T. O. MORRIS

THE WATER SUPPLY RESOURCES OF MALTA

THE GOVERNMENT OF MALTA

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by

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1952

CONTENTS

PAGE

PART I. INTRODUCTION

1. Early Conditions 1
2. The Growth of Urban, Agricultural, and Military Requirements 1
3. The Strategic Aspect 1
4. Local Difficulties 1
5. The Need for Planned Development and Conservation ... 1

PART II. A CRITICAL REVIEW OF WATER SUPPLY DEVELOPMENTS IN MALTA, 1610-1945

6. Conditions on the Arrival of the Knights Hospitallers ... 2
8. The Wignacourt Aqueduct and Its Springs 2
10. Population and Epidemics in the XVIIth, XVIIIth, and XIXth Centuries 3
11. The Fawara Aqueduct and Its Springs 3
12. Later Modifications of the Wignacourt Supply 3
13. Later Modifications of the Fawara Supply 4
15. Nicola Zammit's Theory of Artesian Supplies, 1854 ... 4
16. The Armier Pumping Station and Aqueduct, 1856 ... 4
17. The Cholera Epidemic of 1865 and Sutherland's Report 4
19. Micallef's Extensions to the Wignacourt Supply, 1864-1866 5
20. Lower Table Developments at Curmi and Armier, 1865 and 1867 5
21. Bateman's Visit and Report, 1867 5
24. Faucett and Woolhut's Proposals 6
26. Proposals by Micallef and Dingli for Equalisation of Upper Table Supplies, 1873 and 1875 6
27. Proposals for Open Reservoir in Wied L'Iemu 7
28. Failure of Condensers at Sliema, 1881 7
29. Chadwick's Deputation to Malta 7
30. Scope and Results of Chadwick's Work, 1883-1897 ... 8
51. Modifications and Extensions, 1897-1909 17
52. The Wied il Kbir — Wied is Seuda Gallery 17
54. Research by T. Zammit and A. H. Morris, 1909-1912, and Introduction of Chlorination 17
56. Extensions in the North of the Island and at Fawara, 1910-1914 19
57. Tal Hlas Pumping Station, 1916 19
58. Robertson's Work and Report, 1916-1917 19
64. Rizzo's Continuation of Robertson's Schemes, 1919-1934 22

PAGE

65. Wied Dalam Galleries and Pumping Station, 1920-1925 22
66. Deepening, Widening, and Extension of the Wied il Kbir — Wied is Seuda Galleries, 1919-1939 22
67. Wied il Ghasel Galleries and Pumping Station, 1926-1938 22
68. Works in the Upper Coralline Areas, 1928-1934 ... 23
69. New Service Reservoirs, 1920-1932 23
70. T. Zammit's Paper on Water Supply, 1924 23
71. Rizzo's Report on Geology, Water Supply, Mineral Oil, and Natural Gas, 1928 23
75. The Water Supply Committee of 1934-35 25
79. The Agricultural Irrigation Committee of 1935-36 ... 27
83. Irrigation Supply Developments and Water Pumps Ordinance, 1938 28
84. Sir F. Stockdale's Visit and Report on Irrigation Supplies, 1937 28
86. Revival of Deep Boring Proposals, 1940 28
87. War-time Conditions, 1940-42 30
89. Mr. A. S. Mortimer's Memorandum, 1942 30
90. Dr. E. B. Bailey's Visit and Report, 1943 31
95. Work of No. 3 Boring Section, R.E., and Visits by M.E.F. Geologists, 1943. 33
99. The Position of Supplies at the end of 1943 34
100. The Ta Kali Scheme, 1944 34
101. Emergency Supplies by Tanker, 1944 35
102. Development Work at Ta Kali, 1944-45 35
105. Extensions to the Wied is Sueda Galleries, 1944-45 ... 36
113. Work of No. 7 Boring Section, R.E., 1944-45 41
115. Work of No. 42 Geological Section, S.A.E.C., 1943-44 ... 42
117. Other Technological Work and Results, 1943-45 43

PART III. THE WATER CYCLE IN MALTA

120. The Rainfall 45
121. Evaporation, Run-off, and Percolation 46
122. Evaporation Losses and Proposals for their Reduction ... 46
128. Surface Run-off and its Utilisation 48
136. Percolation to Underground Storage; Malta Limestone Formations 53
137. Porosity and Permeability of Typical Samples 54
138. Lithology of the Coralline Limestones and the Greensand 54
139. The Lower Coralline Limestone Formation and the Main Sea Level Water Table 54
140. The Upper Coralline Limestone Formation; Distribution and General Hydrological Conditions 55
141. Stratigraphical Variation of the Globigerina Limestone Formation and the Blue Clay Formation 55
142. Hydrological Conditions in the Globigerina Limestone ... 56
143. Assessment of Annual Percolation to the Main Sea Level Water Table 56

PAGE

144. Assessment of Annual Percolation in relation to Rainfall in the Upper Coralline Areas 56
146. Chemical Composition of Malta Water Supplies; Major Controlling Factors and Available Data 58
147. Composition of Water from Roof Catchments and from the Upper Coralline Springs 59
148. Composition of Surface Run-off and of the Main Sea Level Table 59
150. Composition of Globigerina Formation Waters 60
151. Recommendations for further studies of Variation in Chemical Composition 61

PART IV. THE DEVELOPMENT AND CONSERVATION OF THE MAIN SEA LEVEL WATER TABLE

152. General Hydrology 62
153. Boundaries of the Table: The Il Ghallis Extension ... 62
154. The Main Area south of the Victoria Lines Fault. Influence of the Mahlak Fault and the Rabat-Dingli Plateau on the Western Region of the Table 63
156. The Northern Region of the Table: Influence of the Victoria Lines Fault 64
157. The Hamrun Syncline and the Central Region of the Table 64
158. The South-Eastern Region of the Table 65
159. Regional Variations of Permeability and Fissuring ... 66
160. The Relation between Standing Water Level and Composition 67
161. The Mean Gradient of the Table: Depth and Total Volume of Potable Water 68
162. Effects of Pumping on Salinity 69
163. Siting of Pumping Stations and Galleries 69
164. Comparison of Gallery and Borehole Production ... 70
165. Plans for Unit Development and Control of the Table 71
166. Objectives of Unit Control 73
167. Control of Fissure Production and Definition of Permissible Salinity Limit 73
168. Programme for further Development and Change-over from Marginal to Central Extraction 74
169. Functions and Equipment of the Gauging Holes ... 74
170. Conservation of the Central Intake Areas 75

PART V. THE DEVELOPMENT AND CONSERVATION OF THE UPPER CORALLINE AREAS

171. Relative Importance of the Main Sea Level Table and the Upper Coralline Areas: Need of Large Reservoirs for both Sources of Supply 76
172. Advantages of Reservoir Construction in the Upper Coralline Areas 76

PAGE

173. Volume of Storage required for the Equalisation of Supplies 77
175. Internal Storage Capacity of the Upper Coralline Formation 78
176. Discharge of the Upper Coralline Springs in relation to Rainfall 78
177. Need of accurate large scale Structural Contour Plans ... 79
178. Major Divisions of the Upper Coralline Areas 80
179. The Rabat-Dingli Area 81
187. Potentialities of the Rabat-Dingli Area compared with those of the Northern Fault Strips 86
188. The Binjemma-Wardia Area and its Subdivisions ... 86
189. The Fomm ir Rih Syncline 87
190. The Binjemma Syncline 87
194. The Falka Syncline 90
196. The Ta Zerp Syncline 91
198. The Ghain Tuffieha Syncline 92
204. The St. Paul's Valley Rift and Sea Level Table ... 95
209. The Mellieha-Baida Area and its Subdivisions 99
211. The Wied tal Mistra Sea Level Table 100
212. The Miziep Syncline 101
216. The Mellieha Ridge 105
218. The Mellieha Bay Sea Level Table and Gudia Anticline 106
222. The Marfa Peninsula 107
225. Essential Measures of Surface Conservation 109

PART VI. THE REORGANISATION OF PRODUCTION, STORAGE, AND DISTRIBUTION

227. The General Plan of Reorganisation 112
228. Bingemma — Falka and Miziep 112
229. Large Reservoir Facilities 112
230. Damming of Wied L'Iemu and Wied Ghemieri 112
233. Jebel Ciantar High Level Reservoirs 113
234. Economies of the Jebel Ciantar Scheme 114
235. Ring Mains 114
236. Avoidance of Temporary Expedients 114

PART VII. THE PRESENT POSITION OF IRRIGATION SUPPLIES AND THE PROSPECTS OF SEWAGE UTILISATION

237. Estimation of Irrigation Supplies 115
238. Average Rates of Crop Irrigation 115
239. Subsoil Watering of Citrus Plantations 116
240. The Effects of Bad Farming Practices on Public Water Supply Galleries 116
241. Comparative Figures of Agricultural Utilisation of Surface Area 116

PAGE

242. Requirements of Agriculture: Present Annual Consumption by the Irrigated Areas and Proposed Future Allocations by Water Department 116
243. The Utilisation of Sanitary Sewage Effluent for Irrigation Purposes 116
245. The Problem of High Salinities in the Ultimate Sewage Effluent 117
246. Site for a Sewage Purification Works 117

PART VIII. THE PROSPECTS OF DEEP BORING BELOW THE SEA LEVEL TABLES

247. Deep Borings below the Main Sea Level Table 119
248. Artesian Supplies of Fresh Water and the Probability of Tapping Supplies of Mineral Oil. Protection of the Main Sea Level Table 119
249. Oil Prospecting by Private Enterprise 119
250. Major Factors which Control the Formation of Oil Accumulations. Evidence in the Maltese Islands 119
251. Correlation of Maltese Stratigraphy with the Stratigraphical Successions of the Surrounding Mediterranean Lands... 120
252. J. H. Cooke's Paper, 1892, recording the Occurrence of Bituminous Limestones and Veins 120

PART IX. CONCLUSIONS

253. Ideal Figures of Average Salinity, Mean Annual Supply from Upper Coralline Catchment Areas, and Annual Extraction from the Main Sea Level Table 121
254. Past Abuse of the Main Sea Level Table and Neglect of the Upper Coralline Catchment Areas 121
255. Estimate of the Total Expenditure for Overall Reorganisation of the Water Supply... 121

PART X. LIST OF PAPERS CONSULTED 122

NOTE on the Prospects of Improving the Water Supply of Gozo 124

TABLES

1. Monthly and Annual Rainfall, 1851-1945, and Monthly Climatic Data, Valletta 1901-1913.
2. Annual Production and Mean Salinity, Main Lower Table Pumping Stations and Boreholes, 1887-1945.
3. Annual Production of Upper Coralline Springs, 1885-1945.
4. Porosity and Permeability of Typical Formation Samples.
5. Rainfall and Discharge of Springs, Rabat-Dingli Area, 1885-86 to 1908-09.
6. Main Sea Level Table Boreholes: Geological and Hydrological Data.
7. Main Sea Level Table Boreholes: Results of Pumping Tests.
8. Main Sea Level Table Boreholes reserved for gauging changes of water level and composition.
9. Daily production of Upper Coralline Springs; 1893-94, 1897-98, and 1942-43.
10. Upper Coralline Boreholes: Results of Pumping Tests.
11. Summary of Binjemma Area Boreholes.
12. Summary of Miziep Area Boreholes.
13. List of Service Reservoirs.
14. Average Irrigation Rates for the principal irrigated crops in Malta.
15. Main Sea Level Water Table, Annual Extraction by Water Department and Mean Salinity of Water Extracted, 1945-46.

LIST OF ILLUSTRATIONS

PLATE 1. Malta Water Supply Resources: Graphical Summary of Developments from 1850 to 1945.

PLATE 2. Variation of Annual Production and Composition of Lower Table Supplies from Armier, Wied il Kbir, and Tal Hlas Pumping Stations.

PLATE 3. Private and Department of Agriculture Wells in relation to the Armier, Wied il Kbir, and Wied is Sueda Galleries, October 1944.

PLATE 4. Extensions to the Wied is Sueda Galleries, 1944-45.

PLATE 4A. Progress Chart, showing variations in production and salinity in relation to length of headings and incidence of rainfall during extensions to the Wied is Sueda Galleries, August 1944 —March 1945.

PLATE 5. Production and Salinity Variation, Wied is Sueda — St. Anton Fissure System, October 1944 — March 1945.

PLATE 6. Variation of Water Level and Salinity in relation to Rainfall and Tides, Wied is Sueda, 11th December 1944 to 3rd February 1945.

PLATE 7. Local Salinity Variations, Lower Water Table, May 1944 to February 1945.

PLATE 8. Map of the Main Sea Level Water Table, showing Existing Works and Proposed Developments.

PLATE 8A. Main Sea Level Table: Borehole Data.

Figure 1. Height of Water Table in relation to Distance from Coast.

Figure 2. Height of Water Table in relation to Salinity.

Figure 3. Salinity in relation to Distance from Coast.

Figure 4. Cross Section of the Table through B.Hs. 78, 77, 35, 76, 75, 74, 60 and 67.

PLATE 9. Map of the Upper Coralline Areas, showing Catchment Areas, Sea Level and Perched Water Tables, B.H. Sites, Existing Galleries, and Proposed Developments.

PLATE 10. Annual Production of Upper Coralline Springs, Rabat Plateau, 1886-1944.

PLATE 11. Structural Contour Map of the Binjemma—Wardia Upper Coralline Area, showing B.H. sites, private wells and irrigated areas, isochlors of the St. Paul's Valley Sea Level Table, and proposed developments.

PLATE 12. Cross Sections through the Falka, Ghain Kattus, and Binjemma Synclines, Binjemma Area.

PLATE 13. Structural Contour Map of the Miziep Syncline.

PLATE 14. Cross Sections through the Miziep Syncline.

PLATE 15. Stratigraphical Sections:

1. Blata il Baida;
2. Jebel Ghauzara;
3. Hemsia-Mdina;
4. Wied Kirda-Ghar Ram;
5. Kalkara-St. Angelo;
6. S.E. Coast (Benghaisa-Shrop il Ghajin);
7. Redum Kammieh;
8. Redum id-Delli;
9. Jeneina Bay;
10. Il Blata Steps;
11. Ghar id-Dwieb;
12. Ras Kullana

With Inset Map, showing location of measured sections.

NOTE ON THE SPELLING OF PLACE NAMES

Constant reference to the published topographical maps of Malta will be found necessary for a full comprehension of the material and discussions of this report. For this reason it has been deemed advisable to adhere, as far as possible, to the spelling of place names used on those maps, although, in many cases, that spelling differs considerably from current Maltese practice. Preference has been given to the spelling adopted on the contoured 2-inches to the mile map, published in 1934, on which a very creditable attempt was made to reproduce Maltese place names according to the then current R.G.S. system. In the numerous cases where local place names are not available on the 2-inch map they have been given according to the 6-inch and 25-inch maps, on which the spelling followed an older and not always consistent system of transliteration. A complete list of the place names used in the report, and on the accompanying illustrations, together with their spelling according to present day local usage, is appended for the convenience of Maltese readers.

Ashiak	Għaxaq
Baida	Bajda
Baida-Shemshiya	Bajda — Xemxija
Benghaisa — Shrop il Ghain ...	Benġħajsa — Xrobb il-Għaġin
Bieb-ir-Rua	Bieb ir-Ruwa
Binjemma	Binġemma
Birzebbugia	Birżebbuġa
Blata il Baida	Blata il-Bajda
Bonua	Bonuwa
Burnuhhala	Bur Nuħħala
Curmi	Qormi
Dahliet il Fekruna	Daħlet il-Fekruna
El Kortin tal Iskorviet	Il-Qortin ta' l-Iskorvit
Fawara	Fawwara
Fomm ir-Rih	Fomm ir-Riħ
Gargur	Għargħur
Ghain Kaiet	Għajn Qajjed
Ghain Kattus	Għajn Qattus
Ghain Klieb	Għajn Klieb
Ghain Rasul	Għajn Rażul
Ghain Tuffieha	Għajn Tuffieħa
Ghain Znuber	Għajn Żnuber
Ghar id Dwieb	Għar id-Dwieb
Ghemieri	Eġħmieri
Gharixiem	Għeriexem
Ghirgenti	Girgenti
Gneina	Ġnejna
Gneina — Tal Hjezen Fault ...	Ġnejna — Tal-Ħżejjen Fault
Gnien ta Binjemma	Ġnien ta' Binġemma
Gudia	Gudja

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Hal Dragu	Hal Dragu
Hal Far	Hal Far
Hamrun	Hamrun
Has Saptan	Has-Sabtan
Hemsia — Mdina	Hemsija — Mdina
Hofriet ir Ritz	Hofret ir-Rizz
Ic Ciaki	Iċ-Ċagħki
Ic Cianti	Iċ-Ċanti
Iddar il Hamra	Id-Dar il-Hamra
Id-Dueira	Id-Dwejra
Il Balluta	Il-Balluta
Il Barumbara	Il-Barumbara
Il Bidnia	Il-Bidnija
Il Blata Steps	Il-Blata Steps
Il Fawara	Il-Fawwara
Il Guida	Il-Gwida
Il Hodba ta Seikla	Il-Ħotba ta' Sejkla
Il Kala	Il-Qala
Il Kamla — Ta Ragha Fault ...	Il-Kamla — Tar-Raġħad Fault
Il Kolla	Il-Qolla
Il Miziep	Il-Miżieb
Il Palma	Il-Palma
Il Puales	Il-Pwales
Imjar	Mġarr
Imkabba	Mqabba
Ix Xaghara il Hamra	Ix-Xagħra l-Hamra
Ix Xaghara ta Iddar Il Baida ...	Ix-Xagħra tad-Dar il-Bajda
Ix Xatba	Ix-Xatba
Iz Zebbieh	Iż-Żebbieġħ
Jebel Ciantar	Ġebel Ċantar
Jebel Ghauzara	Ġebel Għawżara
Jeneina Bay	Ġnejna Bay
Kleigha Reservoirs	Qlejgħa Reservoirs
Krendi	Qrendi
L'Armier	L-Armier
Lia	Lija
L'Iskolba	L-Isqolba
Luca	Luqa
Mahlak	Magħlaq
Marsascala	Marsaskala
Marsa Shlok	Marsaxlokk
Mellieha	Mellieħa
Misida	Msida
Misrah Miel	Misraħ Miel

Misrah Suffara	Misraħ Suffara
Miziep	Miżieb
Musta	Mosta
Nashar	Naxxar
Paula	Paola
Ramla tal Puales	Ramla tal-Pwales
Ras il Griebej Fault	Ras il-Griebeġ Fault
Ras il Pellegrin	Ras il-Pellegrin
Ras il Wahsh	Ras il-Waħx
Redum id Delli	Ddum id-Delli
Redum Kammieh	Rdum Qammieġħ
Redum L'Imdauar	Rdum l-Imdawwar
Redum Mayesa	Rdum Majiesa
Redum ta Zecchenia	Rdum taz-Zekkenija
Sakkaja	Saqqajja
Sakkaya	Saqqajja
Shaghara il Hamra	Xagħra l-Ħamra
Shaghara ta Iddar il Baida ...	Xagħra tad-Dar il-Bajda
Shaghara tal Lippia	Xagħra tal-Lippija
Shaghara tal Mayesa	Xagħra tal-Majiesa
Shaghara ta San Martin ...	Xagħra ta' San Martin
Shatba	Ix-Xatba
Sijuwi	Siġġiewi
Ta Baldu	Ta' Baldu
Ta Berkuka	Ta' Berquqa
Ta Decotzu	Ta' Dekozzu
Ta Furingin	Ta' Furiġin
Ta Garibaldi	Ta' Garibaldi
Ta Hajret	Ta' Ħaġrat
Ta Kali	Ta' Qali
Ta Karagha	Ta' Qargħa
Ta L'Abatia	Ta' l-Abatija
Tal Garrum	Tal-Garrum
Tal Gharbi	Tal-Għarbi
Tal Haddedin	Tal-Ħaddedin
Tal Hlas	Tal-Ħlas
Ta l'Iskof	Ta' l-Isqof
Ta L'Iskorviet	Ta' l-Iskorvit
Tal Madonna	Tal-Madonna
Ta Mreinu	Ta' Mrejnu
Ta Ragha	Tar-Raġħad
Ta Randa	Ta' Randa
Ta Rapa	Ta' Rapa
Tarshin	Tarxien

Ta Sala	Ta' Sala
Ta Santi	Tas-Santi
Ta Sienja	Tas-Sienja
Tas Salib	Tas-Salib
Ta Tarjia	Tat-Tarġa
Ta Teuma	Ta' Tewma
Ta Zerp	Ta' Żerp
Torri Lippia	Torri Lippija
Wardia	Wardija
Wied il Busbies	Wied il-Bużbież
Wied il Ghasel	Wied il-Għasel
Wied il-Hmir	Wied il-Ħmir
Wied il Kbir	Wied il-Kbir
Wied is Sueda	Wied is-Sewda
Wied Kanotta	Wied Qannotta
Wied Kirda — Ghar Ram ...	Wied Qirda — Għar Ram
Wied tal Gneina	Wied tal-Ġnejna
Wied tal Hjezen	Wied tal-Ħżejjen
Wied tal Kleigha	Wied tal-Qlejgħa
Wied tal Puales	Wied tal-Pwales
Wied ta Seikla	Wied ta' Sejkla
Wied ta Zebbieh	Wied taż-Żebbiegħ
Wig-el-Kamla	Wiċċ il-Kamla
Zabbar	Żabbar
Zebbug	Żebbuġ
Zeitun	Żejtun
Zurriek	Żurrieq

I. INTRODUCTION

1. In ancient times there was no water supply problem in Malta. The not inconsiderable winter rainfall, and the storage capacity of the rock formations of which the Island is built, were more than adequate to meet the simple needs of the indigenous population of cultivators, the limited demands of the small garrisons installed by the successive powers which dominated this sector of the Mediterranean, and of the small craft which made use of the Island's harbours. The springs from the Upper Coralline catchment areas, and from the sea level water tables in the lower parts of the main valleys of the island, have been drawn upon from the earliest times. In areas removed from these perennial sources large underground tanks, excavated to store water derived from surface run-off during the winter rain-storms, were in use as far back as early Neolithic times, just as they are at the present day.

2. The need for organised municipal supplies has arisen only during the last four centuries, since Malta became a strategic base of first class importance, and the change commenced from a relatively static, predominantly rural population, to one predominantly urban and increasing rapidly in numbers. During the past ninety years or so, despite occasional severe epidemics and spells of increased emigration, there has been no major interruption to the steady rate of population increase as measured by the decennial censuses. Today, with a resident population of approximately 250,000 (excluding Imperial Navy, Army and Air Force personnel), Malta is the most densely populated island of its size on the face of the earth, and, as a result of the constantly increasing demands for more water for domestic use, more water for local industries, more water for agricultural irrigation, and more water for defence establishments, the problem of maintaining an adequate piped supply of good quality the year round becomes one of considerable difficulty.

3. Unlike smaller fortress areas, such as Gibraltar and Heligoland, the problem in the case of Malta cannot be solved by drastic restriction or by wholesale removal of the civilian population; and, unlike Aden, Singapore, and Hong Kong, there is no nearby mainland under British control from which additional supplies of potable water can be delivered by pipe line. Malta, to be of any value as a fortress, must manage on the resources available from its own limited area of ninety-five square miles.

4. In Britain and in continental countries the whole of such an area containing public underground water supplies would be protected most stringently. Most of the surface area of Malta, however, has been under cultivation for ages, or is occupied by buildings, roads, etc; only a small fraction remains in its original bare rocky condition. Yet the only water of composition suitable for human consumption has to be drawn from underground sources within this area, nowhere from a depth of more than 300 feet below the surface (generally from much smaller depths), from limestone formations seamed through and through with open fissures. Schemes for a complete sewage system for all the villages of the Island, drafted many years ago, are still uncompleted. Plans are being made for a wider dispersal of the population of the congested urban areas, and for further surface and underground appropriations for defence purposes. Further, there is disturbing evidence that the present main sources of supply are deteriorating in composition year by year.

5. The need for an overall plan, on which to base a steady but energetic development policy directed to the best utilisation of the water resources of the Island as a whole, as opposed to the spasmodic piecemeal treatment the matter has received during the past forty years, and to harmonise all the claims which are being made and are likely to be made within the next few years on the surface and interior of this small island, is obvious. Much can be done along the lines detailed in later sections of this report. But as consideration of Plate 1 will demonstrate, a full reconciliation of the present trends of supply and demand threatens to become, within a comparatively short span of years, as much a political and social problem as an engineering one.

II. A CRITICAL REVIEW OF WATER SUPPLY DEVELOPMENTS IN MALTA

1610 — 1945

6. The oft-quoted report of the Commission of Knights despatched by De L'Isle Adam to inspect the Island, before the Knights Hospitallers entered into possession, is a convenient point at which to begin this brief history of public water supply works in Malta. The apparent poverty of the Island in the matter of natural free-flowing sources was regarded by the Commission as one of its major disadvantages as a headquarters for the Order, though their picture of "neither river, nor spring, nor any other fresh water for the most part, save rain preserved in tanks or cisterns, except a few wells, rather brackish," was considerably overdrawn. They do not seem to have noticed the numerous perennial Upper Coralline springs, nor even those used by the inhabitants of Mdina and Rabat, the "sort of ill-walled town, called a capital". The "few wells, rather brackish" was probably a reference to the shallow wells in the margin of the Lower Water Table at the Marsa, which had been used for ages to supply shipping in the Grand Harbour, and by Birgu, and other villages in the neighbourhood, to augment their roof catchments.

7. The total population of Malta at the arrival of the Knights of St. John in 1530 was estimated at about 15,000. At the end of the Great Siege of 1565 it had been reduced to 10,000. By 1582 it had recovered to 20,000 and before the end of the sixteenth century the growing importance of Valletta necessitated plans for more adequate arrangements than roof catchments and water carts from the Marsa wells. A project for delivering fresh water to Valletta, from the Upper Coralline springs of the Rabat Plateau, was placed before Grand Master Garzes in 1596 and received the approval of the Council. It was not, however, until Alof de Wignacourt became Grand Master that funds were made available, in large measure from his own private estate, for carrying out the work. Construction commenced in 1610 and was completed in 1615. An interesting account of the work is given in Ciantar's "Malta Illustrata" (1784); a translated summary of which is included in T. Zammit's 1924 pamphlet.

8. The Wignacourt Aqueduct was designed to collect the waters of several groups of natural springs which issued from the edges of the Upper Coralline outcrop at the head of the Wied tal Kleigha and around the Blue Clay inlier of the Wied L'Iemu. In consequence, although there have been considerable subsequent modifications and additions, these springs are known as the "Wignacourt Springs". To this day, despite the fact that several of the larger springs are no longer utilised by the Water Department, owing to the danger of pollution, the group contributes annually more water to the public supply than all the other Upper Coralline sources of the Island combined. The springs which originally supplied the aqueduct were Migrah ta Misrah Musa (Gharixiem), Nixxia tal Borg tal Mtarfa, Ghain Teuxin (Busugrilla), Ghain Kaiet, Ghain Cirani (Ghain Klieb), Diar Handul, Hofriet ir-Riz, and Wied il-Busbies. While trenches were being cut for the stone channels to gather together the waters of the springs along the Wied L'Iemu many ancient earthenware pipes were found, one foot in diameter by two feet in length, showing that De Wignacourt's engineers were only reviving much more ancient works in this area.

9. As an original piece of construction the Wignacourt Aqueduct may be taken as extending from Fiddien Bridge, at a height of 440 feet above sea level, to the Palace Square, Valletta, at 125 feet above sea level: a distance of about 15,200 yards. From Fiddien to Attard the water was conveyed at grade in stone channels at ground level, taking full advantage of the natural contours of the Upper and Middle Globigerina scarps on the south side of the Wied tal Kleigha and around Bukana and Venezia. The channel was carried

on masonry arches across the long shallow depression between Attard and Hamrun. To convey the water across the deeper depression between San Giuseppe Tower (in present day Hamrun) and Floriana an ingenious expedient of terracotta pipes set in puzzuolano was devised.

10. The increase of population during the Seventeenth and Eighteenth Centuries was very slow and suffered numerous set-backs. By 1741, however, it had reached 110,000, and, at the time of the French occupation in 1798 it was estimated at 114,000. It was not until the census of 1861 that this figure was again reached, and slightly surpassed . Since 1861, as a result of continued security, improving medical services, and the gradual improvement of hygienic conditions and knowledge, there has been a steady rate of increase (Plate 1). The British connection with Malta had continued for more than thirty years before the need for any further water supply work of the magnitude of Wignacourt's Aqueduct began to be felt seriously. By that time the increasing importance of Malta as a trading station and a British naval base, coupled with an awakening realisation that recurrent outbreaks of plague and cholera are primarily a consequence of insanitary conditions, demanded further developments. Every epidemic and every drought from that time onwards has been accompanied by more or less numerous suggestions, from Government officials and from members of the general public, for extension and improvement of the water supply, so that by now the literature of the subject, both published and in Government files, has attained considerable proportions.

11. A succession of dry years between 1834 and 1841 resulted in plans being made, during the governorship of Sir H. F. Bouverie, for the construction of an aqueduct, reproducing all the essential features of the Wignacourt Aqueduct, to supply high level spring water to some of the villages of the eastern part of the Island (Imkabba, Luca, Tarshin, and Paula) and to the Three Cities. This aqueduct, the Fawara Aqueduct, was completed and put into service in 1845, during the régime of Bouverie's successor. It derived its supplies from the springs of San Giorgio, Fawara, and Annunziata, which issue from the foot of the Upper Coralline cliffs on the seaward side of Jebel Ciantar, at the southern end of the Rabat—Dingli Plateau. It was of approximately the same length as the Wignacourt Aqueduct, and its alignment presented similar natural difficulties of construction, viz. a steep gradient along unstable hill slopes at its head, and a wide depression which had to be crossed by an imposing length of masonry arches. The head of the aqueduct at St. George's Box is about 600 feet above sea level. At its lower end the open channel delivered into a small settling tank at Ta Fgura, about 175 feet above sea level, between Tarshin and Zabbar, whence the water was conveyed by a 9-inch cast iron pipe into the old Tank Tal Giasal, about 50 ft. lower, near the Zeitun Gate in the Cottonera Lines, and finally into Cospicua through a tunnel.

12. For more than two hundred years the Wignacourt Aqueduct, with little modification, met all the requirements of Attard, Lia, Balzan, Birkirkara, Musta, Zebbuj, Hamrun, Curmi, Floriana, and Valletta. The only important addition to its sources was that made by the energetic shaft-sinking and tunnelling campaign of 1864-66, in response to the dry years of the early 1860's, which is said to have increased the daily dry weather flow by about half, from half-a-million to three-quarters of a million gallons per day. About this time a 9-inch cast iron main was laid between San Giuseppe Tower and Valletta to supplement the delivery of the old earthenware pipe. In 1881 a 3-inch cast iron main was laid to convey water from San Giuseppe to the new suburb of Sliema. In 1886 a new 9-inch cast iron main was laid between the almost completed Santa Maria Reservoir at Ta Kali and San Giuseppe Tower, where it was connected with the older 9-inch main delivering to Valletta. As the internal diameter of the latter had been considerably reduced by encrustation a peculiar and quite useless attempt was made "to relieve it of a portion of its work" by laying a new 4-inch pipe parallel with the old terracotta pipe for a length of 1,600 yards, and connecting them together at several points. I have

been unable to discover the exact date at which Wignacourt's terracotta-in-cement main finally passed out of use. The open stone channel of the upper portion of the aqueduct, from the Fiddien Bridge Gauging Chamber down to Sta. Maria Reservoir, continued in use until 1910, when its duty was taken over by two 12-inch cast iron pipes.

13. Later modifications to the Fawara Aqueduct followed on lines similar to those made to the Wignacourt System. Piped branches were taken off to supply additional villages in the eastern part of the island (Gudia, Ashiak, Zeitun, and Zabbar). Later, the San Niklaw Reservoir was built along the line of the aqueduct, near Krendi, and branches were taken off from it to supply Krendi, Zurriek, Safi and Kirkop. The old galleries were extended further beneath Jebel Ciantar; and finally, in 1912, replacement of open channels by cast iron pipes was completed.

14. The seasons of scanty rainfall during the 1850's, particularly 1852-53 and 1855-56, do not seem to have produced as strong a reaction locally as the preceding and succeeding periods of deficiency. Even the cholera epidemic of 1854 was regarded as a relatively mild one. Evidently the impact of such stirring external events as the Crimean War and the Indian Mutiny to a large extent diverted attention from local problems of water supply shortage. Two events during these years are worthy of note, however, as both have had a continuing influence down to the present day.

15. One of the most important products of the interest in scientific matters, which Sir William Reid (Governor, 1851 — 1858) strove to encourage, was a paper by Dr. Nicola Zammit, read to the Scientific and Literary Institute in 1854. In this paper Zammit set forth a scheme whereby the potable water supply of the Island was to be increased by sinking deep wells; the expectation being that they would encounter artesian supplies of fresh water, transmitted through the rock formations deep below the surrounding sea floor, from neighbouring continental catchment areas. His argument, on the basis of observations he had made on the rate of evaporation and percolation in Malta, was that the recorded yields of the springs were much greater than could be accounted for by the annual rainfall upon the surface of the Island. Zammit's attractive thesis seems to have been received with enthusiasm, and, despite all the increase of knowledge concerning the geological structure of the Island, and the practical aspects of its water supply, which have accrued during the subsequent ninety years, such speculation is still well received, as is often the case with far-fetched proposals which seem to offer an easy way out of difficulties. In actual fact his arguments showed even less perception of local geological conditions than the much older ideas recorded by Ciantar in 1784. His experimental physical data may be dismissed with Chadwick's remark that "being made under conditions quite different from those existing in nature, they throw little light on the subject."

16. In 1856 a shaft was sunk to the sea level water table in the Globigerina Formation at Ta L'Armier, at the inner edge of the Marsa, and was equipped with a steam engine for pumping water, by way of an aqueduct, to shipping and naval establishments on the south side of the Grand Harbour. This development is interesting from several points of view. It is the first occasion that resort was made to the Main Lower Water Table for an organised public supply; and the site selected on the edge of the rising ground, away from the much shallower wells lower down the Marsa, which had been used in a small way for centuries, foreshadowed the great developments into the interior of the Lower Water Table, which were to follow later under Chadwick's direction.

17. The four seasons 1856-57 to 1859-60 had rainfalls well above the mean, and one of them, 1858-59, is credited with 39.2 inches, the highest seasonal rainfall ever recorded in Malta. By contrast, in five of the seven seasons 1860-61 to 1866-67, rainfall was well below the mean; that of 8.6 inches in 1866-67 being

one of the driest seasons on record. In consequence considerable activity was displayed in the extension of water supply works, spurred on by a serious cholera epidemic in 1865 and a milder one in 1867.

18. The outbreak of cholera in 1865, which lasted four months and caused 1,873 deaths, was responsible for a report by Dr. Sutherland on "The Sanitary Condition of Malta and Gozo", which contains some interesting data concerning water supply and storage conditions at that time. Particularly valuable for purposes of comparison with present day conditions are six analyses, made by Mr. A. A. Abel, W.D. Chemist, Woolwich, quoted in the appendix to the report, which, as far as I am aware, are the only complete analyses of Malta waters that have ever been published.

19. During the years 1864 to 1866, under the direction of Francesco Micallef, Surveyor of Aqueducts, 175 shafts and 8,300 feet of connecting galleries were excavated in the Upper Coralline of the Rabat-Dingli area. This work added the springs of Imtahleb (Bieb-ir-Rua), Misrah Suffara, Tat Tarjia, and Wied Sienja to the Wignacourt supply, and is estimated to have increased the dry weather daily flow by about one-third to one-half of its previous volume.

20. To supplement the very small quota of Wignacourt water received by the village of Curmi a number of shafts were sunk in 1865 in Strada San Sebastiano of that village, and a large spring of "slightly brackish though palatable water" was encountered in the gallery connecting them. In 1867 a pipe line was laid to convey water from the Armier Pumping Station to a reservoir near Santa Teresa in Cospicua, following upon the failure of an attempt to supplement by means of condenser water the inadequate supply derived by the Three Cities from the Fawara Aqueduct. After this, fifteen years elapsed before any further works of significance were undertaken to provide additional public water supplies from either the Upper or the Lower Water Tables.

21. The first visit of a consulting engineer specifically detailed by the Colonial Office to investigate and report on the whole question of water supply in Malta occurred towards the end of the developments of the years 1864-67, noted above. In 1867 J. F. Bateman spent a few months in Malta, to study and report on "the best means of relieving the water shortage". He appears to have developed definite preconceived ideas on the subject after a study, in London, of Spratt's 1843 sketch of the geology of the Island; particularly a conception that Spratt's "Semi-Crystalline Limestone" (the Lower Coralline Formation) could be regarded as an impervious series, thus affording the overlying "Calcareous Sandstone" of Spratt (the Globigerina Formation) extremely good prospects as a water-bearing formation. During his brief stay in Malta he recognised the presence of a continuous water table standing at or near sea level in the Globigerina Formation around the Grand Harbour and the Marsa, and was undoubtedly impressed by the yields of the Armier and Strada San Sebastiano shafts, and the convenience of pumping a steady supply of water from them for the harbour towns, as compared with the much smaller and much more variable supplies which had been procured from the high level springs in the Rabat Upper Coralline area. He thought, erroneously, that the lithology of the "Calcareous Sandstone" was very similar to that of the Bunter Sandstone Series of Merseyside, and argued that as Liverpool and Birkenhead were able to draw upon millions of gallons of freshwater every day from wells sunk in that series, in close proximity to the sea, so Malta should be able to draw an almost unlimited quantity from its "Calcareous Sandstone". He considered that in each case the amount of freshwater concerned was far too great to be derived from local surface rainfall, and put forward what was really, even in 1867, an astonishingly inept theory for an engineer of his reputation, namely, that the greater part of the supply must be derived from sea water, from which part of the soluble salts had been removed by filtration, during lateral migration through the pores of the sandstone formations. A return by a strange and most unexpected route to almost the same views as those recorded by Girolamo

Manduca (1598) and G. A. Ciantar (1784) concerning the origin of the fresh-water of the Lower Water Table.

22. Bateman recommended that a 12 x 6-foot shaft should be sunk to the sea level table, a little to the N.W. of Curmi. From this he was confident at least half-a-million gallons per day would be obtained, sufficient in conjunction with the aqueduct supplies to provide 10 gallons per head per day for the population of Floriana, Valletta, and the Three Cities. He stated that at the time of his visit the Wignacourt and Fawara Aqueducts were providing not more than one gallon per head per day to the towns. The location of his proposed shaft, defined as 1½ miles from salt water, and 1½ miles from the Wignacourt Aqueduct cannot be correlated with the local geography; but as he also stated that the water, after being raised to the surface, would have to be lifted into the aqueduct, or, preferably, forced through about 2½ miles of pipe line to Floriana and Valletta, it would seem that he had in mind some site in the Wied is-Seuda, not far removed from the present Tal-Hlas Pumping Station.

23. In due fairness to Bateman it should be observed that he had also considered the possibilities of both covered tanks and open reservoirs for the storage of surface water, and had decided that it would be impossible to achieve any useful degree of equalisation of supplies by these means; in the first case owing to the immense cost, and in the second case on account of (i) the absence of water-tight basins for damming at a suitable altitude, and (ii) the intense vegetation and evaporation losses in years of deficient rainfall. Thus, pumping from a presumed inexhaustible sea level water table seemed to him the ideal solution of the problem. Unlike Chadwick, twenty years later, he did not realise that the resources of potable water from the Lower Table were not unlimited.

24. About the time of Bateman's visit a similar scheme was proposed by Messrs J. H. Faucett and W. H. Woolhut for the supply of water to the towns from Lower Table Wells at L'Imghieret on the south side of the Marsa. Their estimates of production and costs were much less optimistic than Bateman's. Whereas Bateman considered that a total expenditure of £14,000 would guarante a supply of 500,000 gallons per day, Faucett and Woolhut estimated that a supply of 100,000 gallons would cost £35,000. However, nothing practical came of either scheme.

25. The three seasons 1867-68 to 1869-70 all had rainfall a little in excess of the mean annual figure of 20 inches. During the 1870's there was a regular alternation of seasons with rainfall below and above the mean, with the balance, on the whole, in excess. It is perhaps not surprising, therefore, that no major projects were undertaken for obtaining new supplies of water. The general tenor of discussions seems to have turned to the possibilities of assuring a more even distribution of the available supply throughout the year by means of storage tanks.

26. In 1873 Francesco Micallef advised construction of several large reservoirs along the line of the Wignacourt Aqueduct. Two years later Sir Adrian Dingli put forward a scheme on similar lines, in which he proposed the construction of tanks with a total capacity of 43,000,000 gallons for storage of Wignacourt water, and of 25,000,000 gallons capacity for storage of Fawara water; the laying of a cast iron main between the lower ends of the two aqueducts; and a system of local taxation to meet the cost of these works. Within the next few years the underground tanks Nos. 1, 2, 3, and 4 were constructed at Ta Kali, with a combined capacity of 5½ million gallons, to store Wignacourt water for public supply; the Fgieni Tanks, with a capacity of 1½ million gallons to store Wignacourt water for the San Antonio Gardens; and the Pinto and Bouverie Tanks, with a combined capacity of 3,700,000 gallons, to store water for shipping and establishments in the Grand Harbour. The 11,000,000 gallon Santa Maria Reservoir at Ta Kali, on which Chadwick insisted and which was completed in 1886, was but a further instalment of this

programme. But even to-day, with all the smaller reservoirs that have been added at intervals, the total storage capacity of the public water supply throughout the Island is still far short of the amount proposed and considered financially practicable by Sir Adrian Dingli when the population of the island was only one half of what it is to-day.

27. In 1876 surveys were made and plans drawn up by W. Unsworth, in collaboration with G. Schinas, for the construction of an open reservoir of 70,000,000 gallons capacity on the Blue Clay inlier of the Wied L'Iemu, west of Rabat at an altitude of 400 feet above sea level. This is the only place in the whole island where geological and topographical conditions combine to favour the construction of a large storage work of this type. The valley above the proposed embankment site has a gentle gradient and open cross-section; the Blue Clay Formation provides an absolutely impervious bed; the clays can be easily and economically excavated by mechanical means; and the site is high enough to deliver by gravity to all the towns and villages of the island except Dingli, Rabat, Mellieha, Nashar, Gargur, Nigret, and Bubakra. The scheme was revived by Chadwick a few years later, not so much as a project for equalising the supply of water for domestic use as for storing for irrigation the winter storm surpluses from both the surface run-off from the catchment area and from the surrounding groups of high level springs. In view of the local climatic and soil conditions such a reservoir would be filled from its own catchment area only in very exceptional seasons, as was demonstrated beyond all doubt by Chadwick's measurements of surface discharge at Fiddien Bridge during the three seasons 1883-84, 1884-85 and 1885-86. Large contributions from other sources would be required to guarantee regular irrigation supplies through the dry weather to the extent contemplated by Chadwick. The high evaporation loss which such supplies would suffer; probable serious contamination from the intensely cultivated and heavily manured lands around the reservoir; and the expense of filtration, rule out the use of this site for open storage of domestic supplies. But for the economical construction of large covered reservoirs, employing modern methods of excavation and construction, the site had advantages, which will be discussed later in this report, as attractive as those which appealed to Unsworth and Chadwick in their day for the construction of an open reservoir with an earthen embankment.

28. The very poor rainfall of seasons 1878-79 and 1880-81, only partially compensated by the excess of season 1879-80, together with the rapidly increasing urban population around the harbours, resulted in serious shortages of water supply during the dry weather. Notwithstanding the failure of the attempt at Cospicua in 1867, an effort to alleviate the shortage of supplies in the new suburb of Sliema was made in 1881 by the erection of two condensers on the Tigne Road and the construction of a large underground storage tank. The tank was filled once only, after which a more economical and dependable supply was secured by laying a 3-inch pipe line to deliver water from the Wignacourt Aqueduct at Torri San Giuseppe.

29. Of the ten rainfall seasons 1879-80 to 1889-90 only three attained the annual mean of 20 inches. It was fortunate for Malta, therefore, that the early years of this long dry spell witnessed the inception of a coordinated water supply system on modern lines under the aegis of Osbert Chadwick. Chadwick was deputed to Malta in the latter part of 1883, and for more than four years, until 1888, was continuously occupied with Malta water supply problems. He revisited the island several times in later years for shorter periods of consultation, and after his last visit in 1897 he had the satisfaction of knowing that a large part of Malta had been provided with an efficient water supply system, up to the standard of most municipal supplies of the day, and that conditions seemed assured for a continuous programme of further expansion and improvement, designed not only to keep pace with ever-increasing needs, but to anticipate them.

30. Various circumstances combined to afford Chadwick every facility for prosecuting his schemes for improvement of the water supply. From the outset he had the whole hearted interest and support of a new Lieutenant Governor, Sir Walter Hely-Hutchinson, and of the Crown Advocate, Sir Adrian Dingli, whose previous efforts for improvement of the water supply have been mentioned above; while on the technical side he had the collaboration of Francesco Micallef, for many years Surveyor of Aqueducts, and of Dr. George Schinas, who in 1884 was appointed Resident Engineer of the newly-formed Water Works Department. Only the main items of Chadwick's work in Malta need receive summary and comment here. For a detailed appreciation of all he planned and accomplished it is essential to refer to the series of special and annual reports which he prepared between the years 1883 and 1897, almost every item of which has as much interest and significance to-day as it had fifty years ago. Chadwick, above all, was a practical engineer, who acted on the sound principle that "the first duty of an engineer is to make a measurement; his second, to make a better one". Preconceived general theories, such as influenced Bateman, for example, had little attraction for him, and, realising the difficulties and complexities of local conditions, he was very disinclined to make far-reaching forecasts, or to base practice on anything less than a solid basement of facts ascertained by deliberate tests and surveys. The development of a thorough appreciation of local climatic, topographical, and geological conditions requires several seasons of residence in the islands, not merely a few weeks or months. With the possible exception of C. Rizzo in later years, no one who has been concerned with Malta water supply problems has been favoured with such facilities, untramelled by other duties, over such a length of time as Chadwick was; hence the abiding value of his records, discussions, and recommendations. It can be stated, without the slightest exaggeration, that had Chadwick's reports received the full attention which they merit, and had his recommendations for steadily continued further surveys and development work been carried out subsequent to 1897 along the lines he indicated, instead of only spasmodically under recurrent impulses of sheer necessity, the water supply of Malta would be in much better condition as regards both quality and volume of established resources than it is to-day.

31. Chadwick commenced his study of the existing water supply system in October 1883, by installing gauges for regular measurement of the daily discharge from the high level springs, gauges at points where storm surpluses from the springs discharged, a gauge at Fiddien Bridge to measure the surface run-off from the Wied L'Iemu catchment, and a gauge at Torri San Giuseppe to measure the quantity of water sent forward to Hamrun, Pieta, Msida, Floriana, and Valletta, after Mosta, Zebbuj, Lia, Attard, Balsan, Birkirkara, Curmi, and Sliema had been supplied. His investigations into conditions of storage and distribution within the towns and villages resulted in reports, made in December 1883 and April 1884 respectively, on means whereby the water supplies of Birkirkara and Sliema could be improved from the Wignacourt Aqueduct, and in the pungent criticisms of the existing system of distribution generally contained in his first general report on the Water Supply of Malta, submitted in August 1884. Concurrently he was making a thorough examination of existing wells and galleries in both Upper and Lower Water Tables, in order to evaluate the prospects of additional supplies from these sources; observing local methods of irrigation; and considering various possible sites for open reservoirs with a view to storing flood water for irrigation purposes.

32. With regard to the high level sources of supply for the Wignacourt and Fawara Aqueducts he formed the opinion that, under existing conditions, further works would produce no results comparable with the costs which would be entailed, mainly owing to the defective state of the law concerning rights to underground water supplies. He pointed out that the need to align, along public roads, the galleries constructed in 1864-66, with no rational relation to either surface topography, or to geological structure, had resulted in the construction of galleries of inordinate length compared with the yields obtained, and, as Micallef had emphasised years previously, owners of lands alongside the Government galleries enjoyed perfect liberty to put down shafts and to drive headings to intercept the springs which had been discovered at public expense. He advised (1) the purchase of strips of land to protect the existing galleries from further offsetting by private shafts; (2) that an Act should be passed making all underground waters public property, and conferring on Government the sole right of directing and controlling all operations concerned with their development and use; and (3) that no new works should be undertaken until the contours of the water tables in the region had been proved by numerous trial shafts, and the most suitable and economical lines for galleries decided upon. As far as I am aware no action has ever been taken to implement the first item of Chadwick's advice, poaching and contamination by private works being allowed to proceed to such an extent that some of the most productive springs have had to be cut out from the public supply for many years. No action was taken in the matter of protective legislation, despite subsequent repetitions of Chadwick's advice, until the Water Pumps Ordinance of 1938 and the Underground Water Ordinance of 1943 were enacted, and these ordinances are still inadequate for the full protection of the water resources of the island. With regard to the third point of Chadwick's advice, apart from Robertson's and Rizzo's inadequate efforts (1916-28), no systematic work was undertaken to determine geological contours of water-bearing formations, until Dr. E. B. Bailey's visit early in 1943 and the provision of boring crews and equipment by the Royal Engineers.

33. Several other arguments tentatively advanced by Chadwick in 1884 against the extraction of further public supplies from the Upper Coralline of the Rabat-Dingli area cannot be sustained, and, in fact, were modified in the light of his own subsequent experience. One of these ideas was that exploitation might already have reached such a stage that further Government galleries would have an appreciably adverse effect on the existing private supplies developed for local domestic and agricultural use. Another apprehension was that the greater fluctuations in the discharge of the newer galleries, as compared with that of the older springs, might perhaps indicate that a point had been reached at which the storage properties of the formation were already being destroyed over a wide area. Further consideration of these possibilities did not deter Chadwick from constructing the Via Dingli Pumping Station and galleries in 1885, and after testing this work he was able to report that "the pumping had no material effect, either on adjacent wells, or on government springs". Since Chadwick's time the annual production of the Via Dingli Pumping Station and of private wells has been increased several-fold, but there are still no adequate grounds for supposing that extraction has reached either of the undesirable limits mentioned above, except, perhaps, in certain definitely restricted areas. The supposed demonstration, by Robertson and Rizzo in 1917, accepted by Dr. E. B. Bailey in 1943, that the storage capacity of a large part of the area had been ruined, was based on an erroneous interpretation of the Water Department's records of spring discharges, as will be shown later in this report. Many factors have to be taken into account when analysing and comparing daily and annual variations, such as size and surface character of catchments, local rainfall, and local geological structures, before such definite conclusions can be reached. Under the natural conditions which obtain in the area no two gallery systems can be expected to show the same characteristics in every detail, whether they be old or new; and much more data will have to be collected and subjected to analysis before sound conclusions can be reached concerning the behaviour of individual gallery systems, quite apart from the present position and future prospects of the Rabat-Dingli Upper Coralline area as a whole. The gauging of individual galleries and groups of galleries at two to three day intervals, as instituted by Chadwick, was continued until July 1911, when, for reasons which will appear later, these more detailed records were discontinued until April 1941, when Mr. J. Pace recommenced recording them for certain springs. The seven rainfall gauges instituted by Chadwick in 1886 have continued in use, and probably

provide as adequate a record of this factor as can be desired. But, apart from routine partial analyses of combined spring waters made by the Public Health Department since 1911, this is the sum total of research which has been carried out on the hydrology of the area. When the survey work now contemplated is completed I estimate, tentatively, that about two-thirds of the Rabat-Dingli Upper Coralline catchment will be found to have been little more appropriated by local farmers than it was when Chadwick examined the region in 1884.

34. Chadwick's study of the relation between rainfall and surface run-off at Fiddien Bridge had convinced him that storage of surface waters afforded no satisfactory means of increasing domestic supplies, and that such works were only worthy of consideration for providing additional irrigation water. His study of high level spring discharges, from 1883-84 figures of his own gauges and a few earlier readings made at irregular intervals between 1869 and 1879 by Micallef, had demonstrated that storage for at least 18,000,000 gallons would have been necessary to equalise the daily supply in 1883-84, and much larger reservoir capacity to equalise supplies through several successive years of deficient rainfall. Hence his profound satisfaction at finding that the Lower or Sea Level Water Table could provide all additional supplies immediately required (in order to realise the minimum objective he had set himself of a regular supply of 10 gallons per head per day of the existing population), without incurring immense capital outlay on equalising reservoirs for the high level springs, and without endangering existing agricultural supplies from the Upper Water Table. He made this discovery not by deduction from any general theory, but as the result of a deliberate survey of the waters of existing wells in the Lower Water Table, analyses of which were made for him by Dr. G. Caruana Scicluna. He found that, proceeding inland up the Wied il-Kbir, the brackish waters of the Marsa and Curmi wells were replaced by much sweeter waters, and observed that the change in composition coincided with a change in the lithological characters of the formation in which the wells were sunk. The original remarks of his 1884 report are worthy of quotation. "An examination of existing wells has shown that an extensive water-bearing stratum exists, near the Casal Curmi, at an elevation of from 3 to 10 feet above mean sea level. The waters of this stratum are in some places brackish, in others sweet. This depends upon the characters of the rock through which the water passes. It is not due to the infiltration of sea water, because the water is above sea level. The water is rain water, making its way through the fissures of the rock to the sea. In the valley of Wied il-Kbir and Wied Hanzir trial shafts and existing wells have shown that the underground water is sweet. The extent of country beneath which potable water is found affords hopes of an abundant supply. Good water undoubtedly exists. The question to be solved is, how much can be extracted daily without fail, and without impairing the quality of the water".

35. Despite the conservative attitude to preliminary results evident in the above quotation, and expressed repeatedly in the body of his 1884 report, Chadwick had sufficient confidence to place the cost of 2,000 yards of galleries, and a pumping station with duplicate steam pumps, at the head of his estimates. The work proceeded, and on the 2nd May, 1885 he was able to report a proved production of 52,000 gallons per day, with a maximum salinity of 15 parts chlorine per 100,000, from the length of gallery between shafts 20 and 26, at the junction of Wied Kirda and Wied Hanzir. On the 1st August 1886 Schinas reported that 1,475 yards of gallery had been completed, that the proved yield was more than 175,000 gallons per day, and the estimated total yield not less than 300,000 gallons per day - this from the whole length of the gallery. The Wied il-Kbir Pumping Station was opened on the 26th June 1887 for the supply of the Three Cities, and during June, July, and August of that year water was pumped at an average daily rate of 116,000 gallons. This water all derived from Chadwick's "White Rock" (the Lower Coralline Limestone) at the south-western end of the gallery, conveyed by pipe through that part of the gallery in the "Yellow Rock" (the Globigerina Limestone) of the lower portion of the wied, which had

yielded water which Chadwick considered too saline for his first class supply. As delivered during this first summer's pumping the salinity of the water was 7–11 parts chlorine per 100,000, and, by the application of Clark's process to the whole supply, the hardness was reduced to 9–10 parts CaCO3 per 100,000, from the 26-28 parts per 100,000 as drawn from the rock. In other words, Chadwick had succeeded, temporarily, in his attempt to supply large volume of water from the sea level table practically equivalent in chemical composition to aqueduct water from the high level springs. But even in that first summer a rise of salinity to 17 parts of chlorine per 100,000 was noticed, and the rate of pumping was reduced to restore it to the "normal" amount.

36. There can be no doubt that Chadwick was very pleasantly surprised at both the volume and the quality of the water derived from his Wied il-Kbir gallery, and a note of caution with regard to ultimate limits occurs in all his later reviews of developments in the Lower Water Table. But, having realised so early, that, apart from the unpredictable vagaries of "springs" from discrete fissures, the best water was to be found in the "White Rock" towards the centre of the island, not in the "Calcareous Sandstone" as anticipated by Bateman, and having deliberately commenced the excavation of the galleries in the Lower Coralline outcrop at the junction of Wied Hanzir and Wied Kirda, with a view to further extensions of the system within the "White Rock" below the floor of those valleys, it is impossible not to criticise adversely his location of the Wied il-Kbir Pumping Station. Its retention at the site originally shown on his 1884 plan of "Proposed Water Works for the Five Cities" would appear to have been due to his desire for economical concentration of pumping plant, coupled with the plan to which he was committed for a dual supply of first and second class water to the cities, outweighing considerations of obtaining a maximum supply of first class water with the funds available. Although the projected gallery, shown in the 1884 plan as running north-eastwards from the pumping station site, through the Globigerina Formation beneath Tal Hammieri, was never taken in hand, we find the Armier shaft being connected to the Strada San Sebastiano gallery in Curmi as early as 1885, and, in 1894, the recommendation that a connecting gallery be driven between the Armier shaft and Wied il-Kbir, so that both Armier water and that from the Globigerina Formation shut-off in the lower end of the Wied il-Kbir gallery could be pumped at the Wied il-Kbir Pumping Station, alternately with first class water and by the same pump if possible. In the interest of maintaining both volume and quality of supplies the better plan would have been to have neglected entirely marginal developments in the Globigerina Formation, to have placed the pumping station at Ghar Hanzir, and to have pushed ahead energetically with galleries up Wied Xcora and Wied Ta Kandia, notwithstanding the deeper shafts which would have been required.

37. The history of Chadwicks' other two major works for extraction from the Lower Water Table, the St. Anton and Wied is-Seuda Pumping Stations, the one pumping a second class water from a fissure in Globigerina Limestone, the other a first class supply from the Lower Coralline, is interesting to compare with the parallel developments at Armier and Wied il-Kbir, the two pairs of initial pumping points being only 1½ miles apart in the same monocline. The St. Anton Shaft was sunk in 1884-85 with the sole intention of providing a local supply from the Lower Water Table for watering the St. Anton Gardens, so that the extravagant consumption of Wignacourt Aqueduct water there might be avoided, and the water utilised for domestic consumption instead. Shortly after breaking out the headings from the shaft bottom a strongly flowing fissure was encountered. When opened up on the 13th May, 1885 the water rose rapidly in the shaft, and Chadwick reported that a bailing test, carried out by mules and mot at an estimated rate of 7,200 gallons per day, only lowered the water level for 8 inches. In the light of subsequent experience of this fissure system I have little doubt that this drop of 8 inches was a tidal effect. In 1886 Schinas reported that a test by steam pumps at a rate of 84,000 gallons per day

did not lower the water level appreciably. Installation of a permanent pumping plant was completed in May 1887, and from that time onwards the fissure supplied all the needs of the St. Anton Gardens, with later the addition of the domestic supplies of Nashar and Gargur. It was noted in 1887 that the salinity of the water resembled that of Armier, increasing with pumping, but returning to its original composition after a stoppage of a few hours. So it continued, averaging about 36 parts chlorine per 100,000, until the 11th October 1944, when the fissure system was intersected in the north-westward extension of the Wied is-Seuda gallery, as a result of which its natural equilibrium was still further disturbed.

38. Chadwick's first trial shaft in the Wied is-Seuda was sunk in 1884, at the downstream end of the Lower Coralline inlier, south of Attard, and by 1885 he was already contemplating the possibility of pumping "White Rock" water from Wied is-Seuda into the Ta Kali tanks to augment the Wignacourt supply to Floriana and Valletta. Four additional shafts were commenced in 1885, and by December 1886 more than 90,000 gallons per day had been proved to be available from the galleries connecting them. Regular pumping into the Ta Kali Reservoir commenced in 1887, and was followed immediately by the recommendation that the Wied is-Seuda—Wignacourt and Wied il-Kbir system of supply to the harbour towns should be united by a 12-inch main, so that either pumping station could undertake the duty of the other in the event of a major breakdown. In 1894 Chadwick suggested that considerable extensions should be made in four directions to the 1,000 feet of gallery then existing in the "White Rock" of Wied is-Seuda; namely, upstream beyond the Attard-Zebbuj road bridge, towards the Asylum, where a former danger of contamination from the Asylum's leaky cess-pool no longer existed; in each direction along the Attard-Zebbuj Road; and down the valley towards Curmi. Extensions of only 170, 218, and 264 feet were made in the first three directions before the decision to carry out Chadwick's later recommendation to join up the Wied il-Kbir and Wied is-Seuda galleries led to concentration on the heading down the valley towards Curmi. We know now that the heading up the wied was abandoned within 280 feet of the line of the St. Anton fissure.

39. The suggestion in 1897, of a connecting gallery between Wied il-Kbir and Wied is-Seuda, as a further attempt to centralise pumping plant, was Chadwick's last major contribution to production from the Lower Water Table. It would appear, from reading between the lines of his report, that he had considerable difficulty in obtaining acceptance of this scheme. His former assistant L. Gatt, by this time Superintendent of the Public Works Department, wished to make the connection by a route from the Armier Pumping Station, beneath the village of Curmi, and along the Wied is Seuda, which would have kept the gallery within the Globigerina Formation throughout its length. Fortunately Chadwick, by pointing out that the water in that region was known to be more saline than further inland, and that there would be grave danger of organic contamination from Curmi village, managed to avoid the false economy of the shallower shaft sinking, which was proferred as an advantage of this route. He insisted that the line of gallery should run well to the south and west of Curmi and that it should be kept in the "White Rock" as far as possible, regardless of the depths of the shafts required. In the event, although the village of Curmi was by-passed, the desire to keep the depths of the shafts to a minimum caused the line finally adopted to diverge considerably from the direct line between Wied Kirda and the end of the "White Rock" at sea level in the Wied is Seuda, with the result that the length of gallery driven between Wied is Seuda Pumping Station and the last shaft (No. 42) in Wied Kirda amounted to about 10,000 feet, of which about 4,100 feet was cut in the Globigerina Formation. Had the direct line between the Wied is Seuda Pumping Station and Wied Kirda been taken, the distance would have been reduced to about 7,250 feet, and the whole of this length would have been in the Lower Coralline Limestone, as intended by Chadwick. The work took 12 years to complete and cost £21,000, as compared

with Chadwick's estimates of 5 years and £10,000. No valid excuse can be found for the deviation from Chadwick's recommendations. Two or three days deliberate geological mapping on the excellent 1:2,500 topographical sheets, which were available by 1897, would have determined the contours of the Globigerina—Lower Coralline contact with considerable accuracy in this area; or, alternatively, a light boring outfit would have provided the required evidence much more cheaply and more speedily than the numerous trial shafts which were sunk by L. Gatt and V. Mercieca, and whose evidence was apparently neglected or completely misinterpreted.

40. The success of Chadwick's demonstration that, for the time being, large supplies of potable water could be obtained most expeditiously and economically by pumping from the sea level table, did not completely blind him to the fact that the Island's ultimate resources of fresh water lay in the Upper Water Table. He always insisted that vastly increased storage was essential for equalising the seasonal and annual variation of supplies from the latter source. Ten thousand pounds for an additional reservoir of 10 million gallons capacity, at Ta Kali, in continuation of the policy advocated by Micallef and Dingli, to store some portion of the winter surplus discharge from the Wignacourt Springs, was the largest single item of expenditure recommended in the 1884 report, despite the fact that, at this early stage of his acquaintance with local conditions, Chadwick was hoping that his new "deep wells" in the Lower Table might prove to yield more abundantly in summer than in winter, and that further expenditure to increase storage perhaps might be unnecessary. The Santa Maria Reservoir was completed and put into service in 1886; and it still remains the largest storage work in the island. In a temporary loss of perspective, resulting from enthusiasm at the speedy completion of the reservoir, Chadwick wrote: "Together with the old Ta Kali Reservoirs, it virtually augments the summer supply by 100,000 gallons a day, for 160 days. As this is probably more than will be required, in years of ordinary abundance, it may even give the means of storing the surplus of one year to meet the deficiency of the next". By the end of 1887, however, he had obtained a clearer idea of the limitations of Lower Water Table supplies, and, in view of the considerable extensions of public supplies which were being demanded, he recommended the construction of another large reservoir at Ta Kali with a capacity of 10 to 15 million gallons, pointing out that the collection of data concerning the variations of the high level springs would have to be carried out for many years before any ultimate figure for storage capacity could be given. When reporting in 1897 on his last visit of inspection to Malta, after the 1895-96 "drought of unusual severity, unprecedented during the period in which accurate records of the springs have been kept", Chadwick only regarded his Lower Table developments as having afforded "a most welcome addition to the supply from the High Level Springs". That was the first year in which the pumped supply from the Lower Table exceeded the gravity supply from the Upper Table. In 1906-07, the second of two seasons of abundant rainfall, the yield of the high level springs was the highest on record, and this was the last season in which supplies from that source exceeded those from the sea level table. By that time it should have been obvious from the accumulating records of variations in the annual yield of the high level springs that storage facilities of at least the order of their average discharge would be required to equalise their service through alternating periods of wet and dry seasons; but, despite Chadwick's warnings, his successors had come to regard the Lower Table as a practically inexhaustible reservoir of potable water, to be appropriated when and as the demand increased by construction of further galleries and pumping stations. Storage policy thus remained little more than the construction of service tanks sufficiently large to protect the increasing daily demand against the possibility of a few days breakdown of pumping equipment. After Santa Maria the only large tank constructed during Chadwick's connection with Malta was the Schinas Reservoir near Luca, to hold 1,163,000 gallons of Wied il-Kbir water. Nothing was done until 1920-23 to implement Chadwick's 1887 recommendation for increased storage

capacity at Ta Kali. Then the 5,766,000 gallons Mercieca Tank was constructed at a cost of £12,000; after which the Water Department Annual Report proclaimed: "There is now no danger of a recurrence of the critical circumstances which characterised our water supply in summers following an unfavourable rainy season".

41. The changes originated by Chadwick in the distribution of the public water supply were as extensive and fundamental as those in its mode of production. His reports of 1883 and 1884 marked the beginning of the end of the old system of distribution by open channels into insanitary public and house tanks, and its replacement everywhere in the towns and villages by a piped supply. By 1887 the piped distribution system of Valletta, Floriana, the Three Cities, Birkirkara, Zebbuj, Sijiewi, Rabat, and Mdina had been completed, and a severe cholera epidemic in that year gave additional impetus to Chadwick's plan for providing the remaining villages of the Island with a piped supply.

42. Although in earlier reports he had pressed for adequate mains along the whole of the Wignacourt and Fawara lines of supply, and that the open stone channels should be relegated to agricultural service only, Chadwick deemed it advisable in his later reports (1894 and 1897) to recommend that, where the channels passed through open country and the danger of pollution was not so great, their replacement by iron pipes was not so urgent as the need for pressing on with works for the augmentation of the whole supply. In proffering this advice he was influenced by the fact that even continuous pumping at the Lower Table stations had barely managed to meet the deficit of the Upper Table supplies during the dry seasons of the later 1880's and early 1890's. Accordingly the piping of the aqueduct supplies all the way back to their sources was deferred continually, until the typhoid epidemic of 1909 necessitated the running to waste of immense quantities of aqueduct water and again emphasised the need for as complete protection as possible from contamination.

