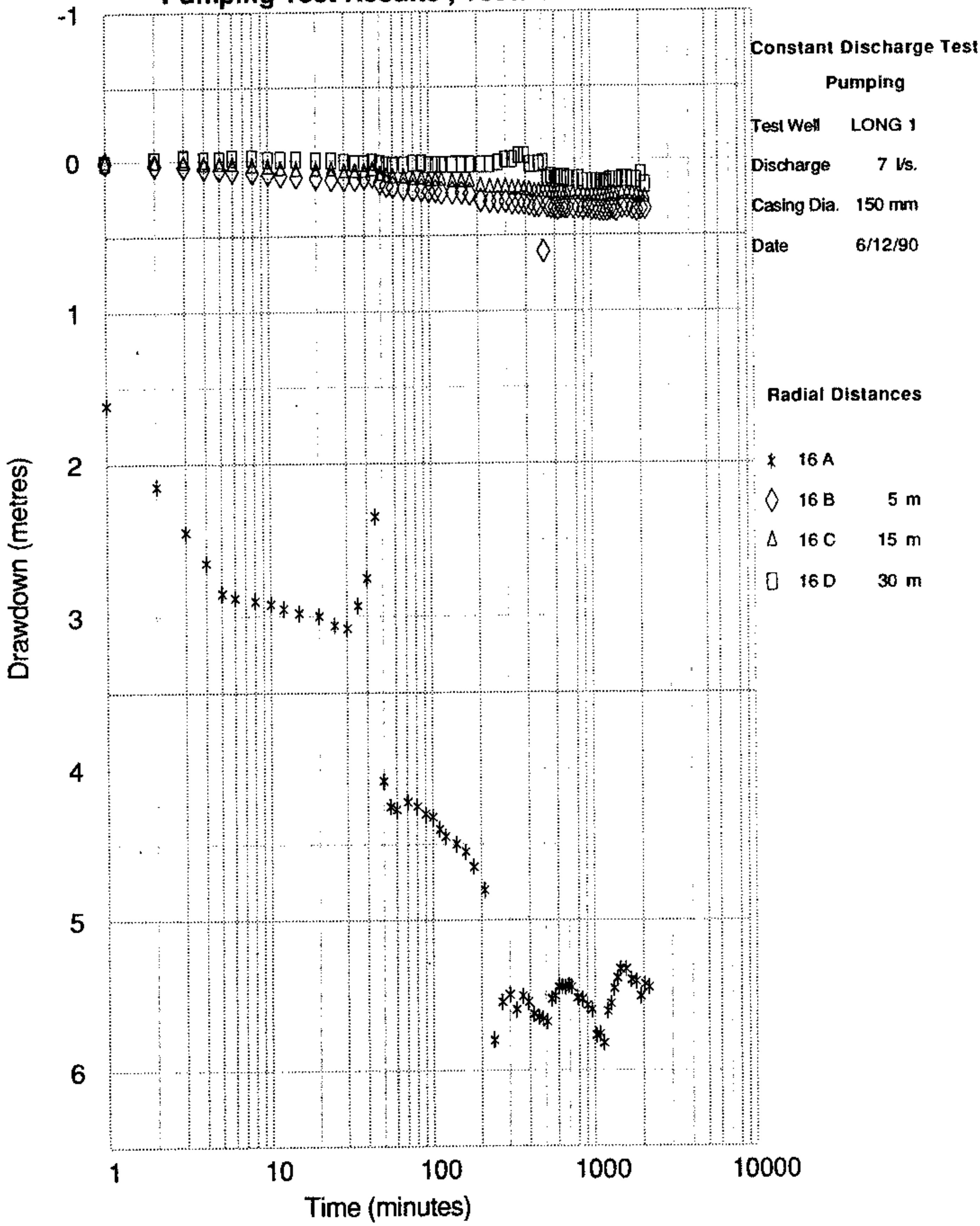


Figure 9

Step-Drawdown Test, Testwell STEP TEST6

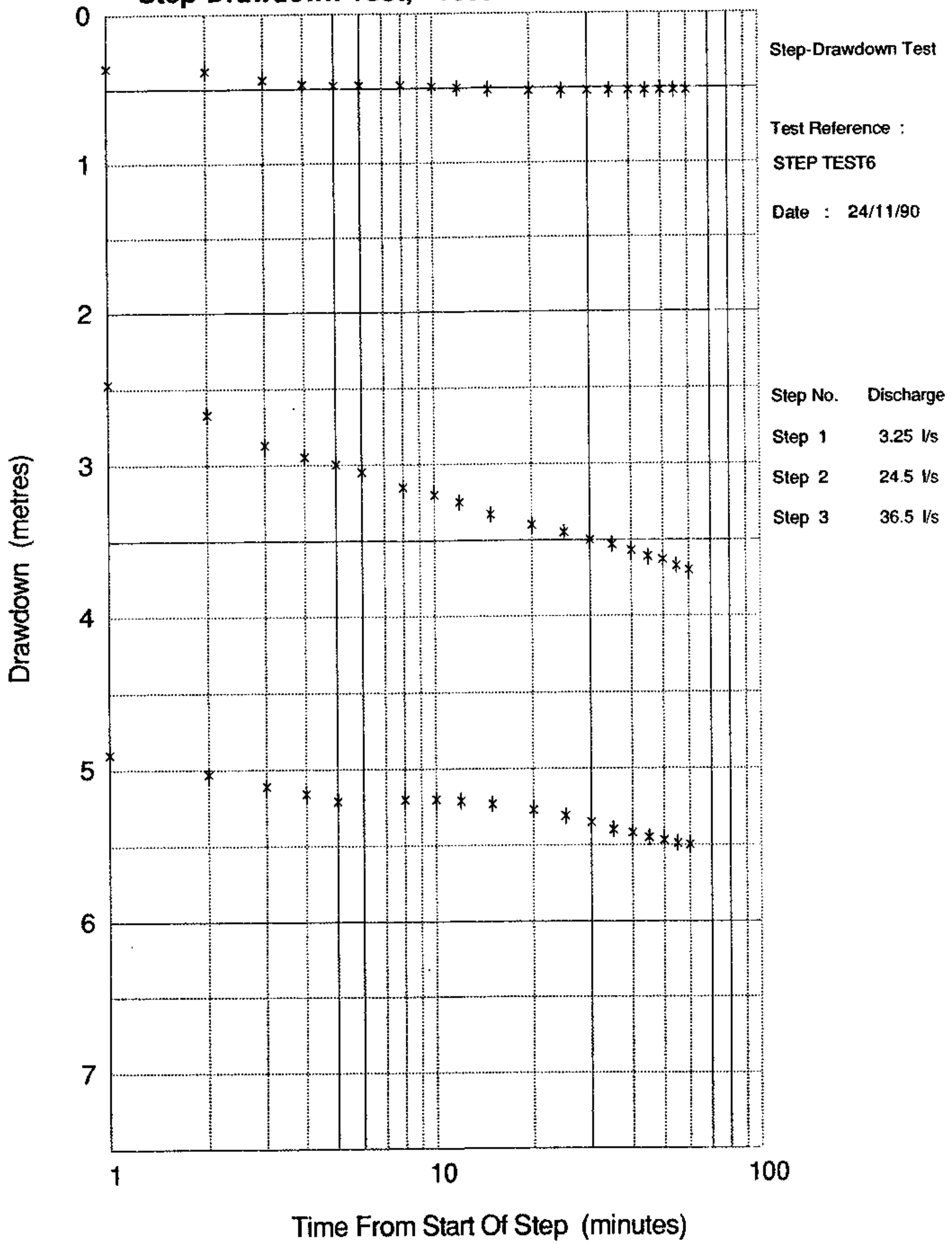


Figure 10

