RECLAMATION OF SALT AFFECTED SOILS IN IRAQ

SOIL HYDROLOGICAL AND AGRICULTURAL STUDIES

RECLAMATION OF SALT AFFECTED SOILS IN IRAQ

SOIL HYDROLOGICAL AND AGRICULTURAL STUDIES

RECLAMATION OF SALT AFFECTED SOILS IN IRAQ

SOIL HYDROLOGICAL AND AGRICULTURAL STUDIES

P. J. DIELEMAN
editor

J. H. BOUMANS
W. C. HULSBOS
H. L. J. LINDENBERGH
P. M. VAN DER SLUIS
contributing authors

INTERNATIONAL INSTITUTE FOR LAND RECLAMATION AND IMPROVEMENT/ILRI
P.O. BOX 45 WAGENINGEN THE NETHERLANDS 1977

First published 1963
Third edition 1977

Contributing authors:

J. H. BOUMANS Chief Soil Hydrologist,
Research Section, Land Improvement and Reclamation Company (Grontmij N.V.), de Bilt (Netherlands).
1953–1959: Chief Soil Hydrologist, Drainage Branch, First Technical Section (subsequently in the Fourth Technical Section), Development Board, Baghdad.

W. C. HULSBOS Drainage and Irrigation Engineer,
International Land Development Consultants (Koninklijke Nederlandsche Heide Maatschappij), Arnhem (Neth.).
1957–1959: Soil Hydrologist, Drainage Branch, First Technical Section (subsequently in the Fourth Technical Section), Development Board Baghdad.

H. L. J. LINDENBERGH Agricultural Economist,
Project Planning and Evaluation,
Government Service for Land and Water Use, Utrecht (Neth.).
1957–1959: Soil Hydrologist, Drainage Branch, First Technical Section (subsequently in the Fourth Technical Section), Development Board, Baghdad.

P. M. VAN DER SLUIS Deputy Director,
International Land Development Consultants (Koninklijke Nederlandsche Heide Maatschappij), Arnhem (Neth.).
1955–1959: Chief Engineer Drainage, First Technical Section, Development Board, Baghdad.

Editor:

P. J. DIELEMAN Land and Water Use Specialist,
International Institute for Land Reclamation and Improvement.
1957–1958: Ass. Soil Hydrologist, Drainage Branch, First Technical Section (subsequently in the Fourth Technical Section), Development Board, Baghdad.

TABLE OF CONTENTS

page		
11		**Preface**
13		**Acknowledgments**
14	**1**	**General Introduction** (P. M. v. d. Sluis and W. C. Hulsbos)
14	1.1	Some general features of Iraq
17	1.2	Salinity in ancient times
18	1.3	Salinity at the present day
21	1.4	Reclamation work before 1950
23	1.5	Reclamation experiments since 1950
27	**2**	**Data on the soils and salts of the Dujailah experimental area** (W. C. Hulsbos)
27	2.1	Soil profile
27	2.2	Permeability and water table
28	2.3	Lime and gypsum contents
30	2.4	The soluble salts
34	2.5	'Leaching rate' of various components of soluble salts
36	**3**	**Leaching of saline soils** (W. C. Hulsbos)
36	3.1	The leaching curve
39	3.2	A simple field test for determining the leaching curve
40	3.3	Use of the leaching curve
42	3.4	Leaching and salt removal by drains
42	3.5	The salt balance in a leached soil
45	3.6	Drain discharge and leaching percentage

page

48 **4** **Alkalinity aspects of leaching of salt affected soils** (J. H. Boumans)
48 4.1 Introduction
49 4.2 The saline-alkali soils of Iraq
50 4.3 Preliminary investigations
51 4.4 Infiltration rate and exchangeable sodium
53 4.5 Exchangeable sodium behaviour in the leaching of field plots
55 4.6 Relationship between exchangeable sodium, pH and salinity

57 **5** **Crop yields and rotations during reclamation** (W. C. Hulsbos)
57 5.1 Introduction
58 5.2 Effect of salinity and fertilizer on yields
63 5.3 Effect of soil nitrate content on yields
66 5.4 Use of crop rotations in the reclamation

69 **6** **Consumptive use** (J. H. Boumans)
69 6.1 Introduction
69 6.2 Experimental consumptive use
74 6.3 Consumptive use according to Blaney-Criddle, Penman and pan-evaporation methods
77 6.4 Discussion
81 6.5 Conclusions

83 **7** **Some principles governing the drainage and irrigation of saline soils** (J. H. Boumans)
83 7.1 Introduction
85 7.2 Drainage formulae
87 7.3 The water and salt balance of the soil
90 7.4 Leaching efficiency
92 7.5 Required irrigation and drainage quantities
94 7.6 Drainage for salinity control and reclamation
95 7.7 Irrigation efficiency and drainage

97 **8** **Some applications and calculations** (J. H. Boumans)
97 8.1 Introduction
97 8.2 Draining permanently cropped soils.
102 8.3 Draining seasonally cropped soils with fallow

page

117 **9** **Some economic aspects of reclamation projects** (H. L. J. Lindenbergh and P. M. van der Sluis)

117 9.1 Introduction

117 9.2 Economic feasibility of reclamation projects in Iraq

119 9.3 Programming of reclamation projects

123 **Annex I** The layout and experimental procedure of the Dujailah drainage and land reclamation farm