43. Another aspect of distribution, repeatedly discussed by Chadwick, is worthy of reemphasis, for it has not received in subsequent years the constant strict attention it should have to maintain any supply at a desirable level of efficiency. Although he advised that every effort should be made, by means of a basic gratis allowance and a cheap water rate, to encourage the use of sufficient water per head of the population to attain a good standard of personal hygiene and to maintain the sewage system in proper working condition, he always insisted upon the necessity to avoid waste. In the early days of the undertaking he allowed that a completely free supply from public stand-pipes was the only method by which a large portion of the population could be induced to utilise the safe piped public supply in preference to contaminated water from roof and street catchments. He endeavoured to guard against the abuse to which this system is always liable, even when self-closing stand pipes are used, by introducing locked fountains, for which householders could obtain keys on payment of a small fee. Long before his connection with Malta ceased, however, he had realised the enormous waste involved, and was advocating that metered house services should be encouraged, or even made compulsory, and the wasteful public taps suppressed.

44. Chadwick repeatedly emphasised also that the other major source of waste, to which every water supply is liable, namely, leakage from mains, should be most strictly guarded against in Malta, where, owing to the nature of much of the sub-soil formation, even very large leakages may continue indefinitely without a trace being seen on the surface of the ground. Sounding alone is inadequate to evaluate what proportion a water supply system loses daily from inevitable leaks, and, warned by an early case of large scale leakage in Birkirkara, Chadwick recommended in 1887 that Deacon's waste detecting meters should be used for maintaining a constant check. Two of these instruments were purchased and were apparently used for a while. But they were no longer in use on the occasion of his last visit in 1897, when he was compelled to insist again that the distribution network should be divided into districts and a complete system of waste-detecting meters installed.

45. Chadwick's interest in maintaining and increasing the supply of water for agriculture was second only to his concern for improvement of urban domestic supplies. His desire to interfere as little as possible with existing agricultural supplies has already been mentioned (para. 33) as one of the reasons which led him to hesitate about undertaking further extraction for domestic supplies from the Rabat-Dingli Upper Coralline area, and caused him to welcome the newly discovered potentialities of the Lower Table. From the very beginning his attitude, as expressed in his 1884 report, was that though "potable water must be provided at any cost", yet "no springs should be diverted from the land unless an equivalent supply of surface water is provided". With a limited rainfall and a population problem such as Malta's, however, it is impossible, as will be demonstrated later in this report, to satisfy even present day demands for both urban and agricultural supplies, and at the same time adhere to the second half of the policy enunciated by Chadwick. The total supplies which could be made available to agriculture, even in a good rainfall season, are strictly limited; the supply from year to year would be very variable; and, although much may still be done, along the lines indicated by Chadwick for saving and utilising every available gallon of the intermittent surface supplies, more particularly in the upland wieds which cross the Blue Clay outcrop, the "springs" (by which term he meant the Upper Table supplies, as distinct from "wells" in the Lower Table) will have to be conserved and appropriated much more extensively for urban supplies, and any compensation or additional water for agriculture provided by following another of Chadwick's 1884 recommendations, namely, the use of the sewage of the towns and villages for irrigation.

46. For appropriation of the surface run-off during the winter rains Chadwick proposed that small masonry dams should be constructed at suitable points in any wied with an adequate catchment, and the storm-waters should be passed along from them to existing field storage tanks by means of open channels or by pipes, if need be, assisted by portable pumping sets. The ultimate height of each dam was to be determined experimentally, commencing with a low dam, and increasing its height according to the actual results observed from year to year. His measurement of the surface run-off at Fiddien Bridge, from the Wied L'Iemu catchment area, during the period December 1883 to March 1884, when only 1.9 per cent of the estimated rainfall on the catchment area passed the gauge, convinced him that no useful increment for domestic supplies could be depended on from this source, but showed that a valuable addition (actually 4½ million gallons during that period) to agricultural supplies could be obtained economically. Accordingly, in 1884, he constructed an experimental dam further downstream in the Kleigha Valley, to intercept the run-off from Wied Ghemieri in addition to that from Wied L'Iemu, and put forward a scheme for conveying the water down to the neighbourhood of Ta Kali by means of a 12-inch pipe line. The dam was based on the uppermost of the two limestone members of the Upper Globigerina Formation, and, with an original height of 14 feet, provided an estimated storage capacity of 2,250,000 gallons. The foundations were made adequate for an ultimate height of 40 feet and a storage capacity of 40,000,000 gallons. During the ensuing raining season (1885-86) the reservoir was filled eight times, equivalent to 18,000,000 gallons, and an unmeasured quantity passed over the crest. In 1887, in addition to recommending £2,500 expenditure for raising the height of the dam, constructing a second similar dam further downstream, and the pipe line to Ta Kali, Chadwick revived Unstone's project for a large reservoir in the Wied L'Iemu to hold 70,000,000 gallons from surface run-off, from rainfall on the reservoir area, and from spring surpluses combined, at an estimated cost of about £10,000. The pipe line was laid during the next few years, but, despite repeated recommendations in 1894 and 1897, it was not until much later that the second dam was built. The first dam was raised in 1927-28 to provide 2,750,000 gallons extra storage; the second was raised, and a

third constructed, still further down the valley, in 1937-38. Owing to the unsuitability of the local topography and the permeability of its foundation, Chadwick's first Wied Tal Kleigha dam has never been raised to the ultimate height for which it was designed, and no other large storage reservoir for surface catchment supplies has been provided, either in Wied L'Iemu, or at the alternative sites proposed later by Chadwick on the lower ground at Hemsia or near Tal Mirakli.

47. Another storm-water dam was constructed at Chadwick's suggestion at the head of the Buskett Valley, but it has never been duplicated downstream. The only other venture of this type at Government expense was the imposing masonry dam thrown across the Wied Hanzir above Ghar Hanzir. This work has probably served a useful purpose in arresting storm discharge from Wied Sillani and Wied ta Kandia and turning it into the intensely fissured Lower Coralline bedrock of the reservoir site, so helping to maintain the freshness of the Lower Table at the western end of the Wied il Kbir galleries. But as a source of irrigation water it was foredoomed to failure, and the delivery pipe was removed long ago.

48. During the course of his investigations into the possibilities of augmenting supplies of water for agriculture Chadwick found it necessary to criticise severely the wasteful methods of irrigation employed in Malta, both in Government and in private gardens. He reported that 95 to 175 gallons per tree was being consumed for each watering of orange gardens, and that the usual rate for mixed garden produce amounted to about 448,000 gallons per tumolo per year. Little attention appears to have been paid to his recommendations for employing more intelligent methods of subsoil irrigation to reduce the enormous wastage. Where abundant supplies of water happen to be available locally the irrigation of orchards still follows the same primitive lines described by him, and the results of surveys made by Mr. Baldacchino during the past year, of the irrigation appropriations in three separate catchment areas, show that water is still being expended on irrigation of mixed garden produce at rates ranging from 270,000 to 400,000 gallons per tumolo per year.

49. One further aspect of Chadwick's work must receive notice in concluding this appreciation of his efforts for the material welfare of the Island, namely, his constant insistence on the need for systematic surveys, adequate records, and repeated studies with the object of maintaining progress and avoiding stagnation. When he came to Malta the only available topographical map was a small scale sheet similar to the Old Series hachured maps of the Ordnance Survey of the United Kingdom; an excellent production for its time and of its style, but totally inadequate for practical engineering requirements. Apart from this there were only "elaborate and doubtless accurate" lands record plans of detached individual properties. Before he could carry out the works which, in a few years, revolutionised the water supply of the Island, Chadwick had to arrange for many miles of traverse and levelling, and it was largely due to his insistence that "an accurate map is one of the first requirements of every civilised country" that the 1:2500 survey sheets of the whole Island were prepared during the 1890's. It is a great pity that they were not used subsequently to better effect. No provision was made for their upkeep, nor for adding accurate contours, with the result that in later years two completely new surveys have had to be carried out to meet modern requirements; first, the aerial survey of 1927, which forms the basis of the current 2 inches to 1 mile contoured map, and, in 1944, the 1:2500 revision of the region around the harbours for town planning purposes.

50. During his residence in Malta Chadwick always made a liberal provision in the estimates for "surveys and studies". Each year he prepared a digest of observations, results achieved, and proposals for future improvements, and it was his intention that these reports should be continued and expanded. "It is most desirable that a report giving the rainfall, discharge of springs, a summary of pumping returns, progress of works, and the like, should be submitted to Government annually. It might be drawn up on the lines of those which I formerly submitted. Much information, of great value when projects for extension are to be studied, will be brought together in an accessible form. The matter doubtless exists, but in scattered and undigested form. Moreover, public attention will be directed to the operations of the Water Works Department, a branch of the administration which is certainly but little less important than any other". This hope of a yearly full appreciation of the situation has never been realised, and, after Chadwick, the "annual report" declined to a few paragraphs, often only a few lines, explanatory of the major items of expenditure for the year. Fortunately, whatever plans and records were made have been well preserved in the Water Department's Office, but they cover the developments of the past fifty years very unevenly, both qualitatively and quantitatively.

51. For more than ten years after Chadwick's last visit to Malta the driving of the gallery between the existing Wied il Kbir and Wied is Seuda systems, and completion of the gallery connecting the Armier Shaft to Wied il Kbir Pumping Station were the only works of major importance undertaken to increase the public supply. No attempts were made to increase production from the Upper Coralline areas, apart from a few yards of trial driving at Bir Nuhhala in 1908. The purpose of this latter work was to ascertain whether the flow of that spring, which already supplied Imjar and Binjemma, could be increased to provide water for St. Paul's Bay and Mellieha, additional to the water from Ghain Tuffieha. The Via Dingli Gallery in the Upper Coralline, in its original condition as left by Chadwick in 1887, was already proving inadequate to meet the growing demands of Rabat, Mdina, Imtarfa, and Dingli, so, in 1905, by arrangement with the War Department, the pumping plant which had formerly lifted water from the Ghemieri Spring up to the Nadur Tanks, for military supplies along the Victoria Lines and to Imtarfa Barracks, was removed to a new site at Ghain Kaiet, where it could draw upon a larger supply from the Wignacourt Group of springs for pumping to both the Rabat and Nadur Tanks. It is to be regretted that the construction of this new pumping station was not combined with the carrying out of a recommendation made by Chadwick in 1894, that a gallery should be driven northwards from Via Dingli to connect that gallery with the aqueduct supply. Had such a gallery been driven to join the old Ghain Kaiet Gallery it would have passed down the pitch of the Ghar Barca Syncline, which is one of the largest natural drainage areas of the Rabat-Dingli Upper Coralline tract, and it is possible that, with a major public supply located there, earlier attention would have been attracted to summer overpumping by farmers' shafts, and measures of control enforced.

52. The Wied il Kbir—Wied is Seuda connecting gallery was completed in August 1909, and, by a fortunate coincidence, it most opportunely provided additional water from the Lower Table to replace a complete stoppage of the Wignacourt supply during the winter of 1909-10, due to an outbreak of typhoid fever which was traced to the water from these springs. The alignment of the gallery has already received criticism (para 39). So also must the poverty of data concerning the Lower Water Table, recorded during the construction of the gallery. Almost all that appears in the annual reports of the Water Department are notes of the amount of excavation carried out in expending each year's vote. In addition it is recorded in 1904-05 that "hard rock was met with" and that "it was difficult to find miners;" in 1908-09, "two centrifugal pumps of a capacity of 1,000,000 gallons per 24 hours had to be kept working day and night to keep the water down", and "the tunnel had to be divided into sections by dams to enable the miners to work;" and in 1909-10, that on completion of the gallery it was estimated the potential production from the Lower Water Table had been increased by 1,000,000 gallons per day. On the plans and sections of the gallery no less than 82 separate fissures are plotted in the 6,300 yards between the Wied il Kbir and Wied is Seuda Pumping Stations, but there are no precise data concerning either water levels, yields of separate fissures or of the sections of the gallery which were pumped separately, or of variations in the composition of the

waters encountered. The only description of hydrological conditions is the broad classification of the fissures into six groups, viz. large fissures through which water flows, fissures through which water flows, fissures oozing water, small fissures oozing water, fissures yielding brackish water, and dry fissures. It would appear from the height of the gallery, as shown on the sections, that conditions within the Lower Coralline continued as far as Shaft 28 much the same as they were in the original part of the gallery at the junction of Wied Kirda and Wied Hanzir, where pumping tests provided Chadwick with his factor of approximately 100 gallons per foot per day for potential yield from the "White Rock". From Shaft 28 to Shaft 42, with the exception of a short distance driven through "loose rock" in the neighbourhood of Shaft 31, the formation must have yielded very little water, as the roof of the gallery is only 6 to 7 feet above mean sea level. From Shaft 42 to Shaft 51 the formation must have been more "open" again, for the roof lies 16 feet above mean sea level with the floor 3 feet above mean sea level, suggesting an original standing water level of 10-12 feet above datum. The main difficulties with strongly-flowing fissures would appear to have been encountered between Shafts 51 and 55, where, in places, the roof is cut at more than 30 feet above mean sea level. From Shaft 55 to Shaft 64, at which point the branch tunnel takes off to the sump of the present Tal Hlas Pumping Station, the roof is again at 6 to 7 feet and the floor at 1 foot above mean sea level. Along the whole length of Wied is Seuda the roof is shown at 6 to 7 feet above, and the floor at mean sea level. As a matter of fact, however, a line of levels, specially run from mean sea level at Marsa Creek in connection with the new work at Wied is Seuda and Ta Kali in 1944, showed that the floor of the gallery had risen to 1.92 feet above mean sea level at Shaft 76 in Wied is Seuda.

53. The only other outstanding piece of work carried out by the Water Department during the period reviewed in the preceding paragraphs was the construction of a service tank of 1,220,000 gallons capacity at Misrah Lewsa, to provide the higher parts of Sliema with a better service than that afforded by the old branch line from Hamrun.

54. The outbreak of typhoid fever in 1909 brought about the most important advance which has been made in Malta water supply practice since Chadwick's initiation of a continuous piped supply. Consequent upon an extensive chemical, bacteriological, and field examination of all sources of supply, both from the sea level table and from the high level springs, which was carried out by Dr. T. Zammit, then Government Analyst, and Major A. H. Morris, R.A.M.C. Sanitary Officer for Malta Command at the time, the long-delayed completion of the piping of aqueduct supplies was carried out (para 42), and sterilization of all public supplies by means of chlorine was commenced. Thus, thanks to the fortunate collaboration of two men fully up-to-date in their respective lines of scientific work, Malta came to have a safely sterilized water supply within a few years of the first introduction of chlorination as a routine measure for the purification of public supplies. The contribution made by this timely work of Zammit and Morris to the protection of public health in an island where all supplies are drawn from such shallow depths, and where so much of the land surface is heavily cultivated and manured, cannot be overestimated.

55. Subsequent to the publication in 1912 of Zammit and Morris's "Report on the Water Supplies of Malta" routine bacteriological and chemical examinations have been continued by the Public Health Department, and the results recorded in the Annual Reports of that Department provide an invaluable history of variations in the composition of the water supply, compensating to some extent for the almost complete neglect of this aspect in the records of the Water Department. Another sequel to their work has produced less fortunate results from the engineering point of view. After certain springs, on their recommendations, had been cut-out from public supply, and the aqueducts had been piped completely, the Water Department discontinued the gauging of spring discharges in detail, which had been commenced by Chadwick, and only

measured the total quantities actually passed down the main from each modified group of springs. Thus it is only for the twenty four seasons from 1885-86 to 1908-09 that the records of high level spring discharges are at all complete and comparable. The gaugings for those years cover two fairly well defined cycles of seasons with deficient and seasons with ample rainfall, but it is very unfortunate that, no matter whether the water discharged was considered suitable for domestic consumption or not, the detailed gaugings were interrupted just at the commencement of the longest spell of dry seasons on record since rainfall gauges were first installed. From 1912-13 to 1926-27 inclusive, only three out of fifteen seasons provided the Rabat gauges with total rainfall figures in excess of the 20 inch mean. From 1911-12 onwards the records of spring discharge (Table 3) are very incomplete until 1941-42, when Mr. J. Pace again commenced routine records of individual springs. In fact the only figure available for every season is that for the total quantity drawn annually through the mains for the public supply. This is a very much smaller figure than the actual total annual discharge of all the springs which were formerly gauged.

56. Considerable improvements in the water services for northern part of the Island were effected during the years 1910-14. Pipes were laid to convey water from Ghain Tuffieha, and any surplus Bir Nuhhala water, to St. Paul's Bay and Mellieha. A service reservoir of 715,000 gallons capacity for St. Paul's Bay was constructed on the Baida Ridge near Il Puales, together with a pumping station to boost water from that site to a service reservoir of 553,000 gallons capacity at Mellieha. The only new work carried out to augment resources during that period was an extension of about 90 yards to the previously existing galleries at Fawwara and Annunziata Springs.

57. During the war years 1914-18 there was no expenditure on new gallery driving, but, in response to the heavy demand made by the military hospitals in the Island, production from the Lower Water Table was increased by the construction of a new pumping station near Tal Hlas, at the point where the gallery from Wied Kirda and Wied il Kbir joins the Wied is Seuda gallery. The expense of construction was met by the War Department. The new station was completed and commenced pumping in 1916, but it was not until 1924, after the installation of an electrically-driven pumping set in addition to the original diesel-driven reciprocating pump, that it was able to take over completely the duty of the Wied is Seuda Pumping Station, which was then closed down.

58. Early in 1916 the urgency of the war-time demand for increased water supplies, coupled with the greatly reduced yield from the high level springs, caused Lord Methuen to seek an overall expert appreciation of the situation from Colonel J. C. Robertson, I.M.S., then Sanitary Officer, Malta Command. As guide to local geological conditions and the past history of water supply developments, Robertson enlisted the aid of C. Rizzo, Sanitary Engineer in the Public Health Department, one of the local school of naturalists who were maintaining the interest in local geological research created by Sir John Murray's visits to Malta in 1889 and 1890. Eighteen months were spent on the examination of existing works and the geology of the main part of the island to the east of the Victoria Lines Fault. Robertson's "Report on the Possibility of Increasing the Fresh Water Supply and of Utilising the Sewage for Crop Irrigation in Malta" was submitted in October 1917, and was published in 1919 with critical minutes by J. A. Galizia, Manager of the Water Department, and by L. Gatt, Superintendent of Public Works, as appendices. The first half of the report consists of a brief description of the climate, topography, and geology of the island, followed by an analysis of the probable effects of the geology on underground water conditions. The second half consists of brief descriptions of the water supply works as they existed in 1917, and the recommendations for their extensions. Only the penultimate paragraph refers to the utilisation of sewage for irrigation, and this does little more than repeat Chadwick's advice, with the addition of calling attention to the areas floored by impermeable

Middle and Upper Globigerina beds in the eastern part of the Island, where there would be little or no danger of contamination of underground water supplies. Robertson's Report has had considerable influence on subsequent water supply discussions and developments in Malta, owing to its attractive conciseness, its illustrative maps and diagrams, and the fact that it is the only approximation to a complete discussion of local water supply problems that has been made since Chadwick's 1884 Report. A careful study of Robertson's work, however, soon reveals the author's lack of practical geological and engineering experience, and the technical value of the report has proved to be far less than that of Chadwick's and Zammit and Morris's contributions.

59. Robertson made two main recommendations concerning further developments in the Lower Water Table; (a) that greatly increased supplies could be had from the existing galleries, without any deterioration in composition, by deepening them sufficiently to enable the pumping level throughout their length to be lowered to mean sea level; and (b) that new galleries and pumping stations should be constructed north-west of Birzebbugia, west of St. Julian's, and at Wied il Ghasel. Despite his own detailed presentation of the hydrostatic theory of a sea level freshwater table and his picture of the Malta limestones as extremely porous, permeable, cavernous, fissured formations, not to mention Chadwick's objective accounts of actual pumping experiences, Robertson failed to appreciate that localised pumping to a lower level must inevitably produce an increased rate of diffusion between the saline and fresh zones of the water table, and especially on the actual upward streaming along the open fissures that pass between the zones. Much of the suggested gallery deepening has been carried out in the years subsequent to 1920, has provided increased annual pumping potential, and has been accompanied by a continual rise in the mean annual salinity of the water pumped. Robertson's selection of sites for new pumping stations down the pitch of presumed synclinal structures in the Lower Coralline Limestone, in every case near the coastal edge of the main sea level water table, and designedly in close proximity to major fault lines, also reveals inability to relate his conception of hydrological conditions within the Lower Water Table to the probable results of actual pumping. Galleries and pumping stations have since been constructed at two of the three sites he recommended, namely at Wied Dalam near Birzebbugia, and at Wied il Ghasel near Fort Musta. In both areas initial trial shafts revealed low salinities at the top of the water table but subsequent experience has been that even a moderate rate of pumping to sea level raises the salinity of the water produced to a proportion almost prohibitive for domestic consumption. It is most unlikely that Robertson's suggested gallery in the Lower Coralline in proximity to St. Julian's and St. George's Bays will ever be taken in hand.

60. Robertson's recommendations concerning the Upper Coralline areas followed much sounder lines. He repeated Zammit and Morris's advice that when adequate arrangements had been made for chlorinating high level spring supplies, even those which had been cut out owing to their shallow origin and liability to serious contamination could once more be included in the domestic supply, with a considerable saving in expense as compared with the cost of pumping an equivalent quantity of water from the Lower Table during the winter months. He remarked upon the deleterious effects of continued and increasing poaching by private shafts and galleries in proximity to the Government works, reinforcing his warnings by comparative production graphs of the Wignacourt, Buskett, and Fawara Springs prepared for him by Rizzo, and repeated Chadwick's recommendations that legislation should be undertaken to place all water supply developments under official control. Surveys of the irrigated areas were recommended, to provide a basis for discussions with regard compensation; as well as a survey of the underground contours of the top of the Blue Clay Formation, to enable plans for development and conservation to be formulated.

61. Little was done to give effect to the above recommendations until the Water Pumps Ordinance of 1938 prohibited the modification of existing private

wells and the sinking of new ones over a large part of the Rabat-Dingli Upper Coralline areas. By that date, however, the increase in the concentration of private wells had reduced the summer output of most of the Wignacourt group of galleries to a mere fraction of their former yield. No measures have been taken to reappropriate to the full their winter storm discharge. No full and accurate survey has yet been made of the private shafts and galleries, their water production, and the extent of the lands irrigated by them. The geological survey of this area carried out by Rizzo in the years subsequent to Robertson's departure from Malta produced only a very imperfect geological map, no contours, only a couple of brief, vague paragraphs on "Possible Water Tables" in his 1928 report, and some 1,900 feet of new gallery constructed during the years 1931-35 to the south-west of Boschetto, to provide additional water for the Government gardens.

62. Robertson also made several suggestions with a view to reducing surface run-off to the sea and increasing percolation to underground storage. He was averse to the construction of further dams of the size of those in Wied tal Kleigha, for fear of providing breeding places for anophelene mosquitoes. Instead he suggested numerous smaller dams to serve the double purpose of retarding storm discharge and collecting silt. It is quite possible that an extensive programme of this type, as envisaged by Robertson, would do more harm than good, by actually reducing the quantity of percolation through the valley floors. A smaller number of large dams, located on suitable outcrops like that on the Lower Coralline in Wied Hanzir, and not designed for the purpose of soil reclamation, would be much more likely to produce the desired result from the water conservation point of view. The case mentioned is worthy of careful study to determine whether the results achieved are likely to justify the expense involved. Robertson's suggestion of extensive deep trenching along rocky hillsides and the planting of trees would probably have a beneficial effect, on the balance, in reducing evaporation loss, if carried out extensively on the Upper and Lower Coralline "xghara". But the expense involved to produce an appreciable improvement on existing natural conditions would be immense. Another suggestion, that early ploughing or harrowing of fields should be made compulsory, was valueless. There can be very little percolation to underground storage through the heavy clay soils of most Maltese fields.

63. Robertson left Malta towards the end of 1917, was awarded the C.M.G., and died in 1924. The history of public water supply developments in Malta during the years following the publication of his report has consisted largely of a disappointing and hopeless struggle to realise in practice the ill-considered and over-optimistic expectations he raised with regard to the potentialities of the Main Lower Water Table. For example, towards the end of his remarks on "Structural Geology", in an attempt to illustrate the possible annual rate of denudation by solution, he hazarded a guess, completely unsupported by any pertinent data, that some 10,000,000,000 gallons of fresh water found their way each year to the underground water tables in that portion of the island to the east of the Victoria Lines Fault. "We have seen that the average annual rainfall is 21,000,000,000, gallons and we may assume that probably about half of this (say 10,000,000,000 gallons) sinks into the rocks and goes to form ground water". Subsequently this incautious figure has been seized upon, with even less consideration, by those who have regarded Robertson's Report as a reliable guide to practice, and has been quoted repeatedly as a valid estimate of the quantity of potable water which should be obtainable annually from the Main Lower Water Table alone. There has been no reflection that a large part of the area of 70 square miles, to which Robertson's over-simplified calculation referred, is covered by such impermeable formations as Blue Clays, Globigerina marls, and thick clay soils, through all of which there can be no appreciable percolation, nor that, even if it were to be shown, by direct measurement, that 10,000,000,000 gallons per annum was a reliable approximation to the mean annual fresh water replenishment of the Main Lower Water Table, this would

not guarantee that anything like that volume of potable water could be recovered in practice from such a body of sea level water. Nevertheless the unfortunate misapprehension appears to have taken firm root, and based on it, and in ignorance of the many other factors concerned, during the last ten years there has arisen an agitation for Governmental provision of vastly increased supplies of water for agricultural use, over and above the ever present demand for improved domestic supplies. In the twenty-two years from 1919-20 to 1940-41 the capital expenditure of the Water Department on new production works amounted to £354,812, an average rate of £16,128 per annum. The increase in volume of production was by no means commensurate with the capital outlay, and the overall composition of the water extracted depreciated continuously (Plate 1).

64. Carmelo Rizzo's association with Robertson during 1916 and 1917 was responsible for his promotion in 1919 from the post of Sanitary Engineer in the Public Health Department to a newly created appointment in the Water Department of Engineer in charge of Extraordinary Works. In addition he received a separate commission to continue and complete the geological survey work he had commenced in conjunction with Robertson. Rizzo was not a young man when he was entrusted with these responsibilities, and he had no formal training as a water engineer or as a field geologist, so that it is not surprising that he learned little from his subsequent experience in endeavouring to carry out Robertson's schemes. The ideas he had imbibed from his brief association with Robertson prevailed with him to the end of his service, and were passed on by him to the deliberations of the Water Supply Committee of 1934-35 and the Agricultural Supply Committee of 1935-36, on both of which he served.

65. In 1920 work commenced on the first of the sites suggested by Robertson for a new pumping station and galleries in the Lower Water Table, at Wied Dalam, north-west of Birzebbugia. A million gallon service tank was built at Axiak during 1922-25 in conjunction with this scheme, and the Wied Dalam Station commenced pumping in 1925. The high hopes which had been entertained that this station would provide a solution of the water supply problem of the eastern part of the island, were disappointed from the very outset. Production for domestic supplies has never exceeded a few million gallons a year, and although annual figures for the station have never been published, Dr. V. J. Mifsud informs me that the mean annual salinity of the water pumped has never been less than 100 parts of chlorides per 100,000.

66. The work of deepening and extending the Wied il Kbir — Wied is Seuda galleries also commenced in 1920, and was continued by small instalments every year until 1939. After the floor of the old galleries had been cut down to sea level throughout their length a programme of widening was commenced in 1935 in the Wied is Seuda gallery, with a view to facilitating flow to the sump of the Tal Hlas Pumping Station. By 1939 a length of 1,266 feet had been enlarged from the original average of 2 feet to a uniform width of 5 feet. The extensions to the system were carried out in two directions, (i) continuing the old branch further along Wied Hanzir and Wied Xcora, where the end of the gallery now stands at a distance of 3,750 feet from Chadwick's old Shaft No. 23 at the junction of Wied Kirda and Wied Hanzir, and (ii) an entirely new branch driven southwards for a distance of 1,850 feet towards Tal Gharbi from Shaft 71 in Wied is Seuda.

67. The first trial shafts at the second of Robertson's suggested sites for additional Lower Table galleries, alongside the Victoria Lines Fault at Wied il Ghasel, were put down in 1926. The low salinity of only 15 parts chlorides per 100,000 was considered to be very favourable, but the low standing water level of only 5 feet above sea level which was recorded should have been a warning against over-optimistic expectations from pumping results. After the 1934-35 Water Supply Committee and the 1935-36 Agricultural Irrigation Committee had re-emphasised the need for increased supplies, funds were made available for the

more rapid prosecution of this work. By 1938 some 6,600 feet of gallery had been driven, the Wied il Ghasel Pumping Station completed, a service tank of 5,320,000 gallons capacity constructed, and a 14 inch main laid to connect this new source of supply with the general distribution system, The saline character of the water produced has already been mentioned (para 59). There has been a tendency to ascribe the poor results to the fact that some portions of the galleries are cut in the Globigerina Formation. This explanation is inadequate, for, as in cases on record from Wied il Kbir and Wied is Seuda, as high salinities as any from the Globigerina Formation have been recorded from fissures in the Lower Coralline Limestones. The gallery system was located in an area of very broken rocks, near the margin of the Main Sea Level Table, with the consequence that even a moderate rate of pumping down to sea level induces strongly localised circulation along open fissures from the more saline zones of the table.

68. The only works carried out in the Upper Coralline areas in Malta during Rizzo's regime as Engineer Water (E) were (i) the new gallery at Buskett (para 61) for the purpose of increasing the supply of water to the gardens, and (ii) extension of the Ghain Tuffieha Gallery to a point about 2,600 feet distant from the original surface spring, for the purpose of increasing the supply of water to Mellieha and St. Paul's Bay. The alignments chosen for these galleries were not determined by any geological work on Rizzo's part, but simply by the old necessity to follow along the verge of public roads to avoid the trouble and expense of having to obtain access to private land. By chance the road along which the Ghain Tuffieha Gallery is driven coincides closely with the westward-pitching synclinal axis responsible for the original surface spring, so that, from the structural point of view, this gallery possesses the most rational alignment of any constructed to date in the Upper Coralline areas.

69. There is little of outstanding importance to note in the way of extensions and modifications of storage and distribution arrangements during the years under review. In 1928, following upon the obvious failure of the Wied Dalam scheme to provide a remedy for the summer shortage in the eastern area, a pipe line was laid to connect the Buskett main with that from the Fawara Springs near Tal Providenza, so that the Fawara supply could be "increased by 37,000 gallons per day, when necessary". A further connecting line from the Ta L'Iskof Springs, mooted at the same time, has never been laid. By the construction of the Mercieca, New Rabat, Axiak, and Luca Tanks in the twelve years 1920 to 1932 reservoir capacity was increased by little more than the amount Chadwick and Schinas provided in the two years 1884-86 by the construction of the Santa Maria Reservoir alone.

70. As an example of the extent to which the whole outlook on the local water supply situation was vitiated by Robertson's attractively optimistic picture of the Lower Water Table it is interesting to refer to a paper on "The Water Supply of the Maltese Islands", written by T. Zammit in 1924. After providing an interesting historical outline of water supply developments and bringing up to date the descriptive portion of his and Morris's 1912 Report, he concludes by advising concentration on further development work in the Lower Water Table as being capable of providing the easiest and most economical solution of Malta's water supply difficulties. Having introduced Rizzo to Robertson in 1916 Zammit no doubt derived considerable satisfaction from the apparently brilliant results of that collaboration; but had he been able to relinquish his administrative and archaeological labours for a year or two, and to devote his keenly critical faculties to an independent detailed consideration of water supply developments from the point where he and Morris had left the matter in 1912, there can be little doubt that he would have felt by no means so complacent about the situation.

71. In the paper referred to in the preceding paragraph Zammit expressed the hope that a more adequate treatment of the subject than he was able to provide would be forthcoming in the near future, presumably as a result of the

work on which Rizzo, by that time, had been specially engaged for several years. Rizzo's "Report on the Geology of the Maltese Islands, including Special Chapters on Possible Water Tables, and on Prospecting for Mineral Oil and Natural Gas" was completed in August, 1928, and finally printed and published in 1932. There is no sign in this Report that Rizzo appreciated the fact that his selection for the dual appointment of Engineer Water (E) and Geological Surveyor or had been prompted primarily by the need for a thorough quantitative investigation of water supply resources. The Report is mainly a compilation of previously published work on the stratigraphy and structure of the islands, with the addition of a few new observations of his own. He excused the brevity of his chapter on "Possible Water Tables" on the grounds that the subject had been amply dealt with already in Robertson's 1917 Report, "which contains most of my views on the general behaviour of the underground water". It is difficult to understand, how, with the disappointing Wied Dalam results fresh in mind, he could bring himself to believe still that the Lower Water Table was "far more reliable..... both from the point of view of potability of water obtainable therefrom, as well as from that concerning its quantity" than the High Level Springs; and why, after repeating Robertson's completely out of scale text book figure of a thick lens-shaped body of freshwater floating on sea water as the only illustration in his Report, he should proceed to detail six separate regions within it as localities at which he considered conditions would be particularly favourable for the formation of "Water Tables". It is perhaps indicative of some dawning hesitation, that, while Wied il Ghasel still figured in this list, Robertson's St. Julian's area was omitted. Rizzo's descriptions of separate smaller sea level tables in the north-western portion of the island, and of possible "Upper Tables", are correct as far as they go, but lack precision.

72. Rizzo's Report was intended to serve as explanation of a complete set of the 1:2500 survey sheets of Malta, on which he claimed to have distinguished, by no less than eleven separate colours, most of the mappable members of the local succession, from Lower Coralline to Quaternary. A footnote to the preface, as published in 1932, states "The Survey Sheets and the 6-inch maps of Malta and Gozo accompanying the original report are not published with this report," and now the whereabouts of the original 1:2500 sheets cannot be discovered. Two ferrogallic prints of tracings of the 6-inch maps of Malta and Gozo, on which many isolated field notes have been entered, and on which the outcrops of certain formations have been indicated by rough masses of crayon, with a conspicuous absence of precise boundary lines, are preserved in the office of the Water Department. It is thought that they are possibly the originals of the 6-inch maps mentioned in the footnote. Reduced to the 2-inch scale they provide in some respects a more adequate picture of the surface geology of the Islands than that afforded by Murray's small scale map of 1890, but the gain is not in proportion to the time and scale Rizzo claims to have devoted to the work, and they are of little or no value for practical engineering purposes. At no time during the tenure of his appointments does Rizzo appear to have made any attempt to organise a deliberate survey of irrigated areas and private water supply works, such as had been advised by Robertson. Complete records of this nature are essential for proper discussion and planning of measures for conservation and development, but it was only in September 1944 that a commencement was made by Messrs. J. Baldacchino and A. Pace.

73. The year 1928, in which Rizzo's Report was submitted, saw the end of the long spell of seasons of deficient rainfall, which had continued, with only three interruptions, since 1913. Some analytical observations on the effects of this long drought, the longest recorded since measurements of rainfall have been systematically observed, might have been expected from Rizzo, for its influence on the composition of the water pumped from the Island's two major pumping stations is very obvious from the analyses of the Public Health Department. No such study was made, nor of the effect of the six consecutive seasons of excess rainfall, 1927-28 to 1932-33, which followed. To Rizzo the water of Mediterranean salinity, which must be reached within five or six hundred feet below the top of the sea level table, served "the purpose of an impermeable stratum"; with Robertson's 10,000,000,000 gallons in mind the difficulty of maintaining an adequate volume of domestic supplies during the summer was a matter which could readily be solved by the construction of more galleries and pumping stations. It never seems to have occurred to him to debate the significance of the progressive deterioration in quality he was witnessing; "the galleries recover quickly after a short interval without pumping", and any summertime increase in salinity was "entirely checked every year by the advent of the winter rains".

74. In 1934 Rizzo's service in the Water Department as Engineer (E) came to an end, and with it the well-intentioned but ill-fated attempt to ensure progress by differentiating the development and maintenance sides of the Department's activities. Mr. A. S. Mortimer joined the Department as Water Engineer in 1934, and in 1935 he was appointed Senior Water Engineer. In this position he inherited the accumulated effects of many years of mistaken policy, found the Department committed to the Wied il Ghasel scheme, was confronted with the renewed and increased appeal for irrigation water, and with the continued influence of Robertson-Rizzo ideas as the result of Rizzo's service in an advisory capacity on the committees of 1934-35 and 1935-36.

75. The Water Supply Committee of 1934-35 and the Agricultural Irrigation Committee of 1935-36 both originated from the desire of the Department of Agriculture to provide more reliable supplies of water for certain irrigated areas where the quantity available from the Water Department was liable to considerable variation from year to year, and to provide entirely new supplies for large areas where landowners and tenants had been unable to develop supplies for themselves. The fact that the initiative came from this direction, and that, when the demand was made, so little by way of results achieved, or by way of reliable quantitative information concerning the Island's undeveloped water supply resources, could be provided by the Water Department engineers, is a most serious reflection on the state into which the outlook of the Water Department had deteriorated since Chadwick's connection with Malta ceased. In a detailed review of agricultural conditions in Malta Sir F. Stockdale had emphasised the fact that the internal food production by dry-farming methods had reached its limit of expansion, and that it appeared to him that most of the areas in which farmers could obtain their own irrigation supplies from underground sources had also been fully developed. He recommended, therefore, that the Water Department should be called upon to ascertain whether further supplies could be economically provided for irrigation, and specifically suggested (i) boring in search of deeper supplies than those already known, and (ii) measures for further conservation of stormwaters. In following up these recommendations the Director of Agriculture endeavoured to obtain quotations of boring costs from various English, French, and Italian firms, and, although its discussions were expanded ultimately to all aspects of the problem, including the annual summer shortage of domestic supplies, it was primarily to consider the prospects of a deep boring campaign, by contract or departmentally, that the 1934-35 Committee was convened. As the Corps of Royal Engineers had drilled shallow holes in the island from time to time, as part of the routine training programme for various sapper tradesmen, the Chief Engineer, Malta Command, (at that time Col. C. Turner-Jones, D.S.O., M.C.), was requested to act as chairman of the committee. The other members were Dr. G. Micallef, Superintendent of Agriculture, Prof. J. L. Gatt, Senior Water Engineer, C. Rizzo, and W. Boothman, representing the Public Works Department.

76. The committee commenced its deliberations in June 1934 and submitted its first report on the 31st August. Robertson's 10,000,000,000 gallons was accepted as the basis of legitimate annual expectations from the Main Lower Water Table, and was described as "probably a conservative estimate", though "indeterminate". Rizzo could supply no more quantitative picture of the régime in the Lower Water Table than that which he had provided to Robertson in 1916.

Opinion concerning methods of increasing the water supply were recorded under five separate heads. (i) With regard to deep boring in hopes of striking an "artesian supply" the Committee considered that there was a "reasonable possibility" of success, and recommended that machinery should be purchased and a driller engaged so that the work could be carried out departmentally, as no private firm would quote acceptable terms for hire of plant or for carrying out the work by contract. (ii) It was considered that before any further extensions of the existing gallery system were carried out the long-term behaviour of the sea level water table should be investigated with some degree of precision by means of small diameter boreholes all over the island. Widening of existing galleries, however, was suggested as an immediate means of increasing production. (iii) Construction of dams for retaining storm waters in the wieds was not recommended as it was considered that the cost of large open storage reservoirs would be prohibitive owing to the valuable agricultural land which would have to be purchased, and the large evaporation losses which would have to be accepted. Even smaller works, on the scale of the Wied tal Kleigha dams were not favoured, as they were held to "merely serve the purpose of increasing the available amount of water during the months when rain falls". (iv) Construction costs of further large artificial storage reservoirs were regarded as prohibitive at the estimated figure of £2,000 per million gallons for reservoirs of more than 10,000,000 gallons capacity. (v) With regard to measures of conservation it was recommended that a series of low dams should be constructed at intervals, after the manner suggested by Robertson, along the Wied tal Kleigha and at the points of infall of its main tributaries, and one in Wied Anglu, to determine to what extent surface run-off to the sea could be impeded; and that an experimental attempt to delay marginal loss from the water table to the sea should be made by drilling holes from 14 feet above to 14 feet below sea level and grouting in cement "under very great pressure, with a view to filling fissures and forming an impermeable barrier to water".

77. By the time the Committee (now with Col. C. W. Bushell, O.B.E., Chief Engineer, as chairman) submitted its second interim report on the 16th November 1934, its views on a number of important points had altered considerably. The idea of deep boring was temporarily abandoned, as such an attempt was considered now to be "a mere gamble", with "all present indications against the likelihood of success". The committee was also influenced by erroneous belief that "any such bore (depth not stated, but 2,000 feet suggested in its first report) might take up two years to drive, and at least another year to put into commission". They considered that the need was urgent to increase the daily summer supply provided by the Water Department to 20 gallons per head per day; that widening of existing galleries would be inadequate to yield the quantity required, and, in any case, would be far too slow; and that the construction of adequate storage reservoirs, besides being too slow, would be far too expensive. The recommendation of the Committee's first report, that a systematic overall investigation of the sea level water table should be carried out by means of numerous shallow boreholes before driving any further new galleries, was abandoned, and the Committee expressed itself to be unanimously of opinion that completion of the Wied il Ghasel scheme should be expedited at a cost of £47,000 spread over the next two years.

78. The third and final report of this committee was submitted on the 3rd April 1935. The main points of this report were (i) that the committee, after studying maps and reports on the geology of Sicily and Tunis, were firmly of opinion that deep boring below the sea level table in search of potable water was foredoomed to failure, and that such an enterprise could only be justified as an item of pure geological research, or as a speculation for oil; and (ii) that further extensions of the Wied tal Kleigha system of storm-waterdams should receive consideration, thus reversing another recommendation of their first report.

79. The Agricultural Irrigation Committee was convened in June 1935 and held its first meeting on the 10th August 1935. The chairman, Dr. G. Micallef, Director of Agriculture; C. Rizzo, now Director of the Valletta Museum; and W. Boothman, representing the Public Works Department, had served on the previous committee. Mr. A. S. Mortimer took the place of Prof. J. L. Gatt (who had been promoted Director of Public Works) as representative of the Water Department; and Mr. O. Sammut, of the Imposts Branch of the Treasury, provided an independent point of view. During the early meetings of the Committee visits were paid to a boring rig which had been hired from the firm Motomeccanica of Milan and which was in operation at the Marsa Cold Stores. The idea of a deep trial boring, which had been turned down a few months previously was again revived, and, before the equipment was returned to Italy, the Committee submitted to the Government a recommendation that a contract be entered upon for a trial boring to a depth of 2,000 feet at a cost of 25/- per foot. This recommendation was not accepted. Thereafter the committee returned to consideration of local time-honoured methods of obtaining additional supplies from surface catchments and from galleries in the Main Lower Water Table, and paid visits of inspection to various localities in Malta and Gozo which had been suggested as sites for such additional works. They also reopened the question of sewage utilization, erroneously crediting Robertson with the recommendation which had been made repeatedly by Chadwick many years previously.

80. The final report of the committee was completed on the 22nd June 1936. It is almost as lacking in fundamental quantitative data concerning the subjects under discussion as were the reports of the preceding committee; even the figures quoted as estimates of areas already under irrigation are self-contradictory and the value of the attempt which was made to estimate the quantity of water being used is likewise very doubtful. In paragraph 3 of the report the average area of vegetable gardens irrigated year by year, in Malta and Gozo combined, is given as 2,387 acres, not including potato and tomato fields, nor orange gardens. In paragraph 9 the total area under irrigation is quoted as only 1,120 acres. Using the latter figure and assuming that the water used amounted to an average of 21 inches over the whole area the Committee calculated that 752 million gallons (should have been 532 million gallons) of water per annum were already being used for irrigation, or $3\frac{1}{2}$ million gallons (should have been $2\frac{1}{2}$ million gallons) per day during the seven dry months of the year. No surveys appear to have been made to determine a reliable average rate for Malta irrigation practice, and the basis for the assumption of 21 inches only was not explained. It is certainly only one-third or one-fourth of the quantity used by farmers who have provided themselves with mechanical means for raising water and who possess wells which yield the supply they consider necessary. A count of the number of mechanical appliances in use for raising water (windmill pumps, engine-driven pumps, water wheels, and "other mechanical appliances") was made in September 1935 and is tabulated in the report, but no check estimate of the quantity of water extracted by these appliances was attempted. However, the table will provide some basis for comparison when the deliberate survey of irrigated areas and private pumping equipment, at present in progress, is completed.

81. The committee again accepted the assumption that 10,000,000,000 gallons of water per annum could be recovered from the Main Lower Table of Malta alone, and inferred that this could be interpreted as meaning 40,000,000 gallons per day throughout the year. With confidence in these assumptions, despite the fact that they indicated that irrigation was already deriving more water per day from underground sources during the dry season than was being extracted for domestic supplies, the committee had no hesitation in recommending that a further 10,000 feet of galleries be constructed in the Lower Water Table solely for the provision of additional irrigation supplies. The Government was stated to own already "about 2 miles of galleries" in the Lower

Water Table, and to draw "about 2 million gallons of water daily" from that source. Actually the length of the Armier-Wied il Kbir-Wied is Seuda gallery system alone was about 5 miles in 1935, and the average total daily water production by Government pumping stations in the Lower Water Table was approximately 2¼ million gallons in 1934-35.

82. The specific proposals made by the committee, as far as Malta was concerned, were (i) 10,000 feet of new galleries in the Lower Water Table; (ii) production of "hard water" from Wied Dalam to be increased, and the whole output to be distributed from the Axiak Tank solely for irrigation; (iii) the two existing dams in Wied tal Kleigha to be raised, and an additional one constructed; (iv) a fourth dam, 30 feet high, to be built further down this valley, near Mosta, on the Lower Coralline outcrop, in the expectation that even if it should fail to hold any appreciable irrigation supplies it would transfer a large surface run-off to underground storage; (v) 200 tees and sluice valves to be fixed on the domestic supply mains throughout the island, and hoses provided in order that any surplus to the requirements of domestic consumers could be distributed for irrigation; and (vi) an experimental borehole to 2,000 feet was again recommended, at a cost now estimated at £4,200. In a minority report Mr. O. Sammut expressed his opinion that the responsibility of deciding when water could be provided for irrigation from the domestic mains (visualised by him "as soon as the winter water level was reached in the galleries") should not be allowed to rest with the Water Department, but with higher authority. More usefully he emphasised the increasingly adverse effect which further uncontrolled sinking of private wells was likely to have on the sources of domestic supply.

83. In 1937-38 one of the existing Tal Kleigha dams was raised 5 feet and a third dam constructed lower down the valley, providing an additional 5 million gallons capacity for diversion of stormwater to irrigation. 155 tees and valves were fixed on various mains for distribution of water, when available, to fields. The suggested dam near Mosta was not proceeded with, and the suggested deep boring was considered unjustified in view of the committee's belief that hardly one-twentieth of the available supply from the Lower Water Table was being utilised. The warnings concerning the adverse effects of uncontrolled private well-sinkings were at last heeded, and resulted in the Water Pumps Ordinance of 1938, whereby applications for permission to sink new shafts, or to modify pumping installations of existing wells, were made compulsory, and a Water Board under the chairmanship of the Manager, Water and Electricity Department, was set up for the purpose of considering such applications.

84. The major schemes for production from the Lower Water Table could not be financed from Local Government resources, so, in June 1937, a loan of £62,800 was applied for from the Colonial Development Fund, on the grounds that it was extremely desirable that the Islands' capacity for internal food production should be developed to the utmost, particularly in view of the possibility of "a time of emergency when there might be difficulty in obtaining the supplies normally received from external sources". It was stated that the proposed schemes would add 600 acres, or 45 per cent, to the irrigated area of the island. The Colonial Development Advisory Committee had some difficulty in appreciating the proposals, owing to a mistaken idea that the quantity of water quoted as being normally supplied by the Water Department for irrigation, and the revenue derived therefrom, referred to the whole of the area already irrigated. They found it difficult to believe that as much as the estimated 640,000 gallons per acre would be taken up by local farmers at there commended price of 4d. per 1,000 gallons. Accordingly Sir F. Stockdale was deputed to visit Malta again in December 1937 to look into the matter. In a five days visit he was able to clear up the misapprehension which had arisen and was convinced that if a regular seasonal supply could be maintained there would be no doubt that, in the new area it was proposed to irrigate in Malta, all the water would be purchased

at the suggested rate, and the financial basis of the scheme was quite sound. He did not consider, however, that the probable demand in Gozo would justify proceeding with the major scheme for that island.

85. Apart from the economic aspects discussed several other points of general interest in Sir F. Stockdale's Report are worthy of comment. He noted that no confirmation had been obtained of the Irrigation Committee's assumption of a 21-inch average rate and estimate of 752½ million gallons annual consumption on land already irrigated, but accepted, without query, a new estimate that no less than 13,720 million gallons of water should be available annually from underground sources to the east of the Victoria Lines Fault. He does not seem to have been favourably impressed by the high salinity of the water it was proposed to use for irrigation, and it should be noted that large quantities of water of much higher salinity than the highest figure supplied to him (80 parts chlorine per 100,000) are being used in Malta. His observation that "the numbers of wells are always high where faults occur between the Lower Coralline and Globigerina Limestones" is incorrect, and does not refer to any known well or group of wells in Malta.

86. A loan of £43,300, free of interest for five years, thereafter capital and interest at 3½ per cent to be repaid in twenty equated annuities, was recommended by the Colonial Development Advisory Committee in March 1938, and was approved by the Treasury in April 1938. Only then was the actual survey work for the scheme put in hand on the ground, and the first plans and estimates were not ready until November 1938. The location decided upon for the galleries in the Lower Water Table was alongside the Victoria Lines Fault, to the west of Fort Mosta. Upon calling for tenders for sinking of shafts and excavation of galleries a contretemps arose in the form of a further revival of the deep boring project, which effectively postponed further action to implement the irrigation scheme already sanctioned, until the outbreak of war placed it altogether out of question. Messrs. C. Darmanin and Son, acting as agents for an Italian firm, offered to sink a deep borehole in search of "artesian" supplies, on the understanding that, should a yield of a million gallons a day be obtained, they should be paid the sum of £17,500 pro rata for yields ranging between half-a-million and million and half gallons, and should be given a monopoly of boring operations in the Island for a period of twenty years. Should the boring prove a failure the firm would require no compensation from Government. The Crown Agents for the Colonies were applied to for further technical advice, but could only suggest more specific terms for the agreement. No consideration in the framing of these terms by the technical advisors to the Crown Agents, just as in previous local discussions of deep boring, was given to the precautions which would be absolutely essential to guard against any possibility of contaminating the main existing source of the island's potable water supply. A committee, with Sir Philip Pullicino as chairman, and Lord Strickland, Col. A. E. Micallef, Prof. J. L. Gatt, Major S. Sammut Tagliaferro, and Mr. A. S. Mortimer as members, was appointed to negotiate with the firm, and the acceptance of tenders for the driving of galleries in the sea level water table was held up pending the outcome of these negotiations. The Committee held its first meeting in February 1940, and transmitted proposed terms to Messrs. Darmanin and Son. Nothing further was heard from the Italian principals, however, and the Italian Government declared war on the 10th June, 1940. There seems to have been a suspicion in the Committee that this Italian-sponsored offer to undertake deep boring, with a view to obtaining a long-term monopoly for such work in Malta, might have been an attempt to evade the Petroleum Boring Ordinance of 1921. This is possible. But in the light of subsequent events it is also permissible to wonder if it might not have been designed, by interests fully conversant with the water supply and agricultural situation in Malta, for the purpose of delaying any action calculated to place those aspects of the Island's internal economy on a more satisfactory basis for meeting the threat of war.

87. In 1940-41, for the first time in many years, the Water Department found itself free of the usual summer outcry for more liberal domestic supplies. This was partly due to good late rain showers in March, April, and May, but mainly to the exodus of population from the harbour towns to the countryside. The increase in consumption thus brought about in the Rabat and Zebbuj areas was met by installing booster pumps at Ta Kali, whereby Tal Hlas water could be lifted to the Rabat and Zebbuj Service Tanks to supplement the supplies from the Upper Coralline which now were totally inadequate, despite an extension of 800 ft. added to the Via Dingli galleries in 1938-39, which was rated as producing an additional 50,000 gallons per day in winter and an additional 20,000 gallons per day in summer. While it was necessary, therefore, to continue production from Tal Hlas at the full normal rate, it was possible to slacken off a little at Wied il Kbir. In view of the high salinity of the water now being admitted to the mains from the new Wied il Ghasel Pumping Station the differentiation between "First" and "Second Class" waters, which had survived from the time when Chadwick had endeavoured to maintain a supply of sea level water no more saline than that drawn from the high level springs, was relinquished. The new limit for "First Class" water was fixed at 120 parts chlorine per 100,000. At Wied il Kbir Pumping Station "Second Class" water from the Armier Gallery was allowed to flow when and as required into the "First Class" sump, and the maximum salinity permissible for mixed waters pumped from this station was fixed at 50 parts chlorine per 100,000.

88. Several of the larger reservoirs inevitably suffered during the air raids owing to their proximity to the Luca and Ta Kali airfields. The Luca Reservoir was hit twice, and on each occasion the walls of the tank were breached sufficiently to put it completely out of action. The Schinas Reservoir was hit by a 250 lb. bomb, which fortunately failed to explode. The Santa Maria Reservoir was breached by a delayed action bomb on the night of the 21st-22nd March 1942, releasing practically its entire contents to flood houses and shelters in Attard, Balzan, and Birkirkara. The pumping stations of the Island escaped unscathed, and strenuous work by the employees of the Water Department in repairing broken mains and bomb damage to smaller service tanks kept the general supply functioning well. The most serious interruption was one of only three days duration in Valletta in the spring of 1941, when the needs of its greatly reduced population were met by the use of mobile water tanks.

89. The water supply situation was more difficult in 1941-42, for, although the total precipitation for the season was well above average, there was very little rainfall after February. Provision of supplies for the dispersed population and military camps kept the Water Department fully extended, and food shortage was emphasising lack of action in providing additional irrigation supplies, either from underground resources or from the sewage system of the Island. Under the pressure of siege conditions previous opposition to the use of crude sewage was relaxed, and large areas were thus irrigated at the Marsa and at Rabat. In September 1942 Mr. A. S. Mortimer was requested by the Governor to supply a memorandum on the water supply situation. In this memorandum, after outlining the general background of the problem and the early history of water supply developments in Malta, Mr. Mortimer gave a detailed account of events from the time he became Water Engineer. His final conclusions were (i) that further water supply development work on any useful scale was impossible under war-time conditions, owing to the shortage of labour and materials; (ii) that work on the proposed gallery system west of Fort Mosta should receive priority in the post-war reconstruction programme, and, should the water obtained prove to be of better quality than that from Wied il Ghasel, it should be used for domestic supplies, and the Wied il Ghasel production diverted to irrigation; (iii) that while the disappointingly high salinity of Wied il Ghasel water might be due to excessive local fissuring of the rock formations, it might also indicate that the annual potential of 10,000 million gallons, so long assumed for the Lower Water Table, was a gross overestimate, and that "it is quite

possible that even now the limit is being approached beyond which extraction would upset the natural balance of the water table"; (iv) that there was "no possibility of extracting any more water from the Upper or Clay Water Table"; and in view of the foregoing considerations it was essential (v) that an attempt should be made to locate deeper supplies of freshwater by boring beneath the Sea Level Table, and (vi) that the use of purified sewage effluent was probably the only way in which any considerable increase could be made in supplies for irrigation.

90. Mr. Mortimer's memorandum was referred to Dr. E. B. Bailey, Director of the Geological Survey of Great Britain, and its implications were discussed at a Colonial Office conference in November, 1942. Dr. Bailey's appreciation of the situation, after consideration of the memorandum and study of Chadwick's first general report on Malta Water Supply, Robertson's and Rizzo's reports, and other papers, was that the Main Lower Water Table still contained "very extensive undersea-level untapped resources of usable water" which could be easily exploited even under war-time conditions. He recommended that for rapid increase of supplies from the Main Lower Water Table a programme of boreholes to 50 feet below sea level should be embarked upon immediately in regions where the top of the Lower Coralline Limestone rose more than 10 feet above sea level, and suggested various precautions to be observed in carrying out this work. The imminence of a greatly increased strain on the Island's water supply, which would be caused by the move of the 8th Army from Africa and the contemplated invasion of Sicily, added force to Dr. Bailey's recommendations, and it was arranged that he should visit Malta early in 1943, and that a Boring Section, R.E., should be made available from M.E.F. to carry out the proposed shallow boring campaign. Dr. Bailey arrived in Malta on the 8th February 1943, and was followed shortly by No. 3 Boring Section, R.E., under the command of Capt. R. Sparkes, R.E.

91. Dr. Bailey's report on "Underground Water in Malta" was written at the conclusion of six weeks field work in the island. The general geology of the Island from the hydrological point of view is described and discussed in this report with a degree of precision that had been conspicuously absent from such work in Malta since Chadwick's surveys. By means of spot heights at selected localities along coastal and inland outcrops Dr. Bailey constructed a 2 inches to the mile plan showing the contours of the Lower Globigerina—Lower Coralline contact at 100 feet vertical intervals from sea level upwards over the area of the Main Lower Water Table. The plan was intended as a guide for boring operations, so that wells might be sited in the portion of the table which lies within the Lower Coralline Formation and so obtain fresher and more copious supplies of water than could be expected from the Globigerina Limestones. The numerous boreholes that have since been put down by No. 3 and No. 7 Boring Sections, R.E., and several months of geological and geophysical surveying by No. 42 Geological Section, S.A.E.C., have necessitated considerable revision of Dr. Bailey's structural plan in certain areas, but the main new feature revealed by his work, the broad north-south anticlinal uplift running right across the island from Il Ghallis to Wied Mahlak, has required comparatively little modification beyond the minor adjustments inevitable in a region previously unexplored by boreholes and which is characterised by gentle dips and numerous small fault displacements.

92. The feeling that the Main Lower Water Table of Malta must contain "very extensive" untapped resources survived Dr. Bailey's examination of the situation on the spot. At the end of his visit he recorded his impression that "the water between the water table and sea level has been extensively, but not exhaustively, exploited", with the qualification that "the under sea level fresh water resources do not offer any possibility of maintaining an average yield over a number of years greater than the percolation derived from rainfall". This replenishment, he thought, must amount to "a large proportion of the local

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rainfall", for he considered that downward percolation to replenish the Sea Level Water Table was possible over the whole surface of the Island occupied by outcrops of the Globigerina and Lower Coralline Formations. This is not so. Quite apart from the thick residual red clay soil which covers much of the area, a large portion of the Globigerina Formation itself, right down to the base of its lowest member, is composed of impervious marls. No account was taken by Dr. Bailey of the pumping results of private wells and the Government Pumping Stations in the Main Lower Water Table, the only remarks on the undesirable composition of water extracted in recent years being references to the general belief, founded on Robertson's work, that water derived from the Globigerina Formation must inevitably tend to be more brackish than that derived from the Lower Coralline, and to the obvious exceptions to this simple and inadequate hypothesis which had been provided by the Wied Dalam and Wied il Ghasel galleries in the Lower Coralline. It remained for Mr. A. S. Mortimer, in his minutes on Dr. Bailey's report, to emphasise that the unpredictable results of fissure production from a sea level table were liable to upset completely any simple ideas based solely on conceptions of relative permeability of formations en masse.

93. Only one borehole, a 10-inch hole near Krendi, was completed and submitted to brief pumpimg tests, at a rate of 1,000 gallons per hour, before the conclusion of Dr. Bailey's visit. No rise in the salinity of the water produced was observed, and the result was considered "extremely promising" and as justifying the adoption of a vigorous boring campaign to remedy the water supply shortage. Thus encouraged the Department of Agriculture submitted a list of forty-one areas for Dr. Bailey's advice as to their prospects of being supplied with borehole water for irrigation. The fact that the total of the areas indicated, approximately 2,728 acres, would have required, according to Maltese standards of irrigation, a large fraction of the mean annual precipitation on the whole area of the Island, and more than four times the volume of water already being extracted from the sea level table by existing Government Pumping Stations, seems to have escaped notice entirely. Under the urgency of war-time demands a scheme was sanctioned for providing borehole water for irrigation at 8d. per thousand gallons, 5,000 gallons per hour borehole pumping sets were made available from M.E.F., a large stock of asbestos cement pipes was obtained, and plans were made, without any survey of the location and results of the numerous private wells already in operation, for commencing the scheme at some of the areas indicated by the Department of Agriculture in the low-lying eastern portion of the island , in the neighbourhood of Tarxien, Zabbar, and Zeitun.

94. In dealing with the water supply prospects of the Upper Coralline areas Dr. Bailey was again strongly influenced by conclusions enunciated by Robertson in 1917. He accepted the view that shaft-sinking and tunnelling by farmers had depreciated very considerably the storage capacity of the limestone formation, and, in consequence also its value as a source of additional urban water supplies. He recommended, therefore, that private exploitation should not only be allowed to continue, but should actually be encouraged, so long as the regulations of the 1938 Water Pumps Ordinance were observed. He repeated previous recommendations for a systematic survey of the Upper Coralline areas, and made practical suggestions with regard to the preparation of a structural contour map, by collection of records of existing shafts to be supplemented by boreholes where necessary, with a view to assisting farmers to select the most favourable sites for their shafts and galleries, and for consideration of the possibilities of increasing storage by means of underground dams. The time at Dr. Bailey's disposal permitted only a few days' reconnaissance of the Upper Coralline catchments and water tables in the northern and western parts of the Island, and, in places, subsequent more deliberate work has necessitated considerable revision of his map lines and structural interpretations, particularly the faults and Blue Clay outcrops of the Mellieha and Baida Ridges.

95. During No. 3 Boring Section's six months work in the Island, from March to August 1943, visits of inspection, for the purpose of locating borehole sites, were paid by two staff geologists from General Headquarters, M.E.F., Capt. E. W. Shotton, R.E., and Major G. L. Paver, S.A.E.C., in April, May, and June 1943. Both contributed brief reports on their geological observations and on the boring operations in progress. A more complete account of No. 3 Section's work together with the result of several resistivity soundings made at various borehole sites, was supplied by the Geological Section, S.A.E.C., in January 1944, under the title "Problems of Water Supply in the Middle East: Boreholes in Malta". A visit from the O.C., 798 Boring Coy., R.E., of which No. 3 Boring Section formed part, resulted in a recommendation that a 30-inch diameter hole should be bored for 50 feet from the bottom of the sump of Tal Hlas Pumping Station, in hope of remedying the shortages experienced at that Pumping Station during the summer of 1943.

96. Thirty-seven boreholes, ranging from 6-inches to 10-inches in diameter, and amounting to 5,856 feet in total length, were put down by No. 3 Boring Section, R.E., for the purpose of water supply exploration and development. Fourteen of these holes, of which five were abandoned before reaching their objective, were devoted to the development of supplies from the Main Lower Water Table along the lines of Dr. Bailey's recommendations. Twenty-three holes were expended on the search for supplies in the Upper Coralline areas, but only five of these, put down into sea level tables in proximity to existing farmers' shafts, secured any useful volume of production; the remainder were either "dry" or obtained nothing more than a few gallons per hour, and the 8th Army camps they were designed to supply had to depend upon the Water Department mains and on pumps installed temporarily in farmers' shafts.

97. No. 3 Section, in addition to the well-boring, also installed six borehole pumping sets for the Water Department, one for the Department of Agriculture, and nine for Army camps. By adding together the rated capacities of these pumping sets and others which were to be installed later in holes which had been provided, and making the assumption of twenty-four hours continuous pumping by every set, it was claimed that the Section's work had increased the potential water supply of the Island by about one and a half million gallons per day. Unfortunately a false impression was created that this additional "potential" had been added to the supply already available for daily distribution through the Water Department mains. As a matter of fact, all the pumping sets which had supplied army camps were removed shortly after the departure of the 8th Army for Sicily, and were never in a position to provide any addition to the permanent public supply of the Island; those installed for irrigation could not contribute to the domestic mains; one well (B.H. 24), at the Birkirkara Service Reservoir, never realised anything approaching the 72,000 gallons per day which had been predicted for it after a brief pumping test, and, even at a much smaller rate, exhibited a prohibitive rise in salinity; frequent breakdowns were experienced with the Lister-Cook 5,000 gallons per hour sets installed in the Axiak, Luca, and St. Anton boreholes; and upon the arrival of four Dandoferry pumping sets, which had been modified to pump 5,000 gallons per hour against heads up to 500 feet, it was found impossible to insert their rising mains in the nominal 10-inch diameter holes which had been drilled to receive them.

98. Several employees of the Water Department were attached to No. 3 Section for training in well-boring during the latter portion of the unit's stay in the Island, and two or three of these men showed considerable aptitude for the work. None of them, however, seemed enthusiastic about adopting the trade as a permanent mode of employment. On the departure of the unit from Malta two 33W Ruston-Bucyrus drilling machines and a selection of drilling and fishing tools were handed over to the Water Department for use in continuing the boring programme. The machines which had seen much service in

Africa before being sent to Malta, were not in very good condition; in particular their Ford B type engines were practically worn out, and the effectiveness of the machines was limited accordingly, quite apart from other minor shortcomings. The loss of a string of 10-inch tools in a borehole (No. 38) alongside the Zebbug Service Tank, in September 1943, provided the occasion for the present writer's detachment to Malta to assist in water supply work.

99. Towards the end of 1943 it was becoming obvious that well-boring under the working conditions then existing was unlikely to make any very considerable or speedy contribution to the solution of the Island's water supply problem; moreover, it appeared almost certain, to judge from the variable and disappointing production results being obtained, both as regards quantity and quality, added to the cost of maintaining many small separate pumping units, that even though a temporary alleviation of the situation might be secured by this means of extraction from the Lower Water Table, it could not be expected to provide an ultimate economical solution of the problem facing the Water Department. The shallow working limits of the Witte-Cook and Lister-Cook borehole pumping sets in possession of the Water Department restricted their use to the low-lying portions of the Island and to the marginal areas of the Main Lower Water Table. Also, no drilling bits larger than 10 inches diameter were available for reaming out the existing deeper holes, or for drilling new ones, to receive the Dandoferry pumping sets, and, in any case, the 33W machines were not in condition to carry heavier strings of tools to the depths required. Appeals were made accordingly to General Headquarters, M.E.F., for heavier equipment and for a further detachment of experienced well-borers. The despatch to Malta of another complete Boring Section was promised in November 1943, but in December, operational requirements necessitated indefinite postponement of assistance from this direction. Meanwhile the continued heavy demand for water by shipping, added to the normal civilian requirements of the harbour towns, was straining the water supply system to the utmost, and the need to use large quantities from Wied il Ghasel Pumping Station in order to maintain the supply was having a very adverse effect on the average salinity of the water delivered to consumers in certain areas.