Pumping Test Results , Testwell LONG 1

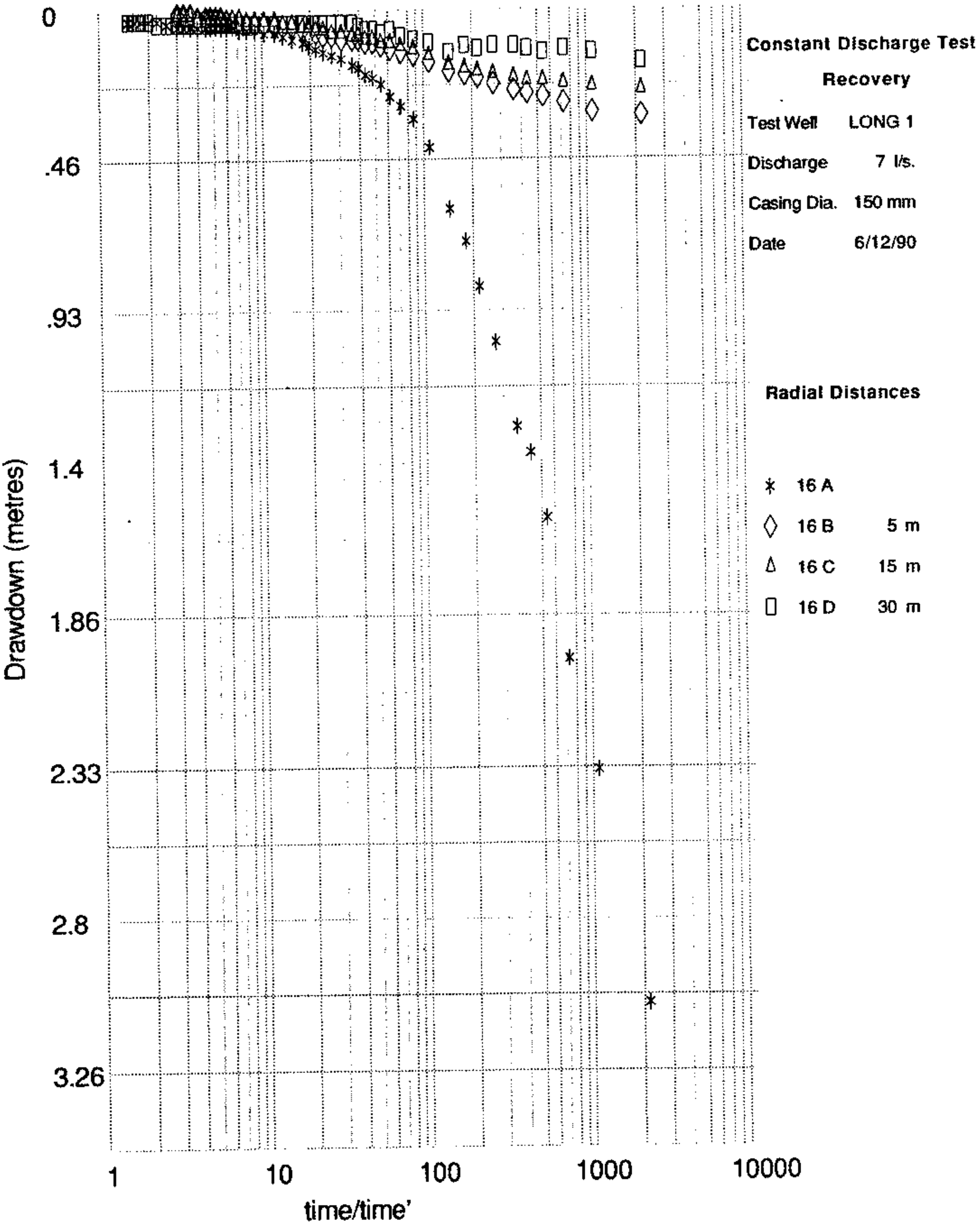


Figure 11

Step-Drawdown Test, Testwell STEP TEST7

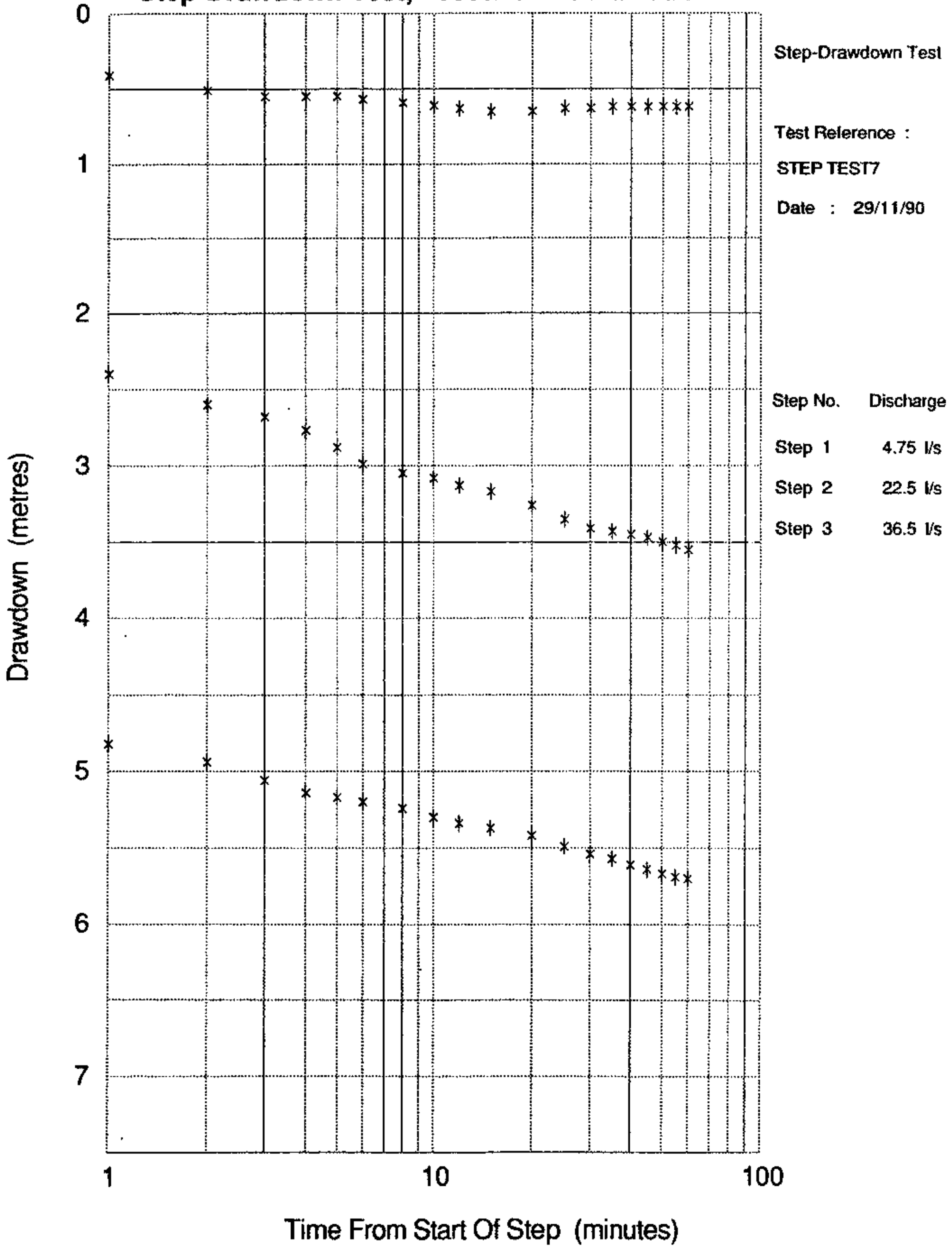


