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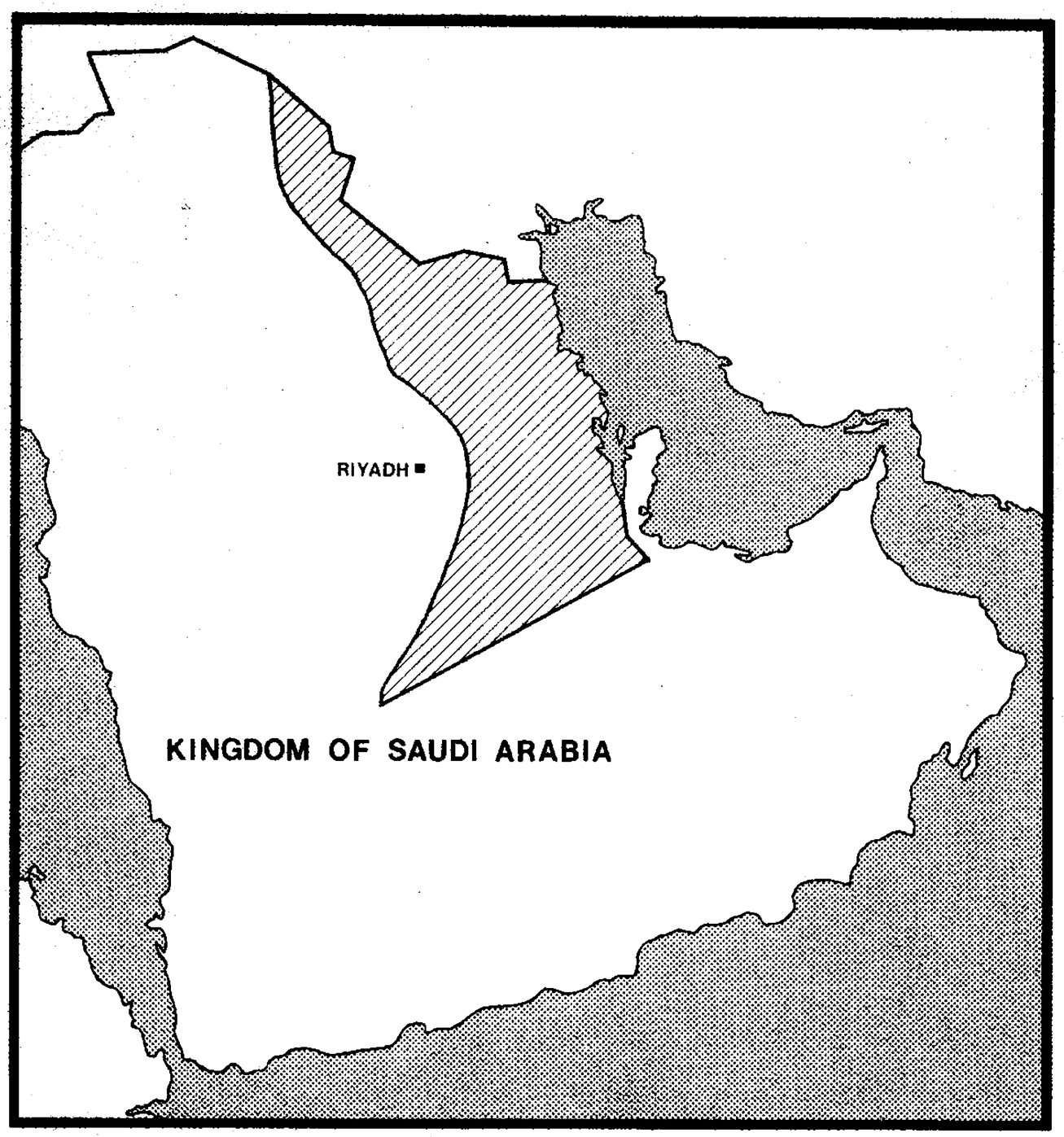
Kingdom of Saudi Arabia
Ministry of Agriculture and Water

Umm Er Radhuma Study

Bahrain Assignment

Soils and Land Classification Report

January 1980



Groundwater Development Consultants (International) Limited

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MAP ALBUM ACCOMPANYING THIS REPORT

Soils Classification 1:10 000 UER/B Nos. 6-11
Land Classification 1:10 000 UER/B Nos. 12-17
Soils Classification 1:50 000 UER/B Nos. 18 and 19

Summary

Detailed soil and land classification surveys were carried out in the Salmabad, Buhayr and Hawrat Inqa areas, covering a total of some 4000 hectares. Soils were classified according to Soil Taxonomy and mapped at series level. The UBSR system was adapted to classify the land according to capability for irrigated land use. Maps at 1:10 000 scale show soils and land capability.

The Buhayr area comprises a small, level depression, infilled with gypsic alluvium. The Salmabad area forms an extensive natural basin, with generally level relief, occupying the northern alluvial plains; the soil parent materials consist of aeolian sands and marine silt loams, overlain by varied amounts of gypsic sand. Sandy alluvium predominates in Hawrat Inqa, which lies btween the limestone backslopes and the coastal sabkhas. Thus sands, silt loams and gypsum form the principal parent materials of the soils studied.

Much of the Salmabad area has been cultivated in the past but has now been abandoned; less than 75 hectares remain in cultivation today. No evidence of past cultivation was recorded in the other areas. The natural vegetation comprises a sparse cover of xerophytes and halophytes; a close relationship has been shown to exist between soil and vegetation types.

The soils are dominated by Typic Gypsiorthids and Cambic Gypsiorthids, which occupy 36 and 28 percent of the area, respectively. The remaining areas comprise Typic and Aquic Paleorthids and Typic Torripsamments on the plains, with Lithic Torriorthents occurring on rocky slopes. Gypsic and Typic Salorthids and Typic Psammaquents occur in depressions and coastal Sabkhas. Within these subgroups, 19 soil series have been defined, some of which have been sub-divided into phases.

The majority of soils are saline, gypsiferous and highly calcareous, resulting in carbonatic, gypsic or mixed mineralogies. The total of gypsum and calcium carbonate in the upper metre often exceeds 50 percent and sometimes rises to 80 percent. Only those soils formed in aeolian quartz sand can be considered true mineral soils in the conventional sense. The high salinities and gypsum contents in the upper horizons result largely from precipitation of soluble salts rising from the saline watertables which occur at shallow depth beneath most of the area. Few soils have salinities (ECe) of less than 10.0 and some exceed 100.0 mmhos cm^{-1}.

Soil profiles are mostly deep, except where limited by calcium carbonate cemented (petrocalcic) horizons or layers of rock (Lithic contact) at shallow depth. Coarse-loamy particle-sizes predominate in the highly gypsic soils of the Salmabad and Buhayr areas. Fine-loamy (silty) particle-sizes are typical of the Cambic Gypsiorthids which occur extensively in the Salmabad area. Sandy soils predominate in Hawrat Inqa and form a small but important component of the soils in the Salmabad area. All soils have a hyperthermic temperature regime.

Infiltration is rapid on all soils, with basic intake rates usually exceeding 100 mm h^{-1}. These rapid rates assist the leaching of salts but limit the methods of irrigation practicable. Hydraulic conductivity in the substratum is similarly rapid and should facilitate drainage and reclamation. Measurements of moisture retention show that fine-loamy soils hold large quantities of water but that moisture depletion is more rapid in the sands. Thus, if crop moisture stress is to be minimised, irrigations would have to be more frequent on sands than silt loams, the more so in view of the additive osmotic effects resulting from the necessary use of saline irrigation water.

In classifying land for irrigation, account has been taken of the extreme physical constraints which apply to agriculture in Bahrain. Principal among these constraints are the scarcity and poor quality of both agricultural land and irrigation water. These severely limit the range and yield

potential of crops that can be grown and make for costly land development. Nevertheless, crops are currently grown on land which would normally be rated unsuitable, using water of a quality not normally to be recommended. In view of the generally low yields obtained it may not be economic in the usually accepted sense but it is being done and cannot be ignored. The USBR land classes have therefore been adapted to embrace the widest variety of land which it is considered could be successfully developed under irrigation. It has been necessary to place some land in Class 5, which implies that it can be considered useable only following reclamation and agronomic measures whose feasibility has yet to be confirmed, whereas Class 6 land has been kept to a minimum.

In the specifications for the six land classes, emphasis has been placed on factors favouring efficient water use. This implies use of piped or channel delivery and trickle or sprinkle application systems. As the table below shows, some 40 per cent of the land is classed as being arable with a further 17 per cent qualifying for limited agricultural use.

Table S.1 Land Classification

Land Classes			Area (ha)	%
Class 1	Arable:	highly suitable for irrigation	-	-
Class 2	Arable:	moderately suitable for irrigation	684	16.6
Class 3	Arable:	marginally suitable for irrigation	938	22.8
Class 4F	Limited Use:	suited to salt-tolerant tree crops and some perennial fodder crops	716	17.4
Class 5	Non-arable:	provisionally designated suitable for amenity, shelterbelt or timber tree planting	960	23.3
Class 6	Non-arable:	not suitable for irrigation.	815	19.9
TOTAL			4 113	100.0

The principal soil factors resulting in downgrading of lands include gypsum contents, salinity, particle-size and profile depth over petrocalcic or lithic horizons. Over large areas of the Salmabad loam plains abandoned irrigation channels form a major micro-relief constraint. Internal drainage deficiencies, chiefly due to high watertables, affect large areas and the risk of subsurface sea water intrusion results in downgrading of low-lying coastal areas.

Overall agricultural development potential is indicated on generalised land suitability maps at 1: 50 000 scale, compiled from the detailed mapping. Classes 2 and 3 are combined as representing areas of primary development potential. It is recommended that the proposed Agricultural Development Centre be located on these lands in the Salmabad area.

1

Introduction

1.1 OBJECTIVES

Soil and land classification surveys, covering some 4 100 hectares, were carried out in the Salmabad, Buhayr and Hawrat 'Inqa areas of northern Bahrain (Figure 1.1). These surveys were conducted to detailed (Level 3) standard, involving a minimum of 25 observation sites per 100 hectares and mapping at a scale of 1:10 000. Mapping was based on the Soil Taxonomy system (USDA,1975).

The purpose of the survey was to evaluate the potential of the land for irrigation and thus provide the basic information essential for subsequent agricultural planning, as required under the terms of reference. The two principal agricultural purposes for which the soils and land classification were required are:-

(a) Agriculture and irrigation development planning in the Level 3 soil survey areas.

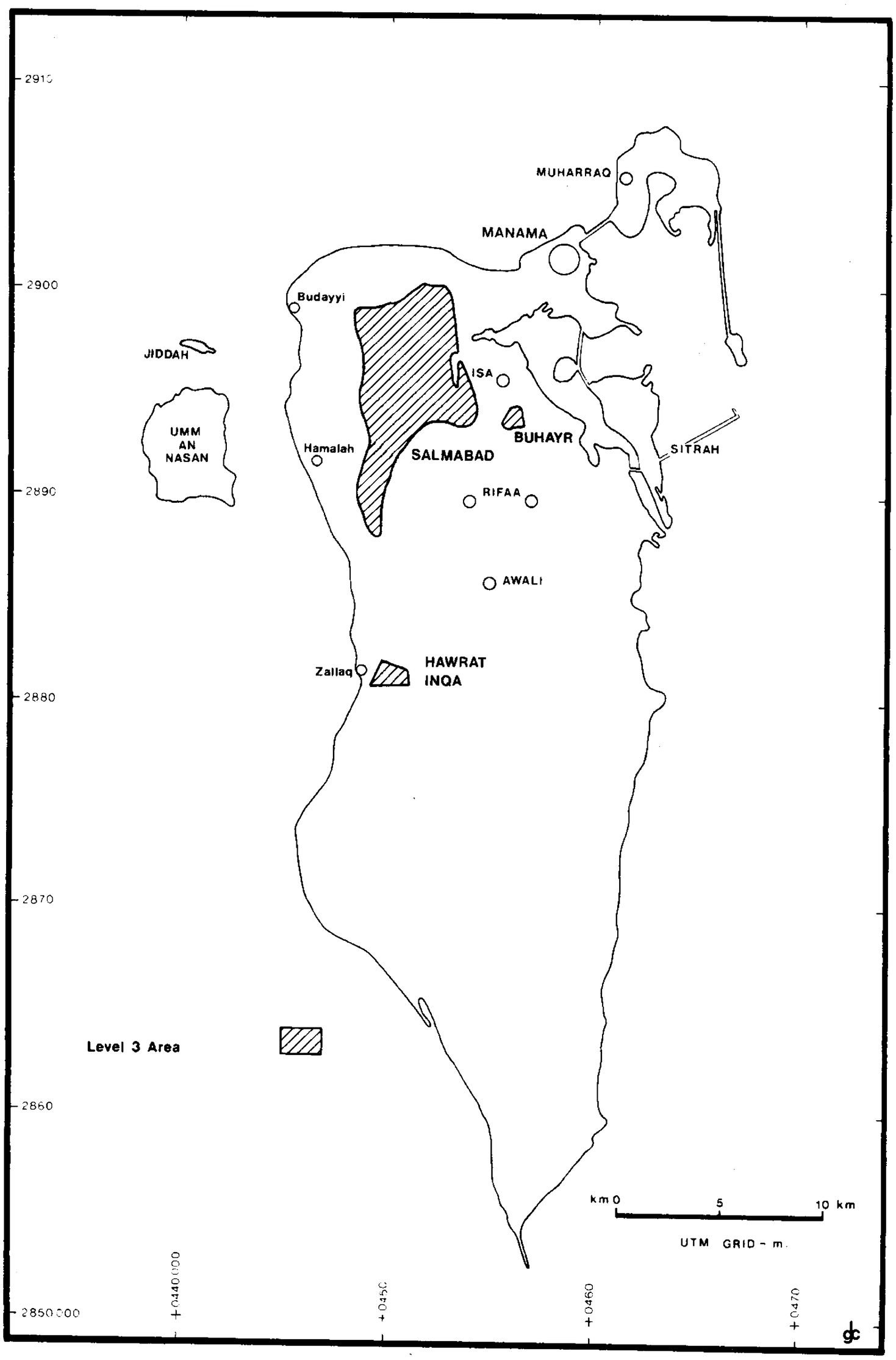
(b) Selection of a site and proposals for the establishment of an Agricultural Development Centre (ADC).

The complete terms of reference for the soil survey and land classification study are given in Appendix J.

1.2 SELECTION AND LOCATION OF LEVEL 3 AREAS

The original intention was for the Level 3 surveys to be carried out on uncultivated but potentially irrigable government-owned land (GDC, 1978a). Land of irrigable quality is scarce in Bahrain, accounting for some 10 to 15 per cent of the island (Ministry of Works, Power and Water, 1976). Much of the

Figure 1.1 Areas for Level 3 Soil Survey



available potentially irrigable land is in private ownership and comprises large areas which were formerly under irrigation but have since been abandoned due to salinization. Government owned land tends to be of lower quality and occur in isolated units. Indeed, most of the available Government land which was provisionally proposed for further irrigation studies (Hunting Technical Services, 1978), would not have justified the expense of detailed soil survey.

Following discussions with members of the Ministry of Commerce and Agriculture, agreement was reached to include both Government and private land within the Level 3 surveys. As a result it was possible to substitute a large tract of land in the Sar - Ali - Salmabad area for the numerous isolated minor areas previously proposed for survey. Locations of the three finally selected areas, namely Salmabad (3740 hectares), Buhayr (103 hectares) and Hawrat 'Inqa (270 hectares), are shown in Figure 1.1. The boundary of the Ercon survey was adopted as the extreme northern and western limits for the present survey: elsewhere natural physiographic boundaries, such as escarpments, or major roads were used.

Substitution of the Salmabad area for numerous isolated areas had several advantages:-

(a) It contains a large area of potentially irrigable land.

(b) It lies close to the site of the proposed Sewage Treatment works at Tubli and is thus well placed to utilise treated sewage effluent.

(c) By adopting natural boundaries the Salmabad area forms a sufficiently large block of land within which to prepare a workable agricultural development plan.

Although the terms of reference (Appendix J) called for Level 3 surveys covering an area of 3800 hectares, the total actually surveyed amounted to 4113 hectares. The extra 313 hectares were included to compensate for the inevitable inclusion of village sites, disturbed ground and areas of rock outcrop, which have no agricultural potential.

1.3 REINTERPRETATION OF SOIL MAP OF BAHRAIN

In addition to the detailed soil and land classification studies of the Level 3 areas, the terms of reference required that a generalised pedological map of Bahrain be produced at a scale of 1:50 000. For this purpose the mapping units of the existing reconnaisance soils map (Ministry of Works, Power and Water,1976) were re-interpreted according to the Soil Taxonomy system (USDA,1975), thus conforming with the Level 3 mapping approach.

2
Survey Methods

2.1 FIELD PROCEDURES

The field surveys were conducted between September 1978 and May 1979 in three stages. The initial stage involved an air-photo interpretation (API) and brief reconnaissance soil survey of the Level 3 areas. The principal purpose of this reconnaissance was to define the survey limits. During the second stage, routine surveys were carried out. The final stage involved a series of specific field tests, often being made concurrently with the routine survey.

2.1.1 Routine survey

The 1977 1 : 10 000 black and white aerial photographs were used throughout the survey for navigation, interpretation of soil boundaries and compilation of technical detail. For the Salmabad and Buhayr areas colour contact prints were also available and were used in preference to the black and white photographs for the API studies.

Soils were investigated using profile pits, hand-operated Jarrett augers (120 mm) and a 'Giddings' mechanical auger mounted on a pick-up truck. Soil profile pits were excavated to a depth of 2.0 m or to rock if present within this depth. Shallow watertables frequently restricted pit excavation below 1.0 m but use of the Giddings screw auger enabled the materials below the watertable to be described.

A free survey technique was adopted, sites being located on the basis of photo-interpretation with a minimum of 25 sites in each 100 hectare block. Where the terrain precluded use of the vehicle, as in abandoned date groves, traverses were made on foot and soils were examined with a hand auger. An overall observation density of some 28 sites per 100 hectares was achieved (Table 2.1): this includes an average of about two profile pits for each 100 hectares.

Soils and sites were described according to the standard procedures established for the Umm Er Radhuma Study (GDC, 1978).

Table 2.1 Observation Site Density

Survey Area	Net Area (ha)	Observation Sites No.	No/100ha	Ha/site
Salmabad	3627	1002	27.4	3.6
Buhayr	103	26	25.2	4.0
Hawrat 'Inqa	270	69	25.5	3.9
Total	4000	1097	27.4	3.6

Note: Net area excludes 113 ha of villages.

2.1.2 Field Tests

Infiltration and hyraulic conductivity tests were carried out to evaluate soil physical properties.

(a) Infiltration Tests

These were carried out at 20 sites using the double-ring infiltrometer method. Tests were located to cover a range of soil and land use types.

(b) Hydraulic Conductivity Tests

Hydraulic conductivity in the substratum was measured using the single auger hole pump-out method. A total of 58 tests were performed, located along a series of traverses across the area. Wherever possible the holes were extended to 5.0m to obtain data on the nature of the substratum and provide information for drainage design.

(c) Available Water Capacity Samples

Undisturbed core samples were collected from selected sites for laboratory moisture retention and bulk density testing.

(d) Salinity Testing of Groundwater

The electrical conductivity of shallow groundwater and some irrigation water was tested in the field using a portable EC meter. Samples were also collected for laboratory analysis.

Apart from the above field tests, which were stipulated in the terms of reference, several additional tests were carried out to assess the effects of irrigation on leaching of salts.

2.2 SOIL SAMPLING AND LABORATORY ANALYSIS

The terms of reference (Appendix J) stipulate that at least three sites representative of each major soil unit shall be sampled and subjected to detailed analysis. Had these requirements been observed strictly, only some 60 sites would have been analysed from within the entire Level 3 areas. Clearly, this would have been totally inadequate for assessing the agricultural potential of soils which are extremely saline and highly gypsic. In order to carry out effectively the Level 3 surveys a far larger number of samples was collected and analysed than required under the contract. On average approximately 30 per cent of all sites were sampled and subjected to laboratory analysis.

Bulk samples were collected from major horizons of profile pits and selected auger hole sites, giving an overall average of eight sites sampled per 100 hectares. Auger sites were sampled down to 1.0 but sampling in pits usually extended to a least 1.5m. All samples were despatched to the Consultant's Riyadh laboratory for routine analysis, as listed in Table 2.2, as well as for cation exchange capacity, exchangeable sodium percentage and particle-size distribution on samples from representative pits.

Table 2.2 Routine Analysis Sampling

Sites Sampled	No. Sites	No. Samples	Type of Analysis: Satu-ration %	pH	$CaCO_3$ %	Gypsum %	EC
Routine Augers	275	664	664	656	174	403	664
Profile Pits	62	208	208	208	193	193	208
Total	337	872	872	864	367	596	872

Note: Results of analyses are given in Appendix B and C.

Samples from selected profile pits, representative of major soil units, were despatched to the Hunting Technical Services laboratory in the United Kingdom for special analyses, which included soluble ions in saturation extract, particle-size distribution of insoluble constituents and topsoil nutrients. Moisture retention characteristics and bulk density were determined on core samples and soluble ion analyses were made on samples of shallow groundwater.

In addition, several samples were sent to the United Kingdom for specialised analyses, such as carbon dating of organic layers, optical microscopic examination of cemented horizons and clay mineral analysis of arable soils.

2.3 MAP COMPILATION

2.3.1 Level 3 maps

Maps have been produced at a scale of 1 : 10 000 using the existing orthophoto map series for topographical detail. Two separate series of maps have been compiled for this report.

(a) Soils

(b) Land Classification

These maps are attached in a separate volume to this report.

Compilation of the maps was aided by the existence of recent aerial photography (1977) at the same scale as the orthophoto maps. Technical detail could therefore be transferred directly from the annotated aerial photographs to the map sheets.

2.3.2 Bahrain Soil Map

Preparation of the 'generalised pedologic map of Bahrain', as required under the contract, was achieved by re-interpretation of the existing 1:50 000 soils map, aided by the findings of the Level 3 surveys and results of brief reconnaisance tours (Appendix I). A few sites in the south of the island were examined and sampled to confirm the soil salinity and gypsum status. Soil units were compiled onto the two 1:50 000 topographic sheets and are included within the report album.

2.4 REPORT

The results of the study are presented in this report. Background information on physiography and land use in the Level 3 areas is contained in chapter 3. This is followed by a discussion of the method of soil classification and, in chapter 5, by brief descriptions of the soil mapping units. In the sixth chapter the characteristics of the soils are discussed in relation to irrigated land use, thus providing a basis for the land classification mapping, which is described in the concluding chapter. Appendices contain details of methods and complete results for all analyses and field tests, including detailed descriptions of soil profiles.

3

Environment

3.1 CLIMATE

Bahrain has an arid climate which is divisible into a hot humid summer season from May to October and a cool winter period from November to April. Table 3.1 shows that rainfall is confined to the cool season; mean annual precipitation is only 73mm and this is both erratic and variable. The modifying maritime influences can be seen in the high humidities, especially during summer and the relatively small diurnal temperature fluctuations. The prevailing winds are from the NNW or WNW for most of the year and average 5.0 m S^{-1}.

Table 3.1 Mean Monthly Climatic Data

Parameter	J	F	M	A	M	J	J	A	S	O	N	D
Rainfall (Monthly)(mm)	19	14	11	10	2	-	-	-	-	Tr	3	15
Temperature (daily °C)max	20	21	25	29	33	36	37	38	36	33	27	22
min	15	15	18	22	26	29	31	31	29	26	22	17
Relative Humidity (daily %) max	89	88	85	82	79	79	80	84	86	89	85	87
min	59	56	50	44	39	40	42	45	45	46	52	57
Potential Evaporation (daily; mm)	2.2	2.8	4.2	5.5	7.0	8.2	8.0	7.9	6.7	5.0	3.3	2.3

Source: Rainfall 1946-1978; Relative Humidity 1964-1978; Temperature 1946-1975. Records for Muharraq - International Aeradio Ltd; Evaporation calculated for northern Bahrain as reference crop potential evapotranspiration.

In terms of soil development and classification the main features of the climate are the high temperatures and very low rainfall. According to the Soil Taxonomy classification (USDA, 1975) the soil moisture regime qualifies as aridic (torric), in that the upper soil profile is dry more than half the time that the soil temperature at a depth of 50cm exceeds 5°C and it is never moist for as long as 90 consecutive days when the soil temperature at 50cm exceeds 8°C. In the Bahrain Level 3 areas this regime is modified by shallow watertables from which moisture migrates upwards, under the influence of high evaporation rates, creating moist and saline conditions in the upper profile. Rainfall is inadequate for leaching and has a negligible effect on soil development, except locally where run-off from hill slopes causes erosion and transport of minor quantities of material.

The soil temperature regime is hyperthermic because, as shown in Table 3.2, the mean annual soil temperature is 22°C or higher, and the difference between mean summer and mean winter soil temperature at 50cm depth exceeds 5°C.

Table 3.2 Soil Temperatures (Muharraq)

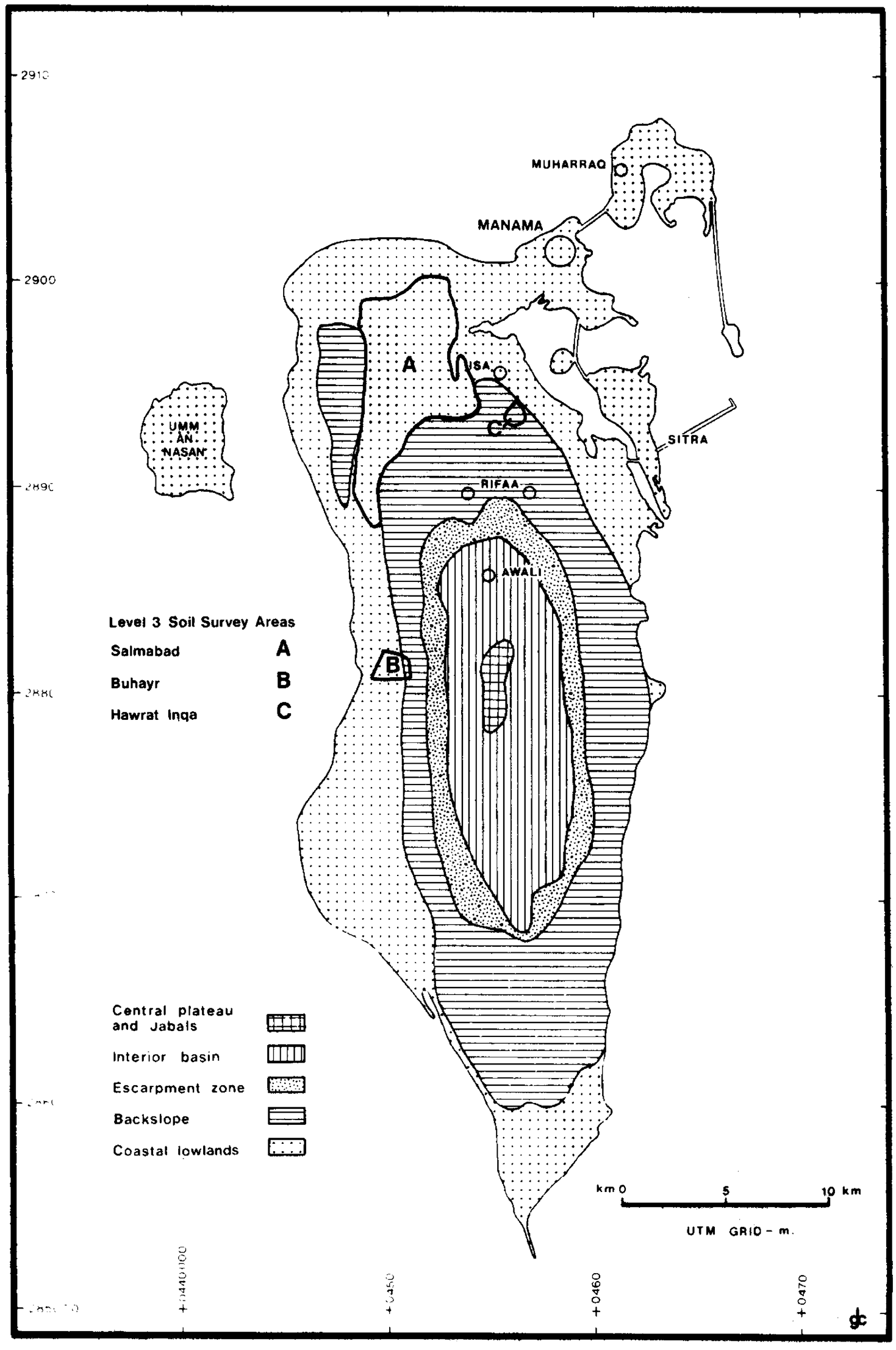
Soil Depth	Mean Monthly 1 230h Temperature (°C)	
(cm)	July 1978	December 1978
0	44.5	28.0
5	39.1	25.5
10	37.0	24.0
30	33.2	22.7
50	31.5	22.0

Note: Values for 50cm extrapolated.

3.2 GEOMORPHOLOGY AND PHYSIOGRAPHY

The geomorphology of Bahrain has been described in detail by the Ministry of Works, Power and Water (1976). The main physiographic regions are shown in Figure 3.1. Relief is dominated by Eocene carbonate rocks which form an eroded anticlinal fold with a prominent concentric relief pattern of a central plateau and interior basin. The highest elevations on

Figure 3.1 Major Physiographic Regions



the island (120m) occur on the residual hills on the central plateau. Around the central core occurs an extensive, gently sloping backslope of carbonate rocks. Around the coasts the backslope is overlain by recent unconsolidated alluvium. It is in these Coastal Lowlands that the Level 3 soil survey areas are located (Figure 3.1).

3.2.1 Salmabad Area

This area lies in the northern Coastal Lowlands (Figure 3.1), forming a shallow basin which slopes from the fringing backslopes eastwards to the Tubli estuary. Relief is subdued. Elevations range from a maximum of around 10m in the west to about sea level near Tubli; most of the land lies at between 3.0 and 5.0m above sea level.

(a) Soil Parent Materials

Superficial deposits of aeolian sand, marine silt loam and gypsiferous sands overlie Alat Limestone of the backslope and remnants of neogene strata. The alluvial sequence was investigated to a depth of 5.0m along a series of traverses (Figure 3.2). The results, shown in Figures 3.3, 3.4 and 3.5, clearly illustrate the widespread occurrence of deep layers of fine quartz sands beneath the area. Locally the sand is interrupted by rocks of Alat Limestone or neogene aeolianite. Overlying the sands are layers of silt loam marine alluvium, rarely more than 2.0m thick, the lower facies of the loam is extremely calcareous. Deposits of coarse grained crystalline gypsum occupy former depressions and thinly overlie much of the m arine silt loams. The gypsiferous sands have been redistributed by wind erosion and augmented by precipitation of gypsum from rising capillary water. Recent deposits of aeolian quartz sand occur in the west and north, overlying earlier alluvium.

(b) Physiography

The area is divisible into nine physiographic zones as illustrated in Figure 3.6.

Figure 3.2 Salmabad : Location of Cross-Profiles

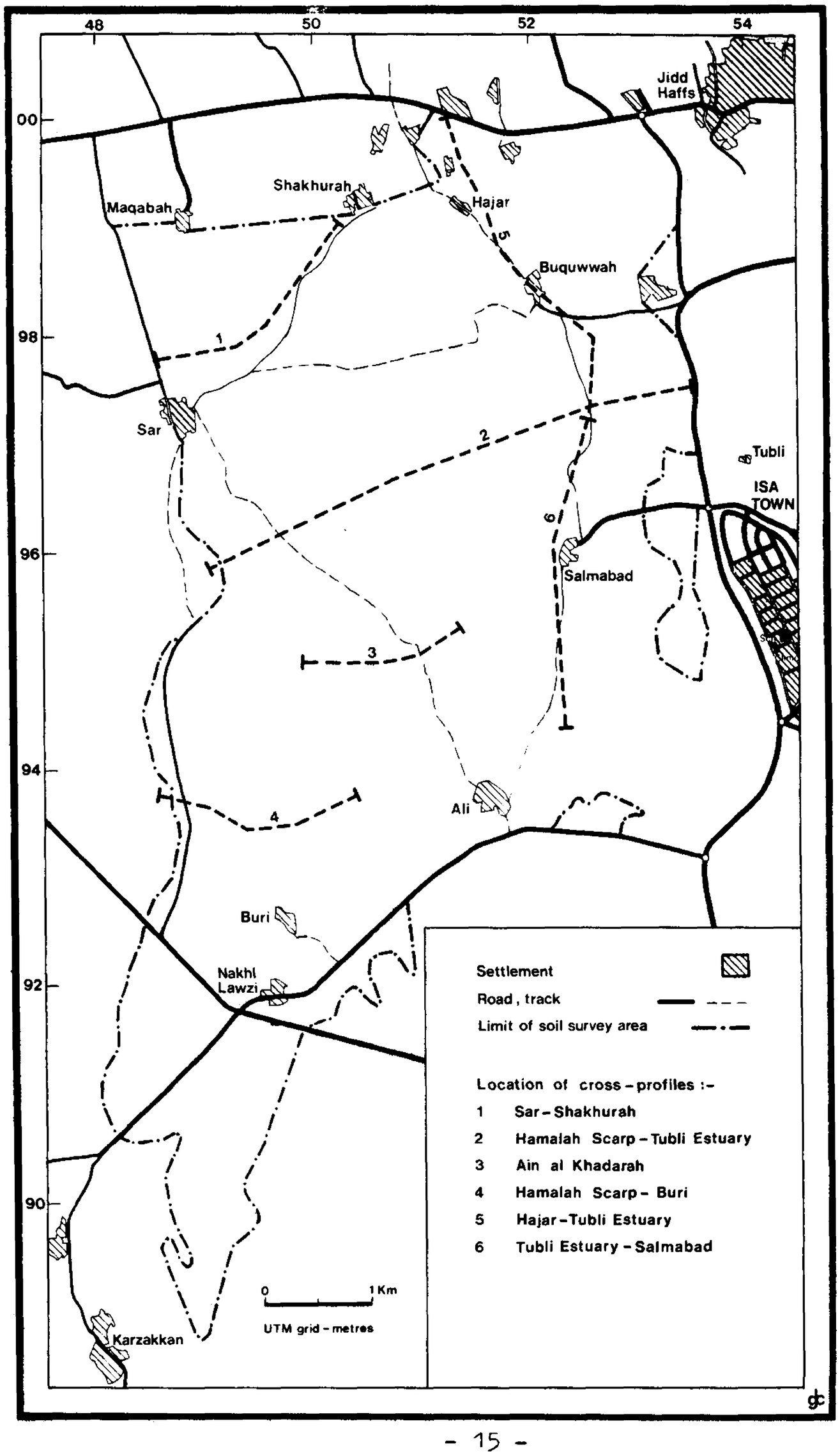


Figure 3.3 Cross - Profiles ; Salmabad Area

Auger boring (depth to scale)

Watertable (at time of testing) .....

Vertical exageration : Surface relief x 50
Soil profile x 100

Location of cross-profiles shown in Figure 3.2; soil mapping units explained in text.

Geologic age	Soil characteristic	
Recent	Aeolian siliceous sand; slightly gypsic	
	Superficial rubble, stone pavements, gravelly sandy loam	
	Gypsic coarse sand, partly aeolian; weakly cemented; locally thin peat layers	
	Fine loamy (silty) marine alluvium; gastropod shells	
	Carbonate-rich silt loam alluvium; minor organic layers	
	Sandy clay loam marine alluvium, bivalve shells	
	Aeolian siliceous fine sand, non-gypsic; non cemented	
Pleistocene	Aeolianite, calcareous/gypsic fine grained sandstone	
Eocene	Alat limestone	
	Alat "Orange Marl"; compact fine sandy clay loam	

1 SAR – SHAKHURAH

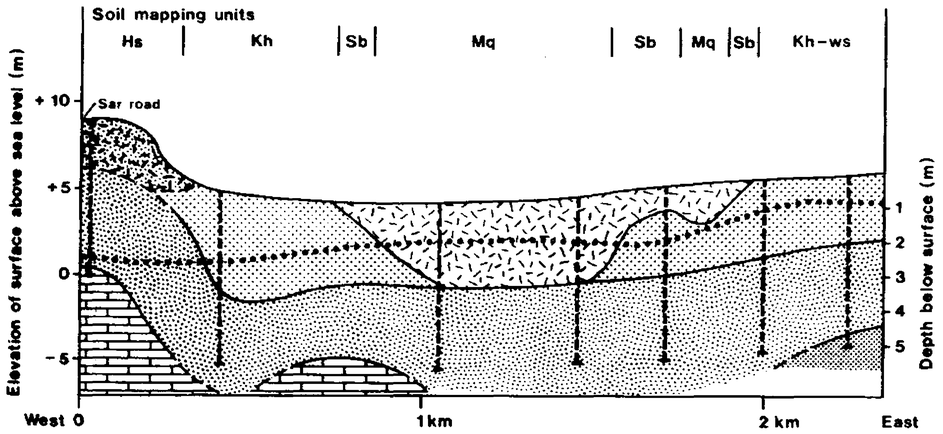


Figure 3.4 Cross - Profiles ; Salmabad Area

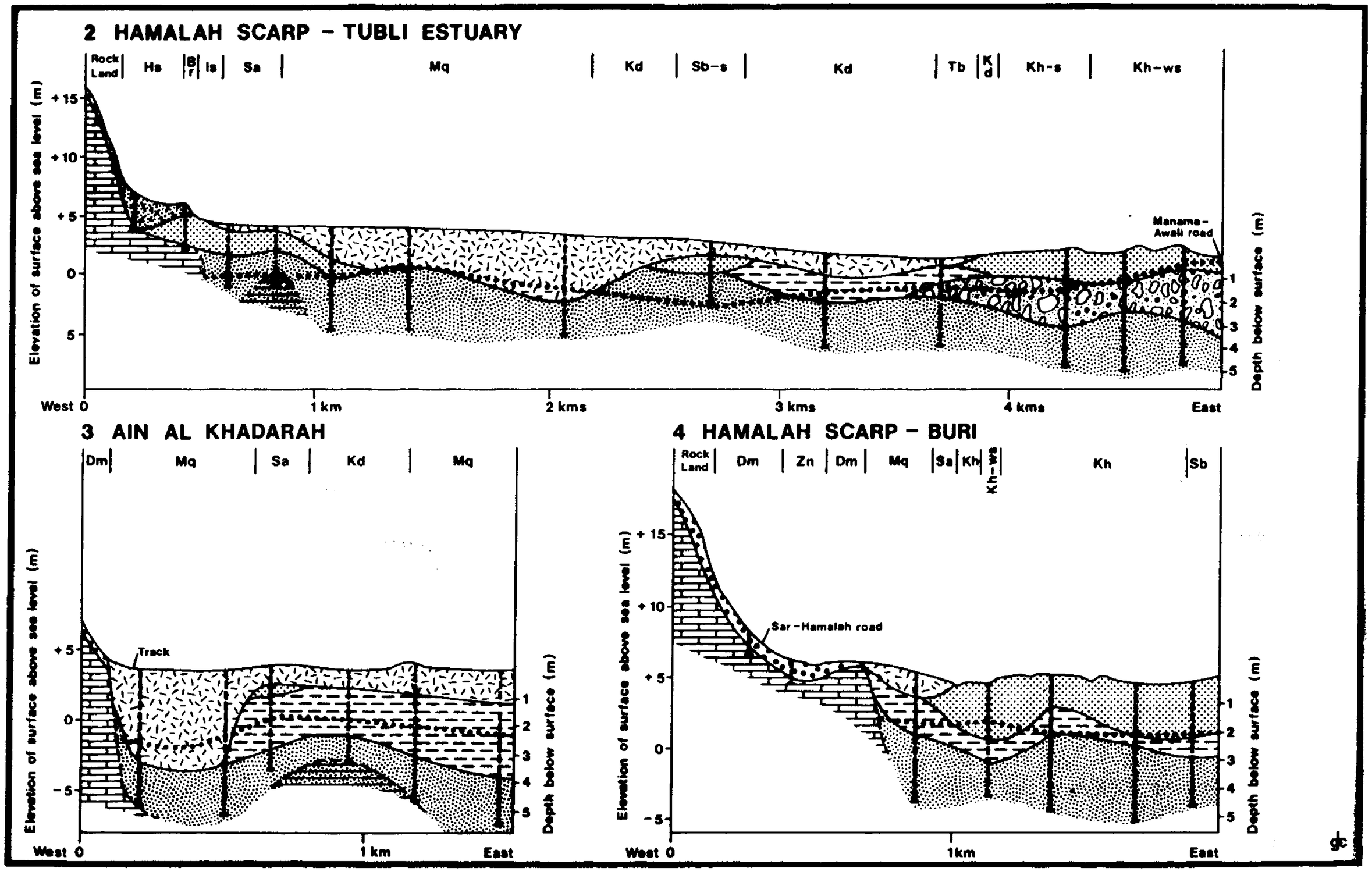


Figure 3.5 Cross - Profiles ; Salmabad Area

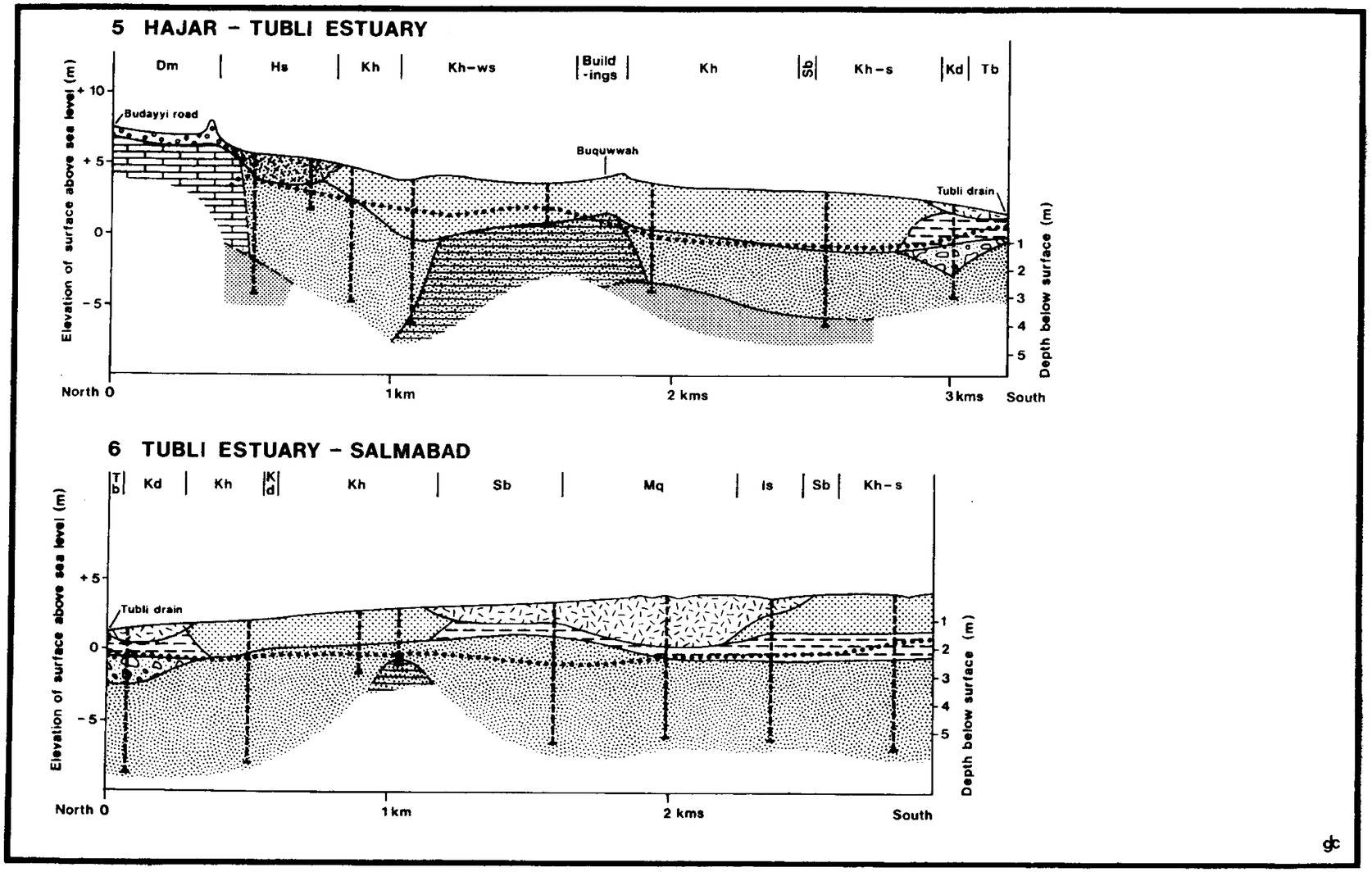
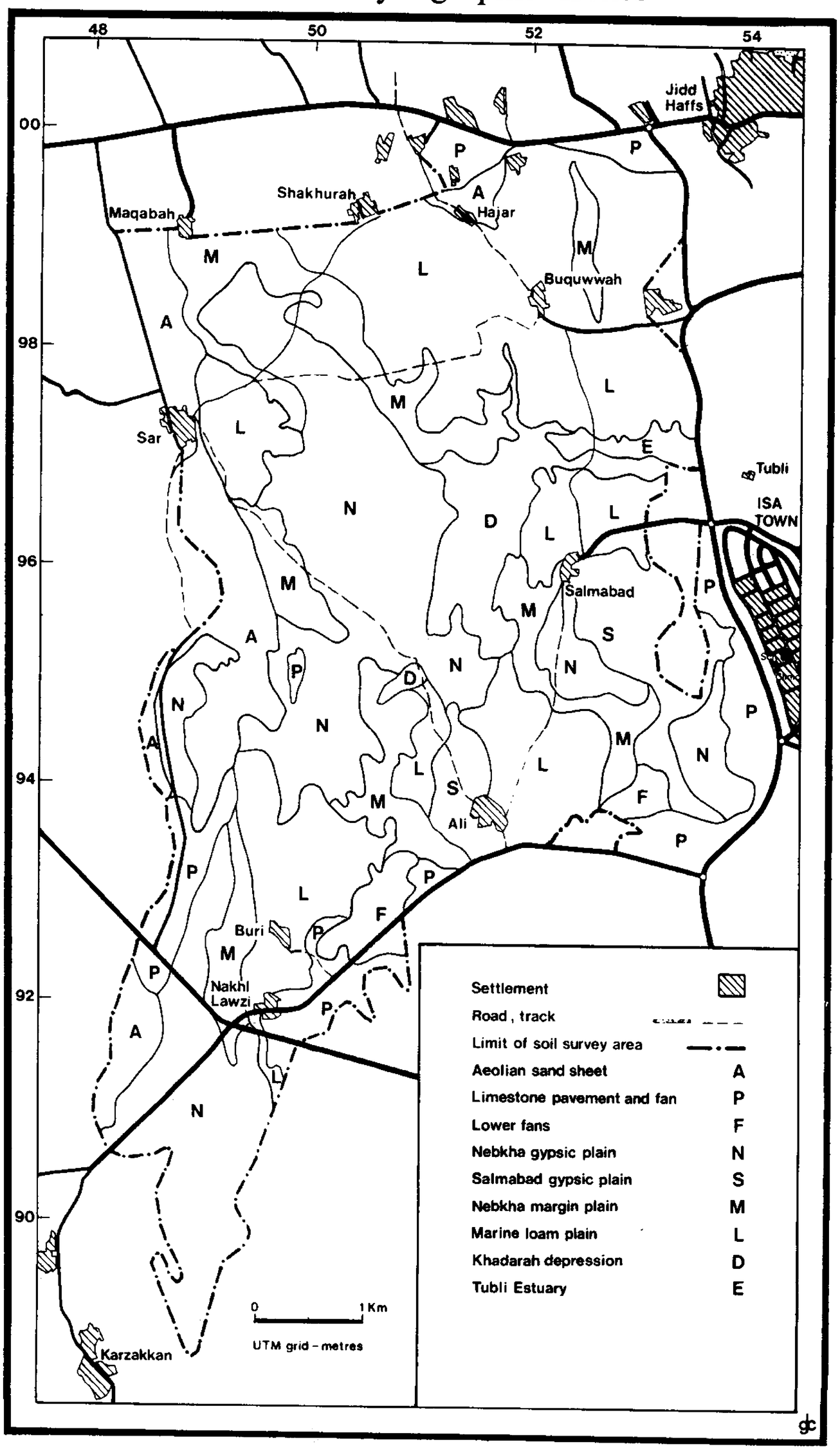


Figure 3.6 Salmabad : Physiographic Zones



(i) Aeolian Sand Sheet. This comprises areas of deep aeolian quartz sand which extend into the area from the north and west. The terrain is generally level except for minor duneforms, which are orientated NW-SE with the prevailing wind.

(ii) Limestone Pavement and Fans fringe the area and also occur locally as minor rock outcrops within the alluvial areas. Storm run -off from the main backslope results in channels and gravelly fans along the southern pavement area.

(iii) Lower Fans. These occur locally near the village of Ali, where very fine silty alluvium has accummulated at the foot of the outwash fans. This results in level plains with clayey soils.

(iv) Nebkha Gypsic Plain. This comprises an extensive area of deep gypsic sand. The terrain is generally level but surface redistribution by wind results in minor 'nebkha' hummocks of gypsum sand. Watertables are usually within 2.0m of the surface.

(v) Salmabad Gypsic Plain. This is similar to the previous unit but has smoother relief. Depths of gypsum over calcareous loam are less and high levels of salinity occur. The area appears to receive subsurface seepage from the backslope areas to the south.

(vi) Marine Loam Plain. These plains were formerly extensively used for date cultivation. Most of the plantations have now been abandoned but the remnant irrigation and drainage channels form a prominent micro-relief. The presence of a saline watertable within the upper 1.5m has resulted in salinization since irrigation ceased.

(vii) Nebkha Margin Plain. This represents the transition zone between the Nebkha and Marine Plains, in which gypsic alluvium overlies marine silt loams. Abandoned channel micro-relief

occurs but is less pronounced than in the more recently abandoned areas on the Low Plain.

(viii) Khadarah Depression. This lies mostly below 3.0m above sea level, stretching from the Ain al Khadarah towards the Tubli estuary. The terrain is level, often with subdued abandoned channel micro-relief. Watertables are close to the surface and result in extreme salinization and accummulation of superficial gypsum.

(ix) Tubli Estuary. This, the lowest part of the Salmabad area, comprises an area of swampy conditions in which marine alluvium overlies saturated sand. The area is in tidal contact with the sea and is very saline.

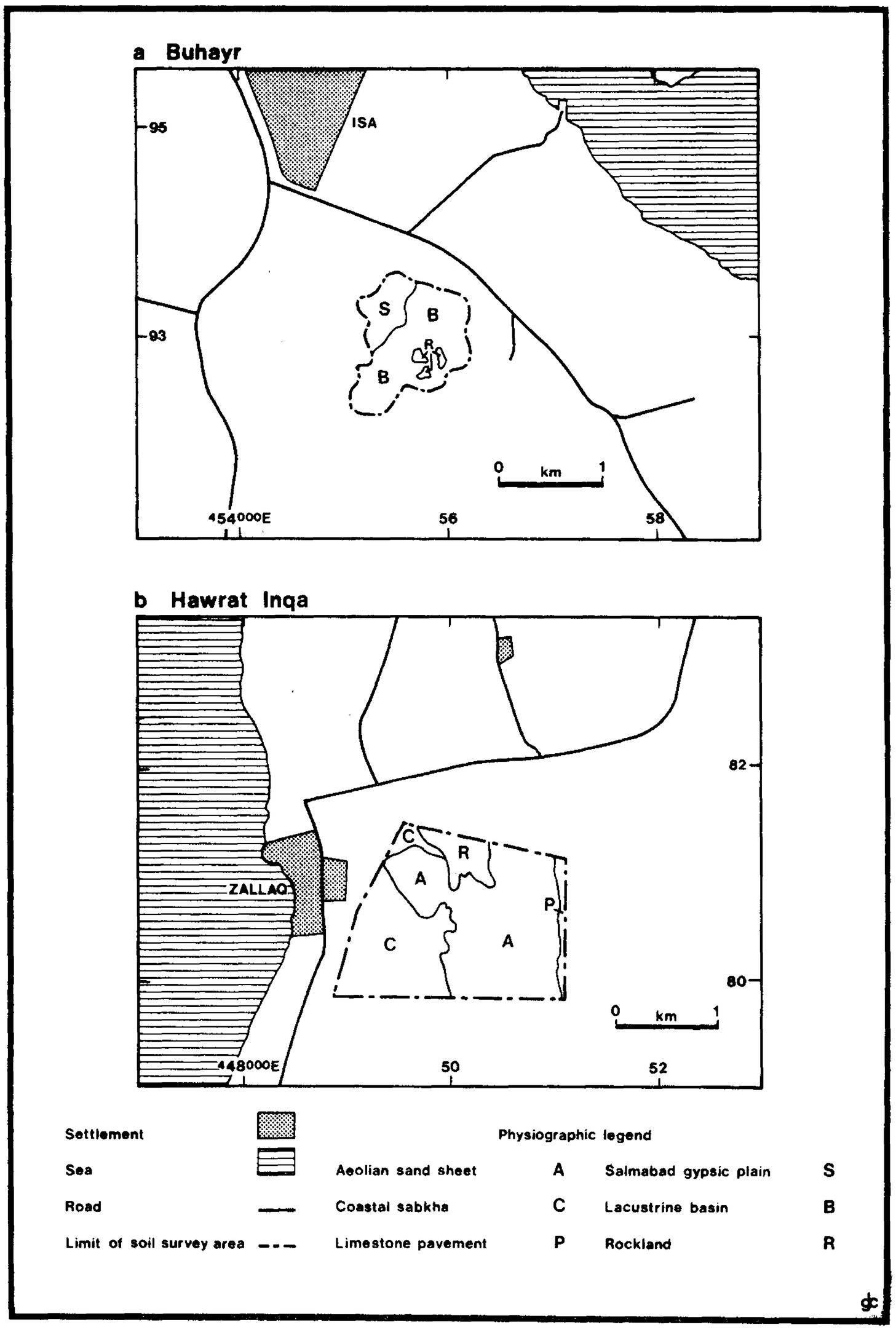
3.2.2 Buhayr Area

The Buhayr area comprises a small depression lying to the east of the Salmabad Area (Figure 3.1). The depression is surrounded by limestone scarps and probably represents a solution collapse feature within the limestone backslope. The eastern section of the depression is infilled by saline lacustrine sediments, stratified with evaporite gypsum, which are overlain by a shallow superficial deposit of aeolian gypsum. To the west the land is similar to the Salmabad Gypsic Plain. Outcrops of limestone are common in the south. As there is no natural drainage outlet, ponding occurs after heavy rains. The terrain is level but much disturbed by refuse disposal operations. Figure 3.7 shows the general physiographic zones.

3.2.3 Hawrat 'Inqa

This area occupies part of the Coastal Lowlands on the west coast due east of Zallaq (Figure 3.1). The land slopes gently from the foot of the limestone backslope, at six metres above sea level, towards the coastal 'Sebkha' at 1m (Figure 3.7). The extreme eastern and north eastern sectors comprise limestone pavement with only shallow alluvial cover and are traversed by weakly braided run-off channels. The central area comprises a level

Figure 3.7
Buhayr and Hawrat Inqa : Physiographic Zones



plain composed of quartz sand admixed with windblown gypsic sand. The micro-relief is slightly uneven due to sand hummocks. The 'Sebkha' along the western fringe is formed in mixed aeolian and marine quartz sand; the land is flat with a thin salt crust and high watertable.

3.3 VEGETATION AND LAND USE

3.3.1 Introduction

The prevailing arid climate and highly saline soils create an extremely harsh environment for plant growth, so that without irrigation only highly adapted and specialised species are capable of surviving.Even under irrigation, productivity is limited by the salinity of the irrigation water and poor drainage.

Records of agriculture in Bahrain go back well over 5000 years (Bibby, 1970). Evidence on the ground and on aerial photographs show that most of the Salmabad area has been under cultivation at some time in the past. Even in areas that have not been cultivated, browsing by livestock has, and still does, modify the natural vegetation. However, despite the considerable disturbance by man over the millennia, the same harsh environment persists and therefore, to a large extent, abandoned lands have probably been re-colonised by a range of species which closely resembles the indigenous natural vegetation: no other plants are specialised enough to tolerate the environment. Consequently, the existing natural vegetation provides a reliable indication of soil type, salinity and moisture status.

3.3.2 Natural Vegetation

The flora of N. Bahrain principally comprises species of the Saharo-Sindian formation but also includes species typical of the Irano-Turanian formation (Zakis, 1978). The species are broadly divisible into three groups:-

(a) Halophytes: species tolerant of high salinity.

(b) Xerophytes: species tolerant of dry conditions.

(c) Mesophytes: species with no special adaptation.

The harsh environment limits mesophytes to the irrigated zones; the halophytes are common on saline soils with high watertables whereas xerophilous plants are confined to the drier sandy soils and limestone backslopes. Most species are woody perennial herbs and ground shrubs.

A checklist of plant species is given in Appendix H, togehter with details of species composition and vegetation cover within the major physiographic zones. Several plant associations were recognised and proved to be closely related to the different physiographic units.

(a) Halophyte Associations

(i) Suaedavermiculata-Cressa cretica Association. These two species predominate on the moist saline soils of the Loam Plains. Capparis spinosa bushes are a characteristic component of the association; Phragmites australis is common in wetter areas and remnant Phoenix dactylifera trees are widespread. The S. vermiculata produces a dense stand of up to 1.0m high and vegetative cover often exceeds 30 per cent.

(ii) Halocnemum strobilaceum - Suaeda vermiculata Association. This association occurs on highly gypsic, imperfectly drained saline soils of the Khadarah Depression, Buhayr and parts of the Salmabad Gypsic Plain and Nebkha Margins. The sparse cover (less than 10 per cent) is characterised by isolated clumps of H.strobilaceum and stunted shrubs of S.pruinosa. Aeluropus lagopoides, Cressacretica and Salsola baryosma form an important component of the association. In the vicinity of Salmabad village Limonium axillare and the halophyte Halopeplis perfoliata are common.

(iii) Arthrocnemum -Salicornia - Avicennia Association. The tidal saline swamps of the Tubli estuary are dominated by highlyspecialised halophytes which are tolerant of saline waterlogged conditions. The dwarf mangrove (Avicennia marina) survives along the main channel; whereas the lagoon areas

are characterised by low bushes of Salicornia herbacea , Arthrocnemum glaucum and Halocnemum strobilaceum. Phragmites australis and Suaeda sp. grow round the swamp margins. The area provides one of the last remaining examples of tidal swamp ecology in Bahrain, which has survived despite intense pollution and industrial disturbance. It provides an example of the most northerly occurrence of the dwarf mangrove (Good, 1955) as well as specimens of several chenopods, such as S.fruticosa, which have not been observed elsewhere on the island.

(iv) Zygophyllum Sabkha Association. This occurs on the Coastal Plains in the west of the Hawrat 'Inqa area. Most of the surface is bare, salt crusted but occasional isolated bushes of Z. qatarense survive in places.

(b) Xerophyte Associations

(i) Zygophyllum - Anabasis Association. Highly gypsic well drained, low salinity soils of the Nebkha Plain are typified by the low perennial bushes of Zygophyllum qatarense and Anabasis articulata Species of Atriplex, Aeluropus, Juncus, Suaeda and Sporobolus are common and thus this association includes both xerophilous and halophilous plants. The vegetation is moderately intensively grazed and cover rarely amounts to more than 10 per cent.

(ii) Atriplex leucoclada - Suaeda vermiculata Association The clayey soils of the Lower Fans carry a low density (10-15 per cent cover) of stunted perennial species composition is relatively rich, dominated by A. leucoclada and S. vermiculata but including Zygophyllum qatarense, Halocnemum strobilaceum, Anabasis articulata, Aeluropus lagopoides and Fagonia indica.

(iii) Heliotropium crispum - Salsola baryosma Association. Predominantly xerophilous species occur on the well drained, low salinity soils of the aeolian sand sheets of the Salmabad area.

The vegetation comprises low perennial ground shrubs, Heliotropium crispum being diagnostic. Cyperus sp., Prosopis farcta and Sporobolus sp. are important components of the flora. Thickets of the tree Prosopis juliflora occur locally. Vegetative cover is varied but usually ranges from 10 to 20 per cent.

(iv) Sporobolus - Helianthemum Association. This occurs on the Hawrat 'Inqa sand sheets. Watertables are closer to the surface and gypsum contents are higher than those in areas of the H. crispum - S. baryosma association but the soils still have low salinity. The flora is dominated by dwarf perennial xerophytes, stunted by grazing but affording 15 to 20 per cent cover. Helianthemum lippii, Sporobolus sp. and Panicum turgidum are characteristic, subdominants include H. crispum, Cyperus sp. and Erempogon foveolatus, with Z. qatarense and Fagonia indica locally.

(v) Salsola vermiculata - Erempogon foveolatus Association. The limestone pavements and upper fans carry a sparse cover (less than 5.0 per cent) of perennial ground shrubs and grasses. S. vermiculata and Erempogon foveolatus are typical but Hammada elegans is frequently co-dominant. Minor components of the flora include Anabasis articulata, Lycium shawii, Limonium axillare and Z. qatarense A characteristic species of flash flood channels in the dwarf shrub Cassia italica.

(c) Weed Species

A number of weed species are common in irrigated areas, some are introduced mesophytes but many are indigenous species. The common weeds, such as Heliotropium sp. Lippia nodiflora, Sesuvium sesavoides, Chenopodium murale, Convolvusarvensis, Mesembryanthemum nodifolium and Meliotus indica, are unable to survive long fallow periods and the indigenous halophytes and xerophytes rapidly recolonise abandoned land. The parasitic plant 'dodder'

(Cuscuta planiflora) affects alfalfa and even citrus trees.

2.3.3 Land Use

As discussed earlier, irrigated agriculture has been practised in Bahrain over many thousands of years. Present land use for the north of Bahrain is shown in the 1: 10 000 series of maps produced by Hunting Technical Services (1979) using 1977 aerial photography. The Buhayr and Hawrat Inqa areas have never been cultivated but most of the Salmabad area has been affected by agriculture at some time in the past. Formerly irrigation was provided by natural springs and qanats feeding a complex system of irrigation and drainage channels. The principal crop has always been dates but in recent years plantations have been abandoned due to deteriorating water quality and a changing economic situation. Today, fewer than 75 hectares of dates remain out of some 880 hectares which had been cultivated in the relatively recent past. Some date areas have been replaced by irrigation of fodder crops (alfalfa), winter vegetables (cabbage, carrots, potatoes, tomatoes) and fruit trees (tamarindus, citrus, mango, Indian almond, ziziphus) but overall less than five per cent of the Salmabad area is currently under cultivation.

Camels and a small number of goats and sheep are grazed in the Salmabad and Hawrat Inqa areas. The grazing is moderately intense and aggravates wind erosion. Other important types of land use include:-

(i) Garbage disposal; refuse tips are common in the area, especially at Buhayr.

(ii) Amenity tree planting; Acacia, Prosopis, Oleander, Parkinsonia and Eucalyptus species are being planted near Isa Town.

(iii) Recreation; there is a horse-racing track and motorcycle circuit in the Salmabad area.

(iv) Sand quarrying; this particularly affects dune areas and the land near Karzakkan.

The principal effects of irrigated land use on soils have been to create prominent micro-relief and reduce soil salinity. In lower-lying areas, however, long periods of irrigation have raised water-tables. This has probably accelerated surface accumulation of gypsum and salts, which are precipitated from rising moisture. Gypsum accumulation has been further augmented by windblown gypsic sand off the adjacent Nebkha Plain.

3.4 EROSION

Three forms of erosion are evident in the areas studied, namely water, wind and solution.

3.4.1 Water Erosion

In view of the low and erratic rainfall, water erosion occurs only where run-off is sufficiently concentrated to cause over-land flow. This occurs on the limestone backslopes and results in minor gullies and gravelly watercourses which disgorge into the Hawrat 'Inqa and southern Salmbad areas. The seasonal flows account for little erosion within the survey area but are responsible for minor accretions of alluvium.

3.4.2 Wind Erosion

Most of the sandy soil parent materials are of aeolian origin. They have a preponderance of particles in the size fraction most vulnerable to wind erosion (0.05 to 0.5mm) and are therefore prone to this type of erosion. This is confirmed by the advance of sands south of Sar and intense wind scouring and deflation in Hawrat 'Inqa. The direction of movement is towards the SE, in the direction of the prevailing winds. Considerable redistribution of gypsum particles occurs on the Nebkha Plain, much of which is deposited on the adjacent land. This encroachment is especially clear north east of Buri village, where gypsic sand from the Nebkha Plain is over-running the marine silt loams. The gypsum crystals are mostly in the particle-size range 0.25 to 2.00mm and thus, allowing for the lower density of gypsum as compared with quartz, they can be moved by a combination of creep and saltation.

3.4.3 Solution Erosion

The proximity to the surface of saline groundwater, high evaporation rates and low rainfall favour accretion rather than removal of salts. This accretion results from the precipitation at the surface of salts dissolved in capillary moisture rising from the shallow watertable. Implementation of drainage and irrigation would largely reverse this trend and cause a net loss of mineral salts from the area.

3.5 SOILS

Several soils studies have been carried out in Bahrain but none have been to the detail of the present surveys. In this section, these earlier soils investigations are reviewed briefly.

The earliest recorded investigations were carried out by MEXE (1969) as part of a terrain evaluation exercise, mostly confined to the south of the island. Italconsult (1971) were intended to carry out semi-detailed soil surveys of the cultivated zone but ultimately concentrated on detailed investigations of sample farms. Specific soils studies were performed by McGowan (1975) in connection with selection of land for the use of treated sewage effluent. The Buhayr area was included in their study and was reported to have highly saline and extremely gypsic soils but to be suitable for production of irrigated fodder crops.

Semi-detailed soil surveys of the northern and north western cultivated zone were carried out by Ercon (1973). On the basis of examining 7.5 sites per 100 hectares a series of broadly defined soil associations were identified and mapped at 1: 10 000 scale. The limits of this survey form the northern and western boundaries of the present survey of the Salmabad area.

The first national soil survey was carried out as part of the Bahrain Surface Materials Resources Survey (Ministry of Works, Power and Water, 1976; Doornkamp, etal, 1979). Brief reconnaisance surveys covered the whole island but much of the information was obtained from photo-interpretation and the results of the Ercon survey. Soils and land capability for agriculture were mapped at a scale of 1:50 000; soils along the northern coast were also mapped at 1:10 000 scale. The soil units represent a compromise between pedologically defined units (Solochaks, Regosols, Raw Mineral Soils) and physiography (salt flats, backslopes, fans). Sub-divisions were also made to show soil texture and depth to watertable. The mapping indicates the general soilquality in Bahrain and provides a useful basis for regional planning. As part of the present study, the soil map was re-interpreted to show Soil Taxonomy (USDA, 1975) and FAO/UNESCO (1974) units (Appendix J).

More recently some soil surveys have been carried out as part of a research study by Ahmed (personal communication, 1979); these cover part of the Salmabad area.

4

Soil Classification

4.1 INTRODUCTION

Under the terms of reference (Appendix J) soil classification must be according to the Soil Taxonomy system devised by the USDA (1975). In addition, these soil units are to be correlated with the units established by FAO-UNESCO (1974) for the Soil Map of the World.

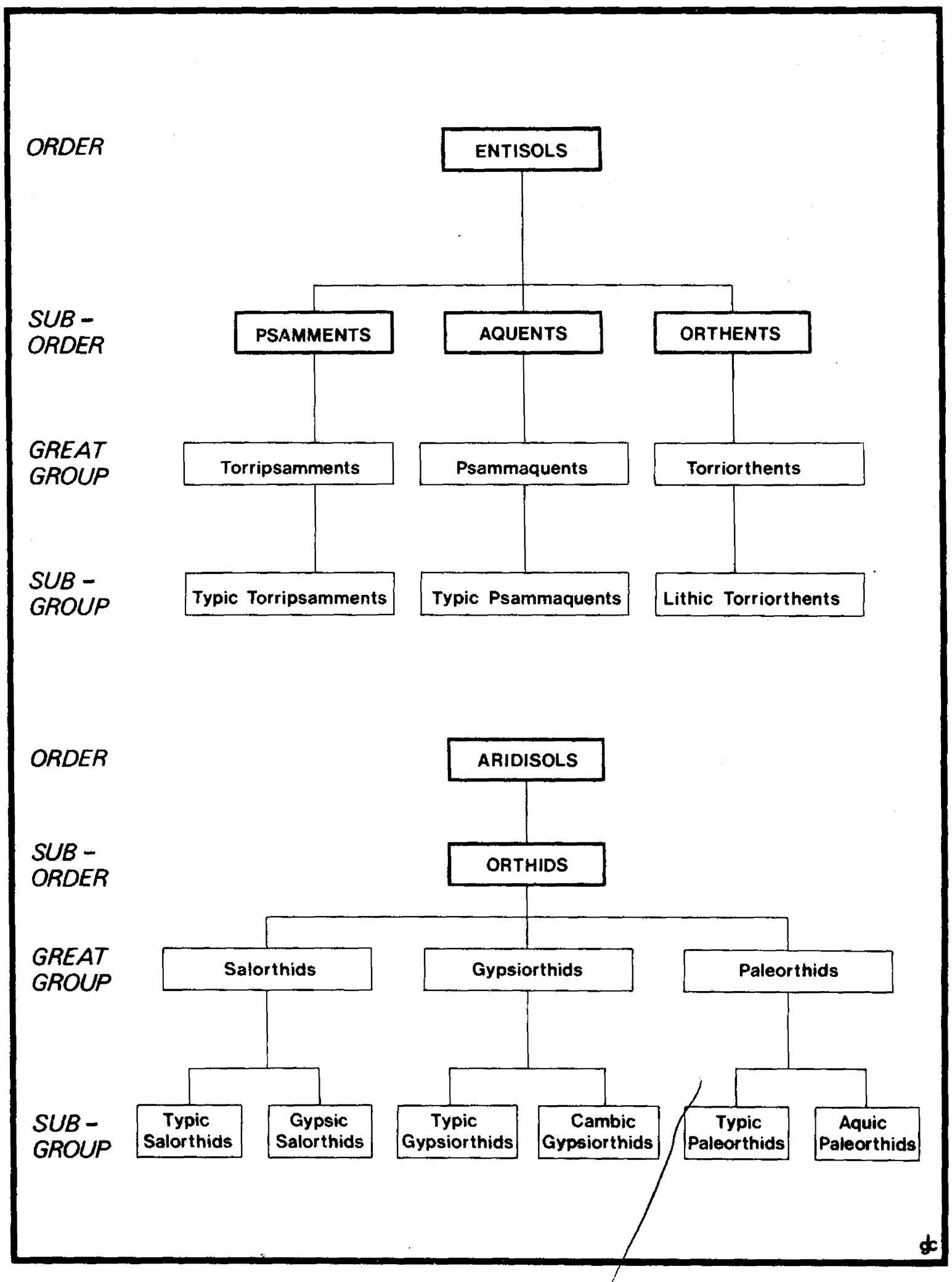
The Soil Taxonomy system consists of six categories; order, sub order, great group, sub group, family and series, in descending sequence. The first four of these are grouped as higher categories (Figure 4.1), the last two as lower categories. In this chapter the principles of Soil Taxonomy are discussed in relation to the soils of the Bahrain Level 3 areas. For convenience, the two main categories, higher and lower, are discussed separately. In Chapter 5 the individual soil series mapped during the Level 3 surveys are described within the Soil Taxonomy framework.

It is important to note that Soil Taxonomy units at order, suborder and great group levels are not mutually exclusive but form a key, for example, Salorthids could qualify also as Gypsiorthids, but in the key sequence Salorthids come before Gypsiorthids. Subgroups and lower categories, on the other hand, are mutually exclusive.

When using Soil Taxonomy, it is essential to bear in mind two important points:-

(a) Taxonomy is a narrower term than classification. It is that part of soil classification concerned primarily with relationships between soils, not

Figure 4.1 Higher Category Classification
Of Bahrain Level 3 Soils



with the practical uses of soils.

(b) Soil Taxonomy is not final; "Changes seem certain, and supplements that revise some of the definitions can be expected." (Preface, Soil Taxonomy, 1975).

The importance of the first point is that it explains the basic difficulty in using Soil Taxonomy for a specific practical purpose, such as land classification for irrigation development. The system tends to create too many units by applying criteria which are often irrelevant to agriculture. This results in extra work and unnecessary complexity on the soil map, but it does provide the "pedologic soil map" stipulated in the contract. Series are reasonably practically-orientated units from which to derive a land classification, but during the present Level 3 surveys it was necessary to use soil phases. Although soil phases are not part of Soil Taxonomy the system recommends their use for directing the classification to a particular survey objective.

The second point is especially relevant to soil surveys in Bahrain because most of the soils in this region are not widespread in the United States, notably highly gypsic soils. As a consequence, Soil Taxonomy classifies such soils in a confusing and sometimes illogical manner. Modificationsare clearly inevitable in these cases. Indeed, as a result of soils investigations carried out as part of the Umm Er Radhuma Study in Eastern Province, Saudi Arabia, several changes were proposed (GDC, 1978) and were provisionally accepted by the USDA soil correlators. Where applicable, these changes have been adopted for use in Bahrain.

4.2 CRITERIA FOR HIGHER CATEGORY CLASSIFICATION

Soil classification in the four higher categories is based on the presence or absence of diagnostic surface and subsurface horizons and of certain soil characteristics which are also considered to be diagnostic. Those which apply to soils in the Level 3 soils areas are discussed below.

4.2.1 Diagnostic Surface Horizons

Soil Taxonomy defines six diagnostic surface horizons, or epipedons, but only the ochric epipedon occurs in the survey

area. Many of the soils have no epipedon or a very thin one, because profiles have been truncated by predominantly erosive geomorphic processes. The ochric epipedon includes all topsoils which lack the more diagnostic features of the other five epipedons. It is pale in colour, low in organic content, and is often thinly developed. It has few or no accessory characteristics.

4.2.2 Diagnostic Subsurface Horizons

The diagnostic subsurface horizons of main importance are gypsic, petrocalcic and salic horizons.

(a) Gypsic Horizon

The gypsic horizon as defined by Soil Taxonomy is a non-cemented or weakly cemented horizon of enrichment with secondary sulphates that is 15cm or more thick, has at least 5 per cent more gypsum than the C horizon or the underlying stratum, and in which the product of the thickness in centimetres and the percentage of gypsum is 150 or more. Thus, a horizon 30cm thick that has 5 per cent gypsum qualifies if gypsum is absent in the underlying horizon. A layer 30cm thick that has 6 per cent gypsum qualifies if the gypsum content of the underlying horizon is not more than 1 per cent. Cementation is weak enough that a dry fragment slakes in water.

This definition of a gypsic horizon, taken from Soil Taxonomy leads to illogical classification if not modified. A soil profile may consist of several horizons which are very high in secondary gypsum, but only the deepest is likely to qualify as a gypsic horizon because the others may not have 5 per cent more than the next horizon down. The following profile illustrates the point:-

Site PV042 Nebkha Plain

Horizon	a	0-30	93.0% gypsum
	b	30-60	88.9% "
	c	60-100	84.0% "
	d	100-145	12.5% "

In this example only horizon C would qualify as gypsic, although all horizons, particularly a and b, evidently should qualify as gypsic horizons.

The best solution seems to be to regard the gypsic horizon as often consisting of more than one soil horizon. Weighted means could be used to give the product of thickness and gypsum percentage for the multiple gypsic horizon as a single figure. This is the approach used here to define a gypsic horizon.

Gypsic horizons are common throughout the Level 3 survey areas, occurring in almost all soil mapping units. Clearly, much of the gypsum is not truly secondary, having been transported by wind from adjacent gypsic sand areas. However, this aeolian gypsum has subsequently been partially recrystallised and enriched by precipitation of gypsum from capillary water rising from gypsum-rich watertables. In some areas (Buhayr) alternating precipitated and aeolian gypsum bands demonstrate former changes in soil development. Elsewhere, aeolian gypsum is absent but finely divided crystals of precipitated gypsum occur in sufficient quantities to meet the requirements of a gypsic horizon. For the purpose of classification, aeolian gypsum is accepted as being secondary provided there is evidence of recrystallisation and weak cementing.

In some instances, especially in soils of the Nebkha Plain, this cementing may be sufficient to meet the requirements of a petrogypsic horizon. Certainly they are hard, cemented, contain in excess of 60 per cent gypsum and air dry fragments do not slake in water. However, the horizons are often not continuous or are less than 15cm thick and for classification purposes they are considered as gypsic horizons.

(b) Petrocalcic Horizon

This horizon is defined as being a continuous,cemented or indurated calcic horizon that is cemented by calcium carbonate or in some cases by calcium and some

magnesium carbonate. Dry fragments do not slake in water and the horizon cannot be penetrated by spade or auger.

Petrocalcic horizons are fairly common in the surveyed areas, particularly on the Salmabad plain and Hawrat 'Inqa. Calcium carbonate (as calcite) appears to have migrated upwards in carbonate-rich groundwater and precipitated in subsoils to cause cementing. This is assumed to have occurred in the post-Pleistocene period. Two forms of petrocalcic horizon are found, one formed in loamy material, the other in sand. The former, which is known as jashab, has formed in calcareous loam subsoils in contact with a watertable, calcite cementing occurring above the capillary fringe. The layer is very hard but porous, especially where cementing has occurred around date roots, leaving tubular channels. This type of petrocalcic layer is probably fairly recent in origin, indeed similar material along the north coast has been found to postdate human settlement, some 6000 years BP (Bibby, 1965). The second form of petrocalcic horizon occurs at the upper boundary of the substratum sand as a dense layer of calcite cementing. This cementing is widespread but is often fractured and frequently occurs as only knobbly concretionary layers in the subsoils, remnants of the original petrocalcic layer. The mineralogy of these horizons is described in Appendix G.

(c) Salic Horizon

A salic horizon is a horizon 15cm or more thick that contains a secondary enrichment of salts more soluble in cold water than gypsum. It contains at least 2 per cent salt, and the product of its thickness in centimetres and salt percentage by weight is 60 or more. Thus, a horizon 20cm thick would need to contain 3 per cent salt to qualify as a salic horizon and a horizon 30cm thick would need 2 per cent. To be saline a salic horizon must be extremely saline.