128 **Annex II** The analytical methods employed

132 **Annex III** Conductivity and salinity of average soil extracts

133 **Annex IV** Nomograph for reducing electrical conductivity or resistance readings of natural waters of temperatures between 10 and 40 centigrades to conductivity at 25 centigrades

134 **Annex V** Calculation of drain spacing according to Ernst

138 **Annex VI** Chart for calculating the drain spacing according to Ernst-Boumans

140 **Annex VII** A drainage formula for two-layered anisotropic soils (H. L. J. Lindenbergh)

149 **Summary**

154 **Résumé**

160 **Zusammenfassung**

166 **Resumen**

171 **References**

174 **Symbols, abbreviations and terms**

Digging a drainage canal

PREFACE

This work is the fruit of the combined efforts of four authors, who during the period 1953–1959 were employed as foreign experts in the First Technical Section (subsequently in the Fourth Technical Section) of the Ministry of Development and Development Board of Iraq. One of their assignments was to report on the prospects and method of reclamation of salt affected areas.
A number of experimental fields were laid out with a view to understanding fully the behaviour of soil, salt and crop under given conditions of irrigation and drainage. The experience gained from these fields was regularly compiled in mimeographed reports which were distributed on a limited scale only. The significance of this research, however, warranted much wider publicity. One of the tasks of the International Institute for Land Reclamation and Improvement at Wageningen being to disseminate the knowledge and experience gained, this body therefore promoted the issue of the subject-matter discussed in the progress reports. The Institute is greatly indebted to the authors, who expressed their willingness to process and rearrange the contents of the progress reports so that they should become attuned to readers outside Iraq.

Rewriting the reports does not mean that the results obtained are applicable without further consideration to areas outside Iraq. As long as by reason of the complex nature of the problems and the lack of a quantitative understanding of a few critical factors, a mathematical description of the salt and water movement is beset with difficulties, opportunities of re-using results are limited.
The main object of rewriting the reports is to give the reader a clear picture of the interrelationship of salinity, irrigation, drainage and crops under the conditions prevailing in the Mesopotamian Plain of Central Iraq. By stating in full (as far as possible) the conditions and data of influence on the salt and water balance, an attempt has been made to facilitate the drawing of a parallel with the reader's own problems.

The first two chapters deal with the background of the experiments and conditions under which they took place. The experimental results are then discussed in chapters three to six. In chapters seven and eight the data obtained from the experiments provide the basis for a fundamental approach to the problem and systematic calculations of the water and salt balance.

Although the authors have not attempted to look on agricultural development (being part of more extensive development schemes) as a subject of discussion, they have found it difficult to disregard altogether certain important aspects of economic justification, organization and synchronization of reclamation projects. A few remarks have therefore been made on this subject in the final chapter.

It follows from the foregoing that not all aspects of the reclamation of salt-affected areas of Iraq have been dealt with in this paper; problems forming particularly the subject of experimental research have been treated only. This means that special attention has not been paid to the manner of setting out – chronologically – the various phases of the investigations with a view to arriving at a project design.

The plan of the present work leads easily to a certain overlapping of the subject-matter. An attempt has been made to reduce the overlapping without detracting from the readibility. Likewise, it proved to be very difficult to standardize all the technical expressions used. Misunderstanding could probably be avoided, however, by clearly restating the authors' intentions where necessary.

The publication of this book will place the compiled results of the research work carried out by authors and Iraqi engineers at the disposal of the Government of Iraq, its specialists and engineers and further of all those engaged in the reclamation of salt-affected soils. We are greatly indebted to the Iraqi Government for consenting to have it published in this form.

THE EDITOR

ACKNOWLEDGMENTS

The authors owe a debt of gratitude both to the Iraq Government and to Mr. K. F. Vernon, Head of the First Technical Section of the Development Board of the Government of Iraq, for his support and guidance during the initial stage of the experiments, to Messrs. Mahmud Hassan, Dr. Dhia Ahmed, Dr. Louya Tahsin Qadri for their support and interest during the subsequent stages of the experiments, to the Directorate General of Irrigation and its divisions at Kut al Hay and Hillah for their helpful co-operation, to the Irrigation and Drainage Laboratory at Tel Mohammed Baghdad for the analyses of the numerous soil and water samples, and finally to Mr. Nuri Majid, irrigation engineer, Mr. Abdullah A'rar, soil hydrologist, Messrs. Bakir Hassan, Abdul Razak Al-Sabty, Ayada Al-Hadithy, Ibrahim Al Samarai, Abdul Sattar Al Haj Abdullal, Hassan Moghrabi, Mohammed Qaddourah, Izzat Qaddourah, Karim Husseini and Mohammed Hassan Ibrahim, technical investigations supervisors, for their valuable co-operation in assembling and processing the experimental data.

1. GENERAL INTRODUCTION

1.1. SOME GENERAL FEATURES OF IRAQ

For background information and a better understanding of the following chapters a brief description of some general features of Iraq is given below.

— *Geographical situation*

Although the territory of Iraq extends between the parallels of 29° and 37° N., and between 39° and 48° E., the Mesopotamian plain in which the salinity problems are concentrated only extends between 30° and 34° N., and between 43° and 48° E. (Fig. 7).