Figure 12

Pumping Test Results , Testwell LONG 2

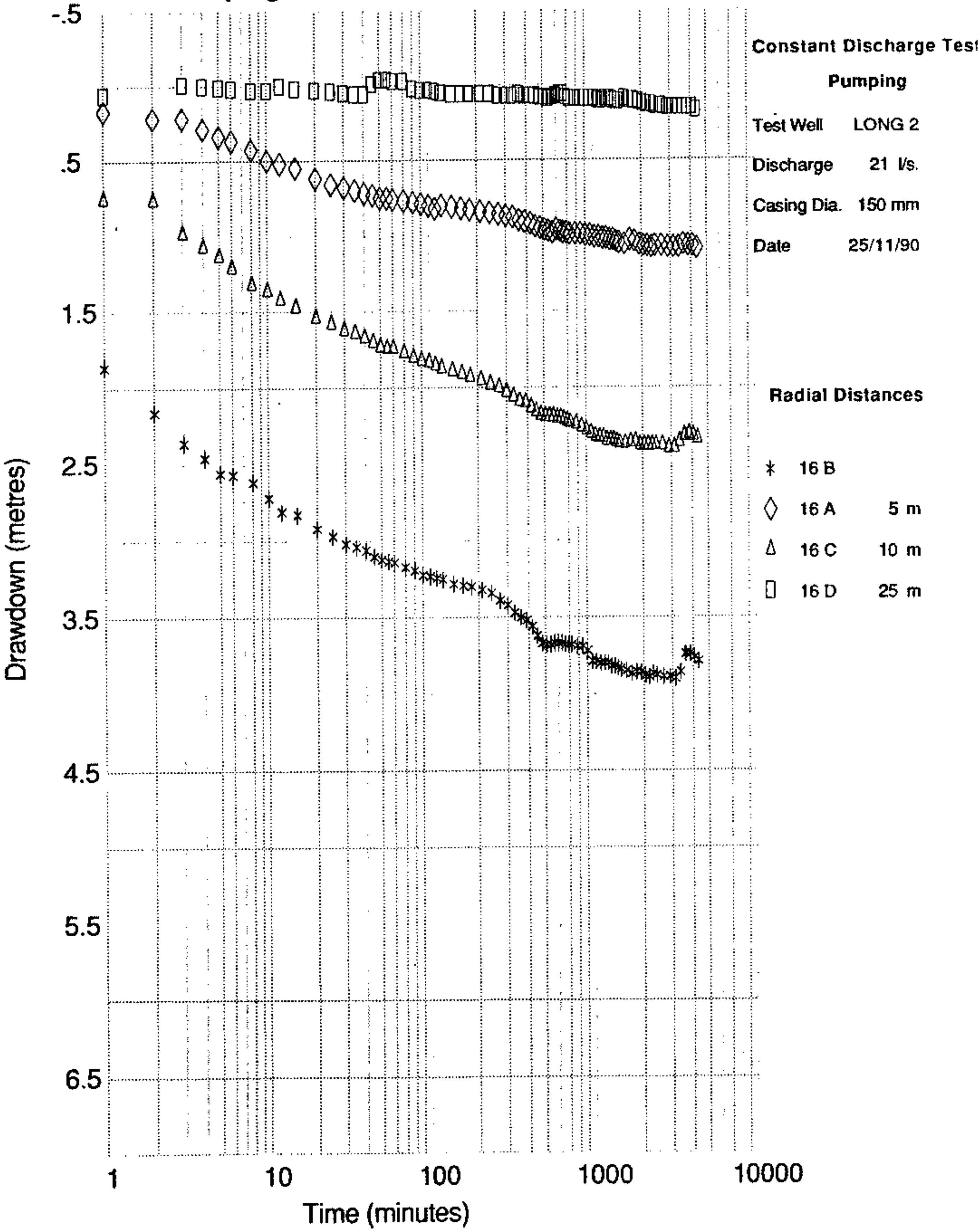
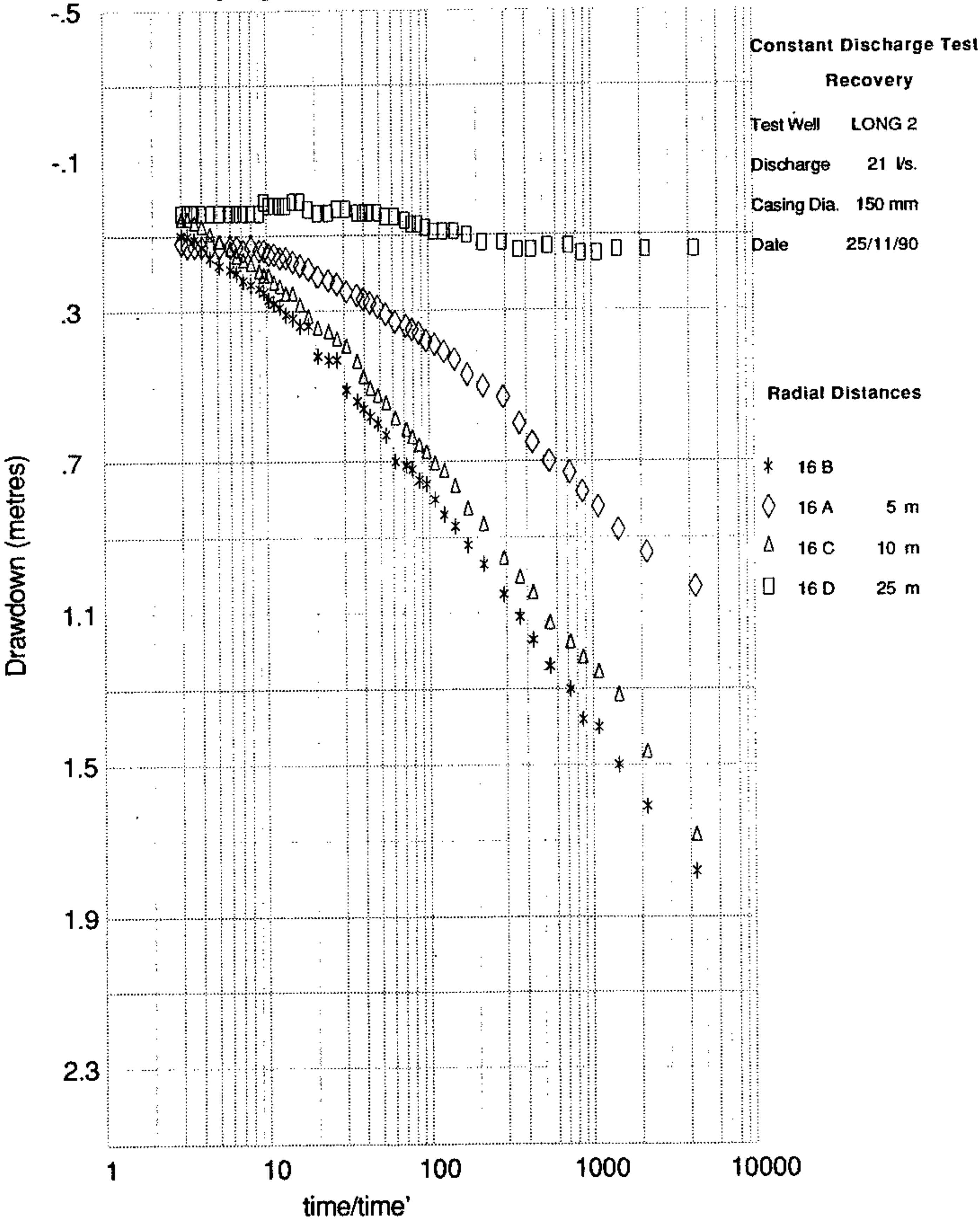