In order to assess a possible salic horizon it is necessary to convert laboratory salinity estimates, expressed as electrical conductivity of the saturation extract (ECe) in mmhos/cm, to percentage soluble salts (PSS), using the saturation percentage (SP) and a constant:-

$$PSS = 0.064 \times \frac{SP}{100} \times ECe \quad \text{(USDA,1954)}$$

From this relationship it is possible to calculate the minimum ECe required within a 30cm horizon to meet the requirements of a salic horizon, this varies with saturation percentage and thus particle size class, as follows:-

Particle Size-Class	Approximate SP	ECe Equivalent to 2% Salts
Sandy-skeletal	25	125
Sandy, loamy-skeletal	30	104
Loamy, clay-skeletal	45	70
Clayey	60	52
Clayey	75	42

For a loamy soil, therefore, the ECe must be in excess of 70 mmhos cm^{-1} in a horizon 30cm thick to qualify as salic. If thinner than 30cm the minimum ECe value must be greater. However, for the purposes of classification it is assumed that if two or more adjacent horizons have salts in excess of 2 per cent they can be considered as a multiple salic horizon, provided their combined PSS x thickness is greater than 60. This approach is similar to that adopted for gypsic horizons.

4.2.3 Other Diagnostic Soil Characteristics

Other soil characteristics diagnostic at higher category levels and found in the survey areas include: particle-size class, lithic contact, paralithic contact, soil moisture regime and soil temperature regime. The virtual absence of clay soils means that characteristics such as gilgai, n-values, coefficient of linear extensibility, and so on are of no importance.

Features which could be mistaken for gilgai occur very locally on fine-textured silty soils, but these are essentially due to collapse of soil into shrinkage cracks rather than to soil heaving which causes gilgai. Soil mottling is another diagnostic characteristic which is not used, because the only mottled soils occur in sites where high salinity and gypsum dominate the classification.

(a) Particle-size Class

Particle-size classes are used mainly in lower category classification at family level. In the Level 3 area soils, they have only one application in higher category differentiation, namely the separation of the Psamment suborder from other Entisols on the basis of a sandy particle-size class within the control section.

A detailed account of particle-size classes is given in the lower category classification, where they are usually the major factor in separation of units. A broad guide only is given here.

Particle-size classes, in contrast to classes of soil texture, are based on both fine earth and rock fragments. Classes of soil texture are based on the grain-size distribution of only the fine-earth fraction, which consists of the particles less than 2mm in diameter.

The limits between classes of particle size do not always follow the limits between classes of texture. The following particle-size classes are used in the higher categories.

Fragmental. Boulders, stones, cobbles, gravel and very coarse sand; fines are too few to fill some of the interstices larger than 1mm.

Sandy. Less than 35 per cent by volume of rock fragments (i.e. 2mm or more); the texture of the fine earth is a sand or a loamy sand that is coarser than very fine sand or loamy very fine sand.

Sandy-skeletal. Thirty-five per cent or more by volume of rock fragments; the fine-earth fraction is as defined for sandy.

Clayey. Less than 35 per cent by volume of rock fragments; the amount of clay in the fine-earth fraction is 35 per cent or more by weight.

Clayey-skeletal. Thirty-five per cent or more by volume of rock fragments; the fine-earth fraction is as defined for clayey.

Loamy. All other classes that have below 35 per cent by volume of rock fragments.

Loamy-skeletal. Thirty-five per cent or more by volume of rock fragments; the fine-earth fraction is as defined for loamy.

(b) Lithic Contact

Soil Taxonomy defines a lithic contact as a boundary between soil and coherent underlying material which must be continuous within the limits of a pedon except for cracks produced in place without significant displacement of the pieces. Cracks should be few, and their average horizontal spacing should be 10cm or more. The underlying material must be sufficiently coherent when moist to make hand digging with a spade impractical, although it may be chipped or scraped with a spade. If it is a single mineral, it must have a hardness by Moh's scale of 3 or more. If it is not a single mineral, chunks of gravel size that can be broken out must not disperse during shaking for 15 hours in water or in sodium hexametaphosphate solution. The underlying material considered here does not include diagnostic soil horizons such as a duripan or a petrocalcic horizon.

A lithic contact is diagnostic at the subgroup level if it is within 50cm of the surface of a mineral soil.

(c) Paralithic Contact

Soil Taxonomy defines a paralithic contact as follows:-

"A paralithic (lithic-like) contact is a boundary between soil and continuous coherent underlying material. It differs from a lithic contact in that the underlying material, if a single mineral, has a hardness by Moh's scale of less than 3. If the underlying material is not a single mineral, chunks of gravel size that can be broken out disperse more or less completely during 15 hours of end-over-end shaking in water or in sodium hexametaphosphate solution and, when moist, the material can be dug with difficulty with a spade. The material underlying a paralithic contact is normally a partly consolidated sedimentary rock such as sandstone, siltstone, marl, or shale, and its bulk density or consolidation is such that roots cannot enter. There may be cracks in the rock, but the horizontal spacing between cracks should be 10cm or more."

This is a difficult definition to apply. In the Bahrain soils, there is a typical sequence from soil into weathered bedrock into solid bedrock. The soil is sometimes derived in situ from weathering of bedrock, especially in its lower profile. This may make the paralithic contact, (between soil and weathered bedrock) gradual and difficult to recognize. Similarly, it is not easy to decide when solid rock has been reached. Frequently it is not reached because the paralithic contact represents the bottom of the soil profile and its agronomic effective depth. Also, augering or digging through paralithic material soon becomes very arduous. All auger-holes and pits were excavated to at least 50cm even in the most shallow soils, in order to establish the presence or absence of a lithic subgroup.

(d) Soil Moisture Regime

These regimes are defined in terms of the groundwater level and the presence or absence of water held at less than 15 bar tension over various periods of the year and at defined depths. An approximate guide to the upper and lower boundaries of the soil moisture control section is as follows:-

fine-loamy, clayey	10-30cm
coarse, loamy	20-60cm
sandy	30-90cm

Two moisture regimes are recognised in the Level 3 soil areas:-

(i) Aquic moisture regime. This is applied where anaerobic conditions result from saturation by groundwater or a capillary fringe. At the highest categories of classification the whole soil must be saturated but at subgroup level only the lower horizons are saturated. A large proportion of the soils examined in the present survey have subsoils saturated by groundwater and would therefore normally qualify as Aquents or aquic subgroups. However, in most cases this classification is superceded by excessive soluble salt and gypsum contents and thus areas of Aquent and aquic subgroups are very restricted.

The moisture regime in the Tubli Estuary is best described using the Soil Taxonomy term "peraquic", applying to soils where the watertable is always near the surface due to an outside source, in this case tidal effects and very low elevation above sea level.

(ii) Aridic (torric) Moisture Regime. In Chapter 3 it was seen that the climate of Bahrain produces an aridic (torric) moisture regime in the soils, unless modified by groundwater. The requirements for the aridic (torric) moisture regime are that the moisture control section should be:-

- Dry in all parts more than half the time (cumulative) that the soil temperature at 50cm depth is above 5°C.
- Never moist in some or all parts for as long as 90 consecutive days when the soil temperature at a depth of 50cm is above 8°C.

(e) Soil Temperature Regime

Again as shown in Chapter 3, the soil temperature regime in Bahrain is hyperthermic. That is the mean annual soil temperature is 22°C or higher, and the difference between mean summer and mean winter soil temperature is more than 5°C at a depth of 50cm or at a lithic or paralithic contact, whichever is shallower.

In the present case the soil temperature regime applies only at the lower category of classification, at family level, and is the same for all soil units.

4.3 HIGHER CATEGORY CLASSIFICATION

Although only two of the ten orders defined by Soil Taxonomy occur in the survey areas, namely Aridisols and Entisols, even at this highest level of separation there arise basic problems of classification. The fundamental difference between Aridisols and Entisols is that the former have certain diagnostic horizons with 75 to 100cm of the surface whereas in the latter there are none or they occur at greater depths. The difficulty arises in profiles with diagnostic horizons developed under earlier, different conditions and subsequently buried.

Difficulties arise, for example, where dune sands overlie soils with distinct gypsic horizons or, as discussed earlier, where superficial gypsum accumlations are primarily of aeolian origin and could therefore be considered as unaltered parent material. In each case these soils could be classified as Entisols. Depth limitations are defined for superficial layers but considerable confusion still exists.

As a result of the soil investigations in Saudi Arabia (GLC,1978) a decision was made to place in the Aridisol order all soils which have diagnostic horizons within the upper 100cm. On

balance the Soil Taxonomy's conflicting statements favour this and from the practical viewpoint it helps greatly in that it avoids having to decide whether or not a profile is buried, and whether horizons are relic features.

4.3.1 Aridisol Order

Aridisols, as their name implies, are soils that do not have water available to mesophytic plants for long periods. During most of the time when the soil is warm enough for plants to grow, water is held at a tension exceeding 15 bars or it is salty, or both. There is no period of three months or more when moisture is continuously available and the soil is warm

Aridisols have one or more pedogenic horizons that may have formed in the present environment or that may be relics from a former pluvial period. The surface horizon or horizons are normally light in colour and have soft consistence when dry. The pedogenic horizons may be the result of translocation and accumulation of salts, carbonates or gypsum, or of cementation by carbonates or gypsum. They also may be only an alteration of the parent materials without any significant accumulation. Some Aridisols formed in Holocene time. Others are on ancient surfaces and have very complex horizons that reflect more than one change in climate.

Vegetation, if any exists without irrigation, consists mostly of ephemeral grasses and scattered xerophytes. Most of the surface is bare most of the time, and if gravel is present in the parent materials, the surface has a desert pavement that forms by deflation of the fine earth.

(a) Suborders

Aridisols contain two suborders, Argids and Orthids. The former is distinguished by the presence of an argillic horizon, that is an accumulation of illuvial clay. Other Aridisols are classed as Orthids. No argillic horizons have been observed in Bahrain and therefore all Aridisols in the present survey are considered to be Crthids.

(b) Great Groups and Subgroups

It is convenient to discuss these two categories together because the name of the former always appears in full as the last part of the subgroup name. The

Level 3 soils include three of the six Orthid great groups, namely Salorthids, Gypsiorthids, Paleorthids (Figure 4.1).

(i) Salorthid Great Group. The Soil Taxonomy definition of Salorthids stipulates a salic horizon within 75cm of the surface, above any calcic or gypsic horizon. It also requires the capillary fringe to be within 100cm for at least one month of the year in most years. However, it is evident that the latter requirement is unsatisfactory. Neither of the two Salorthid examples given in Soil Taxonomy (Appendix IV) meet this requirement. One weakness with it is that the capillary fringe is difficult to detect in auger-holes in certain soils, so that the watertable or first continuous wet layer would be a better indicator. A more important defect is that extremely saline soils typical of the Salorthid concept occur with much deeper watertables than those implied by a capillary fringe within 100cm. Following discussions with soil correlators in Riyadh, it was agreed (GDC,11978) that the Salorthid requirements be modified to:-

- A salic horizon within 75cm of the surface, above any calcic or gypsic horizon.
- A watertable within 200cm of the surface for at least one month in most years.

These conditions are easier to apply, giving a much better correlation with excessively saline soils, and so have been adopted for the Bahrain survey.

At present only two subgroups are recognised within Salorthids: typic and aquollic. The latter has more organic matter than occurs in any of the soils examined in Bahrain so that all Salorthids would be Typic Salorthids. However, in many of the soils having a salic horizon the dominant characteristic, both pedologically and from a practical irrigation viewpoint, is the very high

gypsum content. As a result of further discussions with the soil correlators in Saudi Arabia it was decided to establish a new subgroup.: Gypsic Salorthids (GDC, 1978).

Thus two Salorthid subgroups are found: Typic Salorthids meet the basic requirements given above and may or may not have a gypsic horizon. But if the gypsic content is high enough to meet the stipulations for a Typic Gypsiorthid (see below) the soil is a Gypsic Salorthid.

(ii) Gypsiorthid Great Group. Gypsiorthids have a gypsic horizon whose upper surface is within 100cm of the surface. The following excerpt from Soil Taxonomy summarises the present situation with regard to the classification of these soils:-

"The Gypsiorthids were recognised as a great group very recently, and the classification that follows must be considered provisional. Testing of the classification is impossible in the United States because the soils have such limited extent and variety. The great group is provided mainly for use in other coutries."

Four subgroups are defined as follows:-

- Typic Gypsiorthids are the Gypsiorthids that (a) do not have a petrogypsic horizon whose upper boundary is within 1m of the soil surface; and (b) have a gypsic horizon in which the product of the percentage of gypsum and the thickness in centimetres above a depth of 1.5m is 3 000 or more.

- Calcic Gypsiorthids are like Typic Gypsiorthids except for (b) and have a calcic horizon above the gypsic horizon.

- Cambic Gypsiorthids are like Typic Gypsiorthids except for (b) and do not have a calcic horizon above the gypsic horizon.

- Petrogypsic Gypsiorthids are like Typic Gypsiorthids except for (a) with or without (b).

A major weakness of this subgroup classification, discovered during the Saudi Arabia investigation, is that the numerical definition of Typic Gypsiorthids excludes shallow, highly gypsic soils from the subgroup simply because they lack depth. Few such soils occur in Bahrain but soils with highly gypsic (40-60 per cent) surface horizons are common. Pedologically and agriculturally these soils are dominated by gypsum and yet under the official classification many would be grouped in the Cambic Gypsiorthids, along with soils which may have only five to ten per cent gypsum. Clearly the classification requires modification. Agreement was reached with the soil correlators that, provided no petrogypsic horizon is present, shallow gypsic soils and soils with excessively gypsic upper horizons would be included with the typic subgroup (GDC,1978). Under this revised system, given the minimum thickness of 15cm for the gypsic horizon, Typic Gypsiorthids have been recognised where one or more of the following numerical criteria are met:-

- The product of the gypsum content in per cent and the thickness in centimetres of the gypsic horizon is 1 500 or more in the upper 0-50cm of the profile.
- This product is 2 500 or more in the upper 0-100cm of the profile.
- This product is 3 000 or more in the upper 0-150cm of the profile.

This modification effectively reduced the unsatisfactory broad scope of Cambic Gypsiorthids. In the Bahrain Level 3 areas the natural dividing line between gypsic and highly gypsic soils, in terms of topsoil gypsum content, appeared to lie between 25 and 30 per cent. Indeed, as a result of this observation the numerical limits for the 0-50 and 0-100cm depth zones were increased from

the values of 1 000 and 2 000, as originally proposed.

(iii) Paleorthid Great Group. These are the Orthids that have a petrocalcic horizon. Usually, the upper boundary of this horizon is close to the soil surface and it is thick. Many Paleorthids are formed in parent materials rich in carbonates and occur on gentle slopes which have been stable for long periods, often since the mid-Pleistocene. Some petrocalcic horizons have been shattered and re-cemented. By definition the upper boundary of the petrocalcic horizon must occur within the upper 100cm of the profile for the soil to be a Paleorthid. Similarly, they must not have a salic horizon within 75cm of the surface if the soil is saturated with water within 1.0m of the surface for a month or more in most years.

Two subgroups are found in the Level 3 survey areas:-

- Typic Paleorthids. These are soils which have only an ochric epipedon or a cambic horizon, or both, over a petrocalcic horizon. They are usually restricted to the drier areas of Aridisols.
- Aquic Paleorthids. Unlike the typic subgroup, these soils are saturated with water for 90 consecutive days or more within a depth of 1.0m below the surface. They have low chromas in the saturated horizon. These include soils which, in most years, have shallow groundwater and are moistened by capillary rise.

As presently defined the Paleorthids exclude soils with a petrocalcic horizon overlain by a gypsic horizon: only ochric epipedons or cambic horizons are permitted. This creates a classification dilemma in Bahrain as soils with a petrocalcic horizon have a gypsic surface horizon and indeed are often extremely gypsic. However, in Soil Taxonomy Paleorthids follow immediately after Salorthids in the initial key to great groups of the Aridisol order. Thus soils which do not meet

the requirements for a Salorthid, but which have a petrocalcic horizon within the upper 1.0m, automatically become Paleorthids; gypsic horizons are considered only at a later stage in the key.

If the petrocalcic horizons were assumed to be 'buried', some of these soils would be placed in the Typic Gypsiorthids, but some of the petrocalcic horizons are probably fairly recent pedological features. Furthermore, as stated earlier, it has been agreed that all diagnostic horizons in the upper metre should be used in classification whether or not buried. The Aridisol key clearly indicates that the presence of a petrocalcic horizon should take taxonomic precedence over a gypsic horizon. Indeed, this is logical for the petrocalcic horizon constitutes a more severe restriction to land use than a gypsic horizon.

For the purposes of the present survey, soils with both gypsic and petrocalcic horizons have been accepted within the Typic or Aquic subgroups of the Paleorthids. Clearly though, there is a need to introduce a Gypsic Paleorthid subgroup which would be defined as being similar to the typic subgroup except for having, above the petrocalcic horizon, a gypsic horizon which meets the gypsum requirements of the Typic Gypsiorthids. This would effectively separate highly gypsic soils with petrocalcic horizons, much in the same way as Gypsic Salorthids were differentiated from the typic subgroup.

4.3.2 Entisol Order

Entisols are soils showing little or no evidence of pedogenic horizons, except deep in the profile. Apart from an ochric epipedon, Entisols in the Level 3 areas have no diagnostic horizon within the upper 1.0m of the profile.

(a) Suborders

Three suborders of Entisols occur in the Level 3 area of Bahrain, namely Aquents, Psamments and Orthents (Figure 4.1).

The Aquents have a sandy particle-size class in the upper 1.0m and are therefore Psammaquents. Both the Psamments and Orthents are subdivided according to soil moisture regime, thus in Bahrain they are Torripsamments and Torriorthents.

(b) Great Groups and Subgroups

(i) Psammaquent Great Group. These are the wet Entisols which are saturated for all or most of the year and have an aquic or peraquic moisture regime. They usually occur in recent sediments, as in Bahrain where they occur in recent silicious sandy marine alluvium around Zallaq. One subgroup is recognised, the Typic Psammaquents. Although these soils have very saline groundwater within the upper 1.0m of the profile, only very rarely do they have sufficient soluble salts to meet the requirements of a salic horizon and they are therefore retained in the Entisols. Similarly, salt crusts and thin superficial gypsum layers are common but as they only rarely exceed 15cm in thickness they are not sufficient to place these soils in the Aridisol Order.

(ii) Torripsamment Great Group. These are the sands of arid climates. They are predominantly of aeolian origin but some can be of colluvial/alluvial origin. In the Level 3 areas of Bahrain they occupy stable aeolian sand sheets and the occasional stable dune.

As Psamments, these soils differ from Torriorthents in having a sandy particle-size class throughout the control section of the soil profile (25-100cm or 25cm to a lithic or paralithic contact above 100cm). This definition provided by Soil Taxonomy requires further clarification with regard to the amount of (a) finer material and (b) gravel allowed

before the soil becomes a Torriorthent.

Thin lamellae of finer material are allowed. Here it has been established that any horizon of finer material 10cm or more in thickness places the soil in the Orthent suborder.

Soil Taxonomy states that gravelly sands (15-35 per cent gravel) cannot be Psamments, but then stipulates 35 per cent gravel as the upper limit of gravel content allowed. Here it is assumed that the latter is a mistake and that gravelly sands are not acceptable. Again, any horizon of 10cm or more thickness of gravelly sand is taken as sufficient to preclude Psamments.

Typic Torripsamments, which represent the central concept of the great group as described above, occur in the Level 3 areas. Some of these soils appear from laboratory analyses to possess gypsic horizons, which would normally place them in the Aridisol Order, but as this represents only bands of aeolian gypsic sand, rather than true secondary gypsum, they are retained in the Typic Torripsamments.

(iii) Torriorthent Great Group. Soil Taxonomy describes Orthents as being primarily the Entisols on recent erosional surfaces. Torriorthents are usually dry, they are slightly to moderately saline and differ from the Torripsamments by having either a finer than sandy particle-size class or gravelly layers. Lithic Torriorthents, which have a lithic contact within 50cm, are widespread on the limestone pavements in the Bahrain Level 3 areas. These soils contain varied quantities of aeolian gypsum material. Although this gypsum is therefore not truly secondary, there is evidence of recrystallisation and the formation of pendants beneath coarse fragments.

For the present these soils are not considered to have a gypsic horizon and are classed as Torriorthents but a case exists for introducing a Lithic Gypsiorthid subgroup in the Aridisols to include shallow soils such as these which have gypsum contents sufficient for the Typic Gypsiorthid subgroup.

4.4 LOWER CATEGORY CLASSIFICATION

4.4.1 Introduction

Two lower categories are included in Soil Taxonomy: family and series. At Level 3 soil phases have been mapped within series carrying the classification beyond Soil Taxonomy into a level of detail specifically aimed at the objective of irrigation development.

Lower category classification is intended to be more pragmatic than that for higher categories. The differentiae used are primarily those which affect the response of the soil to management and use, rather than pedogenic relationships.

4.4.2 Soil Family Differentiae

Of the nine possible criteria for family differentiation, only three major ones apply to the Level 3 soils: particle-size class, mineralogy class and soil temperature class.

(a) Particle-size Class

Particle-size refers to grain-size distribution of the whole soil and is not the same as texture, which refers to the fine-earth fraction (diameter less than 2mm). Particle-size classes are a compromise between engineering and pedologic classifications. Because of this the very fine sand fraction can be used flexibly and be treated as sand if the texture is fine sand, loamy fine sand or a coarser class or it can be treated as silt if the texture is very fine sand, loamy very fine sand, sandy loam, silt loam or a finer class.

Soil Taxonomy gives a choice of 7 or 11 particle-size classes:-

(i) Fragmental. Stones, cobbles, gravel and very coarse sand particles; too little fine earth to fill interstices larger than 1mm in diameter.

(ii) Sandy-skeletal. Rock fragments 2mm in diameter or larger make up 35 per cent or more by volume; enough fine earth to fill interstices larger than 1mm; the fraction finer than 2mm is sandy as defined for the sandy particle-size class.

(iii) Loamy-skeletal. Rock fragments make up 35 per cent or more by volume; enough fine earth to fill interstices larger than 1mm; the fraction finer than 2mm is loamy as defined for the loamy particle-size class.

(iv) Clayey-skeletal. Rock fragments make up 35 per cent or more by volume; enough fine earth to fill interstices larger than 1mm; the fraction finer than 2mm is clayey as defined for the clayey particle-size class.

(v) Sandy. The texture of the fine earth is sand or loamy sand but not loamy very fine sand or very fine sand; rock fragments make up less than 35 per cent by volume.

(vi) Loamy. The texture of the fine earth is loamy very fine sand, very fine sand, or finer, but the amount of clay is less than 35 per cent; rock fragments are less than 35 per cent by volume.

The class can be further divided into:-

- Coarse-loamy. By weight, 15 per cent or more of the particles are fine sand (diameter 0.25-0.1mm) or coarser, including fragments up to 7.5cm in diameter; less than 18 per cent clay in the fine-earth fraction.

- Fine-loamy. By weight, 15 per cent or more of the particles are fine sand (diameter 0.25-0.1mm) or coarser, including fragments up to 7.5cm in diamter; 18 to 34 per cent clay in the fine-earth fraction (30 per cent in Vertisols).

- Coarse-silty. By weight, less than 15 per cent of the particles are fine sand (diameter 0.25-0.1mm) or coarser, including fragments up to 7.5cm in diameter; less than 18 per cent clay in the fine-earth fraction.

- Fine-silty. By weight, less than 15 per cent of the particles are fine sand (diameter 0.25-0.1mm) or coarser, including fragments up to 7.5cm in diameter; 18 to 34 per cent clay in the fine earth-fraction.

(vii) Clayey. The fine earth contains 35 per cent or more clay by weight, and rock fragments are less than 35 per cent by volume. The class can be subdivided into:-

- Fine. A clayey particle-size class that has 35 to 59 per cent clay in the fine-earth fraction.

- Very fine. A clayey particle-size class that has 60 per cent or more clay in the fine-earth fraction.

Particles-size class is the major criterion used in family classification of Level 3 soils; most families are separated by particle-size alone. It is used with all soil units except Torripsamments, where the name itself implies a sandy (but not sandy-skeletal) particle-size class. Because of the high contents of gypsum and $CaCO_3$ in the soils, accurate distinction between particle-sizes proved to be difficult both in the laboratory and in the field. For this reason the silty particle-sizes are included with the loamy classes at family level although they are used to define units at series

level. Thus of the 11 particle-sizes listed above, five were used in the Level 3 surveys. These correlate broadly with the traditional textural classes (USDA, 1951) as follows:-

1. Clayey: cl(h), sicl(h), sc, fsc, vfsc, sic, c.
2. Fine-loamy: l(h), scl, fscl, vfscl, sicl, cl.
3. Coarse-loamy: vfs, lvfs, sl, fsl, si, l, sil, vfsl.
4. Sandy: s, fs, ls, lfs.
5 Coarse-loamy-skeletal: very or extremely gravelly coarse-loamy classes.

(Note: The relationship between particle-size classes and textural classes are illustrated in Figure 4.2)

The control section for particle-size classes is from 25 to 100cm or to a lithic or paralithic contact, or petrocalcic or petrogypsic horizon if these are within 100cm. In very shallow soils which have these depth limits at or within 35cm, the control section is from the surface.

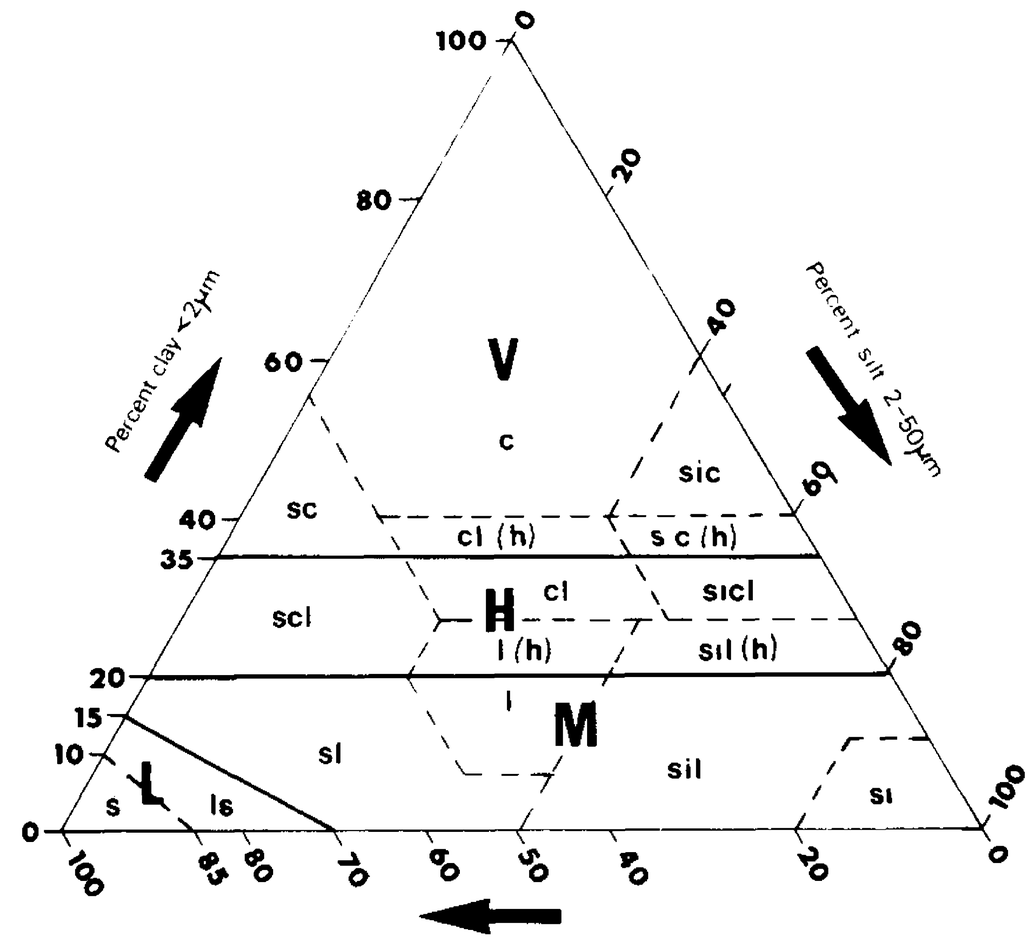
Lateral and vertical variability are both usually greater in arid region soils than in humid region soils. Vertical variability and generally sharp horizon boundaries may result in strongly contrasting particle-size classes, where transitions between contrasting horizons are less than 12.5cm thick. Only one strongly contrasting particle-size family has been mapped, where coarse loamy material abruptly overlies fine loamy (silty) horizons within the control section.

(b) Mineralogy Class

Using the Soil Taxonomy key to mineralogy classes, the following classes are seen to be possible in the Level 3 areas:-

- Carbonatic — more than 40 per cent $CaCO_3$ plus gypsum, $CaCO_3$ more than 65 per cent of the combination.

Figure 4.2 Relationship of Particle-Size Classes to the Traditional Texture Classes



V=clayey
- c–clay
- sc–all sandy clays
- sic–silty clay
- cl(h)–heavy clay loam
- sicl(h)–heavy silty clay loam

M = coarse loamy
- vfs–very fine sand
- lvfs–loamy very fine sand
- sl–sandy loam
- fsl–fine sandy loam
- vfsl–very fine sandy loam
- l–loam
- sil–silt loam
- si–silt

H=fine loamy
- scl–all sandy clay loams
- cl–clay loam
- l(h)–heavy loam
- sicl–silty clay loam
- sil(h)–heavy silt loam

L = sandy
- lfs–loamy fine
- ls–loamy sand
- fs–fine sand
- s–sand

NOTE: Skeletal particle-size classes occur where 35% by volume exceeds 2mm (2000µm) diameter. The fragmental class has ≥ 90% of such material.

gc

- Gypsic — More than 40 per cent $CaCO_3$ plus gypsum, gypsum more than 35 per cent of combination.

- Mixed — Soils with less than 40 per cent of any one mineral other than quartz or felspar.

Of these classes, carbonatic and gypsic occur most frequently and each are important in differentiating soil families.

Mineralogy classes are based on the approximate soil mineralogical compositions within the same control section as used for particle-size, in this case being normally between 25 and 100cm depth. It is particularly important to note that the upper 25cm are excluded from the control section, for in many soils of the Bahrain Level 3 areas this is the zone in which gypsum is concentrated. Although in the higher category classification gypsum is considered from the surface downwards, for family divisions the upper 25cm is ignored. Consequently, some gypsic subgroups have carbonatic, not gypsic, mineralogy.

Contrasting mineralogy classes are treated in a similar fashion to particle-size classes except that the upper qualifier alone is used. Hence, soils with moderately deep superficial gypsic horizons over highly calcareous silt loams are termed "coarse loamy over fine loamy, gypsic" rather than "coarse loamy, gypsic over fine loamy, carbonatic". Similarly, profiles with gypsic coarse sand to a depth of, say, 65cm overlying calcareous silicious sand are described as "sandy, gypsic" not "sandy, gypsic over mixed".

Mixed mineralogy classes apply in those subgroups of the Cambic Gypsiorthids and Typic Paleorthids which have relatively low carbonate and gypsum contents, the control section in the latter is anyway reduced in thickness by the presence of a petrocalcic horizon. This mineralogy class also applies to the Entisol subgroups; both the

Torripsamments and Psammaquents are highly silicious but contain at least ten per cent of calcium carbonate and gypsum in the fine-earth fraction, precluding them from the silicious class.

Calcareous classes are used to further quality soils according to their reaction to dilute HCL. All soils examined were calcareous but as this class is applied to neither Aridisols nor Entisols which have sandy or fragmental particle-size classes, it has not been used in family differentiation during the present survey.

(e) Soil Temperature Class

As discussed earlier in this chapter, the hyperthermic temperature class applies to all soils in Bahrain.

4.4.3 Family Nomenclature

Soil family names usually consist of at least three differentiae. In addition, the subgroup must be stated for the same set of family differentiae can occur in several different subgroups. This produces very complicated and lengthy names at family level, such as "coarse-loamy,skeletal, mixed, hyperthermic family of Lithic Torriorthents" and makes this category of classification rather difficult to use. On the other hand, the family nomenclature does provide practical information on basic features which affect crop production, namely the particle-size and mineralogy class in the root zone and the temperature regime of the soil.

A total of 15 families were defined during the Level 3 surveys, as listed in Table 4.1.

4.4.4 Soil Series Differentiae

The series is the lowest category in the Soil Taxonomy system. The series and the differentiae to be used in classifying it are not rigidly defined in the system; this flexibility is partly to allow as little disturbance as possible of existing series created under previous classification systems. The differentiae used are mostly the same as those used for classes in other categories, but the range permitted in one or more properties is less than is permitted in the family or higher

Table 4.1 Soil Families

Subgroup	Soil Family
Typic Salorthids	Fine-loamy, carbonatic, hyperthermic
Gypsic Salorthids	Fine-loamy, carbonatic, hyperthermic
Typic Gypsiorthids	Sandy, gypsic, hyperthermic Coarse-loamy, gypsic, hyperthermic Coarse-loamy over fine-loamy, gypsic, hyperthermic.
Cambic Gypsiorthids	Coarse-loamy, mixed, hyperthermic Fine-loamy, carbonatic, hyperthermic Clayey, carbonatic, hyperthermic
Typic Paleorthids	Sandy, mixed, hyperthermic Fine-loamy, mixed, hyperthermic Fine-loamy, carbonatic, hyperthermic
Aquic Paleorthids	Coarse-loamy, carbonatic, hyperthermic
Typic Torripsamments	Mixed, hyperthermic
Typic Psammaquents	Mixed, hyperthermic
Lithic Torriorthents	Coarse-loamy, skeletal, mixed, hyperthermic.

categories. As for the family, the system aims to create series that are closely allied to interpretive applications.

A series cannot range across family divisions or between two classes of any higher category. From a specific practical viewpoint, such as irrigation development, this is sometimes a disadvantage because series and even families are created by some pedogenic difference at a higher level, even though for the specific survey objective they are inseparable.

Within a given family, series are distinguished by restrictions in one or more, but not necessarily all, the ranges in properties of the family. Differences in structure, organic content, consistence and so on should be considered at series level. The number of series per family varies greatly but two to four are common figures, with an average of 2.3 series per family in the United States in 1977.

The principal criteria used at Level 3 to separate soil series within a family were as follows:-

(a) Lithic or paralithic contact between 50 and 100cm depth.

(b) The presence of gravels or weakly cemented gravelly layers in the 50 to 100cm zone.

(c) Presence of a petrocalcic horizon between 50 and 100cm depth.

(d) Mineralogy in the subsoil; where contrasting mineralogy occurs the subsoil mineralogy is not cited at family level. At series level it is possible,for example, to separate sandy, gypsic soils which have 1.0m or more of gypsum sand from those which have 65cm of gypsum sand over silicious sand.

(e) Morphology and arrangement of horizons. This was applied to separate soils which have stratified profiles, which indicate alternating deposition of gypsum and insoluble mineral materials during their formation.

4.4.5 Series Nomenclature

Series have been named according to the traditional method of adopting geographical names from the area in which the type profile is described. Two-letter abbreviations are used as

mapping symbols. A total of 19 series were defined during the Level 3 surveys, except for two minor complexes, they were mapped separately. The series are described briefly in Chapter 5 and in detail in Appendix B.

4.4.6 Soil Phases

This category is not covered by Soil Taxonomy but is quoted as being necessary in some instances to separate series where soil differences relevant to the forseeable use of the land are not differentiated at higher levels. Phases mostly concern the topsoil, which is excluded from the control section at higher levels of classification. Characteristics of the topsoil which are expected to affect cultivation or crop rooting have been separated at phase level wherever possible. In the Level 3 surveys phases were separated on the basis of six criteria:-

(i) Salinity. Soils with salinities in the upper 50cm in excess of 64 mmhos cm^{-1} are placed in an extremely saline phase. This does not apply to Salorthids, which by definition are extremely saline.

(ii) High Watertable. In those series where the watertable is normally deeper than 1.0m, a high watertable phase is mapped where the watertable occurs within the 0.5 to 1.0m zone.

(iii) Non-cemented Topsoil. In some highly gypsic soils the upper 50cm comprise loose, friable gypsic sand rather than weakly cemented gypsum. These are separated as a non-cemented topsoil phase.

(iv) Sandy Topsoil. Non-cemented silicious sand overlays to some highly gypsic soils have been separated as the sandy topsoil phase.

(v) Depth to petrocalcic horizon. The petrocalcic horizon usually occurs at a depth of 0.5 to 1.0m but locally it was recorded within the upper 50cm. Strictly speaking, this should have been differentiated at family level but

in view of the very small area concerned it has been separated as a shallow petrocalcic phase.

(vi) Superficial Gypsum. Superficial crusts of weakly cemented gypsum crystals, provided they are less than 15cm thick, do not qualify as gypsic horizons but are significant for agriculture. Where such crusts occur over non-gypsic subsoils they have been identified as the superficial gypsic phase.

In addition to the soil characteristics which have been separated at phase level, land development for irrigation is affected by several non-soil features such as micro-relief, the nature of the substratum and drainage. These features were mapped individually (Chapter 6) and are combined with the interpretive soils data in the land classification mapping (Chapter 7).

4.5 CORRELATION WITH FAO/UNESCO SOIL UNITS

Table 4.2 correlates the soil taxonomy mapping units used in the present survey with the units of the FAO/Unesco (1974) legend for the Soil Map of the World. Close correlation is inevitably difficult to achieve because one is not comparing like systems. The former is a detailed taxonomy for eventual use down to series level whereas the latter is designed as a practical legend for small scale soils maps and is not intended to be a true taxonomy.

The principal difference between the two systems, in so far as the soils of Bahrain are concerned, is in the relative importance attached to gypsiferous and saline horizons. To be classified as a Salorthid a soil must be extremely saline but to meet the requirements of a Solonchak an ECe of more than only 15 mmhos cm^{-1} is necessary. Thus most of the soil series mapped in Bahrain automatically become Solonchaks, solely on account of their high salinities. As no provision is made for separate recognition of highly gypsic soils, they are therefore Orthic Solonchaks.

Table 4.2 Correlation of Soil Taxonomy Classification with FAO/UNESCO Soil Units

Soil Taxonomy	Soil Series	Soil Unit	FAO/UNESCO Texture	Slope	Phase	Symbol
ARIDISOLS						
Typic Salorthids	Tubli	Gleyic Solonchaks	Medium	Level	Phreatic	Zg-2a-w
Gypsic Salorthids	Khadarah	Orthic Solonchaks	Medium	Level	Phreatic	Zo-2a-w
Typic Gypsiorthids	Karzakkan	Gypsic Yermosols	Coarse	Level	Saline	Yy-1a-x
	Hawrah	Gypsic Yermosols	Coarse	Level	Saline	Yy-1a-x
	Buri	Gypsic Yermosols	Coarse	Level	Saline, Phreatic	Yy-2a-x·w
	Maqabah	Orthic Solonchaks	Medium	Level	Phreatic	Zo-2a-w
	Buhayr	Orthic Solonchaks	Medium	Level	Phreatic	Zo-2a-w
	Sar	Orthic Solonchaks	Medium	Level	Phreatic	Zo-2a-w
	Abu Saybi'	Orthic Solonchaks	Medium	Level	Phreatic	Zo-2a-w
Cambic Gypsiorthids	Zaytun	Orthic Solonchaks	Medium	Level	-	Zo-2a
	Khuways	Orthic Solonchaks	Medium	Level	Phreatic	Zo-2a-w
	Lawzi	Orthic Solonchaks	Fine	Level	Phreatic	Zo-3a-w
Typic Paleorthids	Areen	Gypsic Yermosols	Coarse	Level	Petrocalcic, Saline, Phreatic	Yy-1a-cxw
	Salmabad	Orthic Solonchaks	Medium	Level	Petrocalcic, Phreatic	Zo-2a-cw
	Buquwwah	Orthic Solonchaks	Medium	Level	Petrocalcic, Phreatic	Zo-2a-cw
Aquic Paleorthids	Isa	Gleyic Solonchaks	Medium	Level	Petrocalcic, Phreatic	Zg-2a-cw
ENTISOLS						
Typic Torripsamments	Hisham	Albic Arenosols	Coarse	Level	Saline, Phreatic	Qa-1a-xw
Typic Psammaquents	Wasmiyah	Gleyic Solonchaks	Coarse	Level	Phreatic	Zg-1a-w
Lithic Torriorthents	Dilmun	Calcaric Regosols	Medium	Level	Stony,Lithic,Saline	Rc-2a-slx

NOTE: Texture: 1-coarse; 2-medium; 3-fine. Phases: S-stony; l-lithic; c-petrocalcic; w-phreatic; x-saline.

This is not logical, for salinities of this order can be leached, whereas the very high gypsum content, often exceeding 60 per cent of the upper metre, remains a significant feature of the soils. The few gypsiferous soils which areseparately classified as Gypsic Yermosols, are those with low salinity.

Clearly, there is a need to introduce a new unit to distinguish gypsic saline soils; this could be termed a Gypsic Solonchak. Gypsic Solonchaks (Zy) could be defined as 'other Solonchaks having a gypsic horizon within 125 cm of the surface'. The same qualifications on depth would apply as for Gypsic Yermosols.

Differentiation of FAO/Unesco phases is feasible at the series level of mapping. The phreatic phase is most common, indicating a watertable at 3.0 - 5.0m depth. Saline phases (ECe more than 4.0 mmhos cm^{-1}) apply to all soil units which are not already indirectly defined as saline by being classed as Solonchaks.

5

Soil Mapping Units

5.1 INTRODUCTION

The soil survey of the Level 3 areas was based on the identification and mapping of soil series. In addition, some minor areas of little or no soil were delineated as miscellaneous land types. The soils were mapped at a scale of 1:10 000 (see maps) and this mapping formed the basis for subsequent evaluation of the suitability of the land for irrigation agriculture.

5.2 SOIL SERIES

A total of 19 soil series were identified during the course of the study. Taxonomic procedures of series identification have been described already, in this chapter the principal features of each mapping unit are described in terms of physiography and profile morphology. Complete definitions of each series, including analytical data and descriptions of representative profiles, are to be found in Appendix B. A summary of soil characteristics is provided in Table 5.1 and the areas of each series mapping unit are shown in Table 5.2.

The soils were mapped as simple series, phases of series or, rarely, as complexes of two series.

5.2.1 Typic Salorthids

(a) Tubli Series - Tb.

The Tubli series belongs to the fine-loamy, carbonatic, hyperthermic family of Typic Salorthids. The soils have loamy topsoils which are rich in soluble salts and gypsum; these overlie a subsoil of carbonatic silt loam or loam alluvium. These loamy horizons usually extend to at least 1.0m depth and are underlain by grey gleyed sands or sandy clay loams. A shallow watertable lies within the upper 0.5m, upward capillary movement and evaporation from which accounts for the salic surface horizon and superficial salt crust. The natural vegetation is dominated by halophilous species.

such as Salicornia, Arthrocnemum and Avicennia spp. The soils occur in the low-lying area of the Tubli Estuary in which natural drainage is restricted by low elevation above sea level. Artificial drainage would be needed to effect reclamation leaching but lowering

Table 5.1 Summary of Soil Series Characteristics

Sub-group/ Family	Series	Physiography	Profile Characteristics
TYPIC SALORTHIDS			
Fine loamy, carbonatic, hyperthermic	Tubli-Tb	Level; coastal swamps and depressions; marine alluvium; shallow watertable.	Deep; fine-silty over silicious sand; very poorly drained; gypsic surface, extremely saline.
GYPSIC SALORTHIDS			
Fine loamy, carbonatic, hyperthermic	Khadarah -Kd	Level; depressions; marine alluvium; moderately deep watertable.	Deep; gypsic coarse-loamy (silty) over carbonatic fine loamy (silty); poorly drained; extremely gypsic and saline.
TYPIC GYPSICRTHIDS			
Sandy, gypsic, hyperthermic	Karzakkan -Kn	Level plains; gypsum over aeolian sand, extremely deep watertable.	Deep; cemented gypsic coarse sand over fine silicious sand; well drained; extremely gypsic; slightly saline.
	Hawrah -Hw	Level plains; aeolian sand and outwash fan alluvium; deep watertable.	Deep; gypsum cemented loamy sand over fine loam in deep subsoil; well drained; extremely gypsic, slightly saline.
	Buri-Br	Level, slightly uneven; aeolian sand; extremely deep watertable	Deep; gypsum cemented stratified sand over loamy subsoil; well drained; extremely gypsic, usually saline.
Coarse loamy, gypsic, hyperthermic	Maqabah -Mq	Level, slightly uneven gypsic sand, partially aeolian; deep watertable.	Deep; cemented coarse-loamy and sandy gypsum; usually carbonatic loamy deep subsoil; well drained; extremely gypsic, saline.

Table 5.1 Continued

Sub-group/ Family	Series	Physiography	Profile Characteristics
	Buhayr-Bu	Level plain; lacustrine alluvium; deep watertable.	Deep; weakly cemented gypsic sand surface over stratified varved gypsic loam; moderately well drained; extremely gypsic, saline.
Coarse-loamy over fine-loamy, gypsic, hyperthermic	Sar-Sa	Level plains; gypsum over calcareous marine alluvium; deep watertable.	Deep; weakly cemented coarse-loamy gypsum over carbonatic fine-loamy (silty) subsoil, usually gravelly; imperfectly drained; extremely gypsic, saline.
	Abu Saybi - Sb	Level, slightly uneven; gypsum over calcareous marine alluvium, usually deep watertable.	Deep; weaklycemented coarse-loamy gypsum over carbonatic fine-loamy (silty) subsoil;imperfectly drained; extremely gypsic, saline to extremely saline
CAMBIC GYPSIORTHIDS			
Coarse-loamy, mixed, hyperthermic	Zaytun -Zn	Level to slightly uneven plains and footslopes; extremely deep watertable.	Moderately deep coarse-loam (gravelly) over paralithic contact; well drained; gypsic,usually saline.
Fine-loamy, carbonatic, hyperthermic	Khuways -Kh	Level plains with uneven microrelief; marine alluvium; usually deep watertable.	Deep; fine-loamy (silty) over carbonatic fine-loamy; moderately well drained; gypsic, saline or extremely saline.
Clayey, carbonatic hyperthermic	Lawzi-Lw	Level plains; marine and outwash fan alluvium; extremely deep watertable.	Deep; fine clayey (silty) moderately well drained; gypsic, saline.
TYPIC PALEORTHIDS			
Sandy,mixed, hyperthermic	Areen-Ar	Level to gently undulating plains with minor dune forms; aeolian sand; deep watertable.	Moderately deep; gypsic and silicious sand over weakly $CaCO_3$ cemented sand over petrocalcic horizon; well drained; usually gypsic and slightly saline.

Table 5.1 Continued

Sub-group/ Family	Series	Physiography	Profile Characteristics
Fine-loamy, mixed, hyperthermic	Salmabad -Sm	Level plains; gypsic alluvium over carbonate cemented aeolian sand; extremely deep watertable.	Moderately deep; weak gypsum cemented loams over sandy petrocalcic horizon; well drained; gypsic, saline.
Fine-loamy, carbonatic, hyperthermic	Buquwwah -Bw	Level plains with uneven microrelief; marine alluvium over aeolian sand; usually deep watertable.	Moderately deep; fine-loamy with slightly gravelly subsoil overlying petrocalcic horizon; moderately well drained; gypsic, usually extremely saline.
AQUIC PALECRTHIDS			
Coarse-loamy, carbonatic, hyperthermic	Isa-Is	Level plains; carbonate-rich alluvium; usually deep watertable.	Moderately deep; gypsic cemented coarse-loamy over carbonatic slightly gravelly coarse-loamy over porous petrocalcic horizon; imperfectly drained; extremely gypsic, saline.
TYPIC TORRIPSAMMENTS			
Mixed, hyperthermic	Hisham-Hs	Level to slightly sloping plains, often with minor dune forms; aeolian sand; usually extremely deep watertable.	Deep; fine sandy, rarely slightly gravelly in deep subsoil; excessively drained; slightly gypsic, saline.
TYPIC PSAMMAQUENTS			
Mixed, hyperthermic	Wasmiyah -Ws	Level coastal plains; aeolian and marine sands; moderately deep watertable.	Deep; thin salt crust over fine sand; very poorly drained; usually slightly gypsic and saline.
LITHIC TORRICRTHENTS			
Coarse-loamy skeletal, mixed, hyperthermic	Dilmun-Dm	Slightly sloping footslopes and minor ridges; carbonate rock colluvium; extremely deep watertable.	Shallow; very gravelly over lithic contact; gypsum pendants to stones; well drained usually saline and gypsic.

Table 5.2 Areas of Soil Mapping Units

Mapping Unit	Area ha	%
Series		
Tubli	22.2	0.5
Khadarah	198.4	4.8
Karzakkan	39.6	1.0
Hawrah	13.5	0.3
Buri	124.8	3.0
Maqabah	820.1	19.9
Buhayr	77.4	1.9
Sar	208.2	5.1
Abu Saybi	195.8	4.8
Zaytun	64.7	1.6
Khuways	1003.4	24.4
Lawzi	65.3	1.6
Areen	97.6	2.4
Salmabad	76.1	1.9
Buquwwah	61.6	1.5
Isa	192.4	4.7
Hisham	352.3	8.6
Wasmiyah	83.4	2.0
Dilmun	229.3	5.6
Miscellaneous Land Types and Villages	187.2	4.6
TOTAL	4113.0	100.0

NOTE Complexes listed under dominant Series.

the watertable could result in intrusion by sea water.

5.2.2 Gypsic Salorthids

(a) Khadarah Series - Kd

This series belongs to the fine-loamy, carbonatic, hyperthermic family of Gypsic Salorthids. These soils are similar to Tubli series except that the surface horizon is thicker and contains more gypsum. The carbonatic subsoil is often weakly stratified, frequently contains minor peat layers and is weakly cemented by calcite below 1.0m. The watertable is slightly deeper than in Tubli series and drainage is generally more favourable, as indicated by the natural vegetation which includes species of Halocnemum, Zygophyllum, Suaeda and Aeluropus.

The series occurs in the Khadarah Depression and in other minor basins within the Salmabad area at elevations of 1.5 to 4.0m above sea level. Some of the area has been cultivated in the past, as indicated by a micro-relief of abandoned irrigation channels. High watertables and problems of drainage water disposal would have to be overcome before the substantial leaching which is required for reclamation could be effected. Even after leaching, the surface soil would still be extremely gypsic.

5.2.3 Typic Gypsiorthids

(a) Karzakkan Series - Kn

This series belongs to the sandy, gypsic, hyperthermic family of Typic Gypsiorthids. It comprises profiles with a layer of loosely cemented gypsum flakes and crystals abruptly overlying fine grained aeolian quartz sand. This gypsum-rich surface horizon is sufficiently thick to give the soils a gypsic mineralogy. Profiles are dry throughout the upper 2.0m and are only slightly saline. Micro-relief is smooth except for minor hummocks of sand around xerophilous species such as Zygophyllum, Heliotropium and Eragrostis, which predominate on these soils.

The series is mapped as part of the Rebkha Plain in the extreme south west of the Salmabad area.

The cemented superficial gypsic horizon creates a severe limitation to cultivation and root development. Furthermore, the soils have very fast infiltration rates and low natural fertility.

(b) Hawrah Series - Hw

This series belongs to the sandy, gypsic, hyperthermic family of Typic Gypsiorthids. Hawrah soils have a surface horizon of loose loamy sand, some 10 - 25cm thick. This overlies a sandy gypsic horizon which is strongly cemented by hard bands of crystalline gypsum. Cementing decreases in the lower subsoil, which is more friable. A paralithic contact with weathered limestone occurs at between 1.5 and 2.0m. The series occurs locally along the foot of the limestone pavement in the Hawrat 'Inqa area; micro-relief is smooth except for minor hummocks. The soils are dry and carry a cover of xerophytes. The soils have very limited value due to a hard gypsic horizon and the risk of occasional flash flooding off the limestone backslope.

(c) Buri Series - Br

The Buri series also belongs to the sandy, gypsic, hyperthermic family of Typic Gypsiorthids. The soils resemble Hawrah series but have sandy loam subsoils and more distinctly banded gypsum cementing in the gypsic horizon. Minor dunes and hummocks are common. Profiles are dry, moderately saline and carry a cover of xerophytes such as Zygophyllum, Heliotropium, Eragrostis and Stipagrostis spp. As with Hawrah series the gypsum cemented layers severely limit agricultural potential. However, a non-cemented topsoil phase (0-50cm loose sand) has been mapped and this land offers some potential for irrigation despite the underlying gypsic horizons.

(d) Maqabah Series - Mq

This series forms part of the coarse-loamy, gypsic, hyperthermic family of Typic Gypsiorthids. The profiles are dominated by extremely high proportions of crystalline gypsum to depths often exceeding 1.5m. Honeycomb gypsum cementing is common in the upper horizons and thin bands of petrogypsic material often occur. The Maqabah soils occur extensively on the level Nebkha Plains throughout the Salmabad area. A watertable occurs at depths of 1.5 to 2.0m and upward capillary rise and evaporation of moisture accounts for much of the gypsum although there has been considerable redistribution of gypsic sand by wind erosion. Salinity levels are relatively low. The soils have a sparse cover of xerophytes and halophytes, including species of Zygophyllum, Atriplex, Suaeda, Aeluropus, Anabasis, Juncus and Eragrostis.

Agricultural potential is severely restricted by the thickness and high percentage of gypsum and subsoil cementing, which would pose hazards of solution collapse and poor root penetration under irrigation. More favourable conditions apply where the cemented layers are overlain by significant depths of non-cemented aeolian gypsic sand. These areas are separated as the non-cemented topsoil phase.

(e) Buhayr Series - Bu

These soils are also members of the coarse-loamy, gypsic hyperthermic family of Typic Gypsiorthids. They differ from Maqabah series in having a less strongly cemented upper gypsic horizon and a friable subsoil comprising thin varves of gypsic sandy loam and silt loams, the latter being characteristic of this series. Although the watertable does not occur within the upper 2.0m the subsoils are moist and ponding occurs locally after rain. Moderately high salinities were recorded. The soils occur in the Buhayr area: the terrain is level but much disturbed by refuse disposal operations. Topsoil cementing, high salinities and excessive gypsum contents

throughout the profile severely limit the value of these soils for irrigation. Moreover, substratum rock layers and problems of water disposal restrict the feasibility of drainage.

(f) Sar Series - Sa

This series belongs to the coarse-loamy over fine loamy gypsic, hyperthermic family of Typic Gypsiorthids. The profiles have a weakly cemented gypsic sandy loam horizon, less than 65cm thick, which abruptly overlies highly calcareous loams or silt loams. Thin buried layers of organic matter are common. Calcite concretions are present in the subsoil and a weakly developed petrocalcic horizon often occurs at or below 1.0m. The latter usually lies immediately above the watertable and may be actively forming at present. The soils are moist throughout most of their profile and saline due to upward migration of salts from the watertable.

Sar series occupies a transitional position between the Nebkha and Loam Plains and the vegetation contains species typical of each: Suaeda, Cressa, Salsola, Phragmites, Halocnemum and Zygophyllum as well as remnant date palms. Some Sar soils are cultivated but most are abandoned or uncultivated. The soils have low agricultural potential due to superficial gypsum, salinity and internal drainage deficiencies.

(g) Abu Saybi Series - Sb

This series also belongs to the coarse-loamy over fine-loamy, gypsic, hyperthermic family of Typic Gypsiorthids. The soils closely resemble Sar series except for the absence of an incipient petrocalcic horizon and calcite gravels in the subsoil as well as a thinner superficial gypsum horizon. In some areas the watertable is within the 0.5 to 1.0m zone and the soils are separated as a high watertable phase. Abu Saybi soils are saline, especially in their upper horizons; some are extremely saline (ECe more than 64.0 mmhos cm^{-1}) and as such are separated at phase level.

Apart from its occurrence in the transition between Nebkha and Loam Plains, the series also occurs within the Loam Plains in local depressions where superficial gypsum has accumulated. Many of the soils have been cultivated in the past but few areas are irrigated at present. Abu Saybi soils have low potential due to salinity, high watertable and gypsum, although the loam subsoils have moderate fertility potential. Reclamation would involve substantial leaching and extensive drainage and, in low-lying areas, the risk of sea water intrusion.

5.2.4 Cambic Gypsiorthids

(a) Zaytun Series - Zn

This series belongs to the coarse-loamy, mixed, hyperthermic family of Cambic Gypsiorthids. Profiles are moderately deep, comprising loam or sandy loam with varied gravel contents overlying a paralithic contact within the 50 to 100cm zone. The upper horizons are gypsic and usually saline although the watertable is very deep and the profiles are dry. They occur locally adjacent to the Limestone Pavement in the Salmabad area. The sparse cover of xerophytes includes Hammada elegans, Heliotropium tuberculosum and Eragrostis sp. Some Zaytun soils are being irrigated. Although they are limited by profile depth, micro-relief and, locally, erosion hazard, the weathered rock subsoil and slight elevation of the soils do aid drainage.

(b) Khuways Series - Kh

These soils belong to the fine-loamy, carbonatic, hyperthermic family of Cambic Gypsiorthids. They have uniform, deep, silt loam or loam profiles which are moderately well structured and porous. The soils have a high watertable, usually between 1.0 and 2.0m but in some soils, which are mapped as a high watertable phase, it lies in the 0.5 to 1.0m zone. Upward migration of salts from the saturated zone results in high salinities in the upper horizons and a friable salt mulch at the surface. Large areas have extremely high salinities and are identified accordingly at phase level. Gypsum accumulation also occurs in the uppermost horizon, as finely divided particles. Khuways soils carry a distinctive

halophyte cover of Suaeda pruinosa, Cressa cretica and Phragmites australis.

A very large proportion of the Khuways soils have been used for irrigated dates but most of the land has now been abandoned. The soils have a moderately high potential for agriculture, with favourable rooting depth, available moisture and fertility potential, but requiring substantial leaching and drainage as well as land levelling to remove the network of former irrigation channels. In the lower lying parts of the Salmabad area the potential of these soils is reduced by problems of drainage water disposal and sea water intrusion. Measured infiltration rates are remarkably high and compare with those on sands. Even so, they ought to be more suitable for basin irrigation than the sands, as compaction following cultivation should slow the intake rates.

(c) Lawzi Series - Lw

These soils are members of the clayey, carbonatic, hyperthermic family of Cambic Gypsiorthids. Silty clay textures predominate in the control section, making these the finest textured soils in the area. Weakly developed Vertisol features, such as cracking and sink holes, are common in Lawzi series. The soils are usually dry, with watertables below 2.5m, and only moderately saline. The uppermost horizon is classed as gypsic.

The soils occupy the Lower Fans of the Salmabad area. The terrain is level and the land carries a moderately dense cover of vegetation, including species of Zygophyllum, Atriplex, Halocnemum and Suaeda. Lawzi soils have high fertility potential and favourable moisture holding characteristics but their fine textures reduce infiltration and leaching efficiency. Furthermore, the soils have a tendency to cap and would therefore be less suited to overhead irrigation.

5.2.5 Typic Paleorthids

(a) Areen Series - An

These soils belong to the sandy, mixed, hyperthermic family of Typic Paleorthids. The petrocalcic horizon

comprises calcite-cemented sand layers which usually occur at between 75 and 100cm. This is overlain by loose sandy material, often containing calcite-cemented modules, and a weakly cemented gypsic sand superficial horizon. Rarely the profiles are truncated by wind erosion and the petrocalcic horizon occurs within the upper 50cm: these soils are separated at phase level. The soils occur on the Hawrat 'Inqa sand sheets at elevations ranging from 2.0 to 5.0m above sea level. The watertable is usually within 1.5m but soil salinities are low. Typical plants include Helianthemum, Panicum, Eragrostis, Cyperus and Heliotropium species.

The soils have moderate depth and low salinity but high superficial gypsum; micro-relief is uneven locally and drainage will be essential in low-lying areas but only at risk of sea water intrusion.

(b) Salmabad Series - Sm

These soils belong to the fine-loamy, mixed, hyperthermic family of Typic Paleorthids. As in Areen series, the petrocalcic horizon usually lies at between 75 and 100cm but it is thicker and more indurated in Salmabad series. Locally this layer occurs within the upper 50cm of the profile. The petrocalcic horizon is overlain by friable loam or sandy clay loam and a weakly cemented surface horizon of gypsic sandy loam, which is largely of aeolian origin. Watertables are usually below 2.0 to 2.5m but high salinities are recorded in the upper horizons. Salmabad soils occur in the south east of the Salmabad area on level terrain. Some areas have been cultivated in the past but have long since been abandoned and now carry a sparse cover of Suaeda, Salsola and Zygophyllum species and remnant date palms. They have very low potential for agriculture due to superficial gypsum, high salinity and an impenetrable petrocalcic horizon which restricts rooting and creates a problem for drainage.

(c) Buquwwah Series - Bw

These soils are members of the fine-loamy, carbonatic, hyperthermic family of Typic Paleorthids. Profiles are similar to Salmabad series but lack the prominent superficial gypsum horizon. The upper profile in fact resembles Khuways series. Surface horizons are silt loam to fine sandy loam and contain sufficient finely divided gypsum to be gypsic but are not cemented. The subsoil is loam to clay loam with a high carbonate content, resulting in the soils carbonatic mineralogy. This horizon abruptly overlies a calcite-cemented sandy petrocalcic layer at between 50 and 100cm. The watertable is usually deeper than 2.0m but capillary rise accounts for high salinity in many profiles. The soils occur on the Loam Plains in the Salmabad area: most have been cultivated in the past and now have a plant cover dominated by Suaeda and Cressa spp. The soils have the favourable characteristics of Khuways series but the leaching and drainage needed for reclamation will be impeded by the petrocalcic horizon. In addition, much of the area is dissected by abandoned channel micro-relief.

5.2.6 Aquic Paleorthids

Isa Series - Is

Isa series belongs to the coarse-loamy, carbonatic, hyperthermic family of Aquic Paleorthids. Profiles are very similar to those of Salmabad series but the subsoil is saturated by the capillary fringe, the petrocalcic horizon lies at shallower depth (50 - 75cm) and is overlain by coarse textured carbonatic sandy loams containing calcite-cemented gravels. The soils are very saline and locally are separated at phase level as being extremely saline. Isa soils occur south east of Salmabad and in the Buhayr area. Some areas show signs of former cultivation but now carry a moderately dense cover of Halocnemum, Suaeda, Juncus, Halopeplis and Limonium spp. Agricultural potential is extremely low due to the shallow depth to a petrocalcic horizon, high contents of gypsum and high or extremely high

salinities. Reclamation by leaching and drainage would be extremely difficult due to the subsoil cemented layer and would not overcome the presence of the superficial gypsum horizon.

5.2.7 Typic Torripsamments

Hisham Series - Hs

These soils are members of the **mixed, hyperthermic** family of Typic Torripsamments. The profiles are characteristically deep, uniform fine sands or loamy sands. Thin layers of sand-sized aeolian gypsum occur within the control section and thin bands of carbonate nodules are common in the subsoil. The combined gypsum and carbonate contents are sufficient to give the soils a mixed mineralogy class. Unless irrigated, Hisham soils are dry, with watertables usually deeper than 2.0m and salinities are relatively low. They occur on the Sand Sheets of the Salmabad and Hawrat 'Inqa areas. In the uncultivated state the soils have a fairly rich flora of xerophytes, including species of Panicum, Cyperus, Pennisetum, Heliotropium, Salsola and Lagonychium.

Hisham soils are currently used for irrigation of a wide range of crops and have a moderate potential for agriculture. Their deep profiles provide for adequate rooting depth and their sandy particle-size facilitates efficient leaching, although causing poor moisture holding capacity and fertility potential. Gypsum contents are low and in most areas where the soils occur at moderate elevation, there are few problems of drainage. In low-lying areas, such as at Hawrat 'Inqa, drainage is required but at risk of sea water intrusion. Micro-relief poses a minor limitation in areas of low dunes.

5.2.8 Typic Psammaquents

Wasmiyah Series - Ws

This series belongs to the **mixed, hyperthermic** family of Typic Psammaquents. The soils have deep profiles of single grained quartz sand. A saline watertable occurs within the upper metre and the capillary fringe extends into the upper horizons. A thin saline

crust covers the surface but generally the soils are not excessively saline, although an extremely saline phase is mapped locally. Similarly, in some areas a thin (15cm) layer of cemented gypsum crystals has formed at the surface and, again, these soils are separated at phase level. Moderate levels of carbonates are present, giving the soils a mixed mineralogy.

Wasmiyah soils have little vegetative cover apart from an occasional Zygophyllum bush. If drained they would have a moderate potential for agriculture but being only 1.5m above sea level and close to the coast, deep drainage would entail a risk of sea water incursion. The superficial gypsic layer would require scraping prior to cultivation.

5.2.9 Lithic Torriorthents

Dilmun Series - Dm

This series belongs to the coarse-loamy skeletal, mixed, hyperthermic family of Lithic Torriorthents. Profiles have gravelly or stony sandy loam textures and contain angular rock fragments which often have pendants of gypsum to their undersides. A lithic or paralithic contact occurs within the upper 50cm. Dilmun soils occur on Limestone Pavements and on local rock outcrops throughout the area surveyed, they have a very sparse cover of xerophilous species such as Hammada elegans, Salsola vermiculata and Stipagrostis sp. The soils are not cultivated and have no potential for irrigated agriculture, principally due to their skeletal particle-size and very shallow effective depth over rock.

5.3 MISCELLANEOUS LAND TYPES

These land units are defined for areas of little or no natural soil (USDA,1951). Recognition of such units depends partly on the detail required for the objective of the survey. They are named primarily in terms of land form, rather than material. Table 5.3 lists the three miscellaneous land types mapped at Level 2 and briefly describes them.

Table 5.3 Miscellaneous Land Types

Symbol	Miscellaneous Land Type	Characteristics
R	Rockland	Rock outcrops with little or no soil cover.
CC	Channel Complex	Gravelly floors to seasonal stream courses.*
	Swamp	Local depressions and estuaries which are premanently flooded.

* Comparable to the Wadi Channel (Wc) unit in the mainland UER Level 2 Classification.

6

Interpretation of Survey Data

6.1 INTRODUCTION

In the previous chapter the soil mapping units were described in terms of physiography and morphology, emphasising features relating to taxonomy and mapping. The soils are now examined specifically in relation to irrigated agricultural land use in order to assess the effects of soil characteristics on land productivity and management requirements. Aspects of topography, morphology, soil physical properties and soil chemistry are reviewed individually, drawing on data provided in the relevant Appendices. This interpretation of the survey data provides the essential information for the classification of the land according to its capability for irrigated agriculture, which is described in Chapter 7.

6.2 TOPOGRAPHY

6.2.1 Land slope

The overall land form of the areas surveyed is level; slopes rarely exceed 0.5 per cent and thus are not critical for irrigation development planning. Steeper slopes do occur locally on the fringe areas of the Limestone Pavement and escarpments but irrigation in these sites is already precluded by shallow soil depth and skeletal particle-size.

6.2.2 Micro-relief

As compared with the uniformity of slopes, there is considerable variation in micro-relief. This takes the form of sand dunes, vegetation hummocks and abandoned irrigation channels.

(a) Sand Dunes

Small areas of stable dunes occur immediately south of Sar and in the Karzakkan area. The sand layers are deep and as relative elevations rarely exceed 2.0 m, land levelling

would be feasible.

(b) Vegetation hummocks

These hummocks are a prominent feature of many areas, especially the Nebkha Plain and the Hawrah Sand Sheets.

They comprise friable accumulations of windblown quartz and gypsic sand which have been arrested by vegetation clumps. They are usually less than 25 cm high and could be removed during normal land preparation operations.

(c) Abandoned channels

A large proportion of the Salmabad area has been irrigated at some time in the past but in most cases this has long been abandoned and the former channels are barely discernible. However, on the Loam Plain and parts of the Nebkha Margin the abandonment has been relatively recent and there persists a prominent micro-relief of channels and date palm remnants. The frequency and depth of the channels varies but typically they are 0.5 to 0.75 m deep and are orientated on a loose grid pattern of about six metres by ten. This channel relief affects some 24 per cent (880 ha) of the Salmabad area.

This micro-relief and accompanying date palms, will demand considerable land levelling and clearance in addition to the normal land smoothing practices. Furthermore, the inevitable variations in compaction which will be achieved during the initial levelling are likely to necessitate extra land smoothing as irrigation and leaching cause the soils to settle and subside.

Detailed topographic surveys of representative areas of this channel micro-relief show that initial land levelling will involve the movement of some 1 500 m^3 ha^{-1}.

6.2.3 Garbage and excavations

Deposits of household and industrial refuse occur throughout the areas surveyed, usually as uncontrolled tips. Some comprise mostly decomposable material which would be feasible to remove but in some cases the tips comprise solid material, such as concrete, scrap iron and hard core, up to 0.5 m deep. The latter constitute a significant topographic feature, which could be costly to remove, and are specially delineated on the land classification maps.

Excavations for building sand in the south west of the Salmabad area are continuing to destroy the original landscape. Similarly. excavations for refuse disposal are currently altering the land surface in the Buhayr area. For the purposes of mapping topography, the extent of these excavations has been taken from the 1977 aerial photography.

6.3 SOIL MORPHOLOGY

Many of the morphological features of the soil which affect crop growth are recognised by Soil Taxonomy as being diagnostic and are therefore apparent from the soil dassification. Others have been included at phase level. The principal features relevant to cropping in Bahrain are particle-size, cementing and structure.

(a) Particle-size

Particle-size is important through its effect on factors critical for crop growth. In general terms a fine soil particle-size induces slow water movement, high waterholding capacity and high fertility potential. Coarser particles favour rapid water movement, low water holding capacity and lower fertility potential. Each of these features is discussed separately in later sections.

In the area surveyed the commonest particle-sizes are sandy, coarse-loamy and fine-loamy, as shown by the family level classification (Table 4.1). Medium to fine sand and silt particles predominate with clay contents usually less than 15 per cent. The abundance of particles in the size range 0.05 to 0.50mm is typical of aeolian materials.

The sandy particle-size soils predominate on the sand sheets of Salmabad and Hawrat 'Inqa as Hisham, Areen and Wasmiyah series. The sand is predominantly quartz in the medium to fine size class. The abundance of gypsum crystals in the soils of the Nebkha Plain and margins is responsible for the coarser textures but, as discussed in Appendix A, the determination of particle-size in such gypsic materials is unreliable either in the field or in the laboratory. Fine-loamy soils occur on the Loam Plain and Lower Fans (principally as Khuways and Lawzi series). Clay contents in these soils are higher compared with elsewhere and range up to 25 to 35 per cent, although the fine sand fraction still remains high.

(b) Cementing

Soil layers cemented by gypsum or $CaCO_3$ (as calcite) are common in many of the soils: such layers provide a barrier to root growth and water movement.

Gypsum cementing is common in the upper 0.5m of all the Typic Gypsiorthids as well as in most Typic and Aquic Paleorthids. Typically it comprises coarse sand-sized crystals bonded together as a porous 'honeycomb' layer. Due to the very coarse pore sizes of such layers they form a barrier to the rise of capillary water but result in very rapid downward infiltration. Crop root penetration is severely restricted and indeed cultivation is unfeasible unless there is a friable overlay, but tree roots are able to penetrate the honeycomb layers. Localised banding of crystalline gypsum occurs throughout the control section of Hawrat and Buri series and create a more severe restriction. Incipient petrogypsic horizons in Maqabah series pose a similarly severe limitation and preclude most forms of deep cultivation.

The occurrence of calcium carbonate cementing, in the form of dense, hard cemented petrocalcic horizons, is indicated by the soil subgroup, nomenclature;Salmabad, Isa and Buquwwah series have strongly developed petrocalcic horizons within the upper 1.0m which prevent penetration of roots and would considerably increase the cost of excavating drainage channels. Petrocalcic horizon beneath Areen series are less indurated and would probably permit root penetration.

(c) Soil Structure and Consistence

Soil structure is poorly developed in all the soils and, in the case of the gypsic soils, is largely determined by the degree of gypsum cementing. The upper profiles of the gypsic soils are therefore massive and extremely firm moist or hard dry, although there is usually an overlay of friable single grained gypsic sand.

The fine-loamy Cambic Gypsiorthids, notably Khuways series, have moderate medium angular blocky structure with moist firm consistence in their upper horizons. Within this material there are many fine tubular pores, probably root channel remnants, which are orientated vertically down the profile and must

contribute significantly to drainage. The subsoils have little structure and may be weakly $CaCO_3$ cemented below the control section. As salts are leached from Khuways soils some compaction will probably occur and porosity will be reduced, although little difference in consistence was observed between irrigated and non-irrigated sites. Single grained, structureless conditions apply in the sandy profiles except where minor layers of gypsum cementing occur.

With the exception of quartz-rich sandy materials a prominent feature of the soils is their low bulk densities, especially in the substratum (Appendix E.2). This is to be expected when up to 90 per cent of many soils comprise calcium carbonate silt and gypsum sand. The carbonatic silt substratum, which underlies parts of the Salmabad area, has saturation percentages of up to 90 and bulk densities of less than 0.8 g cm^{-3}; in the normal saturated state it is spongy, slimy and has little bearing capacity. By contrast, the gypsum alluvium, which has only slightly higher bulk density, is firm when saturated and remains coherent in channel cuttings even at side angles of 90 degrees. In the same way, gypsum contents in most sandy Hisham soils are sufficient to cement and maintain the sides of channels. In the absence of gypsum, as in the extensive substratum quartz sands, the material loses all coherence and slumps. Deep open channels which penetrate the substratum sands or carbonatic silts should therefore be avoided.

6.4 SOIL-WATER RELATIONS

6.4.1 Introduction

Successful irrigation under arid regimes using high salinity water requires soils through which water can be passed quickly and efficiently, so as to ensure adequate leaching. The most important aspects of soil-water relations are therefore the rate of entry (infiltration) and exit (drainage) of water and its availability to crops while in the soil.

6.4.2 Infiltration

Infiltration tests were performed on each of the major soil units: details of the methods and full results are given in Appendix E.

Very fast infiltration rates were recorded at most sites. Following high initial intake rates within the first 15 minutes, there is little decline over the test period, producing high basic infiltration rates (usually in excess of 100mm h^{-1}) after three to four hours lapsed time. Extending tests to seven or eight hours did not produce any significant decreases in infiltration rates. As is normal for infiltration tests, the results are varied due to differences in soil porosity, watertable level and land use. The test data, excluding anomalous values, are summarised in Table 6.1. The range of results for the principal arable soils (Khuways and Hisham) is shown in Figure 6.1.

Table 6.1 Infiltration Tests: Summarised Data

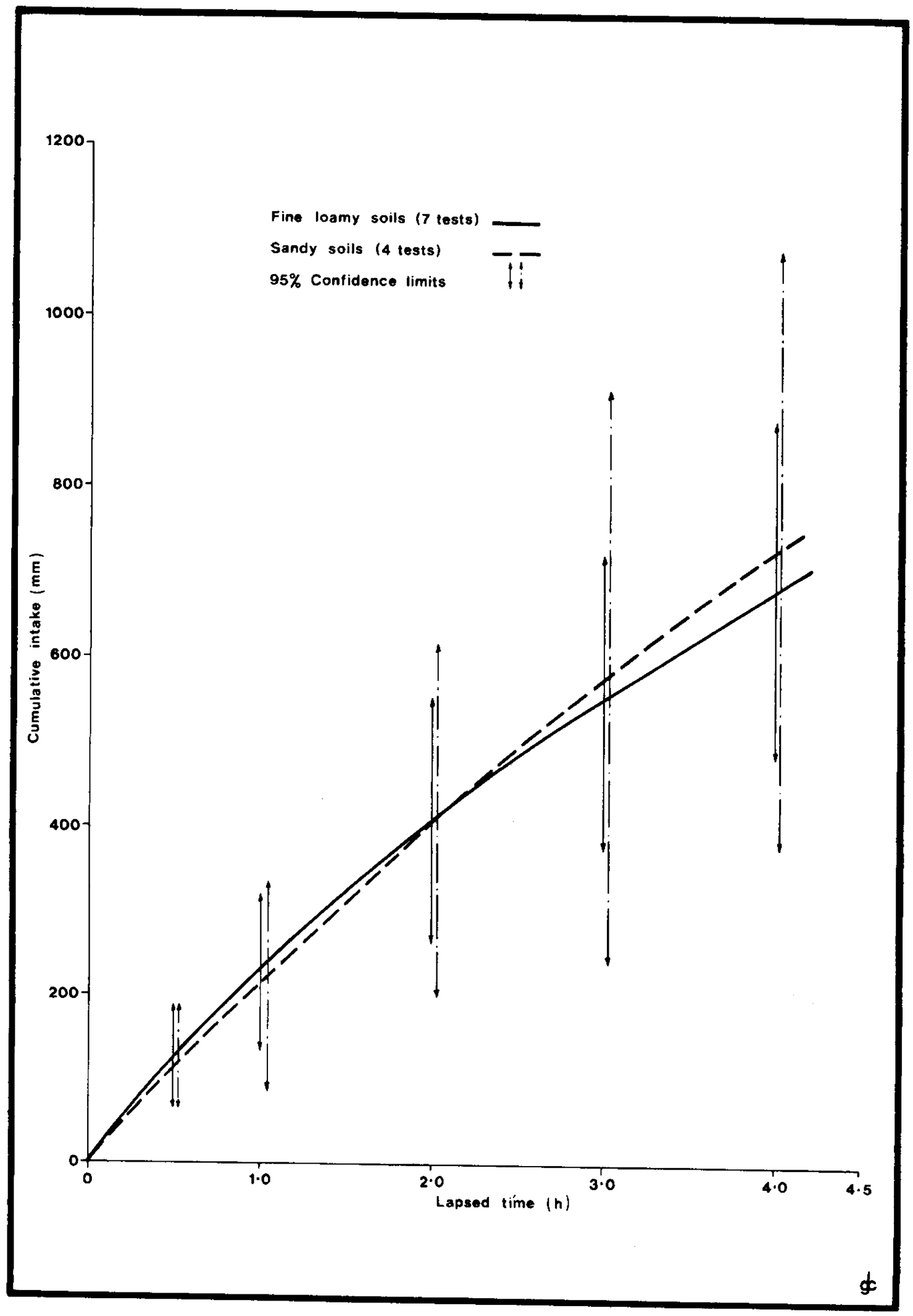
Soil Unit	No.of Tests	Infiltration Rate (mm h^{-1})			
		Initial Rate		Basic Rate	
		Mean	S.D.	Mean	S.D.
Khuways and Buquwwah	7	289	140.1	137	27.1
Hisham and Areen	5	257	71.3	154	42.6
Gypsic Soils	5	345	151.0	187	58.6

Note: Initial Rate at 0-15 minutes; Basic Rate at 3-5 hour lapsed times. S.D. is the standard deviation of the mean.