— *Acreages*

Iraq includes an area of about 180 million mesharas (= 45 million hectares = 450.000 sq.km. = 175.000 sq.m.).
According to the Iraq Agricultural Magazine of January-February-March 1955, the area with rain-fed agriculture in the northern part of Iraq is approximately 16 million mesharas[1]) and the irrigable area approx. 32 million mesharas, together representing only 27 % of Iraqi territory. About 11 million mesharas are irrigated annually, but the same area lies fallow so that there is a potential expansion of irrigated agriculture of some 10 million mesharas.

— *Climate*

The Mesopotamian plain has a distinctly arid climate, as illustrated by the following graphs (Fig. 1, 2, 3).
The most characteristic feature of the climate is the long dry summer, from May to October, with very high temperatures. There is some rain in winter but normal agriculture requires an artificial water supply throughout the year. A detailed description of the climate of Iraq is given by WARTENA (1959).

[1]) meshara: local area unit, 2500 m^2.

— *Soils*

The soils in the Mesopotamian plain are all fluviatile; irrigation deposits and the sedimentation have been largely determined by the subsequent irrigation systems. Levee and basin soils are found as well as transitional soils. For a detailed description of the soil reference may be made to BURINGH (1960).

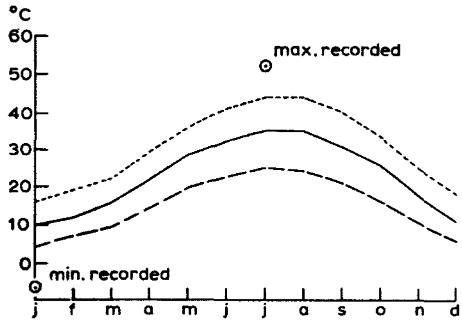

Fig. 1. Temperatures at Baghdad Airport
----- mean maximum daily temperature
—— mean daily temperature
- - - mean minimum daily temperature

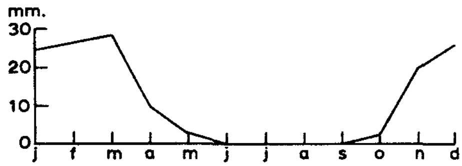

Fig. 2. Average depth of monthly rainfall at Baghdad Airport

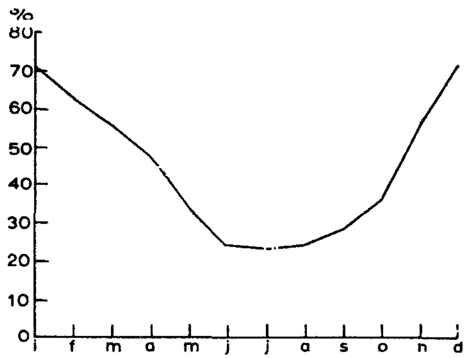

Fig. 3. Monthly average relative air humidity at Baghdad Airport

A striking feature is the very high content of calcium carbonate: 25 % to 30 % of lime is quite common and less than 20 % is rare. As may be expected under the prevailing climatic conditions, the organic matter content is low to very low. The chemical composition of the soils as a whole is determined by the salinization, described in chapters 3–5.

— *Irrigation water*

The only source of irrigation water for the Mesopotamian plain are the Euphrates and Tigris rivers with their tributaries. Both the Euphrates and Tigris rise in Turkey and are partly fed by melting snow.
The rivers are best characterized by the following graphs (Fig. 4, 5, 6).

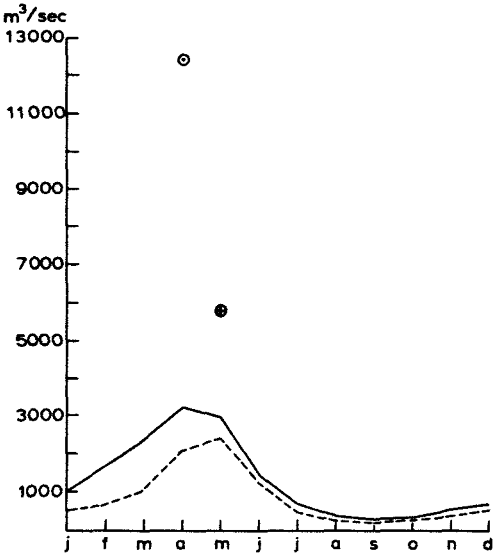

Fig. 4. Average monthly discharges for
—— Tigris river at Samarra
----- Euphrates river at Hit
⊙ max. flood recorded for Tigris at Samarra
⊕ max. flood recorded for Euphrates at Hit

These graphs clearly show that both rivers have a distinct flood period. For many years the Iraq government has been trying to harness the two rivers by building dams and barrages, and by 1959 substantial progress had already been achieved in this field, thus – as a collateral benefit – making more water available for the irrigation of summer crops.

— *Irrigation system*

The irrigation system in Iraq is primarily based on gravity supply, although in some of the higher lands, mostly levee soils, pump irrigation has developed fairly rapidly in recent years.

All main barrages and diversion dams, as well as main feeders, main and secondary canals with all auxiliary structures, are government-built, controlled, operated and maintained.
This means that the government also controls the irrigation duties. For the purpose of illustration it can be said that under the present agricultural system the winter irrigation

duty at the head regulator is approx. 1 m^3/sec. per 12,000 mesharas of gross area actually cultivated (or about 3 mm/day for the gross cultivated area).
The water distribution in the fields is entirely left to the farmers and/or landowners.