Figure 13

Pumping Test Results , Testwell LONG 2



STEP TEST DATA-SHEET
Time-Drawdown Data

Project Name : STEP TEST 1
Test Location : Grid Ref :
Date of Test : 16/11/90
Time Started :

Elapsed Time (mins)	Step No 1 Water Level (m.b.ref)	Step No 1 Drawdn (m)	Step 2 Drawdn (m)	Step 3 Drawdn (m)	Step 4 Drawdn (m)	Step 5 Drawdn (m)
Discharge (l/s)		12.0	18.5	29.0	0.0	0.0
0.0	14.94	0.00	2.97	20.80		
1.0	17.62	2.68	15.46	20.91		
2.0	17.70	2.76	15.54	20.92		
3.0	17.73	2.79		20.93		
4.0	17.75	2.81	20.78	20.94		
5.0	17.78	2.84	20.80	20.95		
6.0	17.79	2.85	20.81	20.95		
8.0	17.82	2.88	20.81	20.96		
10.0	17.85	2.91	20.80	20.96		
12.0	17.88	2.94	20.80	20.96		
15.0	17.90	2.96	20.80	20.96		
20.0	17.91	2.97	20.80	20.96		
25.0	17.91	2.97	20.80	20.96		
30.0	17.91	2.97	20.80	20.96		
35.0	17.91	2.97	20.80	20.96		
40.0	17.91	2.97	20.80	20.96		
45.0	17.91	2.97	20.80	20.96		
50.0	17.91	2.97	20.80	20.96		
55.0	17.91	2.97	20.80	20.96		
60.0	17.91	2.97	20.80	20.96		

STEP TEST DATA-SHEET
Time-Drawdown Data

Project Name : STEP TEST 2
Test Location : Grid Ref :
Date of Test : 20/11/90
Time Started :

Elapsed Time (mins)	Step No 1 Water Level (m.b.ref)	Step No 1 Drawdn (m)	Step 2 Drawdn (m)	Step 3 Drawdn (m)	Step 4 Drawdn (m)	Step 5 Drawdn (m)
Discharge (l/s)		11.5	18.0	29.0	0.0	0.0
0.0	15.06	0.00	2.46	20.69		
1.0	17.20	2.14	14.46	20.78		
2.0	17.30	2.24	15.80	20.79		
3.0	17.40	2.34	16.50	20.80		
4.0	17.45	2.39	19.39	20.81		
5.0	17.47	2.41	20.27	20.82		
6.0	17.48	2.42	20.68	20.83		
8.0	17.50	2.44	20.69	20.83		
10.0	17.50	2.44	20.69	20.84		
12.0	17.51	2.45	20.69	20.84		
15.0	17.53	2.47	20.69	20.84		
20.0	17.52	2.46	20.69	20.84		
25.0	17.52	2.46	20.69	20.84		
30.0	17.52	2.46	20.69	20.84		
35.0	17.52	2.46	20.69	20.84		
40.0	17.52	2.46	20.69	20.85		
45.0	17.52	2.46	20.69	20.84		
50.0	17.52	2.46	20.69	20.85		
55.0	17.52	2.46	20.69	20.85		
60.0	17.52	2.46	20.69	20.85		

STEP TEST DATA-SHEET
Time-Drawdown Data

Project Name : STEP TEST 3
Test Location :
Date of Test : 5/12/90
Time Started :

Grid Ref :

Elapsed Time (mins)	Step No 1 Water Level (m.b.ref)	Step No 1 Drawdn (m)	Step 2 Drawdn (m)	Step 3 Drawdn (m)	Step 4 Drawdn (m)	Step 5 Drawdn (m)
Discharge (l/s)		5.8	18.5	0.0	0.0	0.0
0.0	33.73	0.00	4.13			
1.0	35.80	2.07	11.30			
2.0	36.55	2.82	11.42			
3.0	37.00	3.27	12.42			
4.0	37.30	3.57	12.57			
5.0	37.44	3.71	12.97			
6.0	37.54	3.81	12.99			
8.0	37.63	3.90	13.01			
10.0	37.73	4.00	13.02			
12.0	37.76	4.03	13.17			
15.0	37.81	4.08	13.47			
20.0	37.84	4.11	13.89			
25.0	37.85	4.12				
30.0	37.86	4.13				
35.0	37.86	4.13				
40.0	37.87	4.14				
45.0	37.86	4.13				
50.0	37.86	4.13				
55.0	37.86	4.13				
60.0	37.86	4.13				

STEP TEST DATA-SHEET
Time-Drawdown Data

Project Name : STEP TEST 4
Test Location : Grid Ref :
Date of Test : 5/12/90
Time Started :

Elapsed Time (mins)	Step No 1 Water Level (m.b.ref)	Step No 1 Drawdn (m)	Step 2 Drawdn (m)	Step 3 Drawdn (m)	Step 4 Drawdn (m)	Step 5 Drawdn (m)
Discharge (l/s)		2.5	7.3	11.0	0.0	0.0
0.0	33.75	0.00	2.05	6.10		
1.0	34.20	0.45	3.71	9.90		
2.0	34.35	0.60	4.34	9.90		
3.0	34.58	0.83	4.64	9.92		
4.0	34.65	0.90	5.25	9.95		
5.0	34.74	0.99	5.36	10.06		
6.0	34.82	1.07	5.56	10.12		
8.0	34.93	1.18	5.71	11.65		
10.0	35.10	1.35	5.80	11.81		
12.0	35.13	1.38	5.90	11.90		
15.0	35.15	1.40	5.93	11.91		
20.0	35.33	1.58	5.97	12.15		
25.0	35.52	1.77	5.99	12.25		
30.0	35.74	1.99	6.02	12.37		
35.0	35.78	2.03	6.05	12.45		
40.0	35.77	2.02	6.09	12.55		
45.0	35.77	2.02	6.10	12.64		
50.0	35.77	2.02	6.10	12.75		
55.0	35.62	1.87	6.10	12.78		
60.0	35.80	2.05	6.10	12.80		

STEP TEST DATA-SHEET
Time-Drawdown Data

Project Name : STEP TEST 5
Test Location :
Date of Test : 8/12/90
Time Started :

Grid Ref :

Elapsed Time (mins)	Step No 1 Water Level (m.b.ref)	Step No 1 Drawdn (m)	Step 2 Drawdn (m)	Step 3 Drawdn (m)	Step 4 Drawdn (m)	Step 5 Drawdn (m)
Discharge (l/s)		3.0	6.0	10.3	0.0	0.0
0.0	33.78	0.00	2.03	4.00		
1.0	34.17	0.39	3.23	5.38		
2.0	34.64	0.86	3.57	6.02		
3.0	35.02	1.24	3.72	6.33		
4.0	35.11	1.33	3.72	6.52		
5.0	35.17	1.39	3.73	6.76		
6.0	35.24	1.46	3.73	6.86		
8.0	35.38	1.60	3.74	6.99		
10.0	35.47	1.69	3.77	7.09		
12.0	35.54	1.76	3.78	7.19		
15.0	35.60	1.82	3.79	7.21		
20.0	35.70	1.92	3.80	7.22		
25.0	35.70	1.92	3.82	7.29		
30.0	35.72	1.94	3.84	7.34		
35.0	35.74	1.96	3.87	7.35		
40.0	35.74	1.96	3.91	7.34		
45.0	35.73	1.95	3.94	7.38		
50.0	35.74	1.96	3.99	-33.78		
55.0	35.80	2.02	4.00	7.42		
60.0	35.81	2.03	4.00	7.42		

STEP TEST DATA-SHEET
Time-Drawdown Data

Project Name : STEP TEST 6
Test Location : Grid Ref :
Date of Test : 24/11/90
Time Started :