In soils with such rapid rates of infiltration the critical range lies within the first 15 to 20 minutes lapsed time. However, this is the very period during which the double-ring infiltrometer is at its least accurate. First recordings at tests were made at 15 minutes, so that values for initial intake rates (Table 6.1) represent the mean of intakes from zero to 15 minutes, during which time rates were falling. The true 15 minute instantaneous reading would be considerably lower.

On sandy soils the rapid infiltration rates can be explained by very high proportions of coarse pore sizes. Moisture release curves (Section 6.4.3) show Hisham soils to have 19 to 20 per cent of pores in the diameter range greater than 40 μmm, through

Figure 6.1 Cumulative Infiltration : Mean Values



which gravity flow of water is feasible. This compares with lower values for Khuways series (7.0 to 10.0 per cent) but extremely high visible macro-porosity in the gypsic soils. Infiltration in the Khuways soils is undoubtedly aided by the presence of tubular pores of 1.0 to 2.0mm diameter which would carry disproportionately large volumes of water as compared with the porosity indicated by the moisture release curves. As these soils are leached and compacted by cultivation it is to be expected that infiltration rates will decline.

The infiltration rates recorded are beyond the normally accepted range for basin irrigation (Meer and Messemaeckers, 1974) and this method of irrigation could be used efficiently only if piped delivery systems with high discharge rates are combined with short basin lengths and if in fact the silty Khuways soils do develop slower intakes with cultivation. For overhead irrigation systems the rapid intake rates allow more efficient use of equipment by reducing application times. From the point of view of leaching salts, the rapid rates of movement of water into the soil are desirable

6.4.3 Moisture Retention and Availability

The available water capacity (AWC) of a soil is defined as that portion of the total waterholding capacity which is available to roots to sustain plant life. To absorb water from the soil the plant root has to overcome suction forces which hold the water in the soil The principal forces are divisible into the matric tension, caused chiefly by surface tension within the soil pores, and the osmotic tension due to salts dissolved in the soil solution.

(a) Matric Suction

For the reasons discussed in Appendix E, the matric suctions against which water is available to crop plants have been set at 15 bar for the upper (permanent wilting) point and at 0.2 bar for the suction at which gravity

drainage ceases (usually termed 'field capacity').

Complete data on the moisture retention characteristics of the eight profiles are given in Appendix E. Moisture characteristic curves for selected profiles, representative of principal series with agricultural potential, are illustrated in Figures 6.2, 6.3 and 6.4.

Most of the soils have relatively high available capacities; the loamy soils, both gypsic and non-gypsic, retain large quantities of water, especially in the 0.1 to 15 bar range. Highest values are recorded in the calcareous silt loam subsoils where up to 70 per cent of water is retained at saturation (comparing closely with saturation percentages measured on routine samples). By contrast the sandy soils, Hisham, Areen and Wasmiyah, release most of their moisture in the 0 to 0.2 bar range. This is consistent with soils which are readily drainable but which require very frequent irrigation to maintain crop growth. The loamy soils by contrast have a greater AWC but lower drainable water capacity, indicating a preponderance of small pores (less than 40 mm) which release water more slowly. The contrasting water retention characteristics of the Khuways and Hisham soils are illustrated by Figure 6.5.

The significance of this difference between sandy and silt loamy soils is that moisture depletion will result in more rapidly rising matric suctions, and consequent crop moisture stress, in the sand than the silt loamy soils. Conversely, the greater drainable porosity and preponderance of large pore sizes in the sands can be expected to result in more efficient leaching than in the silt loamy soils.

(b) Osmotic Suctions

The osmotic suction of the soil solution is equivalent to 0.36 bar for every 1.0 mmhos/cm of EC at

Figure 6.2 Moisture Characteristic Curves (Desorption)

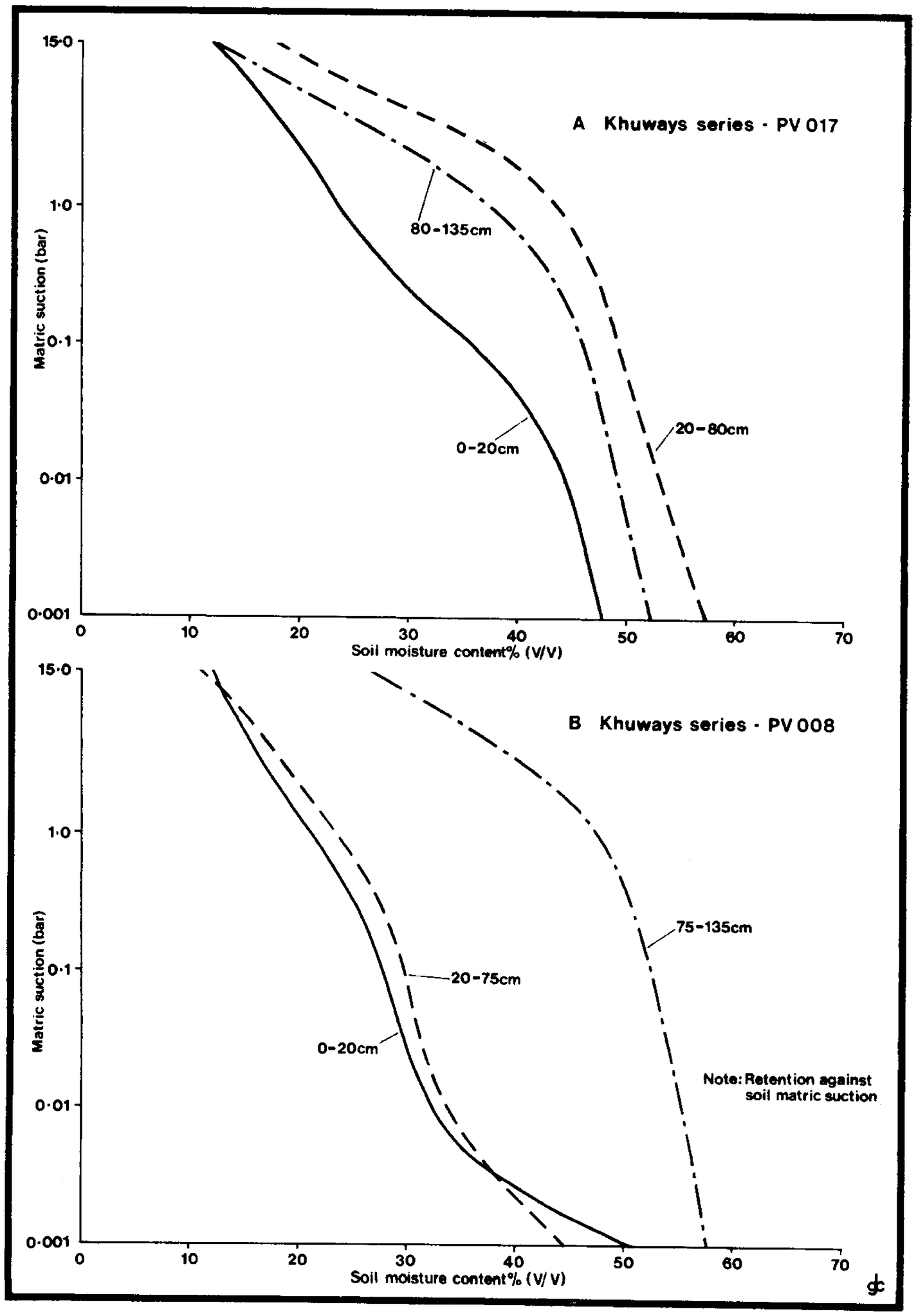


Figure 6.3 Moisture Characteristic Curves (Desorption)

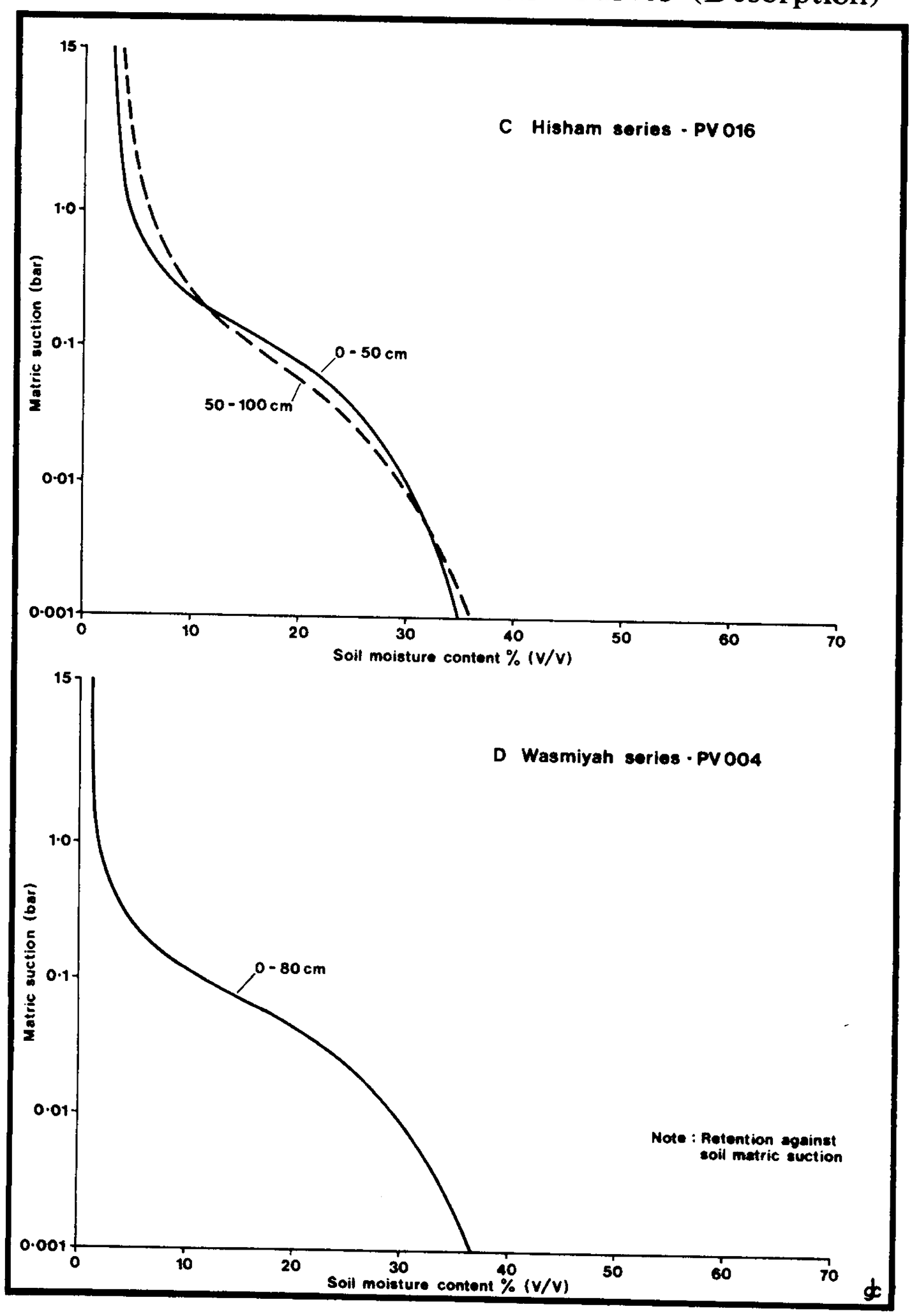


Figure 6.4 Moisture Characteristic Curves (Desorption)

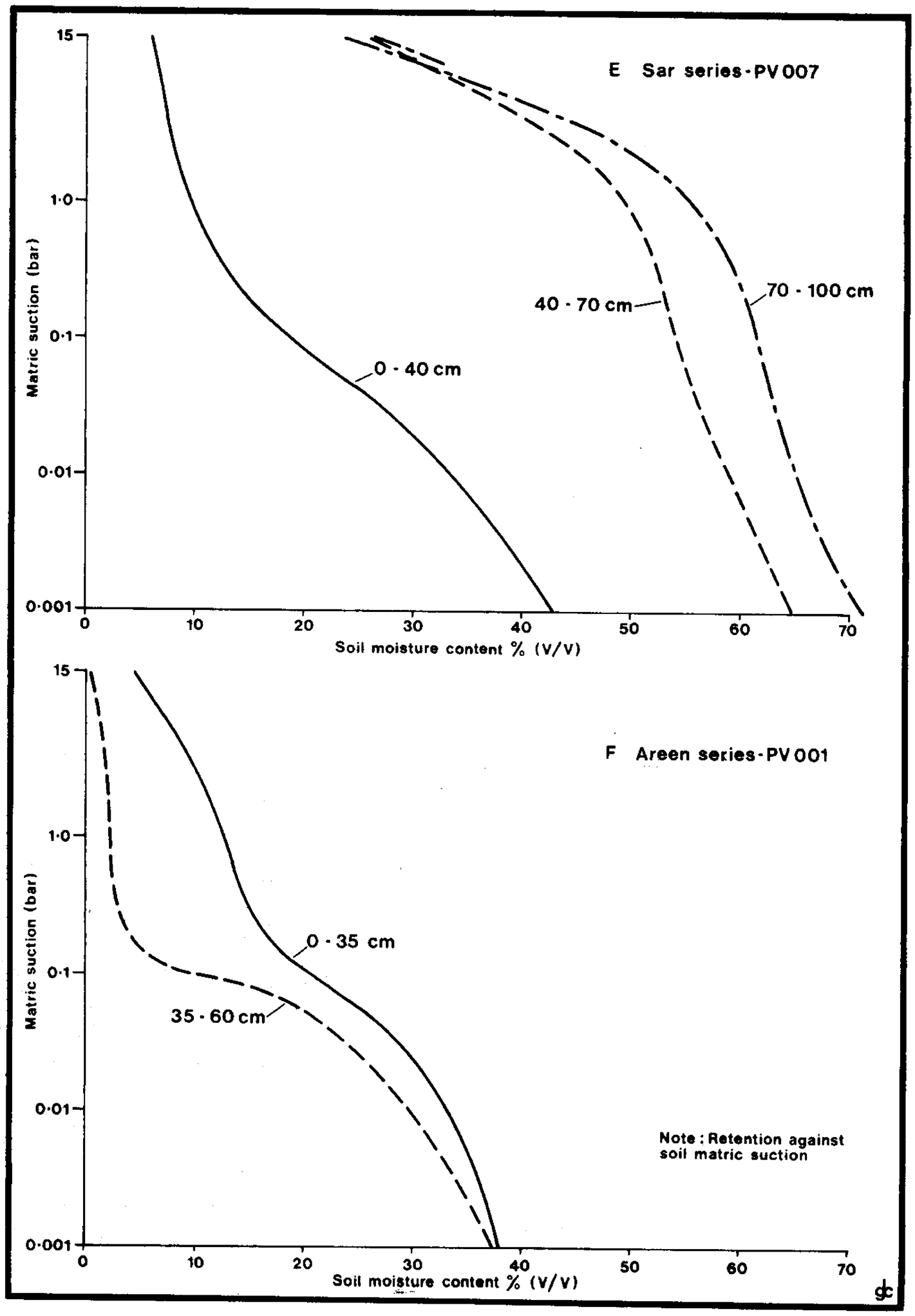
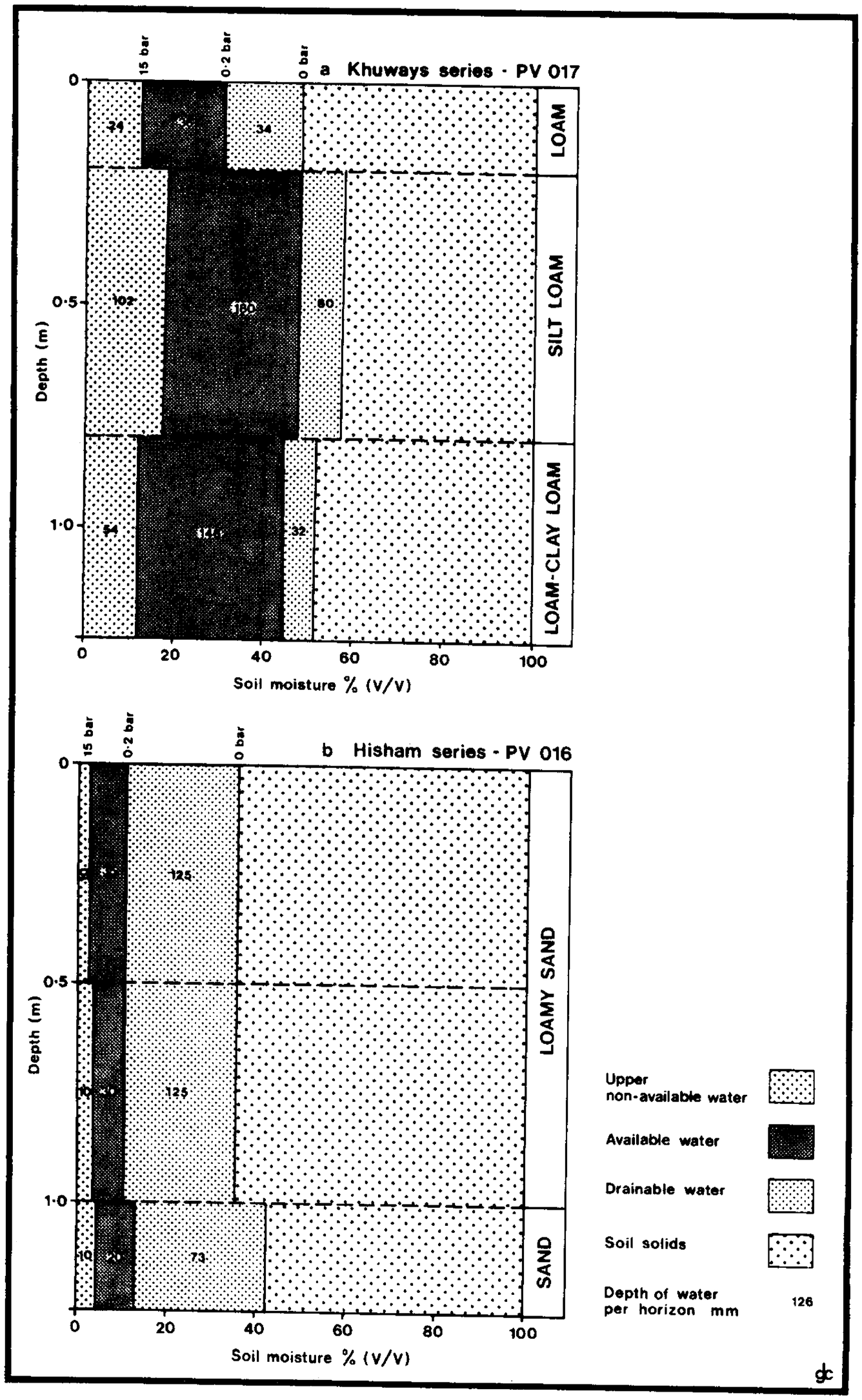


Figure 6.5 Moisture Retention Profiles



the prevailing soil moisture content. As a soil dries under the effects of evapotranspiration, so the salts in the soil solution are concentrated and osmotic suctions rise. However, as they concentrate the less soluble salts (gypsum and $CaCO_3$) will precipitate out to counter this trend. But even by using the best quality water available (3.8 mmhos/cm) the irrigated soils of Bahrain will remain saline and thus the osmotic effects of salinity must be considered in the overall availability of soil water.

Table 6.2 Available Water in Irrigable Soils (Matric Suctions)

Series	Horizon Depth	AWC(1) (mm) Horizon	1.0 m
Khuways			
PV 008	0- 20	35.0	
	20- 75	105.0	
	75-100	61.3	201.3
PV 017	0- 20	35.0	
	20- 80	183.0	
	80-100	64.2	282.2
Hisham			
PV 016	0- 50	41.5	
	50-100	38.0	79.5
Areen			
PV 001	0- 35	38.9	
	35- 60	10.0	48.9

Note: (1) - 0.2 - 15 bar.

Osmotic suctions of the soil moisture increase the effective tension against which the root has to compete for water uptake. However, plants can raise the osmotic suction in their own tissues so as to re-establish the osmotic gradient (Bernstein, 1975) and after an initial period of osmotic adjustment water uptake by plants does not seem to be adversely affected by salinity and turgor is maintained. Indeed, plants appear to be able to adjust to daily changes of up to 0.5 bar osmotic suction (Bernstein, 1963), which is adequate under normal conditions of irrigation.

It is probably the expenditure of energy on osmotic adjustment , rather than restriction of water uptake, which is primarily responsible for yield declines under saline conditions (Bernstein, 1975). Specific ion toxicity is also damaging, especially in woody plants (Mass and Hoffman, 1977), but from the point of view of water uptake, salt tolerance can be defined as the "degree to which osmotic adjustment can be made without significant sacrifice of growth" (Bernstein, 1961).

(c) Combined Suction Effects

Matric and osmotic suctions in the soils each play an important role in water uptake and plant growth. Increases in the former, as a soil dries out, can be tolerated by the plant up to a point (PWP) at which physical limitations prevent water uptake at a sufficient rate. Increases in osmotic suction, on the other hand, can be compensated for by the plant, albeit at the expense of growth. Matric suctions have been measured (Appendix E.) but to evaluate osmotic suction it is first necessary to calculate the effective soil salinity (ECsw) at each soil moisture content. The calculations which follow do not take account of less soluble salts precipitating out, nor the fact that plants are known to adapt to osmotic suction. Both effects are difficult to quantify but would ameliorate the simplified results presented here. More work is to be done on them.

Under normal conditions of irrigation downward movement of applied water is relatively slow and the soil usually takes one or two days to attain 'field capacity'. During this time evapotranspiration proceeds, resulting in a selective removal of water from the soil and causing a concentration of salts in the soil solution. Thus the salinity at field capacity (EC_{fc}) is greater than at initial saturation (given approximately by EC_e). This field capacity EC is conventionally taken to be double EC_e. However, this must vary according to the soil and irrigation method used.

Soils in the Level 3 areas have been shown to have rapid rates of infiltration and therefore attain field capacity within a few hours, rather than days. There is therefore little opportunity for concentration of soil water by evapotranspiration, suggesting that EC_{fc} and EC_e values may be very similar. However, there will inevitably be some saline water held in fine pores which is not effectively leached; this will remain in the soil as the applied water drains from the coarser pores and will therefore result in an overall increase in salinity at field capacity. In sandy soils the displacement of soil water by irrigation water is likely to be more complete (section 6.5.4 (e)) and so EC_{fc} values will be even closer to EC_e values. The relationship between salinities at saturation and at field capacity have been modified accordingly:-

(i) Silt loam soils - $EC_{fc} = 1.5\ EC_e$

(ii) Sandy soils - $EC_{fc} = 1.25\ EC_e$

As evapotranspiration depletes soils moisture beyond field capacity, the soil solution is concentrated and EC_{sw} rises. This concentration and its effect on osmotic suctions can therefore be computed for each point on the soil moisture depletion curve (Appendix E.). Figures 6.6 and 6.7 show the effects of increasing soil salinities on osmotic and total soil moisture tensions. The figures show a range of realistic values of EC_{fc} which should be attainable using the quality of irrigation available: the values for EC_{fc} of 4.0 and 8.0 mmhos/cm are equivalent to EC_e values of 2.7 and 5.3 in silt loams or 3.2 and 6.4 mmhos/cm in sands.

Figure 6.6
Combined Soil Matric and Osmotic Suctions : Khuways Series

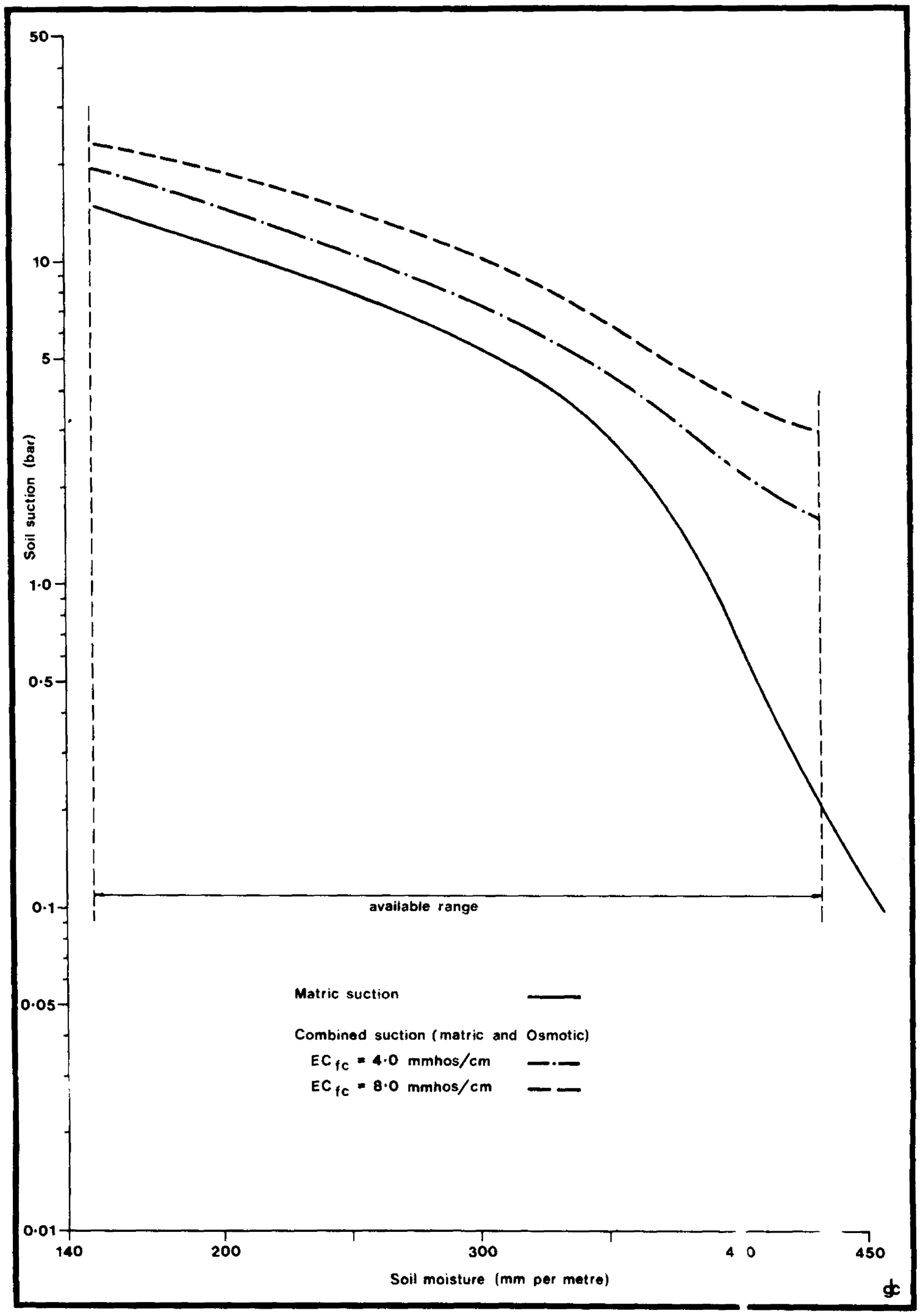
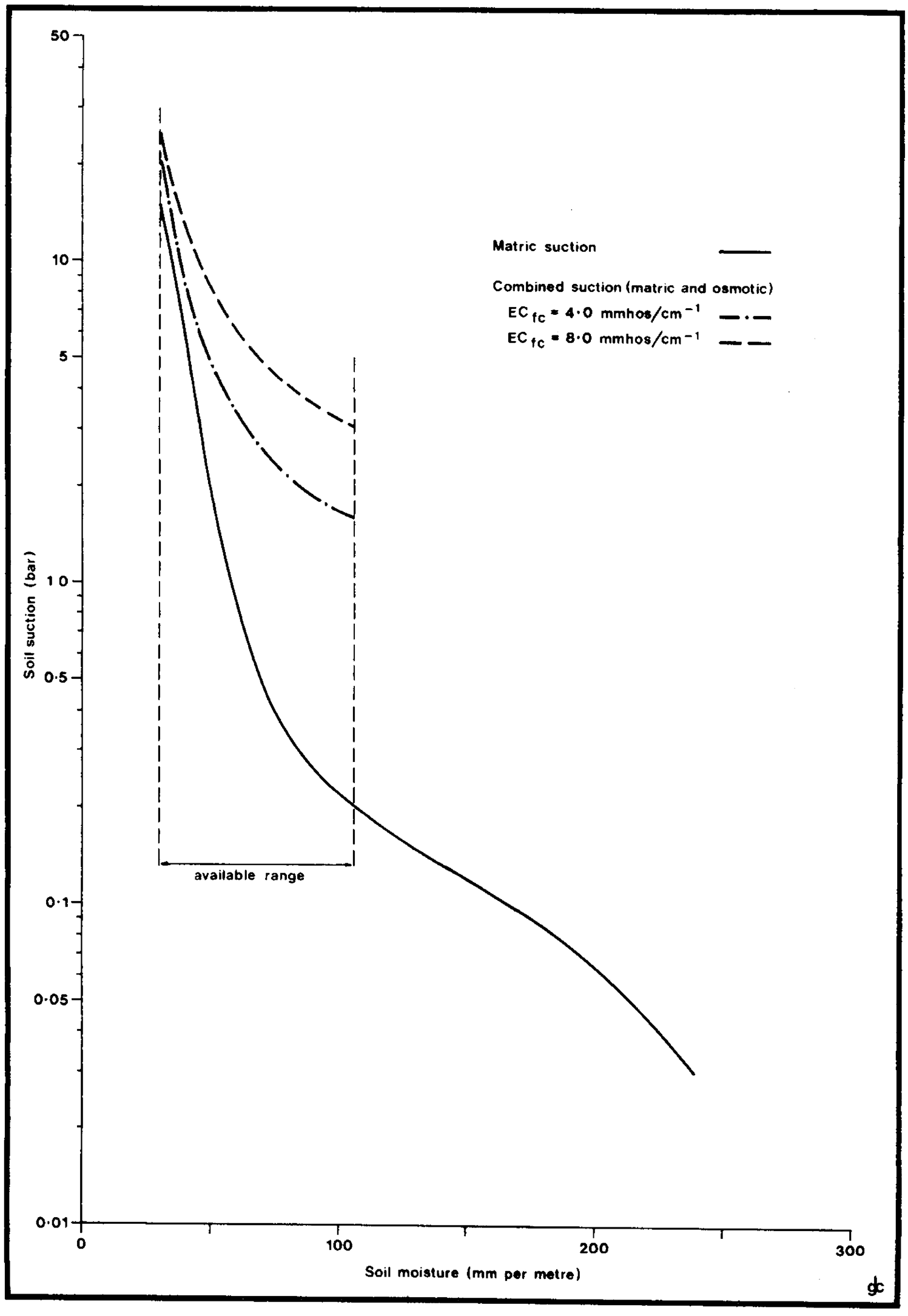


Figure 6.7
Combined Soil Matric and Osmotic Suctions : Hisham Series



The conclusion to be drawn from these results is that although the concepts of AWC is valid in terms of the physical ability of most crop plants to take up water from the soil, this moisture can be attained only at progressively lower yields, due to the additional effects of the soil osmotic suctions. the preceding calculations are based on the best irrigation water likely to be available (EC_w - 3.8 mmhos/cm); with poorer quality water the osmotic effects on crop moisture stress would be even more adverse. However, these calculations do not take into account the effects of precipitation of gypsum and $CaCO_3$, nor of the plants' ability to adapt to osmotic suction. Work is proceeding to try to assess these effects.

From the point of view of irrigation management, it remains important that soil water tensions are kept low if crop moisture stress is to be maintained within reasonable limits. Measurements of available water capacity, based on matric suctions (Appendix B.) provide a guide to irrigation requirements but must be considered in combination with the osmotic effects of saline irrigation water.

6.4.4 Drainage Characteristics

Removal of leaching water by drainage is essential for successful irrigation. This is especially true in the present survey area where high salinity irrigation water is being used on lands with high watertables. Beneath much of the area the watertable lies within 2.0m of the surface (Figures 6.8 and 6.9). Although locally distorted by irrigation, the watertable is a natural feature related to elevation above sea level: shallowest depths being found in the low-lying Tubli estuary and coastal plain of Hawrat 'Inqa.

The high values for infiltration (Chapter 6.4.2) show that water movement through the soil profile is rapid. Artificial drainage will therefore be affected primarily by the nature and hydraulic characteristics of the substratum.

(a) Nature of the Substratum

As described in Chapter 3, the areas surveyed are underlain by marine and aeolian alluvium to depths usually well in excess of 5.0m and the cross-profiles (Figures 3.3 , 3.4 and 3.5) show no major barriers to drainage. Indeed, much of the area is underlain by highly permeable fine quartz sand. Figures 6.9 and 6.10 show that the dominant substratum material to be found within the likely drain-setting zone (2.0m) is either fine sand or calcareous loam.

(b) Hydraulic Characteristics of the Substratum

Measurements of the rate of water movement through a saturated soil, hydraulic conductivity, provide an indication of the drainability of the soil and are used in the calculation of drainage requirements. In the present study 58 hydraulic conductivity tests were performed at 30 sites (Appendix E.3), using the single auger hole method (Van Beers, 1963).

Figure 6.8 Salmabad: Soil Moisture Status

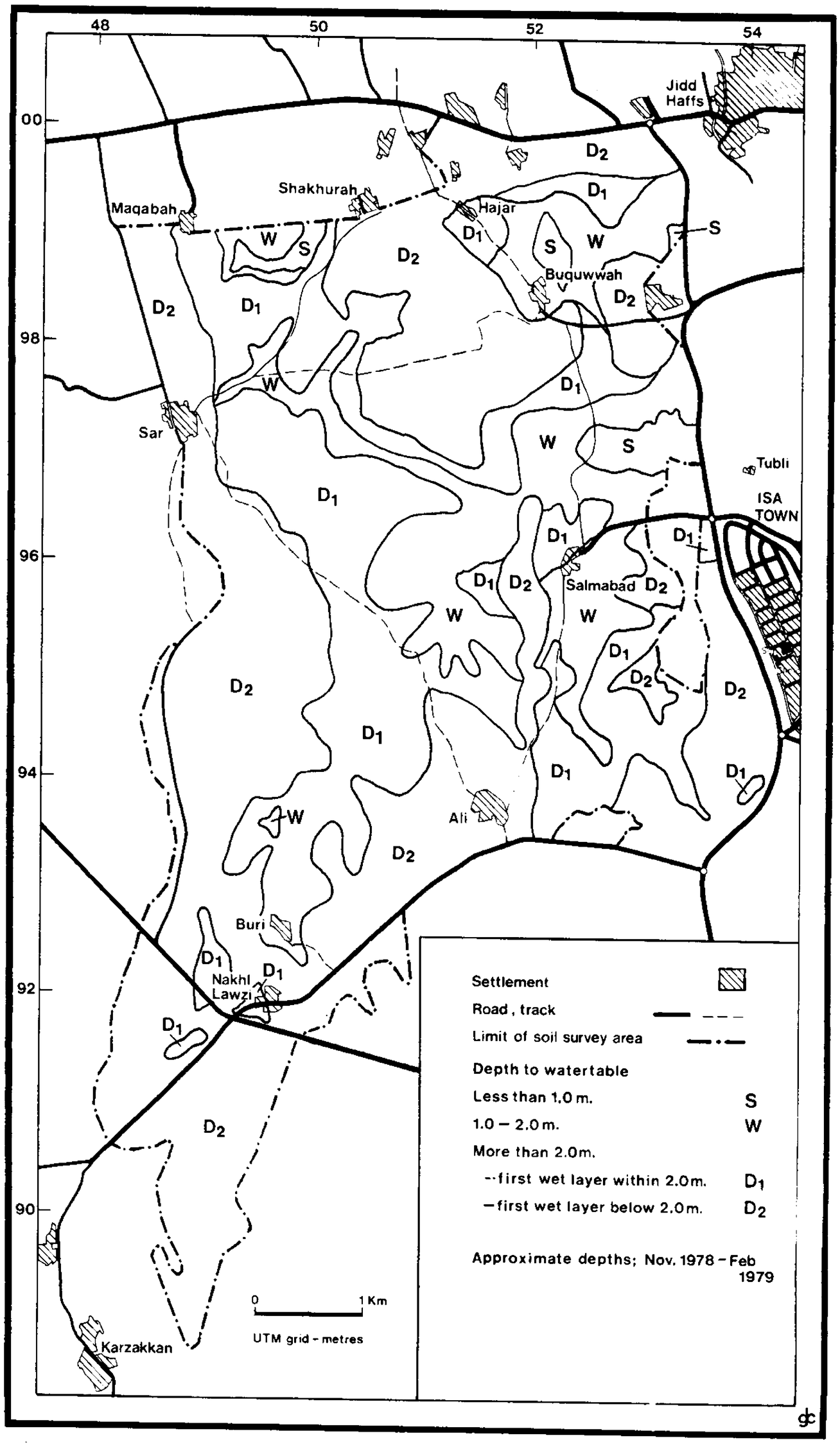


Figure 6.9 Hawrat Inqa :
Soil Moisture Status and Substratum Material

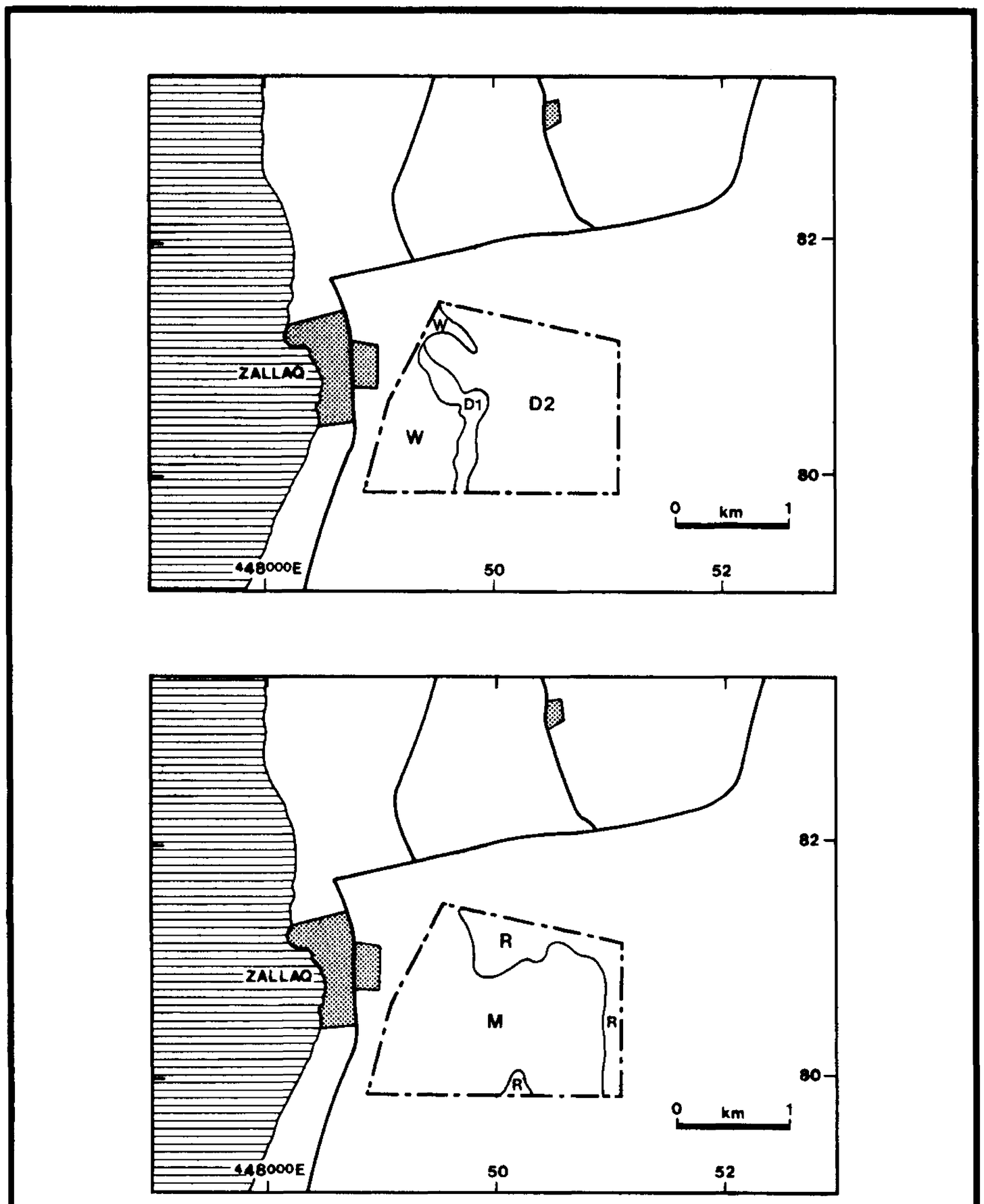
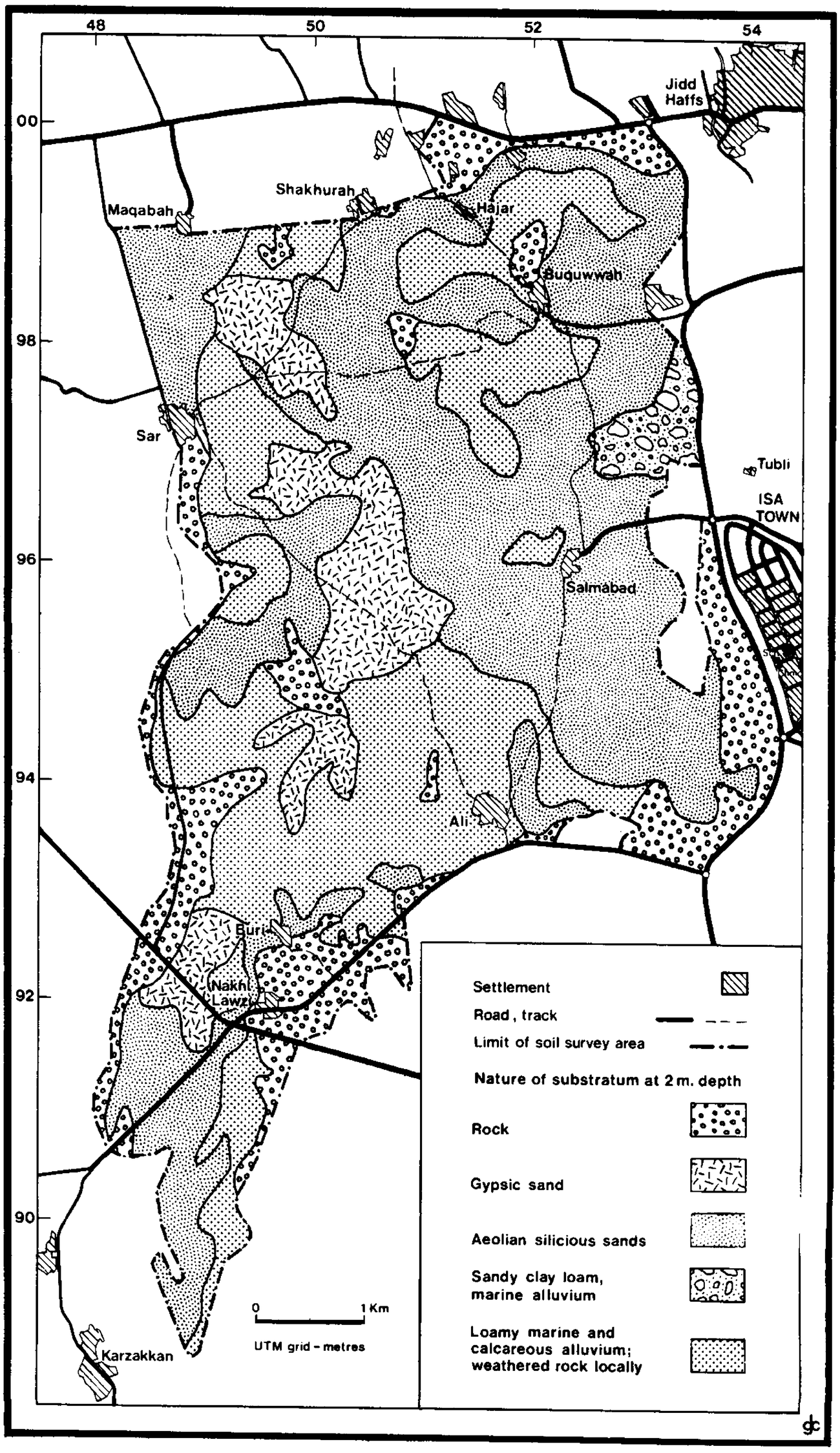


Figure 6.10 Salmabad: Substratum Material



This test **measures** the horizontal component of hydraulic conductivity but as most of the substratum material is assumed to be isotropic, (especially the fine sands), the results can be applied equally to vertical water movement.

Complete results of the hydraulic conductivity tests are included within Appendix E.3. These data are summarised in Table 6.3, separated according to substratum material.

Table 6.3 Hydraulic Conductivity

Substratum Material		No. Tests	No. Sites	Hydraulic Conductivity(md^{-1}) Mean	S.D.	95% C.L.
M	Aeolian Silicious fine sand	25	12	5.58	3.44	2.18 - 7.76
L	Fine-loamy marine alluvium (L)	9	6	1.12	0.58	0.41 - 1.83
L/M	Fine-loamy alluvium over fine sand	9	5	3.11	2.12	0.27 - 5.95
C	Coarse gypsum sand	2	1	16.96	-	-
G/M	Carbonate-rich silt loam alluvium over fine sand	8	4	5.90	2.42	2.05 - 9.75

Notes:
1. Mean results for replicate tests at each site were used to calculate the overall mean hydraulic conductivity for each substratum material type.
2. 95 per cent confidence limits obtained using standard values of tc for small samples, assuming normal distribution.
3. Carbonate-rich silt loams (G) are included with Fine-Loamy-Alluvium (L) of the substratum diagrams.

Table 6.3 shows that hydraulic conductivity values are high in all materials. Predictably, the fine sands have faster rates than the finer textured marine alluvium. The fast rates for carbonate silt loams conform with the recorded high values for drainable porosity in these

materials, whereas very coarse porosity accounts for the extremely rapid hydraulic conductivities in the gypsum sand. The combination of drainable soil profiles, and a thick permeable substratum should facilitate artificial drainage. However, disposal of water could be difficult due to low elevations above sea level. Artificial drainage to normal depths in low-lying areas such as Tubli, Khadarah Depression and Hawrat 'Inqa, would necessitate pumping. Moreover, as the shallow groundwater in these areas probably has a hydraulic connection with the sea, via the substratum sand, deep drainage could cause intrusion of sea water. This intrusion hazard affects about 50 per cent of the Hawrat 'Inqa area and some 8 per cent of the Salmabad area.

Furthermore, although the substratum sands are very permeable they are very unstable when saturated, which will probably preclude open channel drains where the sand occurs within drain-setting depth.

6.5 SOIL CHEMICAL PROPERTIES

The results of the chemical analyses (Appendix B and C) show the majority of soils to be saline, gypsiferous and highly calcareous. Indeed, of the 19 series mapped, six have carbonatic mineralogy, seven are gypsic and the remainder have mixed mineralogy. The total of gypsum and calcium carbonate in the upper metre of many soils often exceeds 50 per cent and sometimes rises to 80 per cent. Few soils have salinities (ECe) less than 10.0 and many exceed 100.0 mmhos cm^{-1}. Only those soils formed in aeolian quartz sand can be considered true mineral soils in the conventional sense.

6.5.1 Gypsum

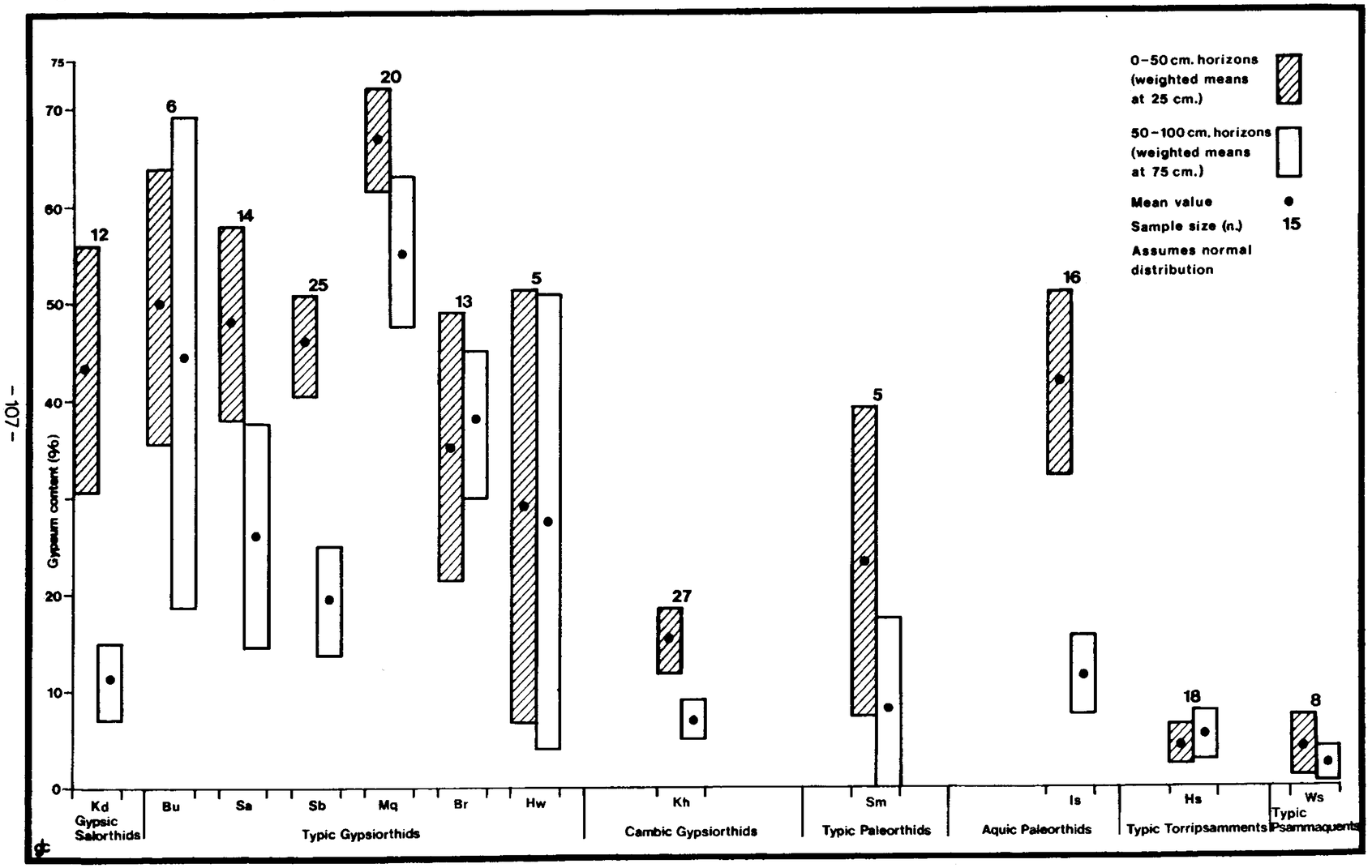
Gypsum contents are very high in most of the soils (Table 6.4) and, as illustrated in Figure 6.11, they are usually greatest in the surface and decline in the subsoil. The gypsum occurs in several forms:-

Table 6.4 Soil Gypsum and Calcium Carbonate: Weighted Means

Soil Series	Depth	Gypsum %			Calcium Carbonate		
	(cm)	Sample (n)	Mean	S.D.	Sample (n)	Mean	S.D.
Typic Salorthids							
Tubli - Tb	0- 50	1	9.3	-	2	63.0	3.9
	50-100	1	3.5	-	2	39.1	12.4
Gypsic Salorthids							
Khadarah - Kd	0- 50	12	43.5	19.6	6	27.1	18.5
	50-100	12	11.1	6.1	6	59.8	7.5
Typic Gypsiorthids							
Karzakkan - Kn	0- 50	2	55.4	7.8	2	12.1	10.1
	50-100	2	7.2	6.2	2	24.6	2.6
Buhayr - Bu	0- 50	6	49.9	14.5	2	11.3	4.3
	50-100	6	43.8	26.5	2	21.3	18.6
Sar - Sa	0- 50	14	48.0	17.4	8	14.7	14.3
	50-100	14	26.1	19.7	8	31.6	19.5
Abu Saybi' - Sb	0- 50	25	46.1	14.2	13	40.6	12.2
	50-100	25	19.3	13.8	13	18.8	9.0
Maqabah - Mq	0- 50	20	67.2	12.0	9	11.5	15.6
	50-100	20	55.3	16.3	9	18.7	13.3
Buri - Br	0- 50	13	35.2	22.4	5	11.4	3.3
	50-100	13	37.6	12.3	5	17.2	6.9
Hawrah - Hw	0- 50	5	29.0	15.7	3	10.9	3.7
	50-100	5	27.4	16.4	3	12.8	4.5
Cambic Gypsiorthids							
Khuways - Kh	0- 50	27	15.3	9.2	19	33.3	8.7
	50-100	27	6.9	5.2	19	42.7	10.9
Lawzi - Lw	0- 50	4	17.3	13.5	4	30.2	9.2
	50-100	4	4.7	1.8	4	35.9	6.6
Zaytun - Zn	0- 50	4	21.0	18.0	-	-	-
	50-100	4	14.4	12.9	-	-	-
Typic Paleorthids							
Areen - An	0- 50	4	45.3	20.9	4	9.4	5.1
	50-100	4	10.5	1.4	4	17.5	2.8
Salmabad - Sm	0- 50	5	23.1	11.5	3	28.7	14.1
	50-100	4	7.9	5.8	3	42.8	24.8
Buquwwah - Bw	0- 50	4	12.3	5.3	3	30.0	10.5
	50-100	4	3.8	2.4	3	40.6	12.2
Aquic Paleorthids							
Isa - Is	0- 50	16	41.7	18.0	11	18.7	10.2
	50-100	15	11.5	7.5	11	43.6	15.7
Typic Torripsamments							
Hisham - Hs	0- 50	18	4.3	3.9	10	18.0	3.3
	50-100	18	5.3	5.0	10	19.5	4.3
Typic Psammacuents							
Nasmiyah - Ns	0- 50	8	4.1	3.7	5	18.7	1.7
	50-100	8	2.4	2.1	5	18.1	1.2

Note: Source - Appendix C.
Mean values derived from weighted means calculated at 25cm and 75cm. S.D. is standard deviation of the mean.

Figure 6.11 Soil Gypsum Content: 95% Confidence Limits for Major Soil Series



(i) Coarse sandy crystals, weakly honeycomb cemented. (Sar, Abu Saybi, Salmabad, Isa series)

(ii) Fine sand particles mixed with aeolian quartz sand (Hisham, Areen series).

(iii) Petro-gypsic material, very hard (locally in Maqabah series).

(iv) Thin crystalline bands (Buri, Hawrah series).

(v) Evaporite, soft-friable deposits (Buhayr).

(vi) Finely divided particles precipitated from capillary water (Khuways, Buquwwah, Lawzi).

There is little published information on the effects of gypsum on crop production but three principal adverse effects cited (Alphen and Romero, 1971) are nutritional imbalance, impeding layers and solution collapse.

(a) Nutritional Imbalance

High concentration of calcium sulphate can render phosphorus, magnesium, potassium and several micro-nutrients unavailable. Moreover, highly gypsic soils have very low cation exchange capacity and therefore are unable to retain nutrients in the root zone.

Crops are being grown with reasonable success on the gypsic soils of the Level 3 areas. Indeed, gypsic sand is traditionally imported for use as a seedbed preparation on fine loamy soils.

Observations indicate that gypsum per se is not harmful to the crops currently grown in the area. However, the nutritional effects of gypsum are currently masked by the effects of high salinity and poor drainage. Once these limitations are removed it is probable that nutritional imbalances on highly gypsic soils would reduce their yield potential.

(b) Impeding Layers

The presence of cemented layers within the gypsic horizon can restrict cultivation and root penetration. Where the gypsum layer is relatively thin (0.5m) and overlies loamy materials (as in Sar and Abu Saybi series), it is probable that tree crops would grow successfully and that roots would penetrate the gypsic layer provided cementing was not strongly developed. More strongly cemented layers and incipient petro-gypsic horizons, as in Maqabah series, present a more serious limitation. The occurrence of gypsum in the surface horizons generally increases the rate of infiltration, especially when the gypsum is coarse-crystalline.

(c) Solution Collapse

Gypsum is slightly soluble in water (2.6g per litre). Solution collapse occurs when irrigation water dissolves subsoil gypsum and causes the surface soil to collapse into the cavity created. Apart from causing damage to rigid structures the collapsing necessitates additional land levelling. Overall reductions in land surface level due to solution and leaching of gypsum can amount to 0.2mm per 100mm of deep percolation losses (Alphen and Romero, 1971).

No evidence of solution collapse was found in the present survey and the existence of gypsum in the upper, rather than lower, profile reduces the hazard of collapse. Irrigation is planned to be based on

piped delivery which will minimise solution hazard by reducing seepage and, by eliminating the need for rigid lined channels, there will be few structures prone to subsidence damage.

The annual deep percolation losses under perennial crops (lucerne) are predicted to be some 1000 to 1500mm: this could cause a 2.0 to 3.0mm overall surface subsidence, depending on the nature of the gypsum and the gypsum saturation of the irrigation water. Coarse crystalline gypsum would be less prone to solution than the finely divided form, but the latter occurs in much smaller quantities and is confined to the surface horizon (as in Khuways series). If gypsum saturated water was used there could be precipitation of gypsum in the soil but use of Khobar water, with a saturation of 20 to 25 per cent (Appendix D) has been shown to dissolve rather than precipitate gypsum (Appendix F4). This tendency could be magnified by the introduction of extensive drainage and a change to using non-gypsum saturated irrigation water.

In conclusion, the evidence in Bahrain suggests that gypsum in itself is not harmful to crops but it indirectly causes considerable reduction in availability of some plant nutrients. However, the nature of the gypsum and its location within the profile are significant and can seriously affect crop production under irrigation. Indeed, these two features must be defined when assessing gypsum hazard: percentages of gypsum alone are insufficient indicators.

In the Level 3 areas, use of moderately low gypsum saturation irrigation water is likely to result in some solution and overall subsidence in highly gypsic soils but in the less gypsic series (such as Khuways and Hisham) there will probably be only redistribution of gypsum throughout the profile (Appendix D). Coarse-crystalline and cemented gypsic horizons are unfavourable for cropping due to low fertility, poor water retention, excessive infiltration and restrictions to root penetration and cultivation. Intensive irrigation with low gypsum saturated water should be avoided on these soils.

6.5.2 Calcium Carbonate

High values of calcium carbonate were recorded in all soil series (Table 6.4). Figure 6.12 illustrates that, by contrast with gypsum, carbonate contents are greatest in the subsoil. In most instances this is a reflection of the finely divided silt-sized carbonate parent material being buried by precipitated and aeolian deposits of gypsum.

Calcium carbonate is insoluble in water but can be slowly dissolved by carbonic acid, which is formed by solution of carbon dioxide in the irrigation water. The resulting bicarbonates can be leached. Solution is most rapid in finely divided $CaCO_3$ particles as found in the subsoils of the Salmabad area.

High $CaCO_3$ contents raise the soil pH and cause nutrient imbalances in crops. The principal effect is chlorosis due to lime-induced iron deficiency but manganese and zinc uptake are also affected. Soils with high contents of $CaCO_3$ therefore demand special fertilizer treatment.

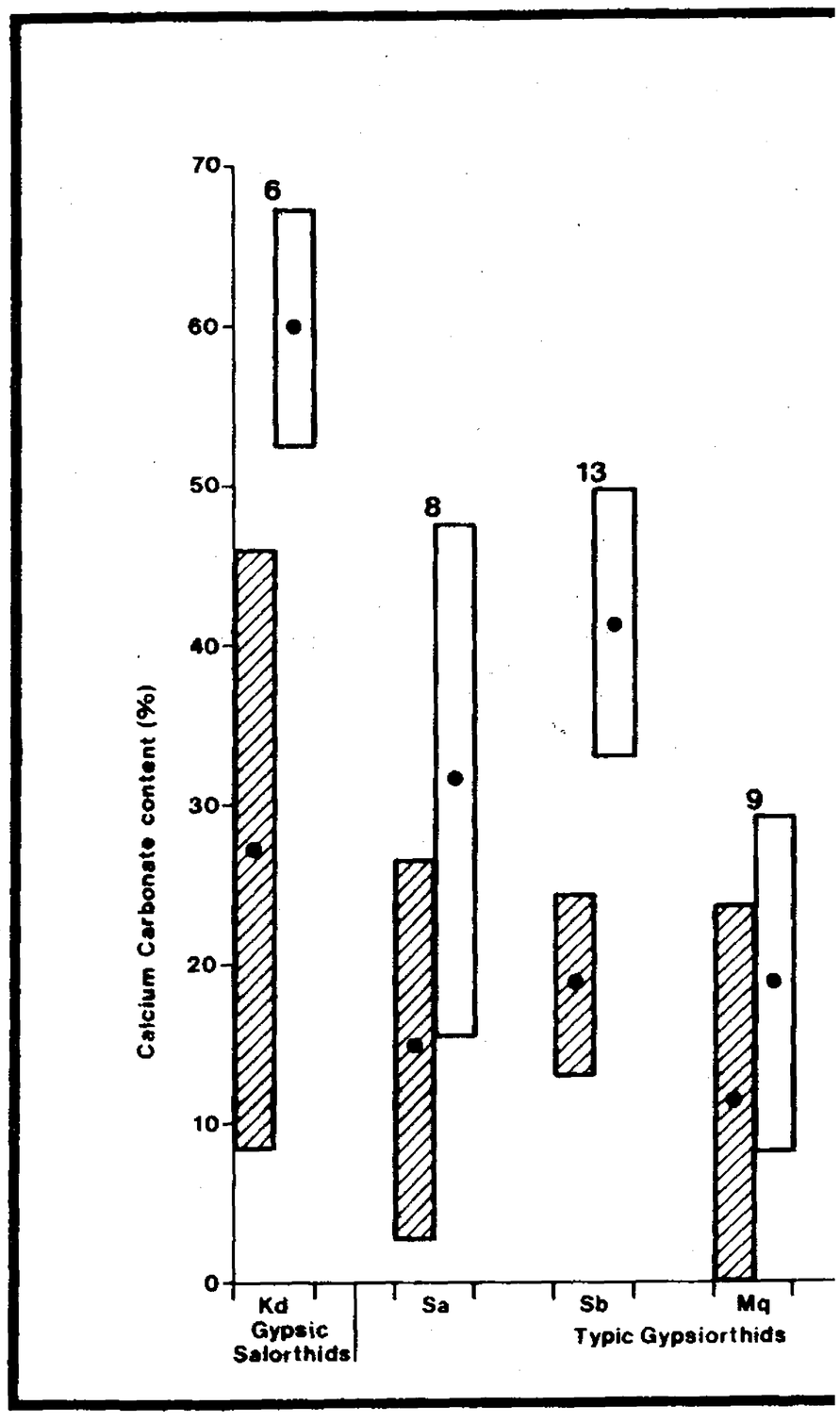
6.5.4 Salinity

Salinity is caused by the presence of soluble salts in the soil solution and is most conveniently determined as the electrical conductivity (EC) of a soil: water extract, expressed in mmhos cm^{-1}. High salinity has an adverse effect on plant growth due to toxicity of specific ions in solution and, as discussed earlier, moisture stress caused by raising the osmotic suction of the soil solution.

(a) Electrical Conductivity

Electrical conductivity was determined on the saturation extract (ECe) and 1.5 soil water extract (EC 1.5) of samples from major horizons of profile pits and all routine analysis sites. Complete results for the 872 EC analyses are given in Appendix C. These results have been summarised in terms of the weighted mean values within the 0-50 and 50-100 cm depths for each soil series (Table 6.5). In the computation of these means, irrigated soils have been excluded, so as to obtain an indication of the natural salinity status. The effects of irrigation on soil salinity (Appendix F) are discussed later

Figure 6.12 Soil Calcium Carbonate



Content: 95% Confidence Limits for Major Soil Series

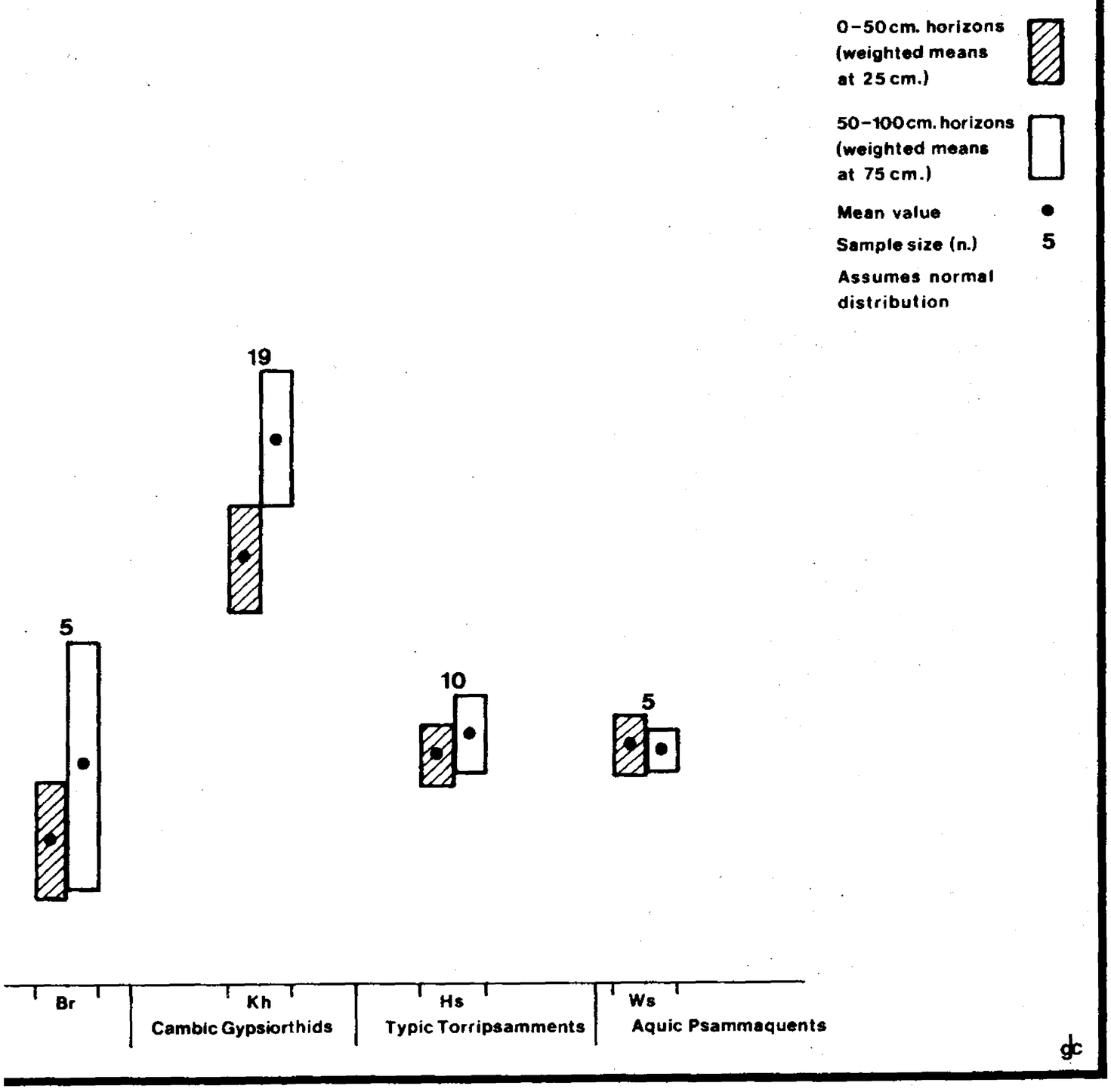


Table 6.5 - Soil Salinity: Weighted Mean Values

Soil Series	Depth (cm)	Sample (n)	Salinity (mmhos cm^{-1}) Mean	S.D.
Typic Salorthids				
Tubli - Tb	0- 50	3	59.9	4.8
	50-100	3	50.2	4.6
Gypsic Salorthids				
Khadarah - Kd	0- 50	24	65.6	20.9
	50-100	24	49.7	17.9
Typic Gypsiorthids				
Karzakkan - Kn	0- 50	5	9.3	4.4
	50-100	5	7.7	3.7
Buhayr - Bu	0- 50	7	44.6	9.4
	50-100	7	38.7	5.9
Sar - Sa	0- 50	16	42.1	19.3
	50-100	16	30.9	10.3
Abu Saybi - Sb	0- 50	31	54.6	16.3
	50-100	31	39.2	12.1
Maqabah - Mq	0- 50	35	22.3	12.2
	50-100	35	19.2	7.6
Buri - Br	0- 50	19	11.8	12.2
	50-100	19	14.5	7.3
Hawrah - Hw	0- 50	5	7.0	2.3
	50-100	5	9.1	3.6
Cambic Gypsiorthids				
Khuways - Kh	0- 50	64	60.7	18.0
	50-100	64	39.3	14.2
Lawzi - Lw	0- 50	4	32.7	14.3
	50-100	4	29.5	8.0
Zaytun - Zn	0- 50	7	22.2	12.2
	50-100	7	18.2	8.7
Typic Paleorthids				
Areen - An	0- 50	4	12.1	6.0
	50-100	4	8.0	4.1
Salmabad - Sm	0- 50	9	46.2	13.7
	50-100	9	31.9	13.1
Buquwwah - Bw	0- 50	5	42.7	24.5
	50-100	5	27.9	11.7
Aquic Paleorthids				
Isa - Is	0- 50	22	41.3	14.2
	50-100	22	34.5	10.8
Typic Torripsamments				
Hisham - Hs	0- 50	20	17.2	14.2
	50-100	20	13.9	8.1
Typic Psammaquents				
Wasmiyah - Ws	0- 50	12	46.6	29.3
	50-100	12	32.8	20.7

Source: Appendix C

Note: Mean values derived from weighted mean values of salinity calculated at 25cm and 75cm depth. Irrigated sites excluded.

in this chapter.

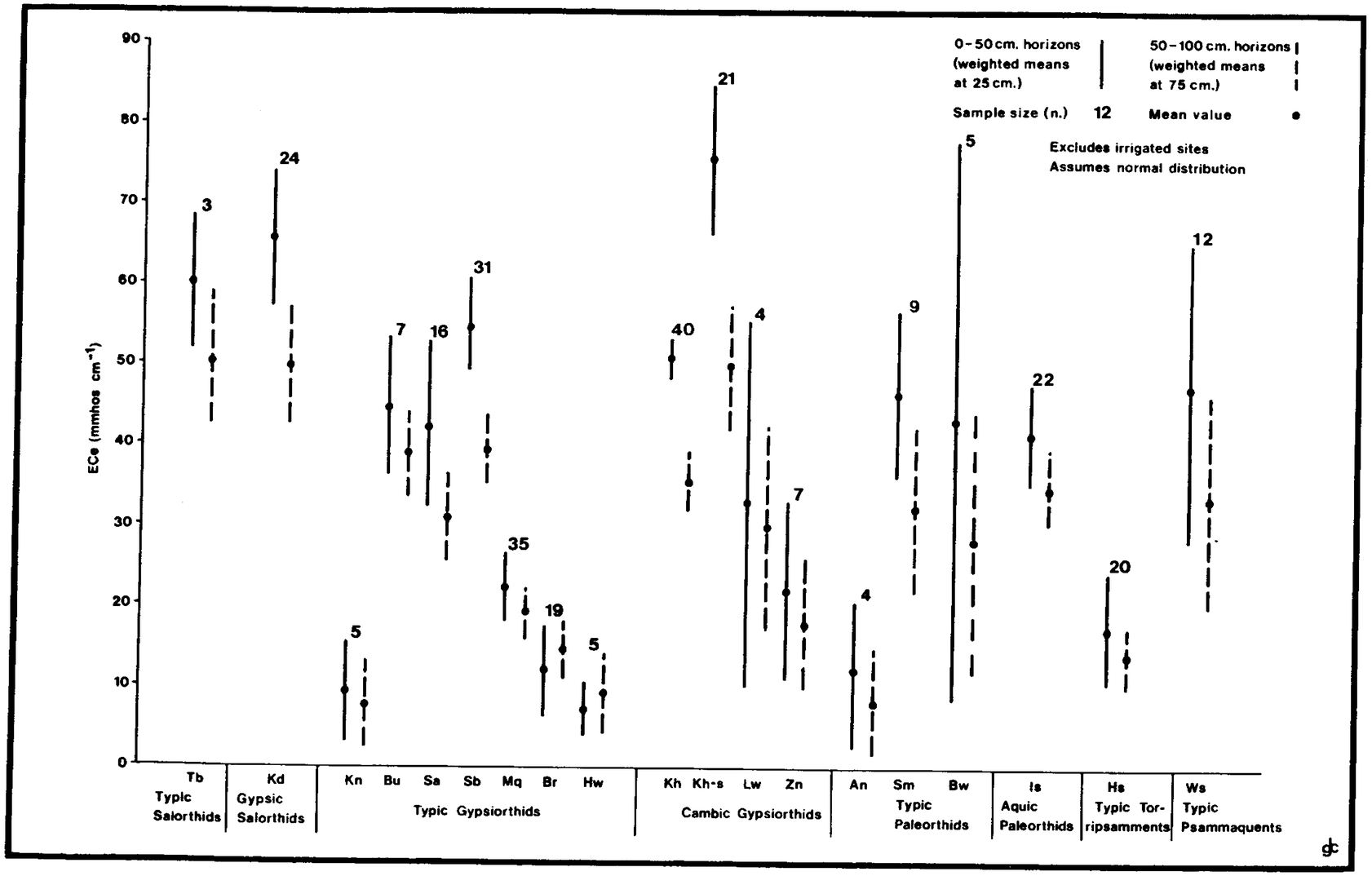
The results (Table 6.5) show that very high salinities are common, few soils have mean Ece values of less than 20 mmhos cm^{-1} whereas three series (Khadarah, Tubli and Khuways saline phase) have means of at least 60 mmhos cm^{-1}. The variation in values within series is illustrated by Figure 6.13, which was compiled from data in Table 6.5. In most series ranges of ECe values are reasonably close but in some a high degree of variance and small sample result in a wide range (notably Buquwwah, Lawzi and Wasmiyah series).

Salinity values are greatest in the upper horizon and decline downwards. This is to be expected in soils in which moisture movement is upwards from a saline watertable: under irrigation this trend is reversed by downward leaching (Appendix F). In fact very high ECe values do occur in the upper horizon but are often masked by the method of calculating the means. The data in Table 6.5 refers to mean values of ECe at 25 and 75cm depth, weighted according to overlying and underlying salinity levels. Thus, highly saline surface horizons, which can be important for soil taxonomy, may not be apparent in the meaned data. However, in terms of crop growth, mean values provide a better indication of the effective salinity than values for individual horizons (Shalhevet and Bernstein, 1968). Two examples of this apparent reduction in ECe values (in mmhos cm^{-1}) are given below:

(i) Khadarah Series: PV044

Measured -		Meaned -	
0-25cm	96.0	0-50cm	62.0
25-60cm	32.6	50-100cm	27.5
60-100cm	20.6		
100-150cm	34.1		

Figure 6.13 Soil Salinity : 95% Confidence Limits for Major Soil Series



(ii) Wasmiyah Series: PV 063

Measured -		Meaned -	
0 - 10 cm	129.5	0-50 cm	79.6
10-80 cm	37.9	50-100 cm	58.0
80-120 cm	52.7		

Although the EC measured in saturation extract most closely simulates salinity conditions in the root zone, the method (Appendix A) is time consuming and the simpler method of measuring EC in an extract of a fixed soil to water ratio is often preferred. However, this takes no account of the saturation percentage of the soil and thus precludes comparisons between EC values for soils of contrasting texture. A regression analysis of EC_e and $EC_{1:5}$ data (Appendix C) produced a positive linear correlation (Figure 6.14) in which $EC_e = 3.19\ EC_{1:5} + 6.31$. This relationship is valid for gypsic and non-gypsic soils in the area studied.

(c) Composition of Soluble Ions

In the soil solution salts dissociate into their constituent Ions. Analyses were performed on saturation extracts of the principla profiles to determine cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) and anions (HCO_3^{-}, Cl^{-}, $SO_4^{=}$ and $CO_3^{=}$). The complete results for these analyses are given in Appendix B.

The proportions of each soluble ion are closely related to the salinity of the soil. Figure 6.14 shows the close correlation between EC_e and chloride ions, which can reach over 2000 me per litre in highly saline soils. At EC_e levels greater than 10.0 mmhos per centimetre the dominant ions are sodium and chloride, with moderately high levels of magnesium in the saline surface horizons. At lower salinities (less than 10 mmhos/cm), calcium and sulphate ions predominate. No soluble carbonate occurs in any of these soils.