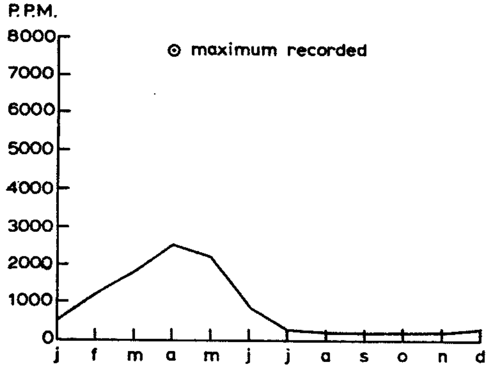

Fig. 5. Average silt content of Tigris river at Baghdad

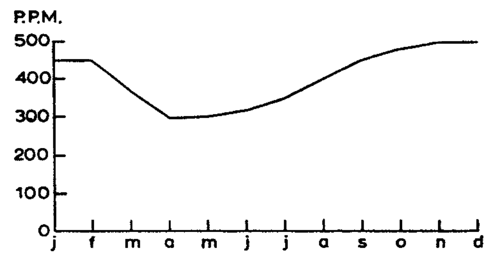

Fig. 6. Average total dissolved salts of Tigris river at Baghdad

— *Crops*

The main winter crop in the delta area is barley, wheat only being cultivated on the non-saline or slightly saline soils.
Date palms are grown on the non-saline, higher river and canal levee soils. The cultivation of summer crops is restricted. Crops growing in summer include cotton, sesame, peas, lentils, beans and other vegetables. In the lower areas with a better spring and/or summer water supply there is a considerable amount of rice-growing.
The low to very low crop yields are mainly due to the high salt content of the soils. For instance, barley yields from 100–300 kg per meshara, an average of 120–150 kg per meshara being quite common.

1.2. SALINITY IN ANCIENT TIMES

It is a well-known fact that the civilisations that previously flourished in the territory of present-day Iraq are among the oldest and most renowned in the world. Agriculture was always one of the foundation pillars of these civilisations and many ancient historians claim to have seen the magnificent crops with their own eyes. As the present salinity situation in Iraq is fairly bad (see 1.3), this has led to speculation as to whether salinity was known in ancient times. Under the auspices of the Iraq Government the Directorate General of Antiquities, Baghdad, together with the Orienta Institute of the University of Chicago, carried out a number of investigations in this connection. An examination of tax records, which gave information on crop yields and the ratio of wheat/barley acreages, led to the following conclusions: –

1. There was no major occurrence of salinity in ancient times and crop yields stood at a high level; for instance, in 2400 B.C. cereals yielded up to 2500 litres per hectare (= approx. 500 kg/meshara).
2. No traces or records were found of artificial drainage, so that it must be concluded that there were no artificial drainage facilities.
3. The first salinity records encountered about 2400 B.C. relate to the present area of Gharraf in East Iraq (Fig. 7). This salinity may well have been caused by intensive irrigation and a rising water table.
4. The area did not recover from this onset of salinity and this phenomena may well have contributed to the decay of the Sumerian Empire, coinciding with this onset.
5. There was a salinity onset in Northern Babylonia around 100 B.C. but it was much less severe and the area recovered. The recovery was very probably due to a deeper water table.
6. Although there may be some fossile marine salt deposits, the genesis of soil salinity in Iraq as a whole must be attributed to the salt content of the irrigation water, however slight this may be. Owing to the high evaporation, caused by the arid climate, this salt accumulates in the soil over the years and the situation becomes more severe with a high water table, when capillary action may cause the evaporation to continue even after the actual irrigation has ceased.

Summarizing, it can be said that salinity was not a severe problem in ancient times, so that the present salinity in Iraq is most probably due to the accumulation of salt from irrigation water over the years.

1.3. SALINITY AT THE PRESENT DAY

There is practically no salinity in the rain-fed area of Northern Iraq, but it is very pronounced in the irrigated area of Central and Southern Iraq. The degree of salinization varies, some areas being only slightly saline, others being highly to extremely saline. This variation may be due to various causes, as differences in irrigation practices, differences in soils and occurrence of natural drainage. In this connection it should be noted that until very recently no artificial drainage facilities existed.