Elapsed Time (mins)	Step No 1 Water Level (m.b.ref)	Step No 1 Drawdn (m)	Step 2 Drawdn (m)	Step 3 Drawdn (m)	Step 4 Drawdn (m)	Step 5 Drawdn (m)
Discharge (l/s)		3.3	24.5	36.5	0.0	0.0
0.0	33.75	0.00	0.52	3.70		
1.0	34.11	0.36	2.47	4.90		
2.0	34.13	0.38	2.67	5.03		
3.0	34.19	0.44	2.87	5.11		
4.0	34.22	0.47	2.95	5.16		
5.0	34.23	0.48	3.00	5.21		
6.0	34.23	0.48	3.05			
8.0	34.23	0.48	3.15	5.20		
10.0	34.24	0.49	3.20	5.20		
12.0	34.25	0.50	3.25	5.21		
15.0	34.26	0.51	3.33	5.23		
20.0	34.27	0.52	3.40	5.27		
25.0	34.27	0.52	3.45	5.31		
30.0	34.27	0.52	3.50	5.35		
35.0	34.27	0.52	3.53	5.40		
40.0	34.27	0.52	3.57	5.42		
45.0	34.27	0.52	3.61	5.45		
50.0	34.27	0.52	3.63	5.47		
55.0	34.27	0.52	3.67	5.49		
60.0	34.27	0.52	3.70	5.50		

STEP TEST DATA-SHEET

Time-Drawdown Data

Project Name : STEP TEST 7
Test Location : Grid Ref :
Date of Test : 29/11/90
Time Started :

Elapsed Time (mins)	Step No 1 Water Level (m.b.ref)	Step No 1 Drawdn (m)	Step 2 Drawdn (m)	Step 3 Drawdn (m)	Step 4 Drawdn (m)	Step 5 Drawdn (m)
Discharge (l/s)		4.8	22.5	36.5	0.0	0.0
0.0	33.88	0.00	0.62	3.55		
1.0	34.29	0.41	2.40	4.82		
2.0	34.39	0.51	2.60	4.94		
3.0	34.43	0.55	2.68	5.06		
4.0	34.43	0.55	2.77	5.14		
5.0	34.43	0.55	2.88	5.17		
6.0	34.45	0.57	2.99	5.20		
8.0	34.47	0.59	3.05	5.24		
10.0	34.49	0.61	3.08	5.30		
12.0	34.51	0.63	3.13	5.34		
15.0	34.53	0.65	3.17	5.37		
20.0	34.53	0.65	3.26	5.42		
25.0	34.51	0.63	3.35	5.49		
30.0	34.51	0.63	3.41	5.54		
35.0	34.50	0.62	3.43	5.57		
40.0	34.50	0.62	3.45	5.61		
45.0	34.50	0.62	3.47	5.64		
50.0	34.50	0.62	3.50	5.67		
55.0	34.50	0.62	3.52	5.69		
60.0	34.50	0.62	3.55	5.70		

AQUIFER TEST DATA-SHEET
Time-Drawdown Data

Project Name : LONG
Test Location :
Grid Ref :
Date of Test : 16/11/90
Time Started :
Av. Discharge: 14.5 l/s

Elapsed Time (mins)	Production Well Water Level (m.b.ref)	Production Well Drawdn (m)	Peiz 1 Drawdn (m)	Peiz 2 Drawdn (m)	Peiz 3 Drawdn (m)	Peiz 4 Drawdn (m)
0.0	15.00	0.00	0.00	0.00		
1.0	19.00	4.00	0.46	0.07		
2.0	19.50	4.50	0.63	0.11		
3.0	19.70	4.70	0.65	0.13		
4.0	19.80	4.80	0.67	0.14		
5.0	19.84	4.84	0.68	0.15		
6.0	19.85	4.85	0.70	0.15		
8.0	19.86	4.86	0.71	0.16		
10.0	19.87	4.87	0.74	0.18		
12.0	19.89	4.89	0.76	0.19		
15.0	19.90	4.90	0.78	0.20		
20.0	19.92	4.92	0.79	0.21		
25.0	19.93	4.93	0.81	0.22		
30.0	19.94	4.94	0.82	0.24		
35.0	19.95	4.95	0.83	0.25		
40.0	19.96	4.96	0.84	0.26		
45.0	19.97	4.97	0.86	0.27		
50.0	19.97	4.97	0.88	0.28		
55.0	19.98	4.98	0.90	0.29		
60.0	19.99	4.99	0.91	0.30		
70.0	20.02	5.02	0.93	0.31		
80.0	20.05	5.05	0.95	0.33		
90.0	20.08	5.08	0.96	0.34		
100.0	20.14	5.14	0.99	0.36		
110.0	20.20	5.20	1.01	0.37		
120.0	20.26	5.26	1.02	0.38		
140.0	20.35	5.35	1.04	0.41		
160.0	20.44	5.44	1.06	0.41		
180.0	20.54	5.54	1.08	0.42		
210.0	20.65	5.65	1.09	0.43		
240.0	20.73	5.73	1.11	0.44		
270.0	20.74	5.74	1.13	0.47		
300.0	20.80	5.80	1.15	0.48		
330.0	20.85	5.85	1.17	0.49		
360.0	20.90	5.90	1.17	0.51		
390.0	20.98	5.98	1.18	0.52		
420.0	21.02	6.02	1.20	0.52		
450.0	21.10	6.10	1.21	0.55		
480.0	21.19	6.19	1.21	0.56		
510.0	21.20	6.20	1.23	0.57		
540.0	21.22	6.22	1.23	0.57		
570.0	21.23	6.23	1.23	0.57		
600.0	21.24	6.24	1.24	0.57		
630.0	21.25	6.25	1.24	0.57		
660.0	21.24	6.24	1.24	0.57		

AQUIFER TEST DATA-SHEET

Time-Drawdown Data

Project Name : LONG

Test Location :

Date of Test : 16/11/90

Time Started :

Grid Ref :

Av. Discharge: 14.5 l/s

Elapsed Time (mins)	Production Well Water Level (m.b.ref)	Production Well Drawdn (m)	Peiz 1 Drawdn (m)	Peiz 2 Drawdn (m)	Peiz 3 Drawdn (m)	Peiz 4 Drawdn (m)
690.0	21.24	6.24	1.23	0.57		
720.0	21.25	6.25	1.24	0.57		
780.0	21.26	6.26	1.25	0.58		
840.0	21.26	6.26	1.25	0.59		
900.0	21.27	6.27	1.26	0.59		
960.0	21.27	6.27	1.27	0.60		
1020.0	21.29	6.29	1.28	0.61		
1080.0	21.32	6.32	1.30	0.62		
1140.0	21.35	6.35	1.31	0.62		
1200.0	21.40	6.40	1.32	0.62		
1260.0	21.41	6.41	1.32	0.63		
1320.0	21.45	6.45	1.32	0.64		
1380.0	21.48	6.48	1.33	0.64		
1440.0	21.53	6.53	1.33	0.64		
1560.0	21.60	6.60	1.35	0.65		
1680.0	21.68	6.68	1.36	0.66		
1800.0	21.76	6.76	1.37	0.67		
1920.0	21.83	6.83	1.38	0.67		
2040.0	21.89	6.89	1.38	0.67		
2160.0	21.87	6.87	1.37	0.68		
2280.0	21.88	6.88	1.37	0.68		
2400.0	21.89	6.89	1.37	0.68		
2640.0	21.90	6.90	1.39	0.70		
2880.0	22.02	7.02	1.40	0.70		
3120.0	22.20	7.20	1.43	0.71		
3360.0	22.35	7.35	1.43	0.71		
3600.0	22.02	7.02	1.43	0.71		
3720.0	22.02	7.02	1.43	0.71		