As the soils are leached under irrigation the proportions of sodium and chloride ions are reduced. Calcium and sulphate contents, on the other hand, remain relatively stable, as these ions are released by slow solution of soil gypsum. A comparison of the $Cl : SO_4$ ratios therefore provides an indication of the degree of leaching. In Table 6.6 soluble ion compositions of irrigated and non-irrigated soils are compared. This shows that irrigation

Figure 6.14
Soluble Chloride and EC 1:5 Relationship to ECe

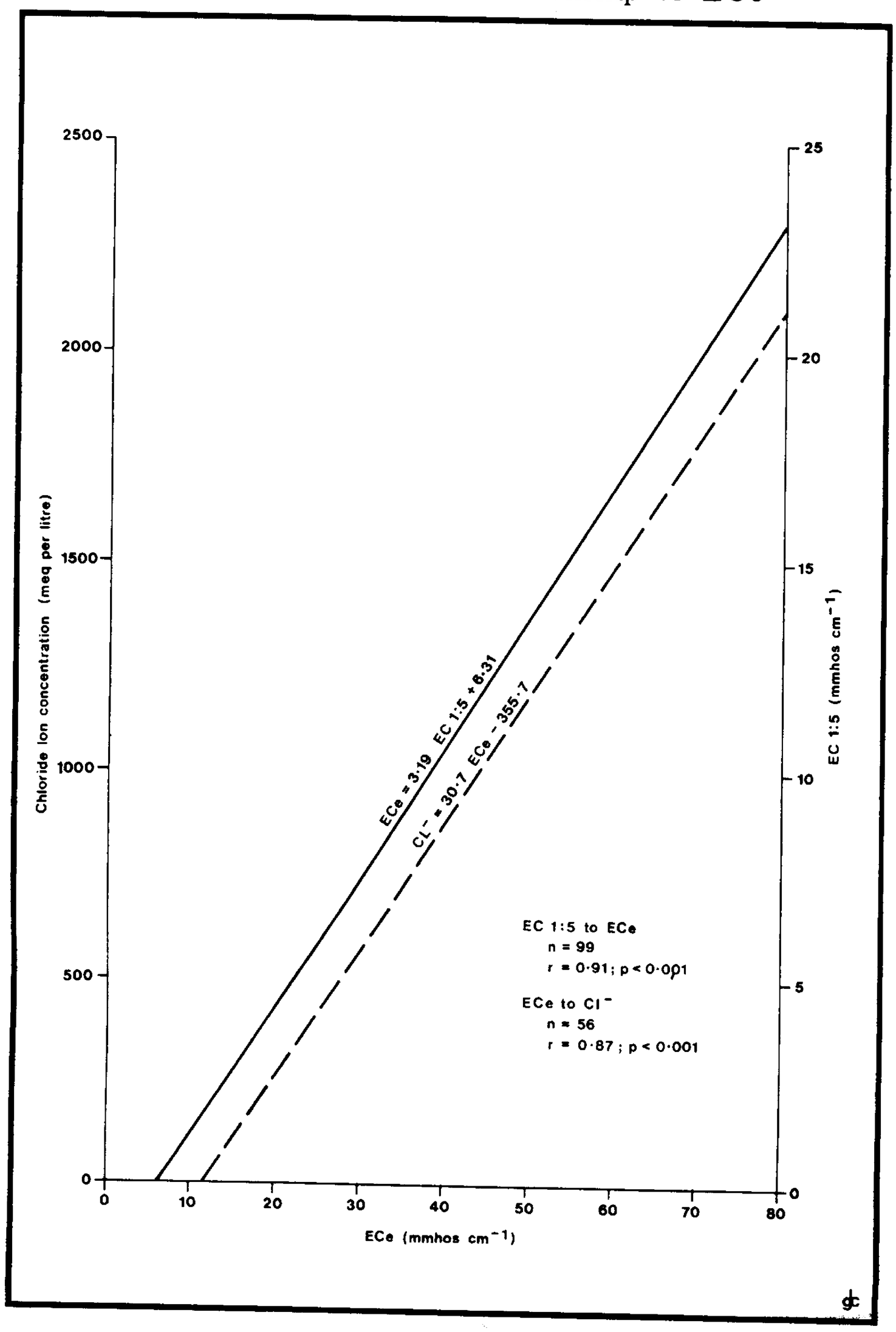


Table 6.6 Soluble Ion Composition: Irrigated

Depth (cm)	ECe	Soluble Ions Ca	Mg	Na
Khuways Series				
PV017-Non-Irrigated				
0-20	66.7	106.5	469.5	1026.9
20-80	38.7	76.0	59.0	361.3
80-135	27.0	54.0	46.0	228.7
V642-Irrigated				
0-25	14.2	55.9	16.1	110.5
25-50	11.0	44.7	14.1	80.0
50-100	12.1	37.4	17.5	85.5
Hisham Series				
PV016-Non-Irrigated				
0-50	30.6	36.3	18.8	152.9
50-65	25.2	35.0	12.5	75.5
65-150	18.3	65.0	46.5	248.1
Z062-Irrigated				
0-50	9.5	38.3	6.4	45.1
50-100	7.5	30.7	11.9	30.5

NOTE (1) Ca/TC is ratio of Soluble Calcium to all

and Non-irrigated sites (m e/litre in saturation extract,

K	HCO_3	Cl	SO_4	Ionic ratios Cl/SO_4	Mg/Ca	Ca/TC[1]
62.5	3.3	1539.0	119.2	12.9	4.41	0.06
21.5	2.3	441.4	74.2	6.0	0.77	0.15
7.5	3.0	259.1	74.2	3.5	0.85	0.16
2.9	2.7	139.6	44.2	3.2	0.29	0.30
2.8	2.4	108.9	28.3	3.8	0.32	0.32
2.5	1.7	113.2	26.9	4.2	0.47	0.26
8.0	2.3	142.9	70.6	2.0	0.51	0.16
3.4	2.0	72.9	51.5	1.4	0.36	0.28
5.9	2.0	295.5	67.9	4.4	0.72	0.18
2.4	2.4	61.2	27.3	2.2	0.17	0.41
3.1	1.6	43.9	29.5	1.5	0.39	0.40

Soluble Cations.

of the highly saline Khuways soils results in a marked decline in the Cl : SO_4 ratio, but that in the Hisham soil, which is far less saline initially, leaching has been less effective and Cl : SO_4 ratios are virtually unchanged. In these examples, however, no artificial drainage was provided and irrigation water applications were probably insufficient to allow adequate leaching.

Cation ratios have been shown to be important in predicting crop yield, regardless of soil salinity or the absolute concentration of ions (Carter et al., 1979). Ratios of magnesium to calcium of greater than 1.0 or calcium to total cations of less than 0.15 are reported to cause crop yield reductions. The comparative figures in Table 6.6 show improvements in these ratios in each of the irrigated sites.

(d) Exchangeable Sodium Percentage (ESP)

For the reasons discussed in Appendix A, conventional methods of measuring exchangeable cations are impractical in soils with very high concentrations of soluble cations. ESP values were therefore derived from the sodium absorption ratio (SAR) using the empirical relationship proposed by USDA (1954). Highly saline soils were pre-leached to reduce the levels of soluble sodium.

High proportions of exchangeable sodium can adversely affect soil permeability by deflocculating clay particles and harming crop nutrition by causing an imbalance with calcium. In the present survey area, however, clay contents are very low and the mean ESP for the 58 samples from all representative sites (Appendix B) is only 5.2 (S.D. = 4.52). Moreover, there are very large soil reserves of calcium ions, as gypsum and $CaCO_3$, which would readily replace sodium ions leached from the exchange complex. Exchangeable sodium therefore presents no hazard to irrigation and cropping. No chemical amendments, such as gypsum, will be required during reclamation leaching.

(e) Control of Salinity under Irrigation

The high salinity values reported earlier in the chapter refer to non-irrigated sites, but with irrigation and drainage these high values can be greatly reduced. However, in order to reduce and maintain salinity under irrigation it is necessary to apply

sufficient water, in excess of crop requirements, to allow downward leaching and removal of soluble salts from the profile. The leaching requirement depends on the desired final salinity and the EC of the irrigation water being used; in this present chapter brief consideration is given to the soil aspects of leaching requirements and efficiency.

The quality of irrigation water used in the area is extremely poor (Appendix D) and yet there is considerable evidence of success in production of adapted crops. This is achieved without artificial drainage but does involve irrigation water application either daily or every other day, and in this way soil salinity is controlled, albeit at the cost of rising watertables. Investigations at Budayyi (Appendix F.) showed that trickle irrigation using water of 3.9 mmhos/cm results in salt accumulation at the surface between rows but no detectable accumulation of gypsum.

Comparisons between basin irrigated and non-irrigated sites (Appendix F.) show that very high soil salinities can be effectively reduced by irrigation, despite the use of highly saline water (3.9 to 17.0 mmhos/cm). The summarised data (Table 6.7) suggest that soil EC_e values can be reduced to 10.0 to 15.0 mmhos/cm, using traditional methods, often extremely saline water and no artificial drainage. The lower EC_e values for sandy soils probably reflect freer drainage. With better quality irrigation water and improved drainage and irrigation efficiency, EC_e values could be reduced still further, but within the limits of the irrigation water salinity.

Table 6.7 Summary of ECe Comparisons

Sites	Sample Depth (cm)	Non-Irrigated Mean n	ECe	S.D.	Irrigated Mean n	ECe	S.D.
All sites	0- 50	12	43.4	26.0	12	11.9	3.4
	50-100	12	28.5	9.9	12	15.6	9.6
Watertable more than 1.0m deep	0- 50	6	44.4	34.0	6	11.1	3.1
	50-100	6	26.5	11.1	6	12.2	4.1
Watertable less than 1.0m deep	0- 50	6	42.5	13.8	6	12.7	3.6
	50-100	6	30.6	8.0	6	18.8	12.0
Fine loamy soil	0- 50	8	52.9	26.6	8	13.3	3.4
	50-100	8	32.8	7.7	8	17.8	10.4
Sandy soils	0- 50	3	23.0	9.6	3	9.0	1.0
	50-100	3	16.5	6.1	3	8.1	2.0

Source: Appendix F.
ECe values in mmhos cm^{-1} at $25^{o}C$, derived from weighted means at 25cm (0-50cm) and 75cm (50-100cm) depths.

The frequent irrigation applications currently used are apparently necessary to reduce rootzone salinity. This involves leaching of salts derived from irrigation water as well as forcing down salts rising in capillary moisture from the watertable. In many irrigated fields the watertable lies within 0.5 to 1.0m of the surface and must contribute to salinization of the rootzone. In loamy soils, such as Khuways series, the capillary fringe extends 0.5 to 0.7m above the watertable while moisture and salinity contents are influenced over twice this distance (Appendix F.). Less capillary rise is observed in sands and the zone of moisture influence is usually less than 0.5m.

In order to minimise the contribution to surface salinity by groundwater and thereby indirectly help to extend the irrigation interval, drainage design should ensure that watertables are maintained at or below a depth of 1.5m under fine loamy soils, although shallower depths would be feasible under sands.

In the calculation of leaching requirements, consideration must be given to the efficiency with which leaching can be achieved. This depends upon the degree to which added water displaces that already present. In soils with stable pores and strong structure, much of the percolating water passes

direct through pores, leaving the body of the soil unleached: in sandy profiles, however, the percolating water displaces up to 80 per cent of the existing soil water (Thomas et al, 1978). In silt loam soils, tests have shown (Quisenberry and Phillips, 1976) that chloride ions applied in the irrigation water are leached direct through the profile with little displacement of ions initially present.

Van der Molen (1973) has proposed leaching efficiencies for soils of different textures; in the soils of the present study area, tentative values are as follows:-

Silty-clay soils	0.4 - 0.5
Silt-loamy soils	0.5 - 0.6
Gypsic-coarse-loamy soils	0.6 - 0.7
Sandy soils	0.7 - 0.8

Assuming that adequate drainage is provided and that account is taken of the leaching efficiency of the soil, it should be possible to reduce the effective salinity of the soils to at least the EC of the irrigation water (minimum of 3.8 mmhos cm^{-1}).

6.5.5 Soil Fertility

The most accurate indication of soil fertility potential can be obtained only by field experimentation. Nevertheless, general aspects of fertility can be inferred from the soil analyses in Appendix B. As discussed earlier, the availability of essential plant nutrients will be severely modified by the high contents of gypsum and carbonates in the soil.

(a) **Nutrient Retention Capacity**

All the soils have low clay contents and therefore low cation exchange capacities (Table 6.8). Consequently they have a low capacity for retaining mineral nutrients against leaching. In view of the high rates of leaching demanded by the saline conditions, this will necessitate frequent applications of fertilizer.

Table 6.8 Cation Exchange Capacities (CEC)

Soil Family and Series	Depth	No. Samples	CEC (meq.per 100g) Mean	S.D.
Clayey, mixed				
Lawzi	0- 50	3	12.1	2.33
	50-100	3	21.1	2.53
Fine-loamy, carbonatic				
Khuways	0- 50	9	8.0	3.84
Buquwwah	50-100	9	9.6	3.38
Tubli, Khadarah	0- 50	2	9.7	2.15
	50-100	2	12.9	5.40
Fine-loamy, mixed				
Salmabad	0- 50	3	9.3	2.93
	50-100	3	12.7	1.51
Coarse-loamy, carbonatic				
Isa	0- 50	3	11.1	5.12
	50-100	3	15.9	4.84
Coarse-loamy over fine-loamy, gypsic.				
Sar, Abu Saybi	0- 50	6	5.3	2.22
	50-100	6	10.3	3.32
Coarse-loamy, gypsic				
Maqabah	0- 50	5	4.1	2.77
Buhayr	50-100	5	2.9	1.80
Coarse-loamy-skeletal,mixed				
Dilmun	0- 50	2	4.1	0.15
Sandy, gypsic				
Karzakkan	0- 50	4	3.5	0.71
Hawrah, Buri	50-100	4	6.0	2.30
Sandy, mixed				
Hisham, Areen,	0- 50	7	6.8	5.94
Wasmiyah	50-100	7	6.5	4.59
Total	0- 50	44	7.1	4.44
	50-100	42	9.3	5.64

Note: Data derived from weighted mean CEC values at 25 and 75cm depths.

(b) Organic material, nitrogen and phosphorus.

Table 6.9 shows the mean value of these materials in the 26 topsoils analysed. There is no apparent difference in contents of nitrogen, carbon or phosphorus between different soil units. Total nitrogen values are consistently low and the high carbon-nitrogen ratios indicate a high degree of mineralisation of nitrogen. The mean organic matter contents are similarly low, as would be expected under the prevailing oxidising conditions. In some profiles (such as Sar Series, PV 005) subsurface horizons proved to have moderate organic carbon contents, confirming the existence of buried A horizons.

Total phosphorus contents are varied but available phosphorus values are universally low.

Favourable crop response to all major plant nutrients can be expected on each of the soils studied.

Table 6.9 Phosphorus, nitrogen and organic material: mean values for 26 sites.

Parameter	Mean	SD
Total N (%)	0.038	0.026
Organic Carbon (%)	0.61	0.448
Organic Matter (%)*	1.05	-
C : N ratio	17.3	10.74
Total Phosphorus (mg/100 g)	49.3	62.36
Available P (mg/100 g)	1.01	0.909

Source: Appendix B, all soils tested.

Note: * - Organic matter calculated as Organic Carbon X 1.72.

7

Land Classification

7.1. INTRODUCTION.

The purpose of agricultural land classification is to rank lands according to their suitability for appropriate types of agriculture. The primary objective of the present study is to identify land for irrigation development, an objective which is to be acheved in the context of scarce and low quality irrigation water. The attributes of the Level 3 lands have been described individually in the previous chapter in relation to their effects on irrigated land use: in this final chapter these attributes are used to classify the land for irrigation agriculture.

7.2. THE USBR SYSTEM OF LAND CLASSIFICATION.

The system of classification used by the United States Bureau of Reclamation (USBR, 1953) forms the basis for the mainland UER land classification studies (GDC, 1978) and has therefore been adopted for use in Bahrain. The USBR system ranks land according to its predicted payment capacity under irrigation. Six classes are defined, in whcih Classes 1,2,3 and 6 represent lands which are, respectively, of good, moderate, marginal and unacceptable quality for irrigation. Class 4 land may be of Class 3 or 6 quality under basic project conditions but if given specially modified conditions(in terms of irrigation method or type of crop) may produce returns equivalent to Classes 1,2 or 3. Class 5 indicates land for which further information is required before it can accurately be classified.

The principles of the six class system are best described by extracts from the original definitions(USBR, 1953).

Class 1 - Arable:

"Lands that are highly suitable for irrigation farming, being capable of producing sustained and relatively high yields of a wide range of climatically adapted crops. These lands potentially have a relatively high payment capacity."

Class 2 - Arable:

"Lands of moderate suitability for irrigation farming, being measurably lower than Class 1 in productive capacity, adapted to a somewhat narrower range of crops. They are not so desirable nor of such high value as lands of Class 1 because of certain correctible or non-correctible limitations. They have intermediate payment capacity".

Class 3 - Arable:

"Lands that are suitable for irrigation development but are approaching marginality for irrigation and are of distinctly restricted suitability because of more extreme deficiencies in the soil, topographic or drainage characteristics than described for Class 2 lands. They are expected to have adequate payment capacity".

Class 4 - Limited arable:

"Lands which have one or more excessive, non-correctible deficiences thereby limiting their use to relatively permanent crops. Class 4 lands may have a range in payment capacity greater than that for associated arable classes".

Class 5 - Non-arable:

"Lands in this class are non-arable under existing conditions but have potential value to warrant segregation for special study prior to completion of the study or they are lands in existing projects whose arability is dependent upon additional scheduled project construction or land improvements.
Class 5 lands are segregated when problems related to land development are involved".

Class 6. Non-arable:

"Lands considered non-arable under the existing project because of failure to meet the minimum requirements for the other classes of land. The lands do not have sufficient payment capacity to warrant consideration for irrigation".

The USBR classification aims at rating land quality in terms of physical capability and level of economic return. While its principles have been widely accepted throughout the world, the system inevitably requires modification when applied in different countries where special conditions, both physical and economic, may apply. In most countries, however, the economic criteria remain basically unchanged in that land which will give the greatest return to investment will be rated highest in the classification, regardless of the absolute rate of return. Class 1 land represents optimum or near-optimum potential for the area being studied. In economic terms this optimum may be quite low, because of the special conditions obtaining in the country, but it does establish a standard against which other land classes can be broadly assessed. The lower returns to be expected from classes 2,3 and 6 are due to either (a) the direct effects of deficiencies on agricultural performance, such as yield depression; or (b) the costs of ameliorating the deficiency. A compromise between the two may often give the best result.

7.3 FACTORS AFFECTING LAND CLASSIFICATION IN BAHRAIN

The physical constraints on agriculture in Bahrain are extreme and must be accounted for when classifying land for irrigation. Principal among these are the scarcity and poor quality of both agricultural land and irrigation water. These severely limit the range and yield potential of crops that can be grown.

(a) Land Scarcity

Bahrain is a small country with only 10 to 15 percent of its land suitable for agriculture. This land has been and still is being, encroached upon by urban and industrial development . Moreover, considerable areas of previously cultivated land have become unusable for agriculture due to salinization, deposition of gypsum or deterioration of groundwater supplies. Thus the area of useable agricultural land has decreased and will continue to do so unless there is a change in government policy whereby arable-quality land is retained solely for agriculture.

(b) Water Quality and Availability.

Supplies of irrigation water are scarce and are likely to become more so in the future, whether from groundwater sources or treated sewage effluent (TSE). Similarly, in recent years the quality of available irrigation water has deteriorated in terms of salinity and in many cases would not normally be considered suitable for irrigation.

(c) Land Quality.

Much of the land currently used for agriculture and most of the potentially useable land is highly saline. Furthermore,many of the soils are extremely gypsic and calcareous.

(d) Drainage

Practically all the currently used land requires artificial drainage to lower the existing saline watertables. Similarly, new lands would require extensive drainage to facilitate reclamation leaching . In an area of low relief and with low elevations above sea level the discharge of the drainage water is difficult.

All these factors make for costly land development. Nevertheless, crops are currently grown on land which would normally be rated unsuitable using water of a quality not normally to be

recommended. In view of the generally low yields obtained (Table 7.1), it may not be economic in the usually accepted sense but it is being done and cannot be ignored. The USBR land classes have therefore been adapted to embrace the widest variety of land which it is considered could be successfully developed under irrigation. It has been necessary to place some land in Class 5, which implies that it can be considered useable only following reclamation and agronomic measures whose feasibility has yet to be confirmed, whereas Class 6 land has been kept to a minimum.

Table 7.1. Estimates of Current Crop Yields

Crop	Yield (t ha^{-1})
Perennial Crops	
Alfalfa	8.0 - 10.0
Winter Crops	
Tomato	11.0
Onion	13.0
Potato	7.0
Turnip	19.0
Cabbage	13.0
Sweet Corn	5.0
Summer Crops	
Melon	19.0
Water Melon	12.0
Okra	5.0

Note: Data for traditional sector farms(Hunting Technical Services, 1978).

7.4. LAND CLASSIFICATION SPECIFICATIONS

In view of the scarcity and poor quality of irrigation water supplies the efficiency of water use in Bahrain should be maximised: this implies use of piped or lined

channel delivery and accurately controlled trickle or sprinkler irrigation systems. The traditional basin irrigation method is wasteful in terms of water use but can be acceptable with piped delivery to the field head (GDC, 1979). The types of crop scheduled to be grown include fruit trees, vegetables and fodder (GDC, 1979).

With such a diversity of irrigation methods and crop types it is difficult to establish a single set of land quality criteria. Indeed, on the UER mainland study a dual system was used to separately identify land for overhead and for surface irrigation. Conditions in Bahrain, however, differ in that the over-riding need is for efficient use of limited and very saline water. The prime considerations for the land classification must therefore be use of an efficient delivery system and efficient leaching of the soil. These considerations affect all forms of landuse and logically favour the use of trickle irrigation on sandy soils. Consequently a single land classification system was developed to apply to all cropping and irrigation methods.

The six classes defined for the level 3 areas are as follows:-

Class 1 Arable: highly suitable for irrigation of a wide range of climatically adapted crops.

Class 2 Arable: suitable for irrigation of a less wide range of climatically adapted crops.

Class 3 Arable: moderately suitable for irrigation of a restricted range of adapted crops.

Class 4F Limited-Use: suited to salt-tolerant tree crops and some perennial fodder crops.

Class 5 Non-arable: provisionally designated suitable for amenity, shelter-belt or timber tree planting.

Class 6 Non-arable: not suitable for irrigation .

Table 7.2 gives the land classification specifications for these six classes in terms of the major soil - land factors, showing how each affects the assessment of the land. The effects of different deficiencies on a particular piece of land are cumulative, so that several Class 2 deficiencies could relegate the land to Class 3. The principal factors affecting irrigation suitability in Bahrain are divisible into soil, drainage and topographic factors.

7.4.1. Soil Factors.

The principal soil characteristics required for successful production under irrigation in Bahrain can be listed as followes:-

(a) Effective Depth:- "s"
A soil depth of 0.5m with no hinderance to root or moisture percolation was taken as the minimum requirement for an arable class. At least 1.0 metre is required for Class 4F to provide adequate rooting depth for tree crops. It should be emphasised that effective depth can differ from profile depth as defined by Soil Taxonomy. Furthermore, in view of the abundance of gypsum in the Bahrain soils, all superficial material is accepted as contributing to soil effective depth: those soils with cemented gypsic layers are downgraded separately on the basis of gypsum (x). In the mainland UER study area, where gypsic soils are less commonly cultivated, effective depth was accepted as ceasing at a layer of crystalline gypsum (GDC , 1978).
The effective depth criterion rules out use of shallow soils over rock and those with petrocalcic horizons in the upper profile.

(b) Sandy or Skeletal Particle-Size Class - "a".

Particle-size is the single most important factor in land classification, given an adequate effective depth, because it influences all other physical characteristics of the

Table 7.2 Land Classification Specifications for Irrigation using Saline Water

Class Limitations		1. Arable	2. Arable	3. Arable	4F. Limited Use-Trees	5. Non-Arable	6. Non-Arable
s b	Soil effective depth(m) Particle-size class; 0 - 1.0m	1.0 Coarse loamy - Fine loamy	0.75 Sandy-fine loamy	0.5 Sandy-clayey	1.0 Sandy-fine loamy	0.5 Sandy-clayey	Land failing to meet the minimum requirements for Classes 1 - 5 are place in Class
i	Initial infiltration rate(1) (mm/h)	⩾20	⩾10	⩾5	⩾5	⩾5	
p	Internal drainage:- - drainage requirement - watertable depth (m) - substratum-hydraulic conductivity (md-1) - depth to restricting layer (m) (5)	Minimal 2.0 1.0 2.0	Moderate 1.0 0.6 2.0	Extensive 0.5 0.1 1.0	Extensive 0.5 0.2 1.0	Moderate 1.0 0.2 1.0	
d	Marine intrusion hazard	None	None	Slight, limiting drainable depth	Moderate, severely limiting drainable depth	Slight, limiting drainable depth	
	Land elevation a.s.l(m)	3.0	3.0	2.0	1.0	2.0	
x	Soil salinity;0-1.0m(2) (ECe mmhos cm-1)	8	64	n.l.	n.l.	64	
y	Gypsum: Inferred by soil sub-group	Non-to slightly gypsic	Cambic Gypsi-orthids	Cambic Gypsi-orthids	Typic Gypsi-orthids or equivalent(3)	Typic Gypsi-orthids or equivalent(3)	
	Gypsum % 0-0.5m	5	30	30	n.l.	n.l.	
	0.5-1.0m	10	10	30	30	n.l.	
	Cementing	non-cemented	non-cemented	Weakly cemented	Weakly cemented	Moderately cemented	
e	Existing erosion(water)	No evidence	Slight rilling	Moderate rilling	n.l.	n.l.	
m/c	Micro-relief:(4) Land smoothing requirements(6) ($m^3 ha^{-1}$)	500	1500	1800	1000	500	
t	Land slope (%)	2	4	4	4	4	

Table 7.2 Continued

Notes: (1) Infiltration rate for initial 100 mm water.
(2) Based on highest ECe value for either 0-0.5 or 0.5-1.0m depths.
(3) Any soil with a gypsic horizon meeting requirements of Typic Gypsiorthid sub-group.
(4) Includes clearance of tree stumps in abandoned date groves (c).
(5) Restrictive layers refer to hard rock; petrocalcic horizons acceptable within half stated minimum depth.

soil, including infiltration, drainage, erosion, fertility potential and moisture holding capacity. In the present context deficiencies in most of these characteristics are presented as separate limitations e.g. infiltration, drainage, erosion - see below. The particle-size limitation applied here is that caused by sandy and, in extreme cases, skeletal particle-size classes. This is because these classes always combine deficiencies in moisture holding capacity and fertility potential. In the sandy particle-size class these deficiencies only downgrade to Class 2 because they are partly compensated by the extra leaching efficiency associated with the sandy soils. Skeletal classes are downgraded to Class 6 because of their excessively gravelly textures which cause extremely low moisture holding capacity and fertility potential.

(c) Infiltration Rate - "i".

The high rates of leaching required to combat soil salinity demand high rates of infiltration. The minimum requirements for basic infiltration rate are therefore set at levels higher than on the mainland. However, field tests suggest that nearly all the soils meet these requirements, so this is not an important factor in the land classification. Although high rates are beneficial for leaching, they do limit the range of practicable irrigation methods, so that preference for trickle or overhead systems is implicit in the land classification specifications; basin irrigation would be feasible only where infiltration rates are likely to decrease somewhat following cultivation e.g. Khuways series.

(d) Soil Salinity - "x"

High levels of salinity reduce crop yields, but leaching of salts is feasible in the Level 3 areas (Chapter 6), thus high salinity per se is not sufficient to class a soil as non-irrigable. However, high salinity does take time to remove and in the interim period only low value, salt-tolerant crops can be grown.

An unusually high salinity of 8.0 mmhos/cm is accepted for Class 1 because the irrigation water itself will create soil salinities of at least 4.0 mmhos/cm, even with adequate leaching fractions.

Salinities in excess of 8.0 mmhos cm^{-1} are likely to considerably restrict the range of crops which can be grown. In the non-irrigated state soil ECe values of upto 64 mmhos cm^{-1} are permitted in Class 2. Land with initial salinities above this level are downgraded on the assumption that such salinities must indicate inherent deficiencies in drainage or saline seepage which would be difficult to correct.

(e) Gypsum - 'y'

As discussed in the preceeding chapter, gypsum is an important constituent of soils in the Level 3 areas. In itself it is not harmful to plant growth but high levels of gypsum

contribute to nutritional imbalances, cementing impedes root penetration and solution collapse can seriously interfer with land levelling. Gypsic soils containing 60 per cent or more gypsum are currently being irrigated with reasonable success but the irrigation water is gypsum- saturated. Use of gypsum-unsaturated Khobar water could, on the otherhand, introduce the hazard of solution collapse as drainage and leaching proceed. The criteria in Table 7.2 therefore favour low proportions of non-cemented gypsum. Relatively high contents (upto 30 per cent) are tolerated in Class 2 provided the gypsum is in the surface, thus minimising the harmful effects likely from solution collapse. Similarly, in Classes 3 and 4F subsoil gypsum contents are restricted to 30 percent: more gypsic soils are placed in Classes 5 or 6.

7.4.2 Drainage factors

Drainage deficiencies apply when the land requires more than the basic system of drains which would be a standard part of the irrigation design. Drainage factors are divisible into those relating to the soil profile and its immediate substratum and those resulting from the topographic location of the site.

(a) Internal Drainage - "p"

The drainability of the soil is dependent upon the permeability of the control section and the hydraulic conductivity of the substratum. As discussed in the previous chapter, neither of these factors are likely to be limiting. The only instances where special drainage measures are likely to be required are in the clayey profiles of Lawzi series and in otherwise permeable soils which overlie a layer of rock within the upper 3.0 to 4.0 m. The latter constitutes a restricting layer and is specified separately in Table 7.2; where a petrocalcic horizon is present the depth limits are relaxed as it should be possible, at extra cost, to penetrate these layers during installation of drains.

The existence of high watertables (less than 1.0 m) are taken as being indicative of areas with inherent drainage problems and such lands are downgraded: this is the commonest form of internal drainage limitation in the Level 3 areas. Field drainage would therefore be essential for their control and to ensure that waterlogging of the rootzone by temporary rise of watertables would be avoided.

In view of the large drainable surplus which is likely to accrue from the relatively high rates of leaching, the minimum requirements for substratum hydraulic conductivity have been raised from the equivalent values used on the UER mainland survey (GDC, 1978). Nevertheless, recorded hydraulic conductivity values (Chapter 6) all exceed the minima and hence this factor is not limiting.

(b) Site Drainage Factors- "d"

One of the major drainage constraints is the physical removal of drainage effluent from the irrigation lands ; this is especially so on an island with low relief and little elevation above sealevel. Most of the Level 3 areas are drainable by gravity although, as described in Chapter 6, in some low-lying areas elevations above sea level limit the effective depth of drainage. Moreover, as these areas are closely linked to the sea by sandy alluvium, there is a risk of marine water intrusion if soils are drained to depths below sea level. The marine intrusion hazard is recognised as a site drainage deficiency in areas close to the sea : an elevation of 3.0m is taken as the minimum to ensure an adequate drained depth for Classes 1 and 2 lands. At lower elevations the feasibility of maintining an adequate drained depth become less and attempts to achive this depth pose an increasing risk of marine intrusion.

7.4.3. Topographic Limitations.

Topographic limitations are separated into slope, microrelief and erosion factors.

(a) Slope - "t".

Land slope is normally the main topographic limitation but in the Level 3 areas slopes only rarely exceed 2.0 per cent. Slope limitations are listed in the specifications (Table 7.2) for completeness.

(b) Microrelief - "m/c".

The degree of microrelief affects the costs of initial land preparation. The land smoothing criteria (Table 7.2)

are very much higher than would normally be allowed but in Bahrain facilities for levelling are available and land smoothing would represent a relatively low once- and- for-all initial cost. Abandoned channels form the principal microrelief limitation ("c") but some natural hummocky relief ("m") occurs, especially on sands. The costs of levelling the abandoned channel relief are increased by the presence of date palm stems.

(c) Erosion - "e".

As rainfall in Bahrain is minimal, erosion by water is confined to sites where run-off is sufficiently concentrated and minor rilling occurs. The erosion limitation applies along the foot of the limestone backslope, associated with run-off channels. Win erosion is active in some areas but could be arrested simply by wind breaks and cropping.

7.5. LAND CLASSIFICATION MAPPING

7.5.1. Representation of Units.

Following the principles outlined in the preceeding sections, each soil mapping unit was classified in terms of soil factors to obtain basic classes (Table 7.3). These were then modified by applying site drainage and topographic deficiencies where appropriate.

By this means land classification maps at 1:10 000 scale were compiled for the level 3 areas (UER Sheets Nos. 12 - 17). The units used for mapping represent subclasses of each USBR class; lower case suffixes denote the deficiencies responsible for downgrading. Hence, land with microrelief and salinity deficiencies, each of Class 2 proportions, is represented on the maps by the code "2 xm". A shortcoming of the code is that it gives no indication of the level of deficiency of each factor. For example, land with gypsum and salinity deficiencies of Class 2 level but with microrelief of Class 3 proportions, would be mapped as "3 xym". By reference to Table 7.3 and the soil map it can be found that the soil in this case has a basic classification of 2xy hence the downgrading

Table 7.3 Land Capability Characteristics of Soil Series

Soil Series/ phase		Class Level of Limitation						
		Depth s	Particle-Size a	Infiltration i	Drainage p	Salinity x	Gypsum y	Basic Soil Class
Tubli	Tb	1	1	1	6	3	2	6 pxy
Khadarah	Kd	1	1	1	3	3	4F	4 Fpxy
Karzakkan	Kn	1	2	1	1	2	6	6 axy
Hawrah	Hw	1	2	1	1	1	5	5 ay
Buri	Br	1	2	1	1	2	5	5 axy
	Br-q	1	2	1	1	2	3	3 axy
Maqabah	Mq	1	1	1	1/2	2	5	5 xy
	Mq-n	1	1	1	2	2	4	4 Fpxy
Buhayr	Bu	1	1	1	1	2	5	5 xy
Sar	Sa	1	1	1	2/3	2	4	4 Fpxy
Abu Saybi	Sb	1	1	1	2	2	4	4 Fpxy
	Sb-w	1	1	1	3	2	4	6 pxy
	Sb-s	1	1	1	2	3	4	4 Fpxy
Zaytun	Zn	3	1	1	1	2	3	3 sxy
Khuways	Kh	1	1	1	2	2	2	2 pxy
	Kh-s	1	1	1	2	3	2	3 pxy
	Kh-ws	1	1	1	3	3	2	3 pxy
Lawzi	Lw	1	1	2	2	2	2	3 ipxy
Areen	An	3	2	1	2	1	3	3 sapy
	An-m	6	2	1	2	1	3	6 sapy
Salmabad	Sm	3	1	1	2	2	4	5 spxy
Buquwwah	Bw	2	1	1	3	2	2	3 spxy
Isa	Is	3	1	1	6	2	4	6 spxy
	Is-s	3	1	1	6	3	4	6 spxy
Hisham	Hs	1	2	1	1/2	2	1	2 ax
Wasmiyah	Ws	1	2	1	2	2	1	2 apx
	Ws-g	1	2	1	2	2	3	3 apxy
	Ws-s	1	2	1	3	3	1	3 apx
Dilmun	Dm	6	6	1	1	2	4	6 saxy
Rockland	R							6 r
Channels	CC							3 sx
Swamp								6 w

Note: Soil complexes classified according to dominant series.

to Class 3 must have been solely on the basis of microrelief.

7.5.2 Land Class Mapping Units.

Table 7.4. summarises the proportion of land classes in each of the Level 3 areas. Some 40 percent of the land is classed as being arable with a further 17 percent being mapped as land of limited agricultural use. A detailed breakdown of individual sub-classes, by survey area, is given Table 7.5.

Table 7.4. Summary of Land Class Areas.

Land class	Salmabad Ha	%	Hawrat Inqa Ha	%	Buhayr Ha	%	Total Area Ha	%
1.Arable	-	-	-	-	-	-	-	-
2.Arable	672	18.0	12	4.4	-	-	684	16.6
3. Arable	840	22.5	98	36.3	-	-	938	22.8
4.Limited-Use	621	16.6	95	35.3	-	-	716	17.4
5.Non arable	864	23.1	19	7.0	77	74.7	960	23.3
6.Non arable	630	16.8	46	17.0	26	25.3	702	17.2
Village. Sites	113	3.0	-	-	-	-	113	2.7
Total	3740	100.0	270	100.0	103	100.0	4113	100.0

The principal characteristics of the land classes are described below:-

(a) Class 1. Land Highly Suitable for Irrigation.

No Class 1 land is recognised. All soils are downgraded due to salinity or gypsum or both, apart from any other limitations.

Table 7.5 Areas of Land Capability Sub-Classes

Sub-Class	Salmabad		Hawrat 'Inqa		Bunayr		Total Area	
	ha	%	ha	%	ha	%	ha	%
1	No Class 1		No Class 1		No Class 1		No Class 1	
2 ax	166.0		2.7		No Class 2		168.7	
2 axm	87.1		9.4				96.5	
2 apx	27.1		-				27.1	
2 sapx	4.8		-				4.8	
2 pxy	84.0		-				84.0	
2 pxyc	303.2		-				303.2	
Sub-Total	672.2	18.0	12.1	4.4			684.3	16.6
3 axm	33.5		-		No Class 3		33.5	
3 axy	17.8		-				17.8	
3 sxy	54.5		-				54.5	
3 axym	26.7		-				26.7	
	20.5		-				20.5	
3 axd	-		20.9				20.9	
3 sapxy	-		44.6				44.6	
3 sapyd	-		29.1				29.1	
3 sapymd	-		3.2				3.2	
3 spxy	43.1		-				43.1	
3 spxyc	17.5		-				17.5	
3 pxy	120.0		-				120.0	
3 ipxy	64.0		-				64.0	
3 pxyc	313.1		-				313.1	
3 pxyd	3.5		-				3.5	
3 pxycd	126.2		-				126.2	
Sub-Total	840.4	22.5	97.8	36.3			938.2	22.8
4 Fxd	-		11.6		No Class 4		11.6	
4 Fpxd	-		73.4				73.4	
4 Fpxy	428.6		-				428.6	
4 Fpxyd	-		9.5				9.5	
4 Fpxym	15.3		-				15.3	
4 Fpxyc	87.1		-				87.1	
4 Fpxyd	57.1		-				57.1	
4 Fpxycd	32.9		-				32.9	
Sub-Total	621.0	16.6	94.5	35.3			715.5	17.4

Table 7.5 (Continued).

Sub-Class	Salmabad ha	%	Hawrat'Inqa ha	%	Buhayr ha	%	Total Area ha	%
5 axy	75.9		-		62.2		138.1	
5 axym	4.2		-		-		4.2	
5 aye	-		18.9		-		18.9	
5 xy	429.9		-		-		429.9	
5 xym	148.9		-		-		148.9	
5spxy	117.7		-		-		117.7	
5 pxy	78.2		-		-		78.2	
5sxye	9.1		-		-		9.1	
5 saxy	-		-		15.2		15.2	
Sub-Total	863.9	23.1	18.9	7.0	77.4	74.7	960.2	23.3
6 sapy	-		16.0		-		16.0	
6 saxy	120.0		-		-		120.0	
6 saxym	135.4		-		-		135.4	
6 spxym	4.5		-		-		4.5	
6 axym	66.1		-		-		66.1	
6 spxy	144.1		-		21.8		165.9	
6 pxy	12.4		-		-		12.4	
6 pxyd	52.0		-		-		52.0	
6 pxycd	17.1		-		-		17.1	
6 axy	29.5		-		-		29.5	
6 sxe	20.6		-		-		20.6	
6 saxyme	-		8.9		-		8.9	
6 pxyc	4.5		-		-		4.5	
6r(1)	10.8		21.4		4.4		36.6	
6w(2)	13.1		-		-		13.1	
Sub-Total	630.1	16.8	46.3	17.0	26.2	25.3	702.6	17.2
Villages	112.8	3.0	-	-	-	-	112.8	2.8
Total	3740.2	100.0	269.6	100.0	103.6	100.0	4113.6	100.0

Note: (1) 6r is mapped on bare rock outcrops
(2) 6w refers to permanent swamp areas

(b) Class 2: Land moderately suitable for Irrigation.

This class is mapped in areas of sand sheets and the Loam Plains. The lands are broadly divisible into two groups on the basis of their principal deficiencies.

(i) Lands with particle size and salinity deficiencies. These comprise extensive areas of sandy soils, principally Hisham series, which have salinity exceeding 8.0 mmhos/cm. Leaching under irrigation should rapidly reduce these values. The sandy particle size causes low moisture holding capacity and poor fertility potential. These lands have a moderate potential for irrigation and are particularly suited to trickle or sprinkler systems. Some Class 2 ax lands are limited by natural microrelief (2 axm), which is similarly rectifiable. High watertables and shallow profiles occur locally within the sand sheets and result in downgrading to 2 apx or 2 bspx.

(ii) Lands comprising silt loam soils of Khuways series, excluding the extremely saline and very high watertable phases. The soils are downgraded from Class 1 on the basis of high watertables which lie within the 1.0 to 2.0 m depth, and moderate salinity and gypsum deficiencies. The lands are mapped as subclass 2 pxy or 2 pxyc, depending on the presence of abandoned channel microrelief. Provided levelling, drainage and reclamation leaching are successfully affected, these lands have a high potential for irrigation. If lower infiltration rates result from cultivation they would permit use of small basin surface irrigation. Careful control of the drainage would be required in these fine-loamy soils to prevent re-salinisation by capillary rise from the watertable.

(c) Class 3: Land marginally suitable for Irrigation.

This land occurs extensively in the Salmabad and Hawrat Inqa areas. As with the previous class, they are divisible broadly in terms of their dominant deficiencies:-

(i) Lands with primarily salinity and gypsum dificiencies, accompanied by the low moisture capacities and poor fertility potential of sandy soils. These include areas of Hisham soils with severe microrelief deficiencies which place them in Class 3axm. The sandy topsoil phase of Buri series is also included but has additional deficiencies in terms of subsoil gypsum (3 axy) and microrelief (3 axym).

(ii) Land with primarily effective depth and gypsum deficiencies. These occur in the Hawrat Inqa area in the sandy soils of Areen series, which also have sandy particle-size deficiencies. Land Class deficiencies include shallow effective depth over petrocalcic horizons, high gypsum contents and shallow watertables. Marine intrusion hazard affects much of the area. The main subclasses mapped are 3 sapxy and 3 sapyd. In the Salmabad area Zaytun series is placed in Subclass 3 sxy in view of shallow depth over rock, salinity and gypsum.

(iii) Lands suffering mainly from internal drainage deficiencies, combined with salinity and gypsum limitations. The fine-loamy soils which fail to meet Class 2 requirements because of salinity are placed in Subclass 3 pxy. The clayey soils of Lawzi series have slow infiltration rates also and form 3 ipxy. Buquwwah soils, which have a petrocalcic horizon within the upper metre, are additionally limited by effective depth (3 spxy). Furthermore, the presence of abandoned channels in many of these areas results in a further subclass deficiency (3 bipxyc, 3 sbipxyc). A marine intrusion hazard of Class 3 proportions applies to some areas of Khuways soils: they are retained in subclass 3 bipxycd but are very marginal as irrigable land.

Lands in this group have a similar potential to the equivalent lands in Class 2 (2 pxy, 2 pxyc) but considerable extra drainage and reclamation measures are anticipated to be required before this full potential can be realised.

(d) Class 4F: Lands with Limited Use, suitable for salt tolerant tree crops and some perennial fodders.

Lands in this class are segregated where gypsum contents or marine intrusion hazards exceed the limits for Classes 1-3.

(i) Lands primarily with gypsum and internal drainage deficiencies. Extensive areas in the Salmabad area have superficial gypsic horizons and very high watertables which exclude them from the normal arable classes. However, provided that drainage is feasible without marine intrusion and that the gypsum is not strongly cemented and overlies loamy alluvium, the lands are acceptable for a limited range of perennial salt-tolerant crops. Solution collapse would be less hazardous under perennial cropping and roots could be expected to exploit the loamy subsoil. The principal soil series in this group are Sar, Abu Saybi and Khadarah, as well as some Khuways soils which are downgraded from Class 3 due to drainage. The commonest subclasses are 4F pxy and 4F pxyc.

(ii) Lands with primarily marine intrusion hazard. The combination of proximity to the sea and low elevation make much of the Hawrat Inqa area, and parts of the Tubli Estuary, prone to seawater intrusion. The level plains and sandy soils in the west of Hawrat Inqa (Areen, Hisham, Wasmiyah) would otherwise qualify as Class 2 or 3 but due to high watertables and low elevations (often below 1.5m) they are relegated to Class 4F, principally as subclass 4F pxd. Capillary rise in sands is less than in silt loams and thus it should be possible to provide sufficient drained depth for tree cropping in the sandy soils.
Most of the fine-loamy soils which otherwise rank as Class 4F have been downgraded to Class 6 unless there is more than 1.0m of drainable depth.

(e) Class 5 : Lands which are non-arable but tentatively designated suitable for tree planting.

These lands have extreme deficiencies, principally due to excessive contents of gypsum throughout the upper 1.0m profile. They include the Typic Gypsiorthid soils of Maqabah, Buhayr, Buri and Hawrah series. The superficially gypsic Salmabad soils are also included. Despite the adverse soil conditions due to gypsum, salinity levels are moderate and internal drainage is usually of Class 1 or 2 standard.
Similar soils elsewhere in Bahrain successfully support Eucalyptus, Casuarina and Prosopis species under irrigation. Therefore, provided water is made available in the initial years it is expected that trees could be grown on these lands . Indeed tree production could eventually be based on recycling of drainage water from adjacent arable areas.

(f) Class 6: Land Unsuitable for Irrigation.

Shallow effective depth is the principal deficiency of Class 6 land, notably in Dilmun series which overlies limestone pavement and in the shallow phase of Areen series, which overlies petrocalcic layers. Elsewhere, downgrading to Class 6 results from a combination of marginal deficiencies such as profile drainage (6 spxy) or marine intrusion hazard (6 pxycd, 6 pxyd). Erosion hazard is sufficient to downgrade some otherwise marginal lands into Class 6. All miscellaneous land units are mapped in Class 6.

7.6. DEVELOPMENT POTENTIAL FOR IRRIGATED AGRICULTURE.

7.6.1 Generalised Land Suitability Mapping.

To provide an overall assessment of the agricultural potential of the Level 3 lands the detailed land classification units have been grouped into generalised land suitability units.

These land suitability units are described briefly as follows:-

a) Land Suitable for Irrigation Agriculture.
This represents land suited to the production of either arable ,fruit or tree crops.

(i) Arable and fruit tree cropping. This comprises all Class 2 and 3 land. Three broad divisions are mapped to show differences in soil texture, as these affect the selection of appropriate irrigation and agronomic techniques.

A1 Sandy soils suited to trickle and overhead sprinkler systems. These include lands which are downgraded to Classes 2 or 3 due to low moisture holding capacity, poor fertility potential, salinity, gypsum, microrelief or internal drainage. The sands are easily drained and leached and thus have reasonable potential for irrigation based on use of saline water.

A2 Silt loam soils. These lands have deficiencies of salinity, gypsum and internal drainage. In addition, they often have a microrelief limitation due to abandoned channels. The lands require considerable reclamation in terms of levelling and leaching as well as drainage. Nevertheless they have a relatively high potential for agriculture and the finer texture should permit these soils to be used for basin irrigation.

A3 Silty Clay Soils. Lands with such fine textured soils are less suitable for irrigation with saline water due to their anticipated low leaching efficiency . The small areas of this land would be suited to basin irrigation but would require special leaching and drainage.

(ii) Limited agricultural use. Suitable only for salt tolerant tree crops. This land suitability unit corresponds with Class 4F as previously mapped. Land quality is limited by superficial gypsum layers, salinity and high watertables. With moderate outlay on drainage the land should have a potential for producing salt tolerant tree crops and possibly some perennial fodders.

(iii) Marginal agricultural use. Parts possibly suitable for planting hardy, salt tolerant trees. This land suitability unit is equivalent to Class 5 land; it comprises deep, highly gypsic soils with moderate salinity and drainage, parts of it could possibly be used for amenity, timber or shelterbelt tree planting.

(b) Land Unsuitable for Irrigation

This includes all very shallow soils, rock lands, permanent swamps and marginal lands which are affected by seawater intrusion. This land is not suited to irrigation under present conditions.

7.6.2 Development Potential of Level 3 Areas.

Figures 7.1 and 7.2 illustrate the distribution and extent of the generalised land suitability units within each of the Level 3 areas. Table 7.6 shows that the greatest potential for agricultural development lies in the Salmabad area, which includes some 1550 hectares of land suited to arable and fruit tree cropping, compared with 130 hectares in Hawrat Inqa and none in Buhayr.

Table 7.6 Generalished Land Suitability, Level 3 Areas

Land Suitability Unit.	Salmabad (ha)	Buhayr (ha)	Hawrat Inqa (ha)	Total (ha)	(%)
Suitable for Irrigation					
A Arable and Fruit tress					
A1 Sandy Soils	330.0	-	127.0	457.0	11.1
A2 Silt Loam Soils	1152.0	-	-	1152.0	28.0
A3 Silty Clay Soils	72.5	-	-	72.5	1.8
B Limited-use tree crops	552.5	-	97.5	650.0	15.8
C Marginal-use tree planting	992.5	77.0	-	1069.5	26.0
Unsuitable for Irrigation (D)	640.0	26.0	45.5	712.0	17.3
Total	3740.0	103.0	270.0	4113.0	100.0

Source: Approximate gross areas measured from Generalised Land Suitability Maps at 1:50 000 scale. Village areas included with D.

Figure 7.1 Salmabad Area :
Generalised Land Suitability

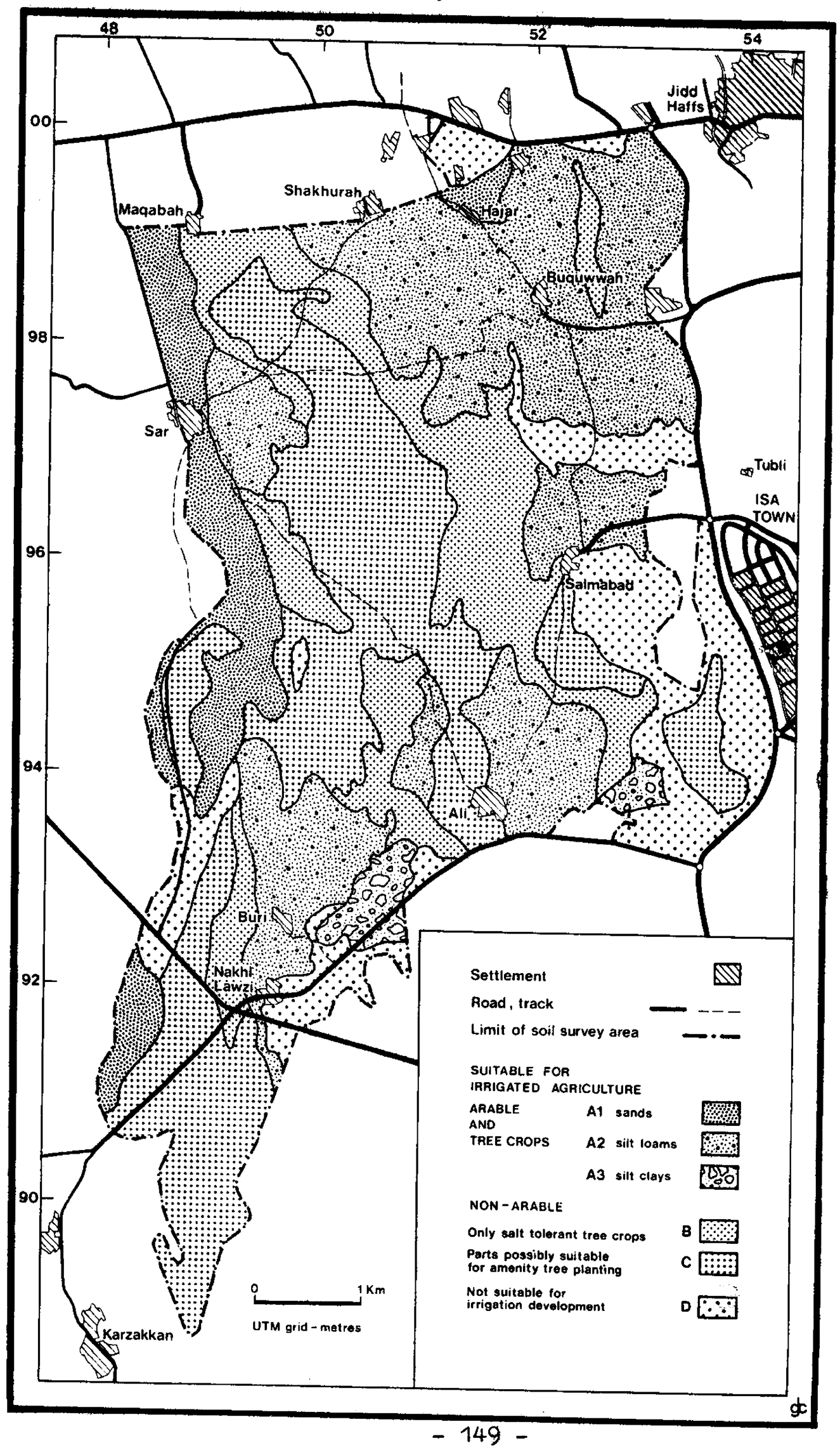
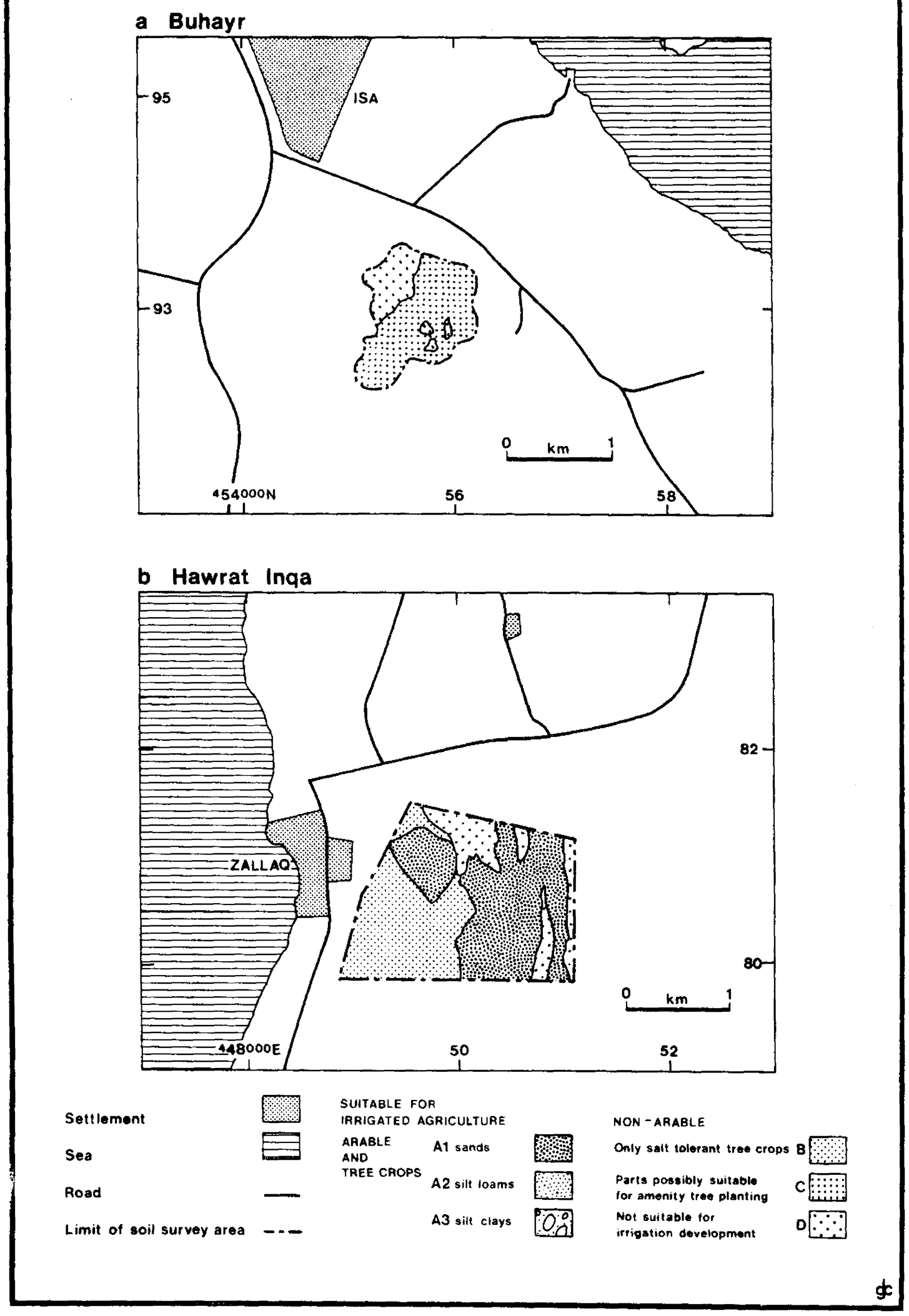


Figure 7.2
Buhayr and Hawrat Inqa : Generalised Land Suitability



(a) Salmabad Area.

Most of the land with potential for arable and fruit tree cropping comprises silt loam soils which should be acceptable for basin irrigation, assuming infiltration rates decrease following cultivation. Sandy soils requiring trickle or sprinkler systems form a minor but important component of this area. Limited - use lands (Unit B), comprising soils with superficial layers of gypsum and high watertables, are moderately extensive. The large areas tentatively indicated as being suited for tree planting comprise the highly gypsic soils of the Nebkha Plain. Non-irrigable land is confined mainly to shallow soils over rock or hard cemented subsoil layers. Villages occupy a small proportion of the Salmabad area but residential development is currently encroaching, especially north of Sar and east of Buquwwah.

(b) Buhayr.

This area has very low potential for irrigation. Most of the soils are very saline, excessively gypsic and suited to only amenity tree planting. The remaining areas are rocky or carry a very shallow depth of extremely saline soil over cemented subsoils. Much of the Buhayr area is currently used for refuse disposal. Tree planting could therfore be beneficial for screening the disposal areas from the adjacent highway, college and residential developments.

(c) Hawrat'Inqa

Sandy soils predominate in this area but low elevations above sea level and very high watertables pose a severe limitation to land use. The more freely drained areas have a moderate potential for arable and fruit tree cropping under trickle or sprinkler systems. Some of the soils have moderate gypsum contents and cemented layers in the subsoil but these should not seriously affect productivity. The low-lying western areas are limited in use to salt - tolerant tree crops due to very high watertables and risks of marine intrusion. Rocky areas in the north and east are unsuited to irrigation.

7.6.3. Selection of Agricultural Development Centre (ADC) Si te.

If future agricultural development is to be concentrated on the best quality land and if the ADC is to act as a pilot farm for this development, it is clearly essential that it be located on the sandy and silt loamy soils (Land Suitability Units A1 and A2) of the Salmabad area. Moreover, these soils extend north and westwards beyond the Level 3 areas and thus the establishment of an ADC as proposed would provide information relevant to an area of primary agricultural potential larger than that contained within the Salmabad area itself.

The ADC should therefore be on the two principal arable soil series of the Salmabad area, namely the silt loamy Khuways series on the Loam Plains and the sandy Hisham series of the Sand Sheets.

Appendices

A

Methods of Laboratory Analysis

A.1 INTRODUCTION

Analyses of soil and water samples were performed at the Hunting Technical Services' Environmental Chemistry Laboratory in the United Kingdom and in the Groundwater Development Consultant's laboratory in Riyadh, Saudi Arabia.

The methods of analysis used are basically as outlined in Handbook 60 "Diagnosis and Improvement of Saline and Alkali Soils" (USDA, 1954). This Handbook represents the basic reference text for the analysis of soils and waters of the arid zone. However, since its publication there have been considerable advances in methods and new analytical equipment has become available. Furthermore, the USDA Salinity Laboratory concepts and definitions of soil salinity have changed markedly in recent years, which has led to a complete revision of the original handbook.

The revised version of Handbook 60 is not yet published but three important existing publications, which do update analytical methods and definitions, are available and have been used in the present study:-

(a) Methods of Soil Analysis (Black, 1965).

(b) Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples (Soil Conservation Service, 1972).

(c) Soil Taxonomy (USDA, 1975).

The methods of analysis used have also been modified slightly to take advantage of the improved efficiency and provision offered by modern analytical equipment.

In the case of Bahrain soils and water, a further problem is posed by the excessive quantities of calcium carbonate, gypsum and easily-soluble salts which interfere with the normal analytical procedures.

These constituents have, therefore, had to be removed prior to analysis or the methods of analysis suitably modified, as described in this Appendix.

A.2 SOIL ANALYSIS

Each soil sample was airdried and ground to pass a 2 millimetre sieve before being despatched to the laboratory. Particles coarser than 2 millimetres represented a very small proportion of the total volume of the soils examined; most comprised gypsum crystals or calcium carbonate concretions.

A.2.1 Particle size analysis

The large quantities of gypsum and calcium carbonate common to Bahrain soils tend to distort estimates of particle-size distribution: gypsum crystals account for much of the 'sand' detected in the field whereas optical mineralogical studies (Appendix G) show that most of the silt fraction is dominated by calcium carbonate.

Two procedures were therefore adopted for particle-size analysis. For both practical and correlation purposes the particle-size distribution was determined on the total soil constituents, including gypsum and calcium carbonate, providing a realistic impression of field soil conditions and comparing closely with field estimates of texture. In addition, selected samples were pretreated to remove gypsum and $CaCO_3$, expressing the results in terms of insoluble soil constituents.

A comparison of the results obtained from these two methods (Appendix B) shows that pretreatment results in destruction of much of the field-determined 'silt' fraction, with consequent relative increases in clay and sand components. This confirms the findings of the mineralogical analyses, in which the silt was shown to be comprised largely of calcium carbonate.

(a) Insoluble soil constituents.

For this method the soil sample was pretreated to eliminate organic and soluble constituents. Organic matter was removed using hydrogen peroxide, soluble salts and gypsum by repeated washings with water and calcium carbonate by using sodium acetate buffered at pH 5. The remaining sample was dispersed

by shaking overnight with sodium hexametaphosphate dispersing agent. The soil was then washed through a 300 mesh sieve. The sand remaining on the sieve was dried and then fractionated by passing through a series of different mesh sized sieves. Each fraction was weighed.

The silt and clay fractions, which passed through the 300 mesh sieve, were collected and diluted with water to one litre. The sediment was dispersed, allowed to settle and samples taken of the suspension at specified depths at specified time intervals using an automatic pipette system. Pipette samples were dried and weighed, corrected for the dispersing agent content and the silt and clay contents calculated.

Results were expressed in terms of percentage weight of the insoluble soil material, using the following fractions:-

Very coarse sand	1 000 - 2 000	(1.0 - 2.0 mm)
Coarse sand	500 - 1 000	(0.5 - 1.0 mm)
Medium sand	250 - 500	(0.25 - 0.50 mm)
Fine sand	100 - 250	(0.10 - 0.25 mm)
Very fine sand	50 - 100	(0.05 - 0.10 mm)
Silt	2 - 50	(0.02 - 0.05 mm)
Clay	less than 2	(less than 0.02 mm)

(b) Total soil constituents.

This procedure was similar to that described above but without the pretreatments to eliminate organic and soluble material.

The sample was dispersed by sodium hexametaphosphate and shaken overnight. The dispersed soil was then transferred to a litre measuring cylinder and diluted to one litre volume. The sample was then dispersed again, allowed to settle and readings taken at appropriate intervals using a Bouyoucos soil hydrometer to obtain measurements of the silt and clay fractions. Readings were corrected for temperature and dispersing agent content.

The sand was fractionated by washing through a series of sieves, each fraction being dried and weighed separately.

The results were calculated and reported in terms of the same fractions as listed above, but expressed as percentages of the total soil constituents.

A.2.2 Chemical analyses

(a) Salinity.

Salinity was determined as the electrical conductivity (EC) of a soil: water extract, expressed in mmho/cm at 25° C. A 1 : 5 soil water extract was prepared by adding 10 millilitres of distilled water to a 2 gramme soil sample in a plastic tube. This was then shaken for 30 minutes, centrifuged and the EC of the supernatant liquid measured using a conductivity meter. Where the EC was greater than 0.5 mmho/cm the sample was re-analysed on the saturated extract (EC_e).

(b) Soil reaction.

Distilled water was added to a sample of soil, with stirring, until the saturation point was reached. The pH of this paste was then measured to the nearest 0.1 pH unit, using a Corning Eel pH meter.

(c) Saturation percentage.

Distilled water was added to a 100 gramme sample of soil and stirred until the saturation point was reached. The sample was then reweighed. The saturation percentage was calculated from the amount of water required to bring 100 grammes soil to saturation point.

For saline soils this saturated soil paste was then extracted using a vacuum system to obtain a clear saturation extract needed for the determination of EC_e and soluble ions.

(d) Soluble ions.

These were determined in the saturation extract, as follows:-

(i) Soluble cations.

Soluble calcium, magnesium, sodium and potassium were measured in the saturation extract utilising atomic absorption techniques, in the presence of strontium chloride as a releasing agent for calcium and magnesium and as an ionisation buffer for sodium and potassium.

(ii) Soluble anions.

- Carbonate and Bicarbonate.

An aliquot was titrated against dilute hydrochloric acid using phenolphtalein as an indicator, when the pink colour was discharged the amount of acid was measured, methyl orange indicator added and the titration continued to the end point. No soluble CO_3 was recorded so this is omitted from the laboratory data in Appendix B.

- Chloride.

Chloride was measured using an EEL chloride meter, which automatically titrates the chloride against silver ions.

- Sulphate.

Sulphate was precipitated as barium sulphate, cooled, filtered, dried and ignited at 650° C.

- Nitrate.

An aliquot of the extract was evaporated to dryness in the presence of calcium carbonate. Phenoldisulphonic acid was then added followed by an excess of ammonia solution. The resulting yellow colour was then measured on a spectrophotometer at 420 nm against a series of standards.

(e) Exchangeable sodium and sodium absorption ratio.

The value of the exchangeable sodium percentage (ESP) in relation to the total cation exchange capacity (CEC) is required for the identification of a natric horizon (USDA, 1975). Under the conventional procedure (USDA, 1954) 2.0 grammes of soil are extracted by shaking with 10 millilitres of N ammonium acetate buffered at pH 8.4. Sodium is then determined by atomic absorption utilising strontium chloride as anionisation buffer.

An alternative approach is to use the sodium absorption ration (SAR) which indicates the equilibrium relationship between soluble and exchangeable cations. This is calculated from the concentrations of soluble cations (as milliequivalents per litre):-

$$SAR = Na^{+} (Ca^{++} + Mg^{++})^{-0.5}$$

For ESP values below 50 a practical correlation exists between ESP and SAR (USDA, 1954).

These methods, however, produce misleading results in highly saline soils due to the excessive quantities of soluble sodium. Since completing the text of Soil Taxonomy, the US Salinity Laboratory redefined sodic (alkali) soils and altered the methods for measuring sodium (USDA, 1975, page 28). Previously, any highly saline soil was invariably dominated by sodium chloride and therefore has a high proportion of exchangeable sodium and was thus classed as 'alkali'. In practice, many of these so-called 'saline-alkali' soils proved to be 'non-alkali' when soluble salts were removed by leaching.

Under the revised definitions for the natric horizon, the following procedures are recommended and were used in the present study:-

(i) For soils with EC_e values of less than 20 mmhos/cm SAR is calculated directly from the soluble cation concentrations.

(ii) For soils with EC_e values in excess of 20 mmhos/cm and with SAR values greater than 10, the SAR is measured on a sample that has already been leached with distilled water until the EC of the leachate decreases to about 4.0 mmhos/cm. An SAR of 13.0 replaces an ESP of 15.0 as the lower limit for a natric horizon in these soils.

(iii) If the EC_e is less than 4.0 mmhos/cm the ESP is determined in the conventional manner.

In view of the high salinity of the soils in Bahrain, the SAR method was used in all cases; very saline soils (EC_e more than 20 mmhos/cm) received the leaching pretreatment. ESP values were obtained using the SAR-ESP nomograph in Handbook 60.

(f) Cation exchange capacity.

The method used was a modified version of method 5.A.5 of Soil Survey and Laboratory Methods (Soil Conservation Service, 1972). The soil was saturated with barium using barium chloride buffered at pH 8.2 with triethanolamine. Excess barium was removed by leaching with water and propanol. The

sample was then shaken with magnesium sulphate of known concentration. Magnesium replaced barium by exchange mechanisms and the released barium was immediately precipitated by the sulphate present. The magnesium remaining in solution was determined by titration against EDTA. However, gypsum tends to interfere with these exchange processes: individual gypsum particles become masked by a coating of barium sulphate which, although insoluble, can be partially removed during the stage of shaking with magnesium sulphate and hence some gypsum is dissolved. Work on gypseous soils in Syria (Garmon and Hesse, 1975) showed that this interference could be overcome by a simple modification.

This modification consists of a separate titration with EDTA for calcium alone. The calcium titre is subtracted from the (Ca + Mg) titre to give a true value for magnesium present. The CEC was calculated from the difference between the amount of magnesium added (a known quantity of a standard solution) and the amount remaining in solution (measured by EDTA titration).

(g) Gypsum content.

The gypsum content was calculated from the difference between the calcium concentration in the saturation extract and in a high soil/water ratio, up to 1 : 500 for very gypsiferous soils. Gypsum was expressed as percentage weight.

(h) Calcium carbonate.

A known weight of soil was treated with dilute HCl in a calcimeter, at constant temperature and pressure. The increase in volume was taken as a direct measurement of carbon dioxide evolved and calculated in terms of calcium carbonate. The results were reported in terms of percentage weight of calcium carbonate.

(i) Fertility analyses.

(i) Total phosphorus.

The soil was digested with perchloric acid. Phosphorus was measured in the digest using the molybdovanadophosphoric acid colorimetric method.

(ii) Total nitrogen content.

A weighed sample of finely ground soil was digested with concentrated sulphuric acid containing potassium sulphate to raise the digestion temperature and selenium as a catalyst. After digestion the sample was made alkaline and the ammonia released was steam distilled into boric acid containing a mixed indicator of bromocresol green/methyl red. After distillation the ammonia dissolved in the boric acid was backtitrated against standard sulphuric acid, and the result expressed as per cent total nitrogen.

(iii) Organic carbon-content.

A weighed sample of finely ground soil was digested with a known amount of potassium dichromate and concentrated sulphuric acid. Excess dichromate, remaining after digestion was complete, was titrated against standard ferrous ammonium sulphate using ferroin as indicator. In the calculation of the result, expressed as per cent organic carbon, it was assumed that only 77 per cent of the organic carbon present had been oxidised. Total organic matter can be derived by multiplying organic carbon percentage (Appendix B) by 1.72.

A.2.3 Soil physical tests

(a) Bulk density.

Soil samples were collected in the field using a special core sampling device. The dry weight of the undisturbed soil in the core was determined and the bulk density calculated.

(b) Moisture retention tests.

An undisturbed soil core sample (50 mm diameter) was saturated with water and the moisture content measured. The core was then placed on a porous plate apparatus and subjected to a tension of 760 mm of mercury (0.1 bar). When the moist sample reached equilibrium with the suction, it was weighed to determine the moisture content. The determination was repeated at 254 mm of mercury (0.3 bar) and 760 mm (1.0 bar). The sample was then transferred to the high pressure chamber (pressure plate) and the soil moisture content determined when in equilibrium with a suction of 15 bar.

In view of the high contents of gypsum in the soils of Bahrain, the method of drying had to be modified to avoid irreversible dehydration of gypsum from $CaSO_4.2H_2O$ to the semihydrate $CaSO_4.0.5\ H_2O$. Momotov (1965) showed considerable deviation in moisture retention of gypsic soils when heated to the normal termperature of 105°C and recommended that temperatures of less than 80°C be used. In the present study cores were dried to a temperature of 60°C maximum.

A.3 WATER ANALYSES

Water samples were analysed for soluble ions, EC and pH using the same analytical procedures as described in the previous section.

B

Soil Series Descriptions

B.1 METHODS OF DESCRIPTION

In this Appendix the 19 soil series identified and mapped during the Level 3 surveys are described in terms of their profile characteristics and physiography. Detailed profile descriptions and laboratory analyses for sites representative of each series are included with series definitions in Appendix B.2, additional detailed laboratory analyses are presented in Appendix B.3. Table B.1 summarises the data available.

The methods of description are according to Soil Taxonomy. Soil colours are given as the Munsell notation in the moist state.

Due to the high levels of gypsum in the soils studied, particle-size classes are based on field estimates of soil texture as these give a more realistic indication of the soil characteristics. Physiographic and parent material names used in the descriptions are explained in Chapter 3.

B.2 SOIL SERIES DEFINITIONS

B.2.1 Typic Salorthids.

(a) Fine-loamy, carbonatic, hyperthermic family.

- Tubli Series - Tb.

Representative description: Profile 1 (PV 010).

Location and physiography: These soils are formed in calcareous silt loams and sandy clay loams of marine origin. They occupy the minor depressional area of the Tubli Estuary in the extreme east of the Salmabad area. The land lies at no more than 1.5 metres above sea level, groundwater is at shallow depth, extremely saline and under direct tidal influence. Microrelief is generally even except for some abandoned irrigation channels and drains.

Land use and vegetation: Tubli soils are not currently cultivated although there is evidence of former date production around the fringes of the depression. The vegetation is dominated by halophilous species of Arthrocnemum, Halocnemum and Salicornia; Avicennia marina and Phragmites australis are common along drainage channels.

Table B.1 Profile Descriptions and Detailed Analyses.

Soil Series	Representative Profile Description No	Site	Laboratory Analyses Complete detailed	Detailed
Tubli	1	PV010	PV010	-
Khadarah	2	PV044	PV044	-
Karzakkan	3	PV040	PV040	-
Hawrah	4	PV003	PV003	-
Buri	5	PV025	PV025	PV028
Maqabah	6	PV018	PV006,PV018,PV036	-
Buhayr	7	PV013	PV013,PV014	-
Sar	8	PV007	PV005,PV007	PV022,PV033
Abu Saybi'	9	PV020	PV020	PV030
Zaytun	10	PV037	PV037	-
Khuways	11	PV017	PV008,PV009,PV017, PV045	PV019
Lawzi	12	PV035	PV035	PV034
Areen	13	PV060	PV001	PV060
Salmabad	14	PV011	PV011	PV043
Buquwwah	15	PV055	PV012	PV055
Isa	16	PV048	PV015	PV048,PV023
Hisham	17	PV016	PV016	PV021,PV024 PV026,PV062
Wasmiyah	18	PV004	PV004	PV061
Dilmun	19	PV027	PV027	PV029

Notes:
1. Representative profile descriptions and respective laboratory analyses accompany series definitions in section B.2. Remaining analyses are presented separately in section B.3.

2. Detailed analyses include salinity, pH, gypsum, CEC, CaCO3 and particle size determinations; complete detailed analyses also include soluble ions, fertility and adjusted particle size values.

Profile: 1 Tubli Series | Site No: PV010

Fine loamy, carbonatic, hyperthermic family of Typic Salorthids.

Date: 18.10.78

Location: About 1.5km west of Tubli village, near Salmabad. GR 526972.

Geomorphic Unit: Tubli Estuary; depression near drainage line.

Parent Material: Loamy calcareous alluvium over shelly silicious fine sands.

Topography: Level; near to natural drainage line.

Microrelief: Slightly uneven due to former cultivation and irrigation channels. Dry, brittle, slightly puffy salt crust.

Vegetation: Abandoned date orchard; ground cover of Arthrocnemum glaucum; Avicennia marina and Phragmites australis in adjacent drainage channel.

Drainage: Poorly drained.

Remarks: Watertable lies at 90cm in layer of marine sand. Site at 1.2m above sea level.

Horizon	Depth(cm)	Profile Description
A_0sa	5-0	Platy saline crust, layered with green glauconite mineral surfaces.
A_1sacs	0-20	Light yellowish brown (10YR 6/4) gypsic loam; moderate coarse angular blocky; friable moist; many fine tubular pores; calcareous; few fine roots; abrupt smooth boundary.
C_1sag	20-90	Light grey (2.5Y 7/2), prominent strong brown stains to vertical root pores; silt loam; weak coarse angular blocky; friable moist to plastic, slightly sticky wet; coarse vertical tubular pores; calcareous; no live roots; abrupt smooth boundary.
IIC_2g	90-120	Grey (5Y 6/1) very gravelly sandy loam; structureless single grained; non-plastic, non-sticky wet; occasional limestone stone, abundant bivalve shells in upper part of horizon; strongly calcareous.
$IIIC_3g$	120-400	(Auger) saturated grey aeolian silicious sand, grey (N6/0).

Profile Description No: 1 Site No: PV010

Series: Tubli - Tb Location: 526972

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-20	30.6	81.9	7.1	6.9	2	37.0	14.8
b	20-90	10.0	45.8	7.5	9.9	8	73.9	1.5
c	90-110	4.8	27.6	7.6	4.7	12	29.2	1.6

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	2	5	9	16	13	37	18	64
b	0	1	2	4	13	12	49	19	55
c	0	4	13	27	35	8	2	11	30

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	1.8	13.8	14.7	16.8	12.3	15.2	25.5	21.6	0.20	0.077
b	0.4	12.2	18.8	22.6	7.2	26.1	12.6	-	-	- -
c	0.6	15.2	17.3	18.9	7.8	17.9	22.3	-	-	- -

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	1.78	180.0	757.5	1925.4	46.6	1.0	2859.3	49.2	1.5
b	-	67.5	133.5	589.9	18.0	2.5	755.6	50.8	3.1
c	-	92.8	108.5	485.6	16.0	2.5	623.7	76.7	3.1
C:N Ratio 23.1									

Profile characteristics: Profiles are deep and very poorly drained. Typically the soils have a 3 - 5 cm thick puffy, brittle sulphate salt crust. The upper horizon is loamy, 20-30 cm thick, rich in secondary accumulation of soluble salts and gypsum. The underlying horizon is fine-loamy, either silt loam or loam, with light grey (2.5 Y 7/2 - 5 Y 7/1) gleyed colours and usually contains a thin layer of bivalve shells. In the permanently saturated fine sandy subsoil, colours are grey (N6/0). The soils have moderately well developed, angular blocky structure in the loamy horizons: pores are common, often as vertical tubular pores derived from former roots.

Chemical characteristics: Analyses for Profile 1 (PV 010) illustrate the concentration of soluble ions in the upper profile, sufficient to meet the requirements of a salic horizon. Very high values for $CaCO_3$ reflect the carbonate content of the parent material.