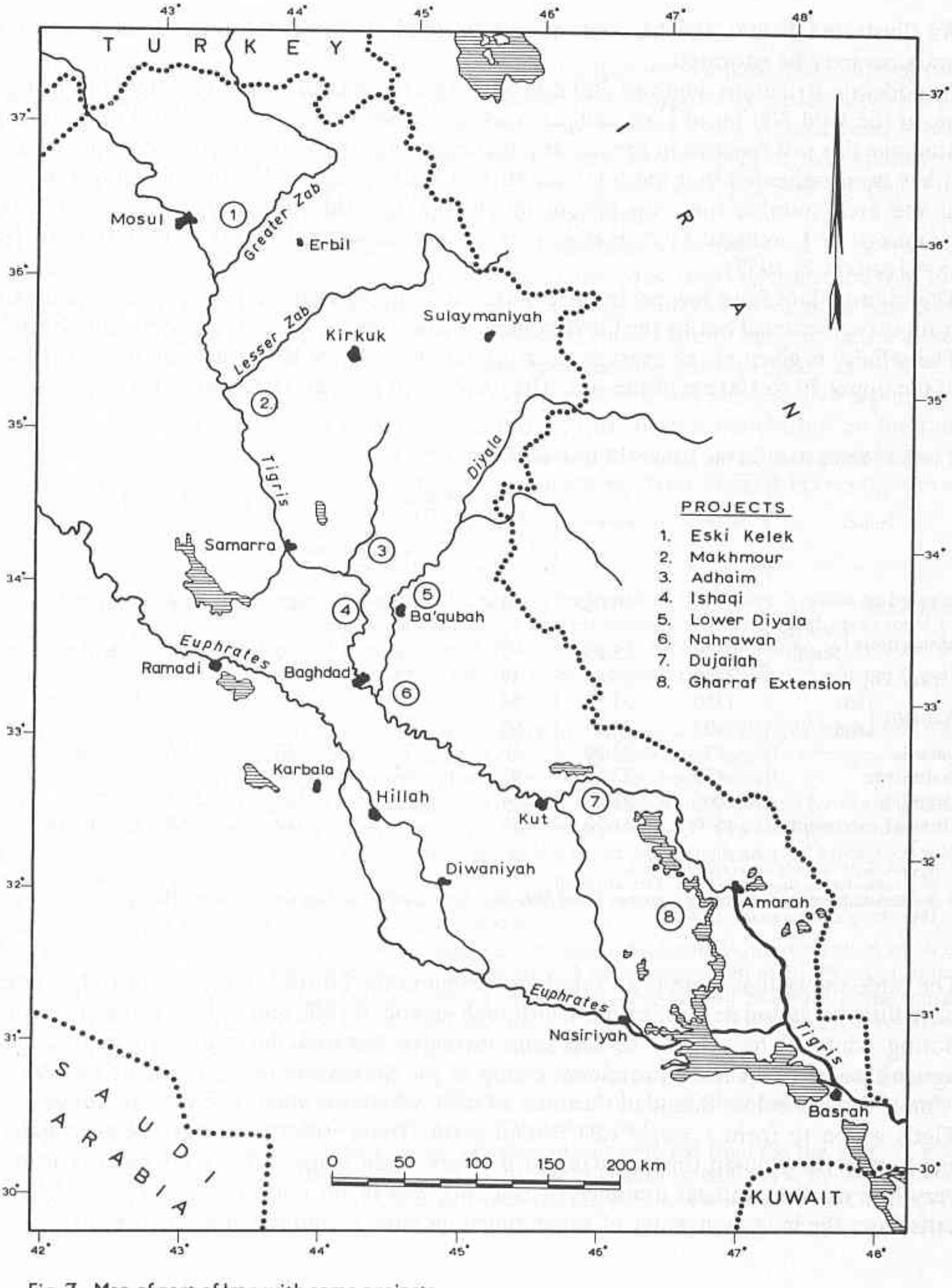

Fig. 7. Map of part of Iraq with some projects

As illustrated below, the amount of salt brought to the fields by normal irrigation practices may be enormous.

A moderate irrigation depth of 300 mm with an average salt content of 400 ppm brings on to the field 300 kg of pure salt per meshara, and if there is no natural or artificial drainage this salt remains in the soil and increases over the years to enormous quantities. It has been estimated that the total quantity of salts present in the upper 5 m of the soil of the area suitable for crop production in the Central and Southern parts of Iraq (amounts to 1 milliard (10^9) metric tons over an area of 150,000 sq.kms (DUJAILAH EXPERIMENTS 6, 1959).

The salinity data for a few project areas are summarized in table 1. The data were taken from surveys carried out by the Government Agencies and Consulting Engineering Firms. The salinity is given as the average electrical conductivity of the saturation extract (EC_e) of the upper 50 to 100 cm of the soil. The location of projects is shown in Fig. 7.

TABLE 1. Some data on the salinity of Iraq soils

Project		Km^2	Latitude[1])	Percentage of project area[2]) with		Meteorological data[3])		
				$EC_e > 8$	$EC_e > 16$	rain mm	temp.°C	station
Eski Kelek		130	36.05	0.4	0.2	382	19.4	Mosul
Makhmour	North			1	0			
	South	2500	35.25	7	1	380	22.0	Kirkuk
Lower Diyalah		4300	33.45	37	17			
Adhaim	left	1350	34.15	54	19			
	right	605	34.15	64	25			
Ishaqi		975	33.50	49	23	140	22.6	Baghdad
Nahrawan		430	33.15	81	62			
Dujailah		1000	32.25	86	–	132	24.1	Hai
Gharraf extension		1660	31.50	85	61	120	23.8	Nasiryah

[1]) Approximate latitude of centre of project.
[2]) EC_e values for the upper 0.5–1.0 m of the soil profile.
[3]) Rainfall and temperature, yearly averages. Mosul 1923–'52; Kirkuk 1938–'52; Baghdad 1937–'52; Hai 1940–'52; Nasiryah 1940–'52; (CLIMATIC MEANS, 1954).