AQUIFER TEST DATA-SHEET
Recovery Data

Project Name : LONG
Test Location : Grid Ref :
Date of Test : 16/11/90
Time Started : Av. Discharge: 14.5 l/s

Elapsed Time since pumpstop (mins)	since pumpstrt (mins)	t/t'	Prod.Well Residual Drawdown (m)	Peiz 1 Drawdn (m)	Peiz 2 Drawdn (m)	Peiz 3 Drawdn (m)	Peiz 4 Drawdn (m)
1.0	3721.0	3720.0	1.38	1.01	0.67		
2.0	3722.0	1860.0	0.98	0.87	0.62		
3.0	3723.0	1240.0	0.95	0.81	0.61		
4.0	3724.0	930.0	0.93	0.79	0.60		
5.0	3725.0	744.0	0.86	0.77	0.59		
6.0	3726.0	620.0	0.85	0.75	0.58		
8.0	3728.0	465.0	0.83	0.72	0.56		
10.0	3730.0	372.0	0.81	0.70	-16.08		
12.0	3732.0	310.0	0.79	0.68	0.55		
15.0	3735.0	248.0	0.76	0.66	0.54		
20.0	3740.0	186.0	0.75	0.62	0.53		
25.0	3745.0	148.8	0.71	0.60	0.52		
30.0	3750.0	124.0	0.68	0.58	0.50		
35.0	3755.0	106.3	0.66	0.55	0.48		
40.0	3760.0	93.0	0.61	0.54	0.47		
45.0	3765.0	82.7	0.60	0.53	0.46		
50.0	3770.0	74.4	0.59	0.52	-16.08		
55.0	3775.0	67.6	0.58	0.51	0.45		
60.0	3780.0	62.0	0.57	0.50	0.44		
70.0	3790.0	53.1	0.55	0.48	0.42		
80.0	3800.0	46.5	0.53	0.46	0.41		
90.0	3810.0	41.3	0.50	0.45	0.40		
100.0	3820.0	37.2	0.48	0.42	0.38		
110.0	3830.0	33.8	0.46	0.41	0.37		
120.0	3840.0	31.0	0.45	0.38	0.35		
140.0	3860.0	26.6	0.42	0.35	-16.08		
160.0	3880.0	23.3	0.40	0.33	0.31		
180.0	3900.0	20.7	0.38	0.31	0.29		
210.0	3930.0	17.7	0.35	0.30	0.28		
240.0	3960.0	15.5	0.32	0.28	0.25		
270.0	3990.0	13.8	0.29	0.26	0.24		
300.0	4020.0	12.4	0.28	0.24	0.24		
330.0	4050.0	11.3	0.25	0.22	0.21		
360.0	4080.0	10.3	0.24	0.20	0.20		
390.0	4110.0	9.5	0.23	0.18	0.18		
420.0	4140.0	8.9	0.22	0.18	0.18		
450.0	4170.0	8.3	0.21	0.16	0.16		
480.0	4200.0	7.8	0.20	0.14	0.15		
540.0	4260.0	6.9	0.19	0.13	0.14		
600.0	4320.0	6.2	0.18	0.11	0.13		
660.0	4380.0	5.6	0.16	0.09	0.11		
720.0	4440.0	5.2	0.14	0.07	0.08		
840.0	4560.0	4.4	0.12	0.05	0.08		
960.0	4680.0	3.9	0.10	0.05	-16.08		
1080.0	4800.0	3.4	0.08	0.03	0.05		

AQUIFER TEST DATA-SHEET
Recovery Data

Project Name : LONG
Test Location :
Date of Test : 16/11/90
Time Started :

Grid Ref :

Av. Discharge: 14.5 l/s

Elapsed Time since pumpstop (mins)	since pumpstrt (mins)	t/t'	Prod.Well Residual Drawdown (m)	Peiz 1 Drawdn (m)	Peiz 2 Drawdn (m)	Peiz 3 Drawdn (m)	Peiz 4 Drawdn (m)
1200.0	4920.0	3.1	0.07	0.03	0.05		
1320.0	5040.0	2.8	0.06	0.02	0.03		
1440.0	5160.0	2.6	0.06	0.02	0.03		

AQUIFER TEST DATA-SHEET
Time-Drawdown Data

Project Name : LONG 1
Test Location :
Date of Test : 6/12/90
Time Started :

Grid Ref :
Av. Discharge: 7 l/s

Elapsed Time (mins)	Production Well Water Level (m.b.ref)	Production Well Drawdn (m)	Peiz 1 Drawdn (m)	Peiz 2 Drawdn (m)	Peiz 3 Drawdn (m)	Peiz 4 Drawdn (m)
0.0	33.75	0.00	0.00	0.00	0.00	
1.0	35.36	1.61	0.01	0.01	0.01	
2.0	35.90	2.15	0.03	0.02	-0.01	
3.0	36.20	2.45	0.04	0.02	-0.02	
4.0	36.40	2.65	0.05	0.03	-0.01	
5.0	36.60	2.85	0.06	0.03	-0.01	
6.0	36.63	2.88	0.07	0.03	-0.02	
8.0	36.65	2.90	0.08	0.04	-0.02	
10.0	36.67	2.92	0.09	0.05	-0.01	
12.0	36.70	2.95	0.10	0.06	-0.01	
15.0	36.73	2.98	0.11	0.07	-0.01	
20.0	36.75	3.00	0.12	0.07	0.00	
25.0	36.81	3.06	0.13	0.07	0.00	
30.0	36.83	3.08	0.13	0.08	0.01	
35.0	36.68	2.93	0.13	0.08	0.02	
40.0	36.50	2.75	0.12	0.08	0.02	
45.0	36.10	2.35	0.11	0.07	0.01	
50.0	37.83	4.08	0.15	0.10	0.02	
55.0	38.00	4.25	0.17	0.11	0.03	
60.0	38.02	4.27	0.18	0.12	0.03	
70.0	37.97	4.22	0.19	0.12	0.03	
80.0	38.00	4.25	0.20	0.13	0.02	
90.0	38.05	4.30	0.20	0.13	0.02	
100.0	38.07	4.32	0.21	0.14	0.03	
110.0	38.15	4.40	0.21	0.14	0.03	
120.0	38.20	4.45	0.22	0.14	0.03	
140.0	38.25	4.50	0.22	0.15	0.03	
160.0	38.30	4.55	0.22	0.15	0.03	
180.0	38.40	4.65	0.23	0.15	0.03	
210.0	38.55	4.80	0.27	0.18	0.03	
240.0	39.55	5.80	0.28	0.19	0.03	
270.0	39.30	5.55	0.28	0.19	0.02	
300.0	39.25	5.50	0.28	0.19	0.00	
330.0	39.35	5.60	0.29	0.20	0.00	
360.0	39.26	5.51	0.29	0.20	-0.03	
390.0	39.30	5.55	0.29	0.21	-0.03	
420.0	39.38	5.63	0.30	0.21	0.03	
450.0	39.40	5.65	0.31	0.22	0.03	
480.0	39.41	5.66	0.31	0.22	0.03	
510.0	39.43	5.68	0.61	0.22	0.02	
540.0	39.28	5.53	0.31	0.22	0.13	
570.0	39.26	5.51	0.32	0.23	0.11	
600.0	39.20	5.45	0.32	0.23	0.13	
630.0	39.20	5.45	0.33	0.23	0.12	
660.0	39.20	5.45	0.32	0.23	0.12	

AQUIFER TEST DATA-SHEET

Recovery Data

Project Name : LONG 1

Test Location :

Date of Test : 6/12/90

Time Started :

Grid Ref :