100. The solution of the problem of providing a large additional supply of good quality water at a point whence it could be fed through the existing distribution system to the main areas of consumption was obviously the construction of a new gallery system and a central pumping station of capacity similar to Wied il Kbir, Tal Hlas, and Wied il Ghasel, but unlike those stations, situated within the central region of the Main Lower Water Table. By reason of the topography any such location naturally involved far more ambitious shaft sinking than had hitherto been contemplated in Malta, and it was fortunate that, in Captain S.E. Pugh, R.E., of 171 Tunnelling Coy., R.E., an officer was available with considerable experience of this type of work. During January 1944 a plan was devised for the rapid construction of an 8 x 8-foot shaft, 300 feet deep, and with a pump chamber at the bottom for installation of a 40,000 gallons per hour Paxman-Gwynne Centrifugal Pumping Set which the Water Department had recently obtained for the Wied il Kbir Pumping Station. A site near the Ta Kali Reservoir was selected for this proposed new pumping station for two main reasons, (i) this region lies further from the seaward margins of the Main Lower Water Table than any other place in the Island, and (ii) the characteristics of the pumping set were such as to ensure delivery at its full rated capacity into at least the Santa Maria Reservoir and the four smaller surface tanks. The scheme was discussed with Civil Government officials, the Chief Engineer, and the General Officer Commanding, and was formally put forward in my "Notes on the Civil Government Water Supply Position as at 31st January 1944". Thanks largely to Lord Gort's determination that the ensuing dry season must find the internal water supply system in a better position to meet all conceivable demands than it was in 1943, the scheme was speedily sanctioned and implemented. A section of the Tunnelling Company was made available

from the Dockyard, and work commenced at the Ta Kali Shaft site on the 14th February.

101. Meanwhile, as it was realised that no considerable increase in output could be expected within a period of at least several months from either tunnelling or boring operations, and as there was every possibility of a sudden increase in demand, particularly from Service establishments, the Naval Authorities agreed to allocate two large tankers for the routine importation of freshwater from Syracuse. In March arrangements were made for the water from the tankers to be discharged into the Bouverie Tank on the east side of Marsa Creek, and to be pumped thence, through a specially laid 6-inch Victaulic pipe line, 1,100 yards in length, connected at the junction of Strada Corradino and Strada Ghain Dwieli with the 12-inch main which feeds the eastern side of the Grand Harbour from the Schinas and Luca Reservoirs. Deliveries from one tanker, the "Arena", commenced in April, and a most useful contribution of four to six million gallons per month was made by this ship throughout the summer. The second tanker was never called upon, thanks to the increase and maintenance of borehole supplies at selected points during the dry season, and to the large new supplies opened up by tunnelling before the end of the year.

102. Excavation of the Ta Kali Shaft to a depth of 291.5 feet below surface (6 inches above standing water level), and construction of a pump chamber (16 x 14 x 18 feet) at the bottom shaft, together with a connecting passage, were completed on the 10th June, 1944, seventeen weeks after the commencement of work at the surface. Of this period three weeks were occupied in sinking and lining the shaft collar, and in completing surface arrangements, which included the construction and erection of a headgear specially designed for the work. It was not until the 6th March that it was possible to go ahead with continuous three-shift sinking. Extensive patches of loose marly ground and ground much broken by joints were encountered from 105 to 110 feet, from 123 to 136 feet, and again from 197 to 281 feet. These required the insertion of much masonry lining, thereby slowing up progress. Altogether the lining which was found necessary amounted to eighteen per cent of the area of the shaft walls down to water level. It had been estimated originally that twelve weeks would be required to sink an 8 x 8-foot shaft to a depth of 300 feet, assuming that the whole depth of the shaft would be in good solid formation and that its walls would stand without support. In view of the unavoidable initial delay in commencing three-shift work and of the amount of lining which was found necessary, the completion of the shaft and pump chamber within seventeen weeks from cutting the first sod was a performance highly creditable to the officers and men concerned.

103. After reaching water level seven weeks were expended on the sinking of a 24-inch diameter borehole from the shaft bottom to a depth of fifty feet; on the installation of the Paxman-Gwynne pumping set; on inserting and connecting up the rising main (for which a composite string of $11\frac{1}{2}$ inch I. D. inserted joint and $11\frac{3}{4}$ inch I. D. socketed borehole casing had to be improvised, owing to the lack of sufficient flanged cast-iron piping of suitable diameter); and on dismantling, moving, and re-erecting the shaft headgear. Then, on attempting to use the Paxman-Gwynne pumping set while excavating the sump, it was found that the quantity of water available was totally inadequate to maintain the pump for runs of more than a few minutes duration. Accordingly a Continental-Cook borehole pump, capable of 5,000 gallons per hour, was inserted down one side of the shaft into the 24 inch diameter borehole. This proved adequate to deal with all water made by the formation while the sinking of the 8 x 8-foot sump to 30 feet below standing water level was in progress, and also with that from a considerable length of the two headings driven later from the sump at sea level. Sump sinking occupied five weeks, owing to the delays caused by the installation of the borehole pump, by replacement of broken rods and worn valve cups on six occasions, and by a five days' hold-up

to clean out the shaft-bottom borehole. The sump was completed at 322.5 feet below surface, and gallery driving commenced, on the 4th September 1944. One gallery was directed south-eastwards with a view to joining-up with the north-westward drive from Wied is Seuda; the other was directed south-westwards towards the interior of the freshwater area of the Lower Table. It was not until the 3rd November, however, by which time the headings had been driven for distances of 153 feet and 222 feet respectively from the sump, that the yield became adequate to maintain the Paxman-Gwynne pumping set in continuous operation, and that the borehole pump could be withdrawn. The increased yield was not due to any change in the general character of the formation, but was entirely the result of the intersection of a fissure upon breaking out a drive to the north-west at 128 feet along the south-east heading. The flow from six 2-inch pilot holes drilled into the fissure ahead of the working face raised the total production to about 26,000 gallons per hour. Unfortunately a series of mechanical defects which developed shortly afterwards in the Paxman-Gwynne pumping set prevented the Tunnelling Coy. from carrying out much more driving at Ta Kali. During the few relatively brief runs which were possible before the Company moved from Malta at the end of March 1945 the south-east and north-west headings were advanced to 168 feet and 240 feet respectively from the shaft. The last seventeen weeks of the Company's work at Ta Kali were devoted mainly to the construction of a second and much larger pump chamber (32 x 24 x 24 feet), on the east side of the shaft bottom, for the reception of a Ruston-Harland pumping set, which was withdrawn later from the Wied il Ghasel Pumping Station and installed at Ta Kali by Water Department personnel. This set has proved much more reliable than the Paxman-Gwynne pumping set, and has been largely responsible for the steady production from April 1945 onwards.

104. Since the departure of 171 Tunnelling Coy., R.E., driving at Ta Kali has been continued steadily by Maltese miners under the direction of Mr. L. Portelli, formerly an officer of No. 2 Works Coy., R.E. By the end of 1945 the south-west heading had been carried to a distance of 634 feet from the shaft bottom; a drive to the north-west, in the direction of B.H. 72, had been taken off from the south-west heading at 25 feet and carried a distance of 180 feet; and a further heading, taken off from 164 feet in the north-west drive and directed westward towards the old well (B.H. 69) at Villa Castelletti had intersected B.H. 36, and had been carried for a distance of 661 feet. The south-east drive was abandoned at 168 feet, in view of the results which had been obtained by then in Wied is Seuda and the demonstration by the boring campaign of the deep inland penetration of low standing water levels and high isochlors already existing in that direction. A gauging tank and a wall, with a 9-inch sluice valve, have been built across it, by means of which the flow from the fissure can be measured and controlled to suit pumping requirements. Daily records of salinity and of the rate of production from the separate headings are being kept, and, when correlated with the progress of the headings and with the seasonal variation of rainfall, will provide valuable information for deciding upon policy at the further central pumping stations which are contemplated to equalize extraction from the Main Lower Water Table.

105. In March 1944 His Excellency the Governor and Commander-in-Chief decided that further sections of 171 Tunnelling Coy., R.E., should be employed on water supply work as and when the various tasks on which they were then engaged in the Dockyard should be completed. After full consideration of possible alternatives, namely, a westward drive from shaft 42 in Wied Kirda towards Wied il Hesri and Wied tal Bakkia, and a continuation of the Wied Hanzir gallery beneath Wied Ta Kandia, it was decided to open up old shaft 76 at the north-western end of the Wied is Seuda gallery and to drive extensions from it, as had been recommended by Chadwick many years previously. The advantages offered by extensions to the existing galleries here were (i) a shaft already in existence sufficiently shallow (only 146.5 feet to

sea level) and wide (4 x 12 feet) to allow winding to keep pace with the driving of two 5 x 6½ foot headings, (ii) a very convenient situation in respect of access from the main road, (iii) a strip of waste ground alongside the wied for the tipping of spoil directly from the top of the shaft, and (iv) that any further supplies of water opened up would be directly available to the existing pumps at Tal Hlas Pumping Station, a fact of prime importance in view of the great difficulty at that time of obtaining new pumping equipment. In addition to the main gallery leading down the wied to Tal Hlas Pumping Station there were already in existence three old 2 x 4½-foot galleries, constructed in Chadwick's time, diverging from the shaft bottom along the line of the Attard-Zebbug Road and up the Wied Incita. The programme set before the Tunnelling Company comprised (i) the enlargement and continuation of the gallery running south-westward along the Zebbug Road, for it was realised that in this direction a sea level heading would continue within the Lower Coralline Formation, with every expectation of leading rapidly into the freshwater area of the Lower Table, and (ii) the construction of a new gallery direction north-westwards to join up with the projected south-eastward drive from the Ta Kali shaft. The distance between the Wied is Seuda shaft 76 and the Ta Kali Shaft is 4,400 feet, and, as the whole length of a sea level gallery between them would lie within the Lower Coralline Formation, it was assumed, on the basis of the available records of previous experience in the Wied il Kbir and Wied is Seuda galleries, and of the low salinities in Boreholes 36 and 50 recently put down at Ta Kali, that there would be a progressive freshening of the water obtained in this direction, and that the yield of the completed gallery would average at least half-a-million gallons per day throughout the year. Within a comparatively short distance from the shaft, however, both headings became involved with an ancient system of underground channels, and, while this accident was responsible for rapid and spectacular results in so far as the volume of production was concerned, its effect on the bulk composition of the water obtained was much less satisfactory.

106. A check line of levels was run from mean sea level at Marsa Creek up to Wied is Seuda and Ta Kali, and a careful surface survey was made along the line between the two shafts. A few men became available for preparatory surface work in May 1944, but it was not until the 9th July that erection of the winch and headgear was completed and it was possible to commence working three-shifts down the shaft. Meanwhile two 12-inch diameter boreholes, Nos. 65 and 70, respectively 280 and 230 feet deep, were put down by 7 Boring Section along the line of the projected heading between the two shafts for ventilation purposes. In the event they were never called upon to serve this purpose, but the changes of water level observed in them later provided some interesting evidence with regard to the size of the drainage area affected by the fissures encountered in the new galleries. Some fifty cubic feet of trimming had to be taken off one side of the old shaft before a 3-foot skip could be passed rapidly and safely. Two pump chambers comprising 3,232 cubic feet of excavation were opened out from the northern and southern sides of the shaft at 5 feet above sea level, the old gallery leading down to Tal Hlas Pumping Station was enlarged to 5 x 10 feet over a length of 24 feet to make room for the construction of four masonry dams and a rectangular weir for gauging purposes, and the 4 x 12-foot shaft was extended down to 12 feet below sea level to form a sump. The enlargement of the old 2 x 4½ feet south-west heading to 5 x 6½ feet cross section, together with the lowering of its floor to sea level, and the driving of the new heading north-westwards towards Ta Kali, commenced on the 9th August 1944. During the extension of the headings as complete a record as possible was maintained of variations in the salinity and in the volume of the water produced, from both the general formation of the headings and from the major fissures encountered. For several weeks it was also possible to take hourly readings of the variation in the standing level of the water table. The results thus obtained, when correlated with the rate of advance of the headings and

with the incidence of rainfall during the period, have provided for the first time a clear quantitative picture of the rate of replenishment of the Main Sea Level Table of Malta, of the influence of the Mediterranean tides, and of the influence of level and rate of extraction on the composition of the water produced (Plates 4, 4A, 5 and 6).

107. The north-west heading towards Ta Kali was driven along the local strike of the Lower Coralline and remained within practically the same horizon of homogeneous chalky "white rock" throughout the entire length of 512 feet to which it was ultimately carried. Regular progress was made at an average rate of about 35 feet per week for the first three hundred feet of the heading. In this portion few conspicuous joints or fissures were met with. Apart from the four indicated on the plan as yielding noticeable localised flows of water the mass of the formation above the capillary fringe appeared quite "dry" during the continuous pumping down to sea level, even after the commencement of the winter rains at the end of September began to produce a conspicuous rise in the total daily discharge from the heading. Beyond 300 feet the formation became noticeably "wetter", and on the 11th October, a fissure, about eighteen inches in average width, was broken into high up on the north-west side of the heading at 330 feet. This fissure proved capable of yielding well over a million gallons a day, and, for the time being, effectively solved the problem of water shortage as far as the central part of the Island was concerned. When initially opened up the water had a salinity of only 12, but, as the flow continued at this rate, a steady rise in salinity was observed, with no signs of a stable level being reached. It was necessary, therefore, to control the rate of flow, otherwise there was grave danger that the limit of potability would soon be exceeded. A cross-cut was made for a distance of 16 feet from the north-east side of the heading, and a masonry wall was built across it to a height of 10.5 feet A.M.S.L., with 9 and 14 inch sluice valves inserted. The dam was completed on the 17th and the valves were closed on the 23rd November. During the forty-three days of open flow some 39 million gallons were drawn from the fissure, and a maximum salinity of 67 was recorded. Evidence as to the extent of the old underground channel system which was being affected by the discharge was sought from the various boreholes which by this time had been put down in the country to the north of Wied is Seuda. Only two, Nos. 65 and 70, gave positive results. These holes are situated at distances of about 2,900 and 750 feet respectively from the point at which the fissure was intersected in the heading. Five days after the fissure had been opened up the water level in both boreholes was found to have fallen to between 5 and 6 feet A.M.S.L., that is, to almost the same level as that at which water was being drawn off in the heading. By the 27th October, however, borehole 65 had recovered to 11 feet A.M.S.L., and borehole 10 to 8.5 feet A.M.S.L. No significant changes were noted in the composition of the water in those boreholes, but on the 26th October it was discovered that the water being produced at St. Anton Pumping Station, 3,800 feet distant, had risen to a salinity of 125, whereas the routine samples taken from that station during the dry months May to August 1944 had exhibited a salinity range of only 39 to 50. Thereafter samples from the St. Anton Pumping Station were taken at regular six hour intervals, as in the case of the Wied is Seuda N.W. 330 fissure. It was found that, while the fissure was allowed to flow at Wied is Seuda, even the shortest of pumping runs at St. Anton tended to bring up water of more than 100 salinity from the fissure there. It was evident that the two points belonged to one and the same system of old underground drainage channels, with branches penetrating deeply into the more saline levels of the water table, in which artificial disturbance of the natural circulation at one point was liable to produce quite unpredictable effects at other points far away.

108. Before construction of the dam to shut off the N.W. 330 fissure the N.W. heading was carried to 364 feet, at which point work was abandoned temporarily, as pilot holes in advance of the face had indicated that another large fissure lay close ahead. It was opened up on the 24th November and proved to be a much more difficult proposition to deal with than the N.W. 330 example. It extended right across the floor of the heading at 365 feet, with an average width of two feet at that level; although partially blocked with debris it yielded at almost the same rate as the N.W. 330 fissure, and its release had a similar reaction on the composition of water pumped at St. Anton. The form of the channels connecting the 330 and 365 fissures is such, however, that while the free flow on the 330 fissure had little effect on the salinity of the water at 365, as soon as the latter was allowed to flow at sea level the salinity of the 330 water, at a point several feet higher in the water table, rose rapidly to more than 100. The introduction of water of such salinity to the top of the water table could not be allowed to continue. It was decided, therefore, to dam-off the 365 fissure, and, in order to continue towards Ta Kali, to break out a by-pass heading on the south-west side of the main drive, on the off-chance of crossing the belt of old channels in some bridge of solid rock. A masonry dam, 3 feet thick, was completed across the north-west heading at 350 feet, with its crest 9 feet A.M.S.L.. on the 9th December, and the flow from the 365 fissure was shut off on the 11th. During the 18 days period of open flow some 15 million gallons were drawn off, with a maximum salinity of 52, reached on the 10th December. The maximum salinity of the water behind the dam of the 330 fissure during this period was 109, attained on the 5th December; on the 6th December a rapid temporary decrease to only 63 commenced, and the water was clouded with much ferruginous clay and fine flakes of limestone. It would appear that the strong flow which had been set up in the channel system had caused some collapse of ground, temporarily restricting the circulation from the deeper part of the water table until the 9th December, when the water cleared and the salinity again rose to 94. The salinity of the 330 water fell rapidly after the 365 fissure was shut-off on the 10th December; the rate of freshening was similar to that at St. Anton, which station had recommenced pumping at full capacity. The decrease in the salinity of the 365 water was much more gradual. No point of sampling showed any accentuated rate of freshening in response to the heavy rains of the last few days of December 1944, and the first few days of January 1945.

109. The north-west by-pass heading failed to realize the hoped-for result. It was taken off from the south-west side of the north-west heading at a point 295 feet from the shaft-bottom, and, after driving for a distance of 96 feet, diverging at 37 degrees from the line of the main heading, it encountered an even wider portion of the old underground channel system. On the night of the 8th January 1945 a large pipe-shaped fissure was broken into, fortunately at a point high up in the roof of the heading and only a few inches below the level of the water table at that time. Nevertheless the hole discharged water at a rate of nearly two million gallons per day, and it is certain that if the pipe had been widely broken into at floor level the Wied is Seuda headings would have been flooded beyond control of all pumping plant then available, perhaps even permanently. The flow was stopped on the 10th January by inserting and bracing a large wooden plug in the hole. An inspection heading was driven 9 feet A.M.S.L. to investigate the form and relationships of the pipe, with the results shown in plan and section on Plate 4. As there seemed to be no possibility of negotiating the obstacle by continued driving in this direction it was decided to return to the main heading and to cement off the 365 fissure before making a final attempt to drive to Ta Kali. A solid masonry stopping was set to reinforce the plug and the wall of the pipe at the end of the by-pass, and a 9-inch C.I. pipe with a sluice valve was laid in the inspection heading, so that water might be drawn off from the fissure at 6.5 feet A.M.S.L. if required. During its brief period of uncontrolled flow 3,600,000 gallons escaped from the by-pass pipe and the salinity of the water rose from 33 to 43 . The composition of the water in the 330 fissure and at St. Anton Pumping Station varied in sympathy; the water of the 365 fissure was affected to a much smaller degree, although only 45 feet away in a direct line.

110. Returning to the north-west heading, decking was erected behind the 350 dam and a 5 x 5-foot cut taken from the roof to facilitate cementing operations. The sealing of the fissure required ten tons of cement and was carried out under water with the assistance of divers from the Dockyard. The dam was then broken down and driving to the north-west was resumed on the 12th February. More than a hundred feet were driven, in formation similar to that of the initial part of the gallery, before the next fissure was encountered at 502 feet, on the south-west wall of the heading. The salinity of the water indicated that it had already been affected by the various circulations set up in dealing with the previously encountered fissures, and that it must be in intimate connection with them. This was confirmed during the six days, 14—20th February, on which production was taken from it, by the manner in which the salinity of the 330 fissure varied in sympathy. A masonry dam was built across it to a height of 7.5 feet A.M.S.L., with a 9-inch sluice valve inserted at 4.7 feet A.M.S.L. Only another ten feet were driven, bringing the total length of the heading to 512 feet, before the Tunnelling Company received orders to cease work.

111. The south-west heading from Wied is Seuda, along the Zebbug Road, was driven in an up-dip direction and formation conditions in the Lower Coralline were more varied in consequence than along the strike direction followed by the north-west heading. Not far beyond the end of the old 2 x 4½ feet gallery at 264 feet the heading passed out of the soft chalky "white rock" into a harder more compact, and minutely fractured lithology, which yielded obvious flows of water from all the small open joints. During the enlargement of the first 200 feet of gallery through the chalky rock the daily yield of water actually diminished, despite heavy bursts of rain on the 11th and 12th August 1944, when nearly two inches of rainfall were recorded throughout the Island. It was not until after the winter rains really commenced in the latter half of September that the rate of production from this heading began to increase and finally exceeded the rate of progress of the driving. Two further repetitions of soft chalky rock and hard well-jointed limestones were passed through. Open joints, yielding copious streams of water, were numerous in the latter type of formation from 420 to 600 feet; the most prominent one crossed the heading at 530 feet and was estimated to be worth about 6,800 gallons a day, pumping down to sea level, after the spell of heavy rain at the end of the year. The expectation that the salinity of the water from the heading would diminish south-westwards was not realised. On the contrary there was a steady increase from a mean figure of 24 at the beginning of September to a mean of 43 in mid-January. Special attention was paid in February and March 1945 to the salinity of the water produced from the most prominent open joints at 530 and at 612 feet, and, when it was established that they were showing an even more pronounced rise, it became fairly certain that the heading was approaching the line of old underground channels which had given so much trouble, and whose salinities had been disturbed so greatly already, in the north-west heading. An examination of surface outcrops supported this conclusion. A belt of strongly-sheared brown and green clays, containing brecciated masses of limestone, was encountered at 618 feet, and, as copious flows of water were issuing from the limestone masses, the clays commenced to slump in badly. It would have been very slow and difficult to have continued driving at sea level through this material, and complete lining of the heading would have been necessary. There was no time to embark upon an exploratory rise, as the departure of the Tunnellng Company was imminent. It was decided, therefore, to abandon the heading at 623 feet. A wall was built across at 618 feet, at the commencement of the clayey ground, and side support was provided here, and along several other loose stretches of the heading, before all work was closed down in March 1945.

112. All the sluice valves on the Wied is Seuda fissure system were closed before the departure of the Tunnelling Company, and the masonry dams and

weir tank in the entrance to the gallery running down to Tal Hlas Pumping Station were removed in order to restore the spill-over level to its original height of 1.92 feet A.M.S.L. During the summer of 1945, however, it was found necessary to open up the valves again to provide additional water for the pumping station. They have now been closed once more, and it is hoped that the shut-down during the current winter rains will permit the water of the fissure system to recover to the salinity distribution which existed before the disturbances set up during the tunnelling operations of winter 1944-45. Should the numerous small fissures of the south west heading fail to respond adequately, a control dam and sluice valve will ultimately be required at about 250 feet, to exert more back pressure and to control the output from this heading also. An electrically-driven centrifugal pumping set was installed at Wied is Seuda in June 1945, with its delivery connected at Attard into the main from Ta Kali to Hamrun, as a stand-by, and for the purpose of taking over part of the duty of Tal Hlas Pumping Station while the old diesel-driven reciprocating pump there, which has been in operation since 1916, is replaced by a diesel-driven centrifugal pumping set.

113. Lord Gort's urgent representations on the subject of water supply were responsible also for speeding up assistance from M.E.F. in connection with the boring side of operations. Four wellborers and four sappers from No. 4 and No. 7 Boring Sections, R.E., arrived by air on the 14th February and were put to reaming out to 12 inches diameter the 10-inch holes which had proved inadequate for the rising mains of the Dandoferry pumps. The main body of 7 Boring Section, R.E., under the command of Capt. A. H. Kneen, R.E., arrived on the 21st March. Owing to delays in Egypt the unit's equipment did not reach Malta until the 5th May, 1944, but before that date the Section had carried out some extremely useful work, both pump-fitting and well-boring. For the latter work the Section was restricted to the two 33W rigs, left behind by No. 3 Section, which had been overhauled and re-engined locally; to an old Edeco 600s rig, overhauled and rebuilt in the Water Department workshop; and to the use of two 12-inch star bits, obtained from M.E.F., and four 18-inch bits, improvised locally, for holes of larger diameter than 10 inches. After the arrival of the Section's full G1098 equipment, which included a 24W Bucyrus-Erie machine and three new 71 Speed Star machines, the rate of boring was speeded up considerably. It was not anticipated at first that the Section would be able to remain in Malta longer than would be necessary to provide holes of adequate diameter, at suitable locations in the Main Lower Water Table, for the available eighteen deep well pumps of 5,000 gallons per hour capacity, and to assist with borehole pump-fitting and maintenance through the dry weather of 1944, by which time it was expected that the yield from the new galleries being constructed by 171 Tunnelling Coy., R.E., would have removed any urgent need for further borehole production. Ultimately, however, the favourable trend of the military situation in the Mediterranean theatre permitted the Section to remain to construct a net-work of gauging boreholes covering the whole area of the Main Sea Level Water Table, whereby, in conjunction with the boreholes sunk for other purposes, an overall plan of the hydrology of this most important water table was obtained for the first time, and the means provided for the continuous future study of its variation in level and salinity. Permission was obtained for the Section to carry out also two separate boring programmes to investigate the structure of the Binjemma and Miziep areas in the north-western portion of the Island. These are tracts of Upper Coralline rocks which have been but little exploited by farmers' wells, and from which it will be possible to obtain large additional supplies of freshwater for public use. The Miziep area has also good prospects for the economical storage of water on a large scale, an urgent necessity for the equalisation of the Island's very variable seasonal supplies. In addition to their major work for the investigation and development of water supply resources the Section put down numerous boreholes for the ventilation of underground chambers and to provide earthing

points for the new electrical supply system. Detailed drilling diaries and graphic logs of all these borings have been deposited in the offices of the C.E., Malta Command, and of the Civil Government Water Department, and will be of permanent value in connection with all matters requiring a precise knowledge of the geological structure of the Island. The data they have contributed to the investigation of water supply resources are summarised in the tables appended to this report.

114. The period of active boring work by 7 Boring Section, R.E., extended from April 1944 to October 1945. During this period, although never up to full strength, and, in the last few months, considerably reduced in numbers by repatriations to the United Kingdom, the unit constructed some thirty thousand feet of boreholes, ranging from 6-inches to 24-inches in diameter, and from 50 to 703 feet in depth. In all one hundred and twenty-two holes, totalling 27,466 feet, were drilled on behalf of the Civil Government and the War Department, for the investigation and utilisation of water supplies. Twenty-four holes, totalling 2,064 feet, were put down on behalf of the Air Ministry Directorate of Works, and three holes, totalling 631 feet, on behalf of the Admiralty. Only eight holes, totalling 873 feet of drilling, were lost and required repetition on account of formation difficulties or unsuccessful fishing jobs. At every site selected, with one exception (B. H. 116—Binjemma), holes were ultimately carried down, in good shape, to the desired objectives.

115. A further direction in which assistance was received from M.E.F. in response to Lort Gort's representations was the offer in January 1944 of a geophysical exploration detachment from 42 Geological Section, S.A.E.C., for a period of six weeks, if it was considered that this type of work would be of value in solving any of the water supply problems of the Island. As Major G. L. Paver, after several weeks work in the Island in June 1943, had formed the opinion that electrical resistivity surveys might be able to plot contours of the Lower Coralline—Lower Globigerina and Upper Coralline—Blue Clays contacts with a considerable degree of accuracy, and perhaps also be able to estimate the salinity variations of the sea-level water tables, the offer was accepted. In view of the limited time for which the detachment was expected to be available attention was directed to three problems of immediate importance in connection with proposed boring operations: (i) the delimitation of the area in which the Lower Coralline Formation occurs above sea level in the eastern portion of the Island, where boreholes were obtaining results considerably out of accord with the contours plotted by Dr. E. B. Bailey, and where freshwater was desired for irrigation areas and for the improvement of the public supply; (ii) the contours of the Upper Coralline—Blue Clays contact in the valley between Imjar and Binjemma, the trough like form of which had been noted by C. Rizzo (1932, p. 31) but which had been represented as a southward-dipping monocline by Major G. L. Paver in 1943; and (iii) the contours of the Upper Coralline — Blue Clays contact in the valley between the Mellieha and Baida Ridges, which had been described as a "depressed orographic block" by C. Rizzo (1932, p. 31), but which was interpreted by Dr. E. B. Bailey and the M.E.F. geologists in 1943 as a faulted monocline with a large inlier of the Blue Clay Formation.

116. A detachment of twelve men from 42 Geological Section, S.A.E.C., under the command of Captain H. D. Roberts, S.A.E.C., arrived in Malta on the 17th March 1944, and, after being introduced to the local geological formations and made acquainted with the latest results of boring operations, commenced combined geological and geophysical surveys to elucidate the problems mentioned above. It was soon realised that geological conditions were too complex to permit the achievement of any very extensive results within the stipulated period of six weeks only, and the detachment was ultimately permitted to continue working in the Island until October 1944. A revision of Dr. E. B. Bailey's 2-inches to the mile structural contour map of the main portion of the Island was issued in January 1945, based on the detachment's work and on the evidence secured by boreholes up to that date. In conjunction with the hydrological

data obtained by the 1944-45 boring and tunnelling programme, and with the adjustments rendered necessary by later boreholes, this map has been of considerable value for discussion of further development policy in the Main Lower Water Table. The detachment's work on the Binjemma — Imjar Upper Coralline area showed that no advantage, with regard to the saving of either time or expense, could be gained, under local formation conditions and relatively shallow drilling depths, as against the employment of portable boring machines for procuring direct and indubitable evidence for the delineation of structure. Two boreholes, Nos. 57 and 63, were put down in May and June 1944 for the purpose of checking computations while the detachment's geological and geophysical survey of the area was in progress. After drilling to only 220 and 162 feet respectively these holes proved the Blue Clays at 102 and 130 feet A.M.S.L. at localities where the geophysical computations had suggested that the top of the Blue Clay Formation would lie below sea level. Later again a provisional contour plan, based on the detachment's geological and geophysical surveys and on the results of the first twelve boreholes of the structure testing programme, was found to require radical revision long before the full testing programme of twenty-nine holes had been completed. The Upper Coralline tract between the Mellieha and Baida Ridges (Miziep area) would probably have provided even greater difficulties for the reliable interpretation of resistivity soundings. Accordingly, in the subsequent investigation of this area during the months of May, June, and July 1945, only geological mapping and borehole evidence were used for elucidation of structure.

117. Concurrently with the technological and liaison work required by the tunnelling and boring operations of 1944-45 the present writer undertook the examination of all available records concerning the investigation of resources and of the production of water from the Upper and Lower Water Tables of Malta. The sites of No. 3 Section's boreholes, several of which had been given map references remote from their true positions, were visited and plotted more accurately on the 6-inch map sheets. A definitive list was prepared in April 1944, correcting various discrepancies and carrying forward the record with consecutive numbering of sites to include the first five holes put down by No. 7 Boring Section. A series of regular salinity determinations on samples taken from certain pumping stations, boreholes, private shafts, and marginal springs of the Main Sea Level Table was commenced in May 1944 and continued throughout the dry season of 1944 and the ensuing winter rains until February 1945, to amplify the data concerning seasonal variations in composition already provided to some extent by the routine determinations made at various points of the supply system by the Government Laboratory, and to provide as ample and accurate a statement as possible of the condition of the water table in 1944-45.

118. In September 1943 nearly two thousand completed forms had been received by the Water Department in response to a questionnaire circulated to owners of private wells. An attempt was made to use this information to evaluate the cumulative effect of those private wells located in the Main Lower Water Table, but the data supplied by the owners were in most cases so inadequate, inaccurate, and often self-contradictory that it was not possible to reach any more precise conclusion than that in the dry weather private daily extraction was probably as great, if not greater, than the total daily production of the Government pumping stations. The introduction of a previously unappreciated factor of such magnitude into considerations of the volume and rate of extraction from the sea-level table emphasised the need for more accurate quantitative data concerning character, extent, and influence of private works throughout the Island. A more comprehensive schedule of the required items of information was drawn up, and in August 1944 the services of Mr. J. Baldacchino were made available for a commencement of deliberate survey work. As a first step a rapid salinity survey was made, between the 23rd August and the 13th September 1944, of the densest concentration of private wells, which draw

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from the Main Lower Water Table in the low-lying area extending from the Marsa, through Curmi, to Attard and Lia, in close proximity to the Armier—Wied il Kbir—Wied is Seuda galleries. Thus a statement of the position in the middle of a dry season was obtained, with which it will be instructive to make comparisons at a later date. On the 18th May 1945 a similar sampling was carried out of the less concentrated group of private wells around Zabbar. During the period September 1944 to August 1945, however, Mr. Baldacchino was mainly occupied by surveys of private wells, gallery systems, and irrigated areas in the Upper Coralline tracts from Binjemma to Il Miziep and Cala Mistra, for co-ordination with my own geological surveying and with the structure testing programme of the Boring Section. His first year's intensive work involved the collection, computing, and plotting of data concerning no less than 270 separate privately-owned water supply works, and has provided precise records which will be of permanent value. But it is obvious that at this rate of progress the survey of all private works in the Island (not to mention Gozo, where similar deliberate survey work is required also) will take several years to complete, whereas an accurate overall plan and statement of the position is urgently required, in order that urban and agricultural interests may be weighed fairly against each other in considering detailed problems of conservation, development, and compensation.

119. By June 1944 analysis of the main factors controlling local water supply prospects had reached a stage at which it was impossible to avoid the conclusion that the Island's present main sources of supply from the sea level table were rapidly depreciating in quality as the result of overpumping, and that, while the general quality of the supply might be improved temporarily by more equal distribution of extraction within the freshwater area of the table, the continued deterioration, which had been evident since at least the commencement of the dry spell of 1911-1927, probably indicated that the volume of annual production from the Main Lower Water Table had passed the limit at which a potable composition could be maintained for many more years. There was no indication that any slackening could be expected in the rate of increase of population, and in the consequent increase of the daily demand for urban water supplies. The inevitable corollary was that a return must be made as soon as possible to the long-neglected Upper Coralline catchments, completely removed from the danger of contamination by sea water, and that the very variable annual supplies obtainable from those sources must be conserved and equalised to offset the deterioration of the Main Sea Level Table, and to reduce the demand being made upon it. The evidence on which these conclusions were based (Plates 1 and 2) was laid before a meeting of the Defence Committee on the 28th June 1944. It was suggested that on the evidence available it would be advisable to accept rough tentative estimates of 1,000 million gallons (of salinity not exceeding 50) and 1,500 million gallons (of salinity 8-12) per annum, from the Lower and Upper Water Tables respectively, as the probable ultimate limits to which the Island's internal supplies of potable water could be developed and maintained, and to relinquish altogether the estimate of 10,000 million gallons per annum from the Lower Table alone, which had been so uncritically accepted from Robertson and Rizzo. Much of the subsequent work of the past eighteen months, outlined in previous paragraphs, has been devoted to devising means by which further quantitative evidence may be secured to subject these conclusions to more critical investigation and discussion, and to the manner in which such apparently limited resources may be developed and utilised to the best advantage of the Island as a whole.

III. THE WATER CYCLE IN MALTA

120. Since all the potable water which is obtained, and is ever likely to be obtained, within the geographical limits of Malta, is derived directly from the rain which falls upon the surface of the Island, a consideration of the rainfall records, which have now been kept systematically for nearly a hundred years, is of prime importance. The monthly and annual totals for the years 1851 to 1945, and the sources from which these figures are derived, are given in Table I. The arithmetic mean of the annual totals approximates very closely to 20 inches, but, as will be readily appreciated from the graph at the foot of Plate I, there are considerable deviations from this mean value, and the seasons in which the rainfall has been notably higher or lower than the mean are far more numerous than those which have coincided closely with it. Considered as a frequency series it will be noted that the years with a rainfall of 18-19 inches are most numerous, but that there is a subordinate peak in the frequency distribution curve within the range of 25 to 29 inches. Most important from the practical water supply point of view is the time distribution of the noteworthy deviations from the mean. In his first general report Chadwick (1884, p. 10) pointed out, from consideration of thirty years records, that it would seem "as if there were long periods below the average, separated by short periods much above the same," and concluded that it would be safer, in water supply work, to take 15-16 inches as a dependable average, instead of 20 inches. Later, on the hypothesis that 16 inches only was the safe average which could be expected to be realised over any three consecutive years, he suggested (1887, p. 2) the following classification for describing the rainfall of any given year: 20 inches or more, "Excessive"; 16 to 20 inches, "Abundant"; 12 to 16 inches, "Deficient"; and under 12 inches, "Drought". From the longer series of observations now available, however, it would appear that the most important point to realise is that there would appear to be definite cycles in the climatic conditions of Malta, which produce well-marked periods of rainfall in excess of the mean, alternating with periods of deficiency. This is most clearly brought out when 5-year means are plotted, as in Plate 1. The maxima and minima of successive cycles were spaced at fairly regular intervals of 8-10 years, until the long spell of seasons of deficient rainfall between 1912-13 and 1926-27 broke the regularity of the succession. Since that period the seasonal rainfall has remained well above the mean, on the average, up to the present; now it would appear that a period of years with average rainfall below the mean must lie close ahead. The apparent long-term periodicity in the rainfall is deserving of a much wider research than that to which I have been able to subject it. It is possible that a thorough analysis of the climatic data from other Mediterranean stations might reveal correlations which could be used to forecast the duration and intensity of future Malta rainfall cycles, information which would be of increasing value for deciding upon conservation and equalisation policy as the demand on the Island's limited annual resources becomes more and more stringent in the years to come. The difficulties engendered by some previous spells of drought have been noted in an earlier part of this Report. While no seasonal total lower than 8 inches has been recorded during the period of accurate gauging, it is worth while to bear in mind that Murray (1890, p. 4) quoted a statement, from a source I have been unable to identify, that during the years 1467 to 1470 no rain whatsoever fell in Malta. The effect of such a spell of drought on the Island's present internal economy would be disastrous. (1)

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(1) Since writing these remarks on the long-term periodicity of the local rainfall, I have had opportunity to discuss the problem with F/O A. Rushton, R.A.F., who, while stationed in Malta during 1941 and 1942, undertook an analysis of all the rainfall records available, up to that date. It is hoped that his paper on "The Rainfall Régime of the Maltese Islands", of considerable interest from both water supply and agricultural points of view, will be published in the near future. He finds that, even within the limited area of Malta itself, there is a considerable and well defined variation in the distribution of rainfall, ranging from a mean annual incidence as high as 25 inches at some points on the Rabat—Dingli Plateau and on the height of land around Naxxar and Gharghur, to as low as 18 inches along a central belt between Musta and Birzebbugia. He considers that the long-term periodicity is controlled by the solar cycle and by two other regional influences, of origin unknown up to the present, but which should yield to further research, and may then explain the variable time distribution and intensity of individual rainy spells during the course of each season.

121. The total quantity of water represented by the mean annual rainfall of 20 inches on the 95 square miles of the Island's surface is approximately 27,550 million gallons. Even such a poor season as that of 1866-67 gave a total precipitation of 11,020 million gallons of water within the confines of the Island. Unfortunately, only a relatively small fraction of these impressive quantities can ever be made available for human use. A large portion of every season's rainfall is returned rapidly to the air by evaporation from the surfaces of soil and rock on which it falls, and by transpiration from the vegetation. Another large portion, particularly of the heavier rainstorms, runs off rapidly to the sea, though some part of this is appropriated for both household and agricultural use by numerous roof, road, and wied catchments. The organised public supplies, and most of the water used for irrigation nowadays, depend on that third portion of the rainfall which soaks into the ground and percolates into the pores and fissures of limestone formations, whence some part of it can be extracted again later by pumping from wells and galleries.

122. Accurate assessment of the evaporation loss from even a single rainstorm is beset with many difficulties under the varied surface conditions of this small Island, and to attempt such an assessment for a whole season's rainfall, when so many inadequately known factors are involved, would only produce a result of extremely doubtful value. Establishment of a reliable ratio for ground and vegetation evaporation losses in Malta must await more adequate determinations of the total annual run-off and of the annual increments of fresh water received by the underground water tables. It must suffice here to emphasise the fact that, under the climatic conditions of strong breezes, long hours of sunshine, and a mean annual shade temperature of 64°F., evaporation from the surface of the ground, and transpiration from vegetation, is intense. Comparisons with larger areas in temperate and sub-tropical regions, where it has been possible to estimate reliably the losses due to evaporation, as the difference between the measured amounts of rainfall, run-off, and underground intake, indicate quite clearly that were it not for the fact that in most seasons a considerable proportion of the annual rainfall of Malta descends in brief heavy downpours, during periods of two, three, or occasionally, more days characterised by cloudy skies and fairly continuous lighter showers, there would be no appreciable surface run-off and no underground percolation whatsoever.

123. The rate of evaporation from a free water surface can be measured simply and directly, though no local determinations have been recorded, despite the importance of the accurate assessment of this factor for consideration of the losses which have be to faced from open storage tanks and reservoirs. When Chadwick (1887) was discussing the pros and cons of his proposed open reservoir for irrigation water in Wied L'Iemu, he had to frame his estimates on the basis of evaporation losses recorded from reservoirs in India, at Nagpur and Bombay. Using Binnie's Nagpur rate (1/10th inch) he decided that the evaporation loss during the dry season would amount to about 8 million gallons of the 70 million gallons which he hoped to have in store at the commencement of each season. It is very doubtful whether the proposed reservoir would ever have been filled from the sources on which he proposed to depend (the surface run-off of the wied, the surplus from the surrounding Upper Coralline springs "after providing the usual supply for town and country," and the rainfall on the surface area of the reservoir itself), and certainly such an annual loss could not be accepted nowadays for water which would have to be pumped to storage. The need for covered reservoirs for public supplies, to reduce evaporation to a negligible minimum, is obvious, quite apart from the need for protection from wind and water-borne contamination. Except for the relatively small dams in Wied tal Kleigha, at Buskett, and in Wied Hanzir, no large scale open storage of water has ever been attempted at Government expense.

124. In 1928-29, presumably after the conclusion of the winter rains, the rate of loss of water was measured at one of the "Chadwick Lakes" in Wied tal

Kleigha, and was found to be 1 foot in 20 days, an average rate of 3/5 of an inch per day. According to the Annual Report of the Water Department, this loss was considered "not excessive, and by growth of trees the rate of loss could be considerably reduced." As a matter of fact no storage tank can be considered efficient which loses water at such a rate, even under the local climatic conditions. In the case in point the loss was probably due at least as much to underground percolation (the dam is bedded on one of the limestone members of the Upper Globigerina Formation) as to evaporation from the free surface of the water, and it is unlikely that the planting of a few trees along the sides of the reservoir has done anything to reduce the rate of loss; probably it has had the reverse effect.

125. A more reliable figure for evaporation loss from a free water surface under local conditions is provided by the large salt pans at Salina Bay, where Major W. E. Clarke, M.B.E., R.E., as the result of many years practical experience, estimates the average daily loss to be about 1/3 of an inch per day during the hot dry period from May to September inclusive. This rate is from large areas of water never permitted to exceed a few inches in depth. From large reservoirs at least several feet in depth the rate of evaporation would be lower. Utilising data which has accumulated since Chadwick's time it would appear that, under the climatic conditions of Malta, the mean daily loss from a free water surface should average 0.173 inches or a total of 5.27 feet for the year. A minimum daily rate of 0.12 inches would be expected in February, and a maximum of 0.26 inches per day in August. During May to September the average daily loss should be about 0.225 inches per day, or more than twice the amount assumed by Chadwick in his consideration of the Wied L'Iemu scheme.

126. A very large proportion of the water drawn from underground storage for irrigation purposes must be lost by evaporation under the crude and wasteful methods current in Malta. In view of the large drain made by private wells on the underground water resources of the Island, which is most accentuated during that season of the year when these resources are least able to recuperate, it is highly desirable that a thorough quantitative study should be made of the whole problem of soil water evaporation, both under conditions of natural rainfall alone, and of natural rainfall combined with the irrigation of typical crops, with a view to devising and propagating less wasteful methods for local application.

127. A smaller proportion of the water extracted privately from underground sources is lost by evaporation from the numerous open tanks in which it is stored temporarily in readiness for irrigation. The cumulative annual loss from all the open tanks in the Island must be considerable. For example, in the St. Paul's Valley, Ta Zerp, and Binjemma catchment areas, recently surveyed by Mr. Baldacchino, the estimated quantities are:—

Area	No. of tanks	Total surface area of tanks	Loss by evaporation at 5.25 ft./year	Estimated total volume produced annually for irrigation	Evaporation Loss
		sq. feet	gallons	gallons	Annual Prod.
St. Paul's Valley	61	25,187	826,000	247,972,000	0.33%
Ta Zerp	10	7,784	255,000	24,315,000	1.06%
Binjemma	8	3,627	119,000	5,941,000	2.00%
Totals	79	36,598	1,200,000	278,228,000	0.43%

In view of the small saving, in terms of current pumping costs, which would accrue annually to individual owners of private works, as compared with the initial cost of roofing even the average 20 x 20 feet tank, it would probably be impossible to insist that every irrigation tank should be adequately roofed to cut out evaporation losses. Nevertheless, it should be insisted that open tanks be restricted to the minimum dimensions compatible with the area of land to be irrigated. Some recent large tanks are out of all proportion to size of the irrigated area concerned, and appear to have been given their large dimensions so that the owners may depend solely on small windmill pumps for maintaining a store of water at surface throughout the summer, instead of having to incur the cost of adequate engine-driven pumps and fuel for pumping from underground storage as and when irrigation water is required.

128. There are no perennial surface streams in Malta, and nowadays it is only for a few hours, or, at the most a few days following a heavy downpour, that water flows along the beds of the major valleys, whose general form and cavernous walls bear witness to the passage of much more voluminous and active streams during comparatively recent geological times. At the end of the dry weather an exceptionally heavy rainstorm is required to produce surface flow, and run-off continues for a few hours only after the climax of the storm. As an example the exceptional storm of the night of the 12th–13th August 1944 may be quoted, when 1.76 inches of rain fell within the space of a few hours. At 4 a.m. on the 13th all wieds and drainage channels were in heavy spate, but by 8 a.m. the flow had died away to a mere trickle. In contrast, after the progress of the rainy season has saturated the dried-out soil cap and re-charged the pores and fissures of the solid rocks, relatively light showers are capable of producing surface run-off for a much longer period. Heavy rainstorms, of which the most spectacular on record registered 16.3 inches at some places on the 16th October 1913, are liable to do considerable damage. After the almost continuous period of rain from the 24th December 1944 to the 5th January 1945, totalling 9.61 inches, of which 3.48 inches fell on the 28th December, an appreciable flow was noted in Wied tal Kleigha at San Paul Tal Kleigha Church, and at King's Corner, Salina Bay, until the end of January, although only a few brief isolated showers, totalling 0.43 inch, occurred after the 8th January.

129. The volume of surface run-off which is shed directly into the sea from bare rocky slopes, small wieds, roads, and lanes around the margin of the Island must form a considerable fraction of the total run-off. It is fortunate for Malta that the major surface drainage lines of the Island do not radiate from a central geographical point, but have their sources in close proximity to the western coast, whence, following the predominant tectonic and topographical slope, they cross the entire width of the Island before entering the sea on the east. Thus the surface flood waters which they collect are afforded the maximum opportunity to find their way to underground storage, particularly as much of the ground at the head of the catchments is predominantly clayey, whereas the central and lower portions of every valley are bedded in well-fissured, permeable limestone formations. It is possible that upland storm drainage, thus concentrated in the beds of the Wied tal Kleigha—Wied il Ghasel and Wied is Seuda—Wied il Kbir systems, contributes a large quota to replenishment of the central freshwater area of the Main Water Table; possibly as much or even more than is added from the rain which falls directly on the Lower Globigerina and Lower Coralline outcrops within that area. This, however, is merely an impression as yet unsupported by any measurements of the variation in the amount of surface discharge at different points along the course of the main valleys, for, despite the repeated discussions to which conservation of surface run-off has been subjected since Chadwick's time, the only attempts which have ever been made to assemble any quantitative data were Chadwick's own imperfect estimates of the surface discharge from the upper portion only of one of the main drainage areas during seasons 1883-84, 1884-85, 1885-86, and 1886-87 when he was considering the prospects of open reservoirs in Wied L'Iemu and

Wied tal Kleigha. His first season's very approximate results, covering the months of December to March only, have often been quoted as indicating that surface run-off is unlikely to represent more than 1.9 per cent of the whole Island's mean annual rainfall. That his second season's observations provided an estimate of 7.5 per cent of the local precipitation, and that conditions in Wied L'Iemu can hardly be regarded as typical of the Island as a whole, are points which appear to have been overlooked completely. It would be well to have Chadwick's measurements checked and extended by up-to-date continuous recording apparatus, for it was only during the last two seasons mentioned above that he himself was satisfied with the performance of the Wied L'Iemu gauge, and was able to arrange for readings of every flood to be taken at half-hourly intervals day and night. Even as they stand the few figures he recorded require corrections for the size of the catchment area (about 2.837 square miles, measured from the modern 2-inches to the mile contoured map, as compared with 2.25 square miles estimated from the best survey available to him) and for the intensity of the rainfall (using mean values for the whole Island, and for the whole rainfall season, not only for the months in which surface flow occurred, instead of the single isolated Dingli gauge, which he himself considered inadequate to provide a reliable mean figure for the whole of the catchment area).

The revised figures may be tabulated:—

Season	Mean Island Rainfall inches	Rainfall on 2.837 sq. miles gallons	Estimated surface run-off at Fiddien Gauge gallons	Ratio of run-off to rainfall
Dec. 1883 — March 1884 ...	8.16	335,674,000	4,534,000	1.35%
1884-85	19.40	798,048,000	44,900,000	5.60%
1885-86	18.84	774,912,000	17,724,000	2.28%
1886-87	19.57	705,041,000	12,000,000	1.70%

It is obvious that the ratios for different seasons with approximately the same total rainfall may vary considerably according to the frequency and intensity of individual rainstorms within the season, and that a much more extended series of observations is required to provide a reliable mean value. Unfortunately the gaugings of surface run-off at Fiddien Bridge were discontinued after 1886-87, the same year that the installation of seven raingauges on the Rabat-Dingli Plateau commenced to provide a more reliable record of the precipitation on that catchment area, despite Chadwick's insistence (1886, p. 5) that the importance of such statistics could not be overrated, and that their collection should be continued permanently. There are no data whatsoever for the amount of surface run-off in years which have had a rainfall far above the mean. The ratio of 1.35 per cent, based on four months only of the 1883-84 season is open to criticism in that it takes no account of an exceptionally heavy rainfall in November 1883. The 1884-85 estimates were based on day-time readings only, at hourly intervals, with the added reservation that "several important floods were only gauged once, and some may have escaped measurement altogether." With regard to 1885-86 and 1886-87 it may be noted that figures recorded for the water trapped by the Wied tal Kleigha dam, downstream from the gauging weir, suggest that the estimates of run-off made from readings at the weir were definitely on the underside of the actual quantities which must have passed the gauge. The run-off from Wied Ghemieri and additional hillslopes, amounting to 0.851 square miles additional to the Wied L'Iemu catchment, is intercepted by the dam, making a total of 3.688 square miles. In 1886-87 it was recorded that 20 million gallons were trapped by the dam,

THE ROYAL NAVAL MALTA

as compared with 12 million gallons estimated to have passed the Fiddien Bridge gauge. The ratio of run-off to precipitation over the whole of the larger area is raised thus to 1.91 per cent, without taking into account any of the evaporation and percolation losses which are known to occur at the dam (para. 124). The Water Department records of the amount of water supplied to down-country irrigation from the "Chadwick Lakes" do not accurately represent the run-off from the whole of the catchment, which now amounts to about 4.579 square miles, intercepted by the three dams, as no record is kept of the quantities which pass the dams, and no allowance is made for the evaporation and percolation losses which occur before the water is delivered to consumers. The figures for the past four years are:

Season	Mean rainfall of Rabat-Dingli gauges inches	Rainfall on 4.579 sq. miles gallons	Irrigation water supplied gallons	Ratio
1941-42	26.42	1,754,169,000	7,460,000	0.43%
1942-43	27.57	1,830,524,000	10,840,900	0.59%
1943-44	21.55	1,430,823,000	7,370,800	0.51%
1944-45	19.39	1,287,409,000	7,619,900	0.59%

On the basis of Chadwick's 1883-1887 figures it would appear that these dams are serving extremely inefficiently the purpose for which they were intended, and the question arises as to whether it would not be advisable to remove them and to allow the upland storm water, which they now intercept, to flow freely downstream as in former time to where it can percolate through the Lower Globigerina and Lower Coralline Formations to help to replenish the Main Lower Water Table. At present the dams are responsible for much loss by evaporation, and by percolation into the two Upper Globigerina Limestones, from which the water can only be tapped again by a few farmers' wells in immediate proximity to the banks of the reservoirs.

130. There can be little doubt, from the considerations detailed in the preceding paragraph, that, in an average year, at least two per cent of the rainfall is disposed of by surface run-off down the main drainage lines of the Island, and that this factor of two per cent may be regarded as a safe and conservative one for discussing the best means of utilising that portion of the surface run-off. As already mentioned (paras. 46 and 47) comparatively few public works have been constructed to follow up Chadwick's recommendations with regard to the appropriation of surface run-off for irrigation supplies. Later, Robertson found the 1904 outbreak of malaria in the Kleigha Valley, and the discovery that the "Chadwick Lakes" had become breeding localities for Anopheles maculipenis, a strong argument against the construction of any further surface reservoirs of the size and number envisaged by Chadwick. He recommended instead the construction of numerous smaller dams, not to exceed 4 feet in height, and not to store water, but merely to retard storm discharge along main drainage lines, so as to serve the dual purpose of increasing percolation to underground storage and retarding the rate of soil erosion (para. 62). The 1934 Committee (paras. 76-78) at first favoured Robertson's proposals, but the third Tal Kleigha dam was the only practical result of their recommendations concerning surface run-off. It is extremely improbable that such an ultimate state of reclamation of valley floors, as visualized by Robertson, could be brought about in practice, in face of the tremendous volume of flood waters which they have to carry from time to time. It is probable, also, that such an extensive silting-up would reduce total percolation underground, rather than increase it. Moreover, the reduction of soil erosion to

a minimum is best achieved by maintaining field walls in good condition. There is a limit to the extent to which the natural processes of erosion can be controlled, and it is not improbable that the average annual loss of soil, which appears to have been causing considerable apprehension at the time of Robertson's commission to advise on the matter, is more than balanced by the processes of formation and conservation of new soil, continually in progress.(1) The prevention of wasteful and irretrievable discharge of surface freshwater to the sea should be pursued not for the purpose of increasing irrigation supplies (sites where economical schemes of this kind can be engineered are not numerous), or of soil reclamation, but primarily to facilitate the transmission of such water to underground storage at points where it would be likely to have the most beneficial effect. The Wied Hanzir dam has already been mentioned (para. 62) as possibly having had an appreciable effect on reducing the rate of increase of salinity of Wied il Kbir underground supplies, as compared with the supplies drawn from Tal Hlas, though there are other local factors which may have contributed also to that end. There can be little doubt that this dam is responsible for transferring underground a considerable portion of the storm discharge received from Wied Ta Kandia and from Wied Sillani. Steps should be taken, by constructing an automatic flood recording gauge upstream, by noting how much water crests the dam on the occasion of major floods, and by routine comparative analyses of surface flood waters and water from the subjacent gallery, to measure the contribution which this dam makes to the Main Lower Water Table. The drainage area of the Wied Hanzir system above the dam site is about 3.582 square miles, as estimated from the contours of the 2-inch map, and, although the formation of the valley floors above the dam are far more pervious than the Blue Clays of Wied L'Iemu, it would not be surprising to discover over a complete cycle of rainfall seasons, that the dam intercepted considerably more than 2 per cent of the mean annual precipitation within its catchment area.

131. Other places on the main drainage lines of the Island where dams would probably divert considerable surface run-off to help to maintain the freshwater of the Main Lower Table are (i) on the Lower Coralline in the bed of Wied ta Isperanza close above the Musta—St. Paul's road bridge, N.W. of Musta; (ii) on the Lower Coralline in the bed of Wied Incita, close above the Attard-Zebbug road bridge; (iii) at the bottom end of the Lower Coralline inlier in the bed of Wied il Bakkia, S. of Zebbug; (iv) at the bottom end of the Lower Coralline inlier in the bed of Wied il Hesri, N. of Siggiewi; and (v) on the Lower Coralline in the bed of Wied Kirda, between shafts 41 and 42 of the Wied il Kbir—Wied is Seuda gallery. The approximate surface drainage areas which would be controlled by dams at these points, and the minimum average annual quantities of water which would be intercepted, on the basis of 2 per cent of the precipitation on the drainage areas, are as follows:—

Dam Site	Drainage Area (Square miles)	Intercepted run-off (Gallons)
Wied ta Isperanza	6.745	39,121,000
Wied Incita	3.348	19,418,000
Wied il Bakkia, Wied il Hesri, and Wied Kirda	5.098	29,568,000
Wied Hanzir	3.582	20,776,000

(1) In 1915 J. Borg quoted 41,681 acres as the total area of cultivated land in the Maltese Islands. Since that date the total area of cultivated land has risen to about 47,000 acres, including both dry and irrigated lands. If these figures are reliable the addition of 5,000 acres within 30 years, despite the expansion of the towns at the expense of the countryside, is as creditable to the persistent energy of the hard-working Maltese and Gozitan peasantry as was the original development of fields on these rocky islands by their Neolithic predecessors. It is an adequate reply to the frequently expressed fears concerning the progress of soil erosion. But it cannot be allowed to continue without having serious repercussions on the volume and quality of underground water resources.

It should be noted that the drainage area of 6.745 square miles above the suggested Wied ta Isperanza dam includes the area of 4.579 square miles at present intercepted by the three existing dams in Wied tal Kleigha, the question of whose utility or otherwise, has already been raised in paragraph 129.

132. No useful purpose, in comparison with the expense involved, would be served by attempting to divert surface run-off to underground storage at the lower ends of the main valleys, where they approach the sea and the margin of the Main Lower Water Table, as, for example, the lower part of the Wied il Ghasel and its tributary valleys Wied ta Ghain Rihana and Wied Kanotta, or the long gently-graded Zurriek—Marsascala Valley in the eastern portion of the Island. In such cases surface run-off is already effectively appropriated by private enterprise, and public works could do little more. There is only one Upper Coralline area where the damming of a major surface drainage line would appear likely to have a beneficial effect on underground resources. A dam thrown across Wied tal Kalkara at the culmination of pitch between Il Miziep and Cala Mistra would hinder a surface storm discharge from continuing on its way down to the sea, and would cause a large portion to return westward down the pitch to underground storage within the Miziep Syncline. The surface drainage area concerned is about 1.403 square miles, and the probable minimum mean annual increased contribution to percolation would be 8,137,000 gallons.

133. The largest flood recorded during Chadwick's brief series of observations at Fiddien bridge was one which lasted from 10.00 to 16.00 hours on the 17th December 1884, during which time 3,327,000 gallons were estimated to have passed the gauge, and the maximum rate of flow measured was 1,112,000 gallons per hour. Much larger flows than this have probably occurred frequently at Fiddien Bridge, and certainly would have to be expected at the suggested dam sites discussed in preceding paragraphs. As, however, the function of the proposed dams is merely to arrest storm discharge while sufficient head is built up to cause rapid percolation underground through well-fissured limestones, it is not anticipated that works of any considerable magnitude would be required. Probably a maximum midstream height of 5 feet below and 10 feet above the bed of the wied would deal effectively with all but the most catastrophic floods, but only actual experience and observation could demonstrate the degree of effectiveness which would be obtained. Should any considerable quantities of water be found to spill over a 10-foot dam at the sites indicated, it would probably be more satisfactory to duplicate the works, or to open up the formation by boreholes, rather than to raise the height of individual dams to more than 10 feet. The precise sites should be chosen to preclude as far as possible any return of water to surface below the dams, or of by-passing around the sites. The essential requirements are to get all storm water underground at the points indicated, and to obtain reliable measurements of the quantities disposed of in this way.

134. Although public works to appropriate or to control the surface run-off have been few in number and their total capacity has not exceeded more than a few million gallons per annum, private works for this purpose are extremely numerous and their total potential storage capacity probably exceeds a thousand million gallons. The cultivators of the Island, from Neolithic times onwards, have excavated underground tanks to store rainwater led into them from the roofs of farm buildings, from lanes and gullies, and collected by small channels cut in neighbouring expanses of bare surface rock. Practically every farmhouse in Malta has such an underground tank to meet the needs of its occupants and their animals, and a glance at the 6-inch and 1:2500 survey maps is sufficient to show that practically every field where there is any possibility of collecting a few hundred or a few thousand gallons a year, for watering seedlings and crops such as tomatoes, melons, and pumpkins during the dry weather, has been similarly equipped in the course of centuries. More than ten thousand such "wells", tanks, and cisterns are indicated on the maps, and probably at least as many again have not been noted. Away from areas where

irrigation water can be easily obtained by other means, new ones are still being constructed, and old ones are continually being cleaned out and enlarged. They vary so considerably in size and shape, according to local catchment facilities and the nature of the rock in which they are hewn, that it would be an extremely difficult and prolonged task to collect the information necessary for an accurate computation of their total capacity, and still more difficult to obtain from the farmers a reliable estimate of the mean annual quantity of surface run-off which they receive.

135. A not inconsiderable portion of the annual rainfall is, or should be, directly appropriated by the roof catchments in the towns and villages of the Island, though, here again, an accurate estimate of the total quantity which is collected annually is not easy to make. An old article of the Police Laws, still in force, requires that every house built in a town or village shall be provided with a well-sealed tank of two cubic feet capacity for every square foot of floor space within the house, and that the tank shall be maintained in a good hygienic condition. The advantages for many domestic purposes of a supply of soft water from a clean roof catchment are obvious, and, were all the compulsory roof catchments and tanks to be maintained and used efficiently, this additional independent water supply of every household could considerably reduce the summertime demand on the public piped supply. A rough estimate of what this soft water supply should amount to can be made on a population basis. In 1884, when discussing the storage, pollution, and wastage of water in Valletta and Floriana, Chadwick (1884, p. 1) calculated that the total area of roof catchments in those two towns was about 72 acres for a population of about 32,000, which approximates closely to 100 square feet per head. If this ratio be applied to the whole of the present day urban and suburban areas of Malta, where we may suppose that Article 79 of the Police Laws has been fairly consistently observed, it would appear that in 1939 the estimated population of 180,000 residents in those areas should have been equipped with at least 405 acres of roof catchment. Allowing ten per cent for evaporation and other losses, 405 acres would provide 165 million gallons of run-off from a mean annual rainfall of 20 inches, or about 2½ gallons per head per day the year round for the population concerned. If the use of such a supply could have been restricted to, say, 150 days of the hot dry weather, it would have relieved the demand on the public supply (then averaging about 13 gallons per head per day for the year) to the extent of 6 gallons per head per day.

136. When due account is taken of its limited superficial area of only 95 square miles it must be admitted that Malta is comparatively well-equipped with rock formations which provide favourable conditions for the rapid transmission of surface waters to underground storage, and in this way help to ameliorate considerably the less favourable factors which control the local water cycle and which have been discussed in previous paragraphs. Many large islands are much less fortunate in their geological constitution; for example the case of Pantalleria's 44 square miles of igneous rock, and its relative unimportance, strategically and historically, immediately occurs to mind. The whole mass of the Maltese Islands, not only above sea level, but to the greatest depths explored by boring up to the present, is built up from two thick series of water-bearing limestones, the Lower and Upper Coralline Limestone Formations, separated by a thick series of, in the main, impervious marly beds: the Globigerina Limestone Formation and the Blue Clay Formation. As the name implies, important beds of limestone form a considerable proportion of the lower part of the marly series, the Globigerina Limestone Formation, but, as they are much more marly and less permeable, on the whole, than the Lower and Upper Coralline Formations, they are of considerably less value for absorbing and for furnishing water supplies. The areal distribution of the Lower and Upper Coralline Limestone Formations is shown on the accompanying maps, Plates 8 and 9; the regional variation in position and thickness of the main Globigerina Limestone horizons will be best appreciated by reference to the vertical sections of strata, Plate 15.

137. The capacity of the Malta limestones for containing water, and for permitting its movement in the body of the rock, varies considerably and rapidly within one and the same formation, as will be realised from the series of determinations of porosity and permeability which were made for Robertson in 1917 by Dr. A. Sultana. The essential data are reproduced in Table 4 accompanying the present Report. From them it will be seen that the fact that a rock has a high porosity, and, therefore, that it will hold a large volume of water, does not necessarily indicate that it will yield a copious supply. Much depends on the shape and size of the individual mineral grains which compose the rock, and on the amount of argillaceous material which is present. On the whole the porosity and permeability of the limestones has probably been reduced considerably from the original condition as deposited, by the long continued processes of compaction, recrystallisation, and cementation. Conversely, this loss of capacity for taking-up and storing water within the body of the limestones has probably been more than compensated, from the practical water supply point of view, by the development of innumerable joints and fissures in such hardened rocks under the stress of earth movements, and the subsequent enlargement of many of them by the passage of subterranean streams of water. It cannot be too strongly emphasised that, in the Malta limestones, open fissures, such as bedding planes, joints, faults, and the channels which have been eroded along them, are of far greater importance in transmitting and storing water underground, and in conditioning the measures adopted for its extraction, than the local porosity and permeability of the rock material itself.

138. The Coralline Limestone Formations are mainly composed of massive white limestone beds of shallow marine origin, generally reefs of Nullipores and other calcareous algae, and banks of washed shelly debris derived from the skeletal remains of algae, foraminifera, serpulids, corals, echinoderms, molluscs, polyzoa, and crustacea. They show all the rapid variations of grading and sorting characteristic of such shallow water deposits. Any particular horizon may vary from hard, compact, and well-cemented, to a soft, rubbly chalk. A few thin marly partings, up to two or three feet in thickness, and full of worm tubes, appear to mark non-sequences of wide extent within the formations. Thicker intercalations of blue, green, and grey clays, up to 34 feet in thickness, have been encountered in shafts, borings, and tunnels, but do not appear to have any very great lateral extent. A variable thickness, sometimes as much as 60 feet, at the base of the Upper Coralline Formation is composed of thinly-bedded alterations of white limestone and yellow and grey marl. The Greensand which intervenes between the Upper Coralline Limestones and the Blue Clays is a deposit which varies considerably, both in lithology and in thickness. Sometimes it is a practically pure glauconite deposit; more frequently it is a glauconitic limestone or a glauconitic marl. Forty feet is the maximum thickness which has been measured, but this is exceptional; over much of the area the horizon is represented by only a foot or two of thinly-bedded glauconitic marl, transitory between the Blue Clays and the marly basal beds of the Upper Coralline. The presence or absence of the Greensand is a matter of considerable importance for such practical considerations as the location and design of galleries; otherwise the horizon plays a very minor role in the local water cycle and may simply be regarded as the basal member of the uppermost water-bearing formation of the Island.