The table shows that there is no salinity problem in the Northern districts of Iraq. These have little irrigation and the rainfall, although erratic, is sufficient to cause some leaching during winter. The salinity of the soils increases towards the south where irrigated agriculture becomes more prominent owing to the decreasing rainfall. The salt problem is most serious below Baghdad (latitude 33°20′), where the valleys of the Euphrates and Tigris widen to form a single vast, broad plain. These valley soils have been irrigated since early Babylonian times. Owing to the very slight slope of the river plains and the very low rainfall, natural drainage or leaching was of no importance. As a result, the salts from the irrigation water of some millennia have accumulated in the topsoil.

1.4. RECLAMATION WORK BEFORE 1950

During the period from 1927 to 1929 the first reclamation experiments were carried out by STRACHAN in the Saklawiyah area. These succeeded in temporarily removing the salts from the root zone of the soil and good rice crops were grown as well as barley and wheat crops during the subsequent shitwi season. But as a reclamation project the experiment was doomed even before it began owing to the wrong choice of site and lay-out. The failure to study the water table was critical (HAWKINS, 1945).
STRACHAN's main conclusion was that it proved possible to remove the salts from a highly saline soil, and to grow crops on the leached soils. Moreover, he indicated that the salts should not be leached in summer, but preferably in winter. The value of this conclusion is not diminished by the fact that the washed plots rapidly became saline again owing to the extensive seepage from a recently excavated irrigation supply canal and a high water table. It merely proved that the experiment did not succeed in keeping the salt out of the soil once it had been leached. But no quantitative conclusion on the rate of salt removal or water use for salt removal could be drawn from his experiments.
It was not until 1944 that a second attempt was made by TURCAN and HAWKINS to reclaim saline soils.

In this year ATKINSON, Director-General of Irrigation, wrote:

'It was perfectly clear that as there is more fertile land available in Iraq than there is water to irrigate, consideration for the future demanded that the fertility and production of the irrigated areas must be improved, and must be maintained at a high level if the country is to survive and to provide for an increasing population and that land drainage and the most economical possible use of water were matters of vital concern.'

It seems that before this could be written it was necessary to overcome a considerable amount of misunderstanding on land drainage and its need and possibilities. Moreover, the special wartime conditions prevented reclamation problems from being studied as thoroughly as they deserved.
The reclamation was approached experimentally and resulted in a report on 'A project for drainage and reclaiming land adjoining the Aqqar Quf', the first comprehensive report of this kind produced in Iraq (TURCAN, 1945). The site selected for the experiments was also in the Saklawiyah area, on saline soils with a shallow water table.
The gross area comprised 64 mesharas of land and was bordered by two collector drains excavated to a minimum depth of 1.25 m with a distance apart of 400 m.
For the leaching trials plots were formed by digging 90 cm deep field drains at distances apart of 50 m and 100 m. The basins were kept continuously inundated with an average depth of 10–15 cm of water. Washing was begun on 5-2-1945 and water supplied almost continuously until 29-4-1945 at the rate of 1 m^3/sec. for 1200 mesharas. A total water depth of 2 m over the gross area was supplied. The results of this experiment, as given by TURCAN, can be summarized as follows:

1. Over the whole area with mixed drain spacing, the subsoil run-off factor, i.e. the percentage of irrigation water removed by field drains, was 34.4. The inner drains were 3.5 times as effective as the outer drains. In the central portion of the plots the run-off was about 54 %.
2. An average of 1.1 per cent (dry weight basis) of chlorides was removed from the top 3 feet of soil. From a depth of 3 to 6 feet the percentage removed was calculated to be 0.4. On the 14 mesharas washed this amounts to 606 tons of chloride, which is equivalent to 1000 tons of NaCl, removed from the soil to a depth of 6 feet.

3. The amount of chloride ion removed by the field drains was calculated to be 140 tons, which was considered low compared to the 606 tons removed from the surface layers.
4. In the first samples taken after washing the average chloride ion content of the soil was approximately 0.10 % at a depth of 6″ and approximately 0.20 % at a depth of from 2′6″ to 3″. However, on 5-7-1945 four more samples were taken at different sites. Two samples at 20° cm contained an average of 0.011 % of chloride and two at 60 cm depth 0.078 % and 0.004 %. Probably the first sampling struck some of the more saline portions of the soil. Two further samples taken at different sites on 1-8-1945 at the root zone gave 0.01 % and 0.007 % of chloride ion.

The work of TURCAN and HAWKINS should be considered very valuable. It showed a proper understanding of the salt problem and under difficult conditions and among people who generally regarded their efforts with scepticism, they succeeded in completing their experiment and concluded that the salt land of Iraq could be converted to good soil capable of producing excellent crops where previously it had only been possible to obtain marginal yields or none at all. It is unfortunate that this work was not continued as additional valuable information could have been assembled which was badly needed at the time in other parts of the country where irrigation schemes were under way (Dujailah). As regards the details of their work and some of their conclusions the following observations can be made (these are partly based on the knowledge obtained from our later work): –