Land Capability: Soil salinity and shallow groundwater are serious limitations to agricultural use of Tubli soils. However, as the land lies at only 1.0 to 1.5 metres above sea level and is underlain by permeable sand, the risk of sea water intrusion poses a more serious constraint to development. Tubli series are rated Class 6 as being non-arable.

Associated Soils: The series is similar to Khadarah series which has a thicker superficial gypsic horizon, occurs at slightly higher elevations and is more freely drained. To seaward Tubli series merges with tidal swamps whereas to the north the soils lie adjacent to the fine-loamy soils of Khuways series.

B.2.2 Gypsic Salorthids

(a) Fine-loamy, carbonatic, hyperthermic family.

- Khadarah Series - Kd.

Representative description: Profile 2 (PV 044).

Location and physiography: Khadarah soils are formed in carbonate-rich silt loam alluvium; they occur extensively in the low-lying areas of the Khadarah Depression as well as in the minor local depressions elsewhere in the Salmabad area. The soils usually have an uneven microrelief of abandoned irrigation channels. Elevations above sea level range from 1.5 to 4.0 metres and the watertable is usually moderately deep.

Profile:2 Khadarah Series — Site No: PV044

Fine loamy, carbonatic, hyperthermic family of Gypsic Salorthids.

Date: 16.1.79

Location: 50m from Ain al Khadarah, 2.0km north of Ali town GR.513956.

Geomorphic Unit: Khadarah Depression - broad low-lying plain; site located near spring.

Parent Material: Gypsic sand (partially aeolian) overlying silty and fine sandy calcareous alluvium; unconsolidated aeolian fine sand at base.

Topography: Level plain sloping very slightly down to west and drainage line.

Micro-relief: Even; puffy, weakly crusted brownish salt efflorescence.

Vegetation: Non-cultivated; moderate cover of Halocnemnum sp and Halopeplis sp. Rarely Suaeda pruinosa and Aeluropus lagopoides.

Drainage: Poorly drained.

Remarks: Hydromorphic profile with watertable at 105cm.

Horizon	Depth(cm)	Profile Description
$A1_{cssa}$	0-25	Brown (10YR 5/3) loamy gypsic sand; single grained structureless; friable moist; locally slight cementing by gypsum; very porous; weakly calcareous; no roots; abrupt smooth boundary.
C1	25-60	Pale brown (10YR 6/3) silt loam; moderate coarse angular blocky; firm moist; few medium tubular pores; gastropod shells; some finely divided gypsum crystals; weakly calcareous; few fine roots; abrupt smooth boundary.
$IIC2_g$	60-80	Pale olive (5Y 6/3) loam; weak medium angular blocky; wet slightly plastic non-sticky; many fine tubular pores; fine white filaments of gypsum in larger pores; locally organic stained layers; weakly calcareous; rare fine roots; abrupt smooth boundary.
$IIIC3_{cag}$	80-100	Light brownish grey (2.5Y 6/2) gravelly fine sandy clay loam; massive; wet non-sticky, non-plastic; common coarse tubular pores; weak cementing by calcite, 20% (estimated) calcite cemented irregular nodules; rare fine roots; calcareous; clear smooth boundary.
$IIIC4_g$	100-180	Light brownish grey (2.5Y 6/2) fine sandy loam; weak medium angular blocky;wet non-plastic, non-sticky; very porous including remnant vertical root channels; no living roots;calcareous;abrupt smooth boundary.
$IVC5_g$	180-200 (in auger)	Grey (5GY 5/1) fine sandy loam; single grained; wet non-plastic, non-sticky; sandy loam grading into fine sand; non-calcareous.

Profile Description No: 2 **Site No:** PV044

Series: Khadarah - Kd **Location:** 513956

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-25	24.5	96.0	7.1	2.7	4.8	2.5	77.6
b	25-60	8.2	32.6	7.5	22.5	10.0	69.8	0.9
c	60-100	7.4	20.6	7.5	19.7	10.5	60.3	0.9
d	100-150	4.3	34.1	7.4	9.7	13.0	90.3	0.8

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	22	15	13	11	22	17	0	71
b	0	1	3	11	20	14	40	11	64
c	20	2	3	5	7	35	25	23	61
d	5	6	10	15	19	12	29	9	64

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	14	21	15	10	4	23	13	14.0	0.33	0.04
b	1	4	17	20	7	43	8	-	-	-
c	2	3	5	8	5	59	18	-	-	-
d	4	12	18	21	8	27	10	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.75	-	-	-	-	-	-	-	-
b	-	-	-	-	-	-	-	-	-
c	-	-	-	-	-	-	-	-	-
d	-	63.8	29.4	180.0	4.9	2.3	235.0	46.3	1.10

Landuse and Vegetation: Although many of the Khadarah soils have at some time in the past been used for date production, they are now uncultivated. Dense clumps of Halocnemum glaucum form the dominant vegetation on these soils: sub-dominants include Zygophyllum qatarense, Suaeda pruinosa and Aeluropus lagopoides, with species of Halopeplis and Salsola locally.

Profile Characteristics: Khadarah soils are deep and imperfectly to poorly drained; they typically have a prominent superficial gypsic horizon overlying a coarse loamy (silty) subsoil. The gypsic horizon comprises sand sized gypsum particles, weakly cemented; although much of this gypsum has probably been precipitated from rising groundwater some is undoubtedly of aeolian origin. The gypsic horizon normally ranges in thickness from 25 to 45cm, but never exceeds half the depth of the control section. Beneath the gypsum occurs a pale brown (10YR 6/3) horizon of highly calcareous loam or silt loam, which is porous and moderately well structured. Many of the larger pores in the lower profile are lined with coatings of white gypsum leached from above. The silt loam horizons are often weakly stratified, contain buried peat layers and may be weakly cemented by calcite in the lower subsoil. Roots rarely penetrate below 1.0m. The soil surface has a puffy sulphate - rich salt crust.

Chemical Characteristics : The upper horizons are normally sufficiently saline to qualify as salic. Gypsum contents are greatest in the surface horizon and meet the requirements of gypsic horizon. Calcium carbonate contents, however, increase downwards often exceeding 90 percent of the soil mass in the calcareous subsoil.

Land Capability : The potential for agriculture of Khadarah soils is limited by their extremely high salinities and their high contents of gypsum. Furthermore, the high carbonate contents in the subsoils could be expected to seriously affect nutrient availability. Provision of artificial drainage is an essential prerequisite for the use of Khadarah soils but even when drained and leached of salt, the gypsum contents would still limit their use to tree crops (Class 4F). In some areas, however, elevations above sea level are insufficient to allow effective drainage without risk of marine intrusion; those areas are placed in Class 6.

Associated Soils : Khadarah soils are similar to Abu Saybi' and Sar series but lack the fine loamy subsoils, have less gypsum and are more saline.

Downslope the Khadarah soils grade into the very poorly drained Tubli series; elsewhere they are normally bounded by Maqabah soils, in which the superficial gypsum layer extends much deeper (dominating the control section) and salinities are lower.

B.2.3 Typic Gypsiorthids.

(a) Sandy, gypsic, hyperthermic family.
(i) Karzakkan Series - Kn.

Representative Description: Profile 3 (PV040)
Location and Physiography: These soils form a minor series which occurs in the southern extension of the Nebkha Plain, in the extreme southwest of the Salmabad area, lying at 5.0 to 10.0 m above sea level. They are formed in a shallow layer of gypsum overlying silicious aeolian sand. The terrain is usually level with even micro-relief; the watertable is deeper than 2.0m.

Land use and vegetation: Karzakkan soils are not cultivated. The sparse natural vegetation includes species of Zygophyllum, Heliotropium, Eragrostis , and locally Anabasis setifera. Much of the area has been quarried for building sand.

Profile Characteristics: Karzakkan soils are deep and well drained. The surface is usually overlain by a shallow (less than 10cm) veneer of aeolian sand. Beneath the sand occurs a gypsic horizon composed of coarse gypsum flakes and crystals cemented into a porous, massive and hard layer of 30 to 50cm thickness. This gypsic layer abruptly overlies friable, loose single grained aeolian sand, which extends down to at least 5.0m.

Chemical Characteristics: The soils are usually only slightly saline; gypsic levels are high in the surface but negligible in the underlying sand. Moderate carbonate contents occur in the sandy subsoil. The soils have very poor fertility.

Land Capability: Karzakkan soils are placed in Class 6 due to the hard cemented superficial gypsic horizon which would severely limit cultivation operations and root penetration. In addition, they have the low moisture capacity and poor fertility potential associated with sandy particle-size.

Associated Soils: The series is bounded by Maqabah soils, which are similar to Karzakkan series but have a deeper and less cemented superficial gypsic horizon and a coarse loamy rather them sandy particle size.

Profile: 3 Karzakkan Series — Site No: PV04C

Sandy, gypsic, hyperthermic family of Typic Gypsiorthids.

Date: 8.1.79

Location: 2.0km north of Karzakkan village. GR 484906.

Geomorphic Units: Edge of Nebkha Plain at foot of scarp of carbonate rocks.

Parent Material: Thin layer of aeolian silicious sand over crystalline gypsum over silicious aeolian sand.

Topography: Level plain.

Micro-relief: Even, occasional low vegetation hummock; hard compacted surface with fine limestone gravels and gypsum crystals.

Vegetation: Not cultivated; sparse Zygophyllum qatarensis Heliotropium sp. and Eragrostis sp. Adjacent to sand quarry.

Drainage: Well drained.

Remarks: Massive layer of weakly cemented 'cornflake' gypsum over sand.

Horizon	Depth (cm)	Profile Description
A1	0-5	Pale brown (10YR 6/3) fine sand; single grained; soft dry; few fine gypsum crystals; very porous; calcareous; no roots; abrupt smooth boundary.
$C1_{cs}$	5-50	Light grey (2.5Y 7/2) medium gypsic sand; structureless massive; very hard dry; layer of cemented coarse 'cornflake' gypsum crystals with aeolian sand in interstices; very porous; non-calcareous; no roots; abrupt smooth boundary.
IIC2	50-200	Light brownish grey (2.5Y 6/3) fine sand; single grained; soft dry; weakly developed aeolian bedding planes; very porous; non-calcareous; few fine and rare coarse roots.

Profile Description No: 3 **Site No:** PV040

Series: Karazakkan - Kn **Location:** 484906

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	5-50	2.3	3.4	7.9	4.3	1	2.1	63.2
b	50-100	0.3	1.7	8.1	9.9	1	22.1	1.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	29	15	21	12	3	6	14	27
b	0	0	15	43	38	4	0	0	24

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	16	21	20	15	2	11	15	7.8	0.0	0.03
b	0	6	61	28	1	4	0	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.37	33.8	6.0	5.6	0.4	2.2	10.0	34.3	5.70
b	-	8.9	3.8	3.6	0.6	2.4	4.0	12.0	0.60

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(ii) Hawrah Series - Hw.

Representative Description: Profile 4 (PV003)
Location and Physiography: Hawrah soils occupy a minor area at the foot of the limestone backslope in the Hawrat 'Inqa area. They are formed in mixed aeolain sand and loamy outwash fan alluvium, usually overlying weathered carbonate rock within 2.0m. The terrain is level with a slight slope to the west. Microrelief is normally even, except for vegetation hummodes and shallow flash flood channels which locally extend into the area from the adjacent backslope.

Land use and vegetation: Have soils have not been cultivated. The moderately dense cover of natural vegetation, which is grazed by camels, includes species of Zygophyllum, Panicum and Cyperus.

Profile Characteristics: Hawrah soils are deep, well drained and prominent cemented subsurface gypsic horizon. The superficial horizon comprises 10 to 25cm of loose aeolian sand. This overlies a loamy sand to sandy horizon which is cemented by thin layers of gypsum. Below 50 or 60cm gypsum cementing decreases and soil structure is better developed and more friable. A paralithic contact is usually encountered at between 1.5 and 2.0m. The fine textural stratification, typical of these soils, reflects changes in deposition of aeòlian and fan alluvium.

Chemical Characteristics. The soils have low salinity but moderately high levels of gypsum in the subsoils, mostly as medium to coarse sand grains. CEC values are low except in the lower subsoil, which has a greater clay content.

Land Capability: The Hawrah soils are limited in use by their hard cemented gypsic horizon, placing them in Class 5. In addition, the soils have minor limitations of internal drainage, due to incidence of rock at less than 2.0 metres, erosion hazard resulting from flash flooding from upslope and the low moisture holding capacity and poor fertility potential associated with sandy particle-size.

Associated Soils: The Hawrah soils are distinguished from the adjacent Areen series by their lack of a petrocalcic horizon and their more strongly cemented gypsic horizon. Hawrah soils occur as an impurity within the Areen mapping unit. To the east the soils merge into the shallow, loamy-skeletal soils of Dilmun series.

Profile:4 Hawrah Series — Site No: PV003

Sandy, gypsic, hyperthermic family of Typic Gypsiorthids.

Date: 9.10.78

Location: About 3.0km southeast of Zallaq. GR 510803.

Geomorphic Unit: Transition between lower fans of limestone backslope and coastal aeolian sand plain.

Parent Material: Gypsic and silicious sands overlying weathered limestone and limestone colluvium.

Topography: Level to slightly sloping to west.

Micro-relief: Even, with minor vegetation hummocks. Dry, slightly hard surface with scattered limestone gravels.

Vegetation: Non-cultivated; moderately dense cover of Zygophyllum, Panicum, Cyperus species.

Drainage: Well drained.

Remarks: Hard gypsum cemented horizon between 15 and 55cm; lithic contact at base of profile.

Horizon	Depth(cm)	Profile Description
A1	0-15	Light yellowish brown (10YR 6/4) loamy sand; structureless single grain; dry loose; porous; calcareous; rare fine roots; gradual smooth boundary.
C1cs	15-55	Light yellowish brown (10YR 6/4) loamy gypsic sand; single grained to locally massive; hard dry; cemented by gypsum crystals in layers; porous; slightly calcareous; few fine roots; clear smooth boundary.
C2	55-80	Light yellowish brown (10YR 6/4) loamy sand; weak fine blocky structure; loose dry; porous; few thin (20mm) gypsum cemented layers; calcareous; few fine roots; clear smooth boundary.
IIC3	8-0130	Very pale brown (10YR 7/3) loam; weak medium subangular blocky; friable moist; few large (40-60mm) platy gypsum crystals; fine pores; strongly calcareous; no roots; abrupt wavy boundary.
R	130+	Lithic contact; chalky limestone.

Profile Description No: 4 **Site No:** PV003

Series: Hawrah - Hw **Location:** 510803

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-15	2.6	4.7	7.8	4.9	1	25.5	5.1
b	15-55	3.4	10.0	8.0	1.6	1	7.7	47.1
c	55-80	3.9	13.1	8.1	2.5	2	12.4	20.0
d	80-130	6.0	15.9	8.1	14.5	7	41.6	10.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	-	5	9	19	32	11	18	6	23
b	-	30	15	19	15	5	7	9	29
c	-	5	7	34	33	5	8	8	28
d	-	2	5	12	20	11	32	18	65

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	0	9.7	13.8	40.5	6.7	17.8	11.5	19.8	1.95	0.024
b	0	1.7	17.6	39.0	4.5	21.7	15.5	-	-	-
c	0	0.8	17.1	55.7	1.3	10.1	14.9	-	-	-
d	0	4.7	10.9	25.6	4.9	30.8	23.1	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.24	44.3	11.8	10.0	2.6	4.0	24.6	40.0	28.3
b	-	47.5	42.5	132.8	5.7	3.0	170.8	54.6	4.3
c	-	40.5	40.8	122.7	5.1	2.5	143.9	63.1	2.5
d	-	45.0	57.0	165.3	6.5	2.0	208.7	63.1	10.0
C:N Ratio 10.0									

(iii) Buri Series - Br.

Representative Description: Profile 5 (PV025)
Location and Physiography: Buri soils occupy parts of the Nebkha plain along the foot of the Hamalah scarp, where a shallow depth of aeolian silicious sand overlies gypsic alluvium. The terrain is level, microrelief is mostly even except in some areas which have prominent sand hummocks and low dunes around vegetation: in the extreme south of the Salmabad area the microrelief is very uneven due to disturbance by sand quarrying. Watertables were not encountered under these soils.

Land use and Vegetation: Channel networks discernble on the aerial photographs indicate that some of the Buri soils have been irrigated at some time in the past although none are used today. Vegetative cover is moderately dense, dominated by species of Eragrostis, Zygophyllum and Aeluropus; species of Salsola, Heliotropium and Stipagrostis occur locally.

Profile Characteristics: Buri soils are deep, well drained and have a sandy particle size. The surface horizon comprises non-gypsic single-grained aeolian silicious sand; this horizon is usually less than 25cm thick in the modal series but where it exceeds 50cm a separate sandy topsoil phase has been mapped (Br - q). The underlying gypsic horizons range from massive hard gypsic gravelly sand to weak augular blocky structured loamy sand cemented by thin discontinuons bands of crystalline gypsum. This stratification of gypsum is typical of the subsoils of this series. Below the control section (1.0m) the gypsum content decreases. The substratum, which is porous, sandy to coarse loamy and weakly structured, usually contains calcite cemented modules which often form an impenetrable layer.

Land Capability: The cemented gypsum horizons limit the use of these soils for irrigation. However, as the cementing layers are discontinuous and the soils porous, they are acceptable for a Class 5 rating. The sandy topsoil phase meets the requirements of Class 3. Salinity, and often microrelief, form minor additional limitations, along with the low moisture holding capacity and poor fertility potential associated with sandy particle-size.

Associated Soils: Buri series is similar to Maqabah series, occurring either adjacent to it or as a complex of Br-Mq. Buri soils differ from Maqabah in having prominent thin banded, gypsum cemented, coarse loamy subsoils and no watertable. The sandy topsoil phase resembles

Profile: 5 Buri Series — Site No: PV025

Sandy, gypsic, hyperthermic family of Typic Gypsiorthids.

Date: 30.11.78

Location: 3.0km south of Sar Village; GR.488942.
Geomorphic Unit: Level area at foot of limestone escarpment.
Parent Material: Aeolian silicious sand overlying gypsum-rich alluvium.
Topography: Almost flat with slight slope (less than 1%)to east.
Micro-relief: Slightly uneven due to vegetation hummocks; soft dry sandy surface.
Vegetation: Not cultivated; scattered tussocks of Eragrostis, Heliotropium, Salsola, Zygophyllum and Aeluropus spp.
Drainage: Moderately well drained; no watertable encountered.
Remarks: Prominent striations of gypsum crystals within subsoil. Aeolian sand overlay.

Horizon	Depth(cm)	Profile Description
$A1_{cs}$	0-35	Light yellowish brown (10YR 6/4) fine sand; structureless, single grained; porous; slightly hard dry; thin layer (5-10cm) of cemented hard gypsum; few calcareous nodules, slightly calcareous; common fine roots; abrupt wavy boundary.
$C1_{cs}$	35-55	Yellowish brown (10YR 5/4) weakly cemented gravelly gypsum; massive; very firm slightly moist; calcareous; no roots; abrupt wavy boundary.
$C2_{cs}$	55-110	Yellowish brown (10YR 5/4) sandy loam; moderate fine angular blocky; firm, slightly moist; discontinuous alternating bands of gypsum cemented soil 20-30mm thick; calcareous; many fine tubular pores; no roots; abrupt smooth boundary.
$C3_{ca}$	110-180	Yellowish brown (10YR 5/4) loam; moderate medium angular blocky; firm moist; 150mm thick layer of calcite cemented concretions at base, random nodules throughout; many fine tubular pores; strongly calcareous; no roots; abrupt smooth boundary
$IIC4_{ca}$	180-200	Light brownish grey (2.5Y 6/2) very gravelly medium sand; structureless, single grained; loose moist; weakly cemented by $CaCO_3$; porous; many irregular, subrounded nodules; strongly calcareous; no roots.

Profile Description No: 5 **Site No:** PV025

Series: Buri-Br **Location:** 488942

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0.35	3.0	9.8	7.9	3.7	1	3.7	58.5
b	35-55	2.4	5.9	7.9	1.5	1	9.7	26.9
c	55-100	3.7	15.4	7.8	6.0	4	5.2	47.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	18	15	17	17	7	21	5	38
b	0	3	19	28	28	6	6	10	27
c	0	11	10	10	12	9	44	4	47

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	11	16	17	20	6	21	9	20.1	0.63	0.014
b	2	17	27	28	4	10	12	–	–	–
c	6	9	10	17	7	44	7	–	–	–

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.19	30.0	14.1	27.8	3.0	2.0	31.0	50.0	1.77
b	–	35.0	4.8	2.3	0.6	2.5	4.0	36.5	2.16
c	–	32.5	14.5	101.0	5.2	3.0	81.0	71.4	0.78

Hisham series in the upper profile but differs by having a prominent gypsic horizon below 50cm.

(b) Coarse-loamy, gypsic, hyperthermic family.

(i) Maqabah Series -Mq.

Representative Description : Profile 6 (PV018)

Location and Physiography: Maqabah series occurs extensively on the Nebkha Plain throghout the Salmabad area at elevations ranging from three to ten metres above sea level. The soils are formed in deep accumulations of gypsum, derived partly from precipitation from rising groundwater but also by deposition of aeolian gypsic sand. The land is level but slight microrelief of low vegetation hummocks is common. The watertable usually lies at 1.5 to 2.0m.

Land use and Vegetation: Maqabah soils have been irrigated at some time in the past, as indicated by channel remnants visible on the aerial photographs.Around Nakhl Lawzi the soils have been abandoned only very recently, leaving only a small area of these soils still under cultivation near Buri. The natural vegetation is regularly grazed by camels. The dominant species include Zygophyllum qatarensis, Aeluropus lagopoides, Juncus acutus and stunted plants of Suaeda pruinosa. Other typical plants include Atriplex sp, Anabasis setifera , Eragrostis sp and Limonium axillare .

Profile Characteristics: The soils have uniform profiles of crystalline gypsic sand which predominates in the control section. The soils are deep and usually well drained. The upper 65cm are formed in coarse grained gypsic sand in which there are bands of honeycomb cementing. In some instances layers of hard petrogypsic material occur in the subsoil but these are rarely sufficient to warrant a separate Petrogypsic Gypsiorthid Series. In most profiles the crystalline gypsic sand extends to depths in excess of 1.5 or 2.0 m, usually overlying a layer of carbonatic silt loams or silicious fine sand.

Structure in the Maqabah soils is controlled by the degree of cementing. In the modal profiles the upper 50cm contains zones of honeycomb cementing but in some areas these upper horizons comprise weakly structured, non-cemented gypsic sandy loam: these soils are mapped as a non-cemented topsoil phase (Mq-h).

Profile: 6 Maqabah Series Site No: PVC'8

Coarse loamy, gypsic, hyperthermic family of Typic Gypsiorthids.

Date: 18.11.78

Location: About 1.5km south of Maqabah village, GR.497979.
Geomorphic Unit: Nebkha plain.
Parent Material: Gypsum, including aeolian and in situ evaporite material.
Topography: Level.
Micro-relief: Even but with minor (less than 25cm) wind blown sand hummocks around vegetation. Dry surface of loose gypsic sand.
Vegetation: Not cultivated; sparse low bushes of Zygophyllum, Atriplex and Anabasis sp.
Drainage: Moderately well drained.
Remarks: Porous profile but contains thin layers of petrogypsic material. Watertable at 160cm with 65cm capillary fringe above.

Horizon	Depth(cm)	Profile Description
A_1cs	0-20	Very pale brown (10YR 7/3) loamy sand; weak medium angular blocky; soft dry; very porous; gypsiferous sand and discrete crystals; non-calcareous; few fine roots; abrupt smooth boundary.
C_1cs	20-50	Light yellowish brown (10YR 6/4) loamy fine sand; weak medium angular blocky; friable moist; granular gypsum crystals; very porous with few fine tubular pores; non-calcareous; few fine roots; clear smooth boundary.
C_2cs	50-70	Yellowish brown (10YR 5/4) loamy medium sand; structureless, single grained; porous; gypsum, locally weakly cemented; calcareous; few fine roots abrupt smooth boundary.
C_3csm	70-95	White (10YR 8/2) hard gypsum, indurated layer; porous; gypsum massive cemented bands; slightly calcareous; no roots; abrupt wavy boundary.
C_4cs	95-125	Very pale brown (10YR 7/4) fine sandy loam; structureless, massive; few tubular pores; 60%(estimate soft noduler gypsum patches; weakly calcareous; no roots; gradual smooth boundary.
C_5cs	125-250 (in auger)	Light grey (2.5Y 7/2) sand with thin silty clay loam bands; structureless;wet non-sticky, non-plastic; finely divided gypsum sand grains.
IIC_6	250-500	Grey (5G 5/1) fine sand; single grained; wet, non-plastic, non-sticky.

Profile Description No: 6 **Site No:** PV018

Series: Maqabah-Mq **Location:** 497979

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-20	4.1	22.2	8.0	2.0	2	1.0	91.6
b	20-50	4.3	18.0	7.9	2.1	4	1.0	81.6
c	50-70	4.4	15.2	7.6	2.0	3	0.8	72.0
d	95-125	5.6	26.0	7.8	3.2	7	2.1	75.1

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	12	28	22	12	7	8	0	40
b	0	14	30	24	13	6	4	0	49
c	0	24	26	20	12	5	4	0	55
d	10	6	8	8	14	16	42	0	46

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	10	24	20	15	6	16	9	12.5	0.55	0.01
b	3	25	27	19	4	13	9	-	-	-
c	15	30	23	11	1	11	9	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.16	37.5	24.0	99.4	2.6	2.2	128.5	30.0	2.99
b	-	43.1	26.8	126.5	3.1	1.6	135.0	65.8	0.82
c	-	45.0	26.8	104.0	2.5	1.5	106.0	68.1	1.54

Chemical Characteristics: The principal feature of these soils is the gypsum content, which usually exceeds 50 percent throughout the upper metre. Calcuim carbonate contents increase downwards as gypsum values decline. The soils are moderately saline with low fertility.

Land Capability: The combination of high percentages and great thickness of gypsum severely limits the potential of these soils for irrigation. This causes hazards of gypsum solution and cemented layers restricting root penatration. Maqabah soils have therefore been assigned to Class 5, as being worthy of consideration for tree planting, should water become available. The non-cemented topsoil phase is placed in Class 4F as being more suitable for irrigation.

Associated Soils: Maqabah soils are distinguished from adjacent Sar and Abu Saybi' soils by the depth of gypsum dominated horizons exceeding 65cm and usually exceeding 1.0m. The upper horizons are similar to Isa Series but Maqabah soils lack a petrocalcic horizon. Buri series has a higher proportion of silicious sand and distinct banding of gypsum.

(ii) Buhayr Series - Bu.

Representative Description: Profile 7 (PV013)
Location and Physiography. Buhayr soils form a minor series which is mapped solely in the Buhayr area. The soils are formed in varved gypsic sandy loam lacustrine alluvium overlying limestone. The terrain is level, with some slightly uneven hummocky microrelief locally. Shallow groundwater was not encountered, although the soils are moist and the aerial photographs indicate that surface ponding of water occurs locally after heavy rain.
Land use and Vegetation: Buhayr soils are not cultivated. The land is used principally for refuse disposal, which has entailed considerable excavation, infilling and surface disturbance, much of it having occurred since the present survey. Where natural vegetation remains it is sparse and dominated by species of Zygophyllum and Halocnemum.

Profile Characteristics: The soils are moderately well to imperfectly drained, highly gypsic and extremely deep. The upper 40 to 50cm are dominated by porous, weakly cemented, coarse crystalline gypsic sandy loam. This abruptly overlies friable gypsic sandy loam interspersed by thin strata of pale grey , white and brownish grey

Profile: 7 Buhayr Series Site No: PV013

Coarse - loamy, gypsic, hyperthermic family of Typic Gypsiorthids.

Date: 29.10.78

Location: Al Buhayr depression 2.0km south of Isa Town. GR.560932.

Geomorphic Unit: Former lacustrine depression surrounded by prominent scarps.

Parent Material: Highly gypsic varved alluvium.

Topography: Level

Micro-relief: Slightly uneven, hummocks of windblown gypsic sand.

Vegetation: Not cultivated; sparse, stunted Zygophyllum qatarensis

Drainage: Imperfectly drained.

Remarks: Horizons stratified, indicating former lake bed deposition.

Horizon	Depth(cm)	Profile Description
A_1cs	0-45	Yellowish brown (10YR 5/4) gypsic sandy loam; weak medium angular blocky; moist friable; many fine tubular pores, no cracks; bands of irregular brown gypsum crystals (6-12mm) 5-15cm thick; calcareous; few fine roots; abrupt smooth boundary.
C_1cs	45-105	Light brownish grey to light grey (2.5Y 6/2 - 2.5Y 7/2) gypsic sandy loam; weak medium angular blocky; moist friable; few fine tubular pores; well stratified varves of sandy loam and fine gypsum; slightly calcareous; no roots; gradual smooth boundary.
C_2cs	105-115	Light brownish grey (2.5Y 6/2) gypsic sandy loam; structureless; wet, slightly sticky and plastic; no cracks or pores; slightly calcareous; no roots; abrupt smooth boundary.
C_3cs	115-200	Grey (5Y 5/1), white (10YR 8/1) and light brownish grey (2.5Y 6/2); silt loam, with gypsum and quartz sand in stratified layers 5mm thick, grey (5Y 5/1); weak coarse platy; moist firm; no cracks, few pores; 30-40% fine sand-sized white gypsum crystals; slightly calcareous; no roots.

Profile Description No: 7 **Site No:** PV013

Series: Buhayr-Bu **Location:** 560932

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-45	6.7	31.9	7.5	3.8	1	7.3	59.6
b	45-110	7.2	33.0	7.6	1.8	1	2.5	81.6
c	110-200	5.7	34.0	7.4	0.2	8	2.9	87.7

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	9	9	12	14	8	35	13	38
b	0	5	12	19	21	10	23	10	39
c	0	3	6	18	33	15	12	13	26

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	1.2	1.2	1.0	2.2	11.7	29.2	53.5	32.8	0.001	0.008
b	0	1.0	6.3	16.5	15.9	6.3	54.0	-	-	-
c	0	6.6	14.4	8.6	0	7.4	62.7	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.17	60.0	43.0	243.9	9.0	2.5	292.7	60.8	1.0
b	-	77.0	62.0	360.5	11.7	2.5	443.3	65.4	1.1
c	-	82.5	71.0	397.9	15.3	2.3	508.5	55.8	1.9
C:N ratio 21.3									

gc

varves of silt loam and gypsic fine sand. This material usually extends to below 2.0m but adjacent to rock outcrops profiles are shallower. Roots rarely penetrate below the upper 0.5m horizon.

Chemical Characteristics : The soils often contain in excess of 70 per cent gypsum but this occurs mainly in the fine particle size range. Salinity levels are moderately high but show little variation with depth.

Land Capability: The high levels of gypsum, as well as weak cementing in the upper horizon, severely restrict the irrigation potential of these soils. Furthermore, salinity values are moderately limiting and soil depth would restrict drainage operations in some areas. The soils are mapped as Class 5.

Associated Soils: The stratified varved subsoils of Buhayr soils are distinctive and unlike other series mapped. In the west the soils are bounded by Isa series, in which a petrocalcic and carbonate-rich layer replaces the varved subsoil of Buhayr.

(c) Coarse-loamy over fine-loamy, gypsic, hyperthermic family.

(i) Sar Series - Sa

Representative Description : Profile 8 (PV007)

Location and Physiography: Sar soils occur moderately extensively along the margins of the Nebkha Plain in the west of the Salmabad area. They have formed in highly calcareous loamy alluvium over which has been deposited a layer of gypsum, derived partly by precipitation from upward rising groundwater and partly by deposition of wind blown gypsic sand. Buried organic layers indicate a complex depositional history. The terrain is level and microrelief is usually even. A shallow watertable occurs within 1.5m of the surface.

Land Use and Vegetation: Irrigation is currently practiced on several areas of Sar soils but mostly they are either uncultivated or have long been abandoned. The natural vegetation is moderately rich, reflecting the transitional position of these soils between the Loam Plain and Nebkha Plain, and comprises a mixture of species typical of each, namely Zygophyllum, Cressa, Suaeda, Salsola, Limonium, Phoenix and Halocnemum.

Profile: 8 Sar Series — Site No: PV007

Coarse loamy over fine loamy, gypsic, hyperthermic family of Typic Gypsiorthids.

Date: 16.10.78

Location: About 1.5km south west of Sar village, GR.497960.

Geomorphic Unit: Transitional area between Nebkha Gypsic Plain and Marine Loam Plain.

Parent Material: Gypsum over loamy alluvium over silicious sands.

Topography: Level.

Micro-relief: Even; dry slightly hard surface crust of gypsic sand.

Vegetation: Scattered abandoned date palms; sparse tussocks of Zygophyllum sp and Cressa, Phragmites and Juncus species locally.

Drainage: Imperfectly drained.

Remarks: Gypsic surface overlying loamy soil with gravelly calcite layer at 40 to 70cm. Darker colours 70-100cm probably indicate organic material in a buried A horizon.

Horizon	Depth(cm)	Profile Description
A_1cs	0-20	Pale brown (10YR 6/3) gypsic loamy sand; structureless single grained; loose dry; porous; no roots; non-calcareous; clear smooth boundary.
C_1cs	20-40	Yellowish brown (10YR 5/4) gypsic coarse sand; structureless; massive; hard dry; non-porous; non-calcareous; no roots; abrupt smooth boundary.
IIC 2cs	40-70	Yellowish brown (10YR 5/4) gravelly gypsic loam; weak medium angular blocky; firm moist; 30% (estimate) platy fragments and subrounded irregular calcite cemented nodules; weakly calcareous; few fine roots; gradual wavy boundary.
IIC 3	70-100	Dark greyish brown (10YR 4/2) silt loam; weak medium angular blocky; firm moist; few hard calcite cemented concretions in discontinuous layers; many tubular pores; weakly calcareous; few fine roots; clear smooth boundary.
II C4	100-130	Greyish brown (2.5Y 5/2) gritty sandy clay loam; weak fine angular blocky; very firm moist; few irregular calcite nodules; calcareous; few roots and shells; abrupt smooth boundary.
III C5	130-140	Light brownish grey (2.5Y 6/2) sandy clay loam; weak medium angular blocky; firm moist; weakly calcareous; many medium and coarse roots; abrupt smooth boundary.
III C6	140-230	Yellowish brown (10YR 5/4) with common fine distinct strong brown mottles; fine sand; single grained; loose moist; vertical tubular root pores; calcareous.
III C7g	230-270	Light yellowish brown (2.5Y 6/4) fine sand; wet non-plastic, non-sticky.

Profile Description No: 8 **Site No:** PV007

Series: Sar-Sa **Location:** 497960

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-40	5.3	19.3	7.8	4.8	7	2.9	60.0
b	40-70	6.6	21.0	7.6	9.2	8	16	17.7
c	70-100	9.5	29.9	7.4	27.2	3	32.6	2.1
d	100-130	3.6	14.6	7.7	10.1	3	76.0	1.3

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	20	18	15	10	7	21	9	50
b	30	7	6	7	7	8	44	21	60
c	5	4	3	5	5	5	59	19	75
d	5	29	16	12	7	3	19	14	49

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	0	4.1	3.7	3.3	2.9	41.3	44.6	25.1	2.30	0.017
b	0	2.2	7.1	12.1	6.0	19.8	52.7	-	-	-
c	0	1.1	8.6	9.8	4.6	9.2	66.7	-	-	-
d	0	2.7	3.1	4.5	1.7	6.9	81.1	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.32	65.0	57.2	164.5	7.3	3.0	226.4	64.6	1.2
b	-	62.5	57.5	182.7	5.2	2.5	249.5	55.8	0.6
c	-	90.0	92.5	274.5	6.3	2.5	412.6	48.1	4.5
d	-	56.5	43.4	125.2	2.9	3.0	179.0	46.0	1.9
C:N Ratio 18.8									

Profile Characteristics: Although profiles of Sar series are variable, they are typically deep, imperfectly drained and overlain by a coarse-loamy gypsic horizon which does not exceed half the control section (less than 65cm). The superficial gypsic horizon is structureless, porous and usually only weakly cemented; it ranges in depth from 25 to 65cm and abruptly overlies a loamy to silt loamy calcareous subsoil. This horizon has weak medium angular blocky structure, is friable and often contains thin (5-10cm) layers of organic staining (see organic carbon analyses for site PV005, Appendix B.3.). In the lower part of the control section there occurs a varied content of calcite cemented nodules, often forming a continuous hard pan between 100 and 120cm depth. Roots are confined mostly to the upper 100cm of the profile but numerous dead roots were observed within the subsoil calcite cemented layers, suggesting that the cementing is a relatively recent phenomenon. Beneath the control section Sar soils usually overlie silicious fine sand.

Chemical Characteristics: The soils are saline throughout the profile with slightly higher EC values near the surface. Gypsum percentages are greatest in the surface, often exceeding 60, but decline rapidly with depth; by contrast CaCO3 values increase with depth and can exceed 80 percent in the 100 - 150cm range.CEC values are relatively high for soils of this area, reflecting the contribation from the moderately high levels of organic matter, clay and silt.

Land Capability : Superficial gypsum accounts for the main capability limitation. In addition, Sar soils are affected by salinity, fine textures, internal drainage deficiencies and, locally, microrelief. The soils are placed in Class 4F on the assumption that tree roots could penetrate the superficial gypsum to exploit the subsoil.

Associated Soils: Sar series is very similar to Abu Saybi' soils but is distinguished by the occurrence of calcite gravels and weak cementing in the lower subsoil. Maqabah soils, which lie adjacent to Sar series, are similar but have more than 65cm of superficial gypsum. Isa series ressembles Sar series but has a calcite cemented (petrocalcic) horizon which is thicker, more massive and occurs within the series control section.

(ii) Abu Saybi' Series - Sb.

Representative Description: Profile 9 (PV020)
Location and Physiography: As with Sar series, the Abu Saybi' soils have formed in shallow deposits of gypsum overlying loamy alluvium. They occur not only along the margins between the Nebkha and loam plains but also as discrete mapping units within the loam plain where sufficient superficial gypsum has accumulated. The soils have level terrain but frequently have uneven microrelief due to abandoned irrigation channels. Normally the watertable is deep (1.0 to 2.0m) but in some localities it occurs within the 0.5 to 1.0m zone and these soils are differentiated as a high watertable phase (Sb-w).

Land Use and Vegetation: Most Abu Saybi' soils have been cultivated at some time in the past, mostly for dates. Although a few areas are currently growing vegetables and fodder under irrigation, most of the soils are unused. Halocnemum is the dominant natural species, with Suaeda and Zygophyllum as sub-dominants. Cressa, Limonium and Phragmites spp. occur locally and Phoenix dactylifera (date) has regenerated in some areas.

Profile Characteristics: The soils have deep, moderately well to imperfectly drained profiles similar to Sar series. The gypsic superficial horizons range from 25 to 50cm in depth and abruptly overlie marine loam and calcareous loam. The subsoil has loamy to silt loamy textures and moderate angular blocky structure; they are friable, porous and contain numerous gastropod shells and ground pearls. This organic stained layers often occur between the gypsum and loam deposits. The deep subsoil may contain some calcitic nodules but does not have the cemented horizon of Sar series. Roots are usually confined to the upper 50cm of the profile, especially where the watertable is close to the surface.

Chemical Characteristics: The soils are saline, with greatest ECe values in the surface horizon; some soils have ECe values in exccess of 64 mmhos cm^{-1} and are mapped as the extremely saline phase (Sb-s). As in Sar series, gypsum contents decrease with depth whereas $CaCO_3$ contents increase. CEC values are moderately high in the subsoil silt loams.

Land Capability: The same limitations apply to Abu Saybi' series as were described for Sar series, except that in the absence of a calcite cemented subsoil horizon, drainage is marginally more favourable. The soils are mapped as Class 4F. An additional limitation due to risks of sea water intrusion is applied to some Abu Saybi' soils in lowlying areas.

Profile: 9 Abu Saybi Series Site No: PV020

Coarse loamy over fine loamy, gypsic, hyperthermic family of Typic Gypsiorthids.

Date: 20.11.78

Location: About 1.5km south west of Abu Saybi village, GR.500984.

Geomorphic Unit: Fringe of Nebkha Plain.

Parent Material: Gypsic sand overlying loamy marine alluvium.

Topography: Level.

Micro-relief: Even; few low vegetation hummocks; moist friable salt efflorescence forming surface mulch 5cm deep.

Vegetation: Abandoned land; few remnant dates, Suaeda and Halocnemnum spp.

Drainage: Moderately well to imperfectly drained.

Remarks: Gypsic sand unconformably overlying loamy alluvium; intervening buried organic horizon. Watertable at 160cm.

Horizon	Depth (cm)	Profile Description
A^1_{cs}	0-30	Yellowish brown (10YR 5/4) sandy loam; weak fine angular blocky to single grain structureless; firm slightly moist; porous; highly gypsic; non-calcareous; few fine roots; gradual smooth boundary.
C^1_{cs}	30-60	Light yellowish brown (10YR 6/4) gypsic sandy loam; weak medium angular blocky; friable moist; porous; locally gypsum cemented; few fine medium roots; calcareous; abrupt smooth boundary.
II A_1	60-65	Dark greyish brown (10YR 4/2) silt loam; moderate medium angular blocky; friable moist; many fine tubular pores; slightly calcareous; few fine roots; abrupt smooth boundary.
II C_1	65-95	Yellowish brown (10YR 5/4) loam; moderate medium angular blocky; friable moist; shells and ground pearls common; many fine tubular pores; slightly calcareous; few dead date roots; abrupt smooth boundary.
II C_2	95-135	Olive grey (5Y 5/2) loam; strong medium angular blocky; friable moist; many fine tubular pores; 10% (estimated) knobbly $CaCO_3$ nodules; slightly calcareous; few dead date roots; abrupt smooth boundary.
II C_3	135-155	Pale yellow (2.5Y 7/4) slightly gritty loam (calcite grit); weak medium angular blocky; firm moist; shells; few fine pores; common fragments of fine grained sandstone; slightly calcareous; many fine roots; gradual smooth boundary.
II C_4	155-250	Brown (10YR 5/3) silt loam; strong medium angular blocky; friable moist to wet; many fine tubular pores; many dead date roots and channels; slightly calcareous.
III C_5	250-500 (195-500 in auger)	Light yellowish brown (2.5Y 6/4) fine sand; single grained; non-plastic, non-sticky wet.

Profile Description No: 9 **Site No:** PV020

Series: Abu Saybi-Sb **Location:** 500984

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-30	7.5	38.3	7.6	0.9	1	4.2	66.5
b	30-60	9.7	40.4	7.4	2.3	2	2.9	74.9
c	60-65	16.4	44.7	7.2	12.1	3	20.8	12.5
d	65-95	8.7	37.2	7.3	13.3	10	29.1	0.4

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	15	18	21	17	4	10	15	35
b	0	7	6	7	15	22	43	0	50
c	0	2	5	12	16	20	45	0	104
d	0	3	8	15	25	6	25	18	78

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

Associated Soils: Abu Saybi' and Sar series are very similar except for the gravelly calcite and cementing in the deep subsoils of the latter. Maqabah has a greater depth of superficial gypsum. Khadarah soils also resemble Abu Saybi' series but have higher salinities, more impeded drainage and coarser particle sized subsoils.

B.2.4 Cambic Gypsiorthids.

(a) Coarse-loamy , mixed, hyperthermic family.
- Zaytun Series - Zn

Representative Description: Profile 10 (PV037)
Location and Physiography: This minor series occurs mainly in the southwest of the Salmabad area. The soils occupy the lower slopes of the limestone pavement, or local outliers of limestone, where a shallow depth of loamy alluvium overlies limestone colluvium. Slightly uneven microrelief is common but the terrain is usually level.

Land Use and Vegetation: Some Zaytun soils are currently under irrigation although most are uncultivated. The natural vegetation is sparse, comprising xerophilous species such as Hammada elegans, Heliotropium sp, and Eragrostis sp.

Profile Characteristics: Zaytun profiles have varied characteristics, especially in respect to gravel content and depth to paralithic contact. The soils are moderately deep, well drained and have loamy textures structure in the upper horizons is moderately well developed angular blocky. Filaments and fine crystals of gypsum are visible in the upper horizons but no superficial concentration of gypsum occurs. Below 50cm the proportion of angular limestone fragments increases; the paralithic contact of weathered limestone colluvium is encountered at between 50 and 100cm.

Chemical Characteristics: The soils are saline, highly calcareous and have gypsum contents averaging 15 to 20 percent.

Land Capability : Zaytun soils are limited in agricultural value by their effective depth. Salinity and gypsum contents form minor limitations and a microrelief deficiency occurs locally. The soils are mapped in Class 3. Around Nakhl Lawzi Zaytun soils are further downgraded to Class 5 due to erosion hazard from flash flooding.

Associated Soils : The upper part of the Zaytun profile resembles Dilmun series but in the latter series the paralithic contact occurs within the upper 50cm.

Profile: 10 Zaytun Series — Site No: PV037

Coarse loamy, mixed, hyperthermic family of Cambic Gypsiorthids.

Date: 4.1.79

Location: 0.5km south of Nakhl Lawzi village. GR 497913.

Geomorphic Unit: Footslope to limestone backslope, transition to alluvium covered plain.

Parent Material: Fine textured alluvium and colluvium over limestone rubble.

Topography: Slight slope (1%) to west.

Micro-relief: Even; occasional small vegetation hummocks. Dry hard surface with few angular gravels.

Vegetation: Non-cultivated; sparse cover of Heliotropium and Limonium, occasional Zygophyllum and Lycium species.

Drainage: Well drained.

Remarks: Lithic contact at between 50 and 60cm depth.

Horizon	Depth(cm)	Profile Description
A_1	0-15	Light yellowish brown (10YR 6/4), loam; weak fine subangular blocky; slightly hard dry; porous; 10% (estimated) angular gravels 10-20mm; calcareous; few fine roots; clear smooth boundary.
C_1cs	15-55	Light yellowish brown to brown (10YR 6/4 - 7.5YR 5/4) loam; weak medium angular blocky; slightly hard dry; few fine tubular pores; few 5-10mm gravels; few fine white filaments of gypsum ; strongly calcareous; fare fine roots; abrupt smooth boundary.
R	55+	Paralithic and lithic contact, angular fragments of crystalline limestone in matrix of gypsum; dry extremely hard.

Profile Description No: 10 **Site No:** PV037

Series: Zaytun-Zn **Location:** 497913

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-15	6.2	46.0	7.5	16.0	7	28.6	2.6
b	15-40	8.5	39.2	7.6	7.5	11	19.2	19.3

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	10	4	7	8	9	9	39	24	31
b	5	2	5	6	9	13	47	18	53

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	4	7	7	9	7	43	23	249.6	0.25	0.09
b	2	4	5	10	6	53	20	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.73								

(b) Fine-Loamy, carbonatic, hyperthermic family.
- Khuways Series - Kh

Representative Description: Profile 11 (PVO 17)
Location and Physiography: Khuways series occurs extensively on the Marine Loam Plain throughout the Salmabad area. The parent material comprises calcareous loamy and silt loamy marine alluvium which overlies silicious fine sand. The terrain is level but the microrelief almost everywhere is dominated by a reticulate pattern of former irrigation channels; these are usually 0.50 to 0.75m deep and form a grid of about 7.0 x 8.0m. Depth to watertable varies but normally is between 1.0 and 2.0m; a shallow watertable phase is mapped where it occurs within the 0.5 to 1.0 m zone (Kh-w).

Land use and Vegetation: Until recently a large propartion of the Khuways soils had been under irrigated date plantations. All but a few of these plantations have since been abandoned, due to a combination of water quality deterioration, rising groundwater and adverse economic factors; small scale irrigation of fodder and vegetable crops has replaced dates in some minor areas. The abandoned lands have been rapidly colonised by Suaeda pruinosa and Cressa cretica, with inclusions of Phragmites sp in high watertable areas and Tamarix sp in very saline soils. Alhagi maurorum, Capparis spinosa and Lagonychium farctum are minor constituents of the flora. Remnant date palms survive in most areas.

Profile Characteristics: Khuways soils have very uniform profile characteristics; they are deep, moderately well drained and have a fine-loamy (silty) particle size throughout the control section (0.25 - 1.00m). Under non-irrigated conditions the soil surface has a thin (3-5cm) fine powdery mulch of salts. The upper horizon, which is somewhat paler brown than the underlying horizons, contains very finely divided particles of gypsum , has a friable consistence and is moderately well structured angular to subangular blocky. Within the control section structure is similarly moderately well developed, consistence is firm and the soil has abundant medium and fine tubular pores . Numerous gastropod shells and ground pearls are a characteristic feature of these horizons. Knobbly calcite cemented nodules commonly occur at the base of the control section and frequently impede penetration of the hand anger below 1.0m. An abrupt boundary with the underlying silicious fine sand occurs at about 1.5m ; this

Profile: 11 Khuways Series Site No: LV017

Fine loamy, carbonatic, hyperthermic family of Cambic Gypsiorthids.

Date: 9.11.78

Location: About 1.3km north of Buri village near Khuways: GR 495938.

Geomorphic Unit: Level plain, near limestone escarpment.

Parent Material: Loamy marine alluvium over sand.

Topography: Level.

Micro-relief: Reticular pattern of 50 to 75cm deep former irrigation channels on grid of 7 x 8m. Friable powdery surface salt efflorescence.

Vegetation: Abandoned date groves; clumps of Suaeda pruinosa and Cressa cretica, Phragmites sp locally.

Drainage: Imperfect to moderately well.

Remarks: A porous fine loamy profile over sand, a weakly cemented calcite pan occurs above the watertable at 180cm.

Horizon	Depth(cm)	Profile Description
A_{1sacs}	0-20	Pale brown (10YR 6/3) loam; moderate coarse angular blocky; friable slightly most; few fine pores; many soft powdery carbonates, strongly calcareous; few coarse roots; abrupt smooth boundary.
C_{1sa}	20-80	Pale brown (10YR 6/3) silt loam; moderate medium angular blocky; friable moist; many medium and fine tubular pores; few gastropod shells; fine soft powdery carbonates, strongly calcareous; many medium roots; gradual smooth boundary.
C_2	80-135	Light grey (10YR 7/2) with few fine faint yellow brown mottles, clay loam; strong medium angular blocky; friable moist; many fine tubular pores; calcareous; many coarse and medium roots; abrupt smooth boundary.
IIC_3	135-180	Light grey (2.5Y 7/3) with common medium prominent strong brown mottles; gritty sandy loam; structureless, massive; friable moist; thin discontinuous calcite cemented pan; few tubular pores and prominent vertical root channels; non-calcareous; many coarse roots; gradual smooth boundary.
$IIIC_4$	180-300 (200-300 in auger)	Olive grey (5Y 5/2) with many fine distinct brown mottles; fine sand; structureless single grained; non-plastic, non-sticky, wet; weak calcite cementing locally, non-calcareous; porous, few prominent vertical root channels.

Profile Description No: 11 **Site No:** PV017

Series: Khuways - Kh **Location:** 495938

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-20	14.7	66.7	7.8	4.6	4	33.3	31.0
b	20-80	7.6	38.7	7.5	6.3	3	41.2	19.2
c	80-135	5.5	27.0	7.8	12.1	10	69.2	1.9

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	4	4	8	17	16	42	9	53
b	0	3	4	7	13	12	48	13	60
c	0	7	6	7	8	8	39	25	60

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	0	1.7	4.7	9.1	3.4	13.5	67.6	40.20	1.15	0.048
b	0	0.5	1.9	10.2	2.7	37.8	40.5	-	-	-
c	0	0.8	3.0	5.9	5.9	4.2	80.2	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.94	106.5	469.5	1022.9	62.5	3.3	1539.0	119.2	23.0
b	-	76.0	59.0	361.3	21.5	2.3	441.4	74.2	14.7
c	-	54.0	46.0	228.7	7.5	3.0	259.1	74.2	2.3
C:N Ratio 19.6									

boundary is invariably associated with the depth of the watertable. In some areas, particularly around Sar and Buri, there is an intervening layer of highly calcareous pale yellow (2.5Y 7/4) fine sandy loam, which is weakly cemented by calcite. Thin humic layers were sometimes observed in this calcareous layer.

Chemical Characteristics : All non-irrigated Khuways soils are saline in their upper horizons. In many cases, especially where the watertable is high, they are extremely saline and have been differentiated as the extremely saline phase (Kh-s). Several profiles in this phase have ECe values exceeding 100 mmhos cm^{-1} and meet the requirements for the Salorthid great group, but they are retained within Khuways series mainly because the flora of the area does not indicate a true Salorthid. Gypsum contents are greatest in the surface 25cm, decreasing rapidly with depth so that most subsoils are non-gypsic. Most of the gypsum probably originates from precipitation from rising groundwater. $CaCO_3$ values are moderately high throughout the profile but can exced 90 percent immediately below the series control section.

Land Capability: The principal limitations of these soils are high salinity and watertables within 2.0 metres and rather gypsic topsoils. Very often these soils have prominent microrelief. Khuways soils are currently being used successfully for irrigation and indeed have been used extensively in the past. With improved drainage the soils would be suited to irrigation; those areas with normal salinity are placed in Class 2 whereas the very high watertable and extremely saline phases are downgraded to Class 3. Low-lying Khuways soils around Tubli Estuary are further downgraded to Class 4F on account of sea water intrusion hazard. The soils are acceptable for basin irrigation.

Associated Soils: Khuways soils are clearly distinguishable from most other soils by the absence of a prominent superficial gypsic horizon. Lawzi series is similar but has a clayey particle size; Zaytun has a gravelly subsoil and paralithic contact; Buquwwah closely resembles Khuways but has a hard petrocalcic horizon with in the upper 1.0m.

(c) Clayey, carbonatic, hyperthermic family.

- Lawzi Series - Lw.

Representative Description: Profile 12 (PV035)

Location and Physiography: This minor series is mapped on the lower fans below the limestone pavement to east and west of Ali. The parent material comprises loamy marine alluvium mixed with fine silty outwash fan material. The lower fans are level with even microrelief.

Land use and Vegetation: None of the Lawzi soils are currently cultivated although the aerial photographs show that they have been irrigated at some time in the past. They currently carry a sparse low ground shrub cover of Zygophyllum, Atriplex and Suaeda with some Aeluropus, Halocnemum, Anabasis and Limonium species.

Profile Characteristics: Lawzi soils are deep, well drained and show slight development of vertical cracking. The cracks extend down to a depth of 1.0m but are insufficiently wide or frequent to meet the requirements of Vertisols. Sink holes and a silty crust are typical features of the soil surface. Textures are usually silty clay in the control section. Profiles have moderately well developed subangular blocky structure in the surface, tending to coarse prismatic in the subsoil. Consistence is firm to very firm and the soil has a low porosity except for the vertical cracking. Below about 75-100cm calcite cemented nodules are common; these often form a dense indurated layer resembling a petrocalcic horizon. Roots seldom penetrate into this layer. The substratum is usually silicious fine sand.

Chemical Characteristics: Lawzi soils have high contents of $CaCO_3$ throughout the profile, whereas gypsum is significant only in the surface. The high silt and clay contents are reflected in high values of CEC (up to 22 me/100 g). The soils are moderately saline throughout.

Land Capability: The soils have only moderately limiting salinity and gypsum values but are downgraded to Class 3 because their clayey textures can be expected to reduce the ease of leaching, infiltration and drainage under irrigation. The cemented deep subsoil is a further constraint on internal drainage.

Associated Soils: The clayey particle size and vertical cracking distinguish these soils from all other series.

Profile: 12 Lawzi Series — Site No: PV035

Clayey, carbonatic, hyperthermic family of Cambic Gypsiorthids.

Date: 31.12.78

Location: About 2.0km north east of Nakhl Lawzi, near village of Ali. GR.506930.

Geomorphic Unit: Lower alluvial fan at foot of limestone backslope.

Parent Material: Fine silty textured alluvium.

Topography: Level plain rising slightly to south towards limestone pavement.

Micro-relief: Even; compact dry surface with thin silt capping, frequent low vegetation hummocks covered with silty powder mulch. Occasional sink holes and collapse features as centres of hollows (incipient gilgai).

Vegetation: Not cultivated. Moderate cover of natural vegetation, species of Zygophyllum, Atriplex and Suaeda common, with occasional Prosopis chiliensis. Species of Aeluropus and Halocnemnum on hummocks.

Drainage: Moderately well drained.

Remarks: A very silty, calcareous profile. Cracks and sink holes indicative of weak Vertisol conditions.

Horizon	Depth(cm)	Profile Description
$A1_{cs}$	0-25	Yellowish brown (10YR 5/4) silty loam; weak medium subangular blocky; firm moist; few fine tubular pores; common fine white mycelia of gypsum;strongly calcareous; few fine roots;gradual smooth boundary.
$C1_{ca}$	25-75	Greyish brown (2.5Y 5/2) silty clay; weak very coarse prismatic to moderate medium angular blocky; very firm moist; many gastropod shells; strongly calcareous; many fine tubular pores, few cracks 5mm wide to 1.0m; few fine roots; clear smooth boundary.
$C2_{ca}$	75-240	Light brownish grey (2.5Y 6/2) with few fine prominent strong brown mottles; silty clay; moderate medium angular blocky; moist very firm; few fine tubular pores; 15 to 20% (estimate) irregular knobbly $CaCO_3$ nodules 20-60mm; strongly calcareous; rare fine roots.
IIC_3	240-370 (in auger)	Light brownish grey (2.5Y 6/2) fine sand; becoming wet below 2.60cm.

Profile Description No: 12 **Site No:** PV035

Series: Lawzi-Lw **Location:** 506930

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-25	8.0	27.9	7.3	11.0	12	32.6	26.4
b	25-75	6.3	24.0	7.4	22.2	18	50.0	1.3
c	75-130	6.5	25.5	7.4	17.5	20	47.5	0.8

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	3	4	5	10	10	58	10	59
b	0	2	3	3	4	8	45	35	63
c	15	3	2	2	2	8	59	24	66

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	1	3	4	11	7	62	12	55.0	0.15	0.04
b	1	2	2	4	2	60	29	-	-	-
c	1	2	3	5	5	62	22	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.49	36.3	7.9	7.8	2.4	3.2	7.5	44.0	1.12

B.2.5 Typic Paleorthids.

(a) Sandy, mixed, hyperthermic family
- Areen Series - An

Representative Description: Profile 13 (PV060)

Location and Physiography. Areen soils are mapped on the sand sheets of the Hawrat 'Inqa area, east of Zallaq. The land ranges in elevation from 2.0 to 4.0m above sea level. The terrain is level but microrelief is often slightly uneven due to minor duneforms and hummocks around vegetation. In the west a watertable is present at about 2.0m but it becomes deeper eastwards. Scouring by wind erosion occurs locally.

Land use and Vegetation: There is no evidence of these soils having been cultivated ; they carry a moderately rich flora of ground cover species, such as Zygophyllum, Helianthmum, Eragrostis, Cyperus, Heliotropium and Aeluropus.

Profile Characteristics : Areen soils are moderately deep and well to somewhat excessively drained. The upper horizon comprises a layer of gypsic fine sand, single grained, uncemented and with soft consistence. The underlying horizon has similar structure but is usually non-gypsic and contains minor quantities of irregular shaped calcite cemented nodules. The proportion of nodules increases with depth; between 75 and 100cm they are cemented into continuous petrocalcic layers but interspersed by layers of non-cemented silicious sand. Below the series control section (in this case the base of the petrocalcic horizon, at 100 to 130cm) the profile grades into non-cemented loose, silicious fine sand. In some profiles the top of the petrocalcic horizon lies within 50cm of the surface, severely restricting rooting depth; these profiles are differentiated as the shallow petrocalcic phase (An-m).

Chemical Characteristics: The soils have high gypsum contents at the surface but little below 25cm. Salinities are low and $CaCO_3$ values are moderate (10-20per cent) throughout the profile, rising in the petrocalcic horizon.

Land Capability: The shallow petrocalcic phase is placed in Class 6, principally on the basis of shallow effective depth, indurated subsoil and high gypsum contents. The normal profiles are mapped in Class 3, limited by superficial gypsum contents and effective depth over petrocalcic horizon. Further limitations are the low moisture capacity and poor fertility potential associated with sandy particle-size. Locally a microrelief limitation is applied. Over

Profile: 13 Areen Series Site No: FVC80

Sandy, mixed, hyperthermic family of Typic Paleorthids.

Date: 6.3.79

Location: 1.0km west of Zallaq; 496809.
Geomorphic Unit: Level sandy plain slightly above coastal plain.
Parent Material: Aeolian silicious sand with shallow overlay of gypsic loam and sand.
Topography: Level but with slight slope down to south west.
Micro-relief: Even; few low vegetation hummocks less than 250mm high. Dry, firm sandy surface with gypsic crust locally and fine fragments of honeycomb gypsum.
Vegetation: Never cultivated; moderately dense cover of Zygophyllum qatarensis, Eragrostis and Cyperus spp; occasional Aeluropus lagopoides.
Drainage: Moderately well drained in upper profile, wet below 1.8m.
Remarks: Massive petrocalcic layer in subsoil; watertable at 2.0m, approximately 3.0m above sea level.

Horizon	Depth(cm)	Profile Description
A1cs	0-15	Light yellowish brown (10YR 6/4) gypsiferous fine sand; single grained; dry soft; many interstitial pores, between gypsum crystals; calcareous; common fine roots; abrupt smooth boundary.
C1	15-45	Brown (10YR 5/3) loamy fine sand; weak medium subangular blocky; friable moist; many fine interstitial and tubular pores; occasional $CaCO_3$ cemented sand concretion, visible gypsum crystals; calcareous; few fine roots; clear smooth boundary.
C2ca	45-80	Light brownish grey (2.5Y 6/2) with few strong brown stains; very gravelly fine sand; single grained to massive locally; very firm moist; 60% (estimated) $CaCO_3$ cemented sand concretions (10-30mm); many interstitial pores; strongly calcareous; few fine roots; gradual smooth boundary.
C3cam	80-100	Massive, continuous, petrocalcic horizon of carbonate cemented sand; fine sand as C2 horizon in pockets; strongly calcareous no roots; abrupt smooth boundary.
C4g	100-240	Pale olive (5Y 6/3) fine sand; single grained; very friable moist becoming non-plastic, non-sticky wet below 180cm; porous; weakly calcareous; no roots.

Profile Description No: 15 **Site No:** PV060

Series: Areen-An **Location:** 496809

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-15	2.6	6.9	7.9	5.3	1	7.1	62.0
b	15-45	3.5	15.9	7.7	14.0	2	18.0	6.2
c	45-80	0.6	2.2	7.9	10.0	3	16.6	1.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	7	10	18	31	9	12	13	29
b	0	1	4	30	41	4	10	10	35
c	55	0	40	1	53	1	1	4	26

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	19	23	16	14	6	10	12	11.0	0.68	0.02
b	4	11	18	24	6	25	12	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.09	33.8	8.7	16.4	0.8	1.8	19.0	39.5	6.58
b	-	43.1	32.0	145.6	5.9	2.7	149.0	78.0	3.52

much of the lowlying western part of the Areen soils the land is downgraded on a sea water intrusion hazard.

Associated Soils: Areen soils resemble Hisham series but have a prominent gypsic surface and hard continuous petrocalcic horizon within 1.0m. Where superficial gypsum levels are low, often due to wind erosion, and the petrocalcic horizon is deeper than 1.0m the Areen soils are mapped as a complex with Hisham (An-Hs). A few rocky outcrops occur within the areas mapped as Areen.

(b) Fine-loamy, mixed, hyperthermic family .

- Salmabad Series - Sm.

Representative Description: Profile 14 (PV011)

Location and physiography. Small areas of Salmabad series are mapped in the southeast of the Salmabad area. They are formed in gypsic loamy alluvium overlying calcite cemented material, usually silicious fine sand. Topographically the soils have level, even relief. The watertable is usually below a depth of 2.0m.

Land use and Vegetation: Some of the Salmabad soils show evidence of former cultivation but apart from some minor areas around Ali, they are currently unutilised. The typical natural vegetation is very sparse; Suaeda, Salsola and Zygophyllum species predominate, with some remnant date palms.

Profile Characteristics: Salmabad soils are limited in depth by a petrocalcic horizon, which occurs usually at between 75 and 100cm depth, but sometimes at shallower depth. The upper horizon, of 20-30cm thickness, is coarse loamy, very gypsic and usually weakly to moderately cemented. This abruptly overlies a loamy to sandy clay loam textured horizon with moderately well developed angular blocky structure and friable consistence. This horizon in turn abruptly overlies an extremely hard petrocalcic horizon, comprising either dense calcite-cemented sand or vesicular, calcite - cemented silt loams ("jashab").
In each case the horizon forms a deep and inpenetrable barrier for roots. Loose silicious sand occurs beneath the petrocalcic horizon, usually becoming saturated below 2.0-2.5m.

Chemical Characteristics: The soils are saline, with highest values in the upper horizons; gypsum is similarly concentrated in the surface, probably originating mainly from aeolian deposition; $CaCO_3$ contents are moderately high throughout the profile, especially in the petrocalcic layer.

Profile: 14 Salmabad Series Site No: PV011

Fine loamy, mixed, hyperthermic family of Typic Paleorthids.

Date: 22.10.78

Location: 0.5km south west of Salmabad town, GR.522954.

Geomorphic Unit: Salmabad gypsic plain.

Parent Material: Shallow aeolian gypsum layer over loamy alluvium silicious aeolian fine sand.

Topography: Level.

Micro-relief: Even micro-relief,occasional low vegetation hummock; dry loose sandy surface containing gypsum and salts.

Vegetation: Not cultivated; occasional Phoenix dactylifera, sparse Zygophyllum, Suaeda and Salsola spp.

Drainage: Well drained.

Remarks: Very hard carbonate cemented sand layer at 70cm depth.

Horizon	Depth(cm)	Profile Description
$A1_{cssa}$	0-15	Brown (10YR 5/3) sandy loam; weak medium angular blocky to platy; slightly hard dry; discontinuous layers of cemented honeycomb gypsum; porous; strongly calcareous; few fine roots; clear smooth boundary.
$C1_{cssa}$	15-35	Light yellowish brown (10YR 6/4) sandy loam; weak fine subangular blocky; friable moist; many fine tubular pores; calcareous; common fine gypsum crystals; few fine roots; gradual smooth boundary.
C2	35-70	Light yellowish brown (10YR 6/4) sandy clay loam; weak medium subangular blocky; firm moist; many fine tubular pores; few irregular sub-rounded knobbly calcareous gravels; strongly calcareous; few medium fine roots; gradual wavy boundary.
$IIC3_{cam}$	70-125	Light grey (10YR 7/2) gravelly fine sand; massive; extremely hard dry; strongly cemented sand, breaking to subrounded knobbly fragments; porous; strongly calcareous; few medium and coarse roots; abrupt smooth boundary.
IIC4	125-185	Light yellowish brown (2.5Y 6/4) fine sand; single grained structureless; friable moist; very porous; few weakly cemented fragments; calcareous; few medium palm roots.

Profile Description No: 14 **Site No:** PV011

Series: Salmabad - Sm **Location:** 522954

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-15	11.3	50.1	7.5	2.7	2	12.0	32.5
b	15-35	7.9	38.1	7.6	5.3	1	16.5	12.9
c	35-70	7.0	30.2	7.6	13.4	10	22.7	0.8
d	70-125	0.8	7.1	7.5	-	-	20.5	-

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	6	16	16	15	8	18	11	31
b	0	3	17	22	17	6	24	11	38
c	10	2	16	18	15	6	22	21	49
d	40	-	-	-	-	-	-	-	21

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	1.8	13.8	14.7	16.8	12.3	15.2	25.5	103.8	2.40	0.036
b	0.4	12.3	18.8	22.6	7.2	26.1	12.6	-	-	-
c	0.6	15.2	17.3	18.9	7.8	17.9	22.3	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.65	137.0	393.0	936.8	80.1	2.5	1456.5	87.9	9.1
b	-	81.0	139.0	420.6	31.5	3.0	594.9	74.2	4.6
c	-	68.0	87.5	380.8	32.5	2.5	522.9	43.3	2.6
C:N ratio 18.1									

Land Capabilety: The petrocalcic horizon poses a severe limitation on cultivation in terms of rooting depth and drainage. Similarly, the soils are limited in value by high gypsum contents and salinity. Consquently they are downgraded to Class 5.

Associated Soils : The series is distingnished from Isa soils, which they resemble, by fine-loamy particle size and a greater depth to the petrocalcic horizon. Buquwwah series is also similar but lacks the prominent superficial gypsic horizon of Salmabad series.

(c) Fine-loamy, carbonatic, hyperthermic family
- Buquwwah Series - Bw.

Representative Description: Profile 15 (PV055)
Location and Physiography : The series occurs in the extreme northeast of the Salmabad area where fine loamy marine alluvium overlies cemented sand. The land is level but microrelief is often uneven due to abandoned irrigation channels. Depth to watertable is usually more than 2.0m.

Land use and Vegetation: Some areas of Buquwwah soils are under irrigation but most have been abandoned. The soils carry a moderately dense natural cover of Suaeda pruinosa and Cressa cretica , with Phragmites , Alhagi and Lagonychium species as sub-dominants.

Profile Characteristics: Buquwwah soils are moderately well drained, moderately deep; depth is limited by an indurated petrocalcic horizon within the 50-100cm depth range. The upper profile has moderately well developed angular blocky structure, sandy clay loam to loam textures and brown colours. Gypsum is visible as fine cryetals in the 0-30cm horizon; gastropod shells and ground pearls are common throughout the upper profile. These fine loamy horizons abruptly overlie a continuous layer of knobbly calcite - cemented nodules. This petrocalcic horizon is porous but prevents penetration of most roots. Below the cemented layer, at 1.2-1.4m, there occurs loose, single grained fine sand.

Chemical Characteristics: The soils are usually very saline in the surface. The whole profile is rich in $CaCO_3$ whereas gypsum is concentrated at the surface. CEC values are moderately high, reflecting the above average clay and silt fractions.

Land Capability: Buquwwah soils are downgraded to Class 3, principally on the basis of poor internal drainage and limited effective depth. Additional minor deficiencies are salinity, gypsum and, in

Profile: 15 Buquwwah Series Site No: PV055

Fine loamy, carbonatic, hyperthermic family of Typic Paleorthids.

Date: 18.2.79

Location: 0.5km south east of Buquwwah village. GR.528981.
Geomorphic Unit: Marine loam plain.
Parent Material: Loamy marine alluvium over calcareous aeolian sand.
Topography: Level; general slope down to south.
Micro-relief: Even; locally former irrigation channels, less than 0.5m deep. Friable mulch surface, few shells.
Vegetation: Abandoned date plantation: moderately dense cover of Suaeda pruinosa and Cressa cretica, occasional Lagonychium farctum bushes.
Drainage: Moderately well drained.
Remarks: Strongly cemented petrocalcic horizon at 85cm depth. Watertable at 290cm.

Horizon	Depth(cm)	Profile Description
A_1 cssa	0-20	Brown (10YR 5/3) fine sandy loam; moderate coarse angular blocky structure; friable moist; few medium and coarse tubular pores; abundant finely divided gypsum; strongly calcareous; no roots; clear smooth boundary.
C_1 cssa	20-45	Pale brown (10YR 6/3) fine sandy loam; moderate medium angular blocky; firm moist; slight layering due to former land levelling; many white flecks of gypsum; many medium and coarse tubular pores; rare fine roots; strongly calcareous; clear smooth boundary.
C2ca	45-85	Greyish brown (2.5Y 5/2) clay loam; moderate medium angular blocky; friable moist; few gastropod shells and ground pearls; many coarse and medium pores; few white gypsum mycelia to root channels; occasional fine (20mm) knobbly $CaCO_3$ nodules; strongly calcareous; few medium roots; abrupt smooth boundary.
C3cam	85-110	Light grey (10YR 7/2) very gravelly fine sandy loam; weak fine angular blocky to massive; extremely firm moist; indurated CaCO3 cemented horizon; many (40%) cemented carbonate nodules; very porous; strongly calcareous; no roots; clear smooth boundary.
C4cam	110-130	Light grey to light greyish brown (10YR 7/2 - 2.5Y 6/2) gravelly sandy loam; massive; very firm moist; many (30%) $CaCO_3$ nodules; strongly calcareous; no roots.
IIC 5	130-300 (in auger)	Light greyish brown (2.5Y 6/2) fine sand; single grained; very friable moist; calcareous; no roots; wet below 280cm.

Profile Description No: 15 **Site No:** PV055

Series: Buquwwah-Bw **Location:** 528981

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-25	21.6	83.2	7.1	3.3	8	29.0	14.1
b	25-45	8.9	44.1	7.4	6.8	2	32.1	20.8
c	45-85	4.5	28.9	7.5	12.3	5	42.3	0.6
d	85-110	2.8	22.2	7.6	11.3	1	58.9	1.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	2	14	11	16	9	38	10	28
b	0	4	13	12	17	9	37	8	45
c	2	4	18	10	15	5	28	20	40
d	40	9	21	11	12	4	23	20	29

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

some cases, microrelief. The soils are acceptable for basin irrigation.

Associated Soils: Buquwwah and Khuways series are very similar in their upper profile but the former has a petrocalcic horizon. Buquwwah soils differ from Salmabad series by lacking the prominent superficial gypsic horizon.

B.2.6Aquic Paleorthids

(a) Coarse-loamy, carbonatic, hyperthermic family.

- Isa Series - Is.

Representative Description : Profile 16 (PV048)

Location and Physiography: Isa soils occur mainly in the southeast of the Salmabad area but also locally in the Buhayr depression and at the foot of the Hamalah scarp. They have formed in highly calcareous loamy alluvium into which there has been seepage of carbonate - rich water, resulting in subsoil cementation. The soils mostly occur on level terrain with even relief. Although the watertable usually lies at more than 1.5m, the soils are normally saturated with water at some level within the upper 1.0m.

Land Use and Vegetation: Isa soils are not presently cultivated although ancient cultivation patterns are just discernible on the aerial photographs. The natural vegetation is often rich in species, including Halocnemum sp.,Halopeplis perfoliata, Limonium axillare, Eragrostis plumosa, Juncus acutus, Crotalaria sp and Suaeda pruinosa.

Profile Characteristics: Isa profiles are varied but all have an extremely hard petrocalcic horizon within the upper 75cm. The soils are usually moderately well to imperfectly drained. The surface horizon comprises weakly cemented gypsic sand or loamy sand. This abruptly overlies a moderately well structured sandy loam horizon which contains fragments of calcite cemented nodules. This in turn overlies a petrocalcic horizon which comprises either a dense layer of calcite - cemented silt loams. The substratum is normally calcareous silt loam alluvium but the series control section may be directly underlain by silicious sand.

Profile: 16 Isa Series — Site No: PV048

Coarse loamy, carbonatic, hyperthermic family of Aquic Paleorthids.

Date: 30.1.79

Location: 1.5km west of Isa Town. GR.527953.

Geomorphic Unit: Salmabad gypsic plain.

Parent Material: Gypsum sand over $CaCO_3$-rich loams over silicious aeolian sand.

Topography: Fringe of slight depression.

Micro-relief: Even; few low vegetation hummocks of gypsic sand.

Vegetation: Non-cultivated. Moderately dense cover of Halocnemum sp. with occasional Halopeplis perfoliata Limonium axillare and Suaeda pruinosa.

Drainage: Moderately well drained.

Remarks: Extremely hard petrocalcic horizon at 70cm; watertable at 200cm.

Horizon	Depth(cm)	Profile Description
Alcs	0-40	Pale brown (10YR 6/3) loamy gypsic sand; single grained; friable moist; abundant gypsum crystals; very porous; few fine roots; non-calcareous; abrupt smooth boundary.
C1	40-70	Brown (10YR 5/3) sandy loam; weak medium angular blocky; firm moist; weakly cemented layers; few (10%) $CaCO_3$ gravels; many tubular pores; no roots; abrupt smooth boundary.
C2cam	70-90	Extremely hard, dry petrocalcic horizon of porous 'jashab' material; massive; strongly calcareous; no roots; clear smooth boundary.
C3	90-220	Pale olive (5Y 6/3) calcareous loam; structureless; slightly sticky, slightly plastic wet; calcareous; no roots.
IIC4	220-230 (Auger)	Greenish grey (5BG 5/1); fine sand; single grained; wet, non-plastic; non-sticky.

Profile Description No: 16 **Site No:** PV048

Series: Isa-Is **Location:** 527953

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-40	10.1	43.8	7.4	3.0	1	3.3	71.3
b	40-70	16.5	54.2	7.3	25.1	13	46.8	2.5
c	70-90	Petrocalcic horizon		-	-	-	-	-
d	90-200	17.7	52.2	7.2	23.9	4	35.1	4.3

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	11	25	22	14	8	14	6	41
b	10	10	12	10	9	11	37	11	81
c	Petrocalcic horizon			-	-	-	-	-	-
d	0	4	6	7	10	8	51	14	94

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

Chemical Characteristics : The soils are saline througout the profile. An extremely saline phase of Isa series (Is-s) is mapped in the Buhayr area. Gypsum, largely of aeolian origin, is concentrated at the surface where it can exceed 70 percent. $CaCO_3$ levels are high within the mineralogical control section, exceeding the 40 percent required for a carbonatic mineralogy. CEC values are moderately high.

Land Capability: Isa soils are severely limited in agricultural potentialy by their effective depth over petrocalcic horizon, their highly gypsic surface and their salinity. In addition, they haveinternal drainage deficiencies which would be extremely difficult to rectify by artificial means due to the presence of the petrocalcic horizon. The soils are therefore placed in Class 6.

Associated Soils: Isa and Salmabad soils are similar but the latter has a fine loamy particle size, usually more than 75cm effective depth and no evidence of saturation within the upper 1.0m. Isa series lies adjacent to Maqabah soils which have much greater depth of superficial gypsum and lack the petrocalcic horizon.

B.2.7 Typic Torripsamments.

Mixed, hyperthermic family.

Hisham Series - Hs.

Representative Description: Profile 17 (PV016)
Location and physiography: Hisham soils occur fairly extensively in the west of the Salmabad area and in the Hawrat 'Inqa area. The parent material consists of deep recent deposits of aeolian silicious sand. Although the terrain is usually level with even microrelief, some areas particularly south of Sar, have more uneven relief due to minor duneforms. Watertables rarely occur at less than 2.0m from the surface.