139. The top of the Lower Coralline Formation is above sea level over an area of 57.5 square miles in the main part of the Island, south of the Victoria Lines Fault, and over a contiguous area of 4.3 square miles on the north side of the fault. The sea level water table within this combined area of 61.8 square miles, together with less easily defined extensions within the surrounding fringe of Lower Globigerina Formation, is the main source of the Island's present public water supply. The recent boring operations have shown that, despite the increasingly heavy annual extraction from its eastern side by both public and private works during the past sixty years, the table still contains water not

exceeding a salinity of 15 parts per 100,000 over an area of 22.8 square miles (Plate 8). The problems of development and conservation of this table will be discussed in more detail in Part IV of this Report, and the question of prospects below the Main Sea Level Water Table in Part VIII. What formations may be found beneath the Lower Coralline and what may be the nature of their fluid content are speculations of considerable interest on account of their bearing on deep boring prospects and procedure, but they have no concern with the formation's functions in the existing water supply régime, for the proven thickness of the Lower Coralline Limestone Formation is adequate to ensure lateral access at depth to water of Mediterranean salinity, even in the central parts of the Main Lower Water Table where the standing water levels are highest and where the top of the formation locally attains heights of more than 400 feet above sea level. Some 300 feet of the formation are open to surface inspection in the deepest accessible sections in Wied il Ghasel and in Wied Mahlak. More than 400 feet can be seen above sea level in the inaccessible cliffs by Ghar Bittia on the south-west coast, and, as the cliffs continue vertically downwards below sea level for a further 300 feet before there are any indications of flattening-out in the submarine profile, it may be safely inferred that the formation is at least 700 feet thick in this neighbourhood. The maximum thickness which has been proved up to the present by boring is 626 feet (Madalena Quarry B.H.), without any indication of approach to the bottom of the formation.

140. The Upper Coralline Formation occupies about 22.57 square miles of the surface of the Island, excluding such small outliers as those of Karraba, Fort Musta, Il Hofra, and San Leonardo, and numerous smaller masses detached from the main outcrops by landslips. Over about 19.69 square miles of this area the base of the formation lies above sea level, and, in consequence, the water which it contains and which is or may be extracted from it is free from all danger of contamination by diffusion of more saline water from the sea, no matter to what degree extraction may proceed. On the other hand rarely more than 100 feet vertical thickness of the formation has survived the inroads of denudation over much of this area of 19.69 square miles, and the danger of contamination from the surface is proportionately high. Furthermore, even the largest tracts are so deeply embayed by the valleys eroded inwards from their margins that few natural structural basins remain unbreached and in suitable condition for permanent storage of water from surrounding catchments. Most of the water which percolates into the formation in the elevated area is able to escape again from springs around the margin of the outcrops, or drains down dip into the areas, totalling 2.82 square miles, where the top of the underlying Blue Clay Formation passes below sea level and the sea level tables in the Upper Coralline are continuous with the water of the Mediterranean (Plate 9). The original upper stratigraphical limit of the Upper Corralline Fomation is not preserved within the Maltese Islands. A thickness of more than 400 feet remains in the middle of the Bingemma Syncline, more than 250 feet in the Miziep Syncline, and more than 300 feet is exposed on Comino, where the position of the base of the formation has not yet been ascertained.

141. The predominantly marly series (Blue Clay and Globigerina Formations) which lies betweem the two Coralline Limestone Formations varies in thickness from a total of 180 feet on Redum Kammieh to more than 700 feet for the Globigerina Formation alone in the east coast region. The most important function of this series, from the water supply point of view, is that it provides an impervious base to the Upper Coralline and Greensand Formations. Fine-grained foraminiferal limestones, however, are developed conspicuously at three horizons within the group; namely, (i) the Lower Globigerina Limestone at the base, which varies in thickness from only 3 feet and 8 feet, at Gneina Bay and on Redum Kammieh, to probably more than 300 feet in some parts of the eastern synclines of the Island, and, (ii) and (iii), the two limestone members of the Upper Globigerina Formation, the lower of which varies from 5 to 30 feet in thickness, and the upper from 15 to 30 feet in the northern and western

outcrops; the two combined exceeding a thickness of 140 feet along the east coast. The light blue calcareous marl which generally separates the two limestone members of the Upper Globigerina Formation attains a maximum thickness of about 50 feet at Blata il Baida; its lithology is identical with that of the lower portion of the Blue Clays, into which the Upper Globigerina Formation passes upwards by rapid transition. The Middle Globigerina Formation consists mainly of white-weathering drab greenish and bluish - grey marls, and varies in thickness from 42 feet on Redum Kammieh to about 380 feet on the east coast.

142. Over wide areas in the eastern part of the Island the Lower Globigerina Limestone contains little argillaceous admixture, and, where the Middle Globigerina marls have long been removed from above it, it has been well cemented and strengthened by the deep weathering of Pliocene and Quaternary times. In this condition a large part of it provides valuable building stone, and, though the permeability of the rock is low, the many open joints and fissures which have been developed in it provide a useful lateral extension to the storage capacity of the Main Lower Water Table. Perhaps even more important, they facilitate the downward percolation of water to the Main Lower Water Table in the Lower Coralline over a wide area of the central portion of the Island, where the latter formation itself has only relatively small outcrops. In the syncline between Imkabba and Zurriek, probably as the result of the presence of impervious marly beds at the base of the formation, the Lower Globigerina Limestone holds a small perched water table, which, however, is of considerable value to the local farmers. The Upper Globigerina Limestones, apart from the seaward-dipping strip along the east coast between Shrop il Ghain and Delimara Point, have only very limited surface outcrops along the slopes beneath the scarps of the Upper Coralline outliers, and, as they have generally a very low permeability, they are not worthy of consideration for any larger water supplies than those which are already obtained from them locally by farmers' wells.

143. At present it is not possible to assess with any confidence the amount by which percolation from the annual rainfall replenishes the Main Sea Level Table in the Lower Coralline and Lower Globigerina Formations. Under the local topographical and geological conditions a reliable estimate could not be made by assuming a mean rate of percolation per unit area of outcrop, even if figures had been already determined experimentally (which they have not) of the relative amounts of evaporation, run-off and percolation on small areas. The presence of a practically impervious clayey soil cap over much of the region, the concentration of large volumes of surface run-off along the main drainage lines across restricted portions of the outcrops, and the irregular distribution of fissures of all shapes and sizes, are all unknown factors which prohibit reliance on simple calculations based on the assumption of uniform permeability over wide areas. A reliable estimate must await the collection and integration of continuous records of changes of level and composition from the twenty-eight boreholes which have been reserved for gauging purposes, and the correlation of these data with estimates of the quantity and composition of the water being withdrawn at the same time by public and private works. At present reliable data are only available for the water which is being extracted by the Government Pumping Stations, and even here the records of variation in composition will require amplification. The accurate survey of private wells, and the evaluation of their influence, is far from complete, and at present only a rough approximation can be made from the imperfect figures supplied by the owners themselves in 1943. The whole problem, and its implications, will be discussed further in the succeeding part of this Report.

144. In the case of the Upper Coralline areas, however, regional data of considerable value for the purpose of estimating the relation between rainfall and percolation are available in the records, commenced by Chadwick in 1883 and continued fairly consistently until 1910 (para. 33), of the discharge from the

springs of the Rabat-Dingli Plateau (Table 3). The following gauging points were established by Chadwick;

i) near Fiddien Bridge, to measure the combined discharge from the Imtahleb (Bieb ir Rua), New Cianti (Wied il Busbies and Bonua), Old Cianti, Hofriet ir Riz and Ta Bàldu, Misrah Suffara, Tat-Tarja,and Wied L'Iemu (Ta Dekotzu) Galleries;

ii) the Ghemieri Gallery;

iii) alongside the Wignacourt Aqueduct at Ta L'Arcata, to measure the combined discharge from the Gharixiem, Busugrilla, and Ghain Kaiet Galleries;

iv) the Ghain Klieb Gallery;

v), vi) and vii) the three Buskett Galleries of Ta Sala, Ta Rapa and Ta Sienja;

viii), ix) and x) the three Fawwara Galleries of San Giorgio, Fawwara, and Annunziata.

xi) the Wied ta L'Iskof Galleries;

xii) the Ghirgenti Gallery; and

xiii) the Sakkaja Gallery.

Chadwick stated that from November 1883 readings were being taken every day during the wet season, and on alternate days during the dry weather, or, "allowing for Sundays," about twelve times per month; but the actual records preserved in the Water Department Office only comprise readings at 2 to 3 day intervals from September 1886 until July 1911. Before the latter date, however, considerable modifications in the régime of the springs had been made in consequence of the outbreak of typhoid in 1909, by the laying of cast iron pipes within the galleries to draw only from such fissures as were considered free from surface contamination, and by the discarding of the entire discharge of some galleries when rendered turbid by surface washings after heavy rain. Only the gauging from season 1885-86 to season 1908-09 can be regarded, therefore, as recording the total flow from approximately the same drainage areas, and under approximately the same conditions. Only one gallery, that of Gharixiem, is known to have been cut-out from the supplies passing the gauges during this period, and that must have occurred at an early stage in the series of observations. According to Chadwick, the Gharixiem gallery was included originally in the "Busugrilla" readings, but was diverted sometime before 1893 (Chadwick, 1894, p. 7), as it was recognised that its water was heavily contaminated by surface washings from the town of Rabat, under the middle of which it passes. The total annual discharge from the springs during the period under consideration, plus the annual production from the Via Dingli Pumping Station, when compared with the annual mean rainfall, derived from the records of the seven rainfall gauges on the Plateau, over their total catchment area, provides reliable minimum values for the ratio of percolation to precipitation, which may be used, as in Part VI of this Report, for estimating the probable yields of underground water in the other Upper Coralline areas of the Island. The Rabat-Dingli values are undoubtedly conservative because (i) there were several privately-owned galleries draining from the same area as the Government springs, and there were many private wells producing also, of whose output there is no record; and (ii) on the whole there is probably a greater area of cultivated soil cap in proportion to bare limestone "xaghara" than in most of the other Upper Coralline catchments of the Island. One factor which has been used is open to debate, and may require adjustment later, when a more detailed and accurate view of the

structure of the region is available. This is the estimate of 3.16 square miles for the total catchment area of the springs concerned, which is made up as follows:—

(i)	Ghemieri Gallery	0.098	sq. miles
(ii)	Wied il Busbies, Bonua, Bieb ir Rua, and Ic Cianti Galleries	0.585	„
(iii)	Hofriet ir Riz, Ta Baldu, Misrah Suffara, and Ta Dekotzu Galleries	0.483	„
(iv)	Ta Tarja, Ghain Klieb, Ghain Kaiet, Busugrilla, and Via Dingli Galleries	0.923	„
(v)	Ta L'Iskof Galleries	0.160	„
(vi)	Buskett Galleries	0.500	„
(vii)	Ghirgenti Gallery	0.138	„
(viii)	Fawwara Galleries	0.250	„
	Total	3.137	sq. miles

It will be seen, on comparison of the above figures with the annual discharges recorded in Table 3, that the catchment areas assigned to the various groups of springs are not in proportion to their respective annual productions, but it is believed that probable local errors of excess and deficiency will be cancelled out when dealing with the areas as a whole. When the local detailed survey of the whole plateau has been completed it will certainly be worth while to attempt to treat each gallery separately, and, with a view to providing up-to-date records of discharge for this, gauging has been resumed at as many galleries, public and private, as possible.

145. The relationship between annual precipitation and the discharge from the Upper Coralline Springs of the Rabat–Dingli Plateau during the seasons 1885-86 to 1908-09 is given in Table 5 accompanying this Report, from which it will be seen that in twenty out of the twenty-four seasons the measured discharge ranged between 20 and 30 per cent of the estimated precipitation on the catchment areas. The only season in which the ratio fell below 21 per cent was 1888-89, which was well up to the mean as far as the rainfall records were concerned, but which was marked by an abnormal fall in the volume of water gauged from the Wied il Busbies, etc., Galleries at Fiddien Box. The three seasons 1894-95, 1906-07, and 1907-08 in which the ratio exceeded 30 per cent were seasons in which the diminution of discharge lagged behind the diminution of rainfall, owing to the ground water accumulated in the formation from previous years of good rainfall. The mean value for the whole period is 26.7 per cent or approximately one-quarter of the mean annual rainfall. If this ratio be applied to the whole of the 19.69 square miles in which the base of the Upper Coralline Formation lies above sea level (para. 140) it would indicate that a mean annual production of at least 1,427 million gallons of fresh water should be available indefinitely from those areas. The maximum ever drawn by the Water Department was 330 million gallons in 1906-07. From 1910-11 to 1943-44 the mean annual total drawn by the Department from the Upper Coralline springs was only 119 million gallons, with a maximum of 240 million gallons in 1932-33.

146. In their passage from rainfall and surface run-off to underground storage Malta waters are modified considerably in composition by (i) the solution of carbonates of lime and magnesia, and other constituents in minor degree, from the limestone and marl formations over which they flow and through

which they percolate, and (ii) the solution of sulphates, chlorides, and nitrates of calcium, magnesium, and sodium, and other minor constituents, derived from the sea, first of all by way of the wind-borne spray which spreads them over the surface of the island, and, later, when the percolating waters reach a sea-level table, by direct diffusion from the body of the Mediterranean. Very few "complete" analyses of Malta rocks and waters have ever been made, so it is not possible to provide a fully detailed account of these processes, but an approximate conception of their relative extent and practical significance can be formed from the determinations of total solids, salinity, and hardness which have been carried out since 1911 by the Medical and Health Department, in the course of routine bacteriological and chemical examinations of the public supplies of the Island. Occasional determinations of lime, magnesia, iron and silica have also been recorded in the Annual Reports of the Department. Five old analyses of Wignacourt, Fawara, Armier, and roof catchment water are given in the Appendix to Sutherland's 1865 Report, which are valuable for comparison with more recent determinations of some constituents; and some useful notes on the mineralogical and chemical constitution of Malta rocks are contained in Murray's paper of 1890.

147. As might be expected in a small island composed of predominantly calcareous rock formations it is practically impossible to secure a sample of water from a natural source that is not slightly "hard" and appreciably saline. The purest and softest water obtainable is that from roof catchments, provided that the first washings of the rainy season, which contain the bulk of the precipitate of sea salts, accumulated from the summer time spray, are rejected. But even such water will be found to contain a few parts of chlorides, sulphates, and carbonates per 100,000. The amount of the soluble bicarbonates of calcium and magnesium in the waters of the Upper Coralline springs gives a "temporary hardness" (removable by boiling) varying between 6 and 12 degrees, expressed as parts of $CaCO_3$ per 100,000. The sulphates, chlorides, and nitrates of calcium and magnesium, responsible for the "permanent hardness" are generally present in approximately similar amount in these waters, though a permanent hardness of 18 degrees has been recorded. The salinity, expressed as chlorides in parts of chlorine per 100,000, varies between 7 and 14. Prior to 1935 it was only on rare occasions, except in the case of galleries such as Gharixiem and Busugrilla which were known to be subject to gross surface contamination and which were excluded on that account from the public supply, that a salinity as high as 10 parts per 100,000 was recorded from the high level springs. But during the past ten years there has been a slight though clearly defined rise in both chloride and total solid content of all these waters, together with a tendency for the permanent hardness to exceed the temporary hardness. There can be little doubt that this results from the continued extension of private shafts and headings in close proximity to the Government galleries, and to the freer access to the public supply thus provided for surface washings from intensely cultivated ground.

148. To assess the composition of the surface waters discharged along the main drainage lines of the Island in times of flood, and which probably make a major contribution to the annual replenishment of the Main Sea Level Table, daily samples of the rapidly flowing stream were taken at San Paul Tal Kleigha and at King's Corner, Salina Bay, during the long rainy spell of 21 December 1944 — 5 January 1945. The samples at the first locality gave salinities varying from 8 to 12 parts, and, at the second locality, from 10 to 14 parts per 100,000. It would seem reasonable to infer, therefore, that the bulk of the surface water which reaches the middle area of the Main Sea Level Table, through the open fissures of the Lower Globigerina and Lower Coralline Limestones, should do so without accumulatimg any higher content of salts than is indicated by these figures. In other words, it should not differ greatly in composition, except, perhaps, in respect of carbonates dissolved from the limestone, from the waters of the high level springs. Any higher proportion of saline constituents found

in samples taken from sea level tables must indicate that the composition of the water at the points from which such samples are taken is being affected either (i) by lateral or vertical diffusion from Mediterranean water, or (ii) by gross contamination of organic origin. This conclusion is supported by the results of the borehole survey of the whole area of the Main Sea Level Table, and by several other lines of evidence. The samples of water taken from the boreholes indicate that the uppermost layers of the table, where it is furthest removed from the sea and where "standing water level" is highest, do not exceed a salinity of 15 parts per 100,000 over an area of more than 22 square miles. In fact, over much of this area the salinity of the "standing" water, as it reaches the table, is no more than 9-10 parts per 100,000. A few abnormally low salinities, of only 4 to 5 parts, have also been recorded in the first samples taken from shafts and boreholes, and, strangely enough, these localities were near the seaward margin of the table, at Wied il Ghasel and at B.H. 40 (50232435). The explanation would appear to be that the points at which such samples were taken were, at the time, under the influence of "freshets" from the cleanly-washed surfaces of Lower Coralline Limestone.

149. The "temporary hardness" values for water samples from the Main Sea Level Water Table in the Lower Coralline are little higher than those for the Upper Coralline springs, on the whole, although the range is greater, from 8.5 to 23 degrees having been recorded. The mean values for Wied il Kbir (1st class water) and Tal Hlas Pumping Station since season 1911-12 are only 12.3 and 12.7 degrees respectively. The lowest "permanent hardness" noted in the Main Lower Water Table is the 6 degrees recorded initially at Tal Hlas Pumping Station. Nowadays, however, the mean annual values of permanent hardness considerably exceed those of temporary hardness at every Lower Table Station, except Ta Kali, owing to the increasing proportion of water drawn from the more saline regions of the table.

150. Water which passes slowly through the relatively impervious Globigerina Limestones is able to dissolve much larger quantities of salts accumulated in the superficial layers, and a much larger proportion of carbonates from the rock itself, than is water which passes relatively rapidly through the much more permeable Lower Coralline Formation. Large masses of both Lower and Upper Globigerina Limestone still remain in their original blue sulphidic condition, and contact with such masses will increase also the sulphate content of percolating water. The total amount of "formation water" contributed to pumped supplies by the Globigerina Limestones, however, must be extremely small in comparison with that derived from open fissures, and so far as the latter are concerned, the quantity and quality of the water they yield depends as much on their individual form and regional position as it does in the case of fissures in the Lower Coralline. Not one of the nine boreholes put down into the Main Sea Level Table within the Globigerina Formation provided any conspicuous yield of water until Lower Coralline Limestones were penetrated, and four of these remained in Globigerina Beds to more than 160 feet below sea level. Of fifty-nine boreholes which passed through Globigerina Limestones entirely above sea level, only three yielded noteworthy flows of water from these beds, and the maximum strike was estimated at only 25 gallons per hour. The salinities ranged from 50 to 60 parts per 100,000. By contrast, in the perched table in the Globigerina Limestone of the Imkabba Syncline, where the water must be held mainly in the fissures of the deeply weathered rock, salinities of only 11 to 27 parts per 100,000 were recorded in the middle of summer 1944, and these from shallow open wells into which the washings from lanes and from farmyards are conducted deliberately. The conception that supplies of water derived from the Globigerina terrain must necessarily be greatly inferior in chemical composition to those derived from the Lower Coralline, is based largely on the inferior quality of Armier and St. Anton water as compared with that procured by Chadwick from the Lower Coralline further inland and with fissure production cut down to a minimum, and on the fact that in order to maintain

a supply from Wied il Kbir equivalent in "sweetness" to high level spring supplies, Chadwick deemed it necessary to exclude from the supply the waters from that portion of the Wied il Kbir Gallery which lies within the Globigerina Formation. It should be remembered, however, that the Armier Pumping Station originally provided water but little inferior to the best of present day supplies from the Main Water Table; that the St. Anton production is drawn from a single fissure, which is now known to have ramifications extending far below the top of the water table; and that when the walled-off portion of the Wied il Kbir Gallery was opened up into the general supply, in the summer of 1944, the water which it contributed did not exceed the limits of composition permissible nowadays at Wied il Kbir.

151. In order to obtain a clearer understanding of the migrations and changes of composition of both Upper and Lower Table waters, as, for example, the seasonal reactions between private wells and Government galleries, the seasonal variations of salinity distribution, and more ample record of the effects of rate of production of individual fissures and whole gallery systems, it is essential that some more rapid and more convenient means be adopted for determination of changes in composition, to supplement the limited number of chemical analyses which the Government Laboratory can be called upon to perform, and to do away with the need to collect and to transport innumerable sample bottles. This can be achieved by the introduction of the Dionic Water Tester for the measurement of electrical conductivity. The outfit is small, portable, simple to use, and it is not essential for its operator to have more than a rudimentary knowledge of physics or chemistry to obtain reliable results. Under the relatively simple conditions which control the mineral content of Malta waters it should be possible to correlate dionic readings closely with the routine analytical checks of total solids, chlorides, and hardness, and to interpret dionic variation studies with confidence. Periodical regional surveys, such as those of the Main Lower Table private wells (Plate 3) and of the St. Paul's Valley Sea Level Table (Plate 11), or investigation of the variation in composition of individual sources within a gallery system, could be completed in a mere fraction of the time required to make an adequate number of chemical analyses for the same purposes, and the routine dionic measurements of the gauging holes, of pumping stations, and of private works, would be directly comparable.

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IV. THE DEVELOPMENT AND CONSERVATION OF THE MAIN SEA LEVEL WATER TABLE

152. The Main Sea Level or Main Lower Water Table of Malta is the extensive underground pool of potable water which occupies the pores and fissures of the Lower Coralline and the Globigerina Formations in the central and eastern parts of the Island; it is in bodily continuity with water of Mediterranean salinity marginally and at depth; and its upper surface level (1) is graded to the sea level round the coast. This body of relatively fresh water is not retained within the confines of the Island by any impermeable base, but owes its existence to the simple fact that every winter the local rainfall adds more fresh water to the underground store than can be dissipated by (i) the direct discharge of its superficial portion around the coast, in response to the head of water inland, and (ii) the deterioration of its composition beyond the limits of potability as the result of diffusion from the highly saline Mediterranean water around it and beneath it. The mean annual excess of fresh water is adequate to maintain the table at a height exceeding ten feet above sea level over many square miles in the central region of the Island, and to maintain a depth of fresh water below sea level sufficient to balance this excess against the surrounding sea water of greater specific gravity. There is no sharply defined plane of separation between the superficial fresh water and the highly saline water which surrounds it, onlya zone of mixing, which must increase considerably in thickness proceeding from the centre of the table towards the coast. The equilibrium of the table is in a constant state of flux; it is affected to varying degrees by every spell of rain which adds more fresh water to its upper surface, by every tidal or other displacement of sea level around the Island, and, nowadays, by the irregularly distributed abstraction from its upper layers of ever-increasing quantities of water for domestic and agricultural use.

153. The area occupied by that most important part of the Main Lower Water Table which occurs within the Lower Coralline Formation is defined naturally and precisely where that formation outcrops along the coast; inland within the eastern synclines of the Island, where the top of the formation descends deeply below sea level, the boundary is most conveniently defined for all practical purposes by the line at which the plane of contact between the Lower Coralline Formation and the Lower Globigerina Formation intersects sea level. As a result of the geological surveys and borings of the past three years this line can now be plotted on the map with a fair degree of precision, and as mentioned previously, it indicates that the top of the Lower Coralline Formation rises above sea level over an area of 57.5 square miles south of the Victoria Lines Fault, and over a smaller contiguous area of 4.3 square miles north of the fault. It is with the area south of the fault that the present section of this Report will be mainly concerned, for it is from that area that eighty to ninety per cent of the Island's public water supply has been drawn in recent years, and the problems of the further development and conservation of the area are of supreme importance and urgency. It does not seem very probable that the small northward extension across the Victoria Lines Fault will ever be able to make any large contribution to public supplies, although the area receives considerable direct replenishment from the rainfall through bare rocky outcrops of Lower Coralline and Lower Globigerina Limestone, and must also receive a considerable quota of the surface run-off from outside catchment areas, discharged

(1) The term "water table", strictly speaking, should refer only to the upper surface of an underground reservoir, as determined from observations of standing water level. But in Malta the term has long been used in a more extended sense to signify the whole mass of an underground body of potable water. Provided this usage is clearly appreciated no confusion need result from the continued application of the term in that sense, and the meaning of such expressions as "at the top of the water table", and "depth within the water table", will be sufficiently obvious. The use of the term "Lower Water Table" as synonymous with "Sea Level Water Table" has also been sanctioned by long usage in Malta, to express the distinction between supplies drawn from sea level sources and those drawn from the "Upper Water Tables", or "High Level Springs", in elevated tracts of the Upper Coralline and Greensand Formations. I have continued the usage, but, as separate sea level tables of importance occur also in the Upper Coralline Limestones among the northern fault strips, I have deemed it advisable to add the prefix "Main" when speaking of the most extensive sea level table of the Island.

along Wied Kanotta, Wied ta Ghain Rihana, and Wied il Ghasel. It is entered deeply by inlets of the sea, broken by numerous large faults, and the salinity results of a gallery, which was driven (mainly in Lower Globigerina Beds) at sea level for a distance of 680 yards beneath the bed of Wied il Ghasel, were the reverse of encouraging. Parts of the area are already exploited extensively by farmers' wells. However, I would not rule out altogether the claims of the area for further consideration but would postpone them until a complete survey of the private shafts of the area has been carried out, and their annual production and variations of water level have been fully assessed. (1)

154. The 37.5 square miles of the Main Sea Level Table within the Lower Coralline Limestone to the south of the Victoria Lines Fault, and more particularly the 22.8 square miles of it in which the salinity of the top water does not exceed 15 parts per 100,000 is roughly crescentic in plan view. Along the southern and western coasts the formation is open to the sea all the way from Fomm ir Rih Bay to Wied is Shakka, near Benghaisa Point, except for a distance of about two miles between Shakka (N.W. of Ghar Lapsi) and Ras il Baiada (W. of Wied is Zurriek), along which a narrow strip of Globigerina beds, Blue Clays, and Upper Coralline Limestone is preserved on the downthrown side of the Mahlak Fault, and considerably impedes the circulation of water between the Lower Coralline Formation and the sea. Although the protecting strip has been breached deeply at three places the preservation of marly beds over a great length of the fault line, from a considerable depth to above sea level, has been a most important factor in conserving the capacity and the quality of the Main Sea Level Table. B.Hs. 85 and 92, put down by No. 7 Boring Section, R.E., have demonstrated that, owing to the presence of the Mahlak Fault seal, the highest and freshest region of the water table approaches far more closely to the coast hereabouts than in any other part of the Island. Without this seal, despite its imperfections, there can be no doubt that a great part of the freshwater area of the table would not exist as we see it today. Two of the three conspicuous breaches of the fault seal, at Ghain Manoel Cove and at Halk it Tafal, where the marly stopping along the fault plane has not been eroded for more than 10-20 feet below sea level, could be repaired artificially. It should be a matter for further study and consideration, when continuous records are available from the gauging holes inland from the fault line, whether the probable gain to the water table would be worth the cost of the work which would be involved. (2)

(1) Apart from the great 61.8 square miles of the Main Sea Level Table there are only two other areas in Malta where the Lower Coralline Formation is known to rise above sea level. These, like the small northward prolongation of the Main Sea Level Table, occur within the northern fault strips of the Island. One is an area which cannot be more than a few acres in extent, on the upthrown side of the Jeneina Fault in the neighbourhood of Il Gudia, at the southern end of Jeneina Bay. The prospects of securing any considerable supplies of potable water from the formation here are negligible, as infiltration of fresh water can only occur through a few square yards of Lower Globigerina and Transition Beds exposed on the floor of Wied Halcun, and the top of the formation cannot be more than three or four feet above sea level at its highest point within the area. The second area lies beneath the southern end of the Marfa Ridge, where, at the eastern end of Redum Kammieh, the top of the Lower Coralline Formation attains a height of about 80 feet above sea level. But here again water supply prospects are negligible, for the area has little width, it is open to the sea along the greater part of its length, and replenishment by freshwater is only possible from the limited outcrop of the Lower Coralline and the Lower Globigerina Formations along the foot of the undercliff. There may be other restricted areas in which the top of the Lower Coralline Formation rises a few feet above sea level beneath the highest structural points of the Mellieha and Wardia Ridges, but this is very doubtful. In any case the Lower Coralline Limestone beneath those ridges is completely sealed by the superincumbent marly formations from any possibility of replenishment by the percolation of freshwater from rainfall.

(2) Two further points connected with the Mahlak Fault are worthy of note. First, it illustrates extremely well the extent to which artificial measures for impeding marginal diffusion and outflow from the Main Sea Level Table, such as those proposed by the Water Supply Committee of 1934-35 (para. 76), would have to be carried to produce any effects of practical value. Second, the springs of freshwater that escape across the bared portions of the fault plane at low tide are the only costal springs I have examined which might possibly be appropriated as intermittent sources of potable water. The most concentrated discharge occurs in the north-west corner of Ghain Manoel Cove. This is presumably the spring to which Rizzo referred (1932, p. 32) as "yielding about 100,000 gallons a day" and being "very brackish". Owing to recent heavy rock falls from the top of the cliff it is impossible at present to get right up to the springs as they pour across the fault plane, to sample the water as it leaves the fissures in the Lower Coralline and to check Rizzo's estimate of the rate of flow. But the discharge is sufficient to render the sea water, two or three yards out from the actual line of the fault, sufficiently fresh to be drinkable. Samples taken from that position at low tides on 5 June 1944 and 5 September 1944 had salinities of only 216 and 244 parts per 100,000. By contrast, other well-known localised marginal outflows, such as Ghain Misida and Ghain ta Sok Korsu, situated inland from the actual shore line, but unprotected from diffusion by any such seal as the Mahlak Fault, never have a salinity of less than 350 parts per 100,000, and any attempt to increase the natural rate of outflow at such places would result in a disproportionate rise of salinity. Along the Mahlak Fault low salinity water probably extends to a considerable depth, on the upthrown side of the fault, right out to the coast, and appropriation of the outflow induced by the falling tide should not lead to any increase of salinity.

155. To the north of the point where the Mahlak Fault runs out to sea N.W. of Ghar Lapsi the westernmost 17 square miles of the Main Sea Level Table receives no direct replenishment from the rainfall, owing to the impervious cap of Blue Clays and Upper and Middle Globigerina marls which extends beneath and around the Rabat-Dingli Plateau. The trend of the top - water isochlors of the sea level table have been traced beneath this region by means of B. Hs. 58, 83, 117, 64, 77, and 78, which have shown that salinification extends farthest inland from the sea in the neighbourhood of Wied tal Kleigha. To the north of this valley B.H. 86 has indicated that the isochlors trend seawards again in response to the contribution of freshwater discharged southwards across the Victoria Lines Fault from the Binjemma Upper Coralline catchment.

156. The northern horn of the crescent-shaped freshwater area of the Main Sea Level Table lies within the elevated tract of the Lower Coralline which extends beneath the Nashar Dome and out to the east coast between Madalena Tower and Sliema. At this end of the area, from Fomm ir Rih Bay to the Pembroke Coast, the Main Sea Level Table attains its maximum width. It would seem, however that local intensification of faulting and fissuring in the Lower Coralline Limestone, in the neighbourhood of Victoria Lines Fault facilitates the dissipation of freshwater to the sea, for while the isochlors swing outwards towards both coasts (in response to the southward spillover of freshwater from the Binjemma Syncline on the west, and probably in response to local high rainfall and ample bare surface outcrops of Lower Coralline and Lower Globigerina Limestones on the east) the expansion of the area of high standing water levels is by no means so pronounced; in fact the contours of the water table ultimately swing inland towards the master fault, on both sides of the Island. A few shallow wells on low ground near the coast in the neighbourhood of St. George's and St. Julian's constitute the total extent of private exploitation of this northern region of the Main Sea Level Water Table. The shafts and galleries for the Water Department's Wied il Ghasel Pumping Station were constructed between 1926 and 1938 on the low ground along the foot of the Victoria Lines Fault scarp in response to the recommendations of Robertson and Rizzo and the 1934-35 Water Supply Committee (paras. 59, 67 and 77). Three boreholes (Nos. 35, 55, and 56) have been put down by R.E. Boring Sections for the specific purpose of augmenting the domestic supply, but, while the composition of the water obtained from these holes is quite satisfactory, the volume of production has been very disappointing (Table 7).

157. The crescentic Lower Coralline uplift forms the rim to three sides of a wide synclinal area, around which the sea level contour on the top of the formation swings inland from the east coast to practically halfway across the Island. (1) In the deepest portion of this asymmetrical syncline Upper Globigerina Beds are preserved at Hamrun, and, as the combined result of dip and eastward thickening of the Globigerina Formations, the top of the Lower Coralline probably reaches a maximum depth of more than four hundred feet below sea level between Hamrun and Floriana. The Grand and Marsamuscetto Harbours and their tributary valley systems are eroded deeply in the Globigerina beds of the syncline, and the coincidence of low topography with the main centres of population has resulted in undue concentration of private and Government works for extraction from the Main Sea Level Water Table in this region. Early wells in the Marsa (para. 6.) were followed by the Armier Shafts (para. 16), and by numerous private wells in and around Curmi and the lower ends of Wied is Seuda and Wied il Kbir. Later, private shaft sinking extended northwards along the higher ground of Hamrun, Birchircara, Balsan, Lia and Attard, reaching finally to the isolated well at Villa Castelletti, near Ta Kali, the

(1) The eastern limit of this major synclinal depression is not known. The general trend of the structures exposed along the north-eastern coast section of the Island suggests that Globigerina Formation outcrops expand eastwards beneath the sea, and that the small foreshore outcrop of Lower Coralline Limestone by Fort Tigne is only the western end of a small anticlinical inlier which rises within the broad basin.

deepest shaft in the Island. (1) It was in this region, too, in the middle limb between the Hamrun Syncline and the Lower Coralline uplift, that Chadwick inaugurated, in Wied il Kbir and Wied is Seuda, the Government galleries which are still the main sources of the Island's public water supply (para. 34). At the present time there are 28,485 feet of Water Department galleries, and more than 130 private and Department of Agriculture wells, within an area of 5½ square miles. The densest concentration of wells, on the Marsa and in and around Curmi, numbers about a hundred within an area of less than one and a half square miles. The Armier Gallery of the Water Department draws from the middle of this concentration. The majority of these wells, and their connected galleries, obtain their water from fissures in the Lower and Middle Globigerina Formations. It is not surprising, therefore, to find that the hardness and salinity of the water produced from this marginal area of the Main Sea Level Table is increasing steadily. In 1865, according to the analysis made for Sutherland (para. 18), Armier water in the summertime had a salinity of only 21 parts per 100,000, and contained only 76 parts per 100,000 of total solids. By 1911-12, according to Zammit and Morris, these values had risen to 36 and 120 respectively. A partial analysis made of a sample taken on 14 September 1944 from the farthest inland shaft of the Armier Gallery at Wied il Kbir Pumping Station revealed a salinity of 100 parts and 215 parts total solids (permanent hardness 54, temporary hardness 22). The composition of the top-water of the table over the whole of this area, in terms of chloride determinations made on samples collected between 23 August and 13 September 1944, is expressed graphically on Plate 3, which should serve as a useful reference point for future surveys. Neglecting certain anomalies, such as the salinities recorded at private wells Nos. 100, 207, 50, 38 and 118, which are obviously due to local disparities in the rate of production at the time of sampling, generalised isochlors for 25 and 100 parts per 100,000 can be plotted, as on Plate 8, from which it would appear that the 25 parts isochlor has advanced half-a-mile inland in this region as a result of the increasing extraction during the past eighty years. The mean annual salinity of the water produced at the Wied il Kbir Pumping Station rose from 15.8 parts in 1911-12 to 53 parts in 1944-45; at the Tal Hlas Pumping Station from 16 parts in 1915-16 to 48 parts in 1944-45.

158. For practical water supply purposes the Imkabba Syncline may be taken as the boundary between the central and south-eastern portions of the Main Sea Level Water Table. Beyond the syncline the influence of the Mahlak Fault soon dies away; there are no major surface drainage lines with catchments comparable with those of the central and northern regions of the water table; there is a lack of Lower Coralline outcrops inland through which replenishment with freshwater could most effectively occur; and only a small fraction of the area lies more than a mile and a half away from the sea. Except in proximity to the southern coast the top of the Lower Coralline Formation rarely attains a height of 200 feet above sea level, and a south-eastern prolongation of the Hamrun Syncline expands far into the middle of the area, almost dividing it into two completely separated portions. Several important strike faults, of regional W.S.W. — E.N.E. trend, in addition to a host of smaller fractures, break up the area, and probably help considerably in the reduction of standing water levels. These latter only attain heights of as much as 10 feet above sea level in very restricted area, probably less than half a square mile in extent, between Tarshin, Zabbar, and Zeitun. One would not expect to pump any very large supplies of freshwater from such a sea level table, and the fact that this portion of the Island was less favoured than others, even in respect of relatively small domestic and irrigation supplies, was realised long ago by Ciantar (1784)

(1) This shaft commences in the Middle Globigerina Formation, at a surface height of 355 feet above sea level. It was sunk by hand, with a diameter of only 3 feet, to a depth of about 349 feet, or 4 feet below the standing water level recorded in July 1944. It has been taken over by the Water Department, and, as B.H. 69, has been deepened by cable tools to a depth of 445 feet, with a diameter of 24 inches, for the purpose of testing quantity and quality of water procurable by large diameter boring down to 100 feet below standing water level in the middle region of the water table.

when commenting on the "springs" of Wied il Ghain (Marsa Scala). Subsequent experience has fully substantiated this opinion, notwithstanding a suggestion put forward by Chadwick (1884, p. ix), at an early stage of his work in Malta, that there were good prospects of procuring additional supplies of potable water "to the south and east of the Three Cities". He had probably noted the outcrops of Lower Coralline south of Cospicua and east of Kalkara, and that the hand-dug wells around Zabbar were producing relatively fresh water from a sea level table in the "White Rock". These observations would inevitably invite comparison with the local conditions at his very promising testing operations in Wied il Kbir, but he apparently realised later that other factors in the eastern region were not so favourable, for the suggestion was never repeated in any of his subsequent reports. The Robertson-Rizzo scheme for a Government pumping station and galleries in Wied Dalam (paras. 59 and 65), only half-a-mile from the sea and aligned along one of the main strike faults of the region, was foredoomed to failure as far as the large scale extraction of potable water was concerned. The result of the boreholes which were put down further inland in 1943 and 1944 have also been very disappointing. B.Hs. 12 and 17 have certainly been useful in easing the chronic summertime shortage in the easternmost villages of the Island, but their salinities run as high as 97 and 190 parts per 100,000 respectively when they are pumped for spells of more than a few hours duration. The longer spells of summertime pumping required at the boreholes put down to supply irrigation areas (B.Hs. 30, 40, 43 and 45) has resulted in the extraction of water which constantly exceeds a mean salinity of 100 parts, and which has risen to as much as 400 parts per 100,000 in the case of B.H. 30 during the summer of 1945 (see also Table 7 and Plate 7). It is not surprising, therefore, that nothing approaching the Marsa-Curmi concentration of wells has resulted from private initiative in this area of the Main Sea Level Table. A sampling of fifteen widely scattered shafts around Zabbar was made at the end of 1944-45 rainy season (on the 18th May), when the top water of the table might have been expected to be at its lowest salinity. The analysis showed that there would be remarkably little gain in quality, as compared with borehole production, by pumping only from sea level galleries. The salinities which were recorded ranged from 43 to 136 parts per 100,000, even when the wells were being pumped at very moderate rates for only a few hours each day.

159. It will be realised from the discussion, in the preceding part of this Report (paras. 137-142), of the lithological characters of the various limestone groups, that the volumetric distribution of water within them is far from homogeneous. If it were possible to prepare sufficiently large scale plans and sections with a graduated stippling to show relative permeabilities, these would display a very complex and streaky pattern, and would be threaded by anastomosing veins of all shapes and sizes, representing water-filled fissures, sometimes fairly straight and very narrow, in the case of bedding planes, joints, and faults, but often following very winding courses of considerable height and width, where the subterranean passage of aerated waters during Pliocene and Quaternary times eroded underground channels, pot-holes, and caverns. In plan view the permeability stippling would be most dense and continuous within the Lower Coralline area, and open fissures of all descriptions would be most abundantly represented within this formation. Outside the Lower Coralline area the stippling would be much less dense in the Lower Globigerina Formation and the streakiness would be rendered even more pronounced by large blank patches representing the extensive unweathered marly parts of the formation, such as are often seen in surface cuttings and were encountered also in the Wied Kirda — Wied is Seuda Gallery and in B.Hs. 62, 84, 162, and 164. There would also be some prominent lines and networks of fissures, but it is unlikely that they would be as conspicuous on the whole as in the Lower Coralline Formation. Outside this again the Middle Globigerina areas of the eastern synclines would be practically blank, apart from occasional fissures and bands of light stippling

representing horizons of marly limestone. There would be little representation of the Upper Globigerina limestone, for that formation only descends to sea level within the confines of the island along the eastern side of the Delimara Peninsula, and in two smaller areas at the seaward ends of Ras il Fenik and Shrop il Ghain.

160. This lack of homogeneity in the limestones which contain the Main Sea Level Table is most important (i) in determining the rate at which the table receives local replenishment from the surface; (ii) in determining the rate at which the annual replenishment can be dissipated to the sea or can be deleteriously affected by diffusion from the lower more saline levels of the table; and (iii) in determining the rate and methods of extraction which must be adopted to make the best use of the table for public water supplies. The recent boring campaign has provided a general view of the geographical variations of standing water level and of composition sufficiently comprehensive to enable a decision to be made at last concerning the plan which future works for extraction must follow, but it will not be possible to arrive at reliable quantitative answers to the questions concerning rate of replenishment, of dissipation, and of permissible extraction until continuous recording of changes in standing water level and in salinity has been in progress for several years over the whole area. The available body of precise data concerning these variations is summarised and expressed graphically on Plates 6, 8, and 8A. Some allowance is required for the fact that most of the boreholes up to the present have only had their water levels determined in the few days which intervened between striking the water table and the final cleaning-out before capping, and that the seasons at which these measurements were made range from April 1943 to October 1945. Nevertheless it does not seem very probable that ultimate mean annual values will be found to depart more than two or three feet from the heights already recorded. It is possible, of course, that local heavy floods may occasion a considerable temporary departure from the mean; that remains to be seen. But, after due allowance has been made on these lines, it will be seen that there is still a conspicuous lack of uniformity in the regional variation of standing water levels in relation to distance from the sea (Plate 8A, Fig. 1). Interpretations of some of these variations have been advanced above (paras. 154-158). In other cases more local causes must be responsible for impeding or facilitating the gravitational movement of water in the pores and fissures of the limestones. For example, the most anomalous case of all, B.H.48, probably owed its high standing water level to effective sealing by clay-filled fissures of a small fault compartment, for the water in the hole was rapidly exhausted by pumping and subsequent recovery to the original standing water level took place very slowly. B.Hs. 37, 87, and 162, near the margin of the large central area of high standing water levels, suggest that there must be a region of "tight" formation in the Lower Coralline beneath the Imkabba — Luca height of land, a feature which may have had considerable influence in reducing the rate of salinification in the neighbouring Wied il Kbir Gallery. A similar local state of affairs is probably responsible for the high standing water level and low salinity of B.H. 56 alongside the Sliema Reservoir, which is only 1,900 yards from the coast. On the other hand to explain remarkably low standing water levels within the central area, as at B.Hs. 76 and 79, it is necessary to postulate local increases of fissuring or of permeability. However, while these discrepancies emphasise the fact that the conditions which govern the movement of water are far from uniform, a general agreement is apparent between high standing water levels and low salinities, and is particularly noteworthy in the distribution of the boreholes which have maintained a low salinity during prolonged periods of pumping. The areas in which the water table rises to a height of ten feet or more above sea level coincide with the areas in which the salinities of boreholes sunk to 50-60 feet below the top of the water table, and pumped at rates up to 5,000 gallons per hour, have not exceeded 25 parts per 100,000. The reasons for this coincidence must be fully appreciated in order to realise the definite limitations which are imposed on the extraction of water from the Main Sea Level Table.

161. If the standing water levels recorded in Table 6 be plotted against the distances of individual boreholes from the nearest point on the coast (Plate 8A, Fig. 1), and allowance be made for cases which are obviously influenced by special local conditions, an approximate curve can be obtained for the probable mean annual gradient of the water table in Lower Coralline rocks under the present hydrological régime. It will be the purpose of the boreholes reserved for gauging purposes (Table 8) to determine the changes in the equilibrium of this surface throughout the seasons and from year to year. It would appear from the data available that the table tends to stand at a height of 4.5 feet above sea level at 1,000 yards from the coast, 7.75 feet at 2,000 yards, 10.0 feet at 3,000 yards, 11.5 feet at 4,000 yards, 12.0 feet at 5,000 yards, and 12.5 feet at 6,000 yards. These figures enable an approximate estimate to be made of the full dimensions of the body of potable water, for if the assumptions be made (i) that a sharp boundary exists between the fresh water and the more saline water which it displaces; (ii) that the rock formations which contain the water are uniformly permeable; and (iii) that conditions are static; then the total depth of freshwater at any point within the water table will be proportionate to the height above sea level of the column of fresh water at that point and the difference between the specific gravities of freshwater and sea water, thus:—

$$\text{Total depth of freshwater} = \frac{\text{Height of water table above mean sea level}}{\text{Specific gravity of sea water} - \text{Specific gravity of fresh water}}$$

The mean specific gravity of the surface water of the Mediterranean around the shores of the Island, as determined from five samples taken in November 1943, is 1.0271 at 20°C, and the mean specific gravity of the uppermost layers of the water table, as determined from samples taken at Wied il Kbir and Tal Hlas Pumping Stations, also in November 1943, is 0.9991 at 20°C. From which an approximate mean section may be calculated and tabulated, thus:

Distance from the coast	3,000	6,000	9,000	12,000	15,000	18,000 feet
Height of W.T. above M.S.L.	4.5	7.75	10.0	11.5	12.0	12.5 „
Total depth of fresh water	161	276	357	411	429	447 „
Depth of fresh water below M.S.L.	156	268	347	400	417	434 „

A cross-section of the water table in the northern region where it attains its maximum width is plotted on Plate 8A, Figure 4, the vertical scale employed being three times the horizontal. The scale is too small to display the variations of the height of the water table above sea level, but the position of the theoretical plane separating water of specific gravity 0.9991 (salinity about 50 parts chlorine per 100,000) from water of specific gravity 1.0271 (salinity about 2,280 parts chlorine per 100,000), when considered in relation to the position of the 15 parts isochlors defined by the boreholes, and in relation to the plane of sea level, demonstrates clearly the greatly varying influence at depth of relatively small differences in standing water levels. It must be understood that the total thicknesses of the body of potable water, as given in the table above and depicted in the cross section, are somewhat more ample than the actual state of affairs, for they take no account of the zone of mixing, developed by diffusion and by oscillations in the level of the table. (1) Even in the middle region, where the table attains its maximum height above sea level, it is probable

(1) It is fortunate for Malta that the amplitude of the Mediterranean tide is so small. A maximum range of only 10.9 inches was determined from observations made at Montebello's Jetty, St. George's Bay, from April 1944 to February 1945. Within that period, from 11 December 1944 to 3 February 1945, the mean tidal range measured in the Wied is Seuda Gallery, at a distance of 2½ miles from the coast, was 3.6 inches, and during the period of observation the height of the water table varied between 7.5 and 9.0 feet in response to rainfall (Plate 6). Even this small tidal range was accompanied by measurable variations in the salinity of the standing water. Larger oscillations of sea level around the coast, produced by strong winds, and by the "tratura" in May and September, rarely continue for more than a few days at a time.

that within 250 feet below sea level the salinity exceeds the limit at present fixed for Lower Table supplies (100 parts of chlorine per 100,000). To make the best of the available evidence, however, it would seem reasonable to assume a mean depth of 320 feet of potable water over the 61.8 square miles of the table as defined in paragraph 153, and to compensate the probability that this estimate of mean depth is somewhat on the high side by assuming a mean formation porosity of 25 per cent, which is probably somewhat on the low side. Using these factors, the figure of 860,000 million gallons is obtained as the total amount of potable water held in the Main Sea Level Table under present conditions.

162. It appears strange at first sight that there should be any great difficulty in abstracting a thousand million gallons of fresh water per annum from an accumulation of the magnitude inferred in the preceding paragraph, particularly when there is reason to believe that this store also receives an annual replenishment of at least several thousand million gallons by percolation from the surface. Little consideration, however, is required to realise that only a minute fraction of the total accumulation can be removed annually without raising the salinity of the water abstracted, and of the water left behind, to a figure well beyond the limit of potability. The reduction of the height of the water table at any point or over any area, whether by pumping from a borehole or from a line of galleries, of necessity leads to an upward coning of the denser and more saline water in the formation beneath. Where wide open fissures are present as in the Malta limestones, the rise of saline water occurs not only gradually and evenly in the mass of the formation, as it would within the pore spaces of a well-sorted sand or gravel, but also, and often predominantly, in the form of narrowly localised, rapidly flowing streams. In this way a single season's "overpumping" may introduce, to a high level in the table, more saline water than can be removed by several seasons rest under natural conditions of replenishment. It is only during the rainy season, at such times as the table is being most actively replenished through the vadose zone, and provided the local rate of abstraction from the top of the table does not exceed the rate of replenishment, that it can be hoped to avoid a deleterious disturbance of the salinity equilibrium. Even then it could only be on very rare occasions and for very brief periods, if ever, that the intake from surface through a strongly fissured mass of rock, or down any particular group of wide-open channels, would balance the rate of localised upward flow and the consequent increase of salinity induced by pumping down to sea level. The need for avoiding production from major fissures and belts of heavily fissured rock, whose rise of salinity under reduction of head shows that their production is drawn vertically rather than horizontally from within the table, is obvious. To take the long view, a small yield per foot run of a sea level gallery should be regarded as a more satisfactory result than a large one. It would be possible to define theoretically, under conditions of homogeneous permeability, the amount of water which should be extracted from any given area to limit definitely the displacement of the equilibrium of the table. Under the local conditions which affect actual practice, however, the optimum quantity which should be taken from any specific work can only be determined experimentally, and, as far as the established pumping stations are concerned, there is no indication that equilibrium has been attained between the rate of pumping and the composition of the water produced. Even at Wied il Kbir Pumping Station, where the peak of annual output was attained more than thirty years ago a new equilibrium has not been reached up to the present, although the rate of deterioration in composition has not been so pronounced here in recent years as it has in the case of Armier and Tal Hlas supplies, and the continued salinification may possibly be due more to the overpumping of neighbouring shafts than to the volume of Water Department extraction from the drainage area of the galleries (Plate 2).

163. Apart from the new station at Ta Kali all the existing Government pumping stations and gallery systems are located in the marginal area of the

Main Sea Level Table (Plate 8 and paras. 156-158), in positions where the composition of the water produced is much more adversely affected by pumping down to sea level than it would be in the central area of the table, where natural standing water levels are higher. To restore the general composition of the public supply to something like the condition in the early days of relatively small annual production, and to preserve the life of the table as a source of potable water, it is essential that further works should be directed to the achievement of two main objectives: (i) the distribution of extraction as uniformly as possible over the fresh water area of the table, accompanied by the progressive reduction and ultimate elimination of production from the marginal stations; and (ii) the provision of adequate pumping equipment and reservoir capacity so that the maximum rate of extraction may be made to coincide with the periods of maximum intake of freshwater during the rains, reducing to a minimum when the rate of replenishment is at its lowest during the summertime. With regard to the first objective it must be emphasised that the time has come to relinquish the old outlook, so conspicuous in the reports of Chadwick, Robertson, and Rizzo, that water supply work in the Main Sea Level Table is something akin to a prospecting enterprise, whose success or failure is to be measured by the quality and the volume of water obtained per unit foot of gallery at any particular locality. The table is a single fluid unit, and it must be treated scientifically and technically as such if continued depreciation in the quality of the water produced is to be avoided. Its limits are now well defined and its utilisation should proceed on an overall plan, carefully coordinated by constant measurement and interpretation of the physical factors which control its ever-changing equilibrium. With regard to the second objective laid down above, it must again be emphasised that ever since 1911-12, when total production from the table amounted to 605 million gallons and the mean salinity of the water produced was only 16 parts per 100,000 the quality of the water produced has deteriorated practically continuously, despite extensions of galleries and a cycle of years of excess rainfall (Plate 1 and Table 2). The new work at Ta Kali will only provide a temporary respite if it, too, is exploited at maximum pumping rate the whole year round. Under the erroneous assumptions that the table could provide practically unlimited supplies of potable water, and that any summertime increase in salinity was removed by the subsequent winter rains, no provision has been made in the past for flexibility of pumping and the reservoir capacity which such procedure would involve. I have ventured the opinion (para. 119) that a mean annual production of about 1,000 million gallons is probably the maximum output that can be expected from the Main Sea Level Water Table if the mean salinity of the supply is not to exceed 50 parts per 100,000. It is to be hoped that rational operation of the whole table as a unit may show this opinion to have been an ultra-conservative one, but, in view of the history of production up to the present, I consider that it would be wise not to anticipate any more favourable results until much more additional precise quantitative evidence is available continuously with regard to changes of level and composition in the gauging holes, with regard to pumping rates and changes of composition in the existing galleries, and from the new galleries in progress at Ta Kali.

164. There can be no doubt that the time-honoured method of driving galleries at sea level is the most economical and satisfactory way of extracting potable water from a sea level table contained in such formations as the Lower Coralline and Globigerina Limestones of Malta. The results of borehole pumping (Table 7) have proved very disappointing. The experiment was justifiable as a wartime expedient under the conditions of 1942, 1943 and 1944, when adequate labour for shaft sinking and tunnelling was not available, and the urgency of the situation sanctioned the diversion of specially trained and fully equipped military units for the work. But, as a long term policy, borehole pumping is most unsuitable, under local conditions, for the extraction of water on a large scale for public supplies, owing to the high cost per gallon of water

raised and the local accentuation of salinity in the upper layers of the water table which each borehole must inevitably produce. Twenty six holes, ranging from 10 to 24 inches in diameter, at widely scattered localities, have been subjected to pumping tests during the past three years. On the experience obtained it can be safely affirmed that the chances of obtaining a production of as much as 5,000 gallons per hour from a small diameter hole, if taken no further than 50-60 feet into the water table, are very small indeed. The smaller productions which have been obtained have been very useful in supplementing existing supplies at certain critical points, but any attempt to exploit the table as a whole by this means would prove extremely uneconomical on account of the large number of holes which would have to be drilled, the number of small separate pumping units which would have to be maintained, and the elaborate system of tanks and pipes which would be required to centralise production. It is most unlikely that uniform extraction would be obtained, even were a close equilateral spacing to be adopted over the whole area, as an adequate yield from the small diameter of a borehole depends to such a great extent on the intersection of well-fissured rock. The required degree of seasonal flexibility of pumping certainly could not be achieved economically by the small borehole pumps which would be employed. While the first cost of driving the headings for the gallery system of extraction may be much more than that of the boreholes required to produce the same volume of water, the system possesses the following great advantages; (i) the bulk of the water produced comes from the uppermost and freshest layer of the water table, and, under equivalent formation conditions, the upward coning of saline water is less pronounced than that produced by a borehole; (ii) excessively localised and deleterious fissure production can be controlled; (iii) uniform distribution of extraction can be obtained by the proper location of pumping stations and the construction of an adequate equilateral network of drainage galleries radiating from them; (iv) every foot run of gallery excavated at sea level provides so much more storage for intake from the surface — about 200 gallons in the case of a 5 x 6½-foot gallery with a 1½ x 2-foot grip — in the most desirable region of the table; (v) pumping costs are most economical, as the plant is concentrated at a few main stations; and (vi) efficient areal control of composition and volume of production can be exercised by the insertion of sluices on major fissures and on sections of the galleries, and by continuous observation of composition and pumping level in the sump. (1)

165. A suggested grid of new pumping stations and galleries for the unit development of the central freshwater area of the Main Sea Level Table was drawn up at an early stage of the recent tunnelling and boring operations (Plate 8). The main objectives of this plan were (i) the equilateral spacing of new pumping centres at intervals of 1½ to 2 miles from one another and from the existing pumping stations and (ii) the inclusion of existing galleries in the drainage pattern. The spacing of stations adopted is the maximum advisable in view of the yields expected and the rate of pumping which would be necessary when the gallery system drained by each station was completed, during the brief periods of high flood level. The plan comprised two new stations situated centrally in the freshwater area betweem the Hamrun Syncline and the west coast, at (I) Ta Kandia, 4237 2012, and at (II) Wied il Bakkia, 4004 2208; and four new stations for the purpose of equalising extraction from the wide northern expansion of the freshwater area, spaced as equilaterally as considerations of local topography permitted, at (III) Wied Giananu, 3889 2774, (IV) Tal Merkliet, 3766 2361, (V) Il Wilgia, 3675 2619, and (VI) L'Inglin, 4216 2710. The connecting galleries required to complete this basic plan, not including radial

(1) It has been suggested that most of the advantages of gallery extraction from the top of the water table could be realised more economically and more expeditiously by drilling horizontal boreholes from the bottom of shafts sunk at sea level. This, however, is most improbable. Directional control of horizontal boreholes would not be a simple matter under local formation conditions, and the proper control of production from major fissures and from belts of strongly fissured rock would be a lengthy and expensive process, unless every boring were stopped at the first fissure which it encountered.

galleries from each station, and omitting possible connections with the existing Wied il Kbir, Wied is Seuda, and Wied il Ghasel Galleries, would be approximately:

Wied Giananu	— L'Inglin	9,900 feet
Wied Giananu	— Ta Kali	7,800 ,,
Wied Giananu	— Il Wilgia	8,100 ,,
Il Wilgia	— Ta Kali	9,450 ,,
Il Wilgia	— Tal Merkliet	8,100 ,,
Ta Kali	— Tal Merkliet	8,550 ,,
Ta Kali	— Wied il Bakkia	9,750 ,,
Wied il Bakkia	— Ta Kandia	9,300 ,,
	Total	70,950 ,,

The approximate depths to sea level of the new shafts would be :

Wied Giananu	... ...	210 feet
Il Wilgia	... ...	300 ,,
L'Inglin	... ...	200 ,,
Tal Merkliet	... ...	450 ,,
Wied il Bakkia	... ...	310 ,,
Ta Kandia	... ...	300 ,,
	Total	1,770 ,,

Reconsideration of this plan since the completion of the borehole survey has confirmed the suitability of the Ta Kandia and Wied il Bakkia locations, but has suggested that the drainage pattern devised for the northern region would prove too widespread for the quantity of freshwater which would be available, and for the low standing water levels which appear to extend for a considerable distance to the south of the Victoria Lines Fault, particularly towards the western and eastern flanks of the region. At present I am inclined to think that gauging hole records will show that the Tal Merkliet, Il Wilgia, and L'Inglin locations are situated too near the margins of the freshwater area, and that the northward continuation of a central line of galleries from Ta Kandia and Wied il Bakkia to Tal Mahznier (3882 2440) and the Tal Hanzira (3819 2716), together with tributary radial galleries from each station and branch galleries from the main inter-station galleries, would be found capable of extracting all that the area could supply, and would be more suitable for avoiding marginal salinification. Records from the gauging holes would show later whether extensions were desirable along the northern horn of the freshwater area, beneath the Nashar Crest. The only change in the plan so far as the proposed Wied il il Bakkia and Ta Kandia Pumping Stations are concerned is that it would probably be more advantageous for uniform drainage of the freshwater area if the location for the latter station were moved a few hundred yards to the south, to 4225 1970 instead of 4237 2012. The basic plan of the revised scheme would involve the construction of the following lengths of galleries:

Ta Kandia — Wied il Bakkia	9,900 feet
Wied il Bakkia — Tal Mahznier	7,950 ,,
Tal Mahznier — Tal Hanzira	8,400 ,,
Radial galleries from Ta Kandia, say	15,000 ,,
Radial galleries from Wied il Bakkia, say	12,000 ,,
Radial galleries from Tal Mahznier, say	12,000 ,,
Radial galleries from Tal Hanzira, say	6,000 ,,
Total	71,250 ,,

The approximate amount of shaft sinking to sea level would be:

Ta Kandia	300 feet
Wied il Bakkia	310 ,,
Tal Mahznier	360 ,,
Tal Hanzira	225 ,,
	1,195 ,,

It will be realised that the total lengths of galleries detailed above would extract, if pumped at an average rate of 100 gallons per foot per day, considerably more water than the present mean daily and annual draught on the tables, and more than the optimum yield it is thought that the whole table can supply without progressive deterioration in composition. This does not mean to say that the proposed lengths are excessive, but that a mean rate of production of as much as 100 gallons per foot per day at sea level throughout the year is far too heavy a rate for the maintenance of low salinity. It is not improbable that it would be found advisable ultimately to exceed considerably the total lengths of 70,000—80,000 feet proposed above. (1)

166. It may perhaps be emphasised that no permanent increase in the total annual production from the Main Sea Level Table is promised as a result of these proposed extensive new works. Their object is (i) to replace the present unduly saline supplies by water no more saline than the state in which it reaches the table, and (ii) to provide the means whereby increased annual production may be taken should subsequent experience indicate that this can be done without causing progressive deterioration in composition. For some years to come any addition to the volume of public supplies in Malta must be sought in the elimination of waste and in the development of Upper Coralline sources. So far as the Main Sea Level Table is concerned new production of low salinity water should be accompanied by an equivalent reduction in the volume of production from the older pumping stations. Except in the case of unavoidable pumping to waste, which may arise from time to time during the construction of galleries, no water should be allowed to be diverted to any use other than the public piped supply, otherwise the impression will be created that "new" and previously unexpected resources of water are being opened up, and further calls for irrigation supplies will follow.

167. It is desirable also that a firm policy should be laid down with regard to the salinity of the water which may be extracted by the Water Department from new developments within the central region of the table. It should be the responsibility of the engineer in charge of the tunnelling to ensure that no fissure and no belt of fissured rock is left in a condition to discharge into a gallery water of a salinity higher than that which percolates from neighbouring unfissured formation. Adherence to this regulation will inevitably lead to much work additional to the straightforward tunnelling, in cementing-off fissures and belts of strongly fissured rock. But to scamp the methodical application of such control on the composition of the water to be drawn from the galleries would defeat

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(1) For purposes of comparison, in conjunction with the production and salinity data of Table 2, it may be noted that the total length of Government galleries constructed up to the end of 1945 for extraction from the Main Sea Level Water Table is:

Armier — Wied il Kbir — Wied is Seuda	28,785 feet
St. Anton	300 ,,
Wied Dalam...	5,600 ,,
Wied il Ghasel	9,194 ,,
Ta Kali	1,724 ,,
Total	45,603

The average width of these galleries, with the exception of those in progress at Ta Kali, the recent extensions in Wied is Seuda, and the length of 1,266 feet in Wied is Seuda which was widened in 1935-39, is only 2 feet. They are mostly sunk to sea level, except the St. Anton and Armier Galleries, whose floors lie at 2 feet and 9 feet below mean sea level respectively.

the primary object of conservation of the table. To state a precise figure, I recommend that no gallery should be left in a condition to yield water at any point exceeding a salinity of 20 parts per 100,000, at any time of the year, when pumping down to sea level. This figure allows ample margin for the summertime rise of isochlors within the table, and, in actual practice, the mean annual composition of the water produced from any gallery should be much closer to the mean value of 13.5 parts per 100,000 given by borehole sampling of formation waters within the area enclosed by the 15 parts per 100,000 isochlor of Plate 8. Results at Ta Kali during the past twelve months have shown that, if pumping rates and fissure production are controlled, this low salinity can be achieved.

168. If water supply works are accorded their due priority in the allocation of funds there is no reason why the greater part of the work required for the systematic utilisation of the Main Sea Level Table as a whole should not be completed in about ten years. It would be inadvisable to attempt to complete the whole programme within a shorter period, for, as noted above, much additional information is required before a final decision can be reached as to the most suitable lay-out of galleries for controlling extraction from the northern part of the area. On the other hand it is equally desirable that the construction of the works required for unit control should proceed energetically, in order that the change-over from marginal to central extraction may commence and be completed as soon as possible. I recommend, therefore, that the work be divided into two stages, and that the first stage be the construction of the proposed new pumping stations and gallery systems at Ta Kandia and Wied il Bakkia, with a view to their completion, to the extent given in para. 165 above, within five years. Pending the construction of a ring main and high level storage reservoirs (see Part VII of this Report) they would discharge into the Luca and Ta Kali Reservoirs respectively, and the delivery of more saline water from Wied il Kbir and Tal Hlas to those reservoirs would be reduced accordingly. The westward drives from the Ta Kali Shaft should be continued to at least the Tal Mahznier — Tal Hanzira Line, since they will fit into whatever gallery plan may be adopted ultimately for the whole of the northern area. At the end of five years the accumulated data from the gauging holes, and from the further works and surveys accomplished, would enable a final plan to be made for completion of a centralised drainage pattern for the northern region within a second period of five years.

169. Full particulars of the depths, diameters, and other features of the twenty-eight boreholes which have been reserved for gauging purposes, and to which reference has frequently been made in preceding paragraphs, are given in Table 8. These holes, in conjunction with the holes which have been put down to the Main Sea Level Water Table for other purposes, have provided the data for the first overall appreciation of the dimensions of the table. Their further function is to provide a continuous detailed record of changes in level and composition over the whole area of the table, so that the interaction of replenishment by percolation from the surface and extraction by pumping may be elucidated, and so that future developments and manipulation of production may rest on a secure observational basis. Integration of the variations recorded from these widely distributed points, when correlated with similar continuous records from the pumping stations, and with the rainfall, should enable a reliable approximation to be made in due course of the amount and periodicity of replenishment, and of the times and rates at which extraction can proceed most efficiently. Casing has been cemented in the top of every hole to prevent any direct influx of surface water, and in some cases considerable lengths of casing have been used to hold back cavings from the Blue Clay and Globigerina Formations and to ensure that no direct infiltration of more saline waters is possible from the thin limestone members of the latter formation. Small concrete houses to contain the recording apparatus have already been erected over every hole. The most suitable system for measuring changes of level will be the continuous air flow type of gauge, as the small diameter of the holes

in proportion to their depth would render float gauges extremely unreliable, and the periodic removal of diaphragm boxes would be extremely inconvenient. To simplify subsequent reading of the charts it is important that the bottom of the bulb be set accurately, once and for all, at mean sea level in every hole, a procedure which will involve meticulous measurements when inserting the apparatus, in addition to the check traverses of first class spirit levelling mentioned in the footnote to Table 8. To protect and support the bulb and capillary tubing it will be advisable to run them inside a special string of 3-inch I.D. pipe inserted to about 10 feet below sea level. As most of the gauging hole sites are remote from the electric mains the necessary supply of compressed air will have to be supplied from a tank, which will require pumping-up at intervals of a few days, according to the size of tank installed and the depth of water being registered. It is recommended that variations in composition be measured by a Dionic meter installed permanently at every hole, and that in this case the absence of a mains supply of electricity be met by the use of batteries, as clock-controlled readings at intervals of 6 hours will be adequate. The electrode tube should be set approximately at sea level, but meticulous accuracy in positioning is not so essential as in the case of the depth-recording apparatus. A heavily armoured cable should provide sufficient support, even in the deepest hole, without an additional string of pipe. The recording of both sets of data should be made on a single 12-inch diameter chart, driven by a 7-day clock. With this size of chart and sea level zero all anticipated changes of level would be recorded with a probable error of less than one inch.