1. The results of the soil sampling show that no reliable average value was obtained, but the data given indicate that the leaching was successful. A salt content of 0.011 % of chloride ion, based on dry weight of soil, at a depth of 20 cm, is extremely low and unlikely to occur.
2. Approximately 30 kgs of salts per square m were removed to a soil depth of 6 feet by an irrigation application of 200 cm and with an average depth of drainage water of 69 cm (34.4 %). This is in fairly good agreement with our later experiments.
3. It was to be expected that only 140 tons of the 606 tons chloride ion leached downwards from the upper 6′ of soil would be removed by the drains. The amount of salt removed is proportionate to the depth of drainage water and its salt content and is not directly related to the amounts of salt washed down in the upper part of the soil profile.
4. The conclusion that the inner drains were 3.5 times as effective as the outer drains is inaccurate. The discharge of the inside drains was probably 3.5 times that of the outside drains; this must be due to boundary effects, as the percolation water of the outside plots mostly passed below the drains and, as stated in the report, it probably moved through the deep subsoil to the broad Khor[1]) south and west of the plots. It would therefore have been better to make a separate evaluation of the results of the central part of the area.
5. One may question the statement in the report that the permeability of all soils improved as washing proceeded as no results of permeability measurements are given. This conclusion is probably based on the observation that the drain discharge increased as the washing proceeded. This was also reported by T.A.M.S. (1957). In later experiments, however, no such an increase could be demonstrated.
6. The recommendation that washing should be continuous to be more effective and that the plots should never be dry throughout the leaching period does not agree with later experiments (DUJAILAH EXP. 4, 1957) But it is possible that the difference in soil texture, especially in relation to the sensitivity for shrinkage upon drying, is responsible for the different results; the Dujailah soil did not shrink appreciably and few cracks appeared during drying.

The leaching trial was followed by a summer cultivation on 50 % of the area. As soon as the soil was dry enough it was ploughed and sown with mash and lubia. Legumes were selected to add nitrogen to the soil and also for green manure since the crop could be ploughed in at the end of the summer season. The crops were grown without applying any further irrigation water. There were two reasons for adopting this programme (TURCAN, 1945), viz.: –

[1]) swampy area.

1. To study the resalinization of a recently washed plot with saline subsoil water some two metres below ground level, and surrounded by salty land under the influence of evaporation.
2. To see whether the soil contained sufficient capillary moisture in the root zone to support a leguminous crop such as mash and lubia through the summer. Since summer water is scarce, it was important to know whether a green manure could grow during the summer season following leaching with little or no supplemental irrigation.

The ideas developed here are very interesting. There are three considerations, viz.: the danger of resalinization after leaching, the need of restoring the leached plant nutrients, especially nitrogen, and in connection with this, the desirability of growing a leguminous crop after leaching. Most of the seedlings had died or were in a stunted condition by the beginning of July. The wilting of the plants was found to be due to lack of moisture. The chloride ion figures were still low. TURCAN remarks that the top foot of soil rapidly lost its moisture under the influence of the hot summer winds, and he thinks that if the seedling can succeed in pushing its roots down below this dangerous zone there may be sufficient residual moisture to maintain growth throughout the growing period in this type of soil. The solution would be either to plant a little earlier in the season or to apply light irrigation, two or three weeks after sowing, to enable the seedlings to extend their roots deep enough into the subsoil before the arrival of the hot winds. It is to be doubted, however, whether summer growth would be possible without a regular water supply, even if the crop was sown early.

There was hardly any resalinization during the summer cropping period, when the water table was more than 2 m below the surface. No soil samples were taken, but barley and wheat (winter crops) were sown after giving only 3 days of water to clear local concentrations of salt. This observation, as well as the rapid drying of the soil during summer, was confirmed by later experiments.

Although TURCAN did not succeed either in establishing the relationship between salinity and the amount of leaching water required to obtain a given salinity level, or in determining such drainage criteria as the run-off and drainspacing and -depth required, the results obtained are interesting. They were discussed in detail because the line of thought is in complete agreement with ideas on reclamation as developed in Dujailah.

1.5. RECLAMATION EXPERIMENTS SINCE 1950

After the second world war, especially after the establishment of the former Development Board in 1950, there was a sudden increase in interest in agricultural problems and many consultant engineering firms were instructed to carry out irrigation and drainage projects and to collect the information required for the planning of a project. Generally speaking their instructions made no provision for the establishment of drainage standards by setting up experimental farms and undertaking elaborate and time-consuming research work.

The experiments required for gaining information on such drainage standards, as

drainage modulus, drainage depth, rate of removal of salts and crop response to leaching and drainage, had to be undertaken by the Government departments.
The First Technical Section of the Development Board was responsible, among other things, for the design and the implementation of a drainage programme, which included the selection of suitable drainage requirements, reclamation methods, etc. In order to implement a research programme, various experimental fields were laid down, the most important being in the Dujailah project area. No justification is needed for laying down experimental fields when it is remembered that neither in Iraq nor in any of the neighbouring countries with comparable soil and climatic conditions has any systematic research been undertaken into reclamation possibilities and techniques.
The Dujailah Land Settlement Area covering 400,000 mesharas, is located south of Kut al Amara. The unfortunate history of this Land Settlement project has been described in detail by HASSAN MOHAMMAD ALI (1955) and DOREEN WARRINER (1957) and only a brief summary will be given here. The Dujailah project is the largest and oldest settlement project in Iraq, having been started in 1946 as a model and experiment. The area allocated to smallholders in the settlement in April 1955 was said to be 180,000 donums[1]), i.e. 1800 families with holdings of 100 donums each.
A large part of the area allocated is not now under cultivation, mostly because of salt. The new irrigation network caused rapid salinization of the soil owing to the lack of drainage. At the end of 1953 the Chief Engineer Drainage reported on the worsening soil salinity conditions in the Dujailah Land Settlement Area. The need for field drainage was particularly stressed and I.D. 10,000[2]) asked for carrying out necessary drainage experiments.
The object of the experiments was defined broadly as the acquisition of more basic knowledge on the reclamation of saline soils in its relation to soil condition, drainage, and irrigation and cultivation practices.