Av. Discharge: 7 l/s

Elapsed Time since pumpstop (mins)	since pumpstrt (mins)	t/t'	Prod.Well Residual Drawdown (m)	Peiz 1 Drawdn (m)	Peiz 2 Drawdn (m)	Peiz 3 Drawdn (m)	Peiz 4 Drawdn (m)
1.0	2161.0	2160.0	3.06	0.33	0.25	0.16	
2.0	2162.0	1080.0	2.34	0.32	0.24	0.13	
3.0	2163.0	720.0	2.00	0.29	0.23	0.12	
4.0	2164.0	540.0	1.57	0.27	0.22	0.13	
5.0	2165.0	432.0	1.37	0.26	0.22	0.12	
6.0	2166.0	360.0	1.29	0.25	0.21	0.11	
8.0	2168.0	270.0	1.03	0.23	0.20	0.11	
10.0	2170.0	216.0	0.86	0.21	0.19	0.12	
12.0	2172.0	180.0	0.72	0.20	0.18	0.11	
15.0	2175.0	144.0	0.62	0.19	0.17	0.13	
20.0	2180.0	108.0	0.43	0.16	0.14	0.10	
25.0	2185.0	86.4	0.34	0.14	0.12	0.09	
30.0	2190.0	72.0	0.30	0.13	0.11	0.08	
35.0	2195.0	61.7	0.27	0.12	0.10	0.06	
40.0	2200.0	54.0	0.23	0.11	0.10	0.07	
45.0	2205.0	48.0	0.21	0.10	0.09	0.06	
50.0	2210.0	43.2	0.20	0.10	0.09	0.06	
55.0	2215.0	39.3	0.18	0.09	0.08	0.05	
60.0	2220.0	36.0	0.17	0.09	0.08	0.04	
70.0	2230.0	30.9	0.15	0.09	0.07	0.04	
80.0	2240.0	27.0	0.14	0.08	0.07	0.04	
90.0	2250.0	24.0	0.13	0.08	0.06	0.04	
100.0	2260.0	21.6	0.12	0.07	0.06	0.04	
110.0	2270.0	19.6	0.11	0.07	0.05	0.04	
120.0	2280.0	18.0	0.10	0.06	0.05	0.04	
140.0	2300.0	15.4	0.09	0.05	0.04	0.04	
160.0	2320.0	13.5	0.08	0.05	0.04	0.04	
180.0	2340.0	12.0	0.07	0.05	0.03	0.04	
210.0	2370.0	10.3	0.07	0.04	0.03	0.04	
240.0	2400.0	9.0	0.06	0.04	0.03	0.04	
270.0	2430.0	8.0	0.06	0.04	0.03	0.04	
300.0	2460.0	7.2	0.06	0.03	0.02	0.04	
330.0	2490.0	6.5	0.05	0.03	0.02	0.04	
360.0	2520.0	6.0	0.05	0.03	0.02	0.04	
390.0	2550.0	5.5	0.05	0.02	0.02	0.04	
420.0	2580.0	5.1	0.05	0.02	0.02	0.04	
450.0	2610.0	4.8	0.05	0.02	0.02	0.04	
480.0	2640.0	4.5	0.05	0.02	0.02	0.04	
540.0	2700.0	4.0	0.05	0.02	0.02	0.04	
600.0	2760.0	3.6	0.05	0.01	0.01	0.04	
660.0	2820.0	3.3	0.05	0.01	0.01	0.04	
720.0	2880.0	3.0	0.05	0.01	0.01	0.04	
840.0	3000.0	2.6	0.04	0.00	0.00	0.04	
960.0	3120.0	2.3	0.03	0.00	0.00	0.04	
1080.0	3240.0	2.0	0.03	0.00	0.00	0.03	

AQUIFER TEST DATA-SHEET
Time-Drawdown Data

Project Name : LONG 1
Test Location : Grid Ref :
Date of Test : 6/12/90
Time Started : Av. Discharge: 7 l/s

Elapsed Time (mins)	Production Well Water Level (m.b.ref)	Production Well Drawdn (m)	Peiz 1 Drawdn (m)	Peiz 2 Drawdn (m)	Peiz 3 Drawdn (m)	Peiz 4 Drawdn (m)
690.0	39.19	5.44	0.32	0.24	0.12	
720.0	39.20	5.45	0.32	0.24	0.13	
780.0	39.27	5.52	0.32	0.24	0.13	
840.0	39.28	5.53	0.32	0.24	0.13	
900.0	39.32	5.57	0.33	0.24	0.15	
960.0	39.35	5.60	0.32	0.25	0.15	
1020.0	39.52	5.77	0.33	0.25	0.15	
1080.0	39.51	5.76	0.33	0.25	0.15	
1140.0	39.57	5.82	0.34	0.25	0.15	
1200.0	39.36	5.61	0.34	0.25	0.16	
1260.0	39.31	5.56	0.34	0.25	0.16	
1320.0	39.21	5.46	0.33	0.24	0.14	
1380.0	39.14	5.39	0.33	0.24	0.14	
1440.0	39.08	5.33	0.34	0.25	0.14	
1560.0	39.08	5.33	0.32	0.24	0.13	
1680.0	39.15	5.40	0.32	0.24	0.13	
1800.0	39.16	5.41	0.33	0.24	0.14	
1920.0	39.26	5.51	0.34	0.25	0.14	
2040.0	39.18	5.43	0.33	0.26	0.10	
2160.0	39.20	5.45	0.33	0.26	0.17	

AQUIFER TEST DATA-SHEET

Time-Drawdown Data

Project Name : LONG 2
Test Location :
Date of Test : 25/11/90
Time Started :

Grid Ref :
Av. Discharge: 21 l/s

Elapsed Time (mins)	Production Well: Water Level (m.b.ref)	Production Well: Drawdn (m)	Peiz 1 Drawdn (m)	Peiz 2 Drawdn (m)	Peiz 3 Drawdn (m)	Peiz 4 Drawdn (m)
0.0	33.78	0.00	0.00	0.00	0.00	
1.0	35.64	1.86	0.17	0.75	0.06	
2.0	35.94	2.16	0.22	0.76		
3.0	36.14	2.36	0.22	0.98	-0.01	
4.0	36.24	2.46	0.29	1.07	0.00	
5.0	36.34	2.56	0.34	1.13	0.01	
6.0	36.35	2.57	0.37	1.21	0.02	
8.0	36.40	2.62	0.43	1.32	0.03	
10.0	36.50	2.72	0.50	1.36	0.03	
12.0	36.59	2.81	0.52	1.42	0.00	
15.0	36.61	2.83	0.55	1.47	0.02	
20.0	36.70	2.92	0.62	1.54	0.03	
25.0	36.75	2.97	0.66	1.58	0.04	
30.0	36.80	3.02	0.68	1.62	0.05	
35.0	36.82	3.04	0.70	1.64	0.06	
40.0	36.84	3.06	0.72	1.67	0.06	
45.0	36.88	3.10	0.73	1.70	-0.01	
50.0	36.90	3.12	0.75	1.73	-0.04	
55.0	36.91	3.13	0.75	1.74	-0.04	
60.0	36.92	3.14	0.76	1.74	-0.03	
70.0	36.95	3.17	0.77	1.77	-0.03	
80.0	36.97	3.19	0.78	1.80	0.02	
90.0	37.00	3.22	0.79	1.82	0.03	
100.0	37.01	3.23	0.80	1.83	0.03	
110.0	37.02	3.24	0.82	1.85	0.04	
120.0	37.03	3.25	0.80	1.87	0.05	
140.0	37.06	3.28	0.81	1.89	0.06	
160.0	37.07	3.29	0.82	1.91	0.06	
180.0	37.08	3.30	0.83	1.93	0.06	
210.0	37.10	3.32	0.84	1.95	0.06	
240.0	37.12	3.34	0.85	1.98	0.06	
270.0	37.17	3.39	0.86	2.00	0.07	
300.0	37.20	3.42	0.87	2.03	0.07	
330.0	37.25	3.47	0.88	2.06	0.07	
360.0	37.28	3.50	0.90	2.09	0.06	
390.0	37.30	3.52	0.91	2.10	0.07	
420.0	37.34	3.56	0.92	2.13	0.07	
450.0	37.40	3.62	0.94	2.16	0.07	
480.0	37.45	3.67	0.95	2.18	0.08	
510.0	37.46	3.68	0.96	2.19	0.08	
540.0	37.46	3.68	0.97	2.19	0.09	
570.0	37.45	3.67	0.98	2.19	0.08	
600.0	37.45	3.67	0.96	2.20	0.07	
630.0	37.45	3.67	0.97	2.20	0.06	
660.0	37.46	3.68	0.98	2.21	0.06	