170. It has been suggested, in paragraphs 130 and 131 above, that a large part of the replenishment of the Main Sea Level Table takes place through the small inliers of Lower Coralline Limestone which outcrop in the central region of the Island. I have little doubt that the gauging hole records will confirm this supposition. It follows, therefore, that every effort should be made to conserve these outcrops, and all the channels which drain into them, in as clean and effective a condition as possible. Their importance in the Island's water supply regime is completely out of proportion to the relatively small superficial area which they occupy. It should be arranged that any planned redistribution of the congested village populations of the interior shall take place in directions away from these inliers, for the valleys which cross them are already too well favoured as receptacles for all types of household refuse and filth. All underground water supplies in Malta travel but little way from the surface before they reach the works designed for their appropriation, and it is foolish to add gratuitously to the Medical and Health Department's work of maintaining the bacteriological purity of the supply.

V. THE DEVELOPMENT AND CONSERVATION OF THE UPPER CORALLINE AREAS

171. The history of the early development of public supplies from the high level springs of the Rabat-Dingli Plateau, the efforts of Micallef and Dingli to persuade the Government of their day to embark on an adequate programme of reservoir construction to equalise supplies from the springs, and the comparative neglect of the area subsequent to Chadwick's demonstration that the Main Sea Level Table could apparently provide a perennial supply of first class water, sufficient for the public requirements of his time, have been outlined in an earlier part of this Report. Now that the limits of the Main Sea Level Table's resources are becoming only too evident, and it is obvious that it too will have to be treated with due regard to seasonal and annual fluctuations of replenishment, it is imperative that the long-neglected Upper Coralline areas shall receive adequate consideration. Some of their advantages and disadvantages have already received comment. Although their total area is not much more than a third of that of the Main Sea Level Table in the Lower Coralline, amounting to only 22.6 as compared with 61.8 square miles, yet they occupy almost a quarter of the total surface area of the Island. In a very real topographical and geological sense they are the natural "upland catchments" of the Island, most remote from the main urban concentration, and preserving to a greater degree than any other parts of the Island their original bare rocky character. They should have been recognised as such and duly conserved long ago. As pointed out in paragraph 140, more than 19.7 square miles of the Upper Coralline outcrops are completely free from the difficulties of salinity control which are an inevitable accompaniment of extraction from any part of a sea level table. The main impediments to their proper utilisation for public supplies have been a disinclination to modify old-fashioned and ill-informed legal conceptions of the sub-surface rights of private landowners, and, of course, the considerable expense of providing adequate storage reservoirs for the equalisation of their very variable seasonal and annual yields. But it will be realised, from what has been said in the preceding part of this Report, that, so far as the long term provision of large public supplies is concerned, they are no different from the Main Sea Level Water Table, and the problem of providing vastly increased storage capacity for supplies from both sources must be faced.

172. The Upper Coralline areas, with their impermeable base of Blue Clays, are as important for attaining at least a partial solution of the storage problem as they are for the purpose of providing new supplies. The Blue Clay inlier of Wied L'Iemu in the Rabat-Dingli Plateau is the only place in the Island which offers for the construction of large surface reservoirs the combined advantages of (i) conditions favourable to the extensive employment of modern mechanical excavators and the prospect of a relatively small cost per million gallons; (ii) an altitude sufficient to provide gravity distribution to all the towns and villages of the Island, except Mellieha, Nashar, Gargur, Rabat, Dingli, Nigret, and Bubakra; and (iii) a high degree of immunity from the danger of breaching as the result of earthquake shock or aerial attack. In the northern fault strips of the Island there are certain natural basins of Upper Coralline Limestone whose present storage capacity could be increased considerably by the construction of underground dams, probably for an even smaller expenditure per million gallons than in the case of any surface work. These underground works would entail little in the way of permanent surface appropriations beyond the normal requirements of pumping stations and pipe lines, and their contents would be practically invulnerable to aerial bombardment. (1)

(1) They would, however, be subject to gradual loss of capacity in course of time, owing to the silting-up of the pores and fissures of the limestone formation, unless adequate arrangements were made for the prior sedimentation or filtration of the storm waters piped into them; whereas such sediment could be removed periodically without difficulty from surface reservoirs.

173. It is unlikely, however, that a completely satisfactory solution of the problem will ever be possible, owing to the small size of the Island, the increase in the demand per head which will probably be made by its large and rapidly increasing population, and the great variation in the total amount of potable water available annually. At present it is not possible to estimate the amount of storage which will be required to achieve a maximum annual output of low salinity water from the Main Sea Level Table. The estimation of the storage capacity required by the Upper Coralline catchments is a more simple matter. As Chadwick pointed out long ago (1884, p. 47, and 1886, pp. 2 and 3) the storage required to equalise monthly supplies, from only a small portion of the total Upper Coralline area, is very considerable. And, when the question of equalisation through long cycles of wet and dry years arises, a brief consideration of the data which have accumulated since his day shows that any approach to equalisation is hardly a matter of practical politics. The quantity of water received by the Water Department from the High Level Springs during the fifty-six years 1889-90 to 1944-45 varied between a maximum of 330.5 million gallons in 1906-07 and a minimum of 55.5 million gallons in 1914-15 (Table 3); the mean annual supply being 158.1 million gallons. To have equalised the supply at the latter figure would have required the accumulation of 1,336 million gallons between 1889-90 and 1911-12, and at the end of 1944-45 there would have been no reserve for future eventualities. The volume of storage required will increase pro rata with increase in the total area exploited, and, above all, there is the fact that knowledge on which to base reliable quantitative forecasts of rainfall cycles is lacking.

174. Complete theoretical equalisation being ruled out as impracticable the question which remains to be decided is the reservoir capacity required to provide, on the basis of anticipated minimum annual production from Lower and Upper Tables combined, and the need to collect and to store most of this during two or three winter months, a reasonable daily supply to a population which may number half-a-million by the end of the century. The minimum annual production received by the Water Department from the "High Level Springs" was 55.5 million gallons in 1914-15. This certainly was not the total discharge which could have been appropriated from the three square miles drainage area of the Rabat-Dingli galleries (para. 144) in that year, had arrangements been made for sedimentation and chlorination of "second class" water; and it takes no account of the amount of private extraction from that area. Acceptance of it, however, as the probable minimum production available from 3 square miles of Upper Coralline catchment at the climax of a dry cycle, makes some allowance for the probable occurrence of periods of even poorer rainfall than those of the three years 1912 to 1915, such as 1467 to 1470, "when no rain fell", 1864-67, and 1895-98. If the area of Upper Coralline exploited for public supplies be raised to 15 square miles, then the expectation of a minimum annual production of at least 275 million gallons from the "High Level Springs" would appear to be justified, and consideration of the relation of the rainfall to actual measured discharges during the years when the latter were being fully recorded (Tables 3 and 5 and para. 145) suggests that probably two or three times this ratio should be obtained under efficient measures for conservation and collection, as witness the minimum production of 120 million gallons in 1897-98, at the climax of an even more pronounced succession of years of deficient rainfall than those which preceded the 55.5 million gallons of 1914-15. The data from the Lower Table (Plate 1 and Table 2) suggest that even in a season of minimum replenishment some 500 million gallons at least should be available from this source without a noteworthy increase in salinity. It would seem safe to conclude, from the existing data, that even at the end of three successive years of deficient rainfall the Upper and Lower Tables combined would be capable of yielding at least 1,000 million gallons of low salinity water. Storage of this order is required, therefore, for the larger portion of such an annual supply, which would be piped to reserve during the winter rainstorms, and to hold any excess accumulated during preceding seasons of more bountiful precipitation.

An annual supply of 1,000 million gallons is equivalent to approximately 5½ gallons per day per head of a population of half-a-million, and a useful additional quantity per head per day should also be available from efficiently maintained roof catchments (para. 135). In years of good rainfall there need be no doubt about the capacity of the Upper and Lower Tables, if managed efficiently, to replenish 1,000 million gallons storage, as well as to maintain an adequate daily supply throughout the year. It is recommended, therefore, that 1,000 million gallons reservoir capacity be adopted as a minimum objective, to be attained within the next five to ten years. Without such storage it will not be possible to work either the Main Sea Level Table or the Upper Coralline catchments to their best advantage.

175. Apart from a few restricted areas (para. 172) whose lower parts lie deeper than the natural spillover level to the sea, the masses of Upper Coralline Limestones in themselves provide relatively poor facilities for lengthy storage of the rainfall which finds its way into them. They are seamed through and through by wide open fissures and caverns developed by the passage of copious underground streams when Malta formed part of a much more extensive and more elevated land area during Pliocene and Quaternary times, and the thickness of limestone which has survived denudation is less than a hundred feet over much of the area. The thinly-bedded alternations of limestone and marl which are characteristic of a variable thickness of the lower part of the formation and the fine-grained basal Greensand, when present, are probably the most effective portions of the formation from the storage point of view. But the main impediment to rapid dispersal of the water taken into the formation during the rains is the clayey matrix of the talus slopes and landslips which have accumulated around the borders of the outcrops. The spring-developed breaches in this seal, whose locations are determined by various accidents of structure and by the intersection of the limestone boundary by ancient underground drainage channels, are very numerous. It is not surprising, therefore, that the rate of discharge of water from the marginal springs, both natural and artificial, follows very closely the incidence of the local rainfall upon the surface of the limestone areas. Reference to Tables 3 and 5, and to Plate 10, will demonstrate how little the rainfall of the season, ample or deficient, influences the production figures of the following season. A large proportion of each year's total discharge is freely-flowing water which has been gathered directly from the surface by open fissures and has never entered the actual pores of the limestone formation. The proportion of the mean annual discharge represented by formation water, which maintains a steady flow, after each rainstorm spate has died away, and through the summer months, is probably well below half the total amount. A comparison of the daily discharges recorded for certain of the Rabat-Dingli galleries during the years 1893-94 and 1897-98 is very enlightening on this point (Tables 3 and 9). In 1893-94 which was a year of heavy rainfall, the total productions recorded for individual galleries and groups of galleries were from 1.4 to 4.9 times, and the gross total 2.2 times, as great as the figures for 1897-98. In the latter year only the Fiddien, Busugrilla, and Ta Sienja gaugings showed any rise in response to the light rainfall: the daily productions of the remainder of the springs declined gradually in the course of the year from the daily maxima to the daily minima recorded in Table 9.

176. The various springs differ considerably in their degree of response to the rainfall, according to the surface character and extent of the areas they drain, and to the depth below surface, the length, and the gradient of the galleries which tap the springs. Annual and monthly figures convey only an inadequate picture of this sensitivity in the case of the galleries with the larger and shallower drainage areas. When daily figures are plotted the variations in response to local rainstorms are often remarkable, and it is not unusual, during an average rainfall season, for the rate of discharge to rise or fall by several hundred per cent within twenty-four hours. This sensitivity introduces a considerable probable error in estimates of the total discharges of the most

copious and most sensitive galleries, and it is possible that maximum flood rates of flow have never been properly gauged. Never more than single daily readings of the weirs have been recorded from Chadwick's time onwards. It is important that these gaugings should be carried out more thoroughly, both for the existing galleries and for any new ones from the very commencement of operations. Properly designed gauging boxes with accurately cut weirs, large enough to pass the largest storm discharges, should be constructed, and continuous float recorders should be installed, so that more accurate measurements of the total production and of storm discharges may be made from continuous charts, instead of being based, as they have been up to the present, on single daily readings. An increase in the number of rainfall gauges is also very desirable. The seven gauges installed by Chadwick probably provide for the Rabat-Dingli area as ample and reliable a statement as it is practicable to obtain; but another twenty would be required to obtain a similarly reliable record of the distribution of precipitation over the varied topography of the Upper Coralline catchments in the northern fault strips. At present there are only two school gauges in this part of the Island, at Mellieha and St. Paul's Bay. The technical value of the data thus secured would soon repay the cost of the apparatus involved, and will be essential for the efficient development and manipulation of production from the Upper Coralline Springs.

177. Any scheme for the complete development of the Upper Coralline areas will of necessity be far from simple, by reason of their diversified outlines, altitudes, and geological structures (Plate 9). The first requirement before satisfactory plans can be drawn up for achieving maximum efficiency of drainage with a minimum length of gallery driving is the accurate determination of the contours on the top of the Blue Clay Formation throughout the various areas. Chadwick, Robertson, and Bailey have all in turn commented on the need for this, and made suggestions how it should be accomplished (Paras. 32, 60, and 94). The following remarks are based upon the experience gained during the recent investigation of two catchment areas, Binjemma and Miziep, which promise to be of immediate value for the augmentation of the existing Upper Coralline supplies. Detailed geological mapping is a first essential, and thorough work on the 1: 2500 scale maps is necessary as a basis for subsequent boring and tunnelling work. Work on the 6-inch scale is inadequate for practical requirements. Geological mapping alone cannot be relied upon to delineate the contours with the degree of accuracy required for tunnelling work, however, owing to (1) rapid intraformational variations in thickness discounting the evidence of low surface dips; (ii) the obscuration of dips over considerable areas by surface tufa and other superficial deposits; and (iii) the difficulty of obtaining precise locations on the top of the Blue Clays around the margins of the areas, owing to the heavy cloak of talus and landslips. Surface mapping, however, does ensure that no underground depressions and water sheds will be overlooked, and, once their approximate positions and form are thus revealed, their contours may then be determined to any desired degree of accuracy by means of a minimum number of boreholes. Evidence from existing shafts should be treated with caution. The assumption that their bottom depth gives the position of the top of the Blue Clays leads to considerable errors. Many shafts obtain sufficient water for their owners' purpose without sinking to the base of the Upper Coralline Limestone; others are carried many feet into the Blue Clays to provide a deep sump for dry weather pumping. In some cases blue clay on a spoil heap without any Greensand, has been found to come from clay beds intercalated among the limestones; on the other hand, the Greensand is not always present between the basal yellow marly beds of the Upper Coralline and the top of the Blue Clays. The line and neighbourhood of any proposed gallery should be well checked by boreholes, to make sure that it follows truly along the axis of a presumed depression, or at a proper gradient if laid out along the strike of a monoclinal area, before sanction is given for its construction. In many areas of low dip it will be advisable to make enough boreholes to provide reliable contours at vertical intervals of 5 feet at the most, sometimes less, particularly

in the neighbourhood of fault lines, for the latter in many places may be more important than the dip in controlling the disposition of the local drainage. The types of portable boring machine which were used by 7 Boring Section in the exploration of the Binjemma and Miziep areas are too large and too expensive in operation for most of the further boring that is required in the Upper Coralline areas. Two or more light slip-winch outfits, with 4½ inch and 3 inch tools, should be obtained to deal steadily and effectively with the programme of work envisaged, as few of the holes will be as much as 200 feet in depth, and all the information required can be obtained satisfactorily from a 3-inch diameter hole. Such outfits can be transported and set up easily in almost any situation likely to be required, and only two men would be required to run each outfit.

178. All the tracts of Upper Coralline rocks which are sufficiently extensive to be of any practical interest from the point of view of water supply are situated in the northern and western parts of the Island, within an area whose maximum length between Marfa Point and Jebel Ciantar is only a little more than ten miles, and whose maximum width, from Wig il Kamla to Jebel Ghauzara is little more than four miles. They are divided by major strike faults into six main structural units, which, from north to south, may be defined thus:

	Area of U. C. L. (Square miles)
Marfa Peninsula, north of the Ghar Bakrat Fault	2.16
Mellieha Bay, between the Ghar Bakrat and Ras il Griebej Faults	1.20
Mellieha and Baida Ridges, between the Ras il Griebej and Dahliet il Fekruna Faults...	4.00
St. Paul's Valley, between the Dahliet il Fekruna and Il Balluta Faults	1.05
Wardia Ridge-Binjemma Area, between the Balluta and Victoria Lines Faults	5.35
Rabat-Dingli Plateau	8.75
Total	22.51

It is estimated that beneath about 3.17 square miles of the total surface area occupied by Upper Coralline outcrops the base of the formation descends below sea level, as follows:

	Area in square miles.
Marfa Peninsula Sea Level Tables	0.78
Mellieha Bay Sea Level Table...	1.04
Miziep Syncline	0.30
Wied tal Mistra and Il Mijnuna Sea Level Tables...	0.07
St. Paul's Valley Sea Level Table	0.93
Binjemma and Ghain Kattus Synclines	0.05
Total	3.17

In the 0.35 square miles of the Binjemma, Ghain Kattus, and Miziep Synclines structural conditions are such that influx of saline water from the sea would be unlikely to occur to any noteworthy extent even if the water level in these synclines was pumped down to sea level continuously. In the other areas where the base of the Upper Coralline Formation lies below sea level, amounting to 2.82 square miles, extraction of potable water is subject to limitations similar to those which affect extraction from the Main Sea Level Table in the Lower Coralline; most notably in the case of the Marfa and Mellieha Sea Level Tables,

but to less degree in the case of the Wied tal Mistra and St. Paul's Valley Sea Level Tables, where access of saline water, as against replenishment by fresh water from upland catchments, is more restricted. In the 19.69 square miles of Upper Coralline terrain, where the base of the formation stands above sea level, extraction of fresh water is possible perpetually, and, on the mean annual ratio of rainfall to percolation derived from the records of the Rabat-Dingli area, should provide a mean annual yield of some 1,427 million gallons (paras. 140 and 145), provided that extraction from the whole area be engineered at least as efficiently as in the case of the old Government galleries of the Rabat-Dingli area. Locally, as, for example, in certain parts of the Rabat-Dingli area, in the Ta Zerp basin of the Wardia Ridge-Binjemma area, and generally from the marginal springs of the more elevated tracts, a considerable proportion of the theoretical potential supply is already being appropriated by both Government and private works. Estimates of the amount of this present extraction have been made already for the Wardia Ridge-Binjemma area, St. Paul's Valley, the Miziep Syncline, and Wied tal Mistra, but, at the present rate of survey progress, it will be several years before estimates will be completed for all the Upper Coralline areas. The volume of present extraction is relatively small, however, compared with the potential yield, in certain areas, such as the Marfa Ridge, Mellieha Ridge, Miziep Syncline, and Binjemma area, and over considerable tracts of the Rabat-Dingli Plateau. It should also be noted that some parts of the Upper Coralline areas receive water by percolation from surface run-off from neighbouring clay slopes, additional to the supplies they receive by underground flow from neighbouring Upper Coralline catchments and from the rainfall upon their own surface. Thorough extraction from what may be termed the upland catchment areas will inevitably react unfavourably on the quality of the water at present being drawn from the sea level tables, though the extent to which this balance could be swayed in actual practice is problematical.

179. The Rabat-Dingli Plateau is the most extensive and the most elevated of the Upper Coralline areas. The total surface area of connected limestone outcrops amounts to about 5,600 acres or 8.75 square miles, and within it, so far as is known, the base of the Upper Coralline nowhere descends lower than 300 feet above sea level. Over most of the area it stands much higher, attaining maximum elevations of nearly 700 feet above sea level in the neighbourhood of Maddalena Chapel and on Jebel Ciantar. While the term "plateau" expresses admirably the appearance of the skyline which the area presents when seen at a distance from the lower parts of the Island, closer inspection reveals that, both topographically and geologically, the form of the area is far from being that of a simple plateau. Its surface is strongly corrugated and there can be no doubt that its geological contours will show a similar complexity when they are fully worked out. At the northern end of the area two broad anticlinal crest maxima can be distinguished about Fort Binjemma and Id-Dueira, which, with the intervening broad syncline of Xaghra ta Binjemma and Xaghra tal Kallelia pitch southwards from the Victoria Lines Fault. To the west of the Fort Binjemma — Tax-Xini crest a broad northward-pitching syncline through the Bahria region carries Upper Coralline outcrops as low as 325 feet above sea level in the neighbourhood of Fomm ir Rih, followed by a renewed rise towards the coast in the narrow strip of outcrops along the western side of Wied il Marja. Further south, in the middle of the plateau, the Blue Clay inlier of Wied Ghemieri and Wied L'Iemu has been opened up by erosion along a continuation of the Fort Binjemma — Tax-Xini uplift, bordered by a synclinal basin on the west, around Wied il Busbies and Hofriet ir Riz, en échelon with that of Bahria. The syncline of Xaghra ta Binjemma and Xaghra tal Kallelia becomes more sharply defined as it pitches southwards by Tas Salib and Ta Coronia, where the Upper Coralline Limestones preserved in it form a conspicuous rock bar, which up to the present, has hindered the headward erosion of the Kleigha Valley into the Wied L'Iemu inlier. There is a rapid reversal of pitch where the synclinal axis crosses the valley, and, on the southern side of the cross-fault which passes by Ghain Kaiet Pumping Station, the

synclinal line is taken up further to the east and trends S.S.E. through the valley of Ghar Barca towards the eastern edge of the plateau at the head of Wied ta L'Iskof. The limestone ridges along the eastern side of Wied L'Iemu, from Ghain Klieb to Santa Katarina, lie in the steeper western limb of this broad syncline; the Imtarfa, Rabat, and Tal Virtu spurs lie in the more gently inclined eastern limb. Southward from the head of Wied L'Iemu the main structural feature of the plateau is a broad deep syncline around the head of Wied is Shagri, en echelon with the Wied L'Iemu and Ghar Barca folds, into which the limestones dip continuously from the north, west, and south, but whose eastern limb has been removed almost completely by erosion. The N.N.W.-S.S.E. fold pattern is cut by at least ten cross-faults of major importance, which trend approximately S.W.-N.E., and which, like the fold axes themselves, have probably been determined by torsional stress between the Victoria Lines and Mahlak Faults. The throw of these faults varies considerably, both in direction and in amount, and, as noted above (para. 177), their effect on local structure and on underground drainage will require careful and thorough investigation in connection with the alignment of any water supply galleries which may be driven across them or in their vicinity.

180. The convenient altitude of the plateau was responsible for the early utilisation of its springs to supply water to the harbour towns by way of the Wignacourt and Fawara Aqueducts, and this convenience for the provision of gravity supplies is still the most attractive feature of the area as compared with the Upper Coralline of the northern fault strips of the Island, from which pumping will be necessary. The driving of galleries to increase the supplies from natural springs to the aqueducts, and to the pipe lines which later replaced the open channels, has never been carried out on other than purely arbitrary lines. If the original natural spring opened on a steep slope a gallery was driven straight into the hillside until sufficient fissures had been opened up to provide an adequate yield. Later, as in the case of Micallef's 1864-66 extensions around Wied L'Iemu for the Wignacourt supply, Chadwick's 1885 Via Dingli galleries for the Rabat supply, and Rizzo's 1931-35 gallery beneath Dahar It-tuil to augment the Buskett Gardens supply, the galleries were aligned along public roads to avoid the trouble and expense of obtaining access to privately owned lands for sinking the numerous shafts which were considered necessary for ventilation and winding purposes. All the galleries constructed in the area up to the present have been of the small 5 x 2½ feet cross section. Detailed records concerning their gradients and the formations and fissures encountered in them have not been preserved; the plans available show only the lines of the galleries in relation to surface topography, the position of the shafts, and the 3 to 6 inch diameter cast iron pipes which were laid along some of them to restrict extraction to fissures which appeared to be free from danger of gross surface contamination. The total lengths of the Government galleries from which domestic supplies have been drawn, and their maximum depths below surface, are approximately as follows:—

Gallery		Deepest Shaft (feet)	Length (feet)
Burnuhhala	About	50	230
Ghemieri		77	840
Bieb ir Rua		70	400
Wied il Busbies		77	7,600
Bonua		60	1,500
Ic Cianti (1)		35	300
Hofriet ir Riz		50	1,400
Ta Baldu		65	2,700
Ta Dekotzu (1)		50	1,200
	Carried forward:		16,170

Gallery	Deepest Shaft (feet)	Length (feet)
Brought forward:		16,170
Misrah Suffara	70	3,800
Ta Randa (1)	15	100
Ta Berkuka (1)	20	130
Ghain Klieb	50	960
Ghain Kaiet	40	290
Ghain Kaiet — Old Gallery (1) ...	Shallow	400
Busugrilla (1)	Shallow	1,850
Gharixiem (1) and Sakkaja (1) ...	Shallow	2,900
Tat Tarja	80	1,400
Via Dingli		5,900
Ta L'Iskof (2)	Shallow	300
Ta Sienja (1)	15	500
Ta Sala } Buskett Galleries	60	150
Ta Rapa	30	270
Dahar It-tuil (3)		1,800
Ghirghenti (3)	Shallow	200
San Giorgio	108	2,115
Fawara	90	100
Annunziata	50	100
Total		39,435

Galleries marked (1) are entirely cut out from the public supply throughout the year, owing to gross surface contamination; there are private rights to a portion of the water derived from (2); and those marked (3) do not contribute to the general public supply.

181. Private shafts and galleries in the Upper Coralline of the Rabat-Dingli Plateau are concentrated mainly in two areas (i) to the west of Wied L'Iemu, in the synclinal and monoclinal strip from the head of Wied il Busbies to Dingli and Tal Vechia; and (ii) to the east of Wied L'Iemu, in and around the Ghar Barca Syncline, from the Rabat-Fiddien Road southwards to Id-Dahar and the head of Wied ta L'Iskof. The survey work at present in progress will probably reveal that the lengths of farmers' galleries in these areas are at least equal to those of the Water Department, and that their extraction of water in the summertime is probably several times as great as that for the public supply. The summertime reduction in public supplies from this area has been the most objectionable result of uncontrolled private enterprise, and one which it will be most difficult at this stage to counteract in the two regions mentioned above, for the mere prohibition of further shaft-sinking and gallery-driving will not remedy the state of affairs which has been reached as the result of so many years of Governmental inaction. The large annual evaporation losses which result from the overlavish irrigation methods employed by the farmers, and from their numerous large open storage tanks, can only be reduced by education in less wasteful methods of irrigation, and by the compulsory adoption of a unified irrigation supply under Government control for which individual consumers would be charged by meter. No useful purpose would be served by attempting to devise such schemes, however, until the fundamental survey work necessary has been completed.

182. It has been stated also that the amount of sediment carried in suspension by flood-time discharges from the Water Department galleries in the two regions mentioned above has increased considerably as the result of private works. In the absence of specific measurements of the extent to which this has occurred it is permissible to doubt whether the increase has been a serious one. With such shallow supplies from an intensely fissured lime-

stone formation, overlain by a residual red clay soil, it is impossible that a considerable quantity of ferruginous clayey material should not be carried in suspension during the winter spells of heavy rainfall. The Upper Coralline supplies are only inferior to those of the Main Sea Level Table in this respect in proportion to the relative depths from which they are drawn. Surface contamination of this nature in the over-developed Upper Coralline areas might be reduced considerably by insisting that the tops of all private shafts be walled-up effectively to prevent the access of surface washings, and this is as far as it is practicable to go where such shallow supplies are concerned. It is impossible to exclude suspended material completely during spells of heavy rainfall, but the presence of this material in the flood discharges from the springs should not have been an excuse for the diversion of so much water for so many years from the public supply. The matter, in fact, was referred to Chadwick many years ago. In reply he pointed out that increased storage beyond the capacity of the Santa Maria Tank, which he had never regarded as final and sufficient, would allow the preliminary deposition of a large proportion of the sediment of such storm waters to take place, and he recommended that this should be followed by slow sand filtration to ensure the bacteriological purity of the supply (1894 a). However, the continued increase in production from the Lower Table galleries, and, later, the introduction of sterilisation by chlorination, effectively diverted attention from his proposals for the filtration of Upper Table storm water, notwithstanding Robertson's subsequent advices on the same subject (1917 pp. 25-26). The turbid storm waters that are cut out at present from the public supply could all be utilised and fed into the existing reservoirs, to the economy of pumped production from the Main Sea Level Table, after passing through rapid sand filters of the pressure type, which would be more suitable than the large filter beds recommended long ago by Chadwick for dealing with intermittent supplies of greatly varying volume. Although reservoir capacity must inevitably be increased considerably in the near future it is probable that, from time to time, there would be an appreciable surplus of turbid storm water after the reservoirs were filled, which could be passed directly to chlorination and consumption if rapid mechanical filtration were included in the supply system. (1)

183. The opening up of the formation by private works in proximity to the Water Department galleries in the two regions of the Rabat-Dingli plateau mentioned above has not had such a deleterious effect on the volume of discharge as was supposed by Robertson (1917, pp. 26-27) and by Dr. E. B. Bailey (1943, p. 6). In interpreting the decline shown in the production graph between the years 1912 and 1917 Robertson attempted no estimate of and took no consideration of the vastly increased quantities of water which farmers' shafts must have been appropriating from the same drainage areas during those dry years. Neither does he seem to have realised sufficiently, in making comparisons with previous dry seasons, that some of the most prolific springs, such as Busugrilla, were no longer being included in the gauging. If complete gaugings were available for all the Government galleries from 1909 onwards they would undoubtedly show that there was a complete recovery from the decline of the dry cycle of years during which Robertson was conducting his enquiry. The graphs for the "Busugrilla" and "Fiddien Box" groups in 1941-45, shown on Plate 10, do not include complete returns for the springs formerly included in those groups, but it will be noticed that Ghemieri and Ghain Klieb annual totals show a similar response to the annual rainfall as in previous years. Similarly the "Total Buskett" production for the years 1941-45 does not include any gaugings of the Ta Sienja Gallery. Consideration of graphs prepared from the daily records that have been kept by Mr. J. Pace since 1941 suggests in fact that, if private pumping were to be completely suppressed, the summertime as well as

(1) At the time of Chadwick's 1893 proposals the benefits of slow sand filtration had long been realised, whereas rapid mechanical filtration was in its infancy, and it was not until after the introduction of complete effective sterilisation by chlorination, twenty years later, that doubts about the relative efficacy of rapid mechanical filtration, in removing bacteria as well as inorganic matter, lost their previous importance.

the wintertime production of the Water Department galleries would be found to be much larger than it was in seasons of similar rainfall forty to sixty years ago. On the daily graphs the days when pumping is in full swing at private shafts are clearly marked by the almost complete absence of discharge from some of the Water Department galleries. On several occasions during the winter of 1944-45 the 12-inch "Busugrilla" V-notch installed by Chadwick was too small to pass all the flow from the Busugrilla and old Ghain Kaiet (Gnien is Sultan) Galleries, which it gauged formerly together with the discharge from the Gharixiem Gallery; but for long periods during the following summer no water whatsoever reached the gauging box from those galleries, although they are in a better position than any others to intercept any downpitch drainage of the Ghar Barca Syncline not appropriated by private works.

184. Away from the intensely cultivated and irrigated areas discussed in the preceding paragraphs there are wide expanses of bare rocky xaghra, with little in the way of soil cap and fields, which are capable of yielding considerable additions to the public supply. In these areas private works for extraction are widely spaced and comparatively few in number. A main central gallery up the pitch of the syncline from Tas Salib to Xaghra tal Kallelia, with branch galleries at grade across the contours of the syncline itself and around the flanks of the adjacent anticlinal rolls, would be able to extract the underground drainage of much of the northern rim of the plateau, from Tax-Xini on the west to Id Dueira on the east. The displacements of the faults which cross this region would require to be thoroughly proved in advance, in order that the galleries may be laid out with suitable gradients and to avoid driving considerable distances within the Blue Clays. It may be possible to tap much of the drainage to the west of the Tax Xini Crest by this route, or alternatively, by way of the Wied il Busbies Syncline. But the lower parts of the western Bahria slope would require collection to a separate pumping station, or gravitation along the northern flank of the plateau to the proposed Binjemma Pumping Station. There is much ground in the western monocline behind the cliffs of L'Imtahleb and Dingli still untapped by government or by private works, which could be exploited by strike galleries, and which, together with reorganised extraction from the Wied il Busbies and Misrah Suffara areas, could be fed by gravity into Wied L'Iemu. At the southern end of the plateau it should be possible to extract much more than the present production of the Buskett, Girgenti, and Fawara Galleries by a gallery system graded efficiently in conformity with the contours of the Girgenti Syncline and the Jebel Ciantar Crest.

185. Only five boreholes have been put down through the Upper Coralline limestones of the Rabat-Dingli Plateau up to the present; B.Hs. 11, 13, and 15 by No. 3 Boring Section, R.E., in May 1943, in search of water supplies for Eighth Army camps, and B.Hs. 80 and 83 by No. 7 Boring Section, R.E., in October and November 1944, intended to serve as gauging holes in the western region of the Main Sea Level Water Table. B.H. 13 was a dry hole; B.Hs. 11, 15, and 80 obtained small flows of water from the Greensand, but the quantity in every case was much less than was being obtained by neighbouring farmers' shafts and galleries, and would have been inadequate to maintain a 1,000 g.p.h. pump. B.H. 83, sited about 500 feet down dip from B.H. 15 towards the middle of the Girgenti Syncline, obtained a better yield and abstracted the water from neighbouring farmers' shafts, but, as it was not intended for production, the Upper Coralline, Greensand, and Blue Clays were cemented-off behind 12-inch casing, and the hole was carried on down to the Main Sea Level Table. None of the five holes was located in a structural position likely to provide a depth of standing water adequate for borehole pumping, and it is improbable that more favourable conditions exist in the Rabat-Dingli area, except possibly at the culmination of pitch in the Tas Salib Syncline and in the middle of the Ghar Barca Syncline.

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186. If it were possible to institute effective drainage of the whole 5,600 acres of the Rabat-Dingli Upper Coralline catchments the mean annual potential production of fresh water would amount to some 633 million gallons, on the assumption that one-quarter of the mean annual rainfall percolated to the underground supply(para. 145). It may prove impracticable or uneconomical to extract from certain narrow outlying strips such as those of western Bahria, the eastern end of Id-Dueira, and the Imtarfa spur; also percolation at the average rate cannot take place within the built-up Rabat urban area. It is advisable, therefore, to make a reduction of 600 acres in the estimate to take account of such regions, leaving a total of 5,000 acres of catchment, with a potential mean annual yield of 565 million gallons. For reasons which have been given previously in discussing the relation of rainfall to percolation in the Upper Coralline areas, this would appear to be a truly conservative estimate. During the past four seasons, 1941-42 to 1944-45, the recorded yield of the Water Department galleries in the area, including production from the Via Dingli Pumping Station, has averaged only 150 million gallons per annum.

187. The 13.76 square miles of Upper Coralline outcrops to the north of the Victoria Lines Fault have been given priority over the Rabat-Dingli area during the past two years' field investigations of water supply resources because, on reconnaissance, the two largest surviving masses, those of Binjemma-Wardia and Baida-Mellieha, were found to contain synclinal structures which not only promised larger and more speedy returns for outlay on shafts and galleries than any parts of the more elevated tract to the south, but also appeared to have been so little breached by erosion that their potentialities for large scale underground storage merited full consideration before embarking upon the construction of large and expensive surface reservoirs. A further immediate attraction of the Upper Coralline areas of this part of the Island is the relatively small extent to which private exploitation has proceeded, away from the sea level tables and the natural marginal springs. Indeed, private developments have been practically negligible up to the present in the main synclinal areas mentioned above. It seemed desirable, therefore, that an overall statement of the prospects of the region should be prepared to some degree of detail as quickly as possible, to serve as a reliable basis for discussion of the part it must play in the unified development of the water supply resources of the whole island, and to emphasise the need to protect these northern areas from further private developments detrimental to the public interest. Their main disadvantage, as compared with the greater part of the Rabat-Dingli Plateau, lies in the fact that gravity supplies to the major population centres of the Island could only be engineered from small portions of the Marfa, Mellieha, Wardia, and Jebel Ghauzara Ridges, where the base of the Upper Coralline rises highest, even by taking a large diameter main along the eastern coast instead of over the 250-foot col between Musta and Lia, to say nothing of the difficulty of devising adequate storage arrangements for such a plan. The possibilities of gravity supplies from the region to the main part of the Island are not, in fact, worthy of further consideration, for it will be far more rational and economical from every point of new to collect the quota of the more elevated parts of the region by pumping from the lower altitudes to which they drain naturally, without introducing unnecessary additional complications into a system which, in order to obtain satisfactory centralisation of all the water supply resources of the region, will be fairly complicated in its final form, owing to the number and varied topographical disposition of the separate drainage areas concerned.

188. The Binjemma-Wardia area (Plates 11 and 12) is the largest of the Upper Coralline areas of the northern part of the Island. The structure of its 5.35 square miles of continuous limestone outcrops between the Victoria Lines Fault and the Balluta Fault is far removed from the simple monoclinal condition shown on Major G. L. Paver's 1943 map, and comprises several distinct anticlinal crests, synclinal basins, and strike faults, which effect a considerable

diversity in the disposition of its underground drainage. For practical water supply considerations the area may be sub-divided as follows:—

	Area (Square miles)	U. C. L. Potential Production at 5" percolation (Million gals./annum).
Ghain Tuffieha Gallery Drainage Area	0.22	15.9
Other U.C.L. catchments draining northwards to St. Paul's Valley	0.70	50.6
Ta Zerp Syncline	0.54	39.1
Binjemma Syncline	1.77	128.0
Falka Syncline	0.23	16.6
Fomm ir Rih Syncline	0.10	7.2
Catchments draining towards Jeneina Bay	0.62	44.8
Catchments draining towards Wied il Ghasel	1.17	84.6
Totals	5.35	386.8

189. A series of deep, narrow synclines, with their southern limbs turned up steeply to the Victoria Lines Fault, form a conspicuous feature along the southern border of the area. A small portion only of the westernmost one has survived erosion and is well exposed, pitching westwards, in the cliff section on the eastern side of Fomm ir Rih Bay, which was figured by Spratt more than a hundred years ago in his paper "On the Geology of Malta and Gozo" (1843). The actual line of contact between the limestones and the underlying Blue Clays is not exposed in the cross-section of the syncline, but, by projecting the horizon southwards from Kala tal Imgiar, in accordance with the dip of the basal yellow marly beds and higher subdivisions of the Upper Coralline Formation, it is estimated that it descends to about 50 feet above sea level at its lowest point, and rises again to about 200 feet above sea level at its contact with the Victoria Lines Fault. One small perennial surface spring, however, issues from the area at the middle of the syncline and is used to irrigate the small fields along the foot of the cliff. The syncline does not continue inland for more than about 400 yards from the top of the cliff. From the observed pitch of the axis and from the cliff section of the limbs of the fold it would appear that the 200-foot contour on the top of the Blue Clays may be taken as a suitable line for defining its drainage area as approximately 64 acres. At the assumed mean annual rate of percolation for Upper Coralline outcrops this would mean that at least 7.2 million gallons of water are passed down the syncline to the coastal cliffs in an average year, only a small fraction of which is appropriated for irrigating the fields of the redum. Probably much more than 7 million gallons percolates down to the sea through the talus and slipped masses of limestone, for the syncline must receive a considerable amount of water from storm discharges down Wied il Hmir at its western end, in addition to percolation from the rainfall upon its restricted surface area. If the water from the Fomm ir Rih Syncline were ever to be appropriated for the public supply the most suitable route for its centralisation would be by pumping over into the western end of the proposed longitudinal gallery of the Binjemma Syncline. Initial access for opening up the drainage of the syncline should be by adit and incline from the foot of the more stable cliffs in the northern limb, where, in places, the top of the Blue Clay is only a few feet below the surface. To enter through the unstable talus opposite the trough of the syncline would be a very expensive and precarious undertaking; while to obtain access to the axial region from the top of the cliffs would require the sinking of a 250-foot shaft.

190. The axis of the Binjemma Syncline can be traced for a distance of a little more than two miles from Farmhouses Ta L'Abatia on the west to Ghain

Kattus on the east. It follows a course roughly parallel with the Victoria Lines Fault and is rarely more than two hundred yards distant from the surface trace of the latter. From Ta L'Abatia, where the top of the Blue Clay is nearly 250 feet above sea level, there appears to be a continuous pitch eastwards, at first at only 2 to 3 degrees, but finally at about 14 degrees into the deepest part of the syncline near Binjemma Village, where B.H. 116 failed to reach the bottom of the Upper Coralline Formation, although the bottom of the hole was carried to a depth of 175 feet below sea level. There is probably a similar steep eastward rise along the axis to the east of the village, followed by a long gently pitching saddle through which the drainage spills westwards from a subsidiary basin at Ghain Kattus, where the Blue Clays again descend below sea level, before rising steeply to the culmination of pitch between the Ghain Kattus and Falka Synclines. Through a wide saddle to the north of the village, between broad anticlinal spurs which pitch down gently from Ta L'Iskorviet and from Hodba ta Seikla, the Binjemma Syncline receives drainage from a wide synclinal area of Upper Coralline beneath the fields of Jeneina, Ramlia, and Wita ta Zebbieh, and from the monoclinal slope beneath the bare rocky xaghra around the village of Imjar and Iz Zebbieh. The total area of Upper Coralline rocks from which the drainage is thus concentrated to the neighbourhood of Binjemma village is about 1,132 acres or 1.77 square miles. Thus the mean annual production obtainable from the middle of the syncline at Binjemma should amount to some 128 million gallons. This may be accepted as a very conservative estimate, for the syncline receives water not only from the Upper Coralline area to the north of the Victoria Lines Fault, but also by percolation from the surface run-off from about 256 acres of clay slopes to the south of the fault line, and underground seepage from the northern scarp of the Rabat-Dingli Upper Coralline tract, through the hill drag, boulder gravels, tufa, and slipped masses of limestone. According to Mr. Baldacchino's survey of private shafts and irrigated lands there are only 13 private shafts within the drainage area of the Binjemma Syncline, which extract a total of about 6 million gallons per annum for the irrigation of about 6 acres.

191. The only appreciable perennial surface discharge of water from the Binjemma Catchment Area takes place from the spring at the head of Wied ta Jeneina, where the top of the Blue Clays, in the trough of the Jeneina Syncline is at a height of about 136 feet above sea level. As this is the lowest point at which that horizon outcrops around the boundary of the catchment area, and as the standing water levels in private wells a short way behind the limestone scarp were found to be several feet higher (Section DD', Plate 12), it was hoped that an extensive water table at about this height above sea level would be found throughout the connected synclines between the Jeneina-Tal Hjesen and Victoria Lines Fault. The elevations of about 200 and 190 feet attained by the Blue Clays against the Victoria Lines Fault in Fomm ir Rih Bay and east of Falka, at the western and eastern limits of the area respectively, also encouraged the hope that they would exert a sealing effect to at least something approaching these heights all the way along the southern side of the area. The great depth of the central part of the Binjemma Syncline, and the low standing water level within it revealed by B.Hs. 100, 105, 109, and 116, destroyed this hope, and showed that opposite the deepest and widest cross-section of the syncline the sealing effect of the Clays cannot extend higher than 9 to 10 feet above sea level. Such a low standing water level immediately raised the suspicion that the body of water within the syncline might actually be continuous to a considerable depth below sea level with the Main Sea Level Table, on the southern side of the fault; a suspicion which received some support from the slight increase in salinity, from 10 to 12.5 parts per 100,000, which was shown by the samples of water taken during the deepening of B.H. 116 to 175 feet below sea level. To check this point and establish in detail the contours on the top of the Blue Clays in proximity to the fault plane, opposite the deepest part of the syncline, will require a number of boreholes at somewhat difficult topographical sites, to be carried out by the light boring outfits mentioned in

paragraph 177. Several other considerations tend to discount the evidence of the slight increase of salinity noted in B.H. 116, and, for the time being, the lowest level at which Upper Coralline water can discharge southwards through the fault plane is regarded as being determined by the turn-up of the Blue Clays in the southern limb of the syncline to a minimum height of about 10 feet above sea level, as shown in Section CC', Plate 12. In B.H. 86, a Main Sea Level Table gauging hole which is situated on the southern side of the fault only 700 feet distant from B.H. 116, the standing water level was found to be only $4\frac{1}{2}$ feet above mean sea level. A gradient of 5 feet in 700 feet is much steeper than would be expected in well-fissured coralline limestones (para. 161) and strongly suggests the presence of some impediment to free gravitational flow to the Main Sea Level Table. The salinity of the water bailed from the top of the Main Sea Level Table in B.H. 86 was 13.8 parts per 100,000 as compared with the maximum salinity of 12.5 parts per 100,000 at 175 feet below sea level in B.H. 116. Further, float measurements of water level which were made at hourly intervals in B.H. 116 showed no signs of tidal influence. It would appear, therefore, that there can be little or no danger of drawing more saline water from the Main Sea Level Table even if the Upper Coralline water within the Binjemma Syncline were to be pumped down to far below sea level.

192. As knowledge of the contours of the Binjemma Syncline stands at present it does not seem that attempts to increase the storage capacity of the structure by means of underground damming would produce results in keeping with the expense which would be involved. The present body of water in the trough of the syncline lies mainly in the thin alternations of limestone bands and yellow marls at the base of the Upper Coralline Formation, and has a capacity of about 99,700,000 cubic feet, or, say, 124,625,000 gallons of water at 20 per cent saturation. Deep underground work along a length of about 2,000 feet of the fault plane might well be necessary to raise the level of the water table to 50 feet above sea level, and would result in the addition of only 74,960,000 cubic feet, or, say, 93,680,000 gallons to the existing storage capacity. An increase to a height of 150 feet above sea level would possibly necessitate damming along a length of 7,000 feet of the fault plane, and even then the extension of the storage area to the north, beyond the narrow limits of the syncline proper, would be comparatively shallow, restricted to the marly basal portion of the Upper Coralline Formation, and would require, in addition, a stop-gap dam across the lip of the Jeneina Syncline behind the spring. Clearly the most suitable function of the Binjemma Syncline is to serve as a locus for the extraction of freshwater and not for storage.

193. It is recommended that a central pumping station be constructed at map reference (3439 2738) at the southern end of Binjemma Village. The surface altitude of the field here is about 370 feet above sea level. Galleries should be driven at sea level eastwards and westwards along the axis of the syncline, as indicated on Plates 9 and 11, until they reach the Greensand or the top of the Blue Clays, and should then follow this horizon up the gentle rise of structure as far as Ta L'Abatia and Ghain Kattus. The total length of these strike galleries would amount to about 10,500 feet. They are essential to ensure as far as possible that all fissure drainage, from both the northern and the southern sides of the syncline, will be concentrated at Binjemma, and that there will be no by-passing of storm discharge along old underground channels during periods of heavy rainfall. Before embarking upon their construction the depth to the Greensand, or, if this is absent, to the top of the Blue Clays, should be checked by boreholes at 100-yard intervals all the way along the proposed alignments, in order that the gradients of the galleries may be laid out in advance, to avoid any irregularities which might be caused by local rises and depressions along the axis unrevealed by the widely-spaced boreholes of the general structure test programme (Table 11 and Plate 11). The N.-S. cross-strike line of gallery along the Binjemma Road and the branch galleries into the Jeneina and Wita ta Zebbieh Synclines are not so essential; they would only be

required if it were considered desirable later to increase the daily rate of extraction from the whole of the catchment area. The local disposal of the spoil from the proper shaft and galleries would occasion some difficulty. Only a small proportion is likely to be suitable for road metal or for lime burning. Unless arrangements could be made for the utilisation of the greater part in some major reclamation scheme it would be best to shoot it over the cliffs of Fomm ir Rih Bay at map reference (3100-2775). Production from the Binjemma Pumping Station could be fed most conveniently into the existing distribution system by way of the Nadur Tank. This would involve lifting the water to a height of 780 feet above sea level and the laying of 3,600 feet of pipe line. It would rapidly do away with the need to boost water from Ta Kali and Ghain Kaiet Pumping Stations for the supplies of Imtarfa, Rabat, and Dingli, and, as production surplus to the requirements of those places became available from Binjemma it could be gravitated down the Wied tal Kleigha main to Ta Kali, pending the completion of a unified production, storage, and distribution system for the whole Island.

194. The easternmost of the deep narrow Upper Coralline synclines in close proximity to the down thrown side of the Victoria Lines Fault can be traced at surface over a length of about three-quarters of a mile, from Il Blajet to Ta Kasrana, and attains its maximum depth and width near the group of farmhouses in front of the old Falka Intrenchment ("Falka Gap" of the 2-inch Survey Map). The catchment area of the syncline in the Upper Coralline to the north of the Victoria Lines Fault is estimated to be 151 acres or 0.23 square mile, which, on the basis of a mean annual percolation of 5 inches should ensure a mean annual yield of at least 16.6 million gallons. The syncline receives an additional supply, less easy to estimate, from the surface run-off from the bare Upper Coralline outcrops, and from the clay-covered slopes which run up to Dueira, on the south side of the fault. The lowest point on the Blue Clays around the northern rim of the syncline is probably about 190 feet above sea level on the southern side of Wied ta Seikla, but it does not look as though there is ever any appreciable spring discharge across it. Neither are there any private shafts for the extraction of water within the catchment area of the syncline. In January 1945 B.H. 90 proved the existence of a water table within the syncline, standing at 132 feet above sea level, and on test yielded more than 100,000 gallons in 24 hours at a steady rate of 4,200 g.p.h., the maximum capacity of the pumping set employed. In April 1945 the level of the water table was found to have fallen to 127 feet above sea level, but, pumping by itself, B.H. 90 produced at practically the same rate as in January. Pumping simultaneously with B.H. 118, which had been put down 750 feet away to the east and fitted with an identical pumping set, B.H. 90 produced steadily at 3,900 g.p.h., during as even hours test, while B.H. 118 yielded only a steady 2,900 g.p.h. The discrepancy beween the yields of the two boreholes illustrates well the influence of the degree of fissuring on borehole production from these limestones, for B.H. 118 is larger in diameter than B.H. 90 and the suction point of the pump in it was set 10 feet lower than that in B.H. 90. Owing to the lack of labour and the need for the pumping sets to be used elsewhere it was not possible to carry out further tests as the dry weather advanced. The maximum depth attained by the top of the Blue Clays in the trough of the syncline is probably about 25 feet above sea level (Section AA', Plate 12). If the minimum height of the Blue Clay seal in the southern limb of the syncline be taken as 125 feet above sea level then the present storage capacity of the syncline may be estimated as 49,820,000 cubic feet, representing 62,275,000 gallons of water at 20 per cent saturation. Owing to the long, narrow shape of the structure the amount of underground work which would be required to increase its natural storage capacity would be completely out of proportion to the results which would be obtained, just as in the case of the Binjemma Syncline. Works along at least 1,500 feet of the fault plane might be required to raise the discharge level to 150 feet above sea level, and the consequent gain in storage capacity would amount to only 34,250,000 gallons.

195. While it offers no solution to the major problem of large scale storage the Falka Syncline has good prospects for (i) providing a freshwater supply of at least the same order as the present annual production of the Via Dingli Pumping Station, from a fraction of the length of galleries already connected with the latter pumping station; and for (ii) providing a summertime reserve of 50-60 million gallons for use as required. Owing to the restricted drainage area of the syncline it should be possible in the dry weather to put down a shaft to the base of the Upper Coralline in the deepest part of the syncline, and to drive galleries at that level, without the employment of unduly large sinking pumps. About 1,000 feet of gallery driven along the axis, as close upon the Blue Clays as possible, would guarantee that the greater part of the water which finds its way into the syncline could be drawn out when and as required. Driving at or close beneath the summertime standing water level would not achieve this, but would only be able to tap the seasonal influx of water as it arrived. The location of the pumping station shaft should not be finally decided upon until the depth to the Blue Clays has been accurately determined by closely-spaced boreholes all the way along that part of the axis shown within the 50-foot contour on Plate 12. The shaft site shown at map reference 3678 2794 on that map is near the deepest part of the syncline according to the observed surface dips and is at the lowest surface elevation (about 280 feet above sea level). Too much reliance should not be placed upon surface pitch indications in such a strongly compressed fold of massive limestone beds, and, from the general outline of the structure in plan view it would seem possible that the maximum depth of the syncline at the horizon of the Greensand may lie a good deal further to the west. A shaft site in the fields to the west of 3678 2794 would be much more accessible from the main road, and the additional 20 to 30 feet of sinking would be amply compensated by the more convenient surface arrangements which would be possible. Disposal of spoil would not present such a problem as at Binjemma. There are several long lanes in the neighbourhood on which the harder limestones from the shaft could be used as road metal, while the old ditch of the Victoria Lines behind the Falka Intrenchment would more than hold all the useless softer spoil from the galleries in the more marly basal beds of the Upper Coralline. Ultimately it would probably be best to pass along production from Falka to join the proposed N.-S. pipe line system for the Upper Coralline areas at Binjemma, but, more immediately, it could be fed into the present distribution system by way of the Ta Kali Reservoirs. The latter procedure would involve the laying of about 6,900 feet of pipe line to join the present Wied tal Kleigha main at Bukana, or about 13,200 feet of line for the complete distance to the Mercieca Reservoir. The pumping plant would have to lift to 390 feet above sea level to clear the height of land at the Falka Gap.

196. The long strike fault which crosses the middle of the Binjemma-Wardia area, from Ras il Pellegrin and Jeneina Bay on the west to Il Kolla on the east, throws down to the north, and from the neighbourhood of Imjar to Wied Kannotta it forms the southern boundary of a broad shallow syncline which appears to have at least a few feet of vertical closure on every side. Intermittent surface spring discharge takes place from the eastern lip of the syncline at the head of Wied Kannotta, where the top of the Blue Clay stands at about 232 feet above sea level at its lowest point of outcrop. Westward pitch is clearly demonstrated hereabouts by the V-outcrop of the limestone crags, and a few private shafts to the north-west and south-east of Ras il Wied provide additional evidence that the northern limb of the syncline is more steep than the southern one and is probably broken by a small normal strike fault. The heavily irrigated fields of Ta Zerp occupy the central part of the syncline, and the compact group of private shafts here is estimated to be raising about 17 million gallons of water annually for the irrigation of about 11 acres. Pumping is practically continuous, and, at the time of survey in the summer of 1945 the water levels in the shafts varied between 225 and 231 feet above sea level. The average altitude of the top of the Blue Clay appears to be about 216 feet above sea level at this locality, that is, about 16 feet lower than on the eastern lip of the

syncline. Another group of private shafts which has grown up on the north-western side of the syncline at Ta Ragha has depths which indicate that this side of the structure is sealed effectively by a diagonal fault with a strong downthrow to the south-east, probably a continuation of the fault which crosses the Jeneina Valley from Wig il Kamla to Misrah Miel. That is the sum total of precise evidence available with regard to structure at the depth of the Blue Clays. There are indications of eastern pitch in the surface outcrops to the north-east of Imjar, but only boreholes can determine satisfactorily for practical purposes the amount and nature of the closure at the western end of the syncline in the angle between the Wig il Kamla-Ta Ragha and Ras il Pellegrin-Il Kolla Faults. If the trend of the 250-feet contour shown on Plate 11 is approximately correct, then the Ta Zerp Syncline will prove of considerable value for underground storage, as only a comparatively low dam will be required at Ras il Wied to restore the former reservoir capacity of this long wide natural basin. The surface level of 288 feet in the middle of the valley at Ras il Wied sets a limit to which the water level may be raised by damming, no less than the spillover levels to the north and south of the basin. On the evidence at present available it would seem that a top water level of 260-270 feet above sea level is the highest feasible. This would be 20-30 feet below the lowest surface level at Ras il Wied and would become progressively deeper below the surface proceeding westwards. The maximum height of the dam required across the axis of the syncline at Ras il Wied would be only 30-40 feet, and, being so near to the surface its construction would be a much cheaper and much less difficult proposition than in the case of any other of the major synclines of the northern fault strips, excepting Ghain Tuffieha. The high altitude (230 feet above sea level) at which gravity supplies could be drawn off is also similar to that of Ghain Tuffieha.

197. The main arguments against the utilization of the Ta Zerp Syncline on the lines suggested above, and also against the construction of a longitudinal gallery to serve as an immediate additional source of seasonal free-flowing high level supplies, are (i) the relatively small catchment area of the syncline, and (ii) the extent to which its resources have already been appropriated by private enterprise. The surface catchment area of the syncline is estimated to be about 0.54 square mile, with a potential mean annual yield of some 39 million gallons, and the fifteen private works within the catchment area are estimated to be raising already more than 24 million gallons a year for irrigation purposes. On the assumption that a dam at Ras il Wied would produce no more ample effect than storage through an average depth of 10 feet of formation within the area enclosed between it and the 250-foot contour on Plate 11, this alone would mean a reservoir capacity of 92 million gallons at 20 per cent saturation. The reservoir would rarely be filled, therefore, from its own catchment area, and water pumped into it for storage would only be increasingly abstracted by the local farmers, unless they were restricted by legislation to their present area of cultivation and amount of water used for irrigation. On the other hand a Government gallery driven along the axis of the syncline for the purpose, let us say, of augmenting the St. Paul's Bay and Mellieha supply, would deprive the farmers of much of the resources which they themselves have developed and to which they have now become accustomed.

198. The Ghain Tuffieha Gallery is the most recent of all Water Department works to be devised and completed within the Upper Coralline Formation, and, owing to the approximate coincidence of the Ghain Tuffieha-Iz Zebbieh Road, alongside which the gallery was driven, with the axis of the Ghain Tuffieha Syncline, its alignment is the most rational of any adopted to date in the whole Island (para. 68). The surface spring from which the gallery was driven owed its existence to the breaching of the western end of the syncline by a tributary valley eroded southwards from the western end of the Wied tal Puales rift valley. The spring was utilised from very ancient times, notably by a large Roman villa, the ruins of which were discovered by Rizzo during the construction of the Water Department's present gallery. The driving of the gallery

eastwards from near the site of the original surface spring was commenced in 1927-28, for the purpose of augmenting the water supply of St. Paul's Bay, Mellieha, and the military camps at Ghain Tuffieha and Mellieha Bays, as it had long been apparent that supplies from the previous short length of gallery at Ghain Tuffieha, from Ghain Astas ("Il Kala Spring"), and from Burnuhhala were totally inadequate to meet the growing local demand. Shaft sinking and gallery driving continued intermittently until 1937-38, and, as it exists at present, the work comprises about 2,560 feet of gallery of 5 x 2½ feet cross-section, connecting eleven shafts which range from 24 to 145 feet in depth. The greater part of the length of the gallery appears to have been driven in the basal thinly-bedded limestone and marl member of the Upper Coralline Formation and in the top of the Greensand. The top of the Blue Clays was determined only in shaft 10, three feet below the present bottom of that shaft, and at an altitude of 241.5 feet above sea level. The average gradient of the gallery between shafts 1 and 11 is about 1 in 250, and this is probably a fair approximation to the pitch of the synclinal axis between those limits. Records of the total annual yield of the gallery are available from 1932-33 onwards, but records of daily production are only available from 1941-42, and there is no rainfall gauge within the catchment area. Had complete records been available, a very useful analysis could have been made of the results to be expected from new galleries in the Upper Coralline areas, for the catchment of this gallery is well defined and there can be little doubt that the existing gallery is drawing practically all the natural gravitational discharge from the catchment area, while there are only two private shafts also extracting significant quantities of water.

199. The history of production at Ghain Tuffieha since the commencement of the new work provides a warning against too optimistic expectations of the indefinite continuation of the initial "flush" productions that are obtained from new galleries, or from extensions of old ones into new ground. According to Robertson (1917, Appendix VI) the short length of gallery in existence at that date was yielding a minimum of 30,000 gallons a day. This figure, however, was probably given to him by Rizzo as the daily mean for the year, not the daily minimum, for the minimum daily production often falls considerably below this level. After the first season's construction of 950 feet of new gallery in 1927-28 the Water Department Annual Report recorded an increased yield of 30,000 gallons per day; and after the second season's work in 1928-29 an additional 32,000 gallons per day. The peak of production appears to have been reached in 1932-33, when a large fissure, described as "the source of the Ghain Tuffieha spring", was intersected, and work had to be temporarily suspended. The total production for that year was some 41 million gallons. Despite further extensions to the length of gallery and considerable variations in the annual rainfall there was a continuous decline from this peak production until 1938-39, by which time the long accumulated surplus in the large fissure system was exhausted, and production has settled down to a new equilibrium, related directly to variations of annual rainfall, at a mean rate of 16.26 million gallons per annum from 1939-40 to 1944-45. As the mean rainfall for these six seasons has been 23.2 inches, according to the Rabat-Dingli gauges, the long term mean production of the Ghain Tuffieha Gallery will probably prove to be somewhat lower than 16 million gallons per annum. Since daily records have been kept the seasonal extremes of discharge have been 18,000 gallons and 85,000 gallons per day. The catchment area of the gallery is estimated to be 141 acres or 0.22 square mile. A mean annual production of 16.26 million gallons from this area suggests a mean annual rate of percolation of 5.1 inches per annum, or 22 per cent of the mean annual rainfall, according to the Rabat-Dingli gauges, for the six years under consideration; an interesting and useful check of the ratio of percolation to rainfall already derived from the records of the Rabat-Dingli Upper Coralline galleries (para. 145).

200. The mean daily rate of discharge during the past six years has been approximately 44,000 gallons, a useful increase on the 30,000 gallons a day

recorded by Robertson. The increase in volume however, has been accompanied by a slight but definite increase in the proportion of salts dissolved in the water. Prior to 1927-28, according to analysis by the Medical and Health Department, total solids never exceeded 34 parts per 100,000; since the construction of the half-a-mile of gallery the annual average has risen to as high as 40 parts. The salinity, which previously never exceeded 8 parts of chlorine per 100,000 has risen to as high as 11.5 parts, and both temporary and permanent hardness have doubled. It is by no means certain that this increase in dissolved salts is primarily the result of the increased rate of circulation from the surface to the supply; on a prior consideration the reverse effect might have been expected. It is more probable that a more immediate cause is increased manuring of the fields within the catchment area, as seems to be also the case with the Wignacourt galleries. The matter is of considerable importance and is one which should be subjected to closer experimental study, by prohibiting the manuring and summertime irrigation of all fields within the catchment area for two or three years and noting the effect on the analytical results. This could be carried out more conveniently at Ghain Tuffieha than on the catchment of any other Upper Coralline gallery, and the findings would have general application to all areas. Notwithstanding this deterioration in composition the Ghain Tuffieha supply to St. Paul's Bay and Mellieha is undoubtedly the best balanced and most satisfactory local supply in the Island at present. In composition the water is not inferior to the best of present day supplies from the Rabat-Dingli area (Fawara, Buskett and Ghemieri), and the total reservoir capacity of 1,268,000 gallons provided by the St. Paul's Bay and Mellieha Reservoir is adequate to equalise all the seasonal variations in discharge from the gallery that have been recorded during the past four years. Periodical variations in the demand from the Army and Navy camps at Ghain Tuffieha and Mellieha, where the capacity of the service tanks is very limited, are a disturbing factor, but even in the summer months it has been possible to avoid any acute shortage up to the present by utilising B.H. 25 in the St. Paul's Valley Sea Level Table, which can contribute an additional 4,000 g.p.h. to the Ghain Tuffieha-St. Paul's Bay main, with a salinity which has not yet exceeded 56 parts per 100,000 even during long spells of pumping. As will be shown later, it would be quite possible by driving galleries within the camp boundaries at both Ghain Tuffieha and Mellieha, to develop freshwater supplies adequate for all probable Service demands at those localities and to contribute a useful surplus to the Civil Government supply when Service demands are at a minimum.

201. The possibilities of increasing the natural storage capacity of the Upper Coralline Formation and of the Greensand within the Ghain Tuffieha Syncline itself are worthy of consideration and of further practical investigation. It would appear from the available surface evidence that an underground dam about 1,000 feet in length, with a maximum height of 20 feet, contructed through Shaft 3 (Surface height: 279 feet A.S.L., estimated altitude of the top of the Blue Clays: 232.5 feet A.S.L.) normal to the axis of the syncline, would hold up water for more than twice this distance along the eastern rise of the syncline, without causing any spill over the rim of the basin to Il Palma or to Ta Zerp. It is impossible without a more accurate and detailed contour plan, based on borehole cross-sections, to make a fully reliable estimate of what total storage capacity would be thus obtained, but, if only a mean depth of 5 feet were realised over the area enclosed between the suggested line of the dam and the the 250-foot contour shown on Plate 11, this would amount to no less than 16,272,000 gallons at 20 per cent saturation of the formation. The actual bulk of the dam would be much less, in all probability, than that of the retaining walls of the Mercieca, Nashar, and Luca Reservoir, which hold only 5 to 6 million gallons each.

202. The well-defined synclinal catchments of the Wardia-Binjemma area discussed in the preceeding paragraphs total 2.86 square miles and have an estimated mean annual potential production of 206 million gallons, which can be

extracted by simple central gallery systems along the synclinal axes. The various tracts outside these synclinal catchments display in the main, undulating monoclinal dips towards the boundary scarps of the area, from which their drainage is discharged by way of a few conspicuous surface springs at favoured localities, and by way of innumerable inappreciable trickles beneath talus and scree. These marginal tracts have a total area of about 2.49 square miles, and are assigned, therefore, a mean annual potential yield of 180 million gallons. The complete appropriation of this potential yield will require the construction of a much greater length of gallery per unit area than in the case of the synclinal hollows, and a thoroughly detailed examination of the contours of the Blue Clay surface beneath them, by map and by boring, will be necessary before the most suitable gallery lay-out can be decided upon, as they contain numerous minor undulations and faults which will exert strong influences on the underground drainage pattern in such regions of very gentle dips. They have been classified in paragraph 188 according to the three surrounding valleys into which their production could be concentrated most conveniently. The drainage of some extensive portions of these marginal areas could probably be led into the neighbouring synclinal basins by contour galleries driven at suitable altitudes. The most suitable route to storage and supply for the remainder of their potential contribution would be by pipe lines into the Miziep Syncline, through a tunnel driven through the Xaghra tal Ghansar Saddle from the foot of the Tal Imbordin Pass.

203. Apart from the structure testing of the Binjemma, Falka, Jeneina and Wita iz Zebbieh Synclines, carried out by No. 7 Boring Section, R.E., in 1944 and 1945, the results of which are detailed in Table 10 and have been discussed above, the only other boreholes put down in the Binjemma-Wardia area up to the present are B.Hs. 9, 10, and 14, which were made by No. 3 Boring Section, R.E., in 1943, in search of water for Eighth Army camps. These three holes are situated around the height of land between the Ghain Tuffieha, Il Palma, and Ta Zerp valleys. They failed to obtain sufficient water for borehole pumping, but the spot heights which they provide on the top of the Blue Clays have been useful, in conjunction with the evidence from neighbouring shafts, for forming a preliminary conception of the structural contours in that region.