Land Use and Vegetation: Relatively large areas of Hisham soils in the Salmabad area are successfully used for irrigation of vegetable and fodder crops. Elsewhere they are uncultivated but the moderately dense cover of natural xerophilous vegetation provides browse for livestock. Typical species include Heliotropium tuberculosum, Salsola sp., Panicum turgidum , Pennisetum divisum and Cyperus sp. Prosopis chiliensis and Lagonychium farctum are also common in the Salmabad area.

Profile: 17 Hisham Series — Site No: PV016

Mixed, hyperthermic family of Typic Torripsamments.

Date: 7.11.78

Location: 100m from Sar road near Hisham Park; GR.484990.
Geomorphic Unit: Aeolian sand sheet.
Parent Material: Aeolian sands containing some shells.
Topography: Almost flat, slopes down to east 1.0-1.5%.
Micro-relief: Slightly uneven, rounded hummocks 0.5-1.0m high spaced 20-25m.
Vegetation: Not cultivated but possibly former habitation; scattered mature Prosopia chiliensis; small clumps of Zygophyllum, Cyperus,,Sporobolus and Heliotropium spp.
Drainage: Excessively drained.
Remarks: Sands contain carbonate-rich layers and gypsum nodules.

Horizon	Depth(cm)	Profile Description
A_1	0-50	Pale brown (10YR 6/3) to yellowish brown (10YR 5/4); loamy medium sand; weak fine angular blocky; soft dry; rare nodule of gypsum; very porous; strongly calcareous; many fine roots; abrupt wavy boundary.
C_1	50-65	Very pale brown (10YR 7/4) loamy medium sand; structureless, single grained; soft dry; porous; common soft patches of white carbonate accumulation; strongly calcareous; common fine and medium roots; abrupt wavy boundary.
C_2	65-150	Light yellowish brown (10YR 6/4) fine sand; structureless, single grained; slightly moist very friable; porous; localised weak carbonate cementing near base of horizon; rare calcareous nodules (20-25mm); shells; strongly calcareous; few fine roots; abrupt smooth boundary.
C_3ca	150-180	Pale yellow (2.5Y 7/4) clay loam; weak coarse angular blocky; firm moist; many fine pores; 10% (estimated) subrounded carbonate concretions; strongly calcareous.

Profile Description No: 17 **Site No:** PV016

Series: Hisham - Hs **Location:** 484990

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-50	3.6	30.6	7.8	1.5	3	20.6	7.4
b	50-65	3.4	25.2	7.9	1.6	3	22.6	11.8
c	65-150	3.1	18.3	7.9	1.5	1	21.2	7.9
d	150-180	4.9	24.5	7.6	14.1	8	59.3	4.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	1	14	35	26	9	4	11	29
b	0	1	11	34	28	10	5	11	28
c	5	1	21	36	23	5	5	9	26
d	5	2	8	14	14	11	36	15	51

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	0	21.9	37.3	19.9	2.4	1.3	17.0	23.30	2.20	0.008
b	0.4	26.1	34.4	22.7	1.9	3.6	10.9	-	-	-
c	0	11.8	18.6	20.7	7.4	3.0	38.5	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.16	36.3	18.8	152.9	8.0	2.3	142.9	70.6	9.6
b	-	35.0	12.5	75.5	3.4	2.0	72.9	51.5	4.1
c	-	65.0	46.5	248.1	5.9	2.0	295.5	67.9	1.7
C:N ratio 20.0									

dc

Profile Characteristics: Hisham soils are very uniform, typically deep, somewhat excessively drained and sandy or loamy sand textured. Apart from some weak, fine subangular blocky structure in the surface, the profiles are single-grained and dry with soft consistence and high interstitial porosity. Horizon differences are related more to depositional history than pedogenesis. Thin bands of discrete calcite-cemented knobbly concretions are common in the series control section but they rarely exceed 5.0 per cent of the horizon. Some calcite-cementing of these concretionary layers occurs at depths below 1.0 metres, representing the buried remnants of a petrocalcic horizon. A lithic contact often occurs at the 1.5 to 2.0 metre depth in soils along the Hamalah scarp.

Chemical Characteristics: The soils usually have low salinity (less than 15 mmhos cm^{-1}) and average $CaCO_3$ contents of about 20 per cent. Gypsum contents are varied, depending upon the contents of the original aeolian material. Mean values for the 0.- 0.5 and 0.5 - 1.0 m depths are 4.3 and 5.3 percent, respectively; values only rarely exceed 10 per cent. Some Hisham profiles do have sufficient gypsum to meet the requirements of a gypsic horizon and could be considered as Cambic Gypsiorthids. However, the gypsum is not pedogenic but simply comprises a minor constituent of the original windblown parent material, occurring in thin discontinuous bands, showing no sign of redistribution or recrystalisation. From the taxonomic point of view, the gypsum is not 'secondary' and the Hisham soils are therefore retained in the Torripsamment subgroup, a classification which conforms more closely with their situation on aeolian sand sheets and dunes. Profile PV016 is an example of a site with above average gypsum contents, examples of less gypsic Hisham soils are given in Appendix B.3.

Land Capability: Hisham soils are moderately suited to irrigation, given trickle or sprinkler systems, using saline water; their deep, sandy profiles allow rapid infiltration and free drainage, thus facilitating leaching. However, the sandy particle-size class also results in low available moisture capacity and poor fertility potential. The soils have been proved to be suitable for vegetable and fodder cropping as well as fruit. In most cases they are downgraded to Class 2 on the basis of moisture capacity, fertility potential and also salinity. Microrelief results in further downgrading in the area south of Sar, and internal drainage deficiencies apply locally. In the lowlying Hawrat 'Inqa area there is a risk of seawater intrusion, resulting in further downgrading Hisham soils to Class 3 and 4F.

Associated soils: The series is readily distinguished from most other soils by the sandy particle size and lack of a prominent superficial gypsic horizon. Areen series, which closely resembles Hisham, can usually be differentiated by the presence of a petrocalcic horizon and cementing by gypsum in the upper horizons;

however, in the Hawrat 'Inqa area the distinction is often difficult and the soils were mapped as a complex (Hs-An). Hisham resembles Buri series, especially the sandy topsoil phase, from which it can be distinguished by the absence of cemented gypsum horizons in the upper 1.0m. The sandy Wasmiyah series has a high watertable.

B.2.8 Typic Psammaquents

Mixed , hyperthermic family
- Wasmiyah series - Ws.

Representative Description: Profile 18 (PV 004).
Location and Physiography: These soils occupy the coastal sand plain in the west of the Hawrat 'Inqa area. These plains have level, even relief and lie at an elevation of 1.5 metres above sea level. A saline watertable (EC 50.0 mmhos/cm) occurs at within 80 to 100 centimetres of the surface.

Land Use and Vegetation : The soils are not cultivated within the area studied but attempts are being made to grow irrigated annual crops on similar land immediately to the south of the Hawrat 'Inqa area. Negligible vegetation occurs naturally except occasional clumps of Zygophyllum sp. Refuse dumping is the only current form of land use.

Profile Characteristics : Wasmiyah soils have very uniform, deep, poorly drained sandy profiles. The soil surface has a coherent, brittle and puffy sulphate salt crust some 2-3cm thick. This crust usually directly overlies the upper sandy horizon but in some cases there is an intervening layer of cemented crystalline gypsum. As this gypsum layer is rarely thicker than 15cm the soils do not meet the minimium requirements of the Gypsiorthid great group : they are differentiated at phase level as Wasmiyah superficial gypsic phase (Ws-g). In the main soil profile structure is very weak to single grained and consistence is very friable moist, to wet non-plastic, non-sticky in the watertable zone. Weak calcite cementing was observed immediately above the watertable but it is insufficient to impede roots or drainage.

Chemical Characteristics : Despite the saline appearance of the soils - a puffy crust, no vegetation and extremely saline ground - water - most of the soils have only moderate salinities. In some profiles, however, the ECe values exceed 64 mmhos cm^{-1} and these areas are separated as the extremely saline phase (Ws-s) ; indeed

Profile: 18 Wasmiyah Series Site No: PV004

Mixed, hyperthermic family of Typic Psammaquents.

Date: 10.10.78

Location:	Hawrat 'Inqa area, 1.0km north east of Wasmiyah village, GR.493802.
Geomorphic Unit:	Coastal sand plain.
Parent Material:	Aeolian and marine sands.
Topography:	Level.
Micro-relief:	Even, dry puffy salt crust.
Vegetation:	Non-cultivated, bare of vegetation.
Drainage:	Poorly drained.
Remarks:	Watertable at 105cm.

Horizon	Depth(cm)	Profile Description
A_1sa	0-15	Brown (7.5YR 5/4) sandy loam; moderate medium blocky; friable moist; patches of salt crystals; strongly calcareous; no roots; abrupt smooth boundary.
C1	15-80	Pale brown (10YR 6/3) fine sand; very weak medium blocky to single grained; very friable moist; strongly calcareous; no roots; base of horizon weakly cemented by calcite; clear smooth boundary.
C_2g	80-350 (120-350 in auger)	Pale brown (10YR 6/3) fine sand; structureless; non-sticky, non-plastic wet; strongly calcareous; no roots.

Profile Description No: 18 **Site No:** PV004

Series: Wasmiyah - Ws **Location:** 493802

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-15	20.1	56.8	7.5	-	-	15.5	2.8
b	15-80	2.0	16.2	8.0	-	-	16.8	1.1
c	80-120	2.7	19.6	8.0	-	-	16.4	1.1

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	1	3	27	37	3	20	9	35
b	0	0	2	15	78	4	1	0	24
c	0	0	2	19	75	3	1	0	24

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	0	1.8	14.4	45.2	3.0	23.3	12.2	18.8	0.40	0.014
b	0	1.4	10.2	41.5	2.8	21.4	11.2	-	-	-
c	0	1.1	7.2	71.7	10.8	3.2	6.0	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.63	120.0	470.0	2235.1	72.5	2.[illegible]	2801.7	93.3	0.6
b	-	13.7	23.8	112.9	4.7	3.[illegible]	134.3	17.7	1.9
c	-	33.0	63.5	314.9	12.1	5.	381.4	37.1	10.8
C:N Ratio 45.0									

some of these soils meet the requirements of the Salorthid great group but overall the salinities are much lower (mean approximately 40 mmhos cm^{-1}). Gypsum contents are very low throughout the profiles except in the surface of the gypsic phase. Carbonates typically average about 20 per cent in all horizons.

Land Capability: Salinity and internal drainage are the major soil deficiencies, with the minor limitations in moisture capacity and fertility potential associated with sandy particle-size. These result in downgrading Wasmiyah soils to Class 2. The gypsic and extremely saline phases meet the soil requirements of Class 3; the gypsic phase would require initial heavy cultivation to fracture the gypsum layer and scraping to remove it. Due to low elevations above sea level (1.5 metres) and proximity to the coast, however, all Wasmiyah soils have a marine intrusion hazard and are mapped in Class 4F.

Associated Soils : Wasmiyah is similar to Areen and Hisham series, which lie adjacent to it but the latter soils are freely drained and, in the case of Areen series, have gypsic and petrocalcic horizons. Some Karzakkan soils resemble Wasmiyah series but have free drainage as well as a thicker and more porous gypsic surface horizon.

B.2.9 Lithic Torriorthents.

Coarse-loamy-skeletal, mixed, hyperthermic family.
- Dilmun Series - Dm.

Representative Description : Profile 19 (PV027)
Location and Physiography : The series is mapped on the limestone pavements around the fringes of the Salmabad and Hawrat 'Inqa areas. They are also associated with minor rock outcrops within the Salmabad area. The parent material comprises gravelly and stony regolith and colluvium of carbonate and aeolianite rocks. The terrain is varied with slopes locally exceeding 4.0 percent along the foot of the Hamalah escarpment; microrelief is similarly varied and usually slightly uneven due to variations in rock hardness or erosion channels. The soils occur at elevations in excess of 5.0m and often up to 15m; the watertable is very deep.

Land use and Vegetation : Dilmun soils are not cultivated. Dilmun

Profile: 19 Dilmun Series Site No: PV027

Coarse loamy skeletal, mixed, hyperthermic family of Lithic Torriorthents.

Date: 7.12.78

Location: Approximately 1.0km east of Hamalah; GR.490932.

Geomorphic Unit: Limestone pavement at foot of main western escarpment.

Parent Material: Shallow colluvium of limestone with gypsum and sand over Alat limestone.

Topography: Almost level with very slight slope up towards minor scarp ridge, east.

Micro-relief: Even; dry hard crusted surface with 20% cover of subrounded limestone gravels (20-30mm).

Vegetation: Non-cultivated. Bare surface, sparse cover of Hammada elegans and Stipagrostis plumosa.

Drainage: Well drained.

Remarks: Very shallow gravelly soil over weathered limestone. Bare limestone pavement occurs locally.

Horizon	Depth(cm)	Profile Description
$A1_{cs}$	0-20	Very pale brown (10YR 7/4) gravelly gypsic coarse sand; structureless single grained; slightly hard dry; interstitial porosity; common subrounded gravels (estimated 25%); non-calcareous; no roots; clear smooth boundary.
C1	20-40	Yellowish brown (10YR 5/4) very gravelly sandy loam; weak medium angular blocky; firm slightly moist; porous; abundant gypsum crystals; 40% (estimated) subangular limestone gravels; calcareous; no roots; clear smooth boundary.
R	40+	Lithic contact with fractured limestone.

Profile Description No: 19 **Site No:** PV027

Series: Dilmun-Dm **Location:** 490932

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–20	2.7	6.3	8.0	2.8	1	4.1	67.9
b	20–40	4.2	19.6	8.2	4.0	5	22.6	8.2

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	25	36	15	15	10	6	7	11	43
b	40	4	12	19	21	14	17	13	37

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

soils form part of the amenity tree planting scheme currently being developed near Isa Town. The shallow depth of these soils, however, has necessitated resort to pneumatic drills for excavating planting holes. The soils carry a sparse vegetation of xerophilous species including Hammala elegans, Salsola vermiculata and Sporobolus sp, with minor inclusions of Lycium , Anabasis, Zygophyllum and Limonium spp

Profile Characteristics : Profiles are very shallow over a paralithic or lithic contact, well drained and with gravelly or stony sandy loam textures. Rock outcrops are common. The profile is very porous, comprising sub-angular rock fragments in a loose matrix of sandy loamy, often very gypsic. Typically, coarse fragments in the soil have pendants of gypsum on their undersides. Fractured rock is encountered within the upper 50cm.

Chemical Characteristics. From the few samples analysed the series is shown to be moderately saline; gypsum contents are very varied but often very high is the soil surface. Indeed this indicates the need for a "Lithic" Gypsiorthid sub-group. Carbonate contents are similarly varied ; they usually exceed 10 per cent and the soils react with dilute HCl.

Land Capability. Dilmun soils are severely limited in agricutural value by their shallow depth and skeletal particle-size ; in addition rock outcrops are common and relief is often a further limiting factor. They are mapped as Class 6.

Associated Soils : Dilmun series represents a shallower and more gravelly version of Zaytun series, which usually occurs downslope of Dilmun soils.

B.2.10 Miscellaneous Land types

Miscellaneous land types are defined (USDA, 1951) for areas of land that have little or no natural soil. Three miscellaneous land types have been mapped during the study :-

(a) Rock land - R.

These include local rock outcrops, usually of Alat limestone or Pleistocene aeolianite, which occur scattered throughout the areas studied. The land is devoid of soil or vegetation and mapped as Class 6.

(b) Channel Complex - CC.

This is mapped in the south and east of the Salmabad area along the courses of flash flood channels which emanate from the limestone backslope. The channels are uneven, subject to water erosion and comprise stony, gravelly, coarse-loamy soils.

These channels have a sparse cover of vegetation, including species of Atriplex, Suaeda and a dwarf Cassia.

(c) Swamps.

These are mapped in the lowest parts of the Tubli Estuary and in minor depressions within the Salmabad area where permanent swamp conditions occur. The wetness is due to a combination seepage of groundwater and, in the case of the Tubli Estuary, restriction of natural drainage by low elevation above sea level. These areas are excluded from the land classification as being non-agricultural.

B.3 Additional Detailed Analyses

In addition to the detailed analysis of profile pits representative of each soil series, samples from a further 24 pits were subjected to detailed analysis. Results for these sites are presented in this section, arranged in the following order:-

Series	Site Number
Buri	PV028
Maqabah	PV006, PV036
Buhayr	PV014
Sar	PV005, PV022, PV033
Abu Saybi	PV030
Khuways	PV008, PV009, PV019, PV045
Lawzi	PV034
Areen	PV001
Salmabad	PV043
Buquwwah	PV012
Isa	PV015, PV023
Hisham	PV021, PV024, PV026, PV062
Wasmiyah	PV061
Dilmun	PV029

Profile Description No: – **Site No:** PV028

Series: Buri-Br **Location:** 493982

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–40	2.1	2.8	8.1	1.3	1	11.1	7.1
b	40–70	4.3	16.7	7.8	3.0	4.4	7.2	61.9
c	70.110	7.8	32.3	7.5	5.4	13.9	39.7	24.7

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	6	44	25	9	10	3	6	28
b	0	19	23	18	4	16	9	11	45
c	0	5	11	11	25	13	35	0	51

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

Profile Description No: -_ Site No: PV006

Series: Maqabah - Mq Location: 500947

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-15	3.9	16.6	7.8	2.5	1	2.3	67.0
b	15-40	5.5	14.9	7.9	10.4	6	1.4	55.5
c	40-100	3.8	9.9	7.8	2.8	3	6.5	48.4
d	100-140	4.3	13.5	7.7	7.4	4	81.8	6.9

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	12	21	23	19	9	7	9	36
b	0	35	22	16	9	4	8	6	59
c	0	39	19	11	6	5	12	8	42
d	0	5	6	7	13	25	39	5	41

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	0	1.7	13.2	46.2	29.5	2.6	6.8	12.6	0.30	0.015
b	0	2.2	7.1	12.1	6.0	19.8	52.7	-	-	-
c	0	1.1	8.6	9.8	4.6	9.2	66.7	-	-	-
d	0	2.2	4.1	12.0	8.2	30.0	43.4	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.15	48.5	24.0	65.7	4.2	2.0	105.2	35.2	1.2
b	-	54.6	42.3	229.0	8.6	5.0	235.1	94.4	2.3
c	-	41.6	20.4	70.3	2.5	3.0	92.1	39.7	1.2
d	-	45.0	36.3	113.3	4.0	2.0	142.0	54.6	3.1
C:N ratio 10.0									

Profile Description No: – **Site No:** PV036

Series: Maqabah – non cemented top soil phase Mq-n **Location:** 494912

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–25	2.5	4.1	7.8	2.8	1	6.2	58.5
b	25–55	3.6	15.4	7.5	5.7	3.7	7.9	59.7
c	55–150	4.0	15.8	7.3	7.1	3.3	14.5	40.6
d	150–190	3.0	7.8	7.5	–	–	22.7	–

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	1	6	19	32	19	12	11	33
b	0	2	5	10	33	20	34	6	31
c	0	2	7	22	23	11	19	16	41
d	30	–	–	–	–	–	–	–	58

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	1	6	26	28	9	18	12	51.8	2.7	0.05
b	1	10	28	15	4	38	4	–	–	–
c	2	15	19	14	4	34	12	–	–	–
d	10	10	8	8	5	42	17	–	–	–

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.39	–	–	–	–	–	–	–	–
b	–	40.6	16.5	98.8	3.3	2.5	109.5	50.3	2.81
c	–	61.9	34.5	121.5	3.4	3.0	191.5	40.8	2.35
d	–	63.8	26.8	98.8	2.7	2.7	145.0	47.5	6.70

Profile Description No: –

Site No: PV014

Series: Buhayr – Bu

Location: 559927

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–15	5.7	37.7	7.4	1.0	6	6.5	57.8
b	15–55	10.6	50.0	7.2	1.3	3	9.4	45.5
c	55–75	10.0	48.9	7.2	nil	1	62.4	30.6
d	75–130	10.6	52.0	7.2	2.3	3	12.5	8.8

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	29	10	7	10	11	18	15	23
b	0	5	7	10	17	16	35	10	40
c	0	6	6	7	23	25	22	11	32
d	0	1	2	5	33	21	24	14	39

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	0	5.4	0.5	0.5	1.0	9.8	82.9	15.36	0.001	0.014
b	0.5	2.0	0.5	0	1.0	20.2	75.8	–	–	–
c	0	1.5	1.0	1.5	1.5	10.0	84.6	–	–	–
d	0	1.2	1.2	5.3	4.7	5.8	81.9	–	–	–

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.15	114.0	58.5	287.5	7.4	2.0	427.0	38.3	5.9
b	–	148.5	124.5	732.5	20.3	1.8	974.9	49.2	0.4
c	–	127.5	85.0	513.3	14.5	2.3	752.3	52.1	11.9
d	–	170.0	148.0	867.7	25.0	2.0	1151.4	57.3	0.9
C:N ratio 10.7									

Profile Description No: –

Site No: PV005

Series: Sar – Sa

Location: 508938

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–25	15.7	47.0	7.7	5.9	4	32.1	38.0
b	25–55	13.5	37.2	7.6	8.8	4	50.7	13.7
c	55–90	11.7	30.4	7.5	12.3	4	55.2	9.2
d	90–150	3.8	30.4	7.6	12.0	3	84.3	1.5

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	2	4	6	18	14	50	6	45
b	0	3	5	6	13	11	57	5	58
c	10	5	7	7	6	4	63	8	71
d	0	5	9	10	11	9	41	15	48

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	0	0.2	0.7	2.2	9.9	30.6	56.3	50.0	1.5	0.054
b	0	1.1	1.9	5.3	10.8	27.7	53.2	–	–	–
c	4.2	0.8	3.9	5.5	3.9	33.5	48.2	–	–	–
d	0	4.9	8.0	4.9	1.9	31.8	48.5	–	–	–

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	1.07	115.0	382.5	1081.2	32.8	1.5	1530.4	79.6	68.2
b	0.84	94.0	142.0	595.4	21.5	2.0	777.2	74.2	27.3
c	1.01	43.0	40.0	218.6	9.4	1.5	278.3	31.3	7.4
d	0.50	62.5	30.8	175.4	8.6	4.0	229.3	44.0	3.7
C:N ratio 19.8									

Profile Description No: –

Site No: PV022

Series: Sar – Sa

Location: Location: 497956

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–45	7.5	36.1	7.8	2.4	1	2.7	77.7
b	45–65	7.4	27.6	7.4	8.6	3	21.1	34.1
c	65–100	6.0	23.9	7.4	18.0	12	62.8	3.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	13	13	15	15	19	25	0	49
b	0	6	7	11	13	8	45	10	76
c	30	8	4	5	6	4	50	23	67

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

Profile Description No: –

Site No: PV033

Series: Sar - Sa

Location: 505949

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–35	14.2	62.6	7.6	4.9	27	16.5	57.0
b	35–60	7.5	33.4	7.5	6.0	13	21.4	50.2
c	60–110	8.4	25.5	7.5	11.2	147	61.0	5.0
d	110–140	2.4	12.1	7.4	11.5	5.6	91.0	1.8

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	8	10	13	17	22	30	0	38
b	0	8	10	12	15	10	35	10	43
c	0	6	5	5	5	8	52	19	76
d	30	7	11	11	12	8	30	21	49

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

Profile Description No: –

Site No: PV030

Series: Abu Saybi - Sb

Location: 503938

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–20	16.7	69.8	7.2	4.6	25.8	8.2	61.6
b	20–105	24.0	102.8	7.5	–	–	54.9	2.6
c	105–150	11.0	43.8	7.4	14.5	21.4	3.6	3.6
d	150–180	12.0	40.6	7.3	22.5	24.8	3.3	3.3

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	4	5	9	18	27	37	0	39
b	0	3	3	4	5	7	45	33	53
c	30	25	11	9	6	6	27	16	56
d	5	6	7	7	8	4	49	19	69

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	2	5	10	23	8	39	13	18.6	1.58	0.08
b	2	3	3	6	5	53	28	–	–	–
c	16	13	9	8	4	35	15	–	–	–

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	1.26								

Profile Description No: – **Site No:** PV008

Series: Khuways – Kh **Location:** 493975

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–20	12.4	68.1	7.2	4.1	2	29.1	14.1
b	20–75	4.8	25.2	7.6	7.0	6	34.3	2.0
c	75–135	3.5	12.3	7.7	14.6	3	64.0	1.7
d	135–200	3.2	12.3	7.9	6.5	4	98.5	1.5

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	2	5	19	27	9	28	10	41
b	0	2	5	22	31	7	19	14	42
c	0	4	6	8	10	4	35	33	59
d	20	20	16	15	13	6	21	9	66

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	0	3.9	17.8	33.5	5.9	28.1	10.8	62.6	0.55	0.042
b	0	5.1	22.7	38.1	6.5	18.0	9.6	–	–	–
c	0	0	2.0	2.0	2.0	82.3	11.8	–	–	–
d	0	3.2	8.1	14.1	3.5	44.4	26.7	–	–	–

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.89	141.0	351.5	1029.1	30.8	2.5	1487.3	62.5	39.1
b	–	68.8	52.2	221.9	7.3	5.0	275.9	69.4	2.5
c	–	46.3	43.8	102.8	3.7	1.5	145.8	50.6	0.6
d	–	42.0	50.0	120.5	3.2	2.5	155.6	57.5	0.6
C:N ratio 21.2									

Profile Description No: – **Site No:** PV009

Series: Khuways-Kh **Location:** 505988

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–40	8.9	36.5	7.4	12.9	2	38.0	4.5
b	40–90	3.2	21.9	7.5	10.6	6	33.7	3.1
c	90–110	1.1	9.9	7.9	5.7	4	19.6	0.9
d	110–180	1.0	9.7	7.7	–	–	20.6	0.8

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	3	7	8	15	9	29	29	43
b	4	7	15	13	24	8	12	21	32
c	2	9	23	19	33	7	0	9	21
d	0	10	26	16	32	10	0	9	22

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	2.4	9.4	8.5	21.1	7.2	17.6	33.8	85.0	2.75	0.062
b	3.8	18.4	12.2	30.5	8.5	19.6	7.0	–	–	–
c	5.6	18.6	15.4	38.6	10.4	10.3	1.0	–	–	–
d	7.6	26.0	12.2	29.1	9.2	15.4	0.5	–	–	–

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	1.0	106.5	105.0	315.2	6.3	5.0	476.0	52.1	3.5
b	–	60.0	70.6	191.5	3.8	5.0	263.0	57.9	1.9
c	–	37.0	24.3	46.6	2.0	5.0	69.5	35.4	21.0
d	–	38.5	26.7	71.1	2.6	3.0	94.2	41.7	16.3
C:N ratio 16.1									

Profile Description No: _ Site No: PV019

Series: Khuways - Kh Location: 493977

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-25	16.7	71.2	7.0	4.4	5	25.7	33.6
b	25-65	9.3	42.8	7.4	5.7	3	32.9	29.2
c	65-105	8.7	33.9	7.4	11.7	6	59.5	1.3
d	105-175	7.4	33.4	7.5	11.9	7	84.0	1.2

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	2	4	11	20	15	39	0	43
b	5	6	4	8	15	9	43	15	54
c	0	4	4	7	11	6	48	20	72
d	20	9	8	10	14	6	43	10	68

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

dc

Profile Description No: –

Site No: PV045

Series: Khuways - Kh

Location: 513979

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	5-0	16.4	72.0	7.4	7.0	3.3	25.0	28.7
b	0-30	11.6	48.0	7.4	5.4	3.0	24.0	19.9
c	30-75	6.1	39.4	7.4	8.3	16.1	30.2	0.9
d	75-100	2.8	19.5	7.4	11.1	8.5	34.1	0.9
e	100-200	0.7	7.7	7.5	4.3	2.3	18.4	0.9

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	1	7	10	10	16	48	8	42
b	0	3	15	23	~~19~~	18	22	0	45
c	0	4	20	19	13	9	19	16	43
d	5	3	21	23	18	9	12	14	34
e	0	3	26	36	28	7	0	0	21

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	2	18	24	13	2	33	8	23.9	0.23	0.05
b	2	19	17	14	2	28	18	-	-	-
c	2	18	20	17	2	26	15	-	-	-
d	2	29	43	17	1	3	5	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.73	-	-	-	-	-	-	-	-
b	-	-	-	-	-	-	-	-	-
c	-	-	-	-	-	-	-	-	-
d	-	30.0	14.1	110.5	3.5	3.0	121.0	30.5	4.86
e	-	31.2	19.8	82.0	2.0	3.0	99.0	35.2	0.49

Profile Description No: – **Site No:** PV034

Series: Lawzi – Lw **Location:** 509925

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–20	4.6	22.3	7.3	11.6	5	31.5	2.5
b	20–55	5.7	24.5	7.4	9.8	10	28.8	10.5
c	55–100	6.0	28.2	7.3	21.5	14	35.7	1.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	1	4	7	13	15	39	21	35
b	0	1	1	6	21	18	37	16	40
c	0	0	1	3	7	14	51	24	48

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

dc

Profile Description No: –

Site No: PV001

Series: Areen – An

Location: 503803

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–15	4.1	15.2	7.7	–	–	7.3	57.1
b	15–35	3.3	8.0	8.0	–	–	1.7	72.8
c	35–60	2.6	10.0	7.9	–	–	18.5	2.8
d	60–150	0.4	3.9	7.8	–	–	15.0	1.3

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	11	25	27	20	6	1	10	31
b	0	14	21	22	16	6	11	10	35
c	0	1	9	33	41	5	5	6	32
d	0	Nil	1	31	63	4	1	Nil	25

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	0	3.1	12.4	34.2	4.4	38.9	7.1	12.8	0.40	0.015
b	0	2.4	6.7	14.6	5.8	36.5	34.0	–	–	–
c	0	5.5	17.3	57.1	3.6	10.2	6.3	–	–	–
d	0	0.5	16.0	72.9	4.2	0.5	6.0	–	–	–

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	0.17	85.0	91.5	222.3	15.0	7.5	345.2	60.8	5.6
b	–	28.0	19.8	50.1	6.9	2.5	45.9	56.3	13.5
c	–	32.2	25.0	71.6	7.8	2.5	72.0	62.2	13.6
d	–	23.8	11.6	15.6	3.1	5.0	13.6	35.4	15.4
C:N ratio 11.3									

Profile Description No: – **Site No:** PV043

Series: Salmabad – Sm **Location:** 514932

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm E e	pH Paste	CEC me/100g	ESP		
a	0–30	9.7	52.9	7.8	–	–	7.3	62.1
b	30–55	13.1	43.2	7.6	19.5	9.7	35.0	3.2
c	55–80	2.3	16.2	7.6	9.6	4.6	35.4	1.4

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	12	13	15	14	16	30	0	44
b	0	2	3	6	6	8	51	24	24
c	45	5	16	27	25	7	11	14	26

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

Profile Description No: _ Site No: PV012

Series: Buquwwah - Bw Location: 528997

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-60	2.3	7.5	7.6	18.0	1	40.9	
b	60-90	3.2	14.3	7.4	18.1	3	53.7	
c	90-110	1.2	18.0	7.5	5.9	3	27.0	1.0
d	110-155	3.1	17.0	7.5	8.1	4	23.9	

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	10	2	8	12	23	10	24	21	39
b	35	6	7	7	10	7	39	24	50
c	40	4	19	22	36	9	4	6	24
d	0	2	9	15	35	13	10	16	41

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	1.9	7.1	10.2	23.3	10.2	19.5	27.8	240.0	1.55	0.09
b	0	7.1	7.4	17.0	7.6	5.4	55.5	-	-	-
c	0	10.7	16.9	37.3	11.0	9.0	15.1	-	-	-
d	2.6	9.1	11.4	37.2	20.2	8.1	11.5	-	-	-

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	1.12	37.5	14.5	30.6	2.0	2.0	46.5	36.2	43.5
b	-	73.8	41.8	96.1	2.5	2.0	175.0	37.1	8.1
c	-	39.2	15.6	63.8	1.5	3.0	72.5	44.7	0.9
d	-	50.0	36.5	98.1	2.6	2.5	143.5	41.3	4.3
C:N Ratio 12.4									

Profile Description No: – Site No: PV015

Series: Isa - Is (disturbed surface). Location: 555933

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-25	22.4	61.5	7.1	17.6	10	18.1	2.1
b	25-55	7.2	37.8	7.4	19.1	10	47.8	0.4

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	3	3	3	4	12	60	15	67
b	40	14	7	4	4	10	41	20	52

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	
a	0	0.7	3.2	14.1	11.2	34.1	36.6	52.6	0.60	0.041
b	0	0.4	1.3	6.1	9.6	17.4	65.2	–	–	–

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	
a	1.22	188.5	302.0	1400.9	34.5	2.0	1861.4	62.5	0.6
b	–	73.5	54.5	321.8	10.0	2.0	398.2	59.6	0.9
C:N Ratio 29.8									

Profile Description No: –

Site No: PV023

Series: Isa - Is

Location: 496964

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–20	7.9	36.1	8.3	3.5	2	7.2	64.3
b	20–60	5.9	26.6	7.7	11.7	21	27.7	0.5

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	7	18	22	16	7	15	15	47
b	0	2	12	21	15	5	23	22	64

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

dc

Profile Description No: –

Site No: PV021

Series: Hisham – Hs

Location: 493959

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–25	0.2	9.3	7.8	1.4	< 1	20.0	0.9
b	25–75	0.2	9.5	7.9	2.6	< 1	21.2	0.7
c	75–150	0.7	9.2	8.0	5.6	1	23.5	0.8

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	1	18	31	35	12	0	3	22
b	5	1	24	46	21	5	0	3	19
c	10	2	13	46	29	5	0	5	19

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

Profile Description No:- Site No: PV024

Series: Hisham - Hs Location: 486949

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-40	0.4	7.0	7.8	2.5	< 1	19.1	1.0
b	40-65	2.4	6.2	7.8	1.1	< 1	18.7	20.5
c	65-120	0.9	6.6	8.0	6.4	1	23.3	1.2
d	120-190	0.6	7.6	8.0	6.1	3	21.1	1.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	1	18	33	34	9	0	5	26
b	0	1	15	25	36	7	6	10	23
c	0	1	25	17	44	7	3	3	23
d	30	1	12	32	45	6	3	1	23

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

Profile Description No: – **Site No:** PV026

Series: Hisham – Hs **Location:** 492946

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–40	2.0	2.6	8.1	1.2	< 1	12.8	3.0
b	40–100	2.6	7.7	7.9	1.4	< 1	10.9	10.7
c	100–115	4.0	14.8	7.7	3.9	4.3	4.1	70.4
d	115–140	7.1	21.2	7.4	16.3	3.8	23.7	5.6

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	0	5	58	30	4	0	3	27
b	0	0	4	40	40	6	0	10	28
c	0	17	19	17	12	10	11	14	47
d	20	2	2	3	5	13	49	26	73

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

Profile Description No: --

Site No: PV062

Series: Hisham - Hs

Location: 508810

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0-30	0.8	7.5	8.0	11.5	3.1	16.7	0.8
b	30-100	3.2	7.2	7.9	14.8	1.8	16.4	6.3
c	100-150	2.6	7.3	7.8	3.8	1.6	10.2	5.9

Sample No.	Gravel % (Estimate)	Particle Size Analysis - % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	0	2	44	46	0	3	5	28
b	0	0	2	39	38	0	8	13	28
c	20	3	9	28	26	6	15	13	32

Sample No.	Particle Size Analysis - % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

Profile Description No: – Site No: PV061

Series: Wasmiyah -Saline phase Ws-s Location: 493809

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–20	15.1	120.0	8.0	19.8	16.1	20.9	1.2
b	20–100	2.0	28.5	8.1	10.3	15.2	19.6	1.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	2	7	21	25	2	28	15	40
b	0	0	7	35	50	3	0	5	25

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

Profile Description No: – **Site No:** PV029

Series: Dilmun – Dm **Location:** 488936

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
a	0–15	0.8	6.5	7.6	9.3	1	26.8	1.0
b	15–45	4.2	18.9	7.6	2.7	4.4	8.2	16.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	20	2	7	24	29	13	14	11	19
b	30	10	16	19	23	9	13	10	34

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

C

Routine Analysis Results

ROUTINE ANALYSIS RESULTS

Results of routine laboratory analyses are listed in this Appendix. Methods of analysis were described in Appendix A.

The analytical results are arranged according to Level 3 survey areas as follows:-

Table C.1	Profile pits,	all areas
Table C.2	Auger sites,	Salmabad area (V samples)
Table C.3	Auger sites,	Salmabad area (Z samples)
Table C.4	Auger sites,	Buhayr area
Table C.5	Auger sites,	Hawrat 'Inqa area

Table C.1

Bahrain Routine Laboratory Data **Area:** Profile Pit Samples

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
PV001	0-15	31	7.7	7.3	57.0	4.1	15.2	An
	15-35	35	8.0	1.7	72.8	3.3	8.0	
	35-60	32	7.9	18.5	2.8	2.6	10.0	
	60-105	25	7.8	15.0	1.3	0.4	3.9	
PV003	0-15	23	7.8	25.5	5.1	2.6	4.7	Hw
	15-55	29	8.0	7.7	47.1	3.4	10.0	
	55-80	28	8.1	12.4	20.0	3.9	13.1	
	80-130	65	8.1	41.6	10.0	6.0	15.9	
PV004	0-15	35	7.5	15.5	2.8	20.1	56.8	Ws
	15-80	24	8.0	16.8	1.1	2.0	16.2	
	80-120	24	8.0	16.4	1.1	2.7	19.6	
PV005	0-25	45	7.7	32.1	38.0	15.7	47.0	Sa
	25-55	58	7.6	50.7	13.7	13.5	37.2	
	55-90	71	7.5	55.2	9.2	11.7	30.4	
	90-150	48	7.6	84.3	1.5	3.8	30.4	
PV006	0-15	36	7.8	2.3	67.0	3.9	16.6	Mq
	15-40	59	7.9	1.4	55.5	5.5	14.9	
	40-100	42	7.8	6.5	48.4	3.8	9.9	
	100-140	41	7.7	81.8	6.9	4.3	13.5	
PV007	0-40	50	7.8	2.9	60.0	5.3	19.3	Sa
	40-70	60	7.6	16.9	17.7	6.6	21.0	
	70-100	75	7.4	32.6	2.1	9.5	29.9	
	100-130	49	7.7	76.0	1.3	3.6	14.6	
PV008	0-20	41	7.2	29.1	14.1	12.4	68.1	Kh
	20-75	42	7.6	34.3	2.0	4.8	25.2	
	75-135	59	7.7	64.0	1.7	3.5	12.3	
	135-200	66	7.9	98.5	1.5	3.2	12.3	
PV009	0-40	43	7.4	38.0	4.5	8.9	36.5	Kh
	40-90	32	7.5	33.7	3.1	3.2	21.9	
	90-110	21	7.9	19.6	0.9	1.1	9.9	
	110-180	22	7.7	20.6	0.8	1.0	9.7	

Table C.1 (continued)

Bahrain Routine Laboratory Data **Area:** Profile Pit Samples

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	Salinity, mmhos/cm ECe	Soil Series
PV010	0-20	64	7.1	37.0	14.8	30.6	81.9	Tb
	20-90	55	7.5	73.9	1.5	10.0	45.8	
	90-110	30	7.6	29.2	1.6	4.8	27.6	
PV011	0-15	31	7.5	12.0	32.5	11.3	50.1	Sm
	15-35	38	7.6	16.5	12.9	7.9	38.1	
	35-70	49	7.6	22.7	0.8	7.0	30.2	
	70-125	21	7.5	20.5	-	0.8	7.1	
PV012	0-60	39	7.6	40.9	-	2.3	7.5	Bw
	60-90	50	7.4	53.7	-	3.2	14.3	
	90-110	24	7.5	27.0	1.0	1.2	18.0	
	110-155	41	7.5	23.9	-	3.1	17.0	
PV013	0-45	38	7.5	7.3	59.6	6.7	31.9	Bu
	45-110	39	7.6	2.5	81.6	7.2	33.0	
	110-200	26	7.4	2.9	87.7	5.7	34.0	
PV014	0-15	23	7.4	6.5	57.8	6.7	37.7	Bu
	15-55	40	7.2	9.4	45.5	10.6	50.0	
	55-75	32	7.2	62.4	30.6	10.0	48.9	
	75-130	39	7.2	12.5	8.8	10.6	52.1	
PV015	0-25	67	7.1	18.1	2.1	22.4	61.5	Is
	25-55	52	7.4	47.8	0.4	7.2	37.8	
PV016	0-50	29	7.8	20.6	7.4	3.6	30.6	Hs
	50-65	28	7.9	22.6	11.8	3.4	25.2	
	65-150	26	7.9	21.2	7.9	3.1	18.3	
	150-180	51	7.6	59.3	4.0	4.9	24.5	
PV017	0-20	53	7.8	33.3	31.0	14.7	66.7	Kh-s
	20-80	60	7.5	41.2	19.2	7.6	38.7	
	80-135	60	7.8	69.2	1.9	5.5	27.0	

Table C.1 (continued)

Bahrain Routine Laboratory Data **Area:** Profile Pit Samples

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
PV018	0-20	40	8.0	1.0	91.6	4.1	22.2	Mq
	20-50	49	7.9	1.0	81.6	4.3	18.0	
	50-70	55	7.6	0.8	72.0	4.4	15.2	
	95-125	46	7.8	2.1	75.1	5.6	26.0	
PV019	0-25	43	7.0	25.7	33.6	16.7	71.2	Kh-s
	25-65	54	7.4	32.9	29.6	9.3	42.8	
	65-105	72	7.4	59.5	1.3	8.7	33.9	
	105-175	68	7.5	84.0	1.2	7.4	33.4	
PV020	0-30	35	7.6	4.2	66.5	7.5	38.3	Sb
	30-60	50	7.4	2.9	74.9	9.7	40.4	
	60-65	104	7.2	20.8	12.5	16.4	44.7	
	65-95	78	7.3	29.1	0.4	8.7	37.2	
PV021	0-25	22	7.8	20.0	0.9	0.2	9.3	Hs
	25-75	19	7.9	21.2	0.7	0.2	9.5	
	75-150	19	8.0	23.5	0.8	0.7	9.2	
PV022	0-45	49	7.8	2.7	77.7	7.5	36.1	Sa
	45-65	76	7.4	21.1	34.1	7.4	27.6	
	65-100	67	7.4	62.8	3.0	6.0	23.9	
PV023	0-20	47	8.3	7.2	64.3	7.9	36.1	Is
	20-60	64	7.7	27.7	0.5	5.9	26.6	
PV024	0-40	26	7.8	19.1	1.0	0.4	7.0	Hs
	40-65	23	7.8	18.7	20.5	2.4	6.2	
	65-120	23	8.0	23.3	1.2	0.9	6.6	
	120-190	23	8.0	21.1	1.0	0.6	7.6	
PV025	0-35	38	7.9	3.7	58.5	3.0	9.8	Br
	35-55	27	7.9	9.7	26.9	2.4	5.9	
	55-100	47	7.8	5.2	47.0	3.7	15.4	

dc

Table C.1 (continued)

Bahrain Routine Laboratory Data **Area:** Profile Pit Samples

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
PV026	0-40	27	8.1	12.8	3.0	2.0	2.6	Hs
	40-100	28	7.9	10.9	10.7	2.6	7.7	
	100-115	47	7.7	4.1	70.4	4.0	14.8	
	115-140	73	7.4	23.7	5.6	7.1	21.2	
PV027	0-20	43	8.0	4.1	67.9	2.7	6.3	Dm
	20-40	37	8.2	22.6	8.2	4.2	19.6	
PV028	0-40	28	8.1	11.1	7.1	2.1	2.8	Br-q
	40-70	45	7.8	7.2	61.9	4.3	16.7	
	70-110	51	7.5	39.7	24.7	7.8	32.3	
PV029	0-15	19	7.6	26.8	1.0	0.8	6.5	Dm
	15-45	34	7.6	8.2	16.0	4.2	18.9	
PV030	0-20	39	7.2	8.2	61.6	16.7	69.8	Kh
	20-105	53	7.5	54.9	2.6	24.0	102.8	
	105-150	56	7.4	71.6	3.6	11.0	43.8	
	150-180	69	7.3	44.7	3.3	12.0	40.6	
PV031	0-25	25	7.5	13.4	23.1	4.9	29.2	Hs
	25-90	22	7.3	18.5	6.9	4.1	25.5	
	90-100	20	7.4	24.1	1.0	2.1	19.8	
PV032	0-35	24	7.8	22.6	4.2	2.8	11.7	Hs
	35-90	20	7.5	25.1	3.1	3.4	19.8	
PV033	0-35	38	7.6	16.5	57.0	14.2	62.6	Sa
	35-60	43	7.5	21.4	50.2	7.5	33.4	
	60-110	76	7.5	61.0	5.0	8.4	25.5	
	110-140	49	7.4	91.0	1.8	2.4	12.1	
PV034	0-20	35	7.3	31.5	2.5	4.6	22.3	Lw
	20-55	40	7.4	28.8	10.5	5.7	24.5	
	55-100	48	7.3	35.7	1.0	6.0	28.2	

Table C.1 (continued)

Bahrain Routine Laboratory Data **Area:** Profile Pit Samples

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
PV035	0-20	59	7.3	32.6	26.4	8.0	27.9	Lw
	20-75	63	7.4	50.0	1.3	6.3	24.0	
	75-130	66	7.4	47.5	0.8	6.5	25.5	
PV036	0-25	33	7.8	6.2	58.5	2.5	4.1	Mq-n
	25-55	31	7.5	7.9	59.7	3.6	15.4	
	55-150	41	7.3	14.5	40.6	4.0	15.8	
	150-190	58	7.5	72.7	-	3.0	7.8	
PV037	0-15	31	7.5	28.6	2.6	6.2	46.0	Zn
	15-40	53	7.6	19.2	19.3	8.5	39.2	
PV038	0-30	27	7.8	-	-	2.8	8.2	Is
	30-75	93	7.8	10.7	-	9.2	29.8	
PV038	0-30	27	7.8	-	-	2.8	8.2	Is
	30-75	93	7.8	10.7	-	9.2	29.8	
PV039	0-25	30	8.0	5.6	55.8	10.0	69.8	Br
	25-100	54	7.6	13.2	46.8	9.1	28.8	
	100-130	70	7.6	70.4	-	6.7	28.8	
PV040	0-50	27	7.9	2.1	63.2	2.3	3.4	Kn
	50-100	24	8.1	22.1	1.0	0.3	1.7	
PV041	0-40	23	8.0	-	-	2.6	3.6	Br
	40-75	38	7.8	-	-	3.3	10.6	
	75-100	56	7.7	-	-	4.9	18.0	
PV042	0-30	38	8.1	1.0	93.0	4.5	14.8	Mq
	30-60	49	7.5	1.0	88.9	5.5	22.3	
	60-100	49	7.6	1.0	84.0	4.5	17.0	
	100-145	98	7.4	20.6	12.5	7.2	24.0	
	145-230	80	7.7	90.6	-	2.2	9.7	
PV043	0-30	44	7.8	7.3	62.1	9.7	52.9	Sm
	30-55	24	7.6	35.0	3.2	13.1	43.2	
	55-80	26	7.6	35.4	1.4	2.3	16.2	

Table C.1 (continued)

Bahrain Routine Laboratory Data **Area**: Profile Pit Samples

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
PV044	0-25	71	7.1	2.5	77.6	24.3	96.0	Kd
	25-60	64	7.5	69.8	0.9	8.2	32.6	
	60-100	61	7.5	60.3	0.9	7.4	20.6	
	100-150	64	7.4	90.3	0.8	4.3	34.1	
PV045	5-0	42	7.4	25.0	28.7	16.4	72.0	Kh-s
	0-30	45	7.4	24,0	19.9	11.6	48.0	
	30-75	43	7.4	30.2	0.9	6.1	39.4	
	75-100	34	7.4	34.1	0.9	2.8	19.5	
	100-200	21	7.5	18.4	0.9	0.7	7.7	
PV046	0-15	30	7.2	-	67.8	42.0	115.2	Kd
	15-45	54	7.3	-	34.1	16.4	69.1	
	45-130	65	7.2	-	1.3	14.4	59.5	
	130-160	19	7.2	-	-	2.2	23.9	
PV047	0-20	64	7.3	-	14.0	27.9	93.1	Kd
	20-50	63	7.2	-	4.5	12.6	49.0	
	50-70	77	7.2	-	0.9	9.9	35.7	
	70-100	67	7.3	-	41.4	8.7	31.1	
PV048	0-40	41	7.4	3.3	71.3	10.1	43.8	Is
	40-70	81	7.3	46.8	2.5	16.5	54.2	
	70-200	94	7.2	35.1	4.3	17.7	52.2	
PV049	0-45	32	7.4	13.1	69.0	10.0	51.1	Sb
	45-95	60	7.3	54.6	20.1	10.0	42.8	
	95-150	37	7.3	63.6	5.3	6.1	34.9	
	150-200	32	7.2	34.9	-	5.1	32.9	
PV050	0-20	32	7.3	15.2	55.7	12.1	67.8	Is
	20-65	45	7.3	62.8	2.8	9.4	50.1	
	65-95	45	7.3	55.4	1.0	5.9	34.9	
	95-155	51	7.4	87.4	-	4.4	26.1	

gc

Table C.1 (continued)

Bahrain Routine Laboratory Data **Area:** Profile Pit Samples

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
PV051	0-25	29	7.4	4.5	76.4	4.0	16.3	Mq
	25-75	34	7.4	2.1	85.3	4.0	28.0	
	75-95	100	7.3	26.3	0.9	9.8	26.1	
	95-125	70	7.3	48.0	0.9	6.2	24.5	
PV052	0-25	31	7.8	2.9	79.0	8.3	17.7	Sm
	25-50	72	7.4	32.8	1.2	10.2	31.8	
	50-80	43	7.4	41.1	0.7	3.8	18.5	
	80-100	11	7.5	23.4	0.9	0.7	6.0	
PV053	0-25	20	7.3	12.3	52.5	13.9	67.8	Lw
	25-60	40	7.3	15.2	36.2	10.3	48.0	
	60-95	67	7.3	28.7	1.5	12.5	41.7	
PV054	0-40	42	8.0	3.7	83.7	11.3	50.9	Sb
	40-60	44	7.6	31.3	32.3	8.7	40.1	
	60-125	50	7.5	40.9	37.2	8.7	43.6	
PV055	0-25	28	7.1	29.0	14.1	21.6	83.2	Bw
	25-45	45	7.4	32.1	20.8	8.9	44.1	
	45-85	40	7.5	42.3	0.6	4.5	28.9	
	85-110	29	7.6	58.9	1.0	2.8	22.2	
PV056	0-25	37	7.8	51.3	20.2	16.0	68.5	Kh-s
	25-110	49	7.6	64.2	12.2	7.2	34.8	
	110-190	44	7.8	88.0	3.3	4.3	25.0	
PV057	0-20	34	7.2	28.0	11.7	12.7	68.5	Bw
	20-75	35	7.4	34.2	5.7	5.7	37.7	
	75-120	22	7.6	24.5	0.9	1.0	15.7	
PV058	0-25	28	7.4	-	8.5	8.7	49.0	Kh
	25-80	35	7.6	-	3.2	4.6	21.7	
	80-150	37	7.5	-	0.8	3.3	23.1	
PV060	0-15	29	7.9	7.1	62.0	2.6	6.9	An
	15-45	35	7.7	18.0	6.2	3.5	15.9	
	45-80	26	7.9	16.6	1.0	0.6	2.2	

Table C.1 (continued)

Bahrain Routine Laboratory Data **Area:** Profile Pit Samples

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
PV061	0-20	40	8.0	20.9	1.2	15.1	120.0	Ws-s
	20-100	25	8.1	19.6	1.0	2.0	28.5	
PV062	0-30	28	8.0	16.7	0.8	0.8	7.5	Hs
	30-100	28	7.9	16.4	6.3	3.2	7.2	
	100-150	32	7.8	10.2	5.9	2.6	7.3	
PV063	0-10	21	7.7	19.0	5.2	16.8	129.5	Ws-s
	10-80	21	7.9	17.6	0.9	2.5	37.9	
	80-120	20	7.8	17.0	1.0	4.7	52.7	
PV064	0-20	36	8.0	4.5	74.1	2.5	4.3	Hw
	20-50	34	7.8	8.0	47.1	2.6	10.0	

Table C.2

Bahrain Routine Laboratory Data **Area:** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V030	0-30	31	7.8	-	75.8	3.0	11.4	Kn
	30-60	20	7.8	-	5.1	2.5	4.1	
	60-100	23	8.0	-	9.4	2.8	6.5	
V031	0-25	39	-	50.7	-	19.9	47.0	Mq
	25-80	48	-	77.7	-	11.0	33.0	
	80-100	23	-	19.2	-	3.8	10.8	
V032	0-25	30	-	9.2	57.1	6.3	24.5	Sa
	25-60	37	-	12.3	52.7	5.5	21.5	
	60-100	60	-	45.0	12.9	4.2	10.6	
V033	0-15	31	-	-	70.1	2.6	4.2	Mq
	15-75	36	-	-	76.6	2.5	4.0	
V034	0-15	36	7.4	-	28.5	4.1	12.6	Zn
	15-40	37	7.7	-	41.4	4.1	13.0	
	40-70	45	7.6	-	31.4	3.9	10.0	
V035	0-15	28	7.8	-	57.2	4.6	15.2	Br
	15-70	42	7.6	-	51.5	5.1	16.5	
V037	0-20	20	7.9	-	15.7	2.4	3.4	Br
	20-80	33	7.7	-	31.4	2.8	10.0	
V038	0-20	25	7.7	7.4	62.9	2.6	4.7	Mq
	20-60	22	7.7	5.3	61.6	2.5	7.4	
	60-100	41	8.0	20.0	50.0	4.1	11.4	
V039	0-50	35	7.6	-	73.0	2.7	5.8	Br
	50-100	44	7.7	-	29.9	3.0	7.0	
V040	0-40	23	7.8	-	1.5	1.9	8.5	Br-q
	40-100	28	8.2	-	45.8	3.3	8.5	
V043	0-25	29	7.9	-	4.4	5.3	21.5	
	25-70	29	7.8	-	2.1	5.2	24.0	

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area:** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V044	0-30	28	7.7	-	41.4	3.5	18.0	Mq-m
	30-45	30	7.8	-	52.9	3.3	15.5	
	45-100	49	7.6	-	55.6	5.0	21.0	
V045	0-40	52	7.6	-	2.0	3.4	19.5	
	40-70	49	7.6	-	15.4	6.0	25.0	
V046	0-40	23	7.6	-	2.4	4.0	27.0	Zn
	40-100	28	7.6	-	2.1	4.6	28.0	
V047	0-5	35	7.0	-	22.1	30.3	84.0	Kh-s
	5-75	47	7.6	-	25.3	9.6	42.0	
	75-100	54	7.5	-	2.8	8.7	30.0	
V048	0-35	39	7.1	-	58.4	21.1	77.0	Kh
	35-70	59	7.3	-	28.5	14.9	55.0	
	70-100	57	7.3	-	6.7	14.4	50.0	
V050	0-55	21	8.0	-	0.9	0.5	5.0	Br
	55-100	32	7.9	-	34.3	3.1	10.4	
V053	0-35	22	8.0	-	7.0	2.2	3.6	Hs
	35-90	24	8.0	-	7.0	2.4	5.2	
V054	0-45	21	8.0	-	1.1	0.9	5.1	Br
	45-100	34	7.9	-	41.5	2.9	8.6	
V055	0-40	32	7.9	-	42.3	2.9	7.8	Mq
	40-100	35	7.9	-	48.5	3.8	14.2	
V056	0-15	44	8.1	-	74.2	9.2	40.0	Mq
	15-55	34	8.0	-	71.4	4.9	20.5	
	55-100	36	7.8	-	62.8	4.4	19.0	
V057	0-50	40	7.9	-	69.8	7.0	29.0	Sa
	50-65	71	7.5	-	27.9	10.0	33.0	
	65-100	69	7.6	-	15.0	10.0	33.0	

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area :** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V059	0-20	44	8.4	-	77.1	10.6	47.0	Mq-m
	20-100	49	7.8	-	54.1	7.2	29.0	
V060	0-10	30	6.6	22.1	18.5	29.9	103.3	Kh-s
	10-50	35	7.6	36.3	6.3	10.0	52.2	
	50-100	33	7.6	48.0	1.7	5.5	32.6	
V061	0-45	21	8.0	-	-	0.4	4.8	Hs
V063	0-20	33	8.0	-	78.6	10.0	50.0	Mq
	20-50	45	7.6	-	68.5	6.7	29.3	
	50-100	36	7.6	-	65.7	4.9	22.3	
V065	0-25	35	7.9	-	67.0	7.9	40.8	Mq
	25-75	31	7.8	-	67.2	3.9	16.6	
	75-100	62	7.7	-	16.9	5.7	17.7	
V066	0-25	40	7.7	-	75.7	10.0	42.9	Mq
	25-80	39	7.8	-	68.6	4.3	16.6	
	80-100	33	7.7	-	62.9	3.8	16.7	
V069	0-25	42	8.1	-	48.5	17.9	67.4	Sb
	25-90	42	7.7	-	48.4	8.3	35.9	
V070	0-25	37	8.2	10.3	56.9	15.9	67.4	Sb
	25-40	46	7.9	19.9	35.5	16.6	63.0	
	40-80	43	7.8	20.1	44.2	11.2	47.8	
V072	0-25	37	8.1	-	74.3	6.5	27.7	Mq
	25-75	44	7.8	-	70.1	3.9	13.0	
	75-100	45	7.6	-	62.9	3.9	12.4	
V073	0-25	35	8.2	4.1	67.0	10.0	41.3	Sb
	25-65	50	7.8	18.5	19.4	10.0	38.0	
	65-100	34	7.7	37.4	10.9	4.8	28.0	

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area :** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V074	0-45	38	7.4	-	65.3	14.7	59.8	Sb
	45-75	57	7.6	-	11.6	12.2	44.6	
	75-100	53	7.6	-	6.3	8.7	30.4	
V076	0-20	43	7.8	-	71.2	15.4	50.0	Kd
	20-60	44	7.5	-	52.5	13.2	54.4	
	60-100	61	7.5	-	8.0	16.5	54.4	
V077	0-20	32	7.2	11.3	61.0	21.4	76.1	Sb
	20-85	44	7.5	14.4	52.7	8.2	35.3	
	85-100	62	7.4	31.2	28.1	10.2	35.9	
V078	0-30	43	7.0	47.2	8.3	17.1	65.2	Kh-s
	30-100	49	7.4	49.3	13.4	10.0	37.0	
V079	0-35	48	7.8	-	72.8	9.8	48.9	Sb
	35-60	52	7.5	-	28.2	9.4	40.4	
	60-80	53	7.6	-	2.5	5.7	25.0	
V080	0-30	41	7.5	15.7	-	14.7	46.0	Kh
	30-75	57	7.5	19.2	-	8.2	29.0	
	75-100	63	7.5	55.3	-	6.7	24.5	
V081	0-30	45	7.0	-	33.3	17.4	76.6	Kh-s
	30-60	57	7.4	-	15.0	10.0	37.2	
	60-100	55	7.5	-	1.3	5.1	25.0	
V082	0-30	50	7.3	-	30.6	19.8	76.6	Kh
	30-65	57	7.6	-	10.4	19.0	43.6	
	65-100	61	7.5	-	2.1	7.6	30.0	
V083	0-25	50	7.5	-	44.6	16.7	69.2	Kh-s
	25-60	58	7.5	-	17.4	1 .5	45.8	
	60-100	51	7.5	-	2.3	7.3	32.5	
V084	0-30	51	7.7	-	52.5	9.8	42.6	Sb
	30-60	61	7.6	-	9.0	9.5	31.3	
	60-100	59	7.6	-	5.6	6.0	23.9	

gc

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area:** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	Salinity, mmhos/cm ECe	Soil Series
V085	0-25	54	7.5	-	50.7	14.5	59.6	Sb-s
	25-70	65	7.5	-	15.6	9.8	36.2	
	70-100	65	7.6	-	2.0	5.9	19.9	
V086	0-25	33	8.1	-	-	6.7	36.2	Hs
	25-50	26	7.7	-	-	5.4	22.9	
	50-100	26	7.9	-	-	2.6	12.1	
V087	0-20	52	7.4	-	52.0	19.7	63.8	Kd
	20-60	63	7.4	-	7.3	16.7	59.6	
	60-100	58	7.5	-	2.3	12.5	51.1	
V088	0-20	49	7.2	-	-	22.7	74.5	Kd
	20-65	63	7.3	-	-	17.6	63.8	
	65-100	40	7.6	-	-	7.9	44.7	
V089	0-30	39	7.9	-	63.2	9.7	31.9	Sb
	30-65	51	7.6	-	38.3	10.0	37.2	
	65-100	61	7.7	-	4.7	9.2	35.1	
V090	0-25	40	7.4	-	53.6	11.2	55.3	Sm
	25-55	42	7.5	-	35.4	8.0	36.2	
	55-80	64	7.5	-	9.0	9.7	24.5	
V091	0-35	35	7.7	-	71.3	10.0	54.2	Kd
	35-60	60	7.5	-	10.9	10.8	45.9	
	60-100	62	7.5	-	2.4	9.6	40.2	
V092	0-30	40	7.8	-	69.8	9.4	54.2	Kd
	30-55	66	7.6	-	42.6	7.9	38.6	
	55-100	55	7.6	-	2.5	5.3	23.5	
V095	0-40	48	7.2	-	-	14.0	50.1	Kh
	40-60	50	7.5	-	-	4.0	22.9	
	60-100	34	7.5	-	-	2.8	21.9	

dc

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area :** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	Salinity, mmhos/cm ECe	Soil Series
V096	0-25	52	7.2	59.1	-	20.5	73.0	Tb
	25-50	43	7.5	67.3	-	9.5	52.2	
	50-100	28	7.5	26.7	-	8.0	51.1	
V097	0-30	60	7.5	-	2.4	9.0	34.9	Is
	30-70	33	7.1	-	48.7	15.6	73.0	
	70-100	39	7.6	-	1.5	4.0	45.9	
V098	0-30	30	7.7	-	75.7	7.0	38.6	Is
	30-75	52	7.6	-	6.7	10.3	43.8	
	75-100	23	7.8	-	1.2	2.1	13.1	
V099	0-40	27	7.4	-	68.1	11.0	58.4	Is
	40-75	84	7.3	-	4.8	21.4	62.6	
	75-100	43	7.3	-	15.3	14.9	61.5	
V100	0-30	39	7.4	-	17.0	11.0	52.2	Sm
	30-50	33	7.4	-	2.1	8.3	45.9	
	50-100	23	7.6	-	1.1	4.1	25.6	
V104	0-15	29	7.5	14.9	35.4	5.5	29.7	Is
	15-60	52	7.7	14.0	35.4	8.2	29.2	
	60-100	61	7.6	30.0	1.1	8.5	30.8	
V106	0-40	48	7.6	16.5	33.9	6.0	23.5	Is
	40-70	63	7.6	33.0	2.9	7.0	25.0	
	70-100	61	7.6	46.5	2.5	5.6	20.3	
V107	0-40	55	7.3	11.2	39.0	1.7	60.5	Is
	40-80	53	7.5	82.6	5.7	6.3	28.5	
	80-100	49	7.5	84.2	5.2	3.6	15.8	
V108	0-60	55	7.3	36.1	10.4	15.4	62.0	Kh
	60-100	62	7.5	42.3	2.1	8.3	30.5	
V109	0-40	52	7.2	28.1	20.2	17.2	64.0	Sm

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area :** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V110	0-65	35	7.7	-	82.9	8.2	37.5	Mq
	65-100	115	7.5	-	10.1	11.5	32.0	
V111	0-50	38	7.5	3.1	75.7	7.2	34.0	Is
	50-75	69	7.5	55.3	8.0	10.0	36.0	
	75-100	58	7.5	72.6	9.2	8.3	33.0	
V112	0-30	22	6.7	-	-	42.8	85.1	Kl-s
	30-70	40	7.5	-	-	8.5	38.0	
	70-100	43	7.5	-	-	6.8	31.5	
V113	0-40	48	7.6	-	-	3.2	10.0	Kh
	40-60	54	7.6	-	-	3.2	10.7	
	60-100	45	7.6	-	-	1.6	7.7	
V114	0-50	21	7.6	-	-	4.1	29.0	Hs
	50-100	22	7.8	-	-	3.2	15.7	
V115	0-40	31	7.3	-	-	13.6	65.0	Kh-s
	40-100	42	7.6	-	-	6.0	26.5	
V116	0-40	48	7.4	-	42.6	12.2	52.0	Sb
	40-80	74	7.5	-	2.9	7.5	26.0	
	80-100	61	7.4	-	5.3	7.2	27.5	
V117	0-20	45	7.5	-	19.0	7.7	34.0	Kh
	20-5C	37	7.4	-	42.3	14.4	65.0	
	50-100	43	7.4	-	19.7	6.0	26.8	
V119	0-40	42	7.4	13.6	22.9	6.4	23.5	Bw
	40-80	43	7.6	24.8	7.8	4.4	13.6	
	80-100	31	7.5	26.8	2.1	3.5	15.3	
V120	0-40	35	7.4	23.7	48.4	7.2	33.5	Is
	40-60	63	7.5	42.3	17.4	5.5	19.0	
	60-100	39	7.6	64.4	2.7	3.7	14.4	

Table C.2 (continued)

Bahrain Routine Laboratory Data — Area: Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V144	0-40	34	7.4	33.7	2.4	8.0	37.2	Kh
	40-100	34	7.6	41.0	1.5	3.5	21.8	
V146	0-40	33	7.6	29.5	13.6	10.3	52.1	Kh
	40-100	35	7.7	39.5	3.7	5.1	24.7	
V151	0-45	46	7.3	-	40.2	10.5	40.7	Kh
	45-100	52	7.4	-	3.6	6.9	26.6	
V152	0-30	39	7.5	-	-	13.5	50.0	Kh
	30-60	47	7.4	-	-	7.3	29.2	
	60-100	59	7.4	-	-	6.8	24.7	
V158	0-20	56	7.2	-	-	7.8	29.8	Mq
	20-70	41	7.5	-	-	3.3	12.8	
V160	0-30	36	7.3	-	34.2	12.4	40.4	Sb
	30-100	44	7.5	-	39.5	6.5	30.9	
V163	0-60	37	6.8	-	44.2	21.4	74.5	Sb-s
V164	0-40	38	6.6	-	42.1	24.5	77.7	Kd
	40-80	30	7.4	-	-	7.4	38.3	
	80-100	47	7.1	-	-	15.3	56.4	
V165	0-40	49	6.8	-	37.1	15.6	57.5	Kd
	40-65	54	7.3	-	-	6.4	26.1	
	65-100	33	7.3	-	-	5.0	64.9	
V170	0-55	47	7.4	-	39.4	8.6	34.0	Kd
	55-100	78	7.4	-	-	8.4	23.4	
V172	0-20	44	7.0	11.5	60.2	15.8	55.3	Kd
	20-60	72	7.1	50.2	5.3	13.5	41.5	
	60-100	48	7.4	76.6	4.9	9.4	32.0	
V178	0-50	45	7.5	-	46.9	4.1	13.9	Sa
	50-100	54	7.4	-	-	4.9	17.0	

Table C.2 (continued)

Bahrain **Routine Laboratory Data** **Area :** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V179	0-55	41	7.6	-	-	9.8	41.5	Sa
	55-100	56	7.4	-	-	8.0	27.7	
V181	0-30	35	7.2	-	-	11.4	46.8	Sa
	30-60	44	7.3	-	-	10.0	35.6	
	60-100	56	7.3	-	-	9.7	29.8	
V183	0-55	45	7.2	-	-	11.2	44.7	Kh
	55-100	52	7.5	-	-	6.1	21.5	
V199	0-30	40	7.6	-	77.7	7.0	28.2	
	30-100	48	7.5	-	8.2	6.4	23.4	
V205	0-40	41	7.0	-	-	14.2	46.8	Kh
	40-100	60	7.4	-	-	7.9	25.5	
V207	0-40	37	6.6	-	-	18.5	60.1	Kh
	40-100	30	6.4	-	-	6.1	59.6	
V211	0-10	31	6.5	-	-	18.6	60.6	Kh
	10-60	61	7.1	-	-	13.8	42.6	
	60-100	51	7.3	-	-	7.7	29.8	
V212	0-15	51	7.5	30.0	14.8	7.5	26.1	Lw
	15-70	80	7.6	38.1	1.7	7.2	20.2	
V224	0-60	37	7.6	-	-	7.5	30.9	Mq
	60-100	66	7.5	-	-	7.2	24.5	
V225	0-50	36	7.3	-	-	9.4	37.2	Sa
	50-100	52	7.2	-	-	10.6	37.2	
V227	0-20	32	7.0	-	46.5	16.8	59.6	Sa
	20-70	55	7.2	-	19.9	11.9	42.6	
	70-100	76	7.3	-	-	10.3	35.5	
V228	0-40	67	7.3	-	-	10.9	39.6	Kh
	40-100	66	7.3	-	-	7.6	28.0	

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area:** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V233	0-35	63	6.9	-	20.5	15.4	52.1	Kh
	35-100	67	7.0	-	-	10.2	38.1	
V248	0-50	36	7.9	-	-	2.7	7.4	Mq
	50-100	71	7.5	-	-	3.9	10.8	
V250	0-50	39	7.9	-	-	6.5	30.2	Mq-n
	50-100	43	7.7	-	-	5.8	23.6	
V252	0-30	39	7.2	13.6	49.9	7.0	31.3	Br
	30-100	41	7.3	18.9	-	4.9	21.9	
V256	0-50	38	7.5	-	-	3.2	10.4	Zn
V257	0-45	52	7.1	-	-	8.5	32.3	Zn
V258	0-45	53	6.9	-	21.3	15.0	53.2	Kh
	45-100	62	7.3	-	-	8.6	30.2	
V268	0-30	44	7.6	12.4	55.8	5.1	11.5	Br
	30-50	49	7.6	8.7	55.8	6.0	22.4	
	50-100	54	7.4	14.4	54.6	6.0	21.4	
V273	0-50	31	7.9	5.1	72.9	2.4	2.8	Mq
	50-100	27	7.8	-	-	2.3	4.0	
V276	0-40	45	8.0	-	-	6.4	26.1	Sa
	40-75	83	7.6	-	-	7.0	26.3	
	75-100	58	7.5	-	-	6.4	22.4	
V283	0-50	26	7.9	-	-	1.5	4.4	Hs
	50-100	21	8.0	-	-	0.8	3.3	
V286	0-40	35	7.8	-	22.3	2.5	6.4	Br
	40-100	38	7.6	-	35.5	3.4	12.3	
V289	0-50	22	7.6	-	-	2.9	12.1	Hs
	50-90	19	7.7	15.4	-	2.5	7.1	

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Table C.2 (continued)

Bahrain Routine Laboratory Data **Area:** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V290	0-50	18	7.9	16.5	3.0	2.5	4.0	Hs
	50-100	25	7.8	14.8	-	1.1	10.0	
V304	0-60	27	7.8	-	-	3.1	10.0	Kn
	60-100	21	7.9	-	-	2.7	9.7	
V315	0-45	23	7.8	-	-	3.3	17.0	Kn
	45-100	22	7.9	-	-	3.1	12.6	
V321	0-55	27	7.6	-	-	2.9	12.7	Zn
V323	0-50	63	7.5	-	-	4.1	14.1	Sa
	50-100	68	7.5	-	-	4.8	17.3	
V333	0-40	23	7.7	21.6	2.6	2.7	7.4	Kn
	40-100	20	7.8	27.6	-	1.1	7.6	
V335	0-25	21	7.8	-	-	2.4	3.2	Br
	25-75	26	7.8	-	-	2.6	6.4	
	75-100	40	7.9	-	-	3.4	10.9	
V339	0-30	19	7.8	-	-	2.6	5.1	Br
	30-90	28	7.7	-	-	3.7	16.2	
V347	0-50	30	7.8	-	-	3.5	12.7	Mq
	50-100	32	7.8	-	-	3.2	9.2	
V349	0-50	25	7.8	-	-	6.7	38.3	Mq-n
	50-100	31	7.6	-	-	4.0	17.5	
V352	0-50	30	7.8	-	-	5.1	29.1	Mq
	50-100	33	7.7	-	-	4.5	24.7	
V353	0-20	26	7.6	-	91.3	10.6	85.7	Kd
	20-60	35	7.7	-	53.6	5.9	33.7	
	60-100	52	7.5	-	5.5	7.4	38.6	

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area:** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V358	0-40	30	7.9	-	-	4.0	16.5	Mq
	40-100	30	7.8	-	-	3.9	19.1	
V361	0-40	27	7.8	-	-	3.6	13.8	Mq
	40-100	36	7.8	-	-	4.2	19.6	
V362	5-0	31	7.0	-	-	46.9	153.0	Kh
	0-50	44	7.3	-	-	17.2	93.0	
	50-100	49	7.3	-	-	7.9	40.6	
V365	0-40	30	8.0	-	74.1	6.6	44.0	Sm
	40-100	51	7.6	-	-	9.2	40.6	
V369	0-40	39	7.3	-	45.4	15.3	95.0	Sa
	40-100	49	7.4	-	-	7.8	40.1	
V372	0-30	42	7.5	-	-	8.2	48.0	Kh-s
	30-100	32	7.5	-	-	15.4	95.9	
V382	0-45	57	7.4	46.9	-	9.8	40.1	Sm
	45-100	52	7.4	78.6	-	6.4	34.8	
V386	0-50	37	7.5	24.7	-	12.4	83.2	Kh
	50-100	59	7.6	63.4	-	8.1	35.4	
V392	0-45	35	7.6	2.3	-	10.4	70.5	Kd
	45-100	55	7.5	61.8	-	10.2	50.9	
V398	0-30	44	7.5	-	50.0	13.3	75.3	Sb-s
	30-100	56	7.5	-	17.5	8.2	37.7	
V402	0-35	41	7.6	-	62.8	10.0	57.8	Sb
	35-100	52	7.5	-	-	6.8	32.8	
V405	0-55	45	7.3	-	51.9	16.4	85.2	Sb-s
	55-100	57	7.4	-	-	9.6	46.0	

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area :** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V407	0-50	37	7.3	-	-	14.2	80.3	Sb-s
	50-100	45	7.3	-	-	9.7	50.0	
V418	0-30	37	7.3	-	-	22.0	117.5	Kh-s
	30-100	48	7.4	-	-	8.1	43.6	
V421	0-30	39	7.4	-	-	24.3	137.1	Kh-s
	30-100	46	7.5	-	-	9.7	53.8	
V424	0-35	49	7.3	-	-	12.9	70.5	Kh-s
	35-100	45	7.4	-	-	5.5	27.2	
V426	0-55	39	7.5	-	31.4	10.3	62.7	Kh
	55-100	45	7.5	-	-	10.6	31.3	
V434	0-20	31	7.6	-	-	5.4	73.4	Hs
	20-70	40	7.7	-	-	5.3	35.1	
	70-100	28	7.6	-	-	4.1	32.6	
V436	0-15	34	7.2	-	-	14.5	97.9	Sb
	15-55	37	7.5	-	44.7	7.0	39.2	
	55-100	55	7.5	-	-	7.5	33.3	
V442	0-20	39	7.6	-	48.0	20.2	117.5	Sb-s
	20-70	55	7.6	-	-	13.2	61.7	
V446	0-40	50	7.3	-	-	14.0	73.4	Kd
	40-90	52	7.3	-	-	10.2	55.8	
V451	0-40	39	7.3	-	-	24.0	127.3	Kd
	40-100	54	7.3	-	-	13.6	72.4	
V457	0-15	25	6.8	-	-	26.5	146.9	Kd
	15-55	34	7.3	-	-	14.5	94.9	
	55-100	57	7.3	-	-	16.7	81.3	
V461	0-50	35	7.7	-	-	6.5	29.4	Mq
	50-100	35	7.8	-	-	5.4	30.1	

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area:** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V464	0-50	35	7.8	-	-	3.2	9.6	Sb-w
	50-100	36	7.7	-	-	4.2	19.9	
V467	0-25	41	7.8	-	34.3	18.7	107.7	Kh-ws
	25-70	49	7.7	-	-	6.4	37.0	
	70-100	48	7.8	-	-	6.0	25.4	
V469	0-40	36	7.7	-	-	3.1	7.2	Kh
	40-100	41	7.7	-	-	3.0	7.0	
V470	0-40	36	7.5	-	-	22.8	124.8	Kh-s
	40-100	49	7.8	-	-	8.6	40.3	
V477	0-40	46	7.6	-	30.2	14.7	67.2	Kh
	40-100	47	7.7	-	-	7.6	37.0	
V493	0-30	55	7.4	-	7.2	12.9	66.2	Kh-s
	30-100	60	7.6	-	-	10.0	44.6	
V497	0-35	40	7.3	-	9.6	16.2	96.0	Kh-s
	35-100	43	7.6	-	-	8.2	52.8	
V499	0-45	35	7.5	-	17.6	14.6	93.1	Kh-s
	45-100	36	7.7	-	-	5.3	34.1	
V507	0-50	44	7.6	-	34.1	13.2	70.1	Kh-ws
	50-100	47	7.6	-	-	7.4	41.0	
V509	0-50	50	7.8	-	1.0	2.3	14.7	Kh-w
	50-100	55	7.7	-	-	4.5	19.7	
V512	0-50	20	7.8	-	-	5.4	43.0	Hs
	50-100	16	8.0	-	-	2.6	14.4	
V516	0-30	41	7.7	-	-	23.0	97.0	Kd
	30-70	51	7.6	-	-	15.7	83.0	
	70-100	52	7.6	-	-	13.4	66.0	