— *The experimental farms*

In the winter of 1954–1955 the construction of the experimental plot was begun on a specially selected area near Shakha 8 of the Dujailah Settlement Project with very salty land which had already been out of production for several years. The soils of this area chiefly consisted of fairly good permeable clay loam and silt loam deposits (see chapter 2).
A plan for a drainage and irrigation system was prepared in such a way as to afford a comparison between open and covered drains and between drains at different depths and with different spacings, the latter varying from 25 to 300 m. Provisions were made for measuring the discharge of the drains and the quantities of irrigation water to be applied.
The area thus prepared covered 200 mesharas. The plan of the experimental farm is described in detail in annex 1, and may serve as an example of a pilot farm for the study of the reclamation of saline areas.
The experimental programme on this plot was begun early in 1956.

[1]) donum: local area unit, 2500 m^2.
[2]) I.D. = Iraq Dinar(s).

Most of the conclusions to be drawn from the Dujailah experiments are of a more general validity and may be applied to the reclamation of large areas of saline soils in Southern Iraq However, some of the experimental results and conclusions are only valid for the soil and hydrological conditions obtaining in the Dujailah area. In order to check our Dujailah findings it was felt necessary to have a number of small pilot areas in other locations with different soil and hydrological conditions. Additional experiments were therefore started in the Annanah and Twarij areas. On these areas a simplified plan and a limited experimental programme were carried out which was more governed by local needs.

The Annanah experiments were begun in 1957 on a plot situated near Annanah village on the western bank of the Hilla canal, facing the Babylon ruins. The main characteristics of the soil of the Annanah plot are: –

1. a heavily textured soil in the upper 1.5 m of the profile.
2. a shallow water table, less than 1 m below the surface.
3. a high salt and exchangeable sodium content in the upper 30 cm of the soil and a very sharp decrease below this layer.

The Annanah plot was chosen on a type of soil known as basin or irrigation depression soil. It has generally been assumed that it is not worthwhile to drain and reclaim these soils which should be consequently excluded from a reclamation project. This idea was based on three assumptions: –

1. The heavy texture of these soils together with their high salinity and exchangeable sodium would cause many difficulties during the process of reclamation.
2. After draining and reclamation the productivity of these soils would be low compared to the lighter textured and better soils.
3. The low level of these soils would have an unfavourable effect on the drainage cost of the project if they were included in the drainage project.

The object of the experimental programme was to test the first two assumptions. The experiments were laid out in a square area of six mesharas extending from the centre of the basin to the nearest irrigation ditch. The area was divided into 36 square basins of 400 m^2 each. A 150 m drain ditch was excavated to such a depth that the permeable layer below the heavily textured upper layer was reached underneath. Drainage water was pumped into the nearest main irrigation canal. Two sets of piezometers and several lines of underground water observation wells were installed.

A second small pilot area, near the Twairij pumping station and adjoining the main drain, was installed in the autumn of 1957. The soil of the Twairij plot is medium textured. The upper four metres of the profile is very stratified and consists of medium textured layers (from loamy sand to light clay). Below a depth of four metres the soil is a heavy clay.

The average salt content of the upper 30 cms of soil was 3,0 % on a very salty strip in the pilot area. On the remainder of the plot the topsoil had a salt content of somewhat less than 1 per cent. The first plan of the plot provided for an area of 12 mesharas to be extended later.
The object of the experiments was to check some results of the Dujailah experiments and to try out different reclamation treatments on this type of soil. As the first experiments were begun in the winter of 1957–1958 only a few results are available.

— *The experimental programme*

For the purpose of a systematic study of the problems involved in the reclamation of saline soils, the experimental programme was divided into three parts: -

1. a soil hydrology section, especially the desalinization of the soil profile in relation to irrigation applications, soil permeability, drain spacing and drain depth.
2. an agricultural section, comprising the crop response during and after the various stages of reclamation.
3. the study of the reclamation procedures to be recommended for the reclamation of certain areas.

The problems mentioned under 1 and 2 may be considered as independent groups which can be investigated separately, while the study of reclamation procedures mentioned under 3 should be considered as a combination of the results of the first two groups with a number of social, economic and other considerations. It will be clear that the latter goes beyond a purely agricultural investigation and will partly fall outside the scope of this work.
An important feature of this experimental programme is that the results also largely determine, or should determine, which standards are to be used in selecting salty land in which reclamation and future development is economically feasible. For instance, the question as to whether gypsum amendments are required for the reclamation of saline-alkali soils (chapter 4) will be an important factor in determining whether the reclamation will be economically sound. Other equally important factors in this respect are the amount of water required to desalinize the soil profile (chapter 3) and the crop response during and after leaching (chapter 5).
It is obviously a very time consuming task to find the final answers to all these vast and complicated problems. It should be remembered that even in the case of the reclamation of waste areas under humid climatic conditions, where a great deal of experience has already been gained, opinions and methods are still being developed. But on the other hand, since scarcely anything is known about the reclamation of saline soils under Iraqi conditions all information collected will be new and may help in formulating provisional concepts and criteria.