204. The St. Paul's Valley Sea Level Table supports the most extensive continuous tract of irrigated land within the whole of the Maltese Islands. It is estimated that from within its superficial area of about 597 acres there are seventy private shafts extracting a total of about 248 million gallons a year for the irrigation of an average area of 169 acres. This rate of irrigation is equivalent to 1,470,000 gallons, or 65 inches, per acre per annum. The low altitude of the floor of the valley, which rises gradually from sea level at Ramla tal Puales to only 70 feet above sea level on the cliff overlooking Ghain Tuffieha North Bay, has made the sinking and pumping of wells an extremely simple and cheap proceeding. More than half the seventy private shafts are less than 50 feet deep, and only one exceeds a depth of 100 feet. The local farmers have been fortunate, too, in the combination of geological circumstances which restrict the connection of the water table with the sea to the narrow eastern end of the valley, and which concentrate within it the freshwater drainage from upland catchments to the north and south which are more than twice as extensive as the superficial area of the sea level table itself. Nevertheless, as will be realised from consideration of the results of the August 1945 salinity survey (Plate 11), the heavy rate of private extraction has raised the summertime salinity of the table beyond the limits desirable either for irrigation or for domestic supplies over about half of the total area. There would appear to be little scope, under the present régime, for additional extraction of water suitable for domestic use, except at the western end and along the southern margin of the valley. It must be remembered, also, that any such additional extraction, and the appropriation of freshwater from the catchments to the north and south of the valley, would lead to a rapid increase in the already high salinity of much of the area of the sea level table.

205. In geological structure the valley is essentially a long narrow syncline, pitching gently from west to east, thrown down between two lines of strike-faulting in the middle limbs between the syncline and the Ras il Jebel-San Martin-Wardia uplift on the south and the Baida Anticline on the north. The floor of the valley is covered with a thick red soil cap from end to end, and the hill slopes on each side are heavily cloaked by hill drag, tufa, and boulder fans. The full width of the Upper Coralline Formation within the rift is open to the sea at the eastern end of the valley, but the depth to which the sea has access cannot be estimated accurately as no solid exposures are available in the axial region of the syncline, except at Ghain Tuffieha Bay. The maximum depth to the Blue Clays at Ramla tal Puales is unlikely to be less than two or three hundred feet, however, as the minimum inward surface dips are 15 degrees on the northern side and 20 degrees on the southern side of the beach, and these outcrops are separated by an interval of 1,200 feet in which there are no exposures of solid rock. It would seem, therefore, that the magnitude and cost of any works designed to prevent the inland diffusion of sea water into the syncline from this end would be prohibitive. But, in view of the size and importance of the water table it would be well worth while to check this conclusion by means of a cross-section line of borings to the Blue Clays along the inland side of the road at Ramla tal Puales. The Blue Clay seal appears to be complete and continuous in the faulted middle limbs all the way along both sides of the rift. At the western end of the valley the top of the Blue Clay stands well above sea level all the way around Ghain Tuffieha Bay, except in the cliff below Torri ta Ghain Tuffieha, where a minor synclinal fold brings the horizon down to approximately mean sea level for several yards. This local syncline appears to pitch inland for a short way before the pitch is reversed to seaward between the Tower and the Hotel. The quantity of sea water, if any, which obtains access to the interior of the valley by this route must be very limited, but in the interest of preservation of the low salinity of the water table at the western end of the valley, the matter deserves further investigation by means of boreholes behind the top of the cliff, and the construction of a small stopping across the bottom of the syncline, should continuous inland pitch be demonstrated at the depth of the Blue Clays. The westermost wells in the sea level table (B.H. 28 and P.W.367) are too far away from the Tower for their evidence to be decisive, but their relatively low salinity and high standing water level do not support the idea of any connection with the sea by this route.

206. The total area underlain by Upper Coralline Limestone between the Dahliet il Fekruna and the Balluta Faults, between Ramla tal Puales and Ghain Tuffieha Bay, is about 672 acres, of which about 595 acres is occupied by the sea level table. At the western end of the valley where the base of the Upper Coralline rises above sea level the underground drainage of about 37 acres probably discharges into Ghain Tuffieha Bay, not eastwards down the pitch of the main syncline. The total internal catchment of the syncline is, therefore, approximately 635 acres. At the assumed mean annual rate of percolation for average Upper Coralline country this area would be capable of transmitting 71,755,000 gallons to underground supplies every year, but the thick clay soil cap probably reduces the ratio of percolation considerably in St. Paul's Valley. From the southern side of the Balluta Fault the sea level table receives that part of the underground discharge of 589 acres of Upper Coralline catchments not already appropriated by the Ghain Tuffieha Gallery and other smaller works and surface springs, together with the seasonal surface run-off from much of this limestone area and from about 272 acres underlain by Blue Clay and Globigerina Beds. The total annual discharge from the numerous surface springs of greatly varied magnitude along the northern border of the Wardia Ridge is small compared with that from the Ghain Tuffieha Gallery, and it is probable that the greater part of the water which percolates into the limestone formation within the catchment area mentioned above is passed into the St. Paul's Valley Syncline through the extensive limestone contacts along the line of the Balluta Fault. This view is supported by the lower salinities and higher standing water levels, on the

whole, of the private wells along the southern side of the valley, as compared with those along the northern side, despite the fact that annual extraction from the southern line of wells is estimated to amount to about 142 million gallons against only about 106 million gallons from the northern group. Deducting the catchment area of the Ghain Tuffieha Gallery (141 acres), but making no allowance for other surface spring and gallery appropriations, such as those of Il Ballut, Il Palma, Il Kala, and San Martino, from which a large part of the production is returned underground, as they are mainly utilised for the irrigation of steep hillsides running down to St. Paul's Valley, a figure of 448 acres of limestone catchment is obtained, with a mean annual potential contribution of 50,624,000 gallons to the sea level table. Replenishment of the sea level table from the northern side of the Dahliet il Fekruna Fault takes place in the form of surface run-off and underground percolation from about 294 acres of Upper Coralline limestone to the south of the crest line of the Baida Anticline, and the run-off from about 30 acres of Blue Clay outcrop in the middle limb. The strip of Blue Clays which rises to the surface all the way along the middle limb from Manikata to Dahliet il Fekruna, except for a distance of about 1,000 feet at Il Puales, restricts this southward underground flow into the syncline to two regions, (i) the neighbourhood of Il Puales, and (ii) the region west of Manikata. The effect of this localisation of replenishment is very evident in the isochlors of Plate 11. The only noteworthy surface spring along this side of the valley occurs at Il Puales. Its discharge was estimated by Dr. E.B. Bailey in March 1943, shortly after a heavy spell of rain, to be about 40,000 gallons daily. More settled rates of discharge have since been measured in dry weather, in May 1945 and March 1946, at 29,000 and 28,000 gallons per day respectively. The total annual surface discharge is probably well in excess of 10 million gallons, but daily gaugings of this spring should be instituted and continued for at least several years in order that any claims for compensation water may be assessed fairly should it be decided at some future date to make public appropriation from the catchment area of the spring. Much water undoubtedly passes underground into the sea level table through the limestones beneath the level of the present surface spring and its short length of gallery. In the region of localised replenishment at the western end of the Blue Clay strip the group of private wells at the northern side of Lands Il Habel il Kbir are more heavily pumped than any other group in the valley, yet even in August 1945, at the height of the dry season, the maximum salinity recorded in the group was 45 parts per 100,000. The total mean annual replenishment received from the catchment area of 294 acres to the north of the Dahliet il Fekruna Fault should amount to not less than 33,222,000 gallons, on the standard assumed rate of 5 inches percolation per annum, bringing the total annual replenishment of the sea level table to 155 million gallons. This volume is greatly exceeded by the estimated annual extraction of 248 million gallons. It is important, therefore, that further salinity surveys should be carried out regularly when Dionic Water Testers are available, say at monthly intervals, to determine whether the deep penetration of highly saline water, shown by the August 1945 survey, is merely a seasonal phenonemon, or whether it marks a stage in a continuous steadily increasing salinification of the whole table. Should the former state of affairs be indicated it would mean that the assumed rate of replenishment is an underestimate, or that the deficit between the estimated rates of annual replenishment and annual extraction is made up by the unassessed contribution of surface run-off from areas outside the valley, and by the return to the sea level table of a large part of the water used to irrigate the fields. Should the fears of continuously increasing salinity be satisfactorily discounted there would be scope for some degree of public appropriation of the freshwater which flows into the valley from the north and from the south. Should progressive deterioration be found to be taking place under the present régime, however, measures of restriction and Government control of the irrigation supply of the whole area would have to be imposed, in order to preserve not only the composition of the water table but also the quality of the soil of the fields.

207. Although, in the present state of knowledge of the local conditions, there would appear to be no prospects of making any large appropriation for public use from the Wied tal Puales Sea Level Table without inducing a high salinity in both the water extracted and that left for private irrigation works, there is much to be said for the inception of a small pumping station and gallery system in the comparatively unexploited freshwater area at the western end of the valley, which could be enlarged later should subsequent experience show expansion to be feasible without too great an increase in salinity. A work of the magnitude of the present Via Dingli system, with an output of, say, ten to twenty million gallons a year is suggested, (i) for the purpose of meeting the demand of the Army and Navy camps at Ghain Tuffieha, and any emergency demand that might arise from the temporary cantonment of much larger forces in the neighbourhood, as in 1943, without drawing upon the limited supply from the Ghain Tuffieha Gallery; (ii) for the purpose of augmenting the present Water Department supply, when necessary, with better quality water than the summer-time production from B.H. 25, and for pumping to storage in the Miziep or other basins; and (iii) for the purpose of appropriating freshwater from the catchment of In-nah-Halia and the southern part of Xaghra tal Mayesa, which at present do not find their way into St. Paul's Valley, and which, except for the spring at map reference 3067 3109 ("Spring Well under Cliff") occasionally drawn upon by the Naval Camp, will never be utilised without the construction of galleries designed to intercept the discharge from them into the sea along the northern shores of Ghain Tuffieha Bay. A gallery system suitably laid-out on the northern side of the valley would be able to realise from the In-nah-Halia catchment and from the Manikata influx of freshwater the annual production suggested, without the salinity exceeding 20 parts per 100,000. Should it be considered desirable later, greatly increased production, at the expense of a slightly higher salinity, could be obtained by driving across the western end of the sea level table, and then close alongside the Balluta Fault, to the south of the existing private shafts on the south side of the valley.

208. Recommendations for the lay-out of the proposed system, to be checked by borings, are as follows. The most suitable site for the central pumping station shaft would be near spot height 67 (map reference 3183 3078) which is the lowest surface altitude within the camp area. There can be little doubt, from the levels on the top of the Blue Clays around Ghain Tuffieha Bay and in B.Hs. 28 and 29, that this site would be slightly within the western margin of the sea level table. A gallery should be driven due west at sea level until it passes into the Greensand, after which it should follow the rise of the bed, outside the area of the sea level table, to the neighbourhood of spot height 75 at the N.E. corner of Ghain Tuffieha Bay; then swing westwards again, along the southern side of the Rifle Range, keeping ten to twenty yards inland from the cliff face, to the neighbourhood of spot height 100 at the N.W. corner of the Bay. The total length of this gallery would be about 2,750 feet and it would intercept all the underground drainage of In-nah-Halia and a good deal from Il Moxa ta Ghain Tuffieha on the upthrown side of the Dahliet il Fekruna Fault. To add the drainage of the southern side of Xaghra tal Mayesa a branch gallery would require to be taken off to pass to the upthrown side of the fault behind the cliffs of Il Minzel tal Mayesa, and to carry along the southern side of Xaghra tal Mayesa a few yards behind the coastal cliff. The length of these galleries would be great as compared with the yield of water expected from them, but their cost of excavation and the removal of spoil would be cheapened by the driving of short adits at intervals from the foot of the sea cliffs. Apart ftom the short initial length, which would pump from the margin of the sea level table, they would collect nothing but freshwater from about 52 acres of upland catchment, which should guarantee a minimum mean annual yield of 7 million gallons. A third gallery from the shaft site should be driven at sea level for about 1,000 feet to the road junction at the foot of Manikata hill (map reference 3209 3098). This drive would probably be within the sea level table in the Upper Coralline Limestone throughout its length, and, provided the

rate of extraction was kept within reasonable limits, the salinity of the water should not at any time exceed 20 parts per 100,000. Private shafts Nos. 361 and 362, near the road junction mentioned above, are estimated to extract together more than 18 million gallons a year, and their salinities in August 1945 were only 22 and 21 parts per 100,000 respectively. A fourth gallery should be driven at sea level across the sea level table, along the line of the wall which divides Lands Il Kasam ta Ghain Tuffieha, for a distance of 1950 feet to the junction of the Manikata, Iz Zebbieh, and St. Paul's Bay roads below Il Fawara. This gallery also would probably remain within the sea level table and within the Upper Coralline Limestone throughout its length, and again, provided the rate of extraction was controlled, the salinity should never exceed 20 parts per 100,000. B. H. 28, which was put down by No. 3 Boring Section, R. E., in June 1943, proved the top of the Blue Clays at a depth of 34 feet below the standing water level of the table, and produced 1000 g.p.h. for several months with a salinity of only 24 parts per 100,000.

209. The Mellieha-Baida Upper Coralline area, between the Ras il Griebej and Dahliet il Fekruna Faults, contains two major uplifts, which determine the main "Ridges" of the surface topography, and are separated by a broad synclinal depression along which the longitudinal valley of Il Miziep, Wied tal Kalkara, and Wied tal Mistra has been eroded. The axis of the southern line of uplift, the Baida Ridge Anticline, follows a somewhat sinuous course from Ras il Wahsh on the western coast to Redum il Bies on the east. A pitch of several degrees can often be measured on the limestone benches along the surface crest line, but six boreholes, which were put down along the axis for the purpose of defining the minimum height of the Blue Clays seal beneath it, showed that the pitch of the top of the Blue Clays rarely exceeded one degree, and suggested that considerable eastward thinning must occur within the Upper Coralline Formation across this part of the Island. Gentle eastward pitch is continuous from Ras il Wahsh as far as a well-defined saddle across the ridge at Xaghra tal Ghansar. A steeper rise along the axis then takes place to a crest maximum beneath Shemshiya Hill, after which eastward pitch is resumed beneath Xaghra tal Kortin and across Cala Mistra and Hariek to Redum il Bies on the eastern coast. Out at sea, the curvature of St. Paul's Island (Selmunett) follows around the strike in the northern limb of the deeply denuded end of the anticline. The syncline between the Baida and Mellieha uplifts differs from the more obvious rift-like valleys to the north and to the south in being faulted only along its northern side. The cliffs of Redum Mayesa provide a clear cross-section of the western end of the syncline, and curved limestone scars around the eastward pitching axis cover much of the Xaghra of Ghain Znuber, Tal Kortin, and Il Hamra. An extensive region of maximum pitch depression coincides with the floor of the Miziep Valley and is covered completely by thick Quaternary deposits of red clay, tufa, and boulder gravel. Westward pitch is evident in the solid outcrops at the narrow eastern end of the valley, where the Kalkara Ravine is deeply incised in the Upper Coralline Limestones and in a small inlier of the Blue Clays at the culmination of pitch between the Miziep Basin and the eastward continuation of the synclinal axis down Wied tal Mistra. There are several strike faults in the middle limb between the Miziep Syncline and the Mellieha Uplift. The southernmost one which determines the spring of Ghain Znuber, is the most important of these and is continuous from coast to coast. The line of the fault is clearly defined in the western cliffs, in Wied Labiat, and at Ghain Znuber itself, but along the northern side of the Miziep fields its outcrop is almost totally concealed by hill drag and tufa. At the eastern end of the valley its position can again be fixed precisely at Il Migh Duma, on the St. Paul's Bay — Mellieha Road, and behind the old limestone quarries of Limalak. In Wied tal Mistra the fault cuts completely across the eastward-pitching synclinal axis, and beyond this point it becomes the dividing line between the Mellieha uplift and the northern limb of the Baida-Shemshiya Anticline. No detailed overall examination of the horstlike Mellieha uplift has yet been attempted. Surface dips are very gentle

over most of the area, and, as known changes of stratigraphical thickness are sufficiently rapid to affect frequently the amount of local dip measurements, accurate structural contouring, by means of levels around the margin of the Upper Coralline outcrop and by means of boreholes, will be required to evaluate all the minor undulations and faults which the area contains, and which, in conjunction with the deeply-embayed character of the Upper Coralline outcrop, will affect the underground drainage of the area to a much greater extent than they influence its surface topography.

210. In accordance with the structural and topographical control, outlined in the previous paragraph, the four square miles of the Upper Coralline outcrop may be divided into the following natural catchment areas. (plate 9):

Catchment Area	Surface Area (Acres)	Potential Mean Annual Percolation (Gallons)
Mellieha — Selmun Plateau	1,064	120,232,000
Wied Gharbiel Fault Masses ...	6	678,000
Il Mijnuna (Hariek) Peninsula ...	34	3,842,000
Wied tal Mistra	88	9,944,000
Shemshiya Southern Slope	32	3,616,000
Miziep Syncline	970	109,610,000
Xaghra tal Mayesa Northern Slope	24	2,712,000
Baida Anticline Southern Slope ...	342	38,646,000
Total	2,560	289,280,000

211. The contribution made to the St. Paul's Valley Sea Level Table by the catchment area to the south of the Baida Anticline watershed has been discussed in paragraph 206, and suggestions made for the appropriation of the western end of this catchment which at present discharges to the sea. The southward watershed from Shemshiya and Xaghra Tal Kortin to St. Paul's Bay could be similarly appropriated by a marginal gallery, and might be led down either to Wied tal Mistra or to Puales should compensation water be required on account of future public extraction from the present supplies of those irrigated areas. Rainfall upon the isolated Mijnuna catchment goes directly to the small sea level table beneath that peninsula, the superficial extent of which is so small that it is not worthy of consideration as a possible source of public supplies. The Wied tal Mistra Upper Coralline catchment of 88 acres, together with the surface run-off from a considerable area of clay slopes, maintains a small sea level table in the Upper Coralline Limestone in the bottom of the Wied tal Mistra Syncline, and in the Middle Globigerina Formation around the head of Cala Mistra, on the opposite side of the Ghain Znuber Fault. This sea level table has long been utilised by means of shaft and sienja for irrigation of the fields along the floor of the valley. At present there are seven shafts, ranging in depth from 10 to 36 feet, in the Middle Globigerina Beds on the upthrown side of the fault, which are estimated to extract 3,040,000 gallons a year for the irrigation of 3 acres, a rate of 1,013,000 gallons or approximately 45 inches per acre. There are fourteen shafts in the sea level table in the Upper Coralline, and two up-dip a little way outside it, which range in depth from 12 to 50 feet, and are estimated to be raising about 14,373,000 gallons a year for the irrigation of about 17 acres. This irrigated area also consumes the surplus of probably more than a million gallons a year from the public spring which discharges on the southern side of the Blue Clay inlier from the northern dip slope of Shemshiya Hill, so that the total irrigation rate is at least 15,373,000 gallons for 17 acres, or about 900,000 gallons or 40 inches per acre per annum. There is no scope for extraction of water for public use from the small sea level table of Wied Tal Mistra, but it would be possible to tap the fresh water beneath much of the limestone slopes, which contribute to it, along the northern and southern sides

of the valley, by means of galleries inclined upwards at a gentle gradient from the eastern end of the Miziep Syncline.

212. The Miziep Syncline (Plates 13 and 14) is the largest completely closed basin structure known within the Island. Private development of extraction from its catchment area has been practically negligible, and no extraction whatever takes place from the extensive freshwater table which has been proved in the trough of the syncline. It is doubly fortunate, therefore, from the point of view of public water supplies, that its existence remained undetected until recently. (1) There are three shafts along the southern side of the Kalkara Ravine at the eastern end of the valley, which were sunk by local farmers many years ago as a natural continuation of their development of the Wied Tal Mistra Sea Level Table. The easternmost of these shafts (P.W. No. 382), at map reference 3495 3270, stands at the culmination of pitch between Wied Tal Mistra and Miziep. It is only 20 feet deep and collects a little water from both flanks of the syncline for the occasional irrigation of about 1½ tumoli of narrow field terraces along the side of the ravine. With a view to increasing the flow of water to this shaft by means of a gallery system two other shafts (Nos. 333 and 334) were put down a few years ago at 3505 3270 and at 3511 3265 up the rise to the Shemshiya Crest. They failed to obtain any significant yield of water, however, and the scheme was never completed. The two other Wied tal Kalkara wells (P. Ws. Nos. 335 and 336) at 3465 3254 and at 3448 3244, are 76 and 84 feet deep respectively and derive small supplies from the northern limb of the Baida-Shemshiya Anticline. It is doubtful whether the total quantity of water bailed from these three wells amounts to as much as 50,000 gallons a year. Their small yields and the increasing depth to water proceeding westwards appears to have deterred effectively the completion of any further sinkings in search of underground water supplies along the southern side of the valley, and the thick superficial deposit of clay and gravel, which would require steining for depths of 20 to 30 feet, appear to have prevented any attempts which, by comparison with the developments in Wied tal Puales, might have been expected along the valley floor. Only four other trial shafts are known in the whole valley. Three of these, at map references 3402 3228, 3399 3211, and 3170 3186, are in the southern limb of the syncline; they stopped far above the Blue Clays and yield no water. The fourth (P. W. No. 325) at 3176 3211 west of Ghain Znuber, was constructed several years ago, and is the deepest (156 feet) and most recent of private attempts in the valley. It reached the Blue Clays in the northern limb of the syncline, but, being outside the standing water table, the small supply of water which is obtained was inadequate for the farmers' requirements. The only two perennial surface discharges within the catchment area of the syncline are thrown out along the northern side of the Ghain Znuber Fault. One of these is the Ghain Znuber itself, which issues from a gallery about 485 feet in length, driven northwards up-dip in the Greensand and basal Upper Coralline beds from the original natural spring. Its mean annual yield is probably somewhat in excess of a million gallons, but in summertime the discharge falls as low as only 100 g.p.h. The second spring, which rarely yields more than a few gallons per hour, rises from the base of the Upper Coralline around the small inlier of Blue Clays in the gully within the hairpin bend on the road from Puales to Mellieha.

213. In view of the size and shape of the Miziep Syncline, and the small amount of water being extracted in comparison with the potential annual yield of its catchment, a programme of thirty-two structure test boreholes, amounting

(1) Rizzo (1932 p. 31) may have suspected a westward continuation of the Wied tal Mistra Sea Level Table into the Miziep Valley, for after his remarks on the sea level table of Mellieha Bay, he added, "What has been stated of this locality holds good also for the Mistra and Puales Valleys", and his mapping of the structure was fairly correct. Dr. E. B. Bailey in 1943 depicted a large monoclinal inlier of Blue Clays occupying much of the floor of the Miziep Valley, and omitted the Ghain Znuber Fault. The M.E.F. geologists later in the same year also failed to notice the presence of the syncline, and on the maps and sections illustrat i ng the G.H.Q., M.E.F. report on "Boreholes for Water in Malta" the Ghain Znuber Fault is again omitted and a wide monoclinal inlier of Blue Clays, strike-faulted along its southern side, is shown as extending all the way along the valley from west of Ghain Znuber out to the east coast, with the "water table cut-out by Blue Clays".

in all to 5311 feet of drilling, was carried out by No. 7 Boring Section, R.E., in May-July 1945, to determine the form and capacity of the structure with greater precision than surface mapping alone could provide, and to define the route by which its surplus water is discharged underground to the sea. The essential data from these boreholes are summarised in Table 12. It was found that the syncline contained a fresh water table more than a mile and a half in length and more than a quarter of a mile in width, with standing water levels from 11.5 feet above sea level upwards, and with as much as 69 feet of water standing above the top of the Blue Clays. Closure by the Blue Clays to a height of 50 feet above sea level was proved at the culmination of pitch between the Miziep and Wied tal Mistra Synclines, and to a height of 49 feet above sea level at the saddle on the Baida-Shemshiya axis behind the Puales Spring. At the point where the axis of the syncline intersects the western sea cliffs the top of the Blue Clays is about 110 feet above sea level. The only route, therefore, along which discharge at grade to the sea can take place from the lowest level of the water table in the Greensand and Upper Coralline Formations of the syncline is northwards across the Ghain Znuber Fault. It was not possible to carry out any very extensive investigation of formation contacts along the fault plane, as topographical conditions were too difficult for the types of boring machine in possession of the Section, but the throw of the Ghain Znuber Fault was proved to increase rapidly from the 25 feet measureable in the western cliffs to nearly 200 feet between the spring and B.H. 160. This increased displacement, in conjunction with the eastward thinning of the Blue Clays, from 180 feet on the western coast below Ghain Znuber Tower to 130 feet on the hillside below Selmun Palace, probably places some part of the pervious beds of the syncline in contact with one or both of the Upper Globigerina Limestones, and so provides a line of discharge to the sea on the western coast, where, at the foot of Redum id Delli, both Upper Globigerina Limestones can be seen to pass below sea level for a considerable distance in the southern flank of the Mellieha uplift. Unless the internal structure of the Mellieha uplift at the level of the Upper Globigerina Formation should prove to be much more deeply furrowed than there is at present any reason to suspect, discharge to the sea northwards beneath the Mellieha Ridge, or out to the eastern coast, is most unlikely. Two areas of localised overdeepening were proved in the floor of the syncline, and it is probable that it is opposite the western hollow at Ghain Znuber that discharge across the fault plane takes place. Here, as will be seen from Section CC', Plate 14, the stratigraphical displacement effected by the fault is considerably greater than opposite the eastern hollow, where B.Hs. 145 and 147 showed that the throw of the fault could not amount to much more than 100 feet, in which case the local thickness of the Blue Clays should be adequate to produce a completely effective seal (Section BB', Plate 14). A series of core-holes, as shown on Plate 13, is required to determine accurately the position of the Upper Globigerina Limestones in close proximity to the northern side of the fault plane, and the position of the top of the Blue Clays in close proximity to its southern side. Percussion drilling is not suitable for the formation conditions on the northern side of the fault, as it is difficult to locate with accuracy the line between the Blue Clays and the Upper Globigerina, and the subdivisions of the latter formation above the the basal nodule bed, in bailed samples of pulverised rock. The line between the Greensand and the Blue Clays on the south side of the fault can be determined fairly accurately in cable-tool holes, but the considerable additional value of dip evidence from cores warrants the use of a core-drilling machine for the whole programme. With core-holes suitably staggered at 100 feet intervals along 4,500 feet of the fault line less than 10,000 feet of hole should be adequate to provide a complete answer to the questions of how much and what type of underground work would be required to raise the standing water level within the syncline to the spillover levels at the Wied tal Kalkara culmination of pitch and at the saddle through the Baida Ridge. The amount of work required would certainly be much smaller than under the conditions presented by the Upper Coralline-Lower Coralline contacts along the

faulted southern limbs of the Binjemma and Falka Synclines. At Miziep all that would be required would be cementation over relatively small heights of the fault plane from the top of the Blue Clays on the downthrown side of the fault to the base of the Blue Clays on the upthrown side, with particular attention to any fissures and old underground stream channels in the Upper Globigerina Limestones. The evidence of the amount of turn-up to the southern side of the fault, secured by B.Hs. 147, 157, and 160, suggests that work below the present standing water level would be required for only comparatively short distances.

214. As it stands at present the Miziep Syncline proposition affords excellent prospects of increasing the Island's permanent supply of freshwater by at least some 109 million gallons a year, in return for the cost of a single central pumping station with a 200-foot shaft and three to four miles of galleries. A gallery plan for the whole structure, including the adjacent catchment areas down Wied tal Mistra and the northern slope of Xaghra tal Mayesa, which at present do not contribute to the Miziep catchment, should be completed before and independently of any sealing operations along the Ghain Znuber Fault. The total length of galleries required to institute completely centralised drainage would not exceed 4 miles, and, in the practical absence of private appropriations from the catchment area, there would be nothing like the wide discrepancy between winter and summertime productions that there is in the case of the major existing Rabat-Dingli galleries. In the summer months, during which the structure test borings were carried out, standing water levels as high as 20 feet above the top of the Blue Clays were observed far up-dip from the standing water table in the bottom of the syncline, and even on the crest line of the Baida Anticline there was sufficient water in the formation in July to give depths 8, 11, and 6 feet of water above the top of the Blue Clays in B.Hs. 149, 150, 152 respectively. The salinity of the samples bailed from the twenty-four holes in which water was encountered ranged from 5.1 to 24.3 parts of chlorides as chlorine in parts per 100,000; two holes yielded water with salinities less than 8 parts per 100,000; twenty holes yielded salinities evenly distributed between the value of 8 and 16 parts per 100,000; the salinities in excess of 20 parts per 100,000, which were yielded by two holes, may be reliably ascribed to local surface contamination from fields and from Ghain Znuber Farm. The arithmetic mean of all the salinity determinations was 11.4 parts per 100,000 and it is unlikely that this mean figure would ever be exceeded appreciably during bulk extraction from the syncline, provided that the surface catchment area were efficiently conserved and provided that only the annual inflow were appropriated as it arrived at the water table. Pumping down to below sea level under present conditions would no doubt lead to the influx of more saline water from the Globigerina Formation to the north of the fault, and possibly, if continued for a lengthy period, to contamination by sea water.

215. Of even greater importance than the annual contribution which the Miziep Syncline can make to the Island's freshwater supply is the solution which it offers to the problem of large scale storage for the equalisation of supplies. It should be possible to provide storage to the extent of at least 1,000 million gallons much more cheaply and safely by the utilisation of the syncline than by the construction of surface reservoirs to hold the same volume of water, even under the most favourable conditions for surface construction presented by the Blue Clays of Wied L'Iemu. The present and potential capacity of the syncline

has been computed, from cross sections on a scale of 100 feet to the inch, at longitudinal intervals of 100 feet, to be as follows:

Vertical Interval (Feet)	Volume of U.C.L. and Greensand (Cubic Feet)	Storage Capacity at 20 per cent saturation (Gallons)
50 to 40	178,970,000	223,712,500
40 to 30	148,720,000	185,900,000
30 to 20	127,920,000	159,900,000
20 to 12	87,400,000	109,250,000
50 to 12	543,010,000	678,762,500
12 to 10	21,810,000	27,262,000
10 to 0	92,346,000	115,425,000
0 to -10	75,930,000	94,912,500
-10 to -20	59,090,000	73,862,500
12 to -20	249,176,000	311,462,000
-20 to -30	33,270,000	41,587,500
-30 to -40	7,930,000	9,912,500
-40 to -50	2,540,000	3,175,000
-50 to -60	960,000	1,200,000
-60 to -70	90,000	112,500
-20 to -70	44,790,000	55,987,500

In the summer of 1945, therefore, the syncline is estimated to have contained 367,450,000 gallons of freshwater, up to the height of 12 feet above sea level, adopted as the probable mean standing water level of the water table on the floor of the syncline, and taking no account of the large quantities of water which were found to be present in the vadose zone above this level. It would not be possible, however, to unwater from a single pumping station both major hollows in the floor of the syncline. The maximum depth proposed for extraction and for driving galleries is 20 feet below mean sea level. Deducting as unavailable the 55,987,500 gallons below this level, the estimated storage capacity of the syncline in its present condition is 311,462,500 gallons. By damming up to 50 feet above sea level it is estimated that storage for an additional 678,762,500 gallons would be provided, bringing the total potential storage capacity to 990,225,000 gallons. The mean ratio of saturation adopted in the above computations is undoubtedly a conservative one for the formations concerned, and it would not be surprising if a ratio nearer 50 per cent were to be realised in actual practice. The distribution of rock types recorded between the top of the Blue Clays and 50 feet above sea level in the 23 boreholes within the area of the 50-foot contour is :

Limestones	65 per cent
Limestones and Clays	26 „ „
Clays	6 „ „
Greensand	3 „ „

The limestones are very porous, pervious, and full of fissures, so much so that it was often difficult, until standing water level was reached, to keep enough water in the hole for drilling purposes. The impressive lines of ancient caverns in the Upper Coralline Limestones of the immediate neighbourhood in the cliffs above Redum Mayesa, along the northern side of the syncline, and along the southern scarp of the Baida Ridge, encourage the expectation that similar great open voids will be present in the limestones within the syncline, and that they will

increase its storage capacity out of all proportion to the actual porosity of the rock material itself. Unless the mean annual potential of only 109 million gallons which is credited to the Miziep catchment should prove to be greatly underestimated it is obvious that up to 50 feet above sea level there would always be a large margin for the storage of surplus winter production from other Upper Coralline areas, and, if future developments should show it to be available at low salinity, from the Main Sea Level Table also. The most suitable route into the syncline for such deliveries from the south would be by tunnelling through the limestone of the saddle N.W. of Il Puales. When the structural contours of the Mellieha Ridge Upper Coralline are known completely and with accuracy it will also be found possible to pipe water from the north into Miziep through a tunnel with a summit height less than 200 feet above sea level, entirely within the limestone formation and able to function also as a drainage gallery, instead of lifting it over the top of the Ridge.

216. The geological structure and the private wells and galleries of the Mellieha Ridge have not yet been surveyed systematically. When this survey work has been carried out it is possible that the present assumed boundary for the Miziep Catchment Area (Plate 9) may require expansion northwards, for the crest of the main line of uplift seems to lie within the northern part of the area and to trend approximately parallel with the Ras il Griebej Fault from the northern end of Redum id Delli on the west coast to the bay of L'Imjiebah on the east. There are, however, significant minor undulations within the 1,064 acres of Upper Coralline outcrop, and it will not be possible to appreciate fully their influence on the underground drainage until a detailed survey of the whole area has been completed. Present extraction from the ravines of Hanzira, Halcun, Gnien Ingrau, Tal Madonna, Ghain Zeituna, Imxuxu, L'Imjiebah, and Ghain Hadid, which cut deeply into the northern half of the uplift, is considerable, and probably accounts for an appreciable fraction of the 120 million gallons mean annual potential which has been credited to this area (para. 210). The only production figures available are for the Government gallery driven southwards from the original Tal Madonna Spring, along the main street of Mellieha village. The total annual production estimates for 1941-42 to 1944-45 are given in Table 3, during which period the maximum and minimum rates of flow recorded were 13,000 and 1,000 gallons a day. The minimum daily yield of this spring was stated by Robertson (1917, App. VI) to be 4,000 gallons a day, but this no doubt was a mistake for the average daily yield, as in the case of the Ghain Tuffieha Spring. There is probably a large subsurface flow from the area into the sea level table of Mellieha Bay, through contacts along the Ras il Griebej Fault and through slipped masses of limestone, hill drag and tufa, but my general impression is that it will still prove possible to appropriate for public use the major portion of the 120 million gallons mean annual potential mentioned above.

217. Six boreholes were put down on the Mellieha Ridge by No. 3 Boring Section R.E., in 1943, in search of water for Eighth Army camps. B.Hs. 16, 18, and 19, north of Selmun Palace were to test for a fault pool on the northern and supposedly downthrown side of the Tal Blata Fault (Shotton, 1943, para. 3). Actually all three holes were located on the southern and upthrown side of the fault, whose position and direction of displacement can be seen clearly in the adjacent Imjiebah Ravine. It is hardly surprising, in view of the continuous seaward dip on both sides of the fault, and the farmers' galleries in close proximity to the borehole sites, that the holes failed to secure any appreciable yield of water. Two other holes in this neighbourhood, B.H. 20 near the head of the Imjiebah Ravine and B.H. 21 on Kortin ta Ghain Zeituna, were also failures. The last borehole on the Mellieha Ridge, B.H. 22, was sited to test for a fault pool on the downthrown side of the fault which passes inland from the western coast between Il Mansap and Ghain Znuber Tower (Shotton, 1943, para. 4). It failed to obtain water from the Upper Coralline Formation, was carried deeper with a view to testing the sea level table in the Globigerina Formation, and was

abandoned, owing to drilling difficulties, after penetrating 90 feet of the Blue Clays (Paver, 1943). An examination of the adjacent cliff section of Redum id Delli, and consideration of the surface height of the borehole, would have shown that the thickness of the Blue Clays, the position of the top of the Globigerina Formation, and the depth to the sea level table, as estimated from a resistivity survey at this site (G.H.Q., M.E.F., 1944, Fig. M 6), were very inaccurate.

218. The Upper Coralline outcrops of Mellieha Bay, between the Ras il Griebej and Ghar Bakrat Faults, cover a superficial area of approximately 1.20 square miles, and display three major structural subdivisions, viz. two strike-faulted synclines, each somewhat narrower than that of Wied tal Puales, separated by an eastward-pitching anticline. A sea level table extends throughout the Upper Coralline where the top of the Blue Clays is below sea level, but, owing to the close proximity of the sea, the amount of freshwater which can be extracted at any point without a prohibitive increase in salinity is very restricted. However, the table has proved adequate for the irrigation of two small but intensely cultivated areas of alluvial soil along the valley of Il Meieli and Il Ghadira to the north, and along the valley of Il Hofra and the lower slopes of Kasam Barrani to the south of the median anticlinal ridge. The bare rocky slopes of Il Gudia and Il Biskra which rise in the middle of the isthmus have provided the site for the Mellieha Camp and Military Hospital. The top of the Blue Clays is above sea level beneath about half the area of this ridge, and the construction of a gallery around the strike of the pitching anticlinal nose is worthy of consideration, as it would provide a small but useful supply of freshwater within the camp area, relatively free from the danger of surface contamination which accompanies any extraction from the adjacent sea level table.

219. The southern synclinal strip lies between the Ras il Griebej Fault and another strong strike fault, which crosses the isthmus from the southern side of Il Praiet (Anchor Bay) to the southern corner of Mellieha Bay and throws down to the south. The depths to which the base of the Upper Coralline descends within this faulted syncline are not known. There can be no doubt that over most of its area the top of the Blue Clays lies well below sea level, but it is possible that the Clays may rise above sea level over restricted areas in proximity to the Ras il Griebej Fault, in which case there would be scope for the collection by galleries of a useful quota of the fresh water from the northward watershed of the Mellieha area (para. 218), before it reaches the sea level table. Since the original cadastral survey of the Island was carried out in the 1890's there has been a considerable increase in the area of cultivated fields along the lower slopes of Kasam Barrani, and in the number of shafts sunk to the sea level table. Two boreholes, Nos. 5 and 8, were put down here by No. 3 Boring Section, R.E., in April and May 1943, to provide supplies for the Mellieha Camp and Hospital, on the supposition that the water was held up in a fault pool (Shotton, 1943, para. A). Actually the boreholes proved the sea level table at a height of 3 to 4 feet above sea level. They were carried to depths of 26 and 20 feet respectively below sea level without reaching the base of the Upper Coralline, and the initial salinities recorded were only 32 and 10 parts of chlorine per 100,000. The supplies soon had to be discontinued, however, as considerable increase of salinity occurred when pumping at a rate of only 1,000 g.p.h., and there was evidence of gross surface contamination.

220. Five smaller faults with varied amounts of southerly downthrow occur in the southern limb of the Gudia Anticline to the north of the main Il Praiet Fault; their throw is partly opposed to the local dips, but the combined effect of dip and faulting, on the eastern side of Il Praiet, is to raise the top of the Blue Clays from below sea level at the Il Praiet Fault to about 70 feet above sea level on the northern side of the Bay, within a cross-strike distance of 500 feet. This is the highest altitude attained by the Clays within the anticlinal area (cf. Bailey, 1943, para. 36). The valley of Il Hofra has been eroded across the isthmus along the faulted zone, and three boreholes which were put down by No. 3 Boring Section, R.E., in Lands Il Hofra and Il Biskra on the northern side of

the fault zone are of value, in conjunction with the west coast section from Il Praiet to It Chumnia and with the excellent exposures on the bare rocky hill top, for obtaining an approximate idea of the trend of the contours around the pitching anticlinal nose. B.H. 6, near the northern edge of the fault zone, proved the top of the Blue Clays at 2 feet above sea level; B.H. 7, 400 feet to the N.E., at 18 feet below sea level; and B.H. 4, on top of the ridge to the west of the camp, at 6 feet below sea level. B.H. 6 obtained no water; B.H. 7 was able to bail only 60 g.p.h. from the sea level table; and B.H. 4 obtained a yield of 60 g.p.h. from above the basal marly beds of the Upper Coralline at 16 feet above sea level, but no additional supply from the base of the formation. (1)

It will be seen from the above evidence that the area in which the Blue Clays rise above sea level does not extend completely across the isthmus, as shown in the G.H.Q., M.E.F., map (1944, Fig. M 2), but only as far east as the neighbourhood of B.H. 6. Contour galleries driven a little above sea level, from a 40-feet shaft hereabouts towards the western coast in Il Praiet and to the north of Ras in Nieshfa, would intercept the freshwater drainage from a surface catchment area of about 102 acres, which should provide a mean annual supply of about 11½ million gallons.

221. Although the sea level table of the synclinal area between the Gudia Anticline and the Ghar Bakrat Fault receives considerable replenishment from Il Gudia and from the southern scarp of the Marfa Peninsula, in addition to its own surface catchment, there is little scope for further extraction in excess of that already utilised for irrigation. It is unlikely that the Blue Clays rise above sea level anywhere within the area, and no point within it is situated more than 700 yards from the coast.

222. The Upper Coralline area of the Marfa Peninsula is bounded on the south by the Ghar Bakrat Fault, which attains its maximum throw at the eastern end of Redum Kammieh. Here, north of Gebel Imbark, some eighty feet of the Lower Coralline are seen above sea level in the fault gully, thrown against beds high in the Upper Coralline succession. The base of the Upper Coralline on the upthrown side of the fault rises to about 300 feet above sea level at this point, its maximum elevation within the Marfa area. On the eastern coast, in the cove of Ghar Bakrat, the fault throws the base of the Upper Globigerina Beds at sea level, against Upper Coralline Limestones on the downthrown side. In the cove of Tal Imgharka, a little further to the north-east, where Middle Globigerina Beds are at sea level on the upthrown side of the fault, the line of the Ghar Bakrat Fault is displaced southwards, beneath the waters of Mellieha Bay, by an important cross fault which throws down to the east. The Tal Imgharka Cross Fault strikes due north towards Armier Bay and divides the Peninsula into two structurally dissimilar portions. On the western side of the cross fault the structure from the Ghar Bakrat Fault is essentially an undulating monocline, in which the base of the Upper Coralline Formation passes below sea level northwards along a line running from the north-east corner of It Chirkaua (Paradise Bay) through Wied Musa and Lands Tamsit, and passes approximately midway between B.Hs. 23 and 27, which were put down by No. 3 Boring Section,

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(1) B.H. 4 is also of interest in being the only borehole to the north of the Victoria Lines Fault which has drilled through all groups of the stratigraphical succession and penetrated the Lower Coralline Limestone. The formation record made by No. 3 Boring Section, R.E., may be correlated thus:

0—118 feet	Soft white limestones	Upper Coralline Limestone.
118—138 feet	Yellow clays with thin limestones	Basal marly member of the Upper Coralline Formation.
138—140 feet	Green silts and clays	Greensand.
140—290 feet	Blue clays	Blue Clay Formation.
290—335 feet	Sandy blue clays	Upper Globigerina Beds.
335—385 feet	Green clays	Middle Globigerina Beds.
385—390 feet	White clays with thin limestone bands	Lower Globigerina Beds.
390—400 feet	Limestone and clays	Transition Beds.
400—418 feet	White limestones	Lower Coralline Limestone.

In addition to the 60 g.p.h. strike of freshwater above the basal marly beds of the Upper Coralline at 118 feet, a second show of water, estimated at 72 g.p.h. (salinity not recorded), was obtained in the Upper Globigerina Beds at 315 feet. A large supply, with a salinity exceeding 1,000 parts per 100,000 was struck in the Lower Coralline Limestone at 404 feet (270 feet below sea level). 6-inch casing, driven to 400 feet, was recovered in 1945 by No. 7 Boring Section, R.E., and the hole was plugged to surface.

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R.E., along the road to Ramla tal Kortin (Sunshine Bay), and proved the top of the Blue Clays at 14 feet above and 10 feet below sea level respectively. To the east of the Tal Imgharka Fault a broad anticlinal crest, parallel to the Ghar Bakrat Fault and the northern coast of Mellieha Bay, trends through Ir Razzet Ta Pore and Ir Razzet ta Xuxien to the neighbourhood of Ponta tal Madonna. The southern limb of the anticline is much steeper than the northern, its axis appears to pitch gently westwards, but the position of the sea level contour on the top of the Blue Clays within it cannot be plotted with precision from the limited surface evidence alone. Much water is extracted for irrigation purposes from the sea level table beneath the northern slope of the Peninsula towards the Comino Channel, and there has been a great increase in the area of cultivation during the past fifty years. However, much of the surface still remains in the condition of bare rocky xaghra, particularly in the western portion rising towards Torri L'Ahmar and the ridge of Id Dahar, and it would be a relatively simple and straightforward matter to obtain a very useful contribution to the public supply of freshwater from strike galleries above sea level within this area. Extraction from the smaller area above sea level in the anticline to the east of the Tal Imgharka Fault would be more difficult to engineer, and, as cultivated fields occupy a much greater proportion of the surface area of this catchment, the quality of the water obtained would almost certainly be much inferior to that from the western portion of the Peninsula.

223. A tentative estimate of the potentialities of the Marfa Peninsula, pending detailed survey of its structural geology and present private water supply works, may be tabulated, thus:—

Catchment Area	Surface Area (Acres)	Potential Mean Annual Percolation (Gallons)
Western Marfa Sea Level Table ...	256	28,928,000
Eastern Marfa Sea Level Table ...	230	25,990,000
Western Marfa Northern Watershed ...	500	56,500,000
Western Marfa Southern and Western Watershed	179	20,227,000
Eastern Marfa Northern Watershed ...	115	12,995,000
Eastern Marfa Southern Watershed ...	90	10,170,000
Eastern Marfa — Mellieha Bay Sea Level Table	13	1,469,000
Total, Marfa Upper Coralline Area	1,383	156,279,000

If the possibility of public appropriation from the sea level tables be ruled out of question, on account of the high salinity of the water which would be obtained (B.H. 27, at the inner edge of the sea level table, had a salinity of 54 parts per 100,000 when pumped at a rate of only 1,000 g.p.h.), and on account of the extensive private extraction already in existence, there remains a total mean annual potential of 99,892,000 gallons draining from the upland catchments, of which the 56½ million gallons from the Western Marfa Northern Watershed would be most immediately available. The ultimate objectives of extraction from the Marfa Peninsula should be the addition of the 20 million gallons which are at present discharged from the western cliffs and the southern scarp, and the 23 million gallons at present draining from the Eastern Marfa Anticline towards the Comino Channel and into Mellieha Bay, so bringing the total mean annual potential supply of freshwater to about 100 million gallons.

224. At least three important strike faults occur within the Western Marfa area, and it will be important to determine by boreholes the effect of these faults on the geological contours before attempting to plan the details of a gallery system. The southernmost two faults throw down to the north, where

seen in clear section in the western cliffs, and, if this direction of throw continues completely across the area, they should not afford any serious impediment to northerly down-dip drainage. About half the catchment area could be drained by a strike gallery at 100 feet above sea level driven for the mile and a half to the western cliffs from the southern scarp of the Peninsula above Tal Imgharka Cove. The remaining half, from the 100-foot contour on the Blue Clays down to the inner edge of the sea level table, will require a gallery about a mile and a quarter in length, driven a few feet above sea level from a central pumping station, with a 50-foot shaft, in Wied Musa or in Wied tal Bir. Accurate determination of the course and throw of the northernmost strike fault will be of importance in connection with the alignment of the sea level gallery. Where clearly exposed in the cliffs on the southern side of It Chirkaua this fault throws down to the south. If it continues eastwards within the above sea level drainage area with this direction of throw it might prove well worth while to locate the lower drainage gallery of the area on the up-dip side of the natural underground dam thus provided. The most suitable gallery plan for the Eastern Marfa Anticline will depend on the form of the Blue Clay contours at the western end of the area. Should the sea level contour close around the crest line to the east of the Tal Imgharka Fault it might prove possible to extract the greater part of the drainage from both sides of the anticline by continuations of the Western Marfa sea level gallery; otherwise a separate gallery system and pumping station will be required for at least the southern watershed.

225. It is hoped that the preceding paragraphs will have demonstrated adequately that the main function of the Upper Coralline areas in the Island's natural internal economy should be that of catchment areas for the public water supply, and that their strict conservation for this purpose should have prior claim to all other aspects of their present and future utilisation. The clash of interests between the local agricultural communities and the much more numerous urban section of the Island's population is inevitable and must be faced, the sooner the better. At the same time as providing the only direction in which the Island's supplies of perpetually freshwater can be increased, the Upper Coralline areas are practically the only parts of the Island in which extensions of cultivatable land are still possible. Reference has already been made (para. 130 and footnote) to the process of soil reclamation and utilisation which is constantly in progress, and to the inevitable deterioration in the volume and quality of previously existing public water supplies in certain areas where the industry of local farmers has led to the extensive appropriation of underground water resources for irrigation purpose. After many years of "laisser faire" the latter process has been halted by legislation forbidding further private water supply developments, although it is obvious, in travelling around the Upper Coralline areas, that the provisions of the successive Ordinances are not yet being fully implemented. There is, however, another factor which basically affects the volume of Upper Coralline water supply resources, and which has not yet received legislative recognition. Every expansion of the permanent soil cap upon the limestone outcrops is accompanied by a proportionate reduction in the amount of percolation, and any further expansion over the upland catchment areas should be prohibited. At first sight the small annual additions which attract attention may seem negligible, and the suggested restriction inadvisable. It is necessary to take out the 1:2,500 Survey Sheets, which were made in the 1890's, to realise adequately the cumulative effect of these additions, over fifty years of steady colonisation of waste lands, in reducing the extent of the bare limestone surfaces, through which percolation underground mainly occurs. Percolation from the rainfall through even a few inches of residual red clay soil is very small, and must be negligible in amount when an accumulated thickness of two or three feet is attained. Robertson's suggestion (1917, p. 23), that extensive trenching and tree planting should be carried out to reduce evaporation losses, seems very attractive at first sight, particularly when envisaged as part of a general programme to improve the scenery and amenities as well as to conserve the underground water resources of the Upper Coralline

uplands. On further consideration, however, it seems very doubtful whether there would be any appreciable gain to underground water supplies, and almost certainly no gain proportionate to the cost of creating permanent woodlands sufficiently dense and extensive to produce a significant reduction in the total annual evaporation from the soil and rock surfaces. The consumption of water by fir and oak plantations is estimated to range between 0.02 and 0.04 inches per day during the annual period of active growth, and the consumption by carob trees, which Robertson specifically recommended owing to their value as a supply of fodder, is not likely to be less than this amount. In areas where the thickness of limestone is small the tree roots would soon extend down to the base of the formation, and it is possible that the loss of water by transpiration would exceed the local mean annual intake to underground storage. The issue could only be decided by a long term experiment, which should be carried out on the xaghra of one of the smaller Upper Coralline catchment areas, such as Ghain Tuffieha, where the total rainfall and total extraction could be assessed with a minimum probable error.

226. In conclusion a most important aspect of conservation which must receive early attention is the growth of centres of population on the Upper Coralline catchments, which unless checked by legislation, will probably be speeded up by the improvement of roads and transport services. In view of the small total extent of the Upper Coralline areas it is as essential that any further extension of towns, villages, and military installations should be avoided as it is that increase in the area of the soil cap should be prevented. There are several long established centres of population which require immediate attention. The water of the old Gharixiem and Sakkaja galleries long ago became too contaminated for domestic use owing to the growth of Rabat. In the interest of existing supplies from the Via Dingli galleries further southward expansion of the town, beyond the Dominican Monastery and the present limits of Hal Baiada, should be prohibited. Expansion westwards should be limited to the eastern side of the ridge which runs from Hal Baiada through Ta L'Abatia towards Tabia, with a view to the possible restoration of the former volume of Wignacourt supplies from the Ghar Barca Syncline. If it is essential that further expansion or redistribution of the population of Rabat should be provided for beyond the capacity of these limits, diversion to the clay lands at the head of the Gharixiem valley is suggested. The village of Dingli should be restricted to its present eastern, southern, and western limits, within which there is still much space for development. Should further expansion be inevitable it should be planned northwards over the Il Kbiela spur towards the head of Wied L'Iemu. The villages of Imjar and Iz-Zebbieh should not be allowed to expand over the northern slopes of the Binjemma catchment area beyond their present limits, and expansion of the small group of farms at Ta L'Abatia, Tal Iskorviet, Binjemma and Falka should also be prohibited. A considerable straggling and insanitary expansion of the hamlet of Manikata has taken place in recent years, directly above the western spill from the southern watershed of the Baida Anticline. It is suggested that further expansion of Manikata should be discouraged, and future appropriations for building sites in this neighbourhood should be diverted to the slopes on the Blue Clays outcrop north of Lands Il Habel il Kbir, Il Habel L'Isuet, and Ghex il Hita in Wied tal Puales. Mellieha has extended far southwards from the original village centre on the spur between the Gnien Ingrau and Tal Madonna ravines, and is spreading widely over the summit of the Mellieha Ridge and into the catchment area of the Miziep Syncline. In view of the probable future importance of the Miziep area in the water supply system of the Island as a whole, and the fortunate combination of circumstances which has almost completely preserved the valley from settlements up to the present (there are only eight small, widely separated farmsteads in the whole valley), steps to prevent all further southward expansion of Mellieha, and any increase in the resident population, human and animal, of the Miziep Catchment Area, should be taken immediately. The workaday interests of many of the inhabitants of Mellieha are centred on the fields around Mellieha Bay and

on the Marfa Peninsula, and it is suggested that one or two newly planned villages, on the lower slopes of Kasam Barrani, or at the foot of the Torri L'Ahmar scarp, where surface appropriations would affect only the small sea level table of Mellieha Bay, would meet their requirements, and modern conceptions of housing amenities, much better than the congested conditions in the present village high up on the ridge.

PART VI. THE REORGANISATION OF PRODUCTION, STORAGE, AND DISTRIBUTION

227. The complete utilisation of available water resources discussed in the preceding parts of this report will require (i) a relatively simple arrangement of three or four main pumping stations, each with a radial system of galleries, along the major axis of the fresh water area of the Main Sea Level Water Table, and (ii) a much more diversified arrangement of galleries and pumping stations for draining the Upper Coralline catchment areas. The régime of the Main Sea Level Table is now sufficiently well defined and understood for the construction of at least two of the proposed new central pumping stations (Ta' Kandia and Wied il Bakkia) to be embarked upon without hesitation, and it will be possible for some time to dispose of their production through relatively minor additions to the existing storage and distribution system. It will not be possible to lay down a final plan for the most rational and economical combination of the supplies from both the Main Sea Level and the Upper Coralline Tables until the detailed structures of the latter areas, and the possibilities of large scale storage, have been fully and accurately investigated. But, as all the Upper Coralline Areas fall within a compact N.–S. belt along the western side of the Island, with the potential large scale storage facilities of Miziep at a low altitude in the north, and the high level facilities for reservoir construction in Wied L'Iemu and on Jebel Ciantar in the south, the centralised arrangement of pumping stations and main pipe lines, shown on Plate 9, would appear to be the ultimate rational plan for which to strive.

228. The structure of two of the Upper Coralline areas, Binjemma-Falka and Miziep, is sufficiently well known for plans and estimates for the construction of pumping stations and gallery systems to be prepared immediately, and development of these two catchments would provide a valuable addition to the relatively small annual freshwater supply which is drawn nowadays by the Water Department from the high level springs. Any pipe lines installed to deliver their production to the existing storage and distribution system serving the main population centres of the island should be aligned along the main N.–S. axis of the Upper Coralline areas, as shown on Plate 9, and arranged to deliver initially down the old Wignacourt line from Fiddien. Thus such pipe lines would not be merely temporary expedients, but would fit into the ultimate rational scheme for the whole of the Upper and Lower Tables. In any case a deep shaft, a central pumping station, and a gallery system will be required at Miziep, not only for the extraction of the local supply but also for the seasonal introduction of additional water from the Main Sea Level Table and from the other Upper Coralline areas, should the large scale storage potentialities of the basin be confirmed by the proposed core-drilling programme. Consequently work at Miziep should receive priority.

229. Even in the anticipated event of the Miziep storage scheme proving feasible and successful some reasonably large reservoir facilities will be required nevertheless, further to the south, to collect seasonal surpluses from the Upper Coralline of the Rabat—Dingli area, and from the Main Sea Level Table for transmission to Miziep for storage, by way of the N.–S. pipe line system. In the event of the scheme for dramming up the Miziep basin to 50 feet above sea level not proving to be economically feasible, the large reservoir capacity required to combine and equalise supplies from the Lower and Upper Tables could probably be developed more economically in the Blue Clay outcrop of Wied L'Iemu, and in the Upper Coralline Limestones of Jebel Ciantar, more economically than anywhere else in the island.

230. The roads from Rabat to Ghemieri and to Tas Salib cross the Wied L'Iemu by bridges based on a rock bar of Upper Coralline Limestone, which is deeply synclinal in form, and has a minimum width of about 1,000 feet at surface, measured from the base of the limestone in the bed of the wied above

the Ghemieri Bridge to the base of the limestone in the bed of the wied below the Tas Salib Bridge. The surface dips in the vicinity of each bridge average about 30 degrees inwards towards the axis of the syncline. Limestone bedrock at the Ghemieri Bridge is at an altitude of about 402 feet above sea level. A narrow concrete core (a thickness of 3 feet would be ample) 600 feet in length and with a summit level of 450 feet A.S.L., embedded in the limestone of the southern limb of the syncline, and carried down into the Blue Clays beneath, would impound upstream an area of about 26 acres, according to the contours of the 2–inch map. The area impounded by increasing the length of the dam to 1,200 feet and increasing its summit height to 475 feet above sea level would be about 97 acres. Open reservoirs would be out of the question, on account of the high evaporation loss and the danger of surface contamination, and the designing of a large covered reservoir, or a group of covered reservoirs on a basement of the Blue Clay Formation, would involve considerable problems of stress distribution. The Blue Clay slopes alongside the wied, however, are much more gentle, thanks to the obstacle to deep erosion imposed by the limestone rock bar, than is usually the case on outcrops of this formation, and it is considered that the prospects of achieving really low construction costs per unit volume by utilising mechanical excavation, by lighter pitching of floors and, sides, and, possibly, by the use of floating roofs, are well worthy of detailed consideration.

231. The first essentials for further study of the scheme is an accurate plan on a scale of 1/1000, contoured at intervals of 5 feet, up to and including the adjacent limestone scarps; and a few boreholes along the line of the wied, to determine the thickness of the alluvium and of the Blue Clays below ground level. B.Hs. Nos. 64 (Sta. Katerina) and 78 (Ghemieri), situated near the southern and the northern ends of the Blue Clays inlier, proved depths of 69 and 47 feet respectively before the top of the Upper Globigerina limestone was reached. If an average reservoir depth of only 20 feet over an area of 50 acres could be achieved in Wied L'Iemu it would mean a storage capacity of more than 250,000,000 gallons, and would provide a very useful contribution to the problem of equalisation of supplies.

232. An additional 1,000 feet length of dam, embedded in the limestone rock bar, would be required to impound the Wied Ghemieri up to the 475-foot contour, and the area covered would be only about 12 acres, owing to the narrowness and steep gradient of the lower part of this tributary valley. The proposed topographical survey, however, should be extended into this wied also. The boundaries and observable structure of the rock bar, and the suggested lines for the concrete cores, have been plotted on 25-inch scale plans deposited with the Civil Government Water Department.

233. As mentioned previously a reservoir in the Wied L'Iemu, discharging at an altitude of 400 feet above sea level, would not provide gravity distribution to all the villages in the main part of the Island. The proposed pipe line system along the Upper Coralline areas should be continued, therefore, to its logical conclusion on Jebel Ciantar, at the southern end of the Rabat-Dingli Plateau, where, with a ground level of about 750 feet above sea level, reservoirs can be constructed with head adequate to serve all the villages of the island, including even Mellieha, Dingli, Rabat, Nashar and Gargur, thereby eliminating all the present boosting stations. Some such scheme seems to have been contemplated in the past, for, near the eastern end of the Jebel, there is an old excavation 80 yards square and with an average depth of 12 feet. The rock is much fissured Upper Coralline Limestone, but the fissures could be grouted easily, and the whole excavation rendered water-tight cheaply by cementation, to contain approximately 4,320,000 gallons as it stands. Owing to the flat-topped character of the Jebel, cut-and-cover tanks could be constructed, at approximately the same ground level, over contiguous areas of 400 by 750 feet and 600 by 1,800 feet, as shown on Plates 8 and 9, and, on the evidence of hand-dug shafts on Lands Ta Fuq Il Fulija, could be carried down to a depth of 50 feet below ground level without reaching the Greensand and Blue Clays. The area

thus defined would contain 86,250,000 gallons for every 10 feet of depth provided, and a total of 431,250,000 gallons if excavated to a uniform depth of 50 feet. The spoil could be disposed of easily along a tramway leading at gentle grade to the cliff-edge at Fakkania, and tipped into the sea down Redum Hurrieka. There are no cultivated field strips on this steep redum, so that there would be no question of claims for compensation on this score. The boundaries of the area under discussion have been indicated on 25 inch plans deposited with the Water Department. They are everywhere sufficiently far removed from the border of the Upper Coralline outcrop to be free from danger of damage by landslips.

234. The scheme of large scale underground reservoir construction on Jebel Ciantar is attractive from many points of view. Excavation costs would be much higher per unit volume than in the Blue Clays of Wied L'Iemu, but might be offset to some extent by the provision of useful building stone. The surface land to be appropriated would be much less valuable. The problem of spoil disposal would be avoided, and so also would the problem of earth stresses involved in any programme of covered reservoir construction in the Blue Clays. At first sight the pumping and pipe line costs, for raising water to a height of 750 feet above sea level, might seem to be a serious disadvantage. But similar heads would have to be faced in pumping from the Main Sea Level Table by the most direct routes to reservoirs in the Wied L'Iemu, and in moving water backwards and forwards, to storage in Miziep and returning it again when required for distribution. The point to be emphasised is, once it is lifted to the summit of Jebel Ciantar, water can be delivered by gravity to practically any point within the limits of the island, whether for storage in Wied L'Iemu or Miziep, or for distribution to consumers.

235. To do away, once and for all, with the difficulties of distribution which are experienced every summer as a result of the present inadequate patchwork of mains and local service tanks, it is proposed that the basic plan for future development should be distribution in two stages from Jebel Ciantar. The first stage would be by descending mains laid alongside Vicolo Tal Pinciott to a pressure control station on the 350-foot contour, south-west of Sijjiewi, near the junction of Valley Ta Manduca and Road tal Providenza. The second stage would consist of a 24-inch diameter ring main, approximately 23.75 miles in length, suitably located to feed both the "Outer" and "Inner" circles of villages, and crossed by a 36-inch diameter line, 3.63 miles in length, directly from the pressure control station to the Marsa, to help in accommodating the particularly heavy peak demands from the Harbour towns. The volume of water required to fill these mains would be about 3,800,000 gallons, and would provide, therefore, a further useful increase in storage capacity. The proposed alignment of the ring mains, as shown on Plate 8, would cater effectively not only for the present day villages, but also for the redistribution of population from the congested area around the harbours, which may be expected to take place within the next ten years, if the recommendations of Messrs. Harrison and Hubbard's town planning report are carried out.

236. The total weight of pipes involved, including the descending mains from the reservoir to the pressure control station, would amount to approximately 18,800 tons, so that, under conditions of post-war shortages, there would seem little possibility of such an order being filled within several years, even were funds available to place it. Difficulties in obtaining supplies of machinery and materials, and the time which must inevitably elapse before all the proposed new extraction works in the Lower and Upper Tables can be operating, may encourage a reversion to the unfortunate patchwork methods of development which have characterised the Water Department's past history, and which have been largely responsible for the present impossibility of meeting the legitimate demands of what, after all, is a very concentrated urban population. Any such tendency should be strongly resisted. No new works of any magnitude should be devised as temporary expedients, but all should be designed to fit together ultimately as rationally connected parts of the plan, presented above, for treating the whole Island as an efficiently reorganised unit.

PART VII. THE PRESENT POSITION OF IRRIGATION SUPPLIES AND THE PROSPECTS OF SEWAGE UTILISATION

237. It is not an easy matter to estimate with precision the quantity of water at present being drawn from underground sources and used for crop irrigation in Malta. Here as elsewhere, the practice of individual farmers varies considerably according to the location of the farm, the type of soil and crop, and, above all, the ease or difficulty with which the water is obtained. Where water is most easily procurable, as, for example from the relatively shallow shafts around the margin of the Main Sea Level Table, in the sea level tables of the northern fault strips, and in structurally favourable positions of the Upper Coralline catchments, such as the Ghar Barca and Ta Zerp Synclines, it is used much more liberally than in areas where the farmers have to husband supplies derived from road and roof catchments, or where they have to purchase their requirements from the Government Water Department. With such a minute subdivision of land, and the variety of crops which obtains in Malta, the only way to obtain really accurate measurements of the water used would be by metering it.

238. On the whole my impression is that irrigation water is not being quite so wastefully used as it apparently was in Chadwick's days, when he had to comment forcibly on the "very crude and wasteful" methods in vogue (para. 48). The average rates for different crops, given in Table 15, have been calculated after full consideration of Mr. Baldacchino's detailed notes of field surveys. They compare quite well with the rates which have been published for similar climatic regions elsewhere, such as Cyprus and California; and in the case of potatoes the Maltese rate is remarkably low. In the only irrigated areas for which detailed surveys have been completed by Mr. Baldacchino we have not found, up to the present, anything quite as wasteful as the average rate of 72 inches for general garden produce, quoted to Chadwick by Francesco Micallef. On the other hand we have found no evidence to substantiate anything as low as the annual rate of 21 inches, assumed for the whole of the irrigated tracts of Malta and Gozo by the 1936 Committee (para. 80). The overall rates for the only three areas in which the complete annual extraction rates have been worked out to date are:

	Gallons per tumolo per annum	Gallons per acre per annum	Inches
St. Paul's Valley	400,000	1,440,000	64
Ta Zerp	374,000	1,346,000	54
Binjemma	270,000	972,000	42

The reduction from the St. Paul's Valley sea level table, by way of the Upper Coralline synclinal tract of Ta Zerp, to the less favourable structural conditions beneath the irrigated lands of the Binjemma area, is significant of the relative difficulties of obtaining water in those areas. It is obvious that there is still much room for improvement in the economy of irrigation methods. If 42 inches is adequate for a year's garden cropping in the Binjemma area, it should be also at Ta Zerp and in St. Paul's Valley. The discrepancy between the range of irrigation rates determined from the minimum number and volume of various crop waterings on individual plots (Table 15) and those quoted above from determinations of the volume of water actually pumped in a given area, also affords a good measure of the waste which occurs when farmers are in a position to extract their own water cheaply, as and when required.