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area :** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V527	0-40	42	7.6	-	13.6	14.7	88.0	Kh-s
	40-100	43	7.9	-	-	5.4	29.5	
V534	0-25	50	7.2	-	14.4	22.2	108.8	Kh-s
	25-70	54	7.7	-	-	8.7	38.1	
	70-100	55	7.7	-	-	6.8	31.7	
V545	0-40	33	8.0	7.2	60.7	15.2	95.2	Sa
	40-75	67	7.6	17.5	-	10.3	48.1	
	75-100	67	7.6	34.4	-	8.2	33.6	
V549	0-30	21	7.8	-	1.6	4.2	34.9	Cc
V559	0-30	28	7.3	-	37.9	15.3	108.8	Sb
	30-70	36	7.7	-	33.6	4.1	27.7	
	70-100	48	7.6	-	-	6.7	31.0	
V568	0-35	32	8.0	-	76.2	12.2	78.9	Sb
	35-65	79	7.7	-	7.7	14.4	52.6	
	65-100	53	7.9	-	-	5.0	21.3	
V573	0-30	41	7.6	8.2	-	5.9	28.1	Is
	30-80	67	7.5	26.8	-	9.7	39.6	
	80-100	54	7.6	57.6	-	7.2	33.5	
V579	0-15	53	7.3	-	-	28.3	132.0	Kd
	15-50	53	7.2	-	-	7.0	37.7	
	50-100	55	7.4	-	-	22.2	99.0	
V582	0-35	40	7.5	-	-	13.6	82.0	Sm
	35-100	28	8.0	23.1	-	2.1	19.5	
V594	0-50	37	7.3	-	-	14.9	91.5	Sb
	50-100	51	7.5	-	-	9.0	42.4	
V600	0-30	37	7.3	-	13.8	10.3	69.5	Kh
	30-100	51	7.6	-	-	5.2	29.9	

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area : .** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V603	0-50	49	7.3	-	10.9	12.0	60.7	Kh
	50-100	52	7.4	-	-	8.4	42.1	
V608	0-70	23	7.6	-	-	4.5	22.2	Mq
	70-100	32	7.6	-	-	4.0	26.2	
V609	0-30	43	7.2	-	59.0	1 .1	67.6	Dm
V614	0-10	36	7.6	-	-	6.2	34.8	Is
	10-50	40	7.5	-	-	6.7	35.7	
	50-100	63	7.5	-	-	9.7	41.1	
V632	0-50	20	8.1	-	0.8	3.7	3.7	Hs
	50-100	32	7.8	-	18.5	3.9	20.3	
V635	0-50	20	8.1	-	0.9	0.3	5.6	Hs
	50-100	19	8.1	-	1.0	0.2	3.0	
V642	0-25	62	7.6	-	-	3.7	16.6	Kh
	25-50	60	7.6	-	-	2.4	12.3	
	50-75	65	7.7	-	-	2.8	12.0	
	75-100	67	7.6	-	-	4.0	14.3	
	100-150	70	7.6	-	-	14.7	19.2	
V643	0-25	43	7.3	-	-	7.2	67.0	Kh
	25-50	52	7.5	-	-	5.2	32.4	
	50-75	54	7.5	-	-	4.3	23.2	
	75-100	54	7.6	-	-	3.8	19.2	
	100-150	49	7.7	-	-	17.3	19.2	
V648	0-40	33	7.1	-	-	6.4	82.0	Kh-s
	40-100	34	7.6	-	-	11.7	41.0	
V651	0-40	34	7.3	-	-	5.9	61.0	Kh
	40-100	46	7.4	-	-	5.8	30.5	

dc

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area:** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V654	0-30	40	7.4	-	-	10.7	57.0	Kh
	30-100	48	7.3	-	-	6.2	21.2	
V655	0-40	44	7.2	-	5.3	14.4	70.7	Kd
	40-100	48	7.4	-	-	5.7	35.3	
V659	0-40	41	7.1	-	-	18.4	86.4	Kd
	40-100	46	7.4	-	-	7.7	40.8	
V669	0-40	53	7.3	-	3.3	7.6	39.4	Kh
	40-100	53	7.2	-	5.1	11.6	54.7	
V674	0-20	43	7.2	-	-	14.6	70.1	Kh
	20-100	50	7.4	-	-	9.6	47.0	
V676	0-40	36	7.3	-	8.9	16.2	81.6	Bw
	40-100	42	7.4	-	2.6	7.1	42.2	
V678	0-20	28	7.2	-	13.8	12.8	73.6	Kh-ws
	20-65	33	7.5	-	-	5.7	41.8	
	65-100	32	7.6	-	-	2.9	29.3	
V682	0-25	29	7.2	-	-	19.7	91.2	Kh-s
	25-70	35	7.6	-	-	5.5	43.2	
	70-100	31	7.6	-	-	5.4	37.0	
V701	0-65	38	7.4	-	-	11 .7	59.5	Sb
	65-100	52	7.6	-	-	6.7	33.1	
V727	0-30	44	7.6	-	-	7.1	35.0	Kh
	30-60	42	7.5	-	-	11.2	55.7	
	60-100	41	7.7	-	-	5.3	29.3	
V729	0-25	32	7.6	35.2	19.1	3.1	13.3	Kh
	25-60	38	7.7	31.7	17.0	2.7	17.1	
	60-100	35	7.6	28.0	23.1	2.6	9.6	

Table C.2 (continued)

Bahrain Routine Laboratory Data **Area :** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V731	0-30	49	7.7	-	0.5	1.8	10.8	Kh-w
	30-100	60	7.6	-	Nil	1.4	11.3	
V735	0-20	24	7.7	-	2.0	1.7	13.0	Hs
	20-55	22	7.8	-	1.4	1.1	8.5	
	55-100	27	8.0	-	1.3	1.0	5.6	
V739	0-50	53	7.4	-	11.7	10.2	46.0	Kh
	50-100	43	7.6	-	3.4	7.1	36.2	
V740	0-50	38	7.7	-	10.6	3.1	11.0	Kh-w
	50-100	28	7.9	-	5.9	1.2	11.5	

Table C.3

Bahrain Routine Laboratory Data **Area :** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC	ECe	Soil Series
Z002	0-40	50	7.0	29.5	30.1	16.7	68.9	Sb
	40-60	72	7.5	45.2	2.7	10.0	38.9	
	60-100	72	7.4	64.4	1.3	10.0	38.0	
Z003	0-35	44	7.6	6.8	74.9	13.5	67.8	Mq
	35-70	49	7.6	10.1	71.2	8.0	36.7	
	70-100	61	7.5	54.1	11.7	8.0	30.6	
Z005	0-15	-	-	-	-	-	-	Sb
	15-45	44	7.5	7.2	72.4	20.4	55.4	
	45-100	57	7.6	62.0	3.0	9.0	40.8	
Z008	0-45	50	7.5	20.9	37.2	9.7	41.3	Sb
	45-100	57	7.4	40.7	5.8	7.2	35.3	
Z009	0-50	82	7.6	55.2	15.6	6.6	22.8	Kd
	50-100	77	7.5	53.5	3.8	7.5	27.2	
Z011	0-45	48	7.7	7.4	67.8	3.1	9.6	Sb-w
	45-100	73	7.6	41.6	32.5	3.6	10.0	
Z016	0-35	31	7.3	6.8	59.2	11.8	67.4	Sb
	35-70	50	7.3	18.9	33.2	10.0	45.7	
	70-100	42	7.3	30.7	1.5	6.9	36.4	
Z021	0-45	29	7.5	14.0	30.5	7.0	38.6	Sb
	45-100	46	7.5	58.9	3.8	6.2	28.0	
Z022	0-50	23	7.9	19.3	-	0.3	-	Hs
	50-100	11	7.9	18.7	-	1.4	10.0	
Z026	0-20	44	7.5	14.2	66.2	10.7	49.0	Sb
	20-50	50	7.5	47.3	27.6	6.0	24.5	
	50-100	56	7.5	56.4	20.2	5.6	21.4	

Table C.3 (continued)

Bahrain Routine Laboratory Data **Area:** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC	ECe	Soil Series
Z027	0-20	44	7.8	22.4	37.3	17.3	68.5	Sb
	20-50	42	7.6	33.7	2.9	9.2	41.3	
	50-100	55	7.6	41.9	3.5	9.5	38.6	
Z028	5-50	42	7.3	12.1	55.4	12.5	57.6	Sb
	50-100	51	7.4	51.7	4.4	9.7	42.4	
Z032	0-50	36	7.2	2.7	79.6	14.1	65.2	Kd
	50-100	62	7.4	68.4	4.8	10.2	40.8	
Z034	0-50	42	7.7	9.2	71.3	8.0	35.9	Sb
	50-70	65	7.6	55.6	10.3	7.6	27.2	
	70-100	62	7.5	68.4	7.1	9.7	33.7	
Z038	0-50	25	7.4	12.9	4.3	5.1	30.4	Hs
	50-100	24	7.5	18.7	1.7	2.8	19.0	
Z048	0-30	48	7.5	9.3	79.8	15.5	57.6	Kd
	30-70	61	7.7	54.1	16.8	8.4	29.3	
	70-100	71	7.4	52.8	8.9	10.0	34.2	
Z050	0-50	37	7.5	24.9	14.0	11.2	53.3	Kh
	50-70	34	7.6	27.2	4.1	8.7	40.2	
	70-100	39	7.5	37.1	3.5	8.2	39.1	
Z052	0-15	54	7.8	-	10.5	3.5	11.3	Kh
	15-40	38	7.8	-	11.6	3.1	8.0	
	40-100	36	7.7	-	1.3	1.7	8.7	
Z059	0-50	38	7.3	27.2	11.2	9.7	43.5	Kh
	50-70	35	7.5	27.9	3.9	7.3	33.5	
	70-100	47	7.7	66.6	3.0	4.2	17.9	
Z062	0-50	20	7.8	19.7	2.0	2.2	9.5	Hs
	50-100	23	7.8	21.0	2.6	2.5	7.5	

Table C.3 (continued)

Bahrain Routine Laboratory Data **Area:** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC	ECe	Soil Series
Z065	0-40	44	7.5	15.5	44.5	11.7	48.0	Sb
	40-60	42	7.5	27.2	19.2	8.9	35.3	
	60-100	47	7.5	41.6	4.2	7.2	27.9	
Z070	0-20	35	8.1	-	77.8	6.5	28.8	Is
	20-60	75	7.6	-	3.5	10.6	38.8	
	60-90	54	7.4	-	2.8	9.5	38.3	
Z071	0.30	36	7.2	2.1	79.7	12.7	57.5	Sa
	30-55	99	7.2	37.9	9.1	10.5	33.5	
	55-95	65	7.4	74.8	2.4	6.2	23.9	
Z075	0-40	36	7.5	6.9	61.9	4.2	20.5	Is
	40-90	54	7.8	30.2	21.2	7.4	30.3	
Z088	0-50	35	7.7	3.1	89.1	4.1	17.8	Mg
	50-100	48	7.8	14.6	64.3	4.6	18.5	
Z092	0-30	49	7.2	35.4	19.8	10.4	46.8	Kh
	30-100	51	7.3	46.6	2.7	4.0	17.2	
Z094	0-40	37	7.2	-	15.7	9.9	45.8	Kh
	40-80	44	7.3	-	3.2	6.5	33.0	
	80-100	64	7.4	-	3.0	6.6	25.5	
Z098	0-30	41	7.6	1.3	78.7	6.9	35.6	Sa
	30-60	77	7.5	26.0	14.7	9.4	30.9	
	60-100	67	7.5	52.0	12.5	6.6	25.0	
Z100	0-40	36	7.9	1.3	82.7	5.2	26.1	Mg
Z103	0-15	35	7.6	6.2	71.3	9.7	50.0	Is
	15-50	45	7.4	13.9	59.4	9.5	41.5	
	50-100	64	7.4	43.7	15.6	9.9	35.6	

Table C.3 (continued)

Bahrain Routine Laboratory Data **Area :** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC	ECe	Soil Series
Z114	0-40	26	8.0	16.2	1.1	1.8	12.4	Hs
	40-80	28	8.0	13.3	16.1	2.8	11.4	
	80-90	30	7.8	11.4	25.9	3.7	18.1	
Z116	0-55	50	7.9	-	52.6	5.3	20.7	Mq
	55-100	42	7.8	-	53.7	4.0	15.6	
Z121	0-55	25	7.7	-	26.0	2.5	8.7	Br
	55-100	33	7.7	-	20.5	3.0	12.7	
Z134	0-30	24	8.0	-	7.9	2.2	4.0	Br-q
	30-95	48	7.9	-	52.6	3.4	11.6	
Z136	0.30	29	8.1	-	7.9	2.7	9.7	Br-q
	30-60	40	7.8	-	52.6	4.8	23.1	
	60-100	57	7.6	-	4.7	6.9	27.2	
Z144	0-35	23	8.0	-	1.6	1.7	2.7	Br-q
	35-70	29	7.8	-	-	2.4	3.8	
	70-100	29	7.8	-	-	3.1	11.7	
Z150	0-30	23	7.8	-	24.2	2.3	4.5	Zn
	30-70	21	7.9	-	-	2.8	9.8	
	70-100	24	7.7	-	-	2.9	14.0	
Z158	0-35	35	7.6	9.7	46,9	9.4	48.0	Zn
	35-70	55	7.6	35.1	8.5	7.0	26.0	
Z161	0-30	31	7.6	-	-	4.5	27.0	Dm
Z169	0-25	32	7.5	-	-	3.1	11.4	Mq
	25-100	28	7.4	-	-	3.1	13.6	
Z178	0-50	49	7.1	-	20.0	9.7	42.0	Kh
	50-100	51	7.2	-	-	8.2	32.0	

Bahrain Routine Laboratory Data **Area:** Salmabad

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC	ECe	Soil Series
Z182	0-15	63	7.2	-	-	16.9	58.0	Kh
	15-50	59	7.0	-	-	14.2	54.0	
	50-100	66	6.9	-	-	17.4	58.0	
Z188	0-20	36	7.5	34.1	4.9	3.0	10.4	Sa
	20-65	47	7.5	-	-	3.2	9.3	
	65-100	50	7.3	-	-	3.5	11.5	
Z189	0-45	44	7.5	-	57.8	3.5	10.2	Sa
Z191	0.45	33	7.4	-	55.7	9.3	49.0	Is
	45-50	52	7.3	-	-	7.4	29.0	
Z194	0-50	26	7.9	-	-	2.6	6.6	Mg-n
	50-100	32	7.8	-	-	3.2	11.0	
Z198	0-50	38	7.6	-	48.2	3.3	10.4	Sa
	50-100	38	7.5	-	80.1	3.2	9.9	
Z201	0-20	27	7.6	-	63.1	3.2	11.2	Sa
	20-60	27	7.7	-	80.2	2.8	9.0	
	60-100	80	7.5	-	-	4.3	11.0	
Z202	0-25	31	7.5	-	28.8	3.3	11.8	Kh
	25-75	54	7.4	-	3.3	3.3	10.6	
	75-100	22	7.5	-	-	1.5	9.3	
Z205	0-20	40	7.3	-	5.1	4.4	17.5	Sa
	20-45	33	7.4	-	53.7	3.6	14.2	
	45-75	37	7.4	-	-	3.9	14.0	
Z210	0-50	27	7.3	-	26.6	7.4	41.0	Sa
	50-100	31	7.5	-	48.2	3.7	15.8	
Z214	0-50	-	-	-	-	-	-	Kh
	50-70	49	7.4	-	-	4.2	14.7	
	70-100	57	7.2	-	-	2.9	12.8	

Table C.4

Bahrain Routine Laboratory Data **Area:** Buhayr

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V014	0-25	29	7.5	-	26.9	10.3	43.1	Bu
	25-45	32	7.6	-	22.5	9.8	40.0	
	45-100	30	7.6	-	7.4	8.0	31.0	
V015	0-25	36	7.3	-	57.9	16.5	50.0	Bu
	25-60	35	7.5	-	55.3	12.0	44.0	
	60-110	25	7.6	-	71.3	9.0	31.0	
V016	0-40	27	7.2	-	56.1	26.0	65.0	Bu
	40-100	36	7.0	-	61.2	9.8	34.0	
V017	0-60	42	7.2	-	43.9	11.4	34.0	Bu
	60-100	48	7.0	-	58.0	12.9	40.0	
V018	0-45	71	7.1	-	25.0	19.9	35.0	Is
	45-100	98	7.1	-	3.2	18.9	35.0	
V123	0-20	31	7.4	-	-	6.5	41.0	Is
	20-65	77	7.4	-	-	9.2	35.6	
	65-100	-	-	-	-	-	-	
V124	0-45	49	7.1	-	-	16.4	63.8	Is
	45-100	55	7.5	-	-	6.8	27.1	
V130	0-25	26	6.7	-	-	18.6	77.1	Is-s
	25-50	52	7.3	-	-	13.6	56.4	
	50-90	39	7.3	-	-	8.5	44.7	
V137	0-50	44	7.4	-	45.5	9.7	41.2	Bu
	50-100	40	7.5	-	19.2	9.2	45.6	
V139	0-10	-	-	-	-	-	-	Is-s
	10-50	63	7.1	-	3.0	18.9	68.9	
	50-100	56	7.4	-	5.6	9.9	41.7	

Table C.5

Bahrain Routine Laboratory Data **Area:** Hawrat 'Inqa

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V001	0-35	23	8.1	-	5.1	4.1	16.6	Ws
	35-100	23	8.4	-	1.9	3.4	17.6	
V002	0-25	24	7.9	-	1.6	6.4	7.9	Ws
	25-70	22	7.9	-	1.6	4.4	7.9	
V005	0-10	35	7.6	-	-	19.1	55.8	Ws
	10-50	22	8.1	-	-	2.6	20.6	
	50-100	22	8.2	-	-	3.6	23.5	
V006	0-25	26	8.1	-	52.7	6.5	27.4	Ws-g
	25-70	26	8.0	-	47.1	5.8	25.5	
	70-100	23	7.9	-	5.9	4.8	24.0	
V007	0-45	24	8.0	-	-	2.7	20.6	Ws
	45-100	22	8.2	-	-	1.3	10.5	
V008	0-30	25	7.9	-	8.8	2.6	4.2	Hs
	30-100	24	7.0	-	3.6	2.5	4.6	
V009	0-20	25	7.9	-	18.2	2.6	2.6	Hw
	20-70	25	7.9	-	9.3	2.5	2.7	
V010	0-30	25	8.0	9.2	25.1	3.1	8.0	Hw
	30-100	31	8.1	15.0	13.3	3.6	11.2	
V741	0-40	21	8.0	-	5.0	0.6	7.2	Hs
	40-100	18	8.0	-	5.0	0.4	11.1	
V746	0-15	26	7.9	-	3.9	2.3	3.9	Hw
	15-50	26	7.5	-	25.1	2.4	4.1	
	50-100	29	7.8	-	31.7	3.1	11.9	
V750	0-40	20	8.0	-	-	3.6	21.2	Hs
	40-100	25	7.8	-	-	1.9	9.9	
V752	0-40	30	7.9	-	-	3.1	3.2	Hs
	40-100	23	8.2	-	-	0.5	7.2	

Table C.5 (continued)

Bahrain Routine Laboratory Data **Area:** Hawra 'Inqa

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
V755	0-10	23	7.6	19.8	1.4	8.7	90.0	Hs
	10-50	24	8.1	21.0	1.0	1.3	16.7	
	50-100	25	8.0	20.6	1.0	1.3	15.5	
V758	0-15	33	8.2	16.9	3.1	4.1	19.8	Hs
	15-50	26	8.3	20.0	1.3	1.0	10.0	
	50-100	26	8.0	16.3	1.0	0.7	5.7	
V761	0-55	38	7.9	6.7	60.8	4.7	22.2	An
	55-70	46	7.7	21.4	8.4	4.6	20.4	
	70-100	24	7.8	20.3	1.5	1.7	9.2	
V766	0-15	32	7.9	5.7	74.2	2.4	3.1	An
	15-60	38	7.9	13.3	16.1	2.5	4.4	
	60-100	28	8.0	23.2	3.2	2.4	5.5	
V770	0-20	43	7.4	-	4.4	29.5	150.0	Ws-s
	20-70	22	8.1	-	1.0	2.2	24.7	
	70-100	28	8.1	-	1.0	2.1	21.2	
V774	0-15	26	8.2	13.9	19.6	6.5	52.0	Ws
	15-45	23	8.1	21.8	1.3	2.9	20.2	
	45-100	26	8.3	18.4	1.2	0.7	7.0	
V778	0-10	23	8.1	-	76.3	11.1	46.0	Ws-g
	10-35	40	7.8	-	6.0	12.8	76.0	
	35-100	21	8.0	-	1.0	3.2	36.5	
V781	0-15	22	7.8	-	55.8	18.2	145.0	Ws-g
	15-35	36	7.8	-	11.9	10.7	68.0	
	35-100	25	7.9	-	-	3.5	42.0	
V788	0-50	27	8.1	19.2	-	2.4	8.7	Hs
	50-100	21	8.2	22.8	-	2.1	9.9	

D
Water Analysis

D.1 INTRODUCTION

Samples collected from shallow watertables were analysed for soluble ions, using the methods in Appendix A. The results are given in Table D.1. Analyses of typical irrigation waters are provided (Table D.2) for comparison. Gypsum saturation, as a percentage of the equilibrium saturation at the temperature of sampling (30°C), has been calculated using the Debye-Huckel (Garrels and Christ, 1965) method which is valid for salinities up to about 16.0 mmhos cm^{-1}. Many of the water and soil extract samples have salinities exceeding this value and thus gypsum saturation figures for these indicate only relative degrees of saturation.

D.2 DISCUSSION

The shallow groundwater is extremely saline and dominated by sodium and chloride ions. The waters are all gypsum saturated, and often supersaturated. As irrigation and drainage are expanded within the area the salinity of the shallow groundwater can be expected to decline as the soluble salts are removed and diluted by leaching water from irrigated areas.

The Khobar water, which will probably be used for the initial stages of irrigation, has relatively low gypsum saturation (24 per cent) and can therefore be expected to dissolve gypsum in the soil. The Khobar-Rus waters (Table D.2), which are widely used at present, have a greater degree of gypsum saturation. The soil saturation extracts (Table D.3) appear to be super-saturated with gypsum although at the prevailing salinities the method of calculation can provide only a general indication of gypsum saturation.

Artificial drainage and prolonged irrigation with relatively low gypsum saturation water, such as Khobar, will inevitably result in solution of gypsum, although the considerable soil reserves (Table D.3) will largely buffer the effects of solution. In low-gypsic fine loamy soils, such as Khuways series, the long term effect would be an overall reduction in gypsum contents and their redistribution down the profile. Redistribution could also be expected in Hisham series but in view of their relatively low gypsum saturation this could be accompanied by some precipitation of gypsum from the irrigation water. The highly gypsic soils would be especially at risk of solution and collapse, particularly if the saturation of the subsurface drainage waters declines significantly.

In the absence of any drained irrigation schemes on highly gypsic soils using low gypsum saturation irrigation water, it was not possible to verify the effects of drainage and irrigation with Khobar water. However, as overall salinity values are reduced the solubility of the soil gypsum will decline and gypsum saturation percentages will remain high. This reduction in solubility will to some extent reduce the hazard of solution collapse on irrigated lands.

Table D.1 Shallow Watertable: Soluble Ion Contents

Location	Soil Series	Depth (m)	EC	Meq. per Litre							ppm			Gypsu Sat. (%)
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	NO_3^{-}	B^{+}	F^{+}	
PV010; Tubli Estuary	Tubli	0.8	49.9	68.8	118.5	581.0	16.9	3.1	63.8	718.3	2.48	3.2	0.6	99.9
PV051; Buri, Loam Plain	Khuways	1.8	25.9	55.0	55.0	240.3	12.9	6.1	78.1	279.0	7.44	2.9	2.1	169.1
Z009; Sar, Nebkha Margin	Swamp	0.2	23.2	50.0	73.0	211.1	9.4	9.7	85.9	247.9	4.96	2.4	2.0	-
PV019: Sar, Loam Plain	Khuways	1.8	41.2	88.8	103.5	444.7	18.6	5.9	66.7	577.5	2.48	3.1	1.7	153.0
Z046; Sar, Nebkha Margin	Abu Saybi	2.3	16.7	55.0	31.2	135.0	3.2	2.4	47.1	175.0	9.92	1.0	0.7	144.5
V161; Nebkha Plain	Maqabah	1.5	30.3	62.2	79.3	292.0	10.4	2.5	70.6	370.4	1.20	-	-	-
PV033; Nebkha Margin	Sar	1.7	13.1	36.3	28.5	83.8	5.0	5.8	39.4	109.8	3.72	-	-	-
PV042; Nebkha Plain	Maqabah	2.0	12.3	39.5	30.0	75.9	2.0	3.2	46.5	99.1	3.72	-	-	-
PV044; Khadarah Depression	Khadarah	1.0	28.2	60.6	42.5	286.2	6.9	3.2	28.8	355.0	0.62	-	-	-
PV047; Nebkha Margin	Khadarah	1.0	17.2	57.5	44.7	153.1	6.3	4.4	69.2	189.7	1.86	-	-	-
PV050; Salmabad Plain	Isa	2.0	18.0	62.6	28.0	147.6	3.6	4.3	52.2	187.1	1.86	1.4	-	-
V464; Loam Plain	Khuways (irrigated)	1.0	14.8	42.5	40.5	105.9	4.3	3.9	50.0	140.9	135.1	82.3	-	-
PV004; Coastal Plain, Hawrat 'Inqa	Wasmiyah	1.2	15.2	34.5	32.1	118.4	5.0	3.6	48.3	139.6	4.34	1.3	-	-

Note: Calculation of gypsum saturation becomes inaccurate above an EC of 16.0 mmhos/cm.
No $CO_3^{=}$ present in any samples.

Table D.2 Typical Irrigation Water: Soluble Ion Contents

Water Type	EC	meq. per litre							B	Gypsum Sat. %	Sodium Absorption Ratio
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	CL^{-}	ppm	($30^{o}C$)	
Khobar Aquifer:											
Hamalah Scarp (561)	3.8	12.1	7.5	20.5	0.9	2.9	11.5	25.1	0.7	24.0	6.55
Khobar affected by Rus Aquifer:											
Buri (404)	8.8	28.8	17.2	62.5	1.7	3.0	29.8	76.2	1.2	78.8	13.03
Ali (291)	12.9	37.5	24.0	98.8	3.0	3.0	24.1	135.7	1.7	65.2	17.82

Source: Annex, Groundwater Studies.

Table D.3 Gypsum Saturation of Soil Extracts

Site	Series	Depth	EC_e	Gypsum Saturation % (30°C)	Soil Gypsum %	
PV010	Tubli	0- 20	81.9	72.9	14.8	Abandoned
		20- 90	45.8	76.6	1.5	
		90-110	27.6	173.5	1.5	
PV044	Khadarah	0- 25	96.0		77.6	Abandoned
		25- 60	32.6		0.9	
		60-100	20.6		0.9	
		100-150	34.1		0.8	
PV003	Hawrah	0- 15	4.7	192.4	5.1	Unused
		15- 55	10.0	140.7	47.1	
		55- 80	13.1	146.3	20.0	
		80-130	15.9	135.8	10.0	
PV018	Maqabah	0- 20	22.2		91.6	Unused
		20- 50	18.0		81.6	
		50- 70	15.2		72.0	
		95-125	26.0		75.1	
PV013	Buhayr	0- 45	31.9	148.2	59.6	Unused
		45-110	33.0	157.0	81.6	
		110-200	34.0	145.0	87.7	
PV007	Sar	0- 40	19.3	188.8	60.0	Unused
		40- 70	21.0	154.0	17.7	
		70-100	29.9	142.5	2.1	
		100-130	14.6	157.3	1.3	
PV020	Abu Saybi	0- 30	38.3		66.5	Abandoned
		30- 60	40.4		74.9	
		60- 65	44.7		12.5	
		65- 95	37.2		0.4	
V464	Abu Saybi	0- 50	9.6		na	Irrigated
		50-100	18.9		na	
PV017	Khuways	0- 20	66.7	160.0	31.0	Abandoned
		20- 80	38.7	174.0	19.2	
		80-135	27.0	167.2	1.9	

Table D.3 (Continued)

Site	Series	Depth	EC_e	Gypsum Saturation % (30°C)	Soil Gypsum %	
V642	Khuways	0- 25	16.6		na	Irrigated
		25- 50	12.3		na	
		50-100	13.0		na	
PV009	Khuways	0- 40	36.5	164.1	4.5	Fallow
		40- 90	21.9	146.5	3.1	
		90-110	9.9	114.7	0.9	
		110-180	9.7	122.0	0.8	
PV001	Areen	0- 15	15.2	209.0	57.0	Unused
		15- 35	8.0	138.9	72.8	
		35- 60	10.0	150.1	2.8	
		60-150	3.9	108.9	1.3	
PV011	Salmabad	0- 15	50.1	161.4	32.5	Unused
		15- 35	38.1	150.6	12.9	
		35- 70	30.2	86.0	0.8	
PV015	Isa	0- 25	61.5	133.9	2.1	Unused
		25- 55	37.8	148.1	0.4	
PV016	Hisham	0- 50	30.6	151.2	7.4	Unused
		50- 65	25.2	152.2	11.8	
		65-150	18.3	174.1	7.9	
Z062	Hisham	0- 50				Irrigated
		50-100				
PV004	Wasmiyah	0- 15	56.8	91.1	2.8	Unused
		15- 80	16.2	19.0	1.1	
		80.120	13.6	45.3	1.1	

Source: Appendices B and C; selected profiles.

Note: Calculation of gypsum saturation becomes inaccurate above an EC of 16.0 mmhos cm^{-1}.

E

Soil Physical Tests

E.1 INFILTRATION

E.1.1 Methods

Infiltration tests were performed at 20 sites representative of the major soil units, using double ring infiltrometers. The method involves the use of two metal cylinders of approximately 300 and 600mm diameter, arranged concentrically and pushed into the soil surface to a depth of some 50mm. The soil surface in the central ring was fractured with a knife to simulate cultivation. Water was then added to the inner and outer rings and records kept of the volume of water required to be added to the central ring to maintain a constant head of 100mm. The water in the outer ring was maintained at the same level as that in the inner ring. Tests at each site were carried out in triplicate, using three double ring sets spaced 5.0m apart from each other. Infiltration was calculated as cumulative intake (mm) against time, using mean values for the three rings for each lapsed time interval. The earlier tests were run for a period of six to seven hours but the slow decline in infiltration rates showed this length of time to be unnecessarily long and tests were subsequently reduced to four hour duration.

Test sites were located on irrigated fields, fallows and non-cultivated land, in order to assess the effects of leaching and cultivation on intake rates.

E.1.2 Results and Discussion

Results for the infiltration tests, representing mean values for the three infiltrometers at each site, are shown as cumulative infiltration curves in Figures E.1, E.2 and E.3. These are broadly grouped according to gypsic, fine loamy and sandy soil series. Figures E.4, E.5 and E.6 show cumulative infiltration on a logarithmic scale.

As is normal with infiltration tests, there is considerable variation between test results, reflecting differences in antecedent moisture conditions, subsoil compaction or cementing, cultivation history and the existence of isolated coarse pores or root channels in the soil. High watertables proved to be the chief factor

limiting infiltration in cultivated areas. In fields with a watertable at 40-50cm depth water intake was severely restricted (site V732a) as compared with adjacent fields where the watertable was deeper (V732b).

In soils with high rates of infiltration the critical range for basin irrigation design lies within the first 15 to 20 minutes of the test. However, this is the very period during which the double-ring method is at its least accurate. At the start of the test all three sets of rings should be filled simultaneously, but even with a three man team this is difficult to achieve. Similarly, inaccuracies due to lateral flow from the central ring are probably at their greatest at the start of the test. Nevertheless, under normal circumstances the errors that inevitably occur in the initial period are evened out over the remainder of the test period. To obtain more accurate measurements after such brief lapsed times it would be preferable to use some form of constant head device and to pre-wet the test site to standardise moisture conditions.

E.2 MOISTURE RETENTION AND AVAILABLE WATER

E.2.1 Introduction

The available water capacity (AWC) of a soil is defined as that portion of the total waterholding capacity which is available to roots to sustain plant life. To absorb water from the soil the plant root has to overcome suction forces which hold the water in the soil. The principal forces are divisible into the matric suction, caused chiefly by surface tension within the soil pores, and the osmotic suction due to salts dissolved in the soil solution.

(a) Matric Suction

The matric suction forces increase with decreasing soil moisture content, from the point where water is freely available - the lower limit of availability - to the point where the plant is no longer able to extract moisture rapidly enough to sustain life - the permanent wilting point (PWP) or upper limit of availability. The difference between soil moisture contents at these two limits provides an estimate of the AWC of

Figure E.1 Cumulative Infiltration: Gypsic Soils

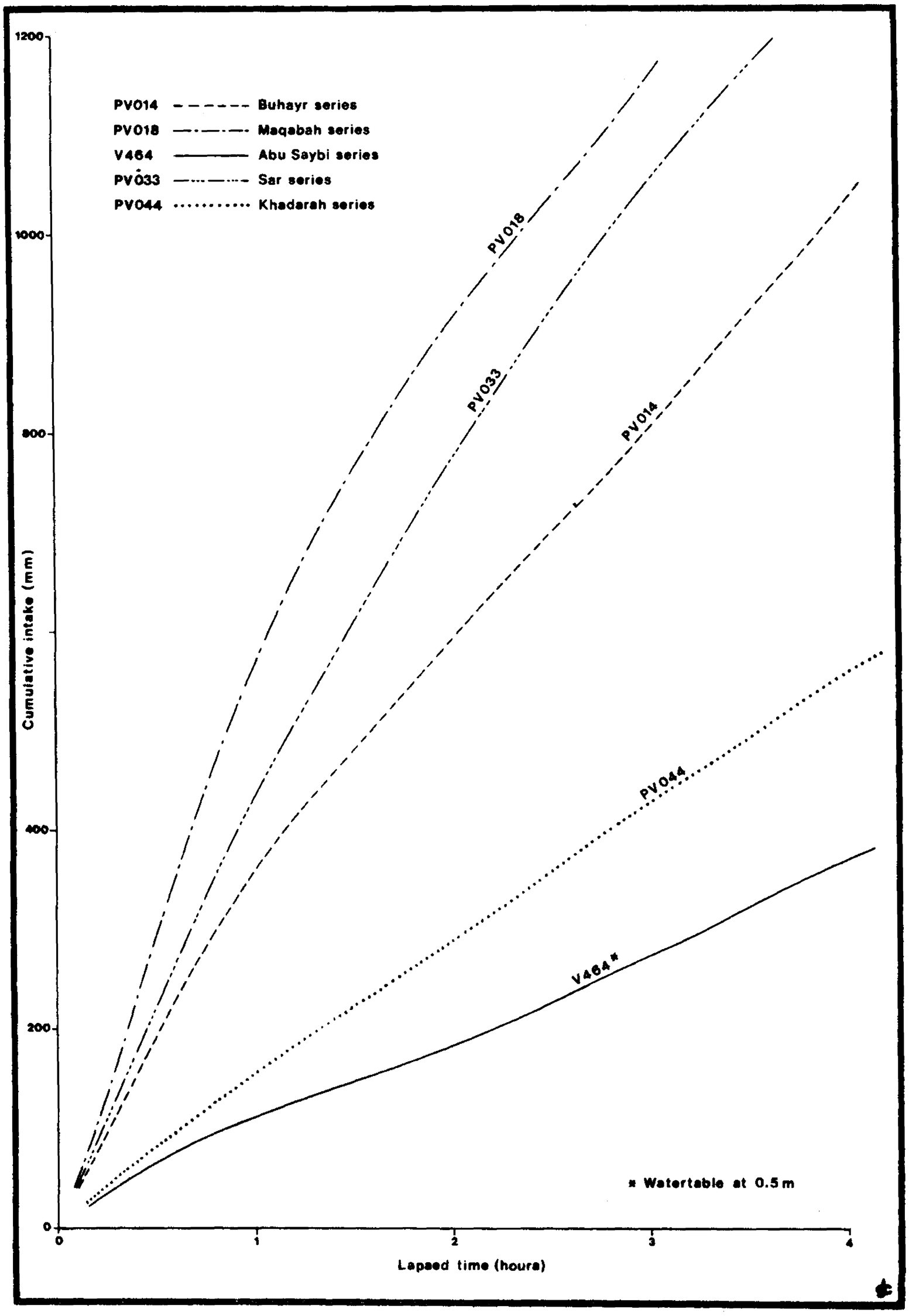


Figure E.2 Cumulative Infiltration: Fine Loamy Soils

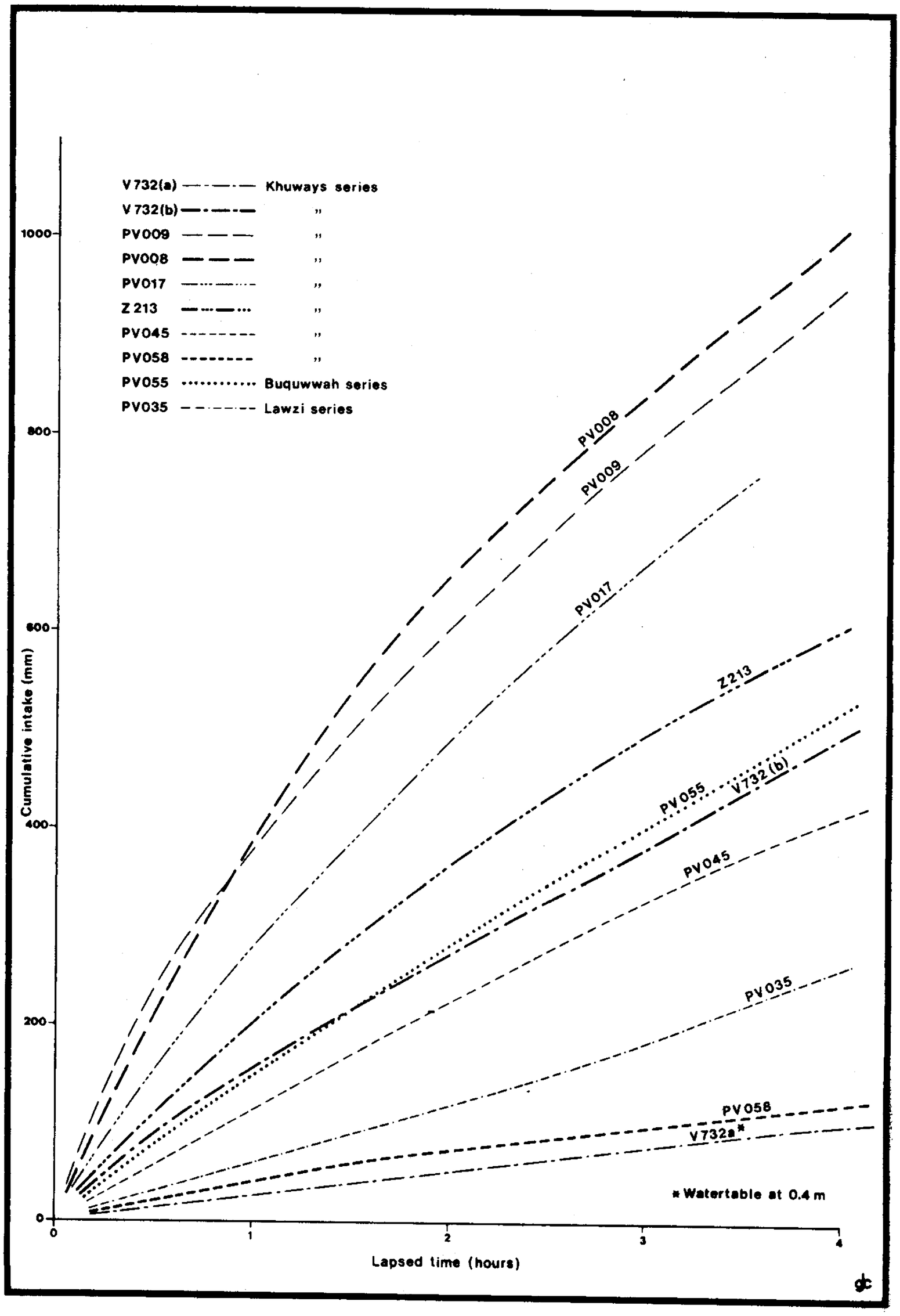


Figure E.3 Cumulative Infiltration: Sandy Soils

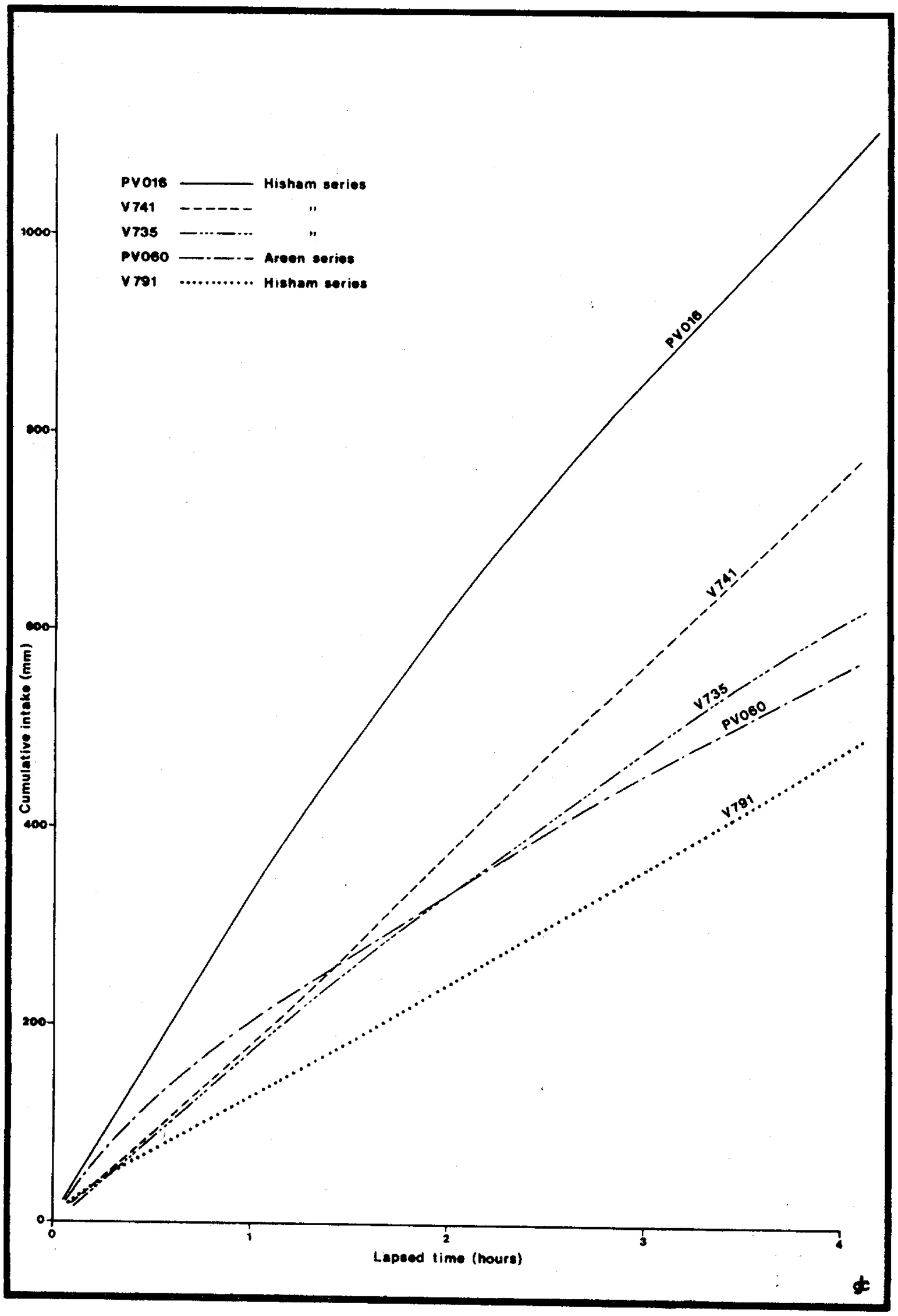


Figure E.4
Cumulative Infiltration (Logarithmic): Gypsic Soils

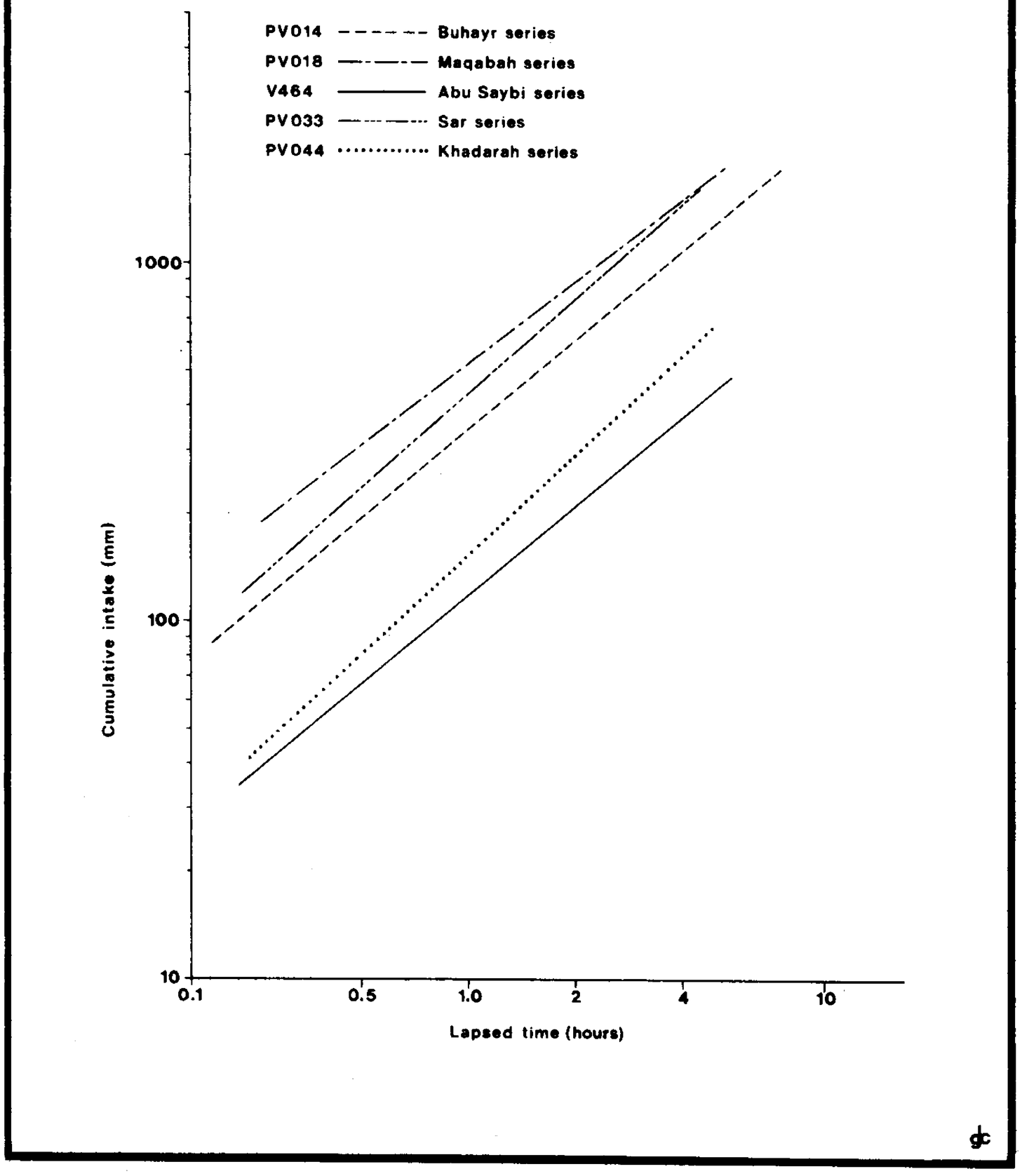


Figure E.5
Cumulative Infiltration (Logarithmic): Fine Loamy Soils

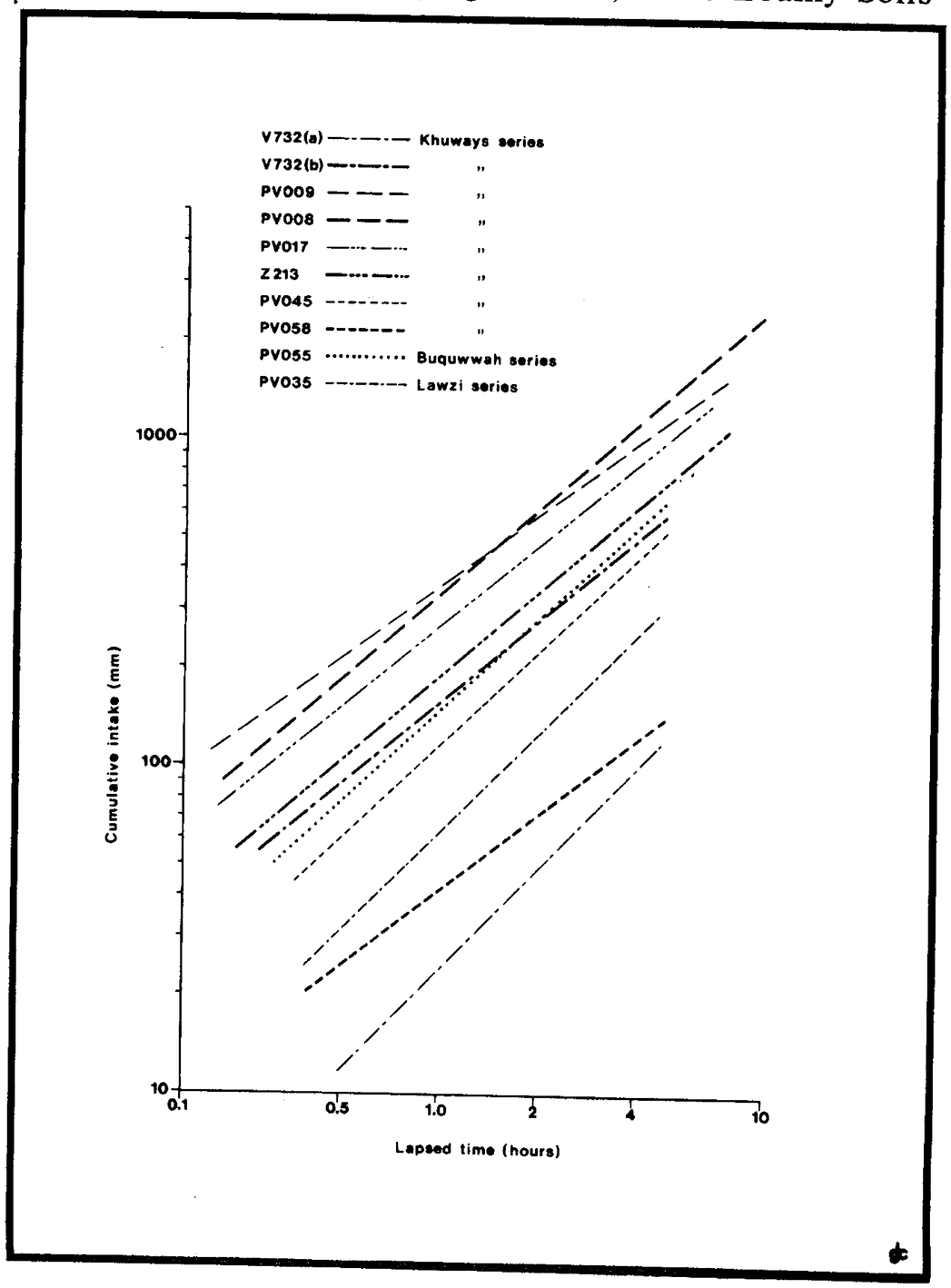
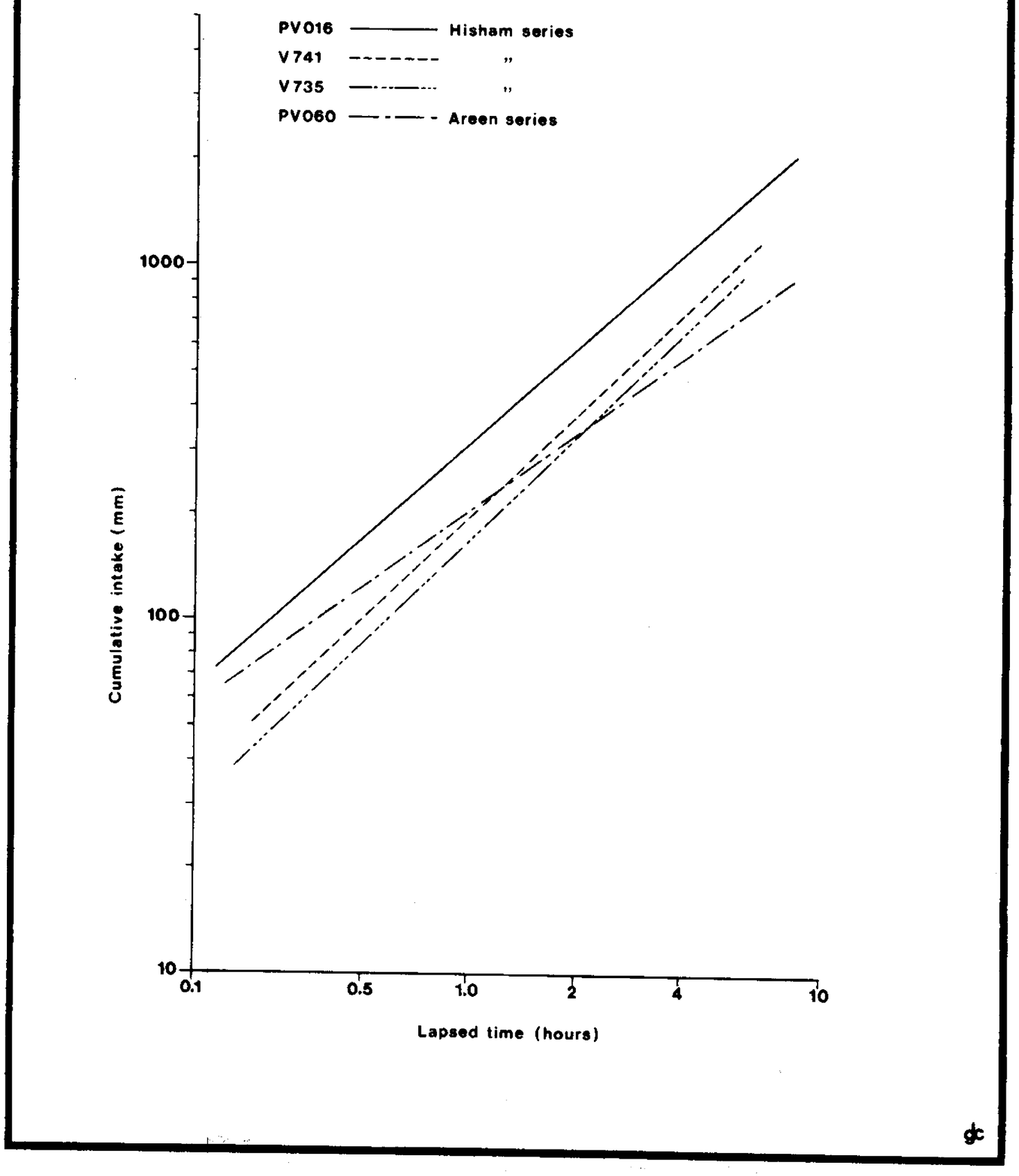


Figure E.6
Cumulative Infiltration (Logarithmic): Sandy Soils



the soil. The limits are usually expressed in terms of the suction head against which the water is held in the soil, measured in bars (1 bar is equivalent to a head of 10m of water or 0.75m of mercury).

Measurements of the moisture retained against a range of suctions were determined in the laboratory (Appendix A) using undisturbed core samples from profile pits representative of seven different soil series. The suctions used (0, 0.1, 0.3, 1.0 and 15 bar) were intended to simulate the effects of plant roots during moisture uptake.

(b) Osmotic Suctions

The preceding definitions refer to the moisture retained against soil matric suctions and take no account of the additional retention forces due to osmotic suction arising from dissolved salts in the soil solution. This suction is equivalent to 0.36 bar for every 1.0 mmho cm^{-1} of EC at the prevailing moisture content. As the soil moisture content is depleted by evapotranspiration, so the EC of the soil solution increases. Thus the contribution by osmotic suction has to be calculated at each point in the moisture range.

Using non-saline irrigation water, soil salinity is minimised by leaching and therefore osmotic suctions are usually ignored as being insignificant as compared with matric suctions. In Bahrain, however, water quality is poor and even by using the best water (3.8 mmhos cm^{-1}) irrigated soils will remain relatively saline. Under these conditions the osmotic effects of salinity must be considered.

E.2.2 Definition of Parameters (Matric Suctions)

In order to estimate the AWC of a soil it is first necessary to define the upper and lower limits of availability. The upper matric suction limit, or permanent wilting point (PWP) is generally

accepted as being the moisture retained against a suction of 15 bar. The lower limit, or field capacity (FC), is usually defined as the moisture content at which a previously saturated soil ceases to drain under gravity. FC cannot be related to a precise matric suction and reproducible measurements are difficult to obtain. It is conventionally accepted as approximating to a soil matric suction of between 0.05 and 0.3 bar, depending on soil porosity characteristics, capillary conductivity and soil temperature (Russell, 1976; Stakman, 1974).

Attempts were made to measure FC in the field. Soil plots were saturated, covered with plastic sheeting and soil moisture contents were determined after 12 and 48 hours lapsed time. However, these tests were largely unsuccessful and recourse had to be made to a particular suction value for FC. A limit of 0.2 bar was selected as being a practical figure; it is higher than would often be used for sandy soils, but is probably acceptable under the prevailing high temperatures (which reduce viscosity of the water and aid drainage under gravity), and conforms with the observed high rates of water intake into the local soils. Furthermore, selection of a higher value should ensure that the irrigation designs provide for more than adequate water capacity. Should trials in the projected ADC indicate that a lower matric suction is more applicable, the 0.2 bar limit can be modified.

Having defined the available water limits it should be stressed that moisture is not equally available to plants over the whole range. At higher suction, usually above 1.0 bar, it becomes increasingly difficult for roots to extract water at a rate sufficient to maintain active growth; similarly, at low suctions, below 0.1 bar, aeration of the soil is progressively reduced and root growth restricted, resulting in reduced rates of water uptake by the plant. Pidgeon (1972) proposed the use of easily available water capacity (EAWC) to indicate the range over which moisture stress is least and optimal growth can be expected. Doorenbos and Pruitt (1977) have proposed that total available water values be reduced by a factor (the p factor) which varies for different crops and for different prevailing avapotranspiration rates. The resulting value provides an estimate of the amount of readily available water permitting unrestricted evapotranspiration and has been used in this study.

E.2.3 Moisture Retention Test Results

Results of tests of moisture retention against matric suctions are given in Table E.1.

E.2.4 Combined Osmotic and Matric Suctions

Assuming initial ECfc values of 4.0 and 8.0 mmhos cm^{-1}, (see Chapter 6.4.3) and using the volumetric moisture contents in Table E.3, the ECsw, and hence the osmotic suction (ECsw x 0.36 bar) has been calculated for each matric suction point from field capacity (0.2 bar) to wilting point. Table E.2 shows the computed osmotic, matric and combined suctions for the upper meter of the two principal irrigable soil series (Khuways and Hisham). Both sets of data are presented graphically as Figures 6.6 and 6.7 in Chapter 6.

Table E.2 Calculated Combined Soil Matric and Osmotic Suction

Initial Salinity ECfc	Parameter	Matric Suction Points (bar) 0.2	0.3	1.0	15.0
Khuways Series (PV017)					
4.0	Water retained (% v/v)	43.3	42.0	39.2	15.3
	Soil salinity (ECsw)	4.0	4.1	4.4	11.3
	Osmotic suction	1.4	1.5	1.6	4.1
	Total suction	1.6	1.8	2.6	19.1
8.0	Water retained (% v/v)	43.3	42.0	39.2	15.3
	Soil salinity (ECsw)	8.0	8.2	8.8	22.6
	Osmotic suction	2.9	3.0	3.2	8.2
	Total suction	3.1	3.3	4.2	23.2
Hisham Series (PV016)					
4.0	Water retained (% v/v)	10.6	8.3	5.8	3.1
	Soil salinity (ECsw)	4.0	5.1	7.3	13.7
	Osmotic suction	1.4	1.8	2.6	4.9
	Total suction	1.6	2.1	3.6	19.9
8.0	Water retained (% v/v)	10.6	8.3	5.8	3.1
	Soil salinity (ECsw)	8.0	10.2	14.6	27.3
	Osmotic suction	2.9	3.7	5.3	9.8
	Total suction	3.1	4.0	6.3	24.9

EC in mmhos cm^{-1}; suctions in bar.
Initial salinity at field capacity, ECfc = 1.5 ECe for Khuways, 1.25 ECe for Hisham series.
Moisture retention data as normal weighted means for the 0-1.0m profile. Assumes no precipitation of salts.

Table E.1 Soil Moisture Retention against Matric Suctions

Soil Series/ Site No.		Texture	Gypsum (%)	Bulk Density (g cm^{-3})	Moisture Retention (% v/v)					AWC (1) (%)
					0 bar	0.1 bar	0.3 bar	1.0 bar	15 bar	
Tubli-Tb										
PV010	0- 20	L	14.8	1.20	54.4	48.8	45.5	38.6	30.0	16.8
	20- 90	SiL	1.5	1.21	56.7	50.6	46.7	42.2	22.3	25.7
Buhayr-Bu										
PV013	0- 45	SL	59.6	1.28	33.7	16.3	12.2	10.6	6.8	7.2
	45- 90	SL	81.6	1.37	42.6	32.7	28.2	23.8	11.8	17.2
	90-110	SL	87.7	1.19	50.1	38.0	26.3	21.1	7.4	22.6
Areen-An										
PV001	0- 35	SL	57.0	1.50	38.0	20.6	14.7	13.1	4.4	11.1
	35- 60	S	72.8	1.60	37.4	9.8	3.0	2.6	1.0	4.0
Sar-Sa										
PV007	0- 40	LS	60.0	1.12	42.8	19.0	12.5	9.4	5.9	8.6
	40- 70	L	17.7	0.82	65.1	53.9	51.0	49.4	26.2	15.3
	70-100	SiL	2.1	0.93	71.2	61.4	58.4	55.7	23.4	36.1
Khuways-Kh										
PV008	0- 20	SL	14.1	1.19	50.8	32.7	28.4	25.8	12.0	17.5
	20- 75	SL	2.0	1.34	44.8	33.4	29.8	27.3	11.5	19.0
	75-135	CL	1.7	1.21	57.2	52.6	50.3	48.3	26.0	24.5
PV017	0- 20	L	31.0	1.19	48.0	35.8	27.1	23.7	12.0	17.5
	20- 80	SiL	19.2	1.11	57.7	49.3	46.6	44.2	17.5	30.5
	80-135	L-CL	1.9	1.19	51.8	45.7	43.2	39.9	11.9	32.1

Table E.1 (Continued)

Soil Series/ Site No.	Texture	Gypsum (%)	Bulk Density ($g\ cm^{-3}$)	Moisture Retention (% v/v) 0 bar	0.1 bar	0.3 bar	1.0 bar	15 bar	AWC (1) (%)
Hisham-Hs									
PV016 0-50	LS	7.4	1.57	35.2	17.1	7.5	5.0	2.7	8.3
50-100	LS	11.8	1.55	35.7	15.7	9.0	6.5	3.4	7.6
100-150	S	7.9	1.51	42.1	18.1	12.2	10.4	4.4	9.6
Wasmiyah-Ws									
PV004 0- 80	S	1.4	1.61	36.5	12.1	4.0	2.3	1.3	4.7

(1) Total available water capacity (0.2 - 15 bar)

E.3 HYDRAULIC CONDUCTIVITY TESTS

E.3.1 Method

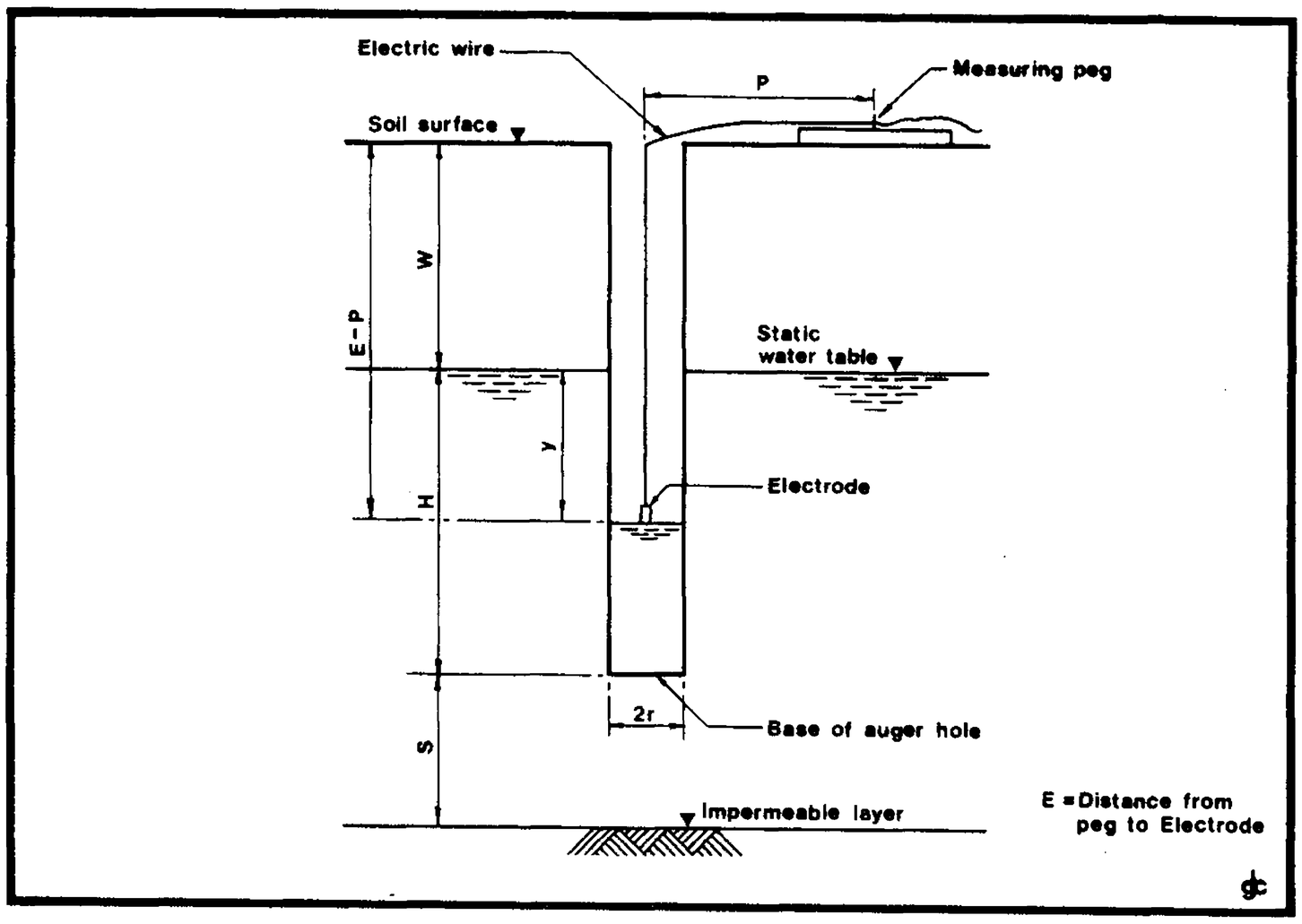
The single auger hole pump out test (Van beers, 1963), was used to assess hydraulic conductivity. The method involved the excavation of a 125mm diameter auger hole to below the water table. Slotted plastic screens were inserted to prevent collapse of the hole and water was then extracted using a centrifugal pump with a capacity of 15 litres per second over 5m head. Immediately the removal of water was completed the test commenced by measuring the rate of rise of the level of the water re-entering the hole from the surrounding soil. The rise of water in the hole was recorded against time until a steady value was obtained.

The actual measurement was achieved using a specially designed device comprising a length of electric cable attached to a weighted electrode (a two-pin plug) wired through a 4 volt dry cell batter and voltmeter. When the electrode was lowered into contact with the water a current passed which was recorded by the voltmeter. The wire and electrode were then withdrawn a known distance from the hole by moving a peg, attached to the upper end of the wire along one or more holes in a metal strip in which holes had been drilled at one centimetre intervals. The time taken for the water to rise and re-establish contact with the electrode was recorded by a stopwatch, the electrode was withdrawn further and the readings repeated. After a relatively fast initial recharge, the rate of rise usually stabilised and then slowly decreased as the dimensions of the cone of depression of the water-table around the hole increased.

On completion of the test, the time and depth to water level were recorded. The water level in the hole was then allowed to regain equilibrium and the depth was remeasured after a lapse of 24 hours. The general arrangement of the test is shown in Figure E.7.

Hydraulic conductivity values (**k**) were calculated according to the formulae derived empirically by Ernst (1950). Two formulae are available for calculating k from the results of the auger hole test, the choice depending upon whether an impermeable layer exists close to the base of the hole ($S = 0$) or at a significant depth below it ($S => 0.5h$):-

Figure E.7
Arrangement of Hydraulic Conductivity Test



S = 0

$$k = \frac{3600r^2}{(H + 10r)\left(2 - \frac{Yx}{H}\right)Yx} \cdot \frac{\Delta y}{\Delta t} \qquad (1)$$

S = 0.5h

$$k = \frac{4000r^2}{(H + 20r)\left(2 - \frac{Yx}{H}\right)Yx} \cdot \frac{\Delta y}{\Delta t} \qquad (2)$$

Where

y = rise of water surface in the auger hole during the time Δ t.

H = total depth of auger hole below stable water level.

Yx = distance from stable water level to level of water in the hole at the time of measuring.

r = radius of the auger hole.

k = hydraulic conductivity in m d^{-1} when other factors are measured in centimetres or in seconds.

s = depth of the impermeable layer below the base of the hole (having a k-value of 10 per cent or less than the overlying horizons).

These formulae are valid provided the following criteria are met:

r = 3 - 7cm

H = 20 - 200cm

Yx = more than 0.2H

y = less than 1/4 yo (yo = initial water level below static watertable).

The auger hole pump-out method gives the mean horizontal hydraulic conductivity of the soil layers extending from the watertable to a small distance below the base of the hole. Measuring the rate at which water enters the auger hole below the watertable closely simulates the flow conditions to a drain and avoids the inaccuracies inherent in the "pour-in" methods, namely soil disturbance, clogging of the pores and incomplete saturation. A frequent disadvantage of the present method is that it requires a watertable but in the current study shallow watertables are sufficiently widespread not to limit the use of the method.

A total of 58 tests were performed, usually as duplicate tests at each site, with a test depth of 2.0 - 3.0m. Most sites were

located along each of six cross profiles (Figure 3.3, 3.4, 3.5). As soon as a hydraulic conductivity test was completed a screw auger was driven down below the screened hole to a depth of 5.0 (unless stopped by rock etc.) and the nature of the material described. This enabled the determination of k-values to be combined with an investigation of the substratum and provided a clearer impression of drainage characteristics than would have been achieved by widely distributed sites. As the deep augers did not penetrate any confining layers they were unlikely to have affected the static watertable values used in the hydraulic conductivity calculations.

E.3.2 Results

Complete results for the 58 tests are shown in Table E3. Reasonable agreement was obtained between duplicate measurements at each site. The principal causes of inconsistent or inaccurate results stemmed from the inability to extract water fast enough to drain the auger hole due to either extremely rapid rates of recharge (on coarse gypsic sands) or clogging of the pipe and pump by sand (on aeolian fine sands). In several cases this resulted in values of Yx being less than the minimum of 0.2H required by the Ernst formulae. Local rock outcrops formed the only impermeable layers encountered with the test zone.

Table E.3 Hydraulic Conductivity Results

Test Site	Series	Hole Depth (m)	Stable Water-table (m)	Hydraulic Head (m)	Hydraulic Conductivity (md^{-1})	Test Zone Material	Remarks
PV061(a)	Wasmiyah	1.70	1.00	0.45-0.55	3.68	Fine sand	Shallow test depth.
(b)		1.70	1.00	0.46	3.17		
PV004(a)	Wasmiyah	1.72	0.80	0.14-0.24	8.19	Fine sand	Shallow test depth.
(b)		1.85	0.80	0.21-0.31	5.54		
Z126 (a)	Khuways	1.65	0.97	0.51	0.75	Silty clay loam	Alat limestone at 1.8m(S=
PV030(a)	"	3.00	1.70	0.23-0.33	4.95	Fine sand	Clay loam at 4.4m.
(b)		3.00	1.70	0.19	4.41		
V643	"	1.90	1.22	0.41	0.85	Silty clay loam	-
PV058(a)	"	2.10	1.45	0.41-0.45	0.84	Silty fine loams over rock at 2.1m.	S = 0
(b)	"	2.10	1.45	0.35-0.39	0.87		
V507	"	1.23	0.90	0.04	1.52	Silty fine loams over limestone at 1.25m.	S = 0: poor result.
V720(a)	"	2.02	0.90	0.61-0.71	0.62	Silty fine loams	Sand below test depth (2.
(b)	"	2.02	0.90	0.66-0.76	0.63		
V675 (a)	Abu Saybi	2.80	1.90	0.20-0.28	0.82	Fine sand	Low values.
(b)	"	2.81	1.90	0.35-0.42	1.74		

Table E.3 (Continued)

Test Site		Series	Hole Depth (m)	Stable Water-table (m)	Hydraulic Head (m)	Hydraulic Conductivity (md^{-1})	Test Zone Material	Remarks
V655	(a)	Khadarah	3.00	1.14	0.57-0.67	0.67	Sandy clay loam	
	(b)	"	3.05	1.14	0.75-0.85	1.11	over fine sand	-
V647	(a)	"	3.05	0.86	0.66-0.76	1.19	Sandy clay loam	
	(b)	"	3.08	0.86	0.56-0.66	1.39	over sand	-
V652	(a)	Khuways	3.00	1.14	0.49-0.59	3.94	Fine sand	-
	(b)	"	3.00	1.14	0.43	5.75		
V575	(a)	Abu Laybi	2.85	2.20	0.29-0.32	0.53	Fine sand	Slow rate for fine sand
	(b)	"	2.85	2.20	0.35-0.39	0.52		
V562	(a)	Maqabah	2.90	2.05	0.09-0.14	10.44	Fine sand	Fast rate
	(b)	"	2.90	2.05	0.12-0.17	13.42		
V111	(a)	"	3.05	2.00	0.37-0.47	2.73	Fine sand	-
	(b)	"	3.05	2.00	0.31-0.41	4.18		
V735	(a)	Hisham	2.90	0.90	0.32	9.44	Fine sand	Impermeable Alat marl la
	(b)	"	2.90	0.90	0.30	10.00		below test depth (3.7m)
V468	(a)	Khuways	2.40	0.70	0.76-0.96	3.63	Silty clay loam	Alat marl at 4.5m
	(b)	"	2.50	0.70	0.69-0.89	3.42	over fine sand	
V069	(a)	"	3.00	0.70	0.32-0.52	2.06	Clay loam over	K value reduced by
	(b)	"	3.00	0.70	-	-	fine sand	clay loam layer

Table E.3 (Continue)

Test Site	Series	Hole Depth (m)	Stable Water-table (m)
PV020 (a)	Abu Saybi	3.00	1.60
(b)	"	3.00	1.60
(c)	"	3.00	1.60
Z014 (a)	Maqabah	3.05	1.45
(b)	"	3.10	1.45
(c)	"	3.10	1.45
PV018 (a)	Maqabah	3.00	1.30
(b)	"	3.05	1.30
V638 (a)	Hisham	4.50	4.00
Z056 (a)	Khuways	3.00	1.97
(b)	"	3.00	1.97
PV054 (a)	Abu Saybi	2.90	1.40
(b)	"	3.00	1.40
Z181 (a)	Khuways	3.00	1.80
(b)	"	3.00	1.80
PV059 (a)	Khadarah	3.05	1.65
(b)	"	3.10	1.65
PV042 (a)	Maqabah	3.10	2.22
(b)	"	3.10	2.22
V663 (a)	Khuways	3.00	1.20
(b)	"	3.00	1.20

Hydraulic Head (m)	Hydraulic Conductivity (md^{-1})	Test Zone Material	Remarks
0.88-0.98	2.67	Shallow silt loam layer over fine sand	-
0.92-1.12	3.43		
0.84-1.24	5.34		
0.01-0.04	5.92	Medium gypsic	Rate of recharge faster
-	Very high	sand over fine	than pumping rate;
0.02-0.06	28.00	sand	unreliable test.
-	Very high	Coarse gypsic	Recharge faster than
-	Very high	over fine sand	pumping rate(1.5litre/s No test possible.
-	-	Fine sand	Watertable too deep for test.
0.41-0.61	7.90	This marl layer	
0.42-0.72	9.07	over fine sand	-
0.57-0.67	3.21	Carbonate silt	Weathered limestone at
0.33-0.43	2.13	loam over fine sand	4.6m.
0.23	7.81	Fine sand	-
0.17-0.27	7.95		
0.24-0.44	8.70	Carbonate silts	Sandstone at 3.20m;
0.47-0.67	8.29	and fine sand	S = 0
0.46-0.61	6.09	Carbonate sandy	Very low density silty
0.29-0.44	6.88	loam over fine sand	substratum
0.33-0.53	8.12	Marine sandy loam	First test insufficient
1.07-1.27	4.90	over fine sand	drained.

Table E.3 (Continued)

Test Site		Series	Hole Depth (m)	Stable Water-table (m)	Hydraulic Head (m)	Hydraulic Conductivity (md^{-1})	Test Zone Material	Remarks
V679	(a)	Khuways	2.10	0.65	0.86-1.06	2.18	Marine sandy loam	Fine sand below 3.2m
	(b)	"	2.10	0.65	0.82-1.02	2.05	& sandy clay loam	
Z212	(a)	Maqabah	2.95	1.80	0.24	6.76	Carbonate silt loam	Difficulty in extract
	(b)	"	2.95	1.80	0.23	5.12	over fine sand	water.

NOTE: Results of single auger hole pump out tests; sites are shown on the Soil Survey Site Location maps at 1:10 000 scale.

F

Soil Salinity Field Tests

F.1 INTRODUCTION

During the course of the Level 3 survey several tests were carried out to determine the effects of irrigation on the salinity and salt distribution in the soils. Three approaches were adopted:-

a) Comparison of irrigated and non-irrigated soil salinity.

b) Monitoring of soil salinity under basin irrigation.

c) Plotting salt distribution under trickle irrigation.

Results of these investigation are presented in this Appendix. However, it should be emphasised that these were only preliminary investigations; indeed they each represent important subjects for detailed research, which is beyond the scope of the current study. All that can be attempted at present is to indicate the likely effects of irrigation on the soils of the area.