AQUIFER TEST DATA-SHEET
Time-Drawdown Data

Project Name : LONG 2
Test Location :
Grid Ref :
Date of Test : 25/11/90
Time Started :
Av. Discharge: 21 l/s

Elapsed Time (mins)	Production Well Water Level (m.b.ref)	Production Well Drawdn (m)	Peiz 1 Drawdn (m)	Peiz 2 Drawdn (m)	Peiz 3 Drawdn (m)	Peiz 4 Drawdn (m)
690.0	37.46	3.68	0.98	2.22	0.08	
720.0	37.46	3.68	0.99	2.23	0.09	
780.0	37.47	3.69	0.99	2.24	0.09	
840.0	37.47	3.69	0.99	2.26	0.09	
900.0	37.50	3.72	1.00	2.28	0.09	
960.0	37.57	3.79	1.00	2.30	0.09	
1020.0	37.57	3.79	1.01	2.32	0.09	
1080.0	37.58	3.80	1.01	2.33	0.10	
1140.0	37.58	3.80	1.02	2.33	0.10	
1200.0	37.58	3.80	1.02	2.35	0.09	
1260.0	37.60	3.82	1.03	2.35	0.09	
1320.0	37.60	3.82	1.03	2.35	0.10	
1380.0	37.61	3.83	1.04	2.36	0.11	
1440.0	37.62	3.84	1.05	2.37	0.11	
1560.0	37.63	3.85	1.06	2.37	0.09	
1680.0	37.65	3.87	1.03	2.36	0.10	
1800.0	37.64	3.86	1.04	2.36	0.10	
1920.0	37.64	3.86	1.06	2.38	0.11	
2040.0	37.66	3.88	1.07	2.38	0.12	
2160.0	37.67	3.89	1.07	2.38	0.13	
2280.0	37.65	3.87	1.08	2.38	0.13	
2400.0	37.66	3.88	1.07	2.38	0.14	
2640.0	37.67	3.89	1.07	2.38	0.14	
2880.0	37.67	3.89	1.08	2.40	0.15	
3120.0	37.68	3.90	1.08	2.40	0.15	
3360.0	37.64	3.86	1.08	2.36	0.15	
3600.0	37.52	3.74	1.06	2.32	0.15	
3840.0	37.52	3.74	1.07	2.31	0.15	
4080.0	37.54	3.76	1.07	2.32	0.15	
4320.0	37.57	3.79	1.09	2.34	0.17	

AQUIFER TEST DATA-SHEET
Recovery Data

Project Name : LONG 2
Test Location : Grid Ref :
Date of Test : 25/11/90
Time Started : Av. Discharge: 21 l/s

Elapsed Time since pumpstop (mins)	Time since pumpstrt (mins)	t/t'	Prod.Well Residual Drawdown (m)	Peiz 1 Drawdn (m)	Peiz 2 Drawdn (m)	Peiz 3 Drawdn (m)	Peiz 4 Drawdn (m)
1.0	4321.0	4320.0	1.78	1.03	1.69	0.14	
2.0	4322.0	2160.0	1.61	0.94	1.47	0.14	
3.0	4323.0	1440.0	1.50	0.88	1.32	0.14	
4.0	4324.0	1080.0	1.40	0.82	1.26	0.15	
5.0	4325.0	864.0	1.38	0.78	1.22	0.15	
6.0	4326.0	720.0	1.30	0.73	1.18	0.13	
8.0	4328.0	540.0	1.24	0.70	1.13	0.13	
10.0	4330.0	432.0	1.17	0.65	1.05	0.14	
12.0	4332.0	360.0	1.11	0.60	1.01	0.14	
15.0	4335.0	288.0	1.05	0.53	0.96	0.12	
20.0	4340.0	216.0	0.97	0.50	0.87	0.12	
25.0	4345.0	172.8	0.92	0.47	0.83	0.10	
30.0	4350.0	144.0	0.87	0.43	0.77	0.09	
35.0	4355.0	123.4	0.84	0.41	0.73	0.09	
40.0	4360.0	108.0	0.80	0.39	0.71	0.09	
45.0	4365.0	96.0	0.76	0.38	0.68	0.08	
50.0	4370.0	86.4	0.75	0.36	0.66	0.07	
55.0	4375.0	78.5	0.72	0.35	0.64	0.07	
60.0	4380.0	72.0	0.71	0.34	0.62	0.06	
70.0	4390.0	61.7	0.70	0.33	0.59	0.05	
80.0	4400.0	54.0	0.63	0.31	0.55	0.05	
90.0	4410.0	48.0	0.60	0.29	0.53	0.04	
100.0	4420.0	43.2	0.58	0.28	0.51	0.04	
110.0	4430.0	39.3	0.56	0.27	0.48	0.04	
120.0	4440.0	36.0	0.54	0.26	0.44	0.04	
140.0	4460.0	30.9	0.51	0.25	0.40	0.03	
160.0	4480.0	27.0	0.43	0.23	0.38	0.03	
180.0	4500.0	24.0	0.43	0.22	0.36	0.04	
210.0	4530.0	20.6	0.42	0.21	0.35	0.04	
240.0	4560.0	18.0	0.34	0.19	0.32	0.03	
270.0	4590.0	16.0	0.34	0.18	0.29	0.01	
300.0	4620.0	14.4	0.32	0.17	0.26	0.01	
330.0	4650.0	13.1	0.31	0.16	0.26	0.02	
360.0	4680.0	12.0	0.29	0.16	0.24	0.02	
390.0	4710.0	11.1	0.28	0.15	0.23	0.02	
420.0	4740.0	10.3	0.27	0.15	0.21	0.02	
450.0	4770.0	9.6	0.25	0.14	0.21	0.01	
480.0	4800.0	9.0	0.24	0.14	0.20	0.04	
540.0	4860.0	8.0	0.23	0.13	0.18	0.04	
600.0	4920.0	7.2	0.22	0.14	0.17	0.04	
660.0	4980.0	6.5	0.20	0.13	0.16	0.04	
720.0	5040.0	6.0	0.19	0.13	0.14	0.04	
840.0	5160.0	5.1	0.18	0.13	0.12	0.04	
960.0	5280.0	4.5	0.16	0.13	0.10	0.04	
1080.0	5400.0	4.0	0.13	0.13	0.08	0.04	

AQUIFER TEST DATA-SHEET
Recovery Data

Project Name : LONG 1
Test Location :
Date of Test : 6/12/90
Time Started :

Grid Ref :
Av. Discharge: 7 l/s

Elapsed Time since pumpstop (mins)	since pumpstrt (mins)	t/t'	Prod.Well Residual Drawdown (m)	Peiz 1 Drawdn (m)	Peiz 2 Drawdn (m)	Peiz 3 Drawdn (m)	Peiz 4 Drawdn (m)
1200.0	3360.0	1.8	0.03	0.00	0.00	0.03	
1320.0	3480.0	1.6	0.03	0.00	0.00	0.03	
1440.0	3600.0	1.5	0.03	0.00	0.00	0.03	