239. In the case of citrus plantations surface watering still appears to be the general rule in Malta. Surely, in an island where fresh water is so scarce and valuable, subsoil watering should be employed. The water thus economised would soon pay for the pipes required, and could be used for an increased area of citrus, or for the irrigation of other crops.

240. It should be pointed out to the farmers concerned that they are doing themselves no good by pouring unnecessary quantities of saline water, from the sea level tables, on to their fields. Its use only necessitates increasingly heavy manuring, not merely to provide a supply of nitrates, but in order to maintain any reasonable soil structure at all. It is probable that the vicious circle thus set up, by pumping increasingly saline water from sea level, then returning by percolation to the water table additional chlorides leached from the field manure, has had an appreciable effect on the rate of salinity increase of the public water supply galleries in the areas around Wied-is-Seuda, Armier, and Wied-il-Kbir (para. 157 and Plate 3). Certainly the increase of salinity of water from the high level galleries in recent years (para. 147 and Plate 1) can only be ascribed to the leaching of chlorides from the manure spread on fields in proximity to the Government galleries.

241. There can be little doubt that the area of irrigated land in Malta has more than doubled during the past ten years. In 1936 there were only about 1,120 acres under irrigation in the whole of Malta and Gozo, whereas the area under irrigation in Malta alone is at present about 2,000 acres. The area under dry cultivation is about 45,000 acres. This means that of the total area of the Island (60,717 acres) no less than 3.3 per cent is under irrigation, and 74.1 per cent under dry cultivation. There is probably no other island or country in the world which can equal these proportions in the agricultural utilisation of its total surface area.

242. Assuming an overall irrigation rate of only 23 inches per annum, which is the average of the rates for various crops listed in Table 15, the 2,000 acres of irrigated land is consuming 1,044 million gallons of water yearly. The rate of 42 inches per annum (para. 238), which is the minimum overall rate yet revealed by areal surveys, suggests a total annual consumption of at least 1,906 million by the irrigated areas, and seems a much more likely approximation to reality. This is far more than is annually extracted by the Government Water Department for urban use, so that, in view of the strictly limited nature of the Island's present and potential supplies, it can hardly be said that agriculture has not been allowed to help itself to a fair share. The impossibility of meeting the request of the Department of Agriculture in 1943 for provision of irrigation water for a further 2,728 acres has already been discussed (para. 93). It is much more likely that, in the near future, the trend of the past ten years will have to be reversed. Instead of permissions being given for further extraction of irrigation water, private shafts in many areas will have to be suppressed completely, in the interest of the public supply as a whole, and the area of crops under irrigation will be drastically reduced until such time as a completely integrated scheme, for the extraction, storage, and distribution of the Island's water resources as a whole has been achieved by the Water Department. Then it may become possible to allocate again to irrigation, more especially during and after seasons of good rainfall, some portion of the limited total resources available, and for this quota to be distributed more equitably to farmers throughout the Island, on the lines recommended somewhat prematurely by the Agricultural Irrigation Committee of 1935-36, instead of being available only in certain restricted areas.

243. In view of the crisis which has been reached between the claims for domestic and for agricultural water supplies, and the effect which the anticipated reduction of irrigation supplies will have on the Island's own food production, it is surely time that firm plans were made for the utilisation of sanitary sewage effluent for irrigation purposes. This was first recommended by Chadwick in 1884, and his recommendation was revived by Robertson in 1917. Apart from the local use of crude sewage to a small extent under the exigencies of siege conditions during the war, nothing practical has been accomplished. Crop irrigation by crude sewage however cannot be recommended under local conditions. There is the obvious danger to public health if vegetables eaten raw are grown on land irrigated with crude sewage, and the danger of contamination of the shallow underground water supplies. Further, large areas of open-sandy soil, which are not available in Malta, are required to ensure a successful project for the disposal of crude sewage by means of irrigation.

244. At present a large portion of the 3½ million gallons of water supplied daily for domestic consumption finds its way into septic tanks, or is discharged through the existing sewer system into the sea, and thereupon ends its usefulness. Given a complete and efficient system of sanitary sewers for the main part of the Island, and treatment by a modern activated sludge plant, the liquid portion of the sewage could be rendered perfectly safe for crop irrigation, and the sludge itself, after processing, would provide a fertiliser valuable to Malta soils by reason of its nitrogen content. With the expected increase of the domestic demand to 5 or more million gallons a day the wastefulness of the present situation will be even more reprehensible, for the volume of utilisable sewage effluent would then be similar to the quantity of water being used daily at present by the Island's 2,000 acres of irrigated land.

245. It is admitted that there are considerable difficulties to be overcome: (i) the slowness with which the centralised sanitary sewage system for the main part of the Island is being completed, (ii) the unsuitability of considerable lengths of the older sewers for the purpose in view; and (iii) the deteriorating composition of the water being supplied for domestic consumption. Here again the problem of high salinities arises. The average salinity of the domestic supply for the main part of the Island already exceeds 60 parts of chlorides per 100,000. By the time it reaches the sewers at least another 5-20 parts per 100,000 will be added, from the salt in food being excreted with body wastes. So that the ultimate sewage effluent would suffer from the same objection, of unduly high salinity, which is advanced against much of the water at present being pumped directly for irrigation purposes from the sea level tables. Further, the main sewer from Sliema, where more water per head is consumed for toilet purposes than in any other section of the Island, is cut in the Lower Globigerina franca, is unlined, and receives a considerable amount of sea water by direct infiltration from the Marsamuscetto.

246. When these impediments have been removed it is recommended that the sanitary sewage from the harbour towns and their suburbs should be pumped to the site for a Sewage Purification Works, on the shore of St. Thomas' Bay, indicated on Plate 8. Several weighty reasons combine to prompt the selection of this site:

(i) Even with the most skilful supervision, there is the danger that odours and other nuisances may arise occasionally from any sewage treatment plant. This site, however, is remote from all the main centres of population. At present there are only a few small isolated farmhouses in the vicinity.

(ii) Pumping costs from the main centres of population would be little higher than they are to the present outfall east of Kalanka tal Patriet.

(iii) Any temporary excess of incoming sewage or of effluent could be discharged directly into the sea without becoming a nuisance to any seaside town or village.

(iv) The flat land alongside the coast at this point is sufficiently extensive for a layout of tanks and other plant adequate to deal with all conceivable requirements.

(v) Within the quadrangle Marsa Scala—San Gregorio (Zijtun) — Marsa Shlok—St. Thomas' Bay there is sufficient area of gently sloping country to utilise most, if not all, of the sewage effluent ever likely to be produced. This area could be irrigated by gravity from a single service tank at about 200 feet above sea level on the ridge between St. Pauls' Battery and Fort Ta Silch. Owing to the great thickness of the marly Middle and Lower Globigerina Formations beneath this area there is absolutely no danger of contamination of any public water supplies drawn from the Main Sea Level Table. For the same reason there are hardly any local supplies of irrigation water at present, and the region is entirely given over to dry cultivation.

PART VIII. THE PROSPECTS OF DEEP BORINGS BELOW THE SEA LEVEL TABLES

247. In the first part of this Report note has been made of the various suggestions, from 1854 onwards, that Malta's deficiency of fresh water might be overcome by sinking deep wells or boreholes to tap artesian supplies fed by catchments in neighbouring continental areas, presumably in Sicily and Northern Africa. It has been noted also that, should such borings be attempted, strict precautions would have to be taken to guard against the contamination of the Island's present major source of potable water, the Main Sea Level Table. The reasons for this warning may now be discussed in greater detail.

248. The geological conditions which provide artesian supplies of fresh water have been well understood for many years. So also, now, is the stratigraphical and structural geology of the Mediterranean lands around Malta. As a result it can be stated most emphatically that there is not the slightest possibility of an artesian supply of fresh water being transmitted from those lands to any geological formation underlying Malta. On the contrary, it is much more probable that any porous formation encountered below the Lower Coralline Limestone of Malta will prove to contain water more saline than that of the Mediterranean, and that, the deeper the formation, the greater will be its salinity. It is also probable that should deep borings be made at suitable locations they will tap supplies of mineral oil, possibly of heavy asphaltum base type with a high sulphur content, and not merely saline waters. Hence the imperative need to ensure that each borehole which may be carried down below the Lower Coralline will be unable to introduce either of these undesirable fluids into the sea level freshwater table contained within that formation and within the surrounding Globigerina Limestones. The protection required is quite simple. In every borehole a string of extra strong casing must be cemented firmly in the first continuous impervious horizon encountered beneath the Lower Coralline, and the cementation must be tested thoroughly before the hole is permitted to drill deeper.

249. Government expenditure on deep boring in Malta, such as that proposed in 1935, in 1936, and again in 1940, in hope of discovering artesian supplies of freshwater, would be a criminal waste of public funds. On the other hand, the encouragement by Government of deep boring for oil by private enterprise would settle finally, by actual demonstration of their absence, the question of the possibility of deep freshwater supplies, and, at the same time, might provide a very useful additional source of income to the local exchequer in the form of royalties on the oil and natural gas discovered. Local geological conditions are sufficiently favourable to justify the speculation, by any major oil company already acquainted with the technique required by such prospecting ventures, of the half-a-million to a million pounds which would be required for the geophysical surveys and for the deep drilling programme necessary to complete the investigation. But more specific terms than those of Ordinance VI of 1921, which at present regulates the grant of concessions for oil prospecting in Malta, will be required to make the proposition attractive to private enterprise.

250. Three major factors control the formation of oil accumulations, and, unless all operate favourably, no accumulation of economic dimensions can be expected. First, a region must contain formations capable of generating oil; second, formations sufficiently porous to act as reservoir rocks must be present also, in contact with the potential generating formations; and third, it is necessary that the geological history of the region, subsequent to the deposition of the potential oil-forming and oil-storing formations; shall have facilitated the migration of the oil into the reservoir rocks, and shall have developed in them structures capable of concentrating and retaining the oil in positions suitable for extraction by boreholes. There is good evidence, both direct and indirect,

that all these factors may have operated favourably within the area now occupied by the Maltese Islands.

251. Correlation of the restricted stratigraphical succession exposed at surface in Malta and Gozo with the much longer stratigraphical successions of Sicily, Tunisia, Tripolitania, and Cyrenaica, suggests that beneath the Lower Coralline Limestone of Malta there is a thick succession of Tertiary and Mesozoic formations, suitable at various horizons for meeting the first and second conditions specified. The exposed upper portion of the Lower Coralline Limestone is of Lower Miocene (Aquitanian) age. In Sicily petroliferous indications are abundant and conspicuous in formations ranging in age from Lower Pliocene to Middle Cretaceous; in Tunisia the range extends downwards to the Triassic. None are known from Tripolitania and Cyrenaica, but the stratigraphy of those regions confirms that geosynclinal sedimentation was probably continuous throughout Mesozoic and Tertiary times over the intervening area, now occupied again by the Mediterranean Sea of the present day. With regard to structural history a comparison of the structure of Malta with that of the surrounding region leads to the conclusion that the area now occupied by the Maltese Islands has remained relatively high throughout the final phase of the Alpine folding and faulting movements during Pliocene and post-Pliocene time. More particularly the detailed geological surveys which have been carried out in Malta during recent years have revealed the presence of surface structures which would have been eminently suitable for the accumulation of oil within the Lower Coralline Limestone, had not this formation been elevated into the zone of sub-aerial denudation at the end of the Pliocene and stripped of its cover of impervious marly formations. Extensive geophysical surveys will be required, before any deep drilling can be undertaken, to determine how far the exposed surface structure may be a reliable guide to structure at the depths at which unbreached accumulations of oil may be expected to occur.

252. Direct evidence of at least the former presence of petroliferous accumulations within the Maltese area has been on record for more than fifty years, but its significance does not appear to have been appreciated. In 1892, in a paper "On the Occurrence of Black Limestones in the Strata of the Maltese Islands", J. H. Cooke recorded the presence of carbonaceous veins and impregnations in the Lower Coralline Limestone near Il Mara and Ghar Hassan in Malta, and in the Gozo "marble" quarries below Qala. In many cases the narrow fissure fillings are lightly slickensided, so that movement along them must have taken place subsequent to the intrusion of the original bitumen, probably during the late-Pliocene and post-Pliocene disturbances mentioned above. The material now is practically pure carbon, having lost all other constituents during the long period of elevation and denudation of the Lower Coralline Limestone. To what extent these vien and impregnations may indicate the continued survival of liquid hydrocarbons in formations below the Lower Coralline Limestone, or whether they may be the only evidence now remaining of former accumulations, only deep drilling will be able to prove conclusively.

PART IX. CONCLUSIONS

253. The island of Malta, despite its small surface area of only 95 square miles and its mean annual rainfall of only 20 inches, is well endowed with natural water supply resources. It is estimated that from the Upper Coralline catchment areas a mean annual supply of about 1,500 million gallons, never exceeding an average salinity of 12 parts of chlorides per 100,000, could be obtained; and from the Main Sea Level Table in the Lower Coralline Limestone a mean annual supply of about 1,000 million gallons, with an average salinity not exceeding 50 parts of chlorides per 100,000. At a rate of consumption of 20 gallons per head per day these resources combined would provide a public supply, with an average salinity of 28 parts of chlorides per 100,000, for a population of 342,000. Further, if the efficient maintenance of roof catchments were enforced according to law, an additional two or three gallons per head per day of very soft water would be available also. Owing to the sharply defined seasonal character, and to the considerable variation in the amount of the annual rainfall, considerable deviations from the above mean annual figures are inevitable, and storage capacity of the order of at least 1,000 million gallons is required to achieve even partial equalisation of the supply from season to season, and from year to year.

254. As the result of grossly exaggerated misconceptions of its potentialities the Main Sea Level Table has been mistakenly allowed to become the Island's main source of public water supplies, and the problem of providing adequate storage facilities has been evaded. This water table is being strongly overpumped by the Government water supply stations, and by numerous works for private extraction. The salinity of supplies drawn from it has risen practically continuously since 1910, and if the present rate of deterioration is permitted to continue, the limit of potability will be reached in a few years' time. It is imperative, therefore, that an early return should be made to the long neglected Upper Coralline catchments, and that the problem of storing their winter surpluses should be tackled energetically. Here, too, private extraction has been allowed unlimited scope in past years, to the considerable detriment of old established sources of public supply.

255. The recommendations for the reorganisation of production, storage, and distribution of the public supply which have been made in this Report practically amount to the creation of an entirely new water works for the Island. On this basis alone is it possible at present to make an estimate of the total expenditure required. The first cost of a water system for continental cities, with populations similar to that of Malta, ranges from £6 to £8 per head, which applied to Malta, would mean about £1,800,000 to £2,400,000, for a population of 300,000, including Imperial Services personnel. In Malta there may be a relative saving on the cost of the distribution system, as the points of extraction are all within a few miles of the points of consumption, and the minor distribution lines already in existence will require but little modification. The cost of the proposed new works for extraction, and of storage reservoirs (unless the Miziep Scheme proves practicable at low cost), will be relatively higher. It is considered, therefore, that for the total expenditure mentioned it should be possible to furnish the Island with a water supply system adequate to meet all reasonable demands of modern civilised life, provided that the population can be stabilised at its present level.

PART X. LIST OF PAPERS CONSULTED

1784	CIANTAR, G.A. ...	"Malta Illustrata".
1854	SPRATT, T. A. B. ...	The Geology of Malta and Gozo.
1854	ZAMMIT, N.	"Ricerche Idrauliche relative al programma per una migliore provista di acque per Malta".
1867	BATEMAN, J. F. ...	Report on Malta Water Supply.
1875	DINGLI, A.	"Memoria sulla Provista dell'Acqua in Malta e nel Gozo".
1877	MICALLEF, F. ...	Report on the Hofriet ir Riz and L'Imtahleb Springs.
1883	CHADWICK, O. ...	Report on Birkirkara Water Supply.
1884	„ ...	Report on the Water Supply of Sliema.
„	„	Report on the Water Supply of Malta.
„	„	Report on the Tal Armier Aqueduct.
1885	„	Report on the Yield of Headings at Wied il Kbir.
„	„	Report on a Shaft sunk near St. Antonio Gardens.
„	„	Report on Irrigation Project.
„	„	Report on various Works in Progress.
„	„	Report on the Via Dingli Shafts and Headings.
„	„	Memorandum on the Irrigation of Orange Gardens.
„	„	Report on Pumping Results at Wied il Kbir.
„	„	Report on rainfall at Dingli, discharge of the Wignacourt Springs, and surface flow at Fiddien Bridge, 1884-85.
1886	SCHINAS, G. C. ...	Report on the Nature and Progress of Various Works.
1887	CHADWICK, O. ...	Report on the Rainfall of Malta and the Yield of Springs, 1885-86.
„	„	Report on a Revised Project for the Improvement of the Water Supply for Agricultural Purposes.
1888	CHADWICK, O., and SCHINAS, G. C.	Report on the Rainfall and Yield of Springs, 1886-87.
„	PISANI, S. L. ...	Report by the President of the Cholera Committee on the Water Supply to villages.
1890	MURRAY, J.	The Maltese Islands with special reference to their Geological Structure.
1894	CHADWICK, O. ...	Report on Filtering Water Supplies derived from Springs in Malta.
„	„	Report on the Water Supply of Malta.
1894	„	Preliminary Report on the Sewerage of Sliema.
1896	„	Report on the Water Supply of Malta.
1897	„	Report on the Water Supply of Malta and Gozo.
„	„	Report on the Sewerage of Malta, with Estimates.
1912	ZAMMIT, T., and MORRIS, A. H.	Report on the Water Supplies of Malta.
1915	BORG, J.	Agriculture and Horticulture in Malta.
1915	AGIUS, T.	The Climate of Malta.
1917	ROBERTSON, J. C. ...	Report on the Possibility of Increasing the Fresh Water Supply and of Utilising the Sewage for Crop Irrigation in Malta.
1918	GALIZIA, J. A. ...	Minutes by the Manager of the Water Works on Col. Robertson's Report.
„	GATT, L.	Observations by the Superintendent of Public Works on Col. Robertson's Report.
1922	PACE, J. H.	Observations on Col. Robertson's Report
1924	ZAMMIT, T.	The Water Supply of the Maltese Islands.
1929	PACE, J. H.	Proposals for the Centralisation of Surface Waters and their Adoption for Potable Supply.
1932	RIZZO, C.	Report on the Geology of the Maltese Islands.
1934	STOCKDALE, F.A. ...	Report on the present Condition of Agriculture in the Maltese Islands.
1934	TURNER JONES C. ... MICALLEF, G. GATT, J. L. RIZZO, C., and BOOTHMAN, W.	(First) Report of the Committee on the Water Supplies of Malta.
1934	BUSHELL, G. W. ... MICALLEF, G. GATT, J. L. RIZZO, G., and BOOTHMAN, W.	(Second) Report of the Committee on the Water Supplies of Malta.
1935	BUSHELL, C. W. ... MICALLEF, G. GATT, J. L. RIZZO, C., and BOOTHMAN, W.	(Third)Report of the Committee on the Water Supplies of Malta.
1936	MICALLEF, G. ... BOOTHMAN, W. MORTIMER, A. S. RIZZO, C., and SAMMUT, O.	Report of the Committee on Agricultural Irrigation.
1937	STOCKDALE, F. A. ...	Report on Water Supply for Irrigation in Malta.
1942	MORTIMER, A. S. ...	Memorandum on the Water Supply of Malta and Gozo.
1943	BAILEY, E. B. ...	Report on Underground Water in Malta and Gozo.
1943	SHOTTON, F. W. ...	Notes on the Selection of Borehole Sites for Military Camps, Malta.
1943	PAVER, G. L. ...	Borehole Sites for Military Camps, Malta.
1944	G. H. Q., MEF. ...	Boreholes for Water in Malta.
1944	MORRIS, T. O. ...	Notes on the Civil Government Water Supply Position, 31 January 1944.
1944	MORRIS, T. O. ...	Amendments to Water Supply Records, M.E.F. — Boreholes for Water in Malta.
1944	MORRIS, T. O. ...	Memorandum on the Position of Water Supply Works in Malta.

Census Reports; 1851, 1861, 1871, 1881, 1891, 1901, 1911, 1921, and 1931.
Water Department Annual Reports, 1904-1943.
Government Analyst's Annual Reports, 1909-1943.
Government of Malta Domestic Water Supply and Agricultural Water Supply Files.
The Underground Water Ordinance, 1943.

Malta Water Supply Records of No. 3 and No. 7 Boring Sections, R.E., No. 171 Tunnelling Coy., R.E., and No. 42 Geological Section, S.A.E.C.

NOTE ON THE PROSPECTS OF IMPROVING THE WATER SUPPLY OF GOZO

1. The major natural sources of public water supply in Gozo are the same as in Malta: (i) a sea level table in the Lower Coralline and Globigerina Limestone Formations; and (ii) discontinuous perched tables in the lower part of the Upper Coralline Limestone and the underlying Greensand. Developments for the appropriation of these sources of supply have followed a course similar to the development of the equivalent sources in Malta. In the early days supplies were drawn almost entirely from the Upper Coralline springs. Later, following upon Chadwick's demonstration of the potentialities of the Main Sea Level Table in Malta, the Government Water Department concentrated its efforts upon extraction from the sea level table in Gozo, and the high level springs were neglected as sources of public supply. During the past ten years the consumption of water from the Government Water Works has practically doubled, and most of this demand (which reached a total of 83,700,000 gallons, for a population of about 28,000, in 1947-48) has been met by increased extraction from the sea level table. The Upper Coralline springs have contributed only an average of 2,900,000 gallons per annum. Now, as in Malta, it is obvious that the sea level galleries are being over-pumped, and that a return will have to be made to the perenially fresh water of the Upper Coralline catchments in order to maintain a supply of potable water and to meet the growing demand.

2. There are two main works for extraction from the sea level table. An older line of galleries, of total length 4,610 feet, along Wied Imgarr-ix-Xini on the southern side of the Island, and a newer line, of total length 6,020 feet, much of which was constructed during the war years, along Wied ta' Marsalforn on the northern side of the Island. The salinity of the water pumped from each of these galleries now averages about 80 parts of chlorides per 100,000. In 1934 the average salinity of the water from Mgarr-ix-Xini was only 20 parts per 100,000. It is very doubtful whether any useful purpose would be served by extending extraction works in the sea level table, as, for example, by joining the inland ends of the existing gallery systems, which are now 8,200 feet apart, through the central region of the water table. No point in the Island is much more than two miles from the coast, and unlike Malta, there are no outcrops of Lower Coralline Limestone (apart from a very small one near Kercem, with only a small catchment area) to facilitate the introduction of an annual replenishment or fresh water to the central part of the sea level table. It might be worthwhile, however, to attempt to assist central replenishment by means of boreholes or shafts sunk to sea level in the bed of the Wied ta Marsalforn at the confluence near the present inland limit of the gallery, with a dam thrown across the wied at this point to intercept the run-off from 2½ square miles of the surface catchment upstream. The results could be observed readily by sampling at the inland shafts of the gallery.

3. The main hope for the future of the potable water supply of the Island, as in Malta, lies in the Upper Coralline areas. The total extent of Upper Coralline outcrops completely above sea level (neglecting such remnants as Il Kolla Safra, Il Mirzuk, and Tad Bieji, which are too small to be of any practical interest) is approximately 6.19 square miles, or about 24 per cent of the total area of the Island — much the same proportion as in the case of the Upper

Coralline Limestone of Malta. Unfortunately for Gozo even its largest Upper Coralline areas have been deeply dissected by erosion, and there is no prospect of discovering any large synclinal basins like those of the northern fault strips of Malta, except possibly in the Ghajn Sielem-Qala area, close alongside the Ras il Qala Fault.

Area	Sq. Miles	Potential yield at 5 inches mean annual percolation Gallons	Remarks
Ghajn Sielem—Qala ...	1.427	103,000,000	Many private shafts and the Ghajn Sielem Galleries in the central part of the strip.
Nadur	2.203	160,000,000	Apparently unusually great thickness of Greensand at the northern end. Ghajn Sellum gallery (700 feet long) at the S.W. corner.
Xaghra	1.450	105,000,000	Ghajn Barrani formerly supplied Marsalforn from the N. end.
Rabat	0.502	36,000,000	Northern portion extensively built over. Ghajn il-Kbira issues from middle of western side.
Kercem	0.172	12,000,000	Ghajn Tuta issues from middle of eastern side.
Zebbug	0.172	12,000,000	Very narrow and extensively-built over.
Ghar Ilma	0.043	3,000,000	Spring issues from southern tip.
Ghajn Abdul	0.043	3,000,000	Spring issues from southern side.
Fort Chambray ...	0.043	—	Almost completely built over.
Tal Kuliat	0.033	2,000,000	
Jurdan	0.026	2,000,000	
Gebel Ghasri	0.020	2,000,000	
Tad Dabrani	0.016	1,000,000	
Il Harrax	0.016	1,000,000	Very narrow.
Rabat Citadel	0.016	—	Completely built over.
Il Ghelmus	0.010	1,000,000	
Totals	6.192	443,000,000	

4. The three largest areas comprise more than five-sixths of the total, and naturally, therefore, should receive first attention by boring operations for the accurate elucidation of their structural contours. The Xaghra and Nadur areas are disconnected portions of an undulating monocline, dipping gently towards the northern coast. They appear to contain several gently-pitching shallow folds and small faults, with axes trending W.S.W. — E.N.E., like the major faults mapped by C. Rizzo in the lower country to the west and south. Groups of private wells to the north of Xaghra possibly mark two of these synclinal hollows. The Greensand, especially beneath Kortin ta Nadur, appears to be much thicker than in Malta. In view of the general northward dip it will probably be possible to devise a suitable system of galleries and pipe lines to gravitate most of the potential yield of the Xaghra and Nadur areas to a central collecting point at the lower end of Wied ir-Ramla, and to pump it thence to storage reservoirs excavated cheaply in the Blue Clay and Upper Globigerina formations on the watershed between the Marsalforn and Hanak valleys. Given adequate storage arrangements it should be possible to develop from the Upper Coralline areas a mean annual supply of some 400,000,000 gallons of perpetually fresh water, which would mean 20 gallons per head per day for a population of 55,000. The total capacity of the present day service tanks of the public supply is only 3,978,000 gallons.

5. The villages on the Upper Coralline outcrops should be restricted to their present limits and private works for the extraction of water from this formation should be prohibited in the interest of future supplies for the general public.

(June 1950)

CLIMATIC D

TABLE I

MONTHLY AND ANNUAL RAINI

RAINFALL YEAR	51-52	52-53	53-54	54-55	5
SEPTEMBER	2·5	—	0·8	0·6	
OCTOBER	3·3	0·7	1·3	1·8	
NOVEMBER	1·8	0·1	5·0	2·4	
DECEMBER	1·1	2·0	4·1	4·8	
JANUARY	1·4	0·6	2·1	1·9	
FEBRUARY	1·7	5·3	3·5	—	
MARCH	2·6	1·6	0·4	3·2	
APRIL	2·8	—	0·4	4·2	
MAY	0·4	—	0·6	—	
JUNE	—	—	—	—	
JULY	—	—	—	—	
AUGUST	0·4	—	0·5	—	
TOTAL	18·0	10·3	21·7	18·9	

85-86	86-87	87-88	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99
0·38	3·26	0·31	0·77	1·89	1·26	0·59	4·38	—	0·26	—	0·04	0·43	1·31
2·22	0·42	8·53	3·28	0·34	5·48	2·04	2·15	3·48	2·07	0·70	2·95	2·24	8·93
3·39	5·49	1·29	1·47	0·93	2·31	1·63	7·18	4·07	5·10	1·94	6·45	1·86	4·17
2·87	3·87	0·94	1·77	8·88	4·23	4·26	2·42	6·71	6·19	2·56	4·01	2·82	9·03
4·89	2·99	2·64	7·66	1·46	3·15	2·85	7·00	4·65	1·44	3·21	0·51	2·12	2·15
3·30	1·62	2·49	1·77	4·34	4·10	1·15	1·00	5·02	0·89	2·04	0·96	2·05	1·95
0·67	0·30	0·91	2·58	1·16	—	0·45	1·44	1·57	0·55	1·56	0·42	0·64	0·73
0·65	0·95	0·13	0·32	0·66	0·42	1·71	0·84	2·35	0·06	3·21	1·89	1·48	—
0·47	0·11	1·55	0·53	0·39	0·18	2·67	—	—	0·59	0·82	1·54	—	—
—	0·03	—	—	0·23	0·29	—	—	—	—	0·08	—	—	—
—	—	—	—	—	—	0·41	—	—	—	—	—	—	—
—	0·53	—	—	—	—	—	—	—	—	0·02	—	—	—
18·84	19·57	18·79	20·15	20·28	21·42	17·76	26·42	27·84	17·16	16·14	18·77	13·65	28·27

RAINFALL YEAR	99-00	00-01	01-02	02-03
SEPTEMBER	1·35	—	—	2·61
OCTOBER	0·74	1·76	4·61	3·74
NOVEMBER	2·66	3·57	4·91	8·11
DECEMBER	5·77	0·93	0·90	4·43
JANUARY	4·91	4·32	1·26	3·26
FEBRUARY	1·14	3·37	1·82	1·61
MARCH	1·01	0·52	0·85	0·92
APRIL	1·84	0·53	1·22	0·45
MAY	0·65	1·29	0·36	—
JUNE	0·43	0·25	—	—
JULY	—	—	—	—
AUGUST	—	—	—	—
TOTAL	20·49	16·53	15·93	25·13

33-34	34-35	35-36	36-37	37-38	38-39	39-40	40-41	41-42	42-43	43-44	44-45	45-46	46-47
0·09	1·81	—	0·07	1·30	—	8·71	0·19	0·23	0·08	—	2·29		
0·14	4·16	0·82	1·43	1·81	2·12	4·73	1·20	1·23	2·55	4·12	1·22		
3·17	6·68	4·74	6·79	2·55	5·79	1·72	2·49	6·16	5·05	3·93	2·01		
4·06	6·78	4·53	5·82	4·99	4·31	1·52	7·36	5·13	7·89	2·29	9·09		
5·91	5·98	0·90	2·00	5·72	1·70	3·49	1·41	5·47	1·94	3·06	2·47		
1·15	0·81	0·82	2·02	7·74	1·99	0·92	1·19	6·92	2·39	2·17	1·01		
1·31	6·02	0·28	0·92	2·10	1·66	2·35	1·50	0·62	6·11	2·55	0·99		
0·58	—	0·94	0·25	0·52	3·82	1·64	1·59	—	0·17	1·67	0·65		
1·11	—	1·20	0·23	0·37	—	0·88	1·48	—	0·82	—	0·18		
—	—	—	—	—	—	—	—	—	0·57	—	—		
—	—	—	—	—	—	—	—	—	—	—	—		
—	—	0·98	—	0·24	—	—	—	0·66	—	1·76	—		
17·62	32·23	15·20	19·52	28·13	21·38	25·96	18·41	26·42	27·57	21·55	19·39		

1851-52 to 1868-69 from Diagram 1, " Water Su

THE ROYAL ... SOCIETY

PRINTED IN GREAT BRITAIN BY EDWARD STANFORD, LTD., LONDON

CLIMATIC DATA

TABLE I

MONTHLY AND ANNUAL RAINFALL, 1851 - 1945

RAINFALL YEAR	51-52	52-53	53-54	54-55	55-56	56-57	57-58	58-59	59-60	60-61	61-62	62-63	63-64	64-65	65-66	66-67	67-68	68-69	69-70	70-71	71-72	72-73	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99
SEPTEMBER	2·5	—	0·8	0·6	—	—	1·1	0·5	0·5	—	1·5	—	1·4	0·5	3·6	—	1·3	0·6	—	2·93	—	—	0·74	—	3·57	—	1·46	—	6·85	1·99	0·44	0·12	0·34	0·31	0·38	3·26	0·31	0·77	1·89	1·26	0·59	4·38	—	0·26	—	0·04	0·43	1·31
OCTOBER	3·3	0·7	1·3	1·8	0·3	9·2	2·2	2·1	—	2·7	7·0	1·7	2·6	4·0	2·0	3·1	1·0	5·1	5·26	1·84	2·50	2·43	2·28	4·87	5·14	3·85	5·26	1·30	1·93	2·53	0·94	1·46	3·34	1·83	2·22	0·42	8·53	3·28	0·34	5·48	2·04	2·15	3·48	2·07	0·70	2·95	2·24	8·93
NOVEMBER	1·8	0·1	5·0	2·4	2·4	6·5	3·2	4·9	12·8	3·1	2·5	5·2	5·1	2·8	2·5	2·2	3·0	4·4	2·61	0·48	3·51	2·07	4·59	6·62	2·63	2·63	3·60	3·15	4·31	1·76	1·50	1·08	5·88	5·99	3·39	5·49	1·29	1·47	0·93	2·31	1·63	7·18	4·07	5·10	1·94	6·45	1·86	4·17
DECEMBER	1·1	2·0	4·1	4·8	1·1	—	4·4	12·6	8·2	2·8	1·6	1·8	5·9	3·8	4·6	0·4	3·2	1·6	3·11	2·45	7·55	1·91	8·97	2·17	9·54	0·75	4·93	2·34	2·40	2·29	7·34	5·77	3·17	5·62	2·87	3·87	0·94	1·77	8·88	4·23	4·26	2·42	6·71	6·19	2·56	4·01	2·82	9·03
JANUARY	1·4	0·6	2·1	1·9	1·8	5·3	7·1	10·1	1·7	6·4	0·9	1·1	6·2	1·5	0·6	0·6	3·1	5·7	2·05	5·27	3·27	1·70	6·50	1·39	2·78	5·09	2·70	2·42	3·22	0·45	2·85	2·08	2·67	4·55	4·89	2·99	2·64	7·66	1·46	3·15	2·85	7·00	4·65	1·44	3·21	0·51	2·12	2·15
FEBRUARY	1·7	5·3	3·5	—	0·3	1·8	2·6	4·0	2·9	—	1·1	2·0	2·1	1·8	2·1	0·1	0·6	0·5	2·00	1·06	1·95	2·83	1·41	3·44	1·63	1·60	1·95	0·73	3·11	1·73	1·98	3·22	0·68	0·39	3·30	1·62	2·49	1·77	4·34	4·10	1·15	1·00	5·02	0·89	2·04	0·96	2·05	1·95
MARCH	2·6	1·6	0·4	3·2	3·4	1·2	0·5	2·2	2·3	0·5	1·2	3·7	0·2	0·2	0·5	0·8	5·8	2·3	3·13	0·75	0·53	2·23	6·56	1·35	0·83	1·03	0·75	2·16	2·55	0·12	3·24	1·77	1·64	0·23	0·67	0·30	0·91	2·58	1·16	—	0·45	1·44	1·57	0·55	1·56	0·42	0·64	0·73
APRIL	2·8	—	0·4	4·2	0·1	1·1	0·2	0·7	0·5	0·3	4·2	1·9	0·7	0·1	—	0·4	2·1	0·6	2·02	0·16	0·94	1·59	0·22	0·75	1·43	0·35	0·45	0·29	0·23	0·70	1·49	0·49	0·29	0·48	0·65	0·95	0·13	0·32	0·66	0·42	1·71	0·84	2·35	0·06	3·21	1·89	1·48	—
MAY	0·4	—	0·6	—	—	1·6	—	0·5	0·3	0·4	0·9	0·1	0·4	—	0·4	—	—	—	0·04	0·45	—	0·84	0·39	—	0·09	—	3·63	1·05	0·51	2·17	0·14	0·07	0·57	—	0·47	0·11	1·55	0·53	0·39	0·18	2·67	—	—	0·59	0·82	1·54	—	—
JUNE	—	—	—	—	—	0·1	0·1	—	0·1	—	—	—	—	—	0·1	—	0·2	—	—	—	—	—	—	—	0·83	—	—	—	—	—	0·13	—	0·34	—	—	0·03	—	—	0·23	0·29	—	—	—	—	0·08	—	—	—
JULY	—	—	—	—	—	—	—	1·1	0·1	—	—	—	—	—	—	—	—	0·2	—	—	—	—	0·91	—	—	—	—	—	—	—	—	0·06	—	—	—	—	—	—	—	—	0·41	—	—	—	—	—	—	—
AUGUST	0·4	—	0·5	—	—	—	0·3	0·5	—	—	—	—	—	—	—	1·0	—	0·6	—	0·74	0·09	—	—	0·25	—	—	—	—	—	—	—	0·11	0·06	—	—	0·53	—	—	—	—	—	—	—	0·02	—	—	—
TOTAL	18·0	10·3	21·7	18·9	9·4	26·8	21·7	39·2	29·4	16·2	20·9	17·5	24·6	14·7	16·4	8·6	20·3	21·6	20·22	15·83	20·37	15·60	32·57	20·84	28·47	15·30	24·73	13·44	25·11	13·74	20·05	16·23	18·98	19·40	18·84	19·57	18·79	20·15	20·28	21·42	17·76	26·42	27·84	17·16	16·14	18·77	13·65	28·27

RAINFALL YEAR	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	28-29	29-30	30-31	31-32	32-33	33-34	34-35	35-36	36-37	37-38	38-39	39-40	40-41	41-42	42-43	43-44	44-45	45-46	46-47
SEPTEMBER	1·35	—	—	2·61	1·20	1·89	0·82	1·42	2·39	2·02	0·57	2·12	1·69	3·11	—	2·17	0·66	2·08	0·75	0·66	1·15	0·59	0·92	—	—	—	0·44	1·04	0·27	2·20	2·63	1·87	0·57	1·11	0·09	1·81	—	0·07	1·30	—	8·71	0·19	0·23	0·08	—	2·29		
OCTOBER	0·74	1·76	4·61	3·74	0·23	5·09	3·45	7·27	2·96	0·66	3·46	0·78	—	0·63	3·91	2·63	1·73	0·61	2·85	2·66	0·96	4·32	0·74	0·85	—	4·00	6·65	0·23	0·47	1·91	0·65	3·38	6·74	5·71	0·14	4·16	0·82	1·43	1·81	2·12	4·73	1·20	1·23	2·55	4·12	1·22		
NOVEMBER	2·66	3·57	4·91	8·11	2·34	3·05	0·76	1·99	3·47	1·99	1·47	1·88	9·69	5·25	1·29	4·82	4·18	4·93	4·67	4·75	4·04	11·93	3·61	1·58	2·47	1·83	3·81	5·37	3·53	6·51	4·47	1·49	3·96	6·15	3·17	6·68	4·74	6·79	2·55	5·79	1·72	2·49	6·16	5·05	3·93	2·01		
DECEMBER	5·77	0·93	0·90	4·43	3·57	3·04	10·83	2·87	1·21	8·78	3·29	6·06	2·80	1·41	2·09	0·90	0·73	0·96	3·70	3·85	2·79	1·63	3·20	5·66	4·36	8·50	0·39	2·01	6·91	4·77	2·41	5·82	4·23	2·16	4·06	6·78	4·53	5·82	4·99	4·31	1·52	7·36	5·13	7·89	2·29	9·09		
JANUARY	4·91	4·32	1·26	3·26	3·97	2·59	5·43	4·24	1·00	5·38	5·24	6·69	4·15	3·40	4·15	1·39	4·00	3·10	0·50	4·02	0·62	3·11	0·76	4·22	3·22	1·73	1·83	2·09	7·59	1·74	4·64	9·42	3·12	7·16	5·91	5·98	0·90	2·00	5·72	1·70	3·49	1·41	5·47	1·94	3·06	2·47		
FEBRUARY	1·14	3·37	1·82	1·61	0·56	1·70	5·84	3·14	2·30	2·30	3·76	0·64	0·68	2·45	1·67	2·89	4·39	1·92	1·87	2·09	3·02	1·29	0·32	4·11	2·26	1·42	1·62	2·02	3·13	3·96	6·10	4·40	6·38	4·15	1·15	0·81	0·82	2·02	7·74	1·99	0·92	1·19	6·92	2·39	2·17	1·01		
MARCH	1·01	0·52	0·85	0·92	1·01	0·79	—	2·98	2·84	1·10	0·99	1·17	0·68	0·96	1·54	1·47	0·29	1·92	4·56	1·14	1·68	1·63	—	0·88	1·94	6·97	2·00	1·35	4·84	3·08	0·35	0·25	2·04	0·21	1·31	6·02	0·28	0·92	2·10	1·66	2·35	1·50	0·62	6·11	2·55	0·99		
APRIL	1·84	0·53	1·22	0·45	—	0·24	0·71	1·04	0·42	1·87	0·49	1·60	1·33	0·98	—	2·46	1·80	0·43	0·43	1·43	0·60	3·26	0·35	1·39	1·32	0·52	1·69	0·59	1·79	1·05	1·07	0·12	0·17	0·09	0·58	—	0·94	0·25	0·52	3·82	1·64	1·59	—	0·17	1·67	0·65		
MAY	0·65	1·29	0·36	—	—	0·33	0·25	—	—	1·01	—	1·48	1·37	0·80	—	—	—	—	0·23	0·72	—	—	—	—	—	1·64	0·43	0·12	—	0·30	—	1·14	—	0·45	1·11	—	1·20	0·23	0·37	—	0·88	1·48	—	0·82	—	0·18			
JUNE	0·43	0·25	—	—	0·17	—	—	—	—	—	—	—	—	—	—	0·76	—	0·46	0·18	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·75	—	—	—	—	—	—	—	—	0·57	—	—			
JULY	—	—	—	—	—	0·95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·05	—	—	1·34	—	—	—	—	—	—	—	—	—	—	—			
AUGUST	—	—	—	—	0·27	—	0·88	0·45	—	—	—	—	—	—	—	0·24	0·23	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·73	—	—	0·98	—	0·24	—	—	—	0·66	—	1·76	—			
TOTAL	20·49	16·53	15·93	25·13	13·32	19·67	28·98	25·40	16·58	25·11	19·27	22·42	22·39	18·99	14·65	19·12	18·01	16·41	19·74	21·32	14·87	27·75	13·64	18·68	15·57	26·72	18·86	15·31	28·53	25·52	22·37	27·88	27·21	30·00	17·62	32·23	15·20	19·52	28·13	21·38	25·96	18·41	26·42	27·57	21·55	19·39		

1851-52 to 1868-69 from Diagram 1, " Water Supply of Malta " Chadwick (1884); 1869-70 to 1889-90 from records of Elementary School Rain Gauges ; 1890-91 to 1943-44 from the Water Dept. Gauges on the Rabat Plateau

MONTHLY MEAN CLIMATIC DATA, UNIVERSITY OBSERVATORY, VALETTA (1901 - 1913)

MONTH	*JAN.*	*FEB.*	*MAR.*	*APR.*	*MAY*	*JUNE*	*JULY*	*AUG.*	*SEPT.*	*OCT.*	*NOV.*	*DEC.*
DAILY MAXIMUM SHADE TEMPERATURE (°F.)	63·5	65·3	67·7	73·4	80·0	85·1	92·8	92·2	88·2	69·8	76·6	67·7
DAILY MEAN SHADE TEMPERATURE (°F.)	53·5	52·9	55·4	59·1	64·8	71·2	76·8	77·9	74·7	64·5	62·2	56·2
DAILY MINIMUM SHADE TEMPERATURE (°F.)	44·6	42·6	46·5	49·0	53·4	61·8	67·1	69·3	63·7	59·2	52·6	46·8
BLACK BULB IN VACUO (°F.)	126·9	130·2	132·8	136·6	139·8	143·1	150·1	150·3	149·6	144·0	137·1	130·4
VAPOUR PRESSURE, 8 A.M. (M/M)	11·2	11·8	12·5	15·5	16·5	21·5	24·3	27·0	24·4	21·1	16·5	12·5
DAILY HOURS BRIGHT SUNSHINE	5·2	6·1	7·2	8·2	10·0	11·3	12·0	11·6	8·9	7·1	5·9	4·8
CLOUDINESS (P.C.)	6·2	5·5	5·2	5·2	4·2	2·8	1·8	1·9	3·3	4·3	5·2	5·4
RAINY DAYS	14	11	8	6	3	1	0·4	0·7	4·3	8·5	12·6	13·2

After T. Agius, " The Climate of Malta ", 1915.

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LOWER TABLE PUMPING STATIONS
ANNUAL PRODUCTION AND MEAN SALINITY. 1887-1944.

TABLE 2.

PUMPING STATION					1887-88		1888-89		1889-90		1890-91		1891-92		1892-93		1893-94		1894-95	
	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.
WIED IL KBIR					25,657,000	13·6	33,908,000	13·9	36,348,000	14·0	39,266,500	14·1	53,328,000	14·2	43,389,000	14·2	32,586,000	14·3	40,656,600	14·4
ARMIER					39,629,200	27·8	51,088,700	28·2	52,839,500	28·5	54,579,100	28·9	72,243,500	29·1	55,957,400	29·5	38,669,600	29·9	52,877,850	30·2
ST. ANTON					2,721,650	36·0	8,433,250	36·0	9,642,300	36·0	10,228,550	36·0	10,347,450	36·0	11,120,200	36·0	7,907,400	36·0	10,590,200	36·0
WIEDA IS SUEDA					12,492,900	13·0	29,570,950	13·0	24,844,550	13·0	31,684,200	13·0	28,954,100	13·0	25,112,000	13·0	13,236,350	13·0	23,777,950	13·0
TOTAL					80,500,750	19·6	123,000,900	20·6	123,674,350	21·8	135,758,350	21·4	164,873,050	21·9	135,578,600	22·1	92,399,350	22·8	127,902,600	22·6
PUMPING STATION	1895-96		1896-97		1897-98		1898-99		1899-00		1900-01		1901-02		1902-03		1903-04		1904-05	
	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.
WIED IL KBIR	74,319,300	14·5	74,372,000	14·5	88,630,100	14·6	56.265,900	14·7	76,280,600	14·8	107,599,800	14·9	159,037,100	14·9	157,235,100	15·0	189,554,100	15·1	234,817,100	15·2
ARMIER	61,438,800	30·5	53,606,800	30·9	61,725,800	31·2	29,971,300	31·5	48,632,700	31·9	85,933,950	32·3	95,280,600	32·5	76,783,900	33·0	92,805,500	33·3	71,924,300	33·6
ST. ANTON	14,083,850	36·0	11,935,950	36·0	10,536,900	36·0	4,954,600	36·0	10,064,950	36·0	12,018,050	36·0	9,301,200	36·0	8,482,750	36·0	13,240,750	36·0	9,688,450	36·0
WIED IS SUEDA	41,621,710	13·0	54,893,400	13·0	74,098,270	13·0	52,305,420	13·0	43,528,100	13·0	67,766,510	13·0	100,771,700	13·0	89,594,150	13·0	154,277,350	13·0	132,964,900	13·0
TOTAL	191,463,660	20·9	194,808,150	19·4	234,991,070	19·5	143,497,220	18·4	178,506,350	20·2	273,318,310	20·9	364,390,600	16·8	332,095,900	19·1	449,877,700	18·8	449,394,750	17·9
PUMPING STATION	1905-06		1906-07		1907-08		1908-09		1909-10		1910-11		1911-12		1912-13		1913-14		1914-15	
	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.
WIED IL KBIR	182,407,100	15·3	127,763,900	15·3	229,993,400	15·4	275,873,000	15·6	301,081,400	15·6	363,755,000	15·7	424,970,000	15·8	377,625,628	17·2	354,263,157	18·0	375,844,026	20·0
ARMIER	61,710,600	33·9	64,773,400	34·3	13,926,500	34·6	22,377,700	35·0	30,703,450	35·3	35,141,000	35·7	35,402,000	36·0	2,749,000	38·0	24,241,000	39·8	30,427,000	41·6
ST. ANTON	8,648,900	36·0	2,803,600	36·0	7,049,020	36·0	6,769,850	36·0	9,610,100	36·0	6,591,000	36·0	7,983,000	36·0	6,729,000	36·0	12,442,000	36·0	10,944,000	36·0
WIED IS SUEDA	103,390,100	13·0	70,571,200	13·0	146,269,900	13·0	133,860,800	13·0	9,611,100	13·0	199,496,900	13·0	200,700,600	13·0	190,518,800	13·6	190,773,700	13·6	190,250,600	14·4
TOTAL	356,156,700	18·3	265,912,100	19·5	397,238,820	15·6	438,881,350	16·1	351,006,050	17·8	604,983,900	15·8	669,055,600	16·2	577,622,428	16·4	581,719,857	17·8	607,465,626	19·6
PUMPING STATION	1915-16		1916-17		1917-18		1918-19		1919-20		1920-21		1921-22		1922-23		1923-24		1924-25	
	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.
WIED IL KBIR	401,790,403	19·2	362,191,536	20·0	346,993,632	21·4	328,928,357	22·7	322,134,481	24·2	315,370,261	24·0	315,776,938	25·0	309,640,841	26·6	335,253,000	27·0	327,016,000	26·5
ARMIER	68,421,000	43·6	37,584,000	45·7	43,539,000	47·8	48,340,000	49·6	5,954,000	51·8	3,868,000	53·8	20,684,000	55·6	47,775,000	57·5	85,495,000	59·7	58,663,000	61·6
ST. ANTON	15,496,000	36·0	15,614,000	36·0	11,348,000	36·0	9,104,000	36·0	10,701,000	36·0	8,031,000	36·0	12,765,000	36·0	12,627,000	36·0	18,796,000	36·0	20,532,000	36·0
WIED IS SUEDA	199,606,200	14·4	172,166,500	14·4	184,858,600	16·2	179,682,900	17·7	187,097,162	19·3	133,038,000	21·0	32,187,000	21·0	16,884,000	26·0	6,648,000	26·0	61,000	26·0
TAL HLAS	11,416,499	16·0	190,920,965	16·0	103,441,715	16·0	94,366,218	16·0	117,869,551	16·0	99,627,600	20·0	243,858,339	21·0	321,648,000	24·0	259,132,000	24·0	313,744,000	25·0
WIED DALAM																			3,520,000	100·0
TOTAL	696,730,102	20·7	778,477,001	19·3	692,180,947	21·0	660,421,475	22·5	643,756,194	23·1	559,934,861	23·0	625,271,277	24·5	708,574,841	27·6	705,324,000	30·1	723,536,000	29·3
PUMPING STATION	1925-26		1926-27		1927-28		1928-29		1929-30		1930-31		1931-32		1932-33		1933-34		1934-35	
	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.
WIED IL KBIR	347,282,000	26·1	360,966,639	26·4	392,409,817	27·5	406,210,000	27·0	307,572,000	27·0	315,123,000	26·0	305,564,000	27·0	322,120,000	27·0	272,830,000	28·0	309,771,000	25·0
ARMIER	84,566,000	63·8	95,850,000	65·7	81,478,000	67·6	88,945,000	69·7	77,704,000	71·5	101,133,000	74·0	122,755,000	75·9	112,204,000	77·9	106,631,000	80·0	113,347,000	81·8
ST. ANTON	19,179,000	36·0	28,260,000	36·0	30,792,000	36·0	29,871,000	36·0	22,405,000	36·0	16,360,000	36·0	10,472,000	36·0	9,106,000	36·0	18,276,000	36·0	17,450,000	36·0
TAL HLAS	323,011,000	26·9	342,062,000	27·0	343,195,000	29·5	340,089,000	29·5	363,570,000	29·0	319,433,000	28·0	362,908,000	29·0	410,494,000	29·0	461,868,000	30·2	370,822,000	30·0
WIED DALAM	7,681,000	100·0	4,602,000	100·0	6,982,000	100·0	5,633,000	100·0	5,070,000	100·0	2,867,000	100·0	4,391,000	100·0	4,470,000	100·0	6,168,000	100·0	5,086,000	100·0
TOTAL	781,719,000	31·4	831,740,639	31·9	854,856,817	32·6	870,748,000	32·9	776,321,000	33·1	754,816,000	33·6	806,090,000	35·8	858,394,000	35·1	865,773,000	36·2	816,476,000	35·9
PUMPING STATION	1935-36		1936-37		1937-38		1938-39		1939-40		1940-41		1941-42		1942-43		1943-44		1944-45	
	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.	GALLONS	M.A.S.
WIED IL KBIR	335,350,000	28·4	331,884,000	28·8	? 472,686,000	28·8	? 448,571,000	26·0	? 464,576,000	26·4	313,024,000	50·0	316,819,000	50·0	366,763,000	50·0	376,436,600	56·5	398,776,200	53·0
ARMIER	144,136,000	84·0	148,489,000	86·0	? 235,445,000	88·0	? 179,970,000	90·0	? 211,865,000	92·0										
ST. ANTON	33,689,000	36·0	32,953,000	36·0	32,193,000	36·0	61,299,000	36·0	83,115,000	36·0	60,679,000	36·0	70,083,000	36·0	77,635,000	36·0	86,639,500	36·0	45,439,500	51·0
TAL HLAS	381,567,000	33·6	406,815,000	30·2	? 656,020,000	30·2	? 643,111,000	38·0	? 598,496,000	42·8	382,870,000	43·0	363,041,000	41·2	339,090,000	42·0	382,722,200	40·1	462,747,800	48·0
WIED DALAM	4,738,000	100·0	3,755,000	100·0	4,167,000	100·0	5,630,000	100·0	7,889,000	100·0	4,815,000	100·0	6,027,000	100·0	8,381,000	100·0	21,595,500	100·0	26,215,000	91·0
WIED IL GHASEL			4,619,000	40·0	49,279,000	57·6	155,104,000	57·6	178,540,000	70·5	204,070,000	129·0	160,758,000	124·0	168,998,000	119·0	208,908,600	130·5	206,461,100	112·0
TOTAL	899,480,000	38·6	928,515,000	42·1	? 1,449,790,000	39·2	? 1,493,685,000	41·6	? 1,544,481,000	47·6	965,458,000	63·5	916,728,000	59·8	960,867,000	58·7	1,076,302,400	64·5	1,226,045,100	60·2
BOREHOLES															10,765,200		67,801,900		68,312,000	58·0
TOTAL FROM L.W.T.															971,632,200		1,144,104,300		1,294,357,100	

TAL HLAS
WIED IS SUEDA

76,903,000 34·0

WIED IL GHASEL
TA KALI

M.A.S. = Mean Annual Salinity in parts chlorides per 100,000.

PRINTED IN GREAT BRITAIN BY EDWARD STANFORD, LTD., LONDON

TABLE 3.

ANNUAL GAUGINGS OF UPPER CORALLINE SPRINGS, 1885-1944.

GAUGE	1885-86	1886-87	1887-88	1888-89	1889-90	1890-91	1891-92	1892-93	1893-94	1894-95	1895-96	1896-97	1897-98	1898-99	1899-1900	1900-01	1901-02	1902-03	1903-04	1904-05	1905-06	1906-07	1907-08	1908-09	1909-10	1910-11	1911-12	1912-13	1913-14	1914-15
GHEMIERI	9,914,018	9,507,799	8,869,403	8,286,822	9,583,952	11,607,636	10,981,204	12,221,753	16,328,975	14,980,910	12,579,030	9,777,735	7,635,026	9,325,878	10,012,392	9,321,132	8,700,518	10,262,227	9,362,714	8,538,013	12,472,919	15,377,714	16,068,201	14,135,410	11,607,426	11,228,630				
FIDDIEN BOX	100,388,495	114,059,822	104,190,138	56,606,520	97,587,897	79,030,470	66,854,141	111,710,327	130,761,213	97,815,247	50,888,490	67,961,035	42,891,567	146,016,159	99,742,031	77,422,278	60,366,678	134,275,852	57,553,275	79,393,509	154,443,447	142,333,757	72,197,108	91,396,656	78,993,752	76,456,477				
GHAIN KLIEB	2,598,814	2,521,957	2,400,662	2,073,195	2,197,127	2,961,064	2,689,344	3,251,183	5,338,263	3,770,935	2,092,934	1,467,817	1,082,645	2,497,405	2,371,035	2,037,939	1,581,848	2,734,900	1,660,842	1,490,440	3,738,080	4,128,133	2,846,696	2,520,700	2,156,788	1,792,702				
BUSUGRILLA	55,774,874	55,531,939	55,618,101	44,852,552	51,258,365	56,094,696	48,180,479	45,549,424	86,363,029	91,929,892	64,897,559	49,695,232	35,140,502	63,227,889	62,864,328	51,293,180	40,680,642	61,804,511	34,339,535	29,255,592	78,338,702	73,211,298	62,925,263	53,216,660	38,891,084	27,464,205				
TOTAL WIGNACOURT	168,676,000	181,441,497	171,078,304	111,819,089	160,627,341	149,693,866	128,705,168	172,732,687	238,791,480	208,496,984	130,458,013	128,901,819	86,749,740	221,067,331	174,989,786	140,074,529	111,329,686	209,077,490	102,916,366	118,667,554	248,993,148	235,050,902	154,037,268	161,269,426	131,649,040	116,942,014		78,200,000	47,600,000	30,500,000
SAKKAJA	2,543,047	2,549,526	2,847,641	2,408,490	2,810,344	2,981,822	2,219,926	4,536,898	5,199,615	4,114,247	1,896,623	1,589,978	685,749	4,016,901	2,368,895	1,938,304	1,641,680	2,768,994	1,342,589	1,196,135	4,695,079	4,941,214	2,206,622	3,055,533	2,653,349	2,837,149				
VIA DINGLI PUMP STA.			1,755,230	3,443,950	3,481,100	2,715,350	3,489,500	3,500,500	3,811,950	4,666,000	5,330,950	5,021,950	5,354,350	5,005,250	5,490,900	5,814,850	5,423,690	5,170,230	6,112,040	5,267,590	5,822,520	6,358,521	7,742,768	6,480,321	6,389,860	6,328,090	7,215,320	6,515,580	5,351,150	4,465,154
TA L'ISKOF	4,835,551	5,503,965	5,199,921	3,505,913	14,768,051	17,348,780	7,361,430	9,051,352	10,000,743	21,169,169	20,199,418	16,318,057	14,525,414	20,551,423	17,426,500	17,704,257	16,475,785	21,360,406	16,215,627	15,721,916	22,410,053	30,162,753	23,234,177	23,686,717	21,339,532	21,059,607				
TA SIENJA	7,301,924	8,323,715	6,867,029	4,749,982	8,125,863	8,598,807	6,398,214	9,022,283	14,989,237	9,159,734	2,048,756	4,342,463	3,660,444	22,597,382	8,718,922	7,436,965	5,415,890	15,101,629	4,976,338	8,962,647	23,449,787	17,338,361	6,343,646	10,977,196	9,271,210	12,144,646				
TA SALA	13,780,603	13,379,417	15,353,606	14,351,105	14,072,909	14,501,754	15,056,105	15,271,715	18,351,062	23,635,095	18,969,484	15,046,735	12,044,744	13,199,049	15,613,386	14,327,747	12,909,506	13,536,456	12,975,132	12,309,848	15,884,307	20,056,952	19,948,046	17,098,242	15,542,935	14,137,420				
TA RAPA	4,130,853	3,909,851	4,397,930	4,146,917	3,862,773	3,933,854	4,085,388	3,713,246	4,343,582	5,670,968	4,614,748	3,559,608	3,070,566	3,310,935	4,363,866	4,242,077	3,789,273	4,012,855	3,767,098	3,283,948	3,748,641	5,454,380	6,186,976	5,280,289	4,331,080	3,895,956				
TOTAL BUSKETT	25,213,000	25,612,983	26,618,565	23,248,004	26,061,545	27,034,415	25,539,707	28,007,244	37,683,881	28,465,797	25,632,988	22,948,806	18,775,754	39,107,366	28,696,174	26,006,789	22,114,669	32,650,940	21,718,568	24,556,443	43,082,735	42,849,693	32,478,668	33,355,727	29,145,225	30,178,022		19,210,000	16,090,000	13,080,000
GHIRGENTI	13,690,508	13,768,589	14,579,651	12,703,129	14,150,028	12,248,056	14,789,889	14,616,460	18,680,354	21,004,184	17,702,096	14,858,502	11,868,672	14,180,824	14,082,789	13,681,646	12,716,557	13,113,711	12,120,432	11,305,527	14,290,259	19,252,273	19,631,212	14,117,183	13,769,406	13,022,917				
SAN GIORGIO	9,955,455	9,732,488	10,129,016	9,495,863	9,684,434	10,646,810	12,151,658	12,119,453	12,079,772	14,601,409	12,505,024	9,477,965	8,048,711	8,568,971	9,247,197	9,205,348	8,632,071	9,260,150	9,710,225	8,752,734	10,359,844	14,726,803	14,946,738	13,264,529	12,783,899	12,214,963				
FAWARA	4,694,744	4,565,011	4,686,493	4,267,981	5,474,274	5,761,219	5,024,398	5,565,543	7,797,528	8,058,290	5,922,681	4,757,972	3,455,653	5,019,001	4,632,756	4,128,835	4,128,835	4,872,894	3,688,391	3,341,542	6,020,437	7,157,549	6,196,135	5,579,625	5,663,645	5,504,641				
ANNUNZIATA	5,792,980	5,388,783	5,363,866	5,067,424	6,020,739	7,264,881	6,612,735	5,969,757	5,081,443	8,130,780	6,389,185	4,768,777	3,715,938	5,394,113	6,005,727	5,318,937	5,318,937	6,220,750	5,471,768	4,797,205	7,410,916	9,342,573	7,377,718	6,379,353	6,556,978	6,043,478				
TOTAL FAWARA	20,443,179	19,686,282	20,159,375	18,831,268	21,179,447	23,672,910	23,788,791	23,654,753	24,958,743	30,790,479	24,816,890	19,004,714	15,320,302	18,982,085	19,885,680	18,653,120	18,079,843	20,353,794	18,870,384	16,891,481	23,791,197	31,226,925	28,520,591	25,223,507	25,004,522	23,763,082		18,060,000	15,040,000	11,970,000
TOTAL RECORDED	235,401,285	248,562,842	242,238,687	175,959,843	243,082,856	235,695,199	205,894,411	256,099,894	339,126,766	318,706,860	226,036,978	208,643,826	153,279,981	322,911,180	262,940,724	223,873,535	187,781,910	304,495,565	179,296,006	193,606,646	363,084,991	369,842,281	267,851,306	267,188,414	229,950,934	214,130,881				
TOTAL SUPPLY RECEIVED BY WATER DEPARTMENT					214,000,000	232,500,000	173,900,000	258,600,000	295,000,000	284,300,000	182,300,000	172,500,000	120,000,000	278,200,000	224,800,000	188,000,000	151,600,000	271,900,000	139,700,000	160,000,000	315,000,000	330,500,000	214,000,000	220,000,000	184,700,000	182,000,000	179,000,000	109,700,000	78,900,000	55,500,000
RAINFALL (ins.)	18·84	19·57	18·79	20·15	20·28	21·42	17·76	26·42	27·84	17·16	16·14	18·77	13·65	28·27	20·49	16·53	15·93	25·13	13·32	19·67	28·98	25·40	16·58	25·11	19·27	22·42	22·39	18·99	14·65	19·12

GAUGE	1915-16	1916-17	1917-18	1918-19	1919-20	1920-21	1921-22	1922-23	1923-24	1924-25	1925-26	1926-27	1927-28	1928-29	1929-30	1930-31	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37	1937-38	1938-39	1939-40	1940-41	1941-42	1942-43	1943-44	1944-45
GHEMIERI																											10,162,300	11,283,100	12,644,500	10,479,000
FIDDIEN BOX																											64,596,600	82,061,500	66,334,200	40,766,700
GHAIN KLIEB																											1,452,000	4,702,700	4,373,900	2,290,900
BUSUGRILLA																											11,536,100	20,605,300	14,786,100	10,177,500
TOTAL WIGNACOURT	36,100,000	22,400,000																									76,210,900+	98,047,300+	73,352,600+	63,714,100
SAKKAJA																														
VIA DINGLI PUMP STA.	3,891,860	3,581,910	3,323,290	3,372,240	3,590,800	3,834,225	4,188,506	3,952,545	4,106,996	4,634,656	3,935,421	5,316,995	5,405,890	7,031,125	7,105,919	7,925,860	8,341,252	8,527,723	8,555,731	8,562,803	7,811,635	5,564,300	6,454,240	13,370,083	17,148,826	15,983,600	14,795,400	15,641,600	18,162,000	16,942,100
TA L'ISKOF														16,736,680	17,683,700	20,884,700	26,941,810	30,106,080	22,828,740	24,537,260	18,898,550	15,830,560	13,903,000	12,363,630			17,108,400	17,820,300	15,772,700	12,216,800
TA SIENJA																														
TA SALA																														
TA RAPA																														
TOTAL BUSKETT	7,450,000	6,670,000										15,262,700	16,739,600	19,369,800	21,240,060	24,186,520	25,079,500	17,704,500	23,925,400	23,160,500	20,630,730	17,395,090	15,864,300	15,287,130			17,312,500	19,564,900	20,233,500	17,009,300
GHIRGENTI																														
SAN GIORGIO																														
FAWARA																														
ANNUNZIATA																														
TOTAL FAWARA	11,510,000	9,560,000										18,763,000	19,602,400	22,886,020	24,235,400	25,452,040	26,848,230	30,170,660	28,290,010	28,582,480	27,220,400	21,289,690	19,342,482	19,956,423			19,216,300	24,786,000	22,337,700	21,323,100
TOTAL RECORDED																											144,641,500	175,860,100	147,070,900	131,205,400
TOTAL SUPPLY RECEIVED BY WATER DEPARTMENT	63,100,000	60,900,000	55,900,000	87,400,000	63,900,000	94,600,000	84,900,000	96,400,000	62,500,000	100,500,000	99,700,000	72,200,000	135,400,000	161,900,000	158,300,000	204,200,000	236,900,000	240,500,000	175,300,000	201,700,000	123,700,000	107,500,000	74,600,000	72,700,000	92,900,000	88,600,000	155,244,000	178,767,900	152,938,100	
RAINFALL (ins.)	18·01	16·41	19·74	21·32	14·87	27·75	13·64	18·68	15·57	26·72	18·86	15·31	28·53	25·52	22·37	27·88	27·21	30·00	17·62	32·23	15·20	19·52	28·13	21·38	25·96	18·41	26·42	27·57	21·55	19·39

SUMMARY OF ANALYSES OF UPPER CORALLINE WATERS, 1911-1943, BY GOVT. LABORATORY IN PARTS PER 100,000

SPRING	TOTAL SOLIDS	CHLORIDES AS CL	TEMP. HARDNESS AS $Ca\ Co_3$	PERM. HARDNESS AS $Ca\ Co_3$
WIGNACOURT	33 — 45	8 — 14	6 — 12	6 — 13
BUSKETT	30 — 44	8 — 11	6 — 11	6 — 13
FAWARA	35 — 46	8 — 9	6 — 11	6 — 10
GHAIN TUFFIEHA	31 — 40	7 — 12	6 — 12	6 — 16

GHAIN TUFFIEHA

1932-33	41,056,700
1933-34	30,672,800
1934-35	30,672,800
1935-36	29,087,200
1936-37	24,024,800
1937-38	20,134,100
1938-39	17,974,100
1939-40	17,998,400
1940-41	15,324,100
1941-42	14,253,400
1942-43	17,599,500
1943-44	17,410,000
1944-45	14,985,900

MELLIEHA

1941-42	1,284,000
1942-43	1,793,100
1943-44	2,930,300
1944-45	1,864,000

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Table 4. POROSITY AND PERMEABILITY OF TYPICAL FORMATION SAMPLES

(ABSTRACTED FROM ROBERTSON, 1917, APPENDICES II AND III)

LITHOLOGY	POROSITY per cent.	Gals./Cub. Ft.	PERMEABILITY
UPPER CORALLINE FORMATION			
1. Very fine-grained, compact limestone	43.4	2.71	17
2. Loose granular limestone	44.1	2.75	318
3. Fine-grained limestone, secondary cement ...	37.0	2.31	1.5
4. Coarse-grained limestone	44.7	2.80	272
5. Friable yellow limestone	33.6	2.10	Not determined
6. Friable white limestone	30.9	1.94	Not determined
	34.7	2.17	
7. Friable white limestone	37.7	2.36	Not determined
GREENSAND FORMATION			
8. Yellow, coarse-grained, somewhat marly ...	26.6	1.66	4.2
9. Dark green, fine-grained, somewhat marly ...	32.7	2.05	1.0
10. Yellow, fine-grained, marly	26.2	1.64	Not determined
11. Typical blue clay	Nil	Nil	Impervious
GLOBIGERINA FORMATION			
12. Very fine-grained, marly limestone	40.04	2.51	Not determined
13. Good compact freestone	38.4	2.40	3.0
14. Compact fine-grained freestone	37.6	2.35	2.0
15. Good, compact, fine-grained freestone	38.7	2.42	1.0
16. Grey, marly limestone, with phosphatic nodules	20.7	1.29	Practically Impervious
17. Yellow marly limestone, with more nodules ...	27.6	1.73	Practically Impervious
18. Yellow marly limestone, with abundant nodules	23.5	1.47	Practically Impervious
19. Blue, very fine-grained	18.4	1.15	Practically Impervious
20. Yellow, compact, granular limestone	31.3	1.96	Not determined
21. White, very fine-grained	25.9	1.62	Not determined
LOWER CORALLINE FORMATION			
22. Hard, granular, compact	30.2	1.89	Not determined
23. Hard, granular, compact	21.8	1.36	Not determined
24. Hard, granular, compact	25.7	1.61	Not determined
25. Hard, granular, compact	32.4	2.02	10.7
26. Loose granular "White Rock"	26.6	1.67	74
27. Loose granular "White Rock", somewhat marly	27.5	1.72	2.5

NOTE:— The relative permeabilities are expressed as the number of cubic centimetres of water passed in one hour through blocks of uniform dimensions ($1\frac{1}{2}$ x $1\frac{1}{2}$ x 2 inches) under a constant head of 12 inches of water.