F.2 COMPARISONS OF IRRIGATED AND NON-IRRIGATED SOIL CONDITIONS

During the routine survey a series of paired sites, located within irrigated fields and on immediately adjacent non-cultivated land, were sampled for salinity analyses. In addition, EC measurements were made of the irrigation water and, wherever possible, the drainage water. The results are presented in Table F.1.

The results of the comparative ECe tests show a considerable reduction in soil salinity under irrigation and a reversal of the normal condition of salinity increasing towards the soil

surface. From the small number of samples available, the sandy Hisham soils appear to be more easily leached than the fine loamy Khuways and Sar soils.

Due to the extreme variance of the basic data, overall differences between irrigated and non-irrigated soil salinities are not statistically significantly different, although individual sites evidently are. Logarithmic transformation of the ECe values according to the approach of Gowing and Baniabbassi (1975), reduces the variance but still shows a barely significant (p = 12%) difference. Similarly, no direct relationship is apparent between soil EC and irrigation water salinity (ECiw), despite the very wide range in quality of water being used (3.9 to 16.0 mmhos cm^{-1}). However, soil salinity is affected by factors other than irrigation water quality, which cannot be accounted for in a study of this type; these include:-

(a) Rise of salts in solution from a high watertable. Those soils with a watertable within 1.0m of the surface tend to have higher ECe values under irrigation than those with deep watertables. The greater depth of the watertable beneath Hisham soils may explain the apparently greater efficiency of leaching in these soils.

(b) Application rates, as well as leaching rates, can be expected to have varied greatly between fields sampled: different sites have inevitably been subjected to different leaching rates and therefore ECe values may not be directly comparable.

(c) Soil salinity varies over the irrigation interval so that higher ECe values could be expected at the end of each interval. No account could be taken of this variation during soil sampling; similarly the results refer to single, non-replicated sites within fields, inevitably resulting in further sampling error.

The salinity distribution differences between an unirrigated and an irrigated Khuways profile are illustrated in Figure F.1. Superficial concentrations of salt are removed by leaching but below 1.0m there is no appreciable difference, reflecting the

Table F.1 Soil Salinity in Relation to Land Use

Land Use	Site No.	Depth (cm)	ECe	ECiw	ECdw	Water-table (cm)
Khuways Series						
Non-Cultivated	V470	0- 50	116.3	-	-	190
		50-100	47.3			
Irrigated	V469	0- 50	7.2	8.9	-	175
		50-100	7.0			
Non-Cultivated	V643	0- 50	42.6	-	-	140
		50-100	25.7			
Irrigated	V642	0- 50	14.3	16.0	16.5	160
		50-100	13.8			
Non-Cultivated	V507	0- 50	70.1	-	-	90
		50-100	41.0			
Irrigated	V509	0- 50	19.7	7.5	12.5	70
		50-100	43.0			
Non-Cultivated	V727	0- 50	40.5	-	-	180
		50-100	33.2			
Irrigated	V731	0- 50	10.9	8.0	10.5	90
		50-100	11.2			
Non-Cultivated	V739	0- 50	46.0	-	-	150
		50-100	36.2			
Irrigated	V739	0- 50	14.9	7.0	38.0	95
		50-100	21.7			
Non-Cultivated	PV058	0- 50	40.0	-	35.0	145
		50-100	27.2			
Irrigated	V740	0- 50	11.0	7.5	12.0	85
		50-100	11.5			
Hisham Series						
Non Cultivated	V114	0- 50	29.0	-	-	200
		50-100	15.7			
Irrigated	V735	0- 50	9.9	8.0	14.0	90
		50-100	6.0			
Non-Cultivated	PV016	0- 50	30.6	-	-	200
		50-100	24.3			
Irrigated	Z062	0- 50	9.5	3.9	-	200
		50-100	7.5			
Non-Cultivated	PV021	0- 50	9.4	-	-	200
		50-100	9.4			
Irrigated	V741	0- 50	7.6	12.0	-	200
		50-100	10.8			

Table F.1 (continued)

Land Use	Site No.	Depth (cm)	ECe	ECiw	ECdw	Water-table (cm)
Sar Series						
Non-Cultivated	V276	0- 50	25.9	-	-	200
		50-100	24.3	-	-	
Irrigated	V323	0- 50	14.1	11.0	-	200
		50-100	17.3			
Non-Cultivated	V179	0- 50	41.5	-	-	170
		50-100	27.7			
Irrigated	V178	0-50	13.9	17.0	17.5	130
		50-100	17.0			
Abu Saybi' Series						
Non-Cultivated	V461	0- 50	29.4	-	-	200
		50-100	30.1			
Irrigated	V464	0- 50	9.6	8.0	15.0	95
		50-100	19.9			

Note: EC values are expressed in mmhos cm^{-1} at 25°C;
ECe values were calculated as weighted means at 25cm and 75cm depths.

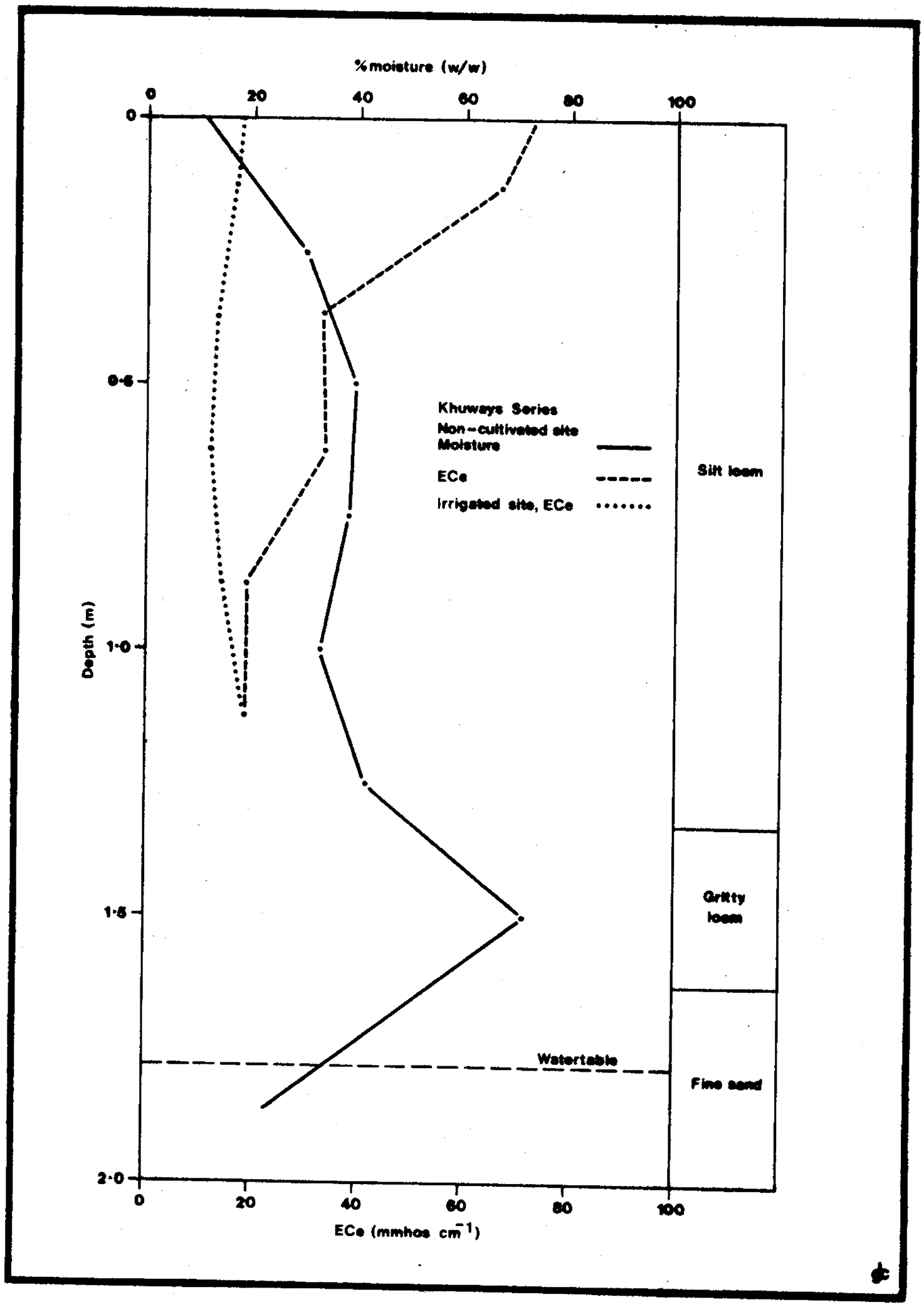
contribution of salts dissolved in rising groundwater. The moisture profile for the unirrigated site indicates that there is considerable upward movement of water from the watertable. Salt accumulation is greatest above 0.5m, in which zone moisture contents decline rapidly.

F.3 SOIL SALINITY UNDER BASIN IRRIGATION

The aim of this exercise was to monitor the salinity profile of a soil, commencing before irrigation and continuing over a series of irrigation water applications.

A site was selected on Khuways series near Sar village (site V739); the land had not been irrigated for two years and had become saline

Figure F.1
Soil Moisture and Salinity Profile



but was scheduled for basin irrigation. The watertable lay at 1.5m below the surface. Irrigation commenced in late February, onions were planted and irrigation continued at two or three daily intervals using water of 7.0 mmhos cm^{-1}. The watertable rose to within 50cm of the surface after a few applications, no artificial drainage was provided. Soils were sampled for salinity analysis at regular intervals. However, due to a combination of poor management, inferior water quality and high watertable, the irrigation was prematurely abandoned after only a few weeks.

The results of the tests (Table F.2) show that high salinity in Khuways can be reduced relatively rapidly, even using poor quality irrigation water and with a saline (38.0 mmhos cm^{-1}) watertable at shallow depth. Had the irrigation not been prematurely curtailed, it is anticipated that ECe values could have been reduced further.

Table F.2 Leaching of Khuways Soils - Sar

Sampling	Depth (cm)	ECe (mmhos cm^{-1})
Before Irrigation	0-50	49.2
	50-100	49.7
After Initial Irrigation		
3 days	0-50	46.0
	50-100	33.8
14 days	0-50	18.4
	50-100	40.5
24 days	0-50	14.9
	50-100	21.7

Note: Results of bulk sampling between 0-50 and 50-100cm.

F.4 SALT DISTRIBUTION UNDER TRICKLE IRRIGATION

F.4.1 Objectives

Trickle irrigation systems are increasingly being used in Bahrain. In order to determine the long term effects on salt distribution under trickle, using saline/gypsic water, a detailed soil sampling investigation was prepared. A suitable site was selected at Budayyi Experimental Station, where a mature vineyard has been under trickle irrigation for four years. The vines are planted in rows, with 2.0m between rows; they were healthy and at an active stage of growth at the time of sampling (March). The irrigation water has an EC of 3.9 mmhos cm^{-1} and is applied automatically for five hours per day at a rate of about 8 litres per hour giving a total daily application of 40 litres per vine.

F.4.2 Methods

A pit was excavated across the row so as to expose the rooting system of a representative vine. The pit extended laterally to the mid-point between rows and downwards to the watertable at 1.25m. The face of the pit on the side of the vine was cleaned back so as to bisect the root at right angles to the row. Immediately following cleaning of the pit face, soil samples were collected across the face on a 25 x 25cm grid (Figure F.1). The samples were air dried, ground to pass a 2mm sieve and analysed for salinity (EC) and pH. In addition samples from one side of the face were tested for gypsum and detailed analyses were performed on a profile from 0 to 100cm.

F.4.3 Soil Profile Description

The soil beneath the vineyards was described as a member of the sandy, mixed, hyperthermic family of Aquic Paleorthids. It has no equivalent in the GDC survey areas but resembles Hisham and Areen series. A detailed profile description is given and the analytical data are presented in Table F.3.

Horizon	Depth (cm)	Description
A1psa	0-30	Brown (10YR 5/3) medium sand; structureless single grained; very friable moist near vines, dry and soft between rows; porous loose sand; occasional fragments of old channel lining; roots common near irrigation emitter; clear wavy boundary.
C1	30-70	Brown (10YR 5/3) medium sand; as above but friable, moist throughout; few mango roots at base of horizon; abrupt smooth boundary.
$C2_{cam}$	70-100	Pale brown (10YR 6/3) medium sand; structureless single grained, very friable moist with massive, extremely firm indurated layers of calcium carbonate cemented sand; porous; a few roots penetrate cemented layers; abrupt smooth boundary.
IIC_3	100-120	Olive grey (5Y 5/2) fine sandy loam to loam, structureless; slightly plastic, sticky wet; rare fine roots; abrupt smooth boundary.
IIC_{4cag}	120+	Olive grey (5Y 5/2) with few faint light yellowish brown mottles; gravelly silt loam; structureless matrix; very porous indurated layers cemented with $CaCO_3$; saturated, slightly plastic, sticky, no roots.

The upper part of the profile comprises sand whereas below 70cm there occurs a petrocalcic horizon. This horizon probably formed by precipitation of carbonates (as calcite) from the underlying watertable. It comprises a hard, continuous layers of cemented sand with intervening pockets of friable material; it is permeable to water but forms a barrier to roots, which are forced to run

Table F.3

Budayyi Vineyard Profile Detailed Analysis

Sample No.	Depth (cm)	Salinity		Alkali			$CaCO_3$ %	Gypsum %
		mmhos/cm EC 1:5	mmhos/cm EC_e	pH Paste	CEC me/100g	ESP		
N2a	0	5.1	44.4	7.3	6.8	5.5	17.6	1.3
N2b	25	0.4	4.9	8.2	8.0	1	20.5	1.0
N2c	50	0.5	4.8	8.2	6.0	2.2	16.8	1.0
N2d	75	0.6	8.9	8.0	9.0	3.0	23.3	1.0
N2e	100	1.0	9.4	7.8	17.3	2.5	29.9	1.0

Sample No.	Gravel % (Estimate)	Particle Size Analysis – % (Total Soil Constituents)							Saturation %
		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
a	0	7	36	28	16	3	0	10	19
b	0	3	36	34	15	4	0	8	21
c	0	0	24	48	21	2	0	5	27
d	0	3	26	31	29	3	3	5	24
e	20	2	6	33	25	4	20	10	36

Sample No.	Particle Size Analysis – % (Insoluble Soil Constituents)							Phosphorus		Nitrogen total %
	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total mg/100g	Available ppm	

Sample No.	% org. Carbon	Soluble Ions in Saturation Extract (me/litre)							NO_3^- ppm
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	

horizontally along its upper surface. Below 1.0m the soil is loamy, saturated and slightly sticky. Capillary rise from the watertable appears to be responsible for the generally moist conditions which occur from a depth of 60cm downwards.

F.4.4 Results

a) Root distribution

Figure F.2 demonstrates the very close concentration of roots within the immediate zone of moisture penetration from the emitter. They form an inverted cone barely 50cm wide at its broadest and tapering to a point just above the petrocalcic horizon. The drawing also emphasises the very small proportion of the total soil volume which is being exploited by roots and suggests that much greater planting densities would be possible.

b) Salinity distribution

A salinity distribution pattern (Figure F.2) was derived from the routine analysis data (Table F.4). This shows that ECe values are lower in the mid-profile rising both towards the surface and downwards. The latter can be explained by salts rising from the saline (6.0 mmhos cm^{-1}) groundwater. Similarly the increase near the surface is the normal result of increasing precipitation of salts across a moisture gradient.

The effects of trickle irrigation are more difficult to determine. The relatively high concentrations of salts between rows at the surface is consistent with moisture and salts migrating outwards and upwards from the moist zone and conforms with published reports (Tscheschke etal, 1974). Similarly, the decrease in salinity in the subsoil may result from leaching by the trickle system, offset somewhat by the petrocalcic layer.

The relatively high concentration of salts around the base of the vine and the salinity gradient passing downwards through the rooting cone are normal for trickle irrigation (Goldberg, 1976). The probable explanation for the apparent anomaly of having a zone

Figure F.2 Budayyi Vineyard: Soil Salinity Distribution Pattern

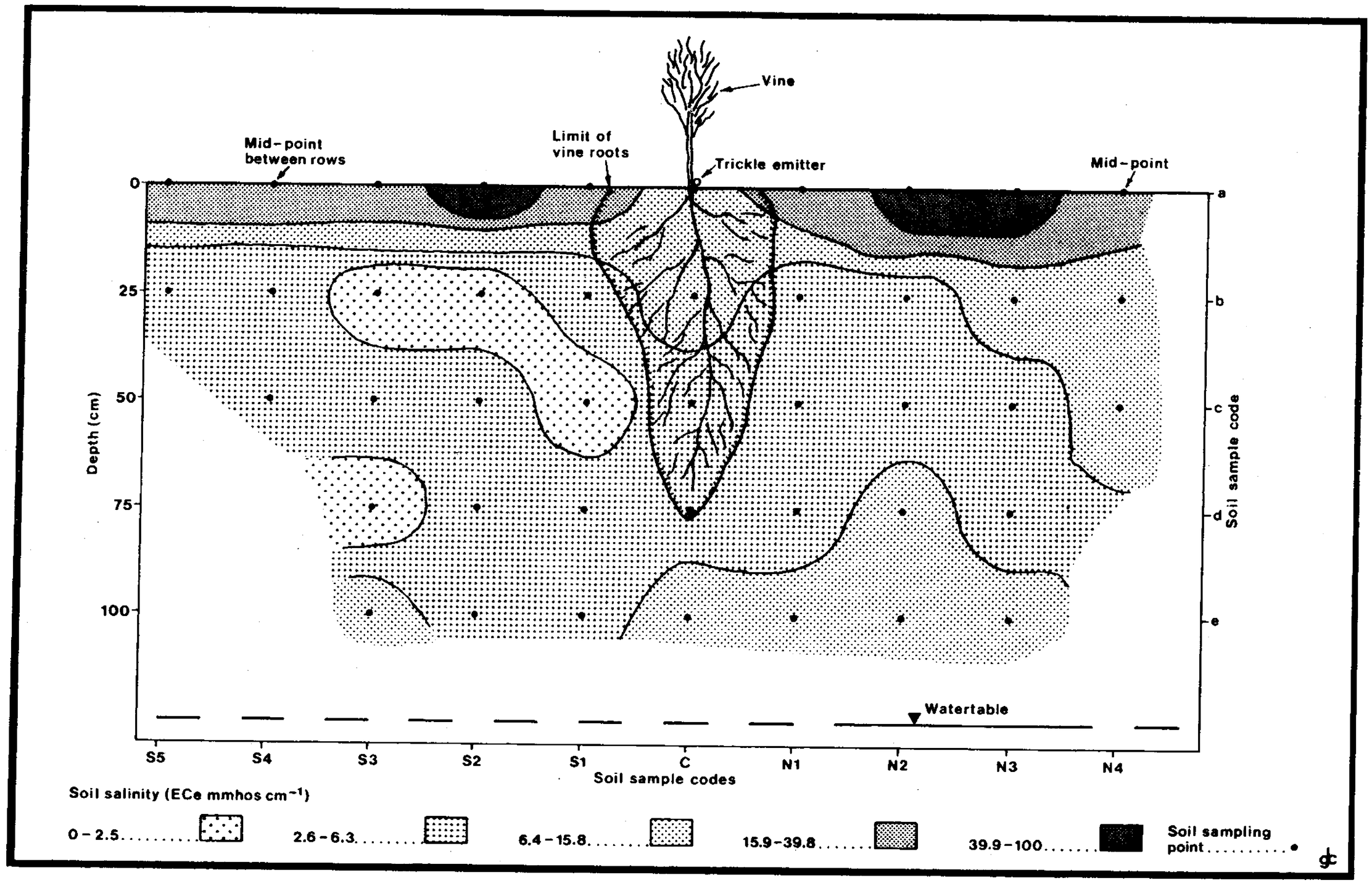


Table F.4 Routine Analyses for Vineyard Samples

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
Ca	0	31	7.6	19.2	0.7	1.0	9.7	
Cb	25	26	7.6	20.5	0.9	1.0	12.2	
Cc	50	22	8.0	19.8	1.0	0.3	5.1	
Cd	75	22	8.0	20.0	1.0	0.3	4.2	
Ce	100	30	7.8	34.2	1.2	0.7	6.4	
N1a	0	22	7.4	17.4	1.6	3.8	27.0	
N1b	25	20	8.2	18.6	1.0	0.2	3.0	
N1c	50	26	8.1	18.4	1.0	0.3	3.3	
N1d	75	22	8.0	26.0	1.1	0.4	3.7	
N1e	100	32	7.8	29.6	1.2	0.7	9.6	
N2a	0	19	7.3	17.6	1.3	5.1	44.4	
N2b	25	21	8.2	20.5	1.0	0.4	4.9	
N2c	50	27	8.2	16.8	1.0	0.5	4.8	
N2d	75	24	8.0	23.3	1.0	0.6	8.9	
N2e	100	36	7.8	29.9	1.0	1.0	9.4	
N3a	0	20	7.3	19.4	1.2	3.4	46.0	
N3b	25	23	8.0	22.5	0.9	0.7	6.4	
N3c	50	24	8.1	16.4	1.0	0.5	6.0	
N3d	75	24	8.0	22.1	1.0	0.6	5.9	
N3e	100	44	7.8	35.4	1.0	1.0	6.5	
N4a	0	19	7.3	20.9	1.1	2.7	36.7	
N4b	25	24	7.6	-	0.9	0.8	7.0	
N4c	50	27	7.9	18.8	0.7	2.3	7.0	
S1a	0	24	7.7	-	-	2.2	26.9	
S1b	25	22	7.9	-	-	0.3	3.2	
S1c	50	24	8.3	-	-	0.2	2.0	
S1d	75	26	8.1	-	-	0.3	2.9	
S1e	100	34	7.9	-	-	0.7	5.9	

Table F.4 - continued.

Sample No.	Depth (cm)	Satn. %	pH paste	$CaCo_3$ %	Gypsum %	Salinity, mmhos/cm EC 1:5	ECe	Soil Series
S2a	0	23	7.4	-	-	3.3	42.1	
S2b	25	25	8.3	-	-	0.2	2.1	
S2c	50	23	8.1	-	-	0.3	3.3	
S2d	75	21	8.1	-	-	0.2	3.0	
S2e	100	32	8.0	-	-	0.6	5.1	
S3a	0	21	7.5	-	-	3.2	35.7	
S3b	25	23	8.4	-	-	0.2	2.3	
S3c	50	26	8.2	-	-	0.3	2.9	
S3d	75	20	8.4	-	-	0.2	2.0	
S3e	100	52	7.8	-	-	1.0	6.2	
S4a	0	20	7.4	-	-	2.6	24.2	
S4b	25	22	7.6	-	-	0.3	4.2	
S4c	50	23	7.8	-	-	0.3	5.3	
S5a	0	22	7.4	-	-	2.5	27.9	
S5b	25	23	9.4	-	-	0.9	5.1	

of high salinity close to the emitter lies in the fact that this is also the zone of maximum water uptake by roots. This would automatically result in a concentration of the salts and a rise in ECe. On the other hand, moisture contents remain much higher in this zone immediately below the emitter and this would result in lower matric and osmotic suctions. Consequently, although salinity levels may be high around the roots, suctions are lower and moisture uptake is therefore easier. This is broadly confirmed by Tscheschke et al (1974), who plotted soil water potential patterns, as opposed to salinity patterns, for a series of trickle irrigation systems.

c) Gypsum distribution

Analyses of gypsum were carried out to confirm whether gypsum dissolved in the irrigation water is precipitated in the soil in appreciable quantities. Analyses for the northern half of the exposed face (Table F.4) show that no accummulation of gypsum has occurred due to the trickle system. Throughout most of the profile gypsum contents are less than 1.1 per cent which probably represents fine particles of gypsum contained in the original parent material. Lower values occur in the vicinity of the emitter and root cone, suggesting a degree of leaching of gypsum; the irrigation water has a relatively low gypsum saturation (21.2 per cent at 30°C) so this would be feasible. Highest gypsum values (1.6 per cent) were recorded at the surface, some 25 to 50cm from the emitter.

Clearly gypsum precipitation is not a hazard on the Budayyi vineyard, although there are indications that solution occurs in the root zone with subsequent redeposition at the surface. In the non-gypsic Budayyi soils this is not significant but could prove to be more of a problem on the gypsic topsoils of the GDC survey area. (See Appendix D).

G

Mineralogical Analyses

G.1 CLAY MINERAL ANALYSIS

G.1.1 Methods

X-ray diffraction and differential thermal analysis techniques were used to identify the clay mineralogy of the soils.

As gypsum, calcium carbonate, soluble salts, organic matter and iron oxides hinder analysis by X-ray diffraction (XRD) and differential thermal analysis (DTA), these constituents were removed before analysis proceeded. Removal was achieved as follows:-

(a) Soluble salts: by extraction with water.

(b) Carbonates: by extraction with sodium acetate at pH 5.0.

(c) Organic matter: by treatment with hydrogen peroxide.

(d) Iron oxides: by extraction with sodium citrate-dithionite.

Samples of the clay fraction were obtained by sedimentation following dispersion using ultrasonic techniques. The clay sample was then subdivided and one part saturated with potassium and the other part saturated with magnesium. Thin films were prepared by pipetting the clay fractions onto glass slides. Potassium saturated samples then heated in a furnace at temperatures of 300°C, 500°C and 600°C. Magnesium saturated samples were treated with ethylene glycol or glycerol.

XRD analysis of the prepared slides was carried out using nickel filtered CuK radiation generated by a Phillips PW 1011 at 40 KV and 20 mA. Diffraction maxima were detected using a Phillips wide range goniometer (PW 1050) with a slit system of 1°/0.1mm/1°, scanning at 1°2θ/minute. The signal was analysed using a Phillips PW 1352 system, employing pulse height analysis, and recorded on a chart running at 1 cm/min. (i.e. 1°2θ/cm) with a damping time constant of 2 seconds and a f.s.d. normally set at 2 000 or 4 000 c.p.s. Successive traces for different treatments were superimposed using a zero offset unit.

G.1.2 Materials

Eight samples taken from the major horizons of the principal soils with agricultural potential were analysed for clay minerals. The profiles and sampling depths were as follows:-

Profile No.	Soil Family	Soil Series	Sample Depth (cm)
PV016	Mixed, hyperthermic family of Typic Torripsamments.	Hisham	0 - 50 50-100
PV107	Fine-loamy, carbonatic hyperthermic family of Cambic Gypsiorthids	Khuways	0 - 20 20- 80 80-135
PV058	Fine-loamy carbonatic hyperthermic family of Cambic Gypsiorthids	Khuways	0 - 25 25- 80 80-150

G.1.3 Results

The results of the semi-quantitative analyses of clay minerals are shown in Table G.1. The low angle portions of the X-ray traces from glycerolated clay fraction preparations are illustrated in Figure G.1.

The clay fractions of these soils consist of varying mixtures of palygorskite, irregular mixed-layer minerals (smectite/mica; smectite/chlorite) and smectite with lesser amounts of mica and chlorite.

The clay mineralogy of each soil appears to remain the same through the profile, although there is marked upward decrease in the intensity of the diffracition pattern of the clay assemblages. This may result from the presence of increasingly greater amounts of X-ray amorphous material in the clay grade fraction in the upper parts of each profile.

G.1.4 Discussion

Chemical weathering tends to be limited under the prevailing climatic conditions (high temperatures and low rainfall) and in the presence of calcium carbonate. Therefore, the clay minerals would be expected to be reasonably stable and the mineralogy would be determined primarily by that of the parent material.

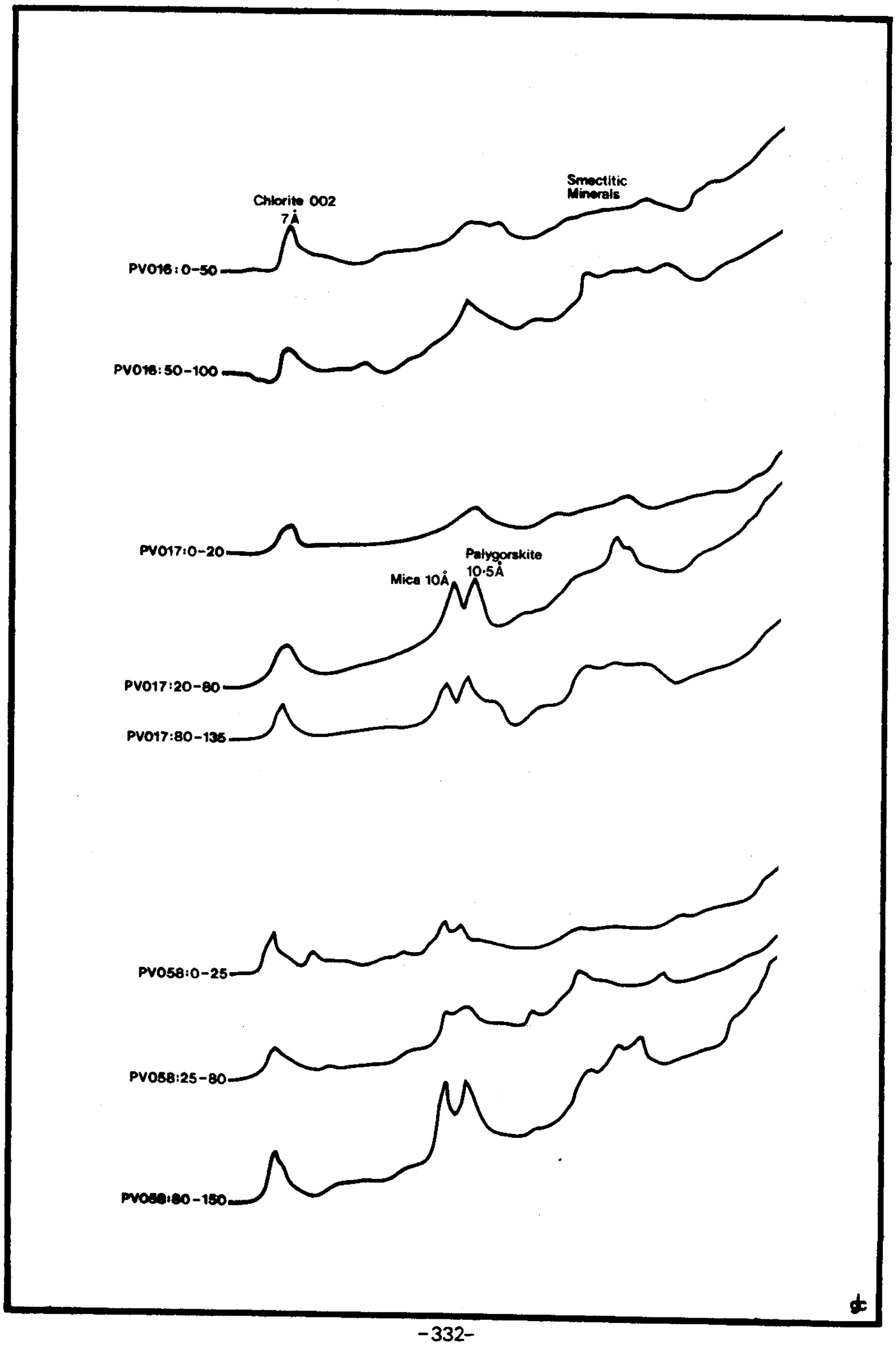
Millot (1949) established that the minerals sepiolite-palygorskite-attapulgite are frequently found in argillaceous sediments associated with high salinity. Such conditions could be expected in the neogene deposits of Bahrain. The presence of palygorskite can be taken as

Table G.1 Relative Proportions of Different Clay Groups in Clay Fractions

Sample	Mica	Kaolinite	Chlorite	Palygorskite	Sepiolite	Smectitic Minerals	Type of Smectitic Minerals	Comments
PV016: 0-50	*	-	*	*	-	**	Smectite/ chlorite	very poor X-ray trace
PV016: 50-100	*	-	*	*	-	**	" "	poor X-ray trace
PV017: 0 - 20	**	-	*	**	-	**		very poor X-ray trace
PV017: 20-80	**	-	*	**	-	**	Smectite/ chlorite	poor X-ray trace
PV017: 80-135	**	-	*	**	-	**	Smectite/ chlorite	poor X-ray trace
PV058: 0-25	**	-	*	**	-	**		very poor X-ray trace
PV058: 25-80	**	-	*	**	-	**	Smectite/ chlorite	poor X-ray trace
PV058: 80-150	**	-	*	**	-	**	Smectite/ chlorite	

Key: * ↓ ** *** **** ***** increasing relative proportion of mineral components

Figure G.1 X-Ray Diffraction Traces
From Glycerolated Clay Fractions - Bahrain



an indication of limited weathering conditions and Barshad (1956) postulated that palygorskite served as an indicator of the transition from limestone to soil. This clay mineral is probably derived from weathering of flat limestone, which is widespread in Northern Bahrain.

Although the clay minerals are most likely inherited primarily from the soil parent material, there are variations in the frequency of the different clay mineral types which can be ascribed to the sedimentation regime and the nature of the contributing sediments. That some alteration has occurred is indicated by the presence of the interstratified minerals.

Smectite (montmorillonite) is an alternation product of mica and also of chlorite and it is likely that it is forming at present by alteration of mica and/or chlorite, resulting in the production of the interstratified clay minerals.

G.2 SOIL MINERALS

G.2.1 Introduction

Samples of cemented nodules and specific soil horizons (petrocalcic and petrogypsic= were examined for soil mineral content using X-ray diffraction and a powder press technique. Selected samples were also examined under an optical microscope.

G.2.2 X-ray diffraction results

The results of this qualitative analysis are given in Table G.2. X-ray diffraction traces of selected samples are illustrated in Figures G.2 and G.3.

Samples are dominated by either calcite or, in the petrogypsic horizon, gypsum. Quartz is present in variable amounts, depending upon the degree of contamination by windblown sand. Felspars are detectable in some samples.

Selected portions of the spectrum were rescanned to check for the presence of magnesium carbonate. The magnesium content of all samples is low (one to three per cent) and the characteristic MgO diffraction peaks completely absent. Therefore, the material does not contain dolomite. Figure G.4 compares a typical diffraction trace of a Bahrain petrocalcic layer against spectrographically pure calcium carbonate and it is clear that the diffraction peaks are coincident.

Table G.2 Mineral Identification (XRD-Powder Press Technique)

Soil/Profile No.	Depth of Sample (cm)	Horizon	Calcite	Gypsum	Quartz	Felspar
Buri Series (Typic Gypsiorthid) PV025	180-200	Buried petrocalcic	**	*	*	*
Maqabah Series (Typic Gypsiorthid) PV042	30-60	Weak petrogypsic	-	*****	-	-
Sar Series (Typic Gypsiorthid) PV007	70-130	Calcite concretions	****	-	*	-
PV002	100-150	Buried petrocalcic	****	-	*	-
Khuways Series (Cambic Gypsiorthid) PV017	135-180	Concretions	****	-	*	-
Areen Series (Typic Paleorthid) PV001	60-150	Petrocalcic	***	-	**	-
Salmabad Series (Typic Paleorthid) PV043	55-80	Petrocalcic	***	-	**	-
Buquwwah Series (Typic Paleorthid) PV057	75-120	Petrocalcic	**	-	**	-
Isa Series (Aquic Paleorthid) PV048	70-90	Petrocalcic	***	-	**	-

Note: Relative proportion of minerals shown on scale of one to five asterisks.

Figure G.2 X-Ray Diffraction Traces of Indurated Soil Layers - Bahrain

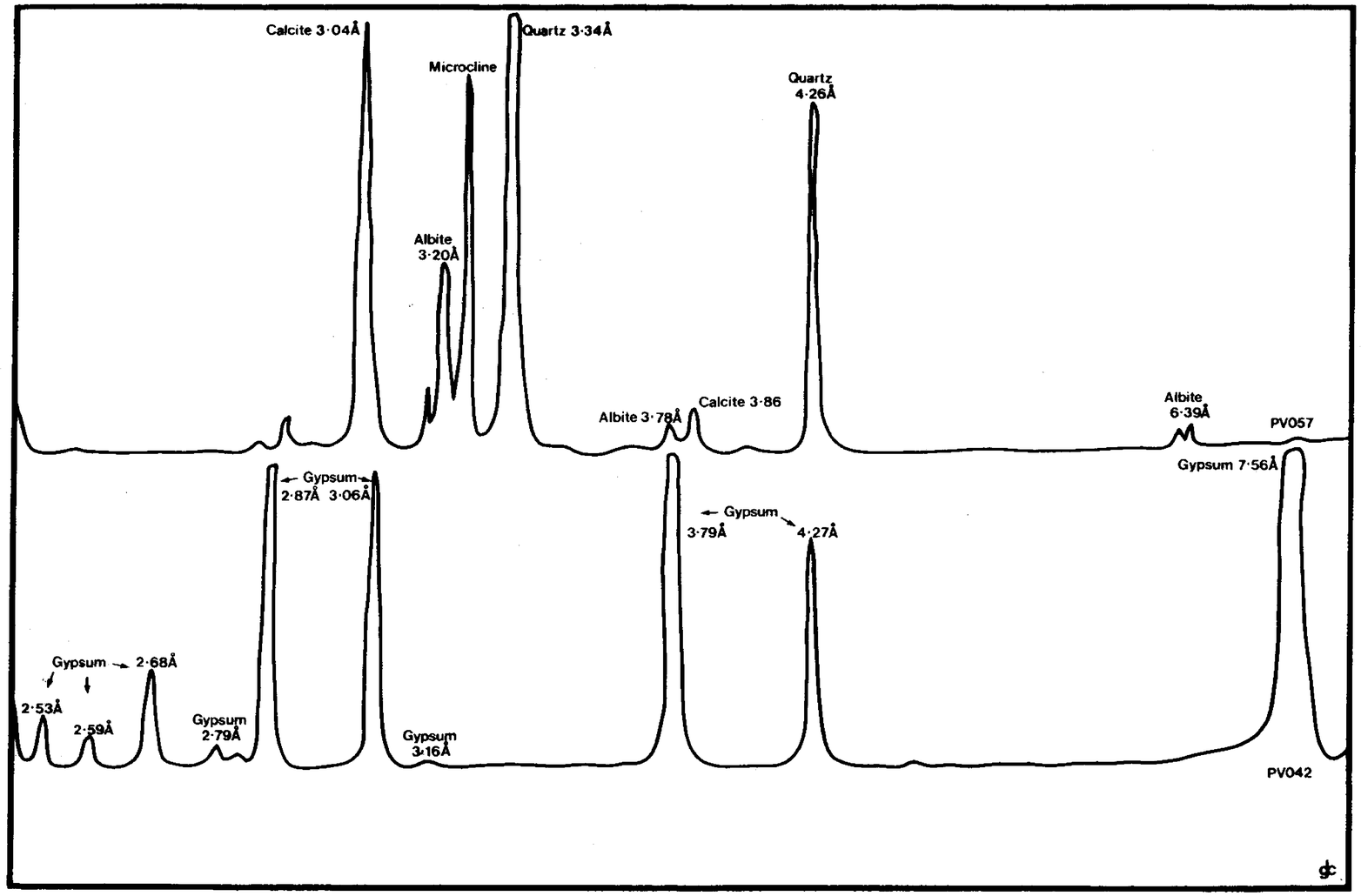


Figure G.3 X-Ray Diffraction Traces of Indurated Soil Layers - Bahrain

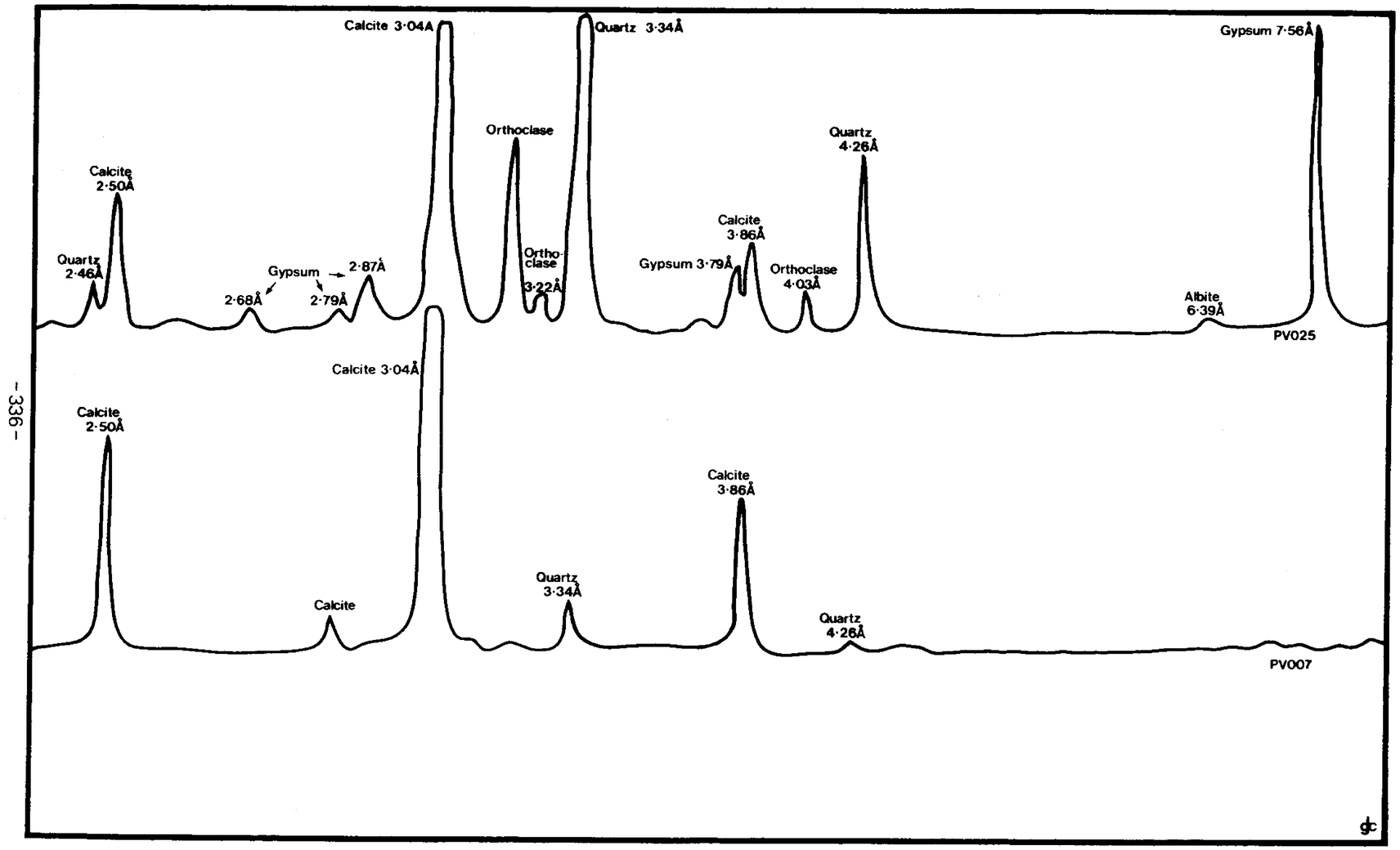
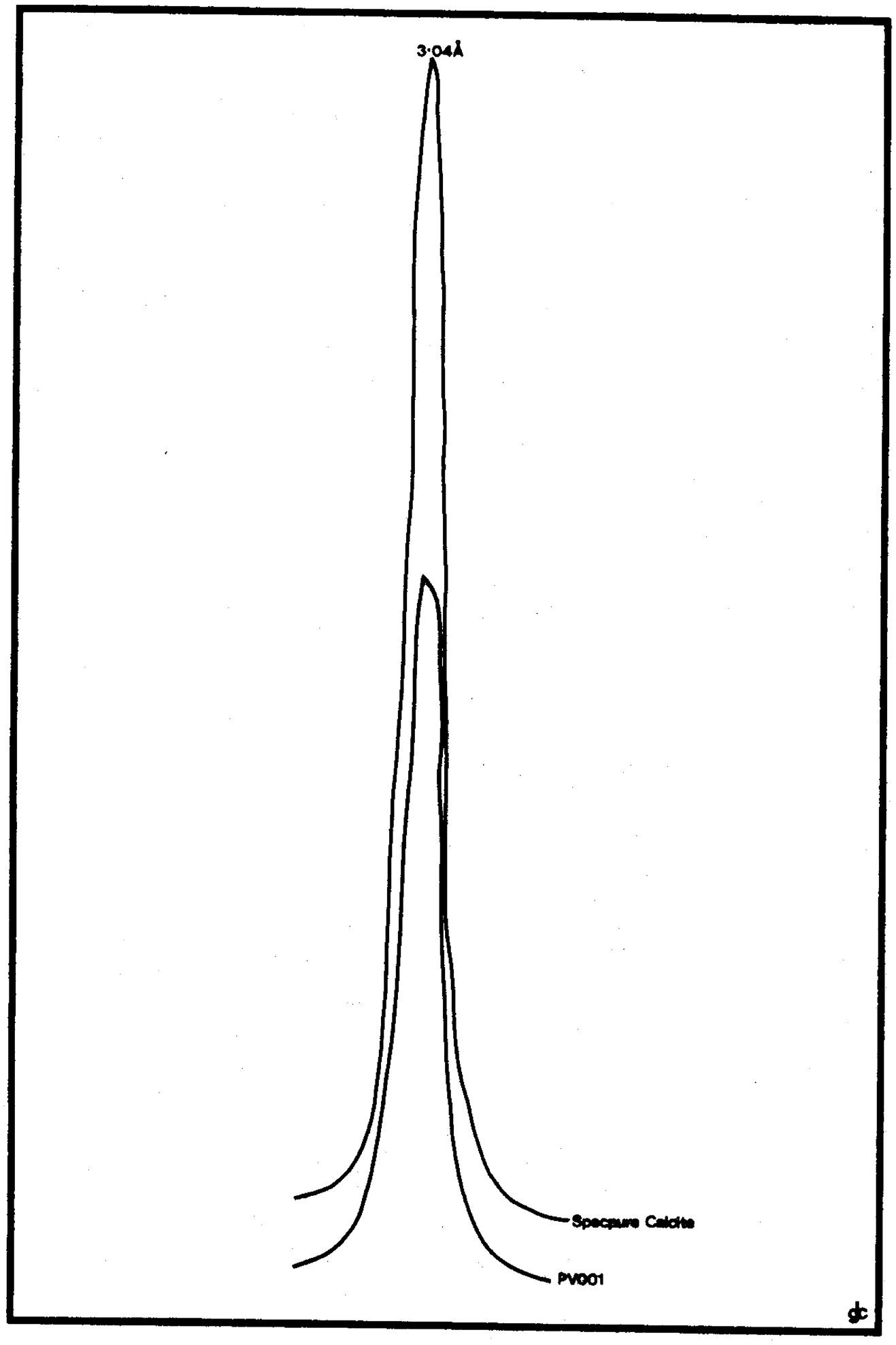


Figure G.4 Expanded X-Ray Diffraction Trace Compared with Calcite



Magnesium in the sample would cause a collapse of the 'd' spacing and result in a lateral shift of the diffraction peak. These results confirm that the petrocalcic horizons formed by cementing by calcite.

G.2.3 Optical microscopy results

These results confirm the XRD studies. Cemented layers in profiles PV007, PV022 and PV017 are dominated by calcite grains of coarse clay and silt size with very little siliceous material. The petrocalcic horizon in profile PV025 consists of silt sized calcite grains, cemented together and forming a distinctive coating to the larger (sand grain size) siliceous material comprising quartz and felspars. In some cases, the calcitic silt grains enclose clay mineral particles.

H

Vegetation

H.1 CHECK LIST OF FLORA

Specimens of vegetation collected from within the Level 3 area were provisionally identified using the Flora of Saudi Arabia (Migahid, 1979). Reference was also made to Good (1955) and Zakis (1978). All specimens were sent to the Royal Botanic Gardens, Kew for confirmatory identification. Plant species identified are listed in Table H.1. This list includes natural vegetation and weed species but excludes introduced crop and tree species.

The species determinations in Table H.1 should be taken as definitive: they may vary slightly from the provisional nomenclatures which appear in the main text.

H.2 VEGETATION TRANSECTS

Detailed studies of the flora in each of the main physiographic zones were made during May and June. Species composition was recorded along two transects, each 90 metres long and arranged at right angles to each other, giving an overall length of 180 metres. The length of transect occupied by each species was used to calculate the overall proportion of each species as well as to estimate the percentage plant cover. For this purpose dead plant material, usually remnants of Suaeda or Salsola spp., was included as 'vegetation' rather than as bare ground.

The results of the transect surveys are given in Table H.2.

Table H.1 Check List of Flora

No.	Name	Family
1	Salsola baryosma	Chenopodiaceae
2	Zygophyllum qatarense	Zygophyllaceae
3	Prosopis farcta	Leguminosae
4	Suaeda vermiculata	Chenopodiaceae
5	Halocnemnum strobilaceum	Chenopodiaceae
6	Heliotropium sp.	Boraginaceae
7	Sporabolus arabicus	Gramineae
8	Tamarix macrocarpa	Tamaricaceae
9	Limonium axillare	Plumbaginaceae
10	Phoenix dactylifera	Palmaceae
11	Cressa cretica	Convolvulaceae
13	Alhagi maurorum	Leguminosae
14	Phragmites australis	Gramineae
15	Schismus barbatus	Gramineae
16	Avicennia marina	Verbenaceae
17	Cassia italica	Leguminosae
18	Lycium shawii	Solanaceae
19	Aeluropus lagopoides	Gramineae
20	Juncus sp.	Juncaceae
21	Capparis spinosa	Capparidaceae
22	Panicum turgidum	Gramineae
23	Cistanche phelipaea	Orobanchaceae
24	Halopeplis perfoliata	Chenopodiaceae
25	Anabasis articulata	Chenopodiaceae
26	Heliotropium crispum	Boraginaceae
27	Taverniera spartea	Leguminosae
28	Atriplex leucoclada	Chenopodiaceae
29	Arthrocnemum glaucum	Chenopodiaceae
30	Arethum graveolens	Umbellifereae
31	Salicornia herbacea	Chenopodiaceae
31a	Halopeplis amplexicaulis	Chenopediaceae
32	Sporobolus spicatus	Gramineae
33	Sesuvium sesuvioides	Aizoaceae
34	Lippia nodiflora	Verbenaceae
35	Heliotropium sp.	Boraginaceae
36	Prosopis juliflora	Leguminosae
37	Launea procumbens	Compositae
38	Senchus oleraceus	Compositae
39	Melilotus indica	Leguminosae
40	Polypogon monspeliensis	Gramineae

Table H.1 (Continued)

No.	Name	Family
41	Helianthemum lippii	Cistaceae
42	Cyperus conglomeratus	Cyperaceae
43	Erempogon foveolatus	Gramineae
44	Chenopodium murale	Chenopodiaceae
45	Zygophyllum simplex	Aizoaceae
46	Cyperus arenarius	Cyperaceae
47	Hammada elegans	Chenopodiaceae
48	Frankenia puluerulenta	Frankeniaceae
49	Cyperus arenarius	Cyperaceae
50	Salsola vermiculata	Chenopodiaceae
51	Senecio glaucus	Compositae
52	Spergularia marina	Caryophyllaceae
53	Mesembryanthemum nodiflorum	Aizoaceae
54	Cynodon dactylon	Gramineae
60	Aeluropus littoralis	Gramineae
61	Spergularia marina	Caryphyllaceae
63	Bassia eriophora	Chenopodiaceae
64	Erempogon foveolatus	Gramineae
65	Convolvulus arvensis	Convolvulaceae
66	Cuscuta planiflora	Cuscutaceae
67	Suaeda maritima	Chenopodiaceae
68	Pennisetum divisum	Gramineae
70	Fagonia indica	Zygophyllaceae
71	Polypogon monspeliensis	Gramineae
72	Aleuropus lagopoides	Gramineae
73	Salsola sp.	Chenopodiaceae
74		
83	Dactyloctenium aegyptium	Gramineae
84	Sporobolus spicatus	Gramineae
85	Portulaca oleracea	Portulacaceae
86	Amaranthus graecizans	Amaranthaceae
87	Zygophyllum qatarense	Zygophyllaceae
88	Cyperius conglomeratus	Cyperaceae
89	Halocnemum strobilaceum	Chenopodiaceae
91	Launea micronata	Compositae
101	Suaeda sp.	Chenopodiaceae
102	Andrachne telephoides	Chenopodiaceae

Table H.2 Vegetation Transects: Density and Type

Species No.	Name		Transect Length m	%	% Plant Cover
A. Aeolian Sand Sheet; Hisham Series					
1	Salsola baryosma		3.20	13.4	
26	Heliotropium crispum	m	6.72	28.2	
7	Sporobolus arabicus		0.96	4.0	
22	Panicum turgidum		0.64	2.7	
11	Cressa cretica		1.28	5.4	
4	Suaeda vermiculata		0.32	1.3	
46	Cyperus arenarius		0.96	4.0	
19	Aeluropus lagopoides		0.16	0.7	
2	Zygophyllum qatarense		0.48	2.0	
36	Prosopis juliflora		0.48	2.0	
43	Erempogon foveolatus		0.16	0.7	
	Dead		8.48	35.6	
	Total Cover		23.84	100.0	13.2
	Bare Ground		156.16	-	86.8
P. Limestone Pavement and Fans; Dilmun Series					
50	Salsola vermiculata		5.92	69.8	
25	Anabasis articulata		0.32	3.8	
64/43	Erempogon foveolatus		1.60	18.9	
2	Zygophyllum qatarense		0.32	3.8	
	Dead		0.32	3.8	
	Total Cover		8.48	100.0	4.9
	Bare Ground		171.52	-	95.1

Table H.2 (Continued)

Species No.	Name	Transect Length m	%	% Plant Cover
F. Lower Fans; Lawzi Series				
2	Zygophyllum qatarense	3.52	18.0	
28	Atriplex leucoclada	5.76	29.5	
5	Halocnemum strobilaceum	2.56	13.1	
25	Anabasis articulata	0.80	4.1	
19	Aeluropus lagopoides	1.76	9.0	
4	Suaeda vermiculata	3.36	17.2	
36	Prosopis juliflora	0.80	4.1	
70	Fagonia indica	0.32	1.6	
11	Cressa cretica	0.16	0.8	
	Dead	0.48	2.6	
	Total Cover	19.5	100.0	10.8
	Bare Ground	160.48	-	89.2
N. Nebkha Gypsic Plain; Maqabah Series				
2	Zygophyllum qatarense	3.84	35.3	
28	Atriplex leucoclada	0.80	7.4	
70	Fagonia indica	0.16	1.5	
19	Aeluropus lagopoides	1.60	14.7	
25	Anabasis articulata	0.64	5.9	
4	Suaeda vermiculata	2.08	19.1	
9	Limonium axillare	0.16	1.5	
5	Halocnemum strobilaceum	0.16	1.5	
26	Heliotropium crispum	0.16	1.5	
	Dead	1.28	11.8	
	Total Cover	10.88	100.0	6.4
	Bare Ground	169.12	-	93.6

Table H.2 (Continued)

Species No.	Name	Transect Length m	%	% Plant Cover
S. Salmabad Gypsic Plain; Isa Series				
5	**Halocnemum strobilaceum**	8.96	80.0	
2	Zygophyllum qatarense	0.16	1.4	
24	Halopeplis perfoliata	0.64	5.7	
9	Limonium axillare	0.16	1.4	
4	**Suaeda vermiculata**	0.64	5.8	
	Dead	0.64	5.7	
	Total Cover	11.20	100.0	6.2
	Bare Ground	168.80	-	93.8
L. Marine Loam Plain; Khuways Series				
4	**Suaeda vermiculata**	29.44	67.6	
11	Cressa cretica	3.20	7.4	
21	Capparis spinosa	0.80	1.8	
10	Phoenix dactylifera	0.32	0.7	
14	Phragmites australis	0.16	0.4	
5	**Halocnemum strobilaceum**	0.16	0.4	
	Dead	9.44	21.7	
	Total Cover	43.52	100.0	31.9
	Bare Ground	136.48	-	68.1
D. Khadarah Depression; Khadarah Series				
4	**Suaeda vermiculata**	3.52	33.3	
19	Aeluropus lagopoides	1.12	10.6	
11	Cressa cretica	1.28	12.1	
5	**Halocnemum strobilaceum**	4.32	40.9	
1	Salsola baryosma	0.16	1.5	
	Dead	0.16	1.5	
	Total Cover	10.56	100.0	6.2
	Bare Ground	169.44	-	93.8

Table H.2 (Continued)

Species No.	Name	Transect Length m	%	% Plant Cover
Hawrat 'Inqa; Areen Series				
7	Sporobolus arabicus	11.52	34.5	
26	Heliotropium crispum	5.60	16.8	
41	Helianthemum lippii	2.40	7.2	
46	Cyperus arenarius	9.44	28.4	
2	Zygophyllum qatarense	1.12	3.4	
19	Aeluropus lagopoides	0.96	2.9	
42	Cyperus conglomeratus	0.80	2.4	
22	Panicum turgidum	0.16	0.5	
43	Erempogon foveolatus	0.16	0.5	
	Dead	1.12	3.4	
	Total Cover	33.28	100.0	18.5
	Bare Ground	146.72	-	81.5

Data based on measured length of each species along transects of 180 metres. Species identified at the Royal Botanic Gardens, Kew. Species numbers refer to checklist in Table H.1.

I

Pedological Map of Bahrain

I.1. INTRODUCTION

The terms of reference (Appendix J) call for the production of a 1:50 000 scale generalised pedological map of Bahrain, to be based on existing data and new survey material. The Reconnaissance Soils Map, produced as part of the Bahrain Surface Materials Resources Survey (BSMRS - Min. Works, Power and Water, 1976), provides a reliable overall indication of soil distribution at the scale required. The soil units, however, are based on a combination of features, including physiography, soil morphology, watertable depth, soil texture and land use, and therefore do not correspond the mapping units employed in the Level 3 surveys. Clearly, a re-classification and re-compilation of the existing BSMRS map according to Soil Taxonomy (USDA, 1975) would provide a soil map of Bahrain which would be compatible with the soil maps of the Level 3 areas and with those of the mainland of Saudi Arabia. Thus the principal objective of the preparation of the new map was re-interpretation according to Soil Taxonomy. At the same time it was deemed to be useful to provide a correlation with the FAO/ Unesco (1974) soil units for the Soil Map of the World.

I.2. MAPPING PROCEDURE

The Generalised Pedological Map is presented in the report album as two sheets at 1:50 000 scale. The map represents a re-interpretation of the original BSMRS map but with modifications to accomodate the findings of the present Level 3 surveys. Similarly some adjustments were necessary to conform with the revised topographic

base maps; the original (1976) soil mapping has been retained although subsequent reclamation, urban expansion and industrial development have altered the landscape in some areas.

Brief reconnaisance tours were made to investigate soils outside the Level 3 areas; this involved some 30 auger and pit sites and the analysis of a few samples to check salinity and gypsum status (Table I.1). For the most part, re-interpretation was based on the experience gained during the Level 3 surveys.

Each mapping unit of the BSMRS Soils map (Table I.2) was reclassified in terms of Soil Taxonomy and FAO/Unesco units. Table I.3 shows the result of this correlation, in which the original units have been re-classified to family Level for Soil Taxonomy and to phase level for the FAO/Unesco units. It should be emphasised that accurate definition of Soil Taxonomy units, even at higher categories of classification, depends on the availability of adequate laboratory data (especially gypsum and salinity in the case of Entisols and Aridisols) but that relatively little laboratory.

TableI.1Routine Analysis Data: Reconnaisance Survey

Site No.	Depth cm	Satn. %	pH paste	Gypsum %	Salinity $EC_{1:5}$	Salinity EC_e	Soil Unit BSMRS	Soil Taxonomy
V1001	0-25	24	7.9	0.8	0.6	7.9	C1a	JCBt
	25-45	36	7.8	0.7	0.9	8.4		
	45-100	20	8.1	0.9	0.3	-		
V1006	0-20	19	7.7	41.7	12.1	110.0	B2a	EBDT
	20-40	19	7.9	61.9	10.0	87.0		
	40-60	20	7.9	72.8	10.4	95.0		
V1008	0-20	22	8.1	4.8	8.5	74.0	C2a	JAFt
	20-60	19	8.8	1.2	5.4	74.0		
	60-90	21	8.6	3.2	9.6	90.0		
V1012	0-50	24	8.7	1.8	6.1	66.0	C2a	JAFt
	50-100	21	8.9	1.0	9.7	100.0		
V1018	0-25	22	7.6	1.5	7.7	66.0	D1b	EBAt
	25-100	20	8.0	1.0	10.4	157.0		
V1023	0-20	20	7.3	1.4	9.8	130.0	D1b	JAFt
	20-75	22	7.6	1.0	4.5	53.0		
	75-100	20	7.5	1.1	7.7	70.0		

Table I.2. Legend for BSMRS Reconnaisance Soil Map.

Soil Group	Subgroup	Mapping Unit
A Cultivated solonchak	A1 loamy	A1a Loamy soil more than im deep
		A1b Loamy soil with limestone at less than 1m
		A1d Loamy soil with saline water-table at less than 1m
	A2 Sandy	A2 Sandy soil with water-table at less than 1m
	A3 Clayey	A3 Clayey soil with water-table at more than 1m
B Natural solonchak	B1 Gypsiferous solonchak	B1a Mainly loamy soils with water-table at less than 1m
		B1b Mainly sandy soils with water-table at less than 1m
	B2 Sebkhas	B2a Quartz-gypsiferous sands
		B2b Carbonate-rich silts with gypsiferous sands
		B2c Salt-pans
		B2d Embanked marine mudflats
C Regosols	C1 Aeolian sands	C1a Stable sands
		C1b Dune sands
	C2 Recent beach deposits	C2a Beach sands with shells,
		C2b Beach sands with shells cemented below 40cm
D Raw mineral soils	D1 Soils of interior basins	D1a Clays and silty clay loams
		D1b Silts and fine sands
		D1c Sands overlying playa deposits
	D2 Soils of detrital fans	D2 Gravelly and sandy soils of detrital fans
	D3 Soils with stone pavement	D3a Gravelly soils of backslopes
		D3b Gravelly soils of Interior Basin
E Rock dominated areas	E1 Areas of little or no soil naturally	E1a On scarp slopes
		E1b On other surfaces
	E2 Worked ground with most soil removed	
F Miscellaneous land categories	F1 Areas with abundant Dilmun mounds	
	F2 Urban and industrial areas	
	F3 Undifferentiated disturbed ground	

Source: Min. Works , Power and Water (1976)

Table I.3 Correlation Key for Soil Mapping Ur

BSMRS (1)		Soil Taxonomy (Subgroup & family(2))
A. Cultivated Solonchaks	A1a	Cambic Gypsiorthids, fine-loamy, carbonatic
	A1b	Cambic Gypsiorthids, coarse-loamy, mixed
	A1c	Cambic Gypsiorthids, fine-loamy, carbonatic
	A1d	Typic Salorthids, fine-loamy, carbonatic
	-	Typic Gypsiorthids, coarse-over fine-loamy gypsic
	-	Typic Paleorthids, fine-loamy, mixed
	-	Gypsic Salorthids, fine-loamy, carbonatic
	-	Aquic Paleorthids, coarse-loamy, carbonatic
	A2	Aquic Paleorthids, sandy, mixed
	A3	Cambic Gypsiorthids, clayey, carbonatic
B. Natural Solonchaks	B1a	Typic Gypsiorthids, coarse-loamy, mixed
	B1b	(i) Typic Gypsiorthids, coarse-loamy, gypsic (ii) Typic Gypsiorthids, sandy, mixed
	B2a	Typic Psammaquents mixed, and

	FAO/Unesco (3)		GDC Soil Series (4)
EBDk	Orthic Solonchaks	Zo-2a-w	Khuways - Kh
EBDk	Orthic Solonchaks	Zo-2a	Zaytun - Zn
EBDk	Gleyic Solonchaks	Zg-2a-w	Khuways - Kh - ws
EBAt	Gleyic Solonchaks	Zy-2a-w	Tubli - Tb
EBDt	Orthic Solonchaks	Zo-2a-w	Sar - Sa Abu Saybi - Sb
EBCt	Orthic Solonchaks	Zo-2a-cw	Salmabad - Sm
EBAy	Orthic Solonchaks	Zo-2a-w	Khadarah - Kh
EBCa	Gleyic Solonchaks	Zg-2a-cw	Isa - Is
EBCa	Calcaric Gleysols	Gc-1a-cxw	-
EBDk	Orthic Solonchaks	Zo-3a-w	Lawzi - Lw
EBDt	Orthic Solonchaks	Zo-2a-w	-
EBDt	Orthic Solonchaks	Zo-2a-w	Maqabah - Mq Buri - Br
EBDt	Orthic Solonchaks	Zo-2a-w	Karzakkan - Kn
JAFt	Gleyic Solonchaks and	Zg-1a-w	Wasmiyah - Ws

			Typic Gypsiorthids, sandy, mixed
		B2b	Typic Psammaquents, mixed
		B2c	Sabkhas
	C. Regosols	C1a	Typic Torripsamments, mixed and Typic Paleorthids, sandy, mixed
		C1b	Typic Torripsamments, mixed
		C2a	Typic Psammaquents, mixed
		C2b	Aquic Paleorthids, sandy, mixed
	D. Raw Mineral Soils	D1a	(i) Typic Torriorthents, loamy, mixed(calcareous)
			(ii) Typic Gypsiorthids, coarse-loamy, gypsic
		D1b	Typic Torripsamments, mixed
		D1c	Typic Psammaquents, mixed and Typic Salorthids, sandy, mixed
		D2	Typic Torriorthents, sandy, skeletal, mixed, (calcareous) and Lithic Torriorthents, sandy-skeletal, mixed
		D3a D3b	Lithic Torriorthents, sandy-skeletal and coarse-loamy skeletal,mixed
	E. Rock Dominated Areas	E1	Rockland
		E2	Rockland (Disturbed)

EBDt	Orthic Solonchaks	Zo-1a-w	-
JAFt	Gleyic Solonchaks	Zg-2a-cw	-
Ss	Salt pans	-	-
JCBt	Albic Arenosols	Qa-1a-xw	Hisham - Hs
and EBCt	Gypsic Yermosols	Yg-1a-cxw	Areen - An
JCBt	Albic Arenosols	Qa-1a-xw	Hisham - Hs
JAFt	Gleyic Solonchaks	Zg-1a-w	-
EBCa	Gleyic Solonchaks	Zg-1a-cw	-
JEBt	Haplic Yermosols	Yh-2a-x	-
EBDt	Orthic Solonchaks	Zo-2a-w	Buhayr - Bu
JCBt	Albic Arenosols,	Qa-1a-xw	-
JAFt	Gleyic Solonchaks	Zg-1a-w	-
and EBAt	Orthic Solonchaks	Zo-2a-w	-
JEBt	Albic Arenosols	Qa-1a-sx	-
and JEBl	Calcaric Regosols	Rc-1a-slx	-
JEBl	Calcaric Regosols	Rc-2a-slx	Dilmun - Dm
and	Lithosols	I-2a/b-s	Rockland - R
	Lithosols	I-1a/b-s	Rockland - R
	No Soil	-	Rockland - R

Notes: (1) Miscellaneous Land Categories are used by BSMRS to delineate burial mounds (F1), Urban areas (F2) and disturbed land (F3).

(2) A hyperthermic temperature regime applies to all soils but is omitted from the family classification in the interests of simplicity.

(3) FAO/UNESCO phase symbols:- Texture = 1 - coarse; 2- medium; 3 - fine. Slope = a - 0-8%; b - 8-30%. Phases = s - stony; l - lithic; c - petrocalcic; y - petrogypsic; w - phreatic; x - saline.

(4) Series as described in Chapter 5 of this report, minor series omitted.

data were available from the previous surveys. Some reliance therefore land to be placed on extrapolation from the Level 3 data, supplemented by a few additional routine analyses (Table I. 1).

Hav ing prepared the correlation key (Table I.3), the Soil Taxonomy units were then recompiled as a legend (Table I.4), which formed the basis of the mapping units for the Generalised Pedological Map. The mapping comprises ten subgroups of the Aridisols and Entisols, four Associations and several Miscellaneous Land Types. The subgroup units were further divided into families, based on particle-size distribution and mineralogy: all soils have a hyperthermic temperature regime.

The principal changes made to the original mapping are as follows:-

a) Several new units were introduced to accomodate soils mapped during the Level 3 surveys; boundaries were re-drawn accordingly.

b) The Raw Mineral Soils (Unit D1a) were split into two units so that the distinctive Typic Gypsiorthids of the Buhayr area could be identified separately from the finer textured, less gypsic Torriorthents of the Interior Basin.

c) Areas of sabkha on the southwest coast have been combined and enlarged to conform with the Salt Pans of the Geomorphology and Superficial Materials map (Min. Works, Power and Water, 1976 a). This region represents a sump for the accumulation of run-off and is better described as a salt pan.

d) Some soil units have been combined for the purposes of generalisation. These include the complex units of the Interior Basin (D1b and D1c) and the very shallow rocky soils of the backslopes and hills (D3a and D3b).

e) Areas of little or no soil (E1a, E1b and E2), and Sabkhas have been grouped into Miscellaneous Land Types.

Table I.4. Legend for Generalised Pedological Map of Bahrain

Subgroup	Family (1)	Symbol
ARIDISOLS		
Typic Salorthids	Fine-loamy,cabonatic	S1
Gypsic Salorthids	Fine-loamy,carbonatic	S2
Typic Gypsiorthids	Sandy, mixed	G1
	Coarse-loamy, mixed	G2
	Coarse-loamy, gypsic	G3
	Coarse over fine-loamy gypsic	G4
Cambic Gypsiorthids	Clayey,carbonatic	G5
	Fine-loamy,carbonatic	G6
	Coarse-loamy, mixed	G7
Typic Paleorthids	Fine-loamy, mixed	P1
Aquic Paleorthids	Coarse-loamy,carbonatic	P2
	Sandy, mixed	P3
ENTISOLS		
Typic Torripsamments	Sandy, mixed	T1
Typic Psammaquents	Sandy,mixed	M1
Typic Torriorthents	Loamy,mixed(calcareous)	R1
Lithic Torriorthents	Sandy-skeletal and coarse-loamy-skeletal, mixed.	R2
ASSOCIATIONS		
Typic Gypsiorthids Typic Psammaquents	Sandy, mixed	A1
Typic Salorthids Typic Psammaquents, Typic Torripsamments	Sandy,mixed	A2
Typic Paleorthids, Typic Torripsamments	Sandy,mixed	A3
Typic Torriorthents, Lithic Torriorthents	Sandy-skeletal mixed(calcareous)	A4
MISCELLANEOUS LAND TYPES		
Rockland		R
Burial mounds		Em
Disturbed land		Ed
Sabkha		Ss

Note:(1) All families have a hyperthermic temperature regime

J

Terms of Reference

The terms of reference for the Soil Survey and Land Classification, forming part of the Bahrain Assignment of the Umm Er Radhuma Study, are as follows:-

"Carry out soil surveys and land classification for potentially arable land (estimated to be some 3 800 hectares).

The objective of the intended studies are to:

i) Identify, describe and geographically locate arable land areas.

ii) Classify arable land areas, according to suitability for irrigated agriculture.

iii) Prepare a pedologic soil map for the region in accordance with U.S. Soil Taxonomy and correlate the units with "Definitions of soil units for the soil map of the world", FAO, 1968.

iv) These soil maps should show different kinds of soil and their characteristics: all possible information being collected necessary for site selection and planning for irrigated agricultural projects.

v) Obtain all information about soils, which are necessary for agricultural projects planning and designs.

vi) Develop agronomic management systems suitable for different soil classes in the region."

"The CONSULTANT shall carry out the studies and investigations in accordance with the following specifications, which are to be to the same standards as those in the main Umm Er Radhuma study.

1. FIELD INVESTIGATIONS

1.1 Produce a generalised pedological map of Bahrain island to a scale of 1:50 000 based on existing and new survey data and showing location of detailed survey areas.

1.2 Map potential development areas to a scale of 1:10 000 with contours at 1.0 metre intervals (these maps will be used for drawing soil maps for the individual tracts) (Level 3). The estimated development area is about 3 800 hectares.

1.3 Examine and describe the land's physiography and relief.

1.4 Examine and describe the vegetative cover, including type and density.

1.5 Examine and evaluate the natural drainage conditions.

1.6 Examine and evaluate the land's susceptibility to erosion and/or deposition hazards.

1.7 For Level 3 - 1:10 000; examine auger hole borings at an average rate of 1 boring per 4 hectares and describe at least one profile (pits) per square kilometre, to the depth of two (2) metres or the depth of solid rock, hard pan or impervious layer, provided that a minimum of three (3) such pits, considered representative of each kind of soil, be examined and sampled for analysis. Wherever drainage is required, the pits will be extended to five (5) metre depth or to solid rock, hard pan or impervious layers to carry out necessary tests and obtain necessary data for drainage design. These extensions may be done using core type power augers about six (6) inch diameter which give a clear sample for the required analysis. Examine additional borings in the arable areas, as may be necessary to trace any changes in soil characteristics so as to permit accurate

delineation of areas as small as two (2) hectares, if they have a set of properties that contrast for land use and management with surrounding areas.

1.8 The profile descriptions shall include the following properties:

1.8a - soil depth to the solid rock, hard pan or impervious layer.

1.8b - sequence, thickness of soil horizons or layers and total depth of the profile studied.

1.8c - description of each horizon or layer in regard to moist and/or dry colour (Munsell notations), texture, structure, consistency, mottling, porosity, presence of salinity or alkali, field measured pH, presence of lime and/or gypsum, root density and presence of nodules or concretions etc.

1.9 Obtain soil samples for laboratory analysis from different layers or horizons in the representative pits mentioned above.

1.10 Obtain groundwater samples for analysis, whenever it appears in the pits at the time of their examination, and record the watertable depth.

1.11 Obtain water samples from existing wells in or near each tract, for the determination of their quality, suitability for irrigation and/or possible suitability for leaching the soils if required.

1.12 Carry out field tests for the infiltration rate and hydraulic conductivity of the major soil types identified.

1.13 Delineate soil boundaries according to differences in soil properties as they appear from field studies and laboratory investigations below, and accurately draw the soil boundaries.

1.14 Collect, compile and discuss all data and information that has practical significance to agricultural development under the prevailing conditions in the Study Area."

"2. LABORATORY INVESTIGATIONS

The laboratory investigations shall include the analysis of soil and water samples for the determination of soil characteristics, possible relationship between soil salinity and groundwater salinity, the quality of well waters and their suitability for irrigation and/or soil leaching if needed. These determinations shall be carried out according to the U.S. Salinity Laboratory procedures, as described in the USDA Handbook No.60.

2.1 The soil analysis shall include the determination of the following soil properties:

2.1.1 Particle-size distribution:

2.1.2 Bulk density and porosity:

2.1.3 Soil moisture content at 1/10, 1/3, 1.0 and 15 atmosphere tensions, on representative samples only:

2.1.4 pH in water saturated soil paste:

2.1.5 Analysis of the saturation extracts for the determination of the electric conductivity (in millimhos/cm at 25°C) and calcium magnesium, sodium, potassium, carbonate, bicarbonate, chloride and sulphate (in milli-equivalents per litre) and soluble nitrate (in parts per million);

2.1.6 Cation exchange capacity (CEC) and exchangeable sodium (in milli-equivalents/100g) and calculation of exchangeable sodium percentage (ESP):

2.1.7 Percent gypsum and calcium carbonate contents:

2.1.8 Gypsum requirements (only for surface samples having ESP values higher than 15):

2.1.9 Total carbon, total nitrogen, C/N ratio and organic matter content, in surface only:

2.1.10 Total and assimilable (available) phosphorus, in surface samples only; and

2.1.11 Clay mineral identification (in samples from different depths of representative profiles only)."

"3. WATER ANALYSIS

The water samples shall be analysed for the determination of the electric conductivity, soluble cations as mentioned above in the analysis of the saturation extracts. Boron shall be determined in all well water samples only if it affects the water suitability for irrigation."

"4. SOIL SURVEY AND LAND CLASSIFICATION REPORTS

All reports and maps called for under this heading will initially be produced in ten (10) copies as attachment to Technical Progress Reports. Final production will be in one hundred (100) copies, in English with summary in Arabic, and will form part of the Final Report.

4.1 As potentially arable land is likely to occur in a number of discrete units, the CONSULTANT will submit "Soil and Land Classification Reports" of such discrete units or potential development tracts (Level 3) either separately or grouped, as appropriate.

Each of these reports shall include, but will not be restricted to:-

4.1a - General description of the area including geographic location, physiography, geomorphology, geology, topography, native vegetation, climate, natural drainage etc.

4.1b - Soil and Land Classification, including:-

(i) Pedologic soil classification to the lowest possible category according to U.S. Soil Taxonomy and correlate the units with "Definitions of Soil Units for the Soil Map of the World". (FAO, 1968).

(ii) Land classification for selected (adapted) crops, according to suitability for irrigated agriculture.

(iii) A description of each mapping unit that describes the dominant soil and the range of distinguishing characteristics, kind and amount of inclusions of contrasting soils, position in the landscape and related physical

land features which affect land use and management. The areal extent of each mapping unit so described will also be given.

4.1c - Data of field investigations and tests and laboratory analysis

4.1d - Maps:-

(1) In regional units where Level 3 survey is undertaken, pedologic soil map and land classification map, scale 1:10 000 with contours at 1.0 metre intervals for potential development tracts. (For 3 800 ha Level 3).

(ii) The pedologic soil maps and the soil irrigability classification maps shall be made such that all delineations for each recognised soil mapping unit be properly symbolised relating it to the proper mapping units.

Symbols for drainage ways and special features shall be defined and used consistent with the definition.

The mapping legend shall include accurate definitions for all mapping symbols. All soil borings and pits will be located on the field sheets.

For Level 3, soil borings and pits will be shown on a map included in the report.

4.1e - For Level 3 surveys, make soil survey interpretations and recommendations regarding proper land use and management for each soil and/or land class including land levelling, gypsum, leaching and drainage requirements, cropping patterns, irrigation, fertilisation, control of erosion and/or floods or creeping sands, etc.

4.1f - Detailed design and specifications for the most appropriate irrigation and drainage system for the areas covered by Level 3 survey."

NOTE: Aspects of design and specification for irrigation and drainage systems (4.1f) are covered in the Engineering Study, drawing on information provided by the Soil Survey and Land Classification Studies.

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