Table 5. RAINFALL AND DISCHARGE OF SPRINGS

RABAT—DINGLI PLATEAU 1885-86 TO 1908-09

Season	Rainfall (inches)	Precipitation on 3.16 sq. miles (million gallons)	Measured discharge from springs (million gallons)	Ratio of Discharge to Precipitation (per cent)
1885-86	18.84	865	235	27.2
1886-87	19.57	898	249	27.8
1887-88	18.79	862	242	28.1
1888-89	20.15	931	176	18.8
1889-90	20.28	942	243	25.8
1890-91	21.42	984	236	24.0
1891-92	17.76	815	206	25.3
1892-93	26.42	1,213	256	21.1
1893-94	27.84	1,278	339	26.5
1894-95	17.16	787	319	40.5
1895-96	16.14	741	226	21.8
1896-97	18.77	860	209	24.3
1897-98	13.65	626	153	24.4
1898-99	28.27	1,298	323	24.9
1899-00	20.49	940	263	27.9
1900-01	16.53	758	224	29.5
1901-02	15.93	730	188	25.7
1902-03	25.13	1,152	304	26.4
1903-04	13.32	821	179	21.8
1904-05	19.67	902	194	21.5
1905-06	28.98	1,330	363	27.3
1906-07	25.40	1,165	370	34.2
1907-08	16.58	761	268	35.2
1908-09	25.11	1,151	267	23.2
Mean	20.51	940	251	26.7

Table 6. MAIN LOWER WATER TABLE BOREHOLES: GEOLOGICAL AND HYDROLOGICAL DATA

Serial No. of B.H.	Map Reference		Surface Height A.M.S.L. (Feet)	Height of base of Glob. A.M.S.L. (Feet)	Height of Water Table A.M.S.L. (Feet)	Initial Salinity at top of Water Table (parts Cl. per 100,000)	Distance from the coast (Yards)	REMARKS
1	4148	1902	342.0	312	11.0	10.8	2,000	Production well, C.G. Water Dept. Krendi.
12	4831	1994	243.0	147	6.0	62.0	2,400	Production well, C.G. Water Dept. Ashiak Reservoir.
17	5108	2345	97.5	68	9.5	36.0	1,500	Production well, C.G. Water Dept. Zabbar.
24	4300	2549	182.4	–181	9.4	20.0	2,700	Gauging well, C.G. Water Dept. l'Imriehel.
30	5022	2217	120.1	– 26	?	39.0	2,400	Irrigation well C.G. Water Dept. Ta Bulebel.
31	4159	2565	177.8	32	9.8	12.0	4,100	Production well, C.G. Water Dept. St. Anton. Cf. with B.H. 62, only 10 feet away.
33	4807	2186	139.0	Below –161	?	26.4	2,100	Plugged to surface — did not reach base of Glob. Formation. C.G. Water Dept. Tarshin.
35	3782	2632	295.0	240	15.0	10.8	5,800	Abandoned production well — to be used for gauging. C.G. Water Dept. Bukana.
36	3970	2540	310.9	282	12.9	12.0	6,100	Production well, C.G. Water Dept. Santa Maria Reservoir.
37	4513	2124	275.0	155	25.0	10.8	2,900	Production well, C.G. Water Dept. Luca Reservoir.
39	5041	2263	129.4	– 36	6.4	22.8	2,200	Trial Irrigation well — to be used for gauging. C.G. Water Dept. Zabbar.
40	5025	2435	156.6	Above 156	1.6	5.0	1,000	Irrigation well, C.G. Water Dept. Kalkara. The low initial salinity was lost on deepening and pumping.
41	4952	2192	149.6	–162	15.6	19.0	2,300	Trial Irrigation well, C.G. Water Dept. Ta Bulebel.
42	4943	2126	123.9	– 81	8.9	16.0	2,800	Trial Irrigation well, C.G. Water Dept. Zeitun. To be used for gauging.
43	5058	2060	189.4	28	4.4	60.0	1,500	Irrigation well, C.G. Water Dept. Zeitun.
45	4998	2294	173.4	133	3.4	20.0	1,700	Irrigation well, C.G. Water Dept. Zabbar.
48	4894	2235	182.1	22	46.1	21.0	1,800	Trial Irrigation well, C.G. Water Dept. Tarshin.
49	5110	2262	135.1	62	6.1	22.0	1,900	Trial Irrigation well, C.G. Water Dept. Zabbar.
50	3984	2538	304.2	276	11.2	12.0	5,900	Ventilating shaft, C.G. Water Dept. Ta' Kali Pumping Station.
51	3925	2267	406.0	376	18.0	10.0	4,200	Production well, C.G. Water Dept. Zebbug Reservoir.
54	4727	2497	15.0	Below –169	0.0	1000.0	80	Trial production well, W.D. Cold Stores, Magazine Bastion.
55	4082	2871	367.4	Above 367	9.4	10.0	3,000	Production well, C.G. Water Dept. Nashar Reservoir.
56	4437	2738	268.0	73	14.0	14.0	1,900	Production well, C.G. Water Dept. Sliema Reservoir.
58	3903	2047	492.1	381	12.1	14.0	2,200	Gauging well, C.G. Water Dept. Ta Ziri.
60	4352	2779	315.3	218	7.3	14.4	2,400	Gauging well, C.G. Water Dept. Tal Balal.
61	4515	2966	115.4	Above 115	0.4	94.8	500	Well for testing pumping sets, W.D. Pembroke Battery.
62	4159	2565	177.0	42	7.0	28.8	4,100	Production well, C.G. Govt. Dept. St. Anton Cf. with B.H. 73, only 35 yards away.
64	3519	2268	563.4	295	10.4	50.4	2,100	Gauging well, C.G. Water Dept. Sta. Katerina.
65	4017	2519	278.7	275	10.7	13.8	5,600	Ventilating hole for proposed Wied is Seuda—Ta Kali heading C.G. Water Dept. Attard.
67	4504	2841	54.1	36	3.1	24.6	800	Gauging well, C.G. Water Dept. Wied Ghomor.
68	4407	2949	243.6	223	5.6	57.6	1,300	Trial production well, W.D. St. Patrick's Cf. with B.H. 73, only 35 yards away.
69	3894	2536	355.1	?	10.1	12.3	6,400	Production well, C.G. Water Dept. Villa Castelletti, Ta Kali.
70	4079	2482	218.7	209	8.7	14.4	5,100	Ventilating hole for proposed Wied is-Seuda—Ta Kali heading C.G. Water Dept. Attard.
71	4160	2578	172.4	27	8.4	34.2	4,100	Production well, C.G. Water Dept. St. Anton.
72	3970	2553	311.6	285	12.6	14.4	6,100	Production well, C.G. Water Dept. Santa Maria Reservoir.
73	4408	2946	243.0	211	6.0	38.4	1,300	Trial production well, W.D. St Patrick's Cf. with B.H. 68, only 35 yards away.
74	4214	2727	240.4	202	9.4	17.4	3,800	Gauging well, C.G. Water Dept. L'Iclin.
75	4066	2692	234.1	188	11.1	11.4	4,600	Gauging well, C.G. Water Dept. Lia.
76	3903	2659	303.8	258	8.8	10.5	5,400	Gauging well, C.G. Water Dept. Musta.
77	3630	2602	336.7	230	10.7	12.0	5,100	Gauging well, C.G. Water Dept. Wied Tal Kleigha.
78	3411	2539	516.8	299	9.8	48.3	3,100	Gauging well, C.G. Water Dept. Ghemieri.
79	4072	2036	308.6	242	8.6	13.5	3,000	Gauging well, C.G. Water Dept. Sijjewi
81	4237	2016	268.9	184	13.9	10.8	3,300	Gauging well, C.G. Water Dept. Ta Kandia.
82	3948	2373	340.4	291	13.4	13.8	5,200	Gauging well, C.G. Water Dept. San Giacomo.
83	3714	2026	653.4	310	10.4	27.9	1,000	Gauging well, C.G. Water Dept. Girgenti.
84	4650	2190	193.7	52	4.7	14.4	1,900	Gauging well, C.G. Water Dept. Hal Saflini.
85	3956	1871	419.6	359	9.6	17.1	1,100	Gauging well, C.G. Water Dept. Wied Lapsi.
86	3446	2716	406.5	331	4.5	13.8	3,400	Gauging well, C.G. Water Dept. Gnien ta' Binjemma.
87	4431	2046	304.6	172	17.6	9.6	3,900	Gauging well, C.G. Water Dept. Ta Ghadaima.
89	4150	2385	267.0	167	12.0	24.0	4,700	Gauging well, C.G. Water Dept. Tal Gharbi.
92	4201	1784	406.3	317	11.3	14.1	1,000	Gauging well, C.G. Water Dept. Krendi.
93	4295	2962	249.3	197	6.3	25.5	1,200	Gauging well, C.G. Water Dept. Wied id Dis.
95	4487	1757	382.0	289	4.0	11.4	1,500	Gauging well, C.G. Water Dept. Bubakra.
96	3842	2832	274.3	252	13.3	16.5	3,700	Gauging well, C.G. Water Dept. Tarja Gap.
97	4690	1837	244.4	194	5.4	9.0	2,500	Gauging well, C.G. Water Dept. Ta Klantun.
117	3743	2266	489.2	369	14.2	14.7	3,300	Gauging well, C.G. Water Dept. Wied ta L'Iskof.
126	4176	1881	389.8	301	9.8	18.9	1,900	Production well, C.G. Water Dept. San Niklaw Reservoir.
127	3821	2467	458.5	265	16.5	20.7	5,400	Earthing hole, R.N.A.S., Ta Kali.
162	4482	2231	140.2	– 23	20.2	26.4	2,300	Earthing hole, A.M.D.W., Tax Xieref.
163	4641	1664	228.8	181	0.8	33.3	1,100	Earthing hole, A.M.D.W., Hal Far.
164	4395	2202	88.6	42	17.6	9.3	3,100	Earthing hole, A.M.D.W., Wied il Kbir.
165	4979	1624	44.4	– 40	1.4	—	400	Earthing hole, A.M.D.W., Kalafrana.
168	4305	2007	297.3	217	11.3	9.9	3,200	Earthing hole, A.M.D.W., Sijuwi.
172	4632	1722	317.4	257	1.4	9.0	1,300	Production well, A.M.D.W., Hal Far Service Reservoir.

NOTE:—For details concerning the construction of individual boreholes, the strata drilled through, and changes of salinity observed while deepening below the top of the water table, reference should be made to the drilling diaries and graphic logs deposited in the Offices of the Chief Engineer, Malta Command, and of the Manager, Civil Government Water Department.

Table 7. COMPARATIVE LIST OF BOREHOLES IN THE MAIN LOWER WATER TABLE AT WHICH PUMPING TESTS HAVE BEEN MADE

Serial No. of B.H.	Diameter (Inches)	Depth of hole in Water Table (Feet)	Maximum rate of Production (G.P.H.)	Yield G.P.H./ Depth in W.T.	REMARKS
1	10	59	1,000	17	Test of brief duration made with 1,000 g.p.h. pumping set in 1943. Hole has since been reamed to 12 inches diameter. Salinity: 10 parts chlorides/100,000.
12	10	48	4,350	91	Salinity initially 37 parts/100,000 at top of the water table; 51/100,000 bailed at the bottom of the hole. Pumps steadily at 73-79/100,000 throughout the year.
17	10	87	3,000	35	Salinity rises to 190/100,000 during long spells of pumping.
24	10	252	3,000	12	190 ft. of water table in Globigerina Formation, 104 ft in Lower Coralline Limestone. Yield inadequate to maintain 3,000 g.p.h. Salinity: 100/100,000.
30	10	140	3,600	26	36 ft. of water table in Globigerina Formation, 104 ft. in Lower Coralline Limestone. Salinity recorded originally 39/100,000. While pumping 947,700 gals. for irrigation during May-November the salinity rose from 199 to 295 parts/100,000.
31	10	30	3,900	43	Salinity: 35 parts Cl/100,000 Cf. with B.H. No. 62 which was drilled close alongside owing to crookedness of B.H. No. 31.
33	10	145	1,000	47	Salinity: 26/100,000. Water Table entirely in Globigerina Formation.
35	12	70	1,443	20	Salinity: 18/100,000.
36	12	68	4,800	71	Salinity: 12/100,000.
37	10	65	2,740	42	Salinity: 10/100,000.
39	10	110	1,700	15	42 ft. of water table is in Globigerina Formation, 68 ft. in Lower Coralline Limestone. Salinity: 35/100,000. Two 50 lb shots of gelignite failed to increase yield appreciably.
40	10	45	3,600	80	Salinity rises to 135/100,000 after 4 days pumping.
43	10	57	3,000	53	During 60 hours pumping test at 3,000 g.p.h. salinity rose from 60 to 164/100,000.
45	10	50	4,000	80	During 72 hours pumping test at 4,000 g.p.h. salinity rose from 20 to 100 parts Cl/100,000.
48	10	85	1,000	12	Salinity 21 parts Cl/100,000.
49	10	51	380	7	Salinity: 22 parts Cl/100,000. After deepening 10 ft.
	10	61	550	9	Salinity: 28 parts Cl/100,000.
51	12	60	1,420	24	Salinity: 10-12 parts Cl/100,000. Deepened 50 feet to provide more water for Zebbug Reservoir.
	12	110	2,160	20	Salinity increased to 22 parts Cl/100,000 (21.4.45).
55	12	58	2,050	35	Salinity: 8-12 parts Cl/100,000.
56	12	60	2,860	48	Salinity: 14-17 parts Cl/100,000.
61	10	43	1,000	23	Salinity: 437 parts Cl/100,000. Situated 550 yards from the coast. Only used for testing reconditioned pumping sets. Cf. B.Hs. Nos. 68 and 73, 1,250 yards from the coast.
62	18	47	1,500	32	Salinity: 28 parts Cl/100,000. Pumping at this depth did not reduce the yield of No. 31, only 8 ft. away.
	18	90	3,600	40	Depeened 30 ft. to same depth as No. 31 resulted in salinity of 36 parts Cl/100,000.
68	12	22	550	25	Salinity: 51 parts Cl/100,000. Situated 1,250 yards from the coast, and 100 ft. from No. 73.
69	24	60	3,700	62	Salinity: 12 parts Cl/100,000. Deepened 50 ft. to provide more water for Ta Qali Reservoir.
	24	110			
71	12	91	3,600	40	Salinity: 41 parts Cl/100,000. Situated 400 ft. from No. 62.
73	10	43	460	11	Salinity: 49 parts Cl/100,000. Situated 1,250 yards from the coast and 100 ft. from No. 68.
126	15	70	1,300	19	Salinity: 20 parts Cl/100,000, when handed over to C. G. Water Dept. for production. Pumping discontinued after unsatisfactory yield tests 24-28.7.45. No analyses made of water pumped.

Table 8. LIST OF BOREHOLES RESERVED FOR GAUGING CHANGES OF LEVEL AND COMPOSITION OF THE MAIN LOWER TABLE, MALTA

Map Reference	Serial No. of B.H.	Surface height above M.S.L.	Diameter of Borehole	Casing I.D. Length	Depth to S.W.L. below G.L.	Height of S.W.L. above M.S.L.	Salinity at top of Water Table
34462716	86	406.47	0–106—18" 106–462—12"	12"—86'	402' (12.12.44)	4.47'	13.8 (12.12.44)
34823832	96	274.29	0– 45—15" 45– 70—10" 70–322— 8"	12"—37'6"	261' (12.2.45)	13.29'	16.5 (10.2.45)
42952962	93	249.28	0– 53—10" 53–303— 6"	6"—54'6"	243' (17.1.45)	6.28'	25.5 (17.1.45)
34112539	78	516.82	0– 18—12" 18–222—10" 222–567— 8"	8"—225'	507' (27.10.44)	9.82'	48.3 (28.10.44)
36302602	77	336.66	0– 15—12" 15–270—10" 270–386— 8"	8"—110"	326' (3.10.44)	10.66'	12 (3.10.44)
37822632	35	295.04	0–350—12"	12"—10'	280' (25.3.44)	15.04'	10.8
39032659	76	303.80	0–360—12"	8"—33'4"	294' (17.4.45)	7.8'	10.5 (24.10.44)
40662692	75	234.12	0–283—12"	12"—14'6"	223' (22.9.44)	11.12'	11.4 (22.9.44)
42142727	74	240.39	0– 5—12" 5–281— 8"	8"—32'	231' (11.8.44)	9.39'	17.4 (8.8.44)
43522779	60	315.26	0– 29—12" 29–368— 8"	8"—30'	308' (19.6.44)	7.26'	14.4 (27.6.44)
45042841	67	54.09	0– 32—10" 32– 90— 8"	8"—32'6"	51' (4.7.44)	3.09'	24.6 (4.7.44)
35192268	64	565.38	0– 93—15" 93–299—10" 299–615— 8"	8"—273'6"	555' (10.10.44)	10.38'	50.4 (9.10.44)
37432266	117	489.23	0–177—15" 177–450—12" 450–545—10"	12"—177'3" (Plus 3' extension above G.L.)	475' (28.3.45)	14.23'	14.7 (27.3.45)
39482373	82	340.37	0– 62—15" 62–393—10"	12"—56'	327' (18.4.45)	13.37'	13.8 (30.11.44)
41502385	89	267.03	0–103—10" 103–315— 6"	6"—104' 6"—104'	255' (11.12.44)	12.03'	24.0 (12.12.44)
43002549	24	182.35	0–425—10"	10"—10'	173' (27.11.43)	9.35'	20.0 (27.11.43)
37142026	83	653.35	0–128—15" 128–348—12" 348–703— 8"	8"—350'	643' (17.11.44)	10.35'	27.9 (17.11.44)
39032047	58	492.05	0–203—18" 103–540—12"	12"—104'6"	480' (1.6.44)	12.05'	14.0 (1.6.44)
40722036	79	308.6	0–360—10"	8"—68'	300' (23.10.44)	8.6'	13.5
42372016	81	268.94	0–247—10" 247–305— 8"	8"—94'	255' (14.11.44)	13.94'	10.8 (14.11.44)
44312046	87	304.59	0–136—10" 136–347— 6"	6"—136'10"	287' (19.12.44)	17.59'	9.6 (20.12.44)
46502190	84	193.74	0–145—10" 145–249— 8"	8"—146'4"	189' (27.11.44)	4.74'	14.4 (28.11.44)
39561871	85	419.64	0– 71—15"	12"—69'	410' (18.12.44)	0.64'	17.1 (15.12.44)
42012784	92	406.31	0– 92— 8"	6"—94'6"	395' (12.1.45)	11.31'	14.1 (12.1.45)
44871757	95	381.98	0–103—10" 103–438— 6"	6"—94'6"	378' (26.1.45)	3.98'	11.4 (26.1.45)
46901837	97	244.37	0– 66—12" 66–300—10"	10"—67'	239' (2.2.45)	5.37'	9.0 (1.2.45)
49432126	42	123.88	0–170—10" 170–285— 8"	10"—10'	115' (10.1.44)	8.88'	16.0 (10.1.44)
51102262	49	135.14	0–190—10"		129' (8.3.44)	6.14'	22 (8.3.44)

NOTE: Discrepancies, sometimes amounting to several feet, have occurred in determinations of individual surface heights from different P.W. Dept., and old Survey bench marks. Prior to the installation of continuous recording apparatus accurate redeterminations to the top of the casing cemented in each hole, by means of closed traverses from the Survey Datum Posts at Kalanka tal Patriet and Marsaxlokk, will be required. The values for Standing Water Level and for Salinity (in parts of chlorides per 100,000) refer only to the dates quoted. They are subject to tidal and seasonal variations in every case (cf. Plates 5 and 6).

Table 9. DAILY PRODUCTION OF UPPER CORALLINE SPRINGS

Group	Gallery	1893-94 Max. (1,000 gallons)	1893-94 Mean (1,000 gallons)	1893-94 Min. (1,000 gallons)	1897-98 Max. (1,000 gallons)	1897-98 Mean (1,000 gallons)	1897-98 Min. (1,000 gallons)	1942-43 Max. (1,000 gallons)	1942-43 Mean (1,000 gallons)	1942-43 Mean May—Aug. incl. (1,000 gallons)	1942-43 Min. (1,000 gallons)
Wignacourt											
"Fiddien"	Wied Il Busbies	560	358	138	173	118	88	313	73	49	0+
	Hofriet ir Riz							43	12	5	0+
	Misrah Suffara							797	161	82	5+
	Tat Tarija							421	68	22	3+
								20	8	6	8
"Busugrilla"	Gharixiem										
	Busugrilla	323	236	112	131	104	76				
	Ghain Kaiet							242	56	32	3+
	Ghain Klieb	31	15	8	4	3	2	20	13	12	5+
	Ghemieri	155	45	30	23	21	18	94	31	28	15
Ta L'Isqof		63	27	9	43	40	31	195	49	37	10
Buskett	Ta Sienja	170	41	4	23	10	5				
	Ta Sala	64	50	40	39	33	30	97	53	58	36
	Ta Rapa	16	12	8	10	9	8				
	Ghirgenti	195	51	39	29	32	24				
Fawara	San Giorgio	59	33	30	24	22	20				
	Annunziata	40	16	14	13	10	8	134	68	64	43
	Fawara	60	21	13	11	9	8				
	Ghain Tuffieha							85	48	57	18
	Tal Madonna							10	5	6	2
Mean rainfall recorded by Rabat-Dingli Gauges		27.84 inches			13.65 inches			27.57 inches			

NOTES:—

(1) *Wignacourt.* The 1942-43 figures for the "Fiddien" group include fewer galleries than in 1893-94 and 1897-98. Ghariexem was cut out from the "Busugrilla" gaugings before 1894, and the Busugrilla gallery itself was cut out after 1909. The form of the daily graphs for 1942-43 indicate clearly that the minimum readings marked+ were made on days when private wells in proximity to the Government galleries were pumping strongly and that the daily means for the months May to August inclusive are a more suitable measurement of what the minimum natural summertime yield of the galleries would be without outside pumping interference.

(2) *Buskett.* Ta Sienja was cut out from the public supply after 1909 and production figures are not available for 1942-43. Late local rain was responsible for raising the May-August mean above the mean for the year.

(3) *Ghirgenti.* Ghirgenti production figures not available for 1942-43.

(4) *Fawara.* The three galleries of the Fawara Group were not gauged separately in 1942-43.

(5) *Ghain Tuffieha.* Daily gauging records not available before 1932-33.

(6) *Tal Madonna.* Daily gauging records not available before 1941-42.

Table 10. UPPER CORALLINE BOREHOLES:

RESULTS OF PUMPING TESTS

Serial No. of Bore	Surface Height (A.M.S.L.)	Diameter	Height of W.T. above M.S.L.	Depth of Hole in Water Table	Maximum Rate of Production	REMARKS
27	90'	10"	10'	20'	1,000 g.p.h.	In Marfa Sea-Level Table. Salinity: 54/100,000. Supply discontinued on removal of 8th Army camps.
5	64'	10"	4'	30'	1,000 g.p.h.	In Mellieha Bay Sea-Level Table. Initial salinity 32/100,000, rose to 97/100,000 when pumping. Pumping to Mellieha Camp discontinued owing to high salinity.
8	70'	10"	2'	22'	1,000 g.p.h.	In Mellieha Bay Sea-Level Table. Pumping salinity only 10.2/100,000, but supply to Mellieha Camp discontinued owing to surface contamination.
25	50'	10"	4'	19'	4,000 g.p.h.	In St. Paul's Valley Sea-Level Table. Salinity: 26/100,000. Used to augment Mellieha and St. Paul's Bay supply.
28	65'	10"	4'	41'	1,000 g.p.h.	In St. Paul's Valley Sea-Level Table. Salinity: 24/100,000. Used to augment supplies to Ghain Tuffieha Camps in 1943.
90	328'	8"	130'	100'	4,200 g.p.h. 3,900 g.p.h.	In Falka Syncline Water Table. Salinity: 9.3/100,000. Tested at 4,200 g.p.h. in Feb. and at 3,900 g.p.h. in April 1945 when B.H. 118 pumping also.
118	292'	10"	127'	84'	2,900 g.p.h.	In Falka Syncline Water Table. Salinity: 9.5/100,000. Steady yield at this rate in April 1945.

Table 11. SUMMARY OF BINJEMMA AREA BOREHOLES

Map Reference	Serial No.	Surface Height A.M.S.L.	Top of Blue Clays A.M.S.L.	Thickness of Greensand	Thickness of Basal U.C.L. Beds	Height of S.W.L. A.M.S.L.	REMARKS
		(Feet)	(Feet)	(Feet)	(Feet)	(Feet)	
34582778	57	322	102	N.R.	N.R.	N.W.	Filled up to 217 ft. B.G.L. (Feb. 1944)
34702803	63	292	130	6"	N.R.	N.W.	Filled up to 93 ft. B.G.L. (Feb. 1944)
36512784	90	330	32	N.R.	29	132	S.W.L. constant from Jan. to April 1945. 12 inch. I.D. pipe with cap grouted in at surface so that check observations of S.W.L. may be made, or B.H. pumping set installed.
35942803	98	287	193	N.R.	24	N.W.	Plugged to surface.
36312787	99	302	146	N.R.	N.R.	N.W.	Plugged to surface.
34402748	100	346	—90	N.R.	11	10 (21.2.45)	1½ inch I.D. pipe with cap grouted in at surface so that hole may be cleaned out and used for B.H. pump if required.
35502776	101	338	20	3	44	54 (17.2.45)	8 inch I.D. pipe with cap grouted in at surface so that check observations of S.WL. may be made.
35512831	102	240	185	2½	N.R.	N.W.	Plugged to surface.
35352788	103	292	91	2	N.R.	N.W.	Plugged to surface.
33902740	105	370	35	1	7	N.W.	Plugged to surface.
33712771	106	317	155	2½	6	N.W.	Plugged to surface.
34212835	107	285	173	2	6	N.W.	Plugged to surface.
34212822	108	288	158	2	7	N.W.	Plugged to surface.
34362756	109	339	4	3	22	N.W.	Plugged to surface.
34222808	110	294	143	2½	18	154	12 inch I.D. pipe with cap grouted in at surface so that check observations of S.W.L. may be made.
33562837	111	254	135	3	8	162 (22.3.45)	9 inch I.D. pipe with cap grouted in at surface so that check observations of S.W.L. may be made.
32632745	112	356	180	N.R.	31	N.W.	Plugged to surface.
37052808	113	239	149	6	6	N.W.	Plugged to surface.
34252791	114	302	121	2½	7½	N.W.	8 inch I.D. pipe with cap grouted in at surface to keep hole open.
33682800	115	276	131	4	11	155	12 inch I.D. pipe, with cap, grouted in at surface so that check observations of S.W.L. may be made.
34452739	116	355	Below —175	not reached	—	9.5 (11.5.45)	12 inch I.D. pipe, with cap, grouted in at surface and 4 inch I.D. slotted pipe run to bottom of hole so that check observations of S.W.L. may be made.
36712792	118	292	43	2	60	127 (29.3.45)	12 inch I.D. pipe with cap, grouted in at surface so that check observations of S.W.L. may be made, or B.H. pumping set installed.
32642738	119	370	165	N.R.	15	195 (7.4.45)	8 inch I.D. pipe, with cap, grouted in at surface so that check observations of S.W.L. may be made.
33302809	120	265	137	2½	32½	165 (13.4.45)	Plugged to surface.
34232872	121	346	275	2½	3½	N.W.	Plugged to surface.
33562820	122	260	139	3	18	N.W.	Plugged to surface.
34292779	123	318	96	3	48	N.W.	Plugged to surface.
34772845	124	280	165	2	30	N.W.	Plugged to surface.
34802822	125	273	152	2	41	N.W.	Plugged to surface.

Abbreviations: N.R. — Not recognised in formation samples taken.
N.W. — No appreciable quantity of water recorded.

Table 12. SUMMARY OF MIZIEP AREA BOREHOLES

Map Reference	Serial No.	Surface Height A.M.S.L. (Feet)	Height of top of Blue Clays (Feet)	Height of S.W.L. A.M.S.L. (Feet)	Salinity in parts chlorides 100,000	REMARKS
3505 3279	130	43.84	c. + 50	N.W.	—	Proved presence of Blue Clay outcrop at surface, beneath landslips and hill drag, on synclinal axis at culmination of pitch between Miziep and Cala Mistra.
3303 3213	131	143.97	— 28	11.5	12.9	12 inch I.D. pipe, with cap, grouted in at surface to allow further observations of S.W.L.
3373 3229	132	132.11	— 26	11.5	13.8	12 inch I.D. pipe, with cap, grouted in at surface to allow further observations of S.W.L.
3219 3210	133	154.95	— 41	13	14.7	12 inch I.D. pipe, with cap, grouted in at surface to allow further observations of S.W.L.
3134 3187	134	177.17	+ 52	72	24.3	Up dip from standing water table. Easily bailed down.
3307 3180	135	154.66	+ 46	59	15	Up dip from standing water table. Easily bailed down.
3307 3223	136	159.56	— 30	13.5	13.2	
3303 3199	137	133.00	— 28	12.5	9.9	
3222 3204	138	146.86	— 30	19	6.3	
3226 3175	139	168.58	— 0.5	33	8.1	Near edge of standing water table.
3306 3232	140	176.92	— 57	12	11.4	
3385 3217	141	114.55	— 8.5	13	5.1	
3227 3189	142	154.42	— 17.6	12.5	10.2	
3374 3249	143	171.61	+ 24.6	N.W.	—	
3222 3218	144	178.84	— 35.2	14.8	20.7	
3302 3241	145	194.03	+ 104	N.W.	—	On upthrown side of Ghain Znuber Fault.
3176 3198	146	150.53	+ 8.5	49.5	14.6	Near margin of standing water table. Easily bailed down.
3302 3238	147	191.42	— 46.6	13.5	12.5	
3375 3242	148	150.19	+ 5.2	N.W.	—	Near margin of standing water table.
3229 3142	149	238.59	+ 71.6	79.5	13.3	On crest of Baida Anticline. Water easily bailed down.
3310 3151	150	245.08	+ 56	67	10.7	On crest of Baida Anticline. Water easily bailed down.
3389 3207	151	140.77	+ 26.8	N.W.	—	Outside the standing water table.
3393 3189	152	198.13	+ 53	59	9.9	On crest of Baida Anticline. Water easily bailed down.
3267 3227	153	171.91	— 21.1	37	14.4	
3419 3204	154	220.72	+ 49	N.W.	—	On crest of Baida Anticline.
3439 3209	155	200.47	+ 66	N.W.	—	On crest of Baida Anticline.
3268 3220	156	157.05	— 24	13	9.6	
3265 3233	157	201.41	— 3.6	19.5	12	
3457 3210	158	206.76	+ 69.8	N.W.	—	On crest of Baida Anticline.
3267 3210	159	146.88	— 20	13.4	10.8	
3223 3224	160	203.67	+ 3.7	12.7	11.2	
3270 3196	161	139.52	— 25.5	14.5	9.5	

Abbreviation: N.W.—No appreciable quantity of water recorded.

Table 13. LIST OF SERVICE RESERVOIRS

Reservoir	Date Completed	Capacity in gallons	Present source of supply, etc.
Tal Madonna ...	—	10,000	Tal Madonna Gallery
Mellieha	1911	553,000	Ghain Tuffieha Gallery and B.H. 25
St. Paul's Bay ...	1914	715,000	Ghain Tuffieha Gallery and B.H. 25
Imjar	—	5,000	Burnohhala Gallery and Nadur Tank
Bingemma	—	5,000	Burnohhala Gallery and Nadur Tank
Nadur (W.D.) ...	—	2,132,000	Ghain Kaiet Pumping Station
Tas Salib	—	1,207,600	Wignacourt Springs
Rabat (Old) ...	1886	42,500	Ghain Kaiet and Via Dingli Pumping Stations
Rabat (New) ...	1922	490,000	Ghain Kaiet and Via Dingli Pumping Stations
Dingli	1933	300,000	Via Dingli Pumping Station
Gargur (Old) ...	—	76,900	San Antonio Pumping Station and B.Hs. Nos. 62 and 71
Gargur (New) ...	—	50,700	San Antonio Pumping Station and B.Hs. Nos. 62 and 71
Nashar	1938	5,320,000	Wied il Ghasel Pumping Station and B.H. No. 55
Sliema	1908	1,220,000	Ta Kali and Nashar Reservoirs, and B.H. No. 56
Mosta	—	(53,100)	Wignacourt Springs. Completely demolished by bombs, 1942
Mercieca	1923	5,766,000	Tal Hlas and Ta Kali Pumping Stations, Wignacourt Springs and B.H. 69
Santa Maria ...	1886	10,841,000	Tal Hlas and Ta Kali Pumping Stations, Wignacourt Springs, Buskett Springs, and B.H. No. 36 Breached and completely emptied by delayed action bomb, March 1942
Ta Kali No. 1 ...	—	1,350,300	Tal Hlas and Ta Kali Pumping Stations and Buskett Springs
Ta Kali No. 2 ...	—	1,464,050	Tal Hlas and Ta Kali Pumping Stations and Buskett Springs
Ta Kali No. 3 ...	—	1,400,000	Tal Hlas and Ta Kali Pumping Stations and Buskett Springs Slight Bomb Damage, January 1942
Ta Kali No. 4 ...	—	1,250,000	Tal Hlas and Ta Kali Pumping Stations and Buskett Springs
Birchircara	1884	30,600	Ta Kali Reservoirs
Zebbuj	1886	19,700	Buskett and Ta L'Iskof Springs, B.H. No. 51, and Ta Kali Booster Pump
Curmi	—	15,700	Buskett and Ta L'Iskof Springs, B.H. No. 51, and Ta Kali Booster Pump
Pinto	—	1,301,000	Ta Kali and Nashar Reservoirs
St. James Cavalier	1886	263,000	Wied il Kbir Pumping Station. Considerable bomb damage, April 1941
Bouverie	1878	2,400,000	Schinas or Luca Reservoirs
St. Clements B. ...	—	200,000	Schinas or Luca Reservoirs
St. Clements C. ...	—	468,000	Schinas or Luca Reservoirs
			Tank A was constructed in 1886 and destroyed by bombs in March 1941. Tanks B and C were transferred from the War Department to the C. G. Water Dept. in 1929
Schinas	1895	1,163,000	Wied il Kbir Pumping Station. Slight bomb damage, November 1940
Luca (Naval) ...	—	10,000,000	Wied il Kbir Pumping Station
Luca (C. Govt.) ...	1932	5,597,000	Wied il Kbir Pumping Station and B.H. No. 37. Considerable bomb damage, September 1940 and January 1942
Sijjuwi	—	5,000	Buskett Springs
San Niklau ...	—	181,500	Fawwara and Buskett Springs
Nigret (Old) ...	1888	128,600	Fawwara Springs
Nigret (New) ...	1934	1,110,000	Fawwara Springs
Halfar (R.A.F.) ...	—	100,000	Schinas Booster Pump
Ashiak	1925	1,000,000	San Niklau Tank, Wied Dalam Pumping Station and B.H. No. 12
Xerriek (R.A.F.) ...	—	100,000	Ashiak Tank
Marsa Shlok ...	1929	120,000	Ashiak Tank
Total Civil Government		46,070,150	gallons
„ Navy		10,000,000	„
„ W.D.		2,132,000	„
„ R.A.F....		200,000	„
Grand Total		58,402,150	„

Table 14. AVERAGE IRRIGATION RATES FOR THE PRINCIPAL IRRIGATED CROPS IN MALTA

Crop	Season	No. of Waterings	Quantity used for each watering (Gals./Tumolo)	Total consumption per tumolo (gallons)	Inches
Potatoes	Jan. — April	15	6,000	90,000	15
„	Aug. — Nov. ...	4	6,000	24,000	4
Pumpkins	April, in pots ...	10	470	4,700	1
„	May —Aug.	27	7,000	189,000	30
Long marrows ...	Apr., and May in pots	10	470	4,700	1
„	May — Sept.	30	7,000	210,000	33
Green pepper ...	Jan. — Apr. in pots...	30	500	15,000	2.5
„	May — Sept.	35	7,600	273,000	45
Tomatoes	Mar. — May in pots	26	120	3,120	0.5
„	May — Aug.	21	5,500	115,500	18
Artichokes ...	Mar. — Oct.	36	5,500	198,000	31
Cauliflowers ...	Seedlings	22	120	2,640	0.5
„	Planted out	27	5,500	148,500	23
Cabbages	Seedlings	22	120	2,640	0.5
„	Planted out	27	5,500	148,500	23
Kohlrabi	Seedlings	20	120	2,400	0.5
„	Planted out	20	5,500	100,000	16
Strawberries ...		—	—	116,000	18
Carrots		—	—	102,000	16

The above estimates are based on Mr. J. Baldacchino's observations while engaged on surveys for the Department of Agriculture and for the Water Department during 1942-45.

1 tumolo = 0.28 acres.

Table 15. MAIN SEA LEVEL WATER TABLE, ANNUAL EXTRACTION BY WATER DEPARTMENT AND MEAN SALINITY OF WATER EXTRACTED

Source	1945-46		1946-47		1947-48		1948-49	
	Gallons	M.A.S.	Gallons	M.A.S.	Gallons	M.A.S.	Gallons	M.A.S.
Wied-il-Kbir and Armier	416,637,000	62.3	456,439,000	60.4	411,632,000	65.9	391,865,000	60.5
San Anton	14,653,000	86.1	21,136,000	109.6	38,777,000	112.2	12,933,000	110.5
Tal-Hlas	400,248,000	71.7	364,311,000	87.1	410,378,000	129.0	447,014,000	118.9
Wied-is-Sewda	128,402,000	91.4	119,658,000	125.2	37,883,000	172.3	4,472,000	123.2
Wied-Dalam	32,267,000	79.8	39,883,000	82.0	32,275,000	84.9	30,266,000	83.7
Wied-il-Ghasel	196,692,000	142.4	198,265,000	149.2	181,629,000	176.2	174,116,000	183.9
Ta' Qali	218,780,000	30.7	273,443,000	33.6	304,776,000	44.6	225,500,000	38.0
Boreholes	51,960,000	72.0	112,747,000	43.0	155,168,000	52.0	203,289,000	48.0
Total	1,459,639,000	74.4	1,585,882,000	77.4	1,572,518,000	93.7	1,489,455,000	87.8

(M.A.S.—Mean Annual Salinity, in parts chlorides per 100,000. These figures may safely be doubled to obtain approximately the "total solids" content).

NOTES:—This tabulation, which should be appended to Table 2, demonstrates conclusively that the Main Sea Level Table is being grossly overpumped. In a few years' time no water fit for human consumption will remain, unless the present rate of extraction is reduced drastically. Extraction by private works must be suppressed completely, and the production of the Water Department's pumping stations and boreholes must be reduced to the 1,000,000,000 gallons recommended as probably the maximum rate of mean annual extraction which the Main Sea Level Table will be able to stand without rapidly increasing deterioration in composition.

(June 1950)

PLATE I.

1856. ORIGINAL L'ARMIER PUMPING STATION AND GALLERY.

1865. SUTHERLAND'S REPORT.
1864-66. GALLERIES IN UPPER TABLE TO INCREASE WIGNACOURT SUPPLY.

1867. BATEMAN'S VISIT AND REPORT.

1875. DINGLI'S REPORT.
1876. UNSWORTH'S VISIT AND REPORT.

1883. CHADWICK'S FIRST VISIT AND REPORTS.

1885. FIRST DAM IN WIED TAL KLEIGHA.
1886. STA. MARIA RESERVOIR COMPLETED.
1887. WIED IL KBIR, WIED IS SUEDA, ST. ANTON, AND VIA DINGLI PUMPING STATIONS COMPLETED.

1897. CHADWICK'S LAST VISIT AND REPORTS ON MALTA WATER SUPPLY AND SEWERAGE.
L'ARMIER GALLERIES CONNECTED WITH WIED IL KBIR PUMPING STATION.

1905. GHAIN KNIET PUMPING STATION COMPLETED.

1909. CONNECTION OF WIED IL KBIR AND WIED IS SUEDA GALLERIES COMPLETED.

1911. GHERUXIEM AND BUSUGRILLA SPRINGS CUT OFF FROM WIGNACOURT SUPPLY.
1912. ZAMMIT AND MORRIS REPORT. COMMENCEMENT OF CHLORINATION AND OF ROUTINE BACTERIOLOGICAL AND CHEMICAL ANALYSES.

1917. TAL HLAS PUMPING STATION COMPLETED. ROBERTSON'S REPORT.

1923. MERCIECA RESERVOIR COMPLETED.
1924. ZAMMIT'S PAPER ON WATER SUPPLY.
1925. WIED DALAM PUMPING STATION AND AXIAK RESERVOIR COMPLETED.

1928. RIZZO'S REPORT ON MALTA GEOLOGY AND WATER SUPPLIES.

1933. LUCA RESERVOIR COMPLETED.
1934. TAL GHARBI BRANCH JOINED TO MAIN WIED IS SUEDA GALLERY.
1934-35. REPORTS OF TURNER JONES AND BUSHELL COMMITTEES ON WATER SUPPLY.
1936. BOARD OF IRRIGATION COMMITTEE.
1937. WIED IL GHAJEL PUMPING STATION AND NAXXAR RESERVOIR COMPLETED. SIR F. STOCKDALE'S VISIT AND REPORT ON WATER SUPPLY FOR IRRIGATION.
1938. WATER PUMPS ORDINANCE.
1939. VIA DINGLI GALLERY EXTENDED.

1941. DISTINCTION BETWEEN 1st AND 2nd CLASS SUPPLIES RELINQUISHED. THIRD DAM IN WIED TAL KLEIGHA.
1942. MR. A. S. MORTIMER'S MEMORANDUM. 1 HYDRANTS FOR IRRIGATION SUPPLIES FITTED ON MAIN UNDERGROUND WATER ORDINANCE.
1943. VISITS AND REPORTS BY DR. E. B. BAILEY, CAPT. F. W. SHOTTON, AND MAJ. G. L. PAYER. BORING OPERATIONS BY 3 BORING SECTION, R.E.
1944. CONSTRUCTION OF TA KALI PUMPING STATION AND EXTENSIONS TO WIED IS SUEDA GALLERIES BY 171 TUNNELLING COY., R.E.
BORING OPERATIONS BY 7 BORING SECTION, R.E. GEOLOGICAL AND GEOPHYSICAL SURVEYS BY 42 GOELOGICAL SECTION, S.A.E.C.

1850 60 70 80 90 1900 10 20 30 40 50 60 70 80 90 2000

3000 2500 2000 1500 1000 900 800 700 600 500 400 300 200 100 90 80 70 60 50 40 30 20 10 9 8

2,500,000,000 GALLONS.
PROBABLE MAXIMUM OF MEAN ANNUAL SUPPLIES OF FIRST QUALITY POTABLE WATER AVAILABLE FROM UPPER AND LOWER TABLES COMBINED.

WATER REQUIRED AT 20 GALS. PER HEAD PER DAY.

TOTAL WATER DRAWN BY WATER DEPT. FROM UPPER AND LOWER TABLES COMBINED. (IN MILLION GALLONS).

WATER REQUIRED AT 10 GALS. PER HEAD PER DAY.

TOTAL WATER DRAWN BY WATER DEPT. FROM LOWER WATER TABLE (IN MILLION GALLONS).

CUMULATIVE CAPITAL EXPENDITURE OF WATER DEPT. (IN £1,000's).

446,000 407,000 366,000 330,000 298,000 268,000 242,000

POPULATION OF MALTA, EXCLUSIVE OF IMPERIAL NAVAL, MILITARY, AND AIR FORCE PERSONNEL. (IN THOUSANDS).

TOTAL WATER DRAWN BY WATER DEPT. FROM UPPER TABLES (IN MILLION GALLONS).

MEAN CHLORIDE CONTENT OF COMBINED PRODUCTION FROM LOWER TABLE PUMPING STATIONS. (IN PARTS PER 100,000)

MEAN CHLORIDE CONTENT OF UPPER TABLE SPRINGS. (IN PARTS PER 100,000)

RAINFALL IN INCHES

5-YEAR MEAN.

MEAN OF 93 YEARS' OBSERVATIONS = 20 INCHES.

RAINFALL YEAR ENDING AUGUST

D.Sc., F.G.S., M.M.G.I., R.E.
NOV., 1944.

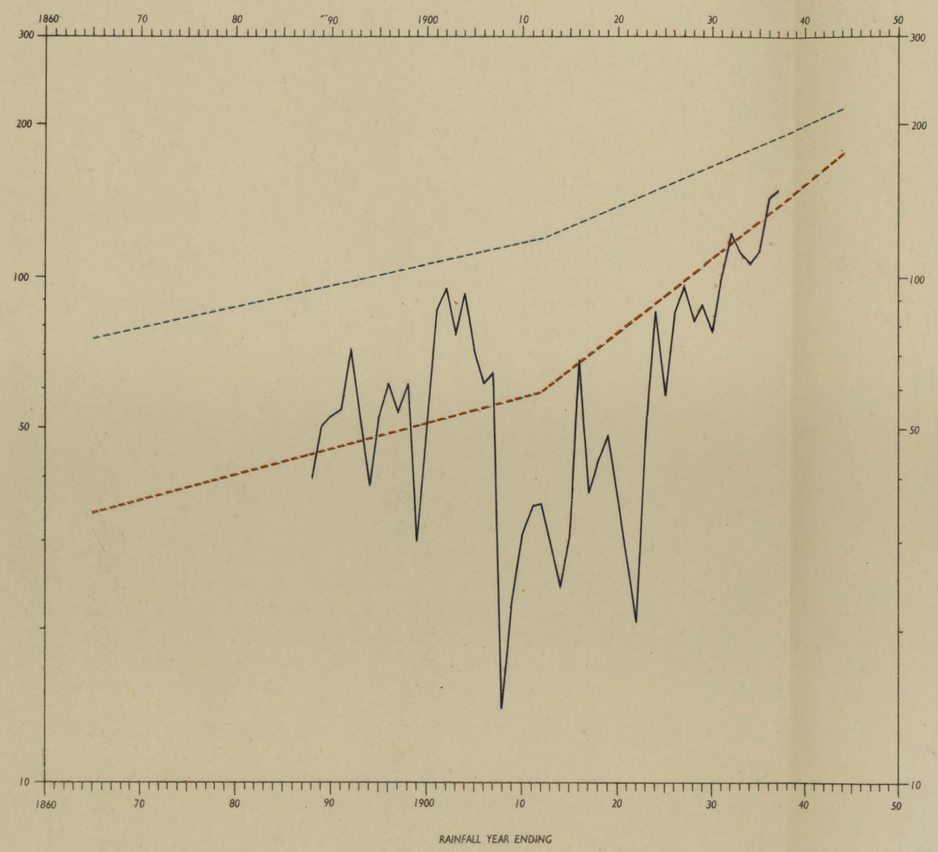
MALTA WATER SUPPLY RESOURCES.
SUMMARY OF DEVELOPMENTS TO 1944.

PRINTED IN GREAT BRITAIN BY EDWARD STANFORD, LTD., LONDON

PLATE 2

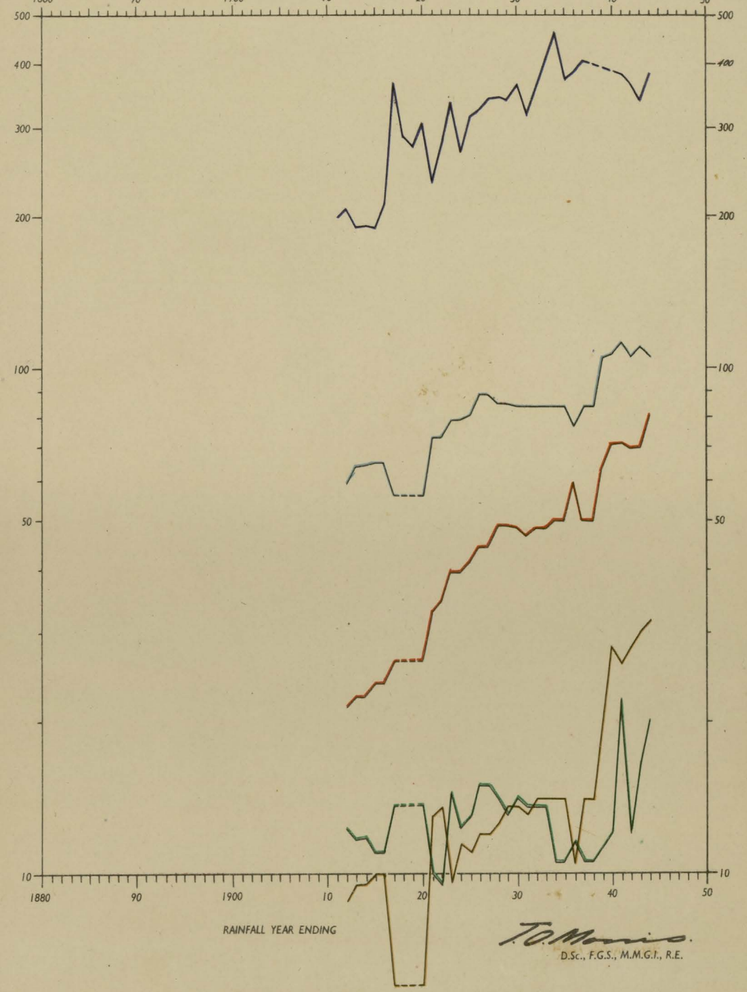
PRODUCTION AND COMPOSITION OF LOWER TABLE SUPPLIES

ARMIER



WIED IL KBIR 1st CLASS

WIED IS SUEDA AND TAL HLAS



D.Sc., F.G.S., M.M.G.I., R.E.

ANNUAL WATER PRODUCTION IN MILLION GALLONS

TOTAL SOLIDS, PARTS/100,000

CHLORIDES AS Na Cl, PARTS/100,000

TEMPORARY HARDNESS AS $CaCo_3$, PARTS/100,000

PERMANENT HARDNESS AS $CaCo_3$, PARTS/100,000

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PLATE 3

40

25

45

TA KALI PUMPING STATION

WIED IS SUEDA SHAFT

WIED IS SUEDA PUMPING STA. (DISUSED)

Widened to 5ft. 1935-39

Base of Glob. at S.L.

ST. ANTON PUMPING STATION

TAL HLAS PUMPING STATION

Loose Rock

Misida Spring

MISIDA CREEK

MARSA CREEK

ARMIER PUMPING STATION (DISUSED)

WIED IL KBIR PUMPING STATION

Water from this portion of gallery excluded from supply, 1885-1938.

METHOD OF PRODUCTION

- Well bailed by hand
- Well pumped by waterwheel
- Well pumped by windmill
- Well pumped by I.C. engine
- Boreholes constructed 1943-44
- Water Department shafts and galleries constructed between 1860 and 1938
- Gallery construction programme, 1944-45

DF = Dry fissure. WF = Wet fissure. B.W.F. = Brackish water fissure

SALINITY SURVEY, 23.8.44—13.9.44

- Less than 25 parts Cl/100,000
- 25-50 parts Cl/100,000
- 50-75 parts Cl/100,000
- 75-100 parts Cl/100,000
- More than 100 parts Cl/100,000

1000 0 5000 FEET

Coordinates of the 1,000-yard Military Grid

T. O. Morris

D.Sc., F.G.S., M.M.G.I., R.E.

PRIVATE AND DEPARTMENT OF AGRICULTURE WELLS IN RELATION TO WATER DEPARTMENT GALLERIES, LOWER WATER TABLE, MALTA.

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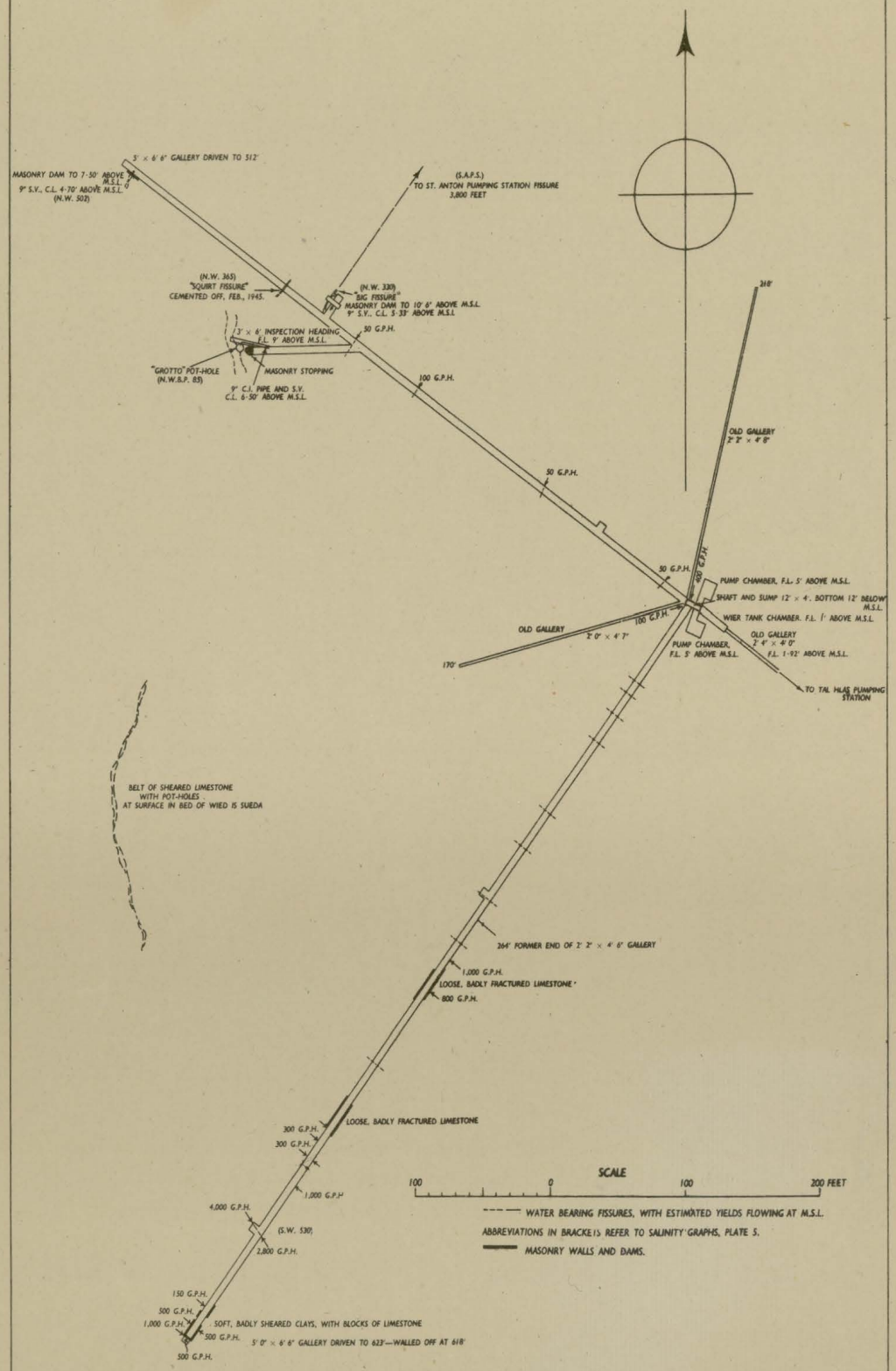
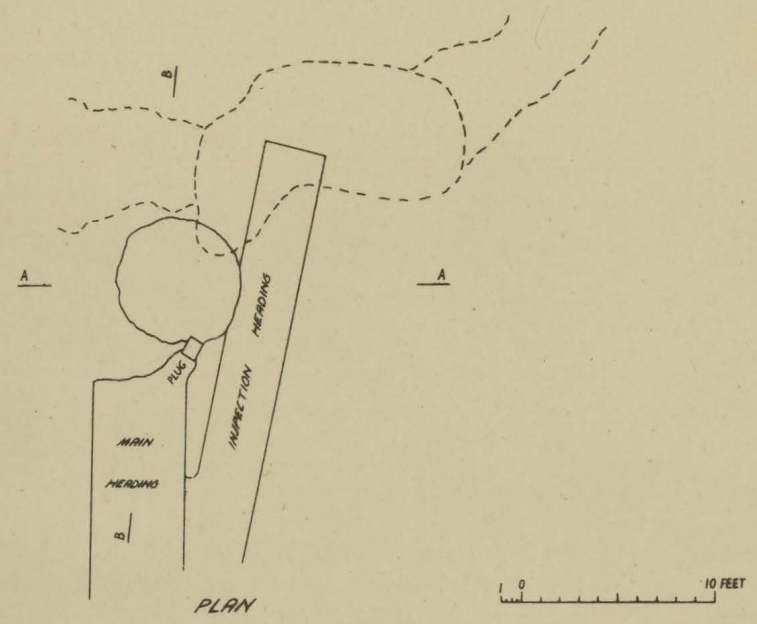
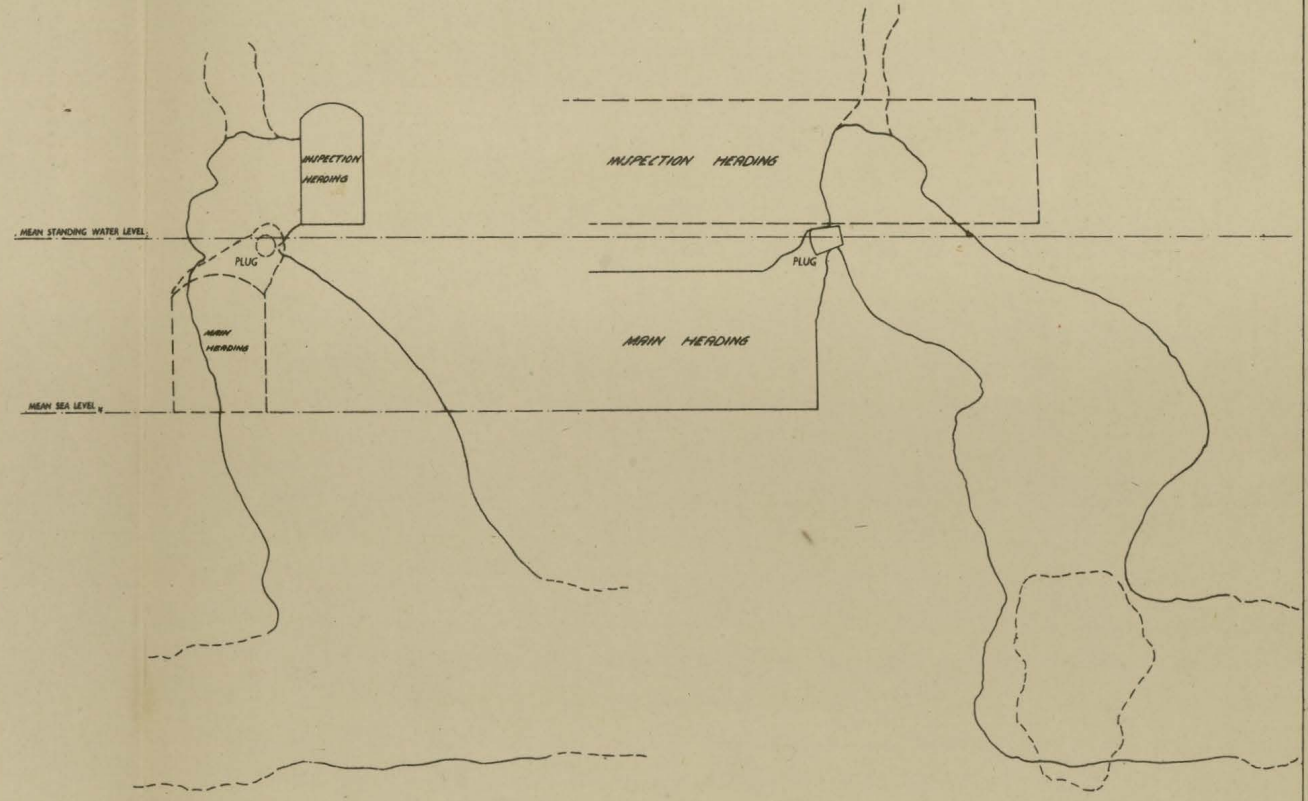
EXTENSIONS TO THE WIED IS SUEDA GALLERIES, 1944-45.







SECTION ON A-A

SECTION ON B-B

PLAN AND SECTIONS OF POT HOLE IN N.W. BY-PASS

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PLATE 4A

WIED IS SUEDA EXTENSIONS— PROGRESS CHART, 1944—5

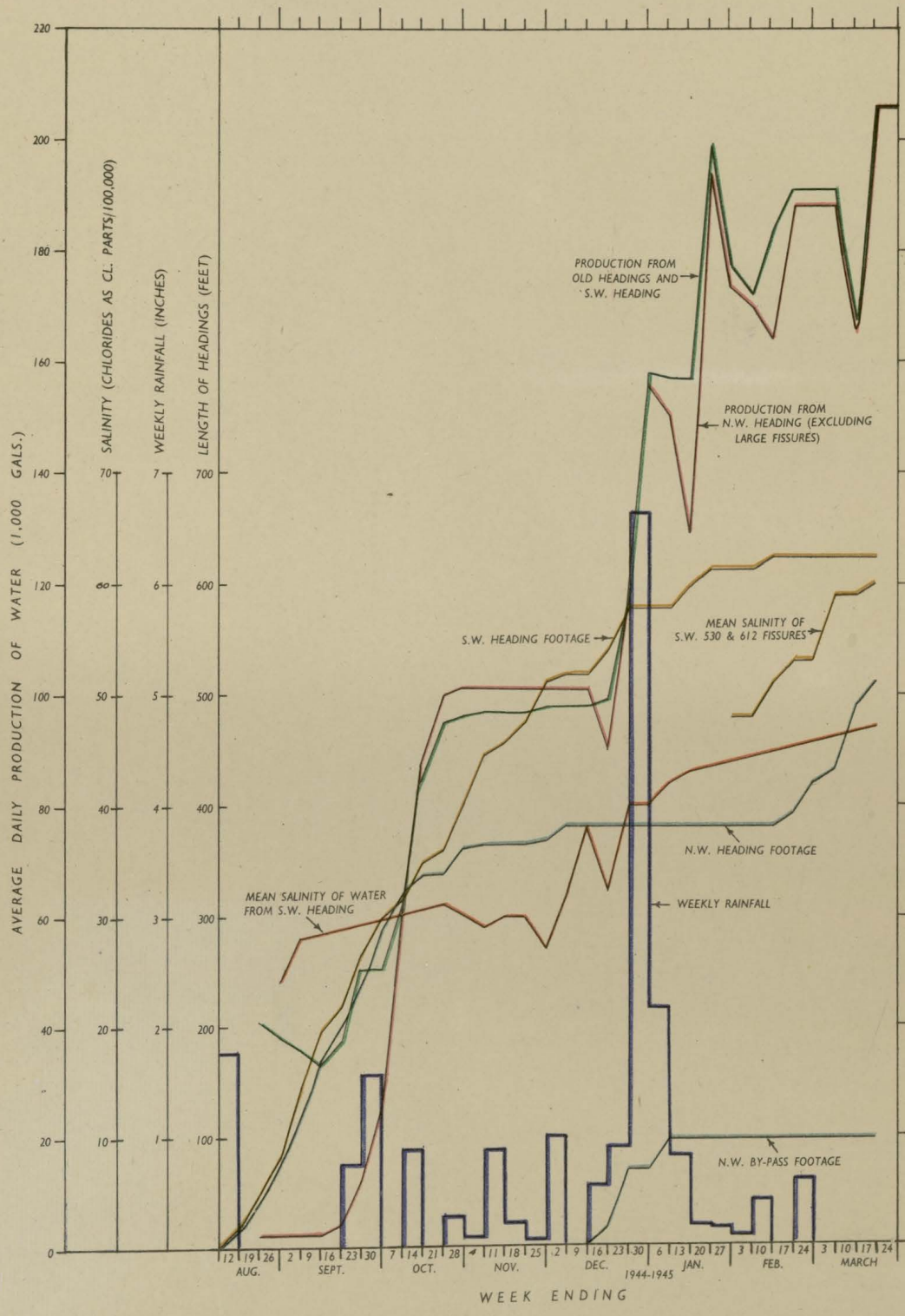

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PLATE 5

PRODUCTION AND SALINITY VARIATION, ST. ANTON—WIED IS SUEDA FISSURE SYSTEM, 11.10.44.—22.3.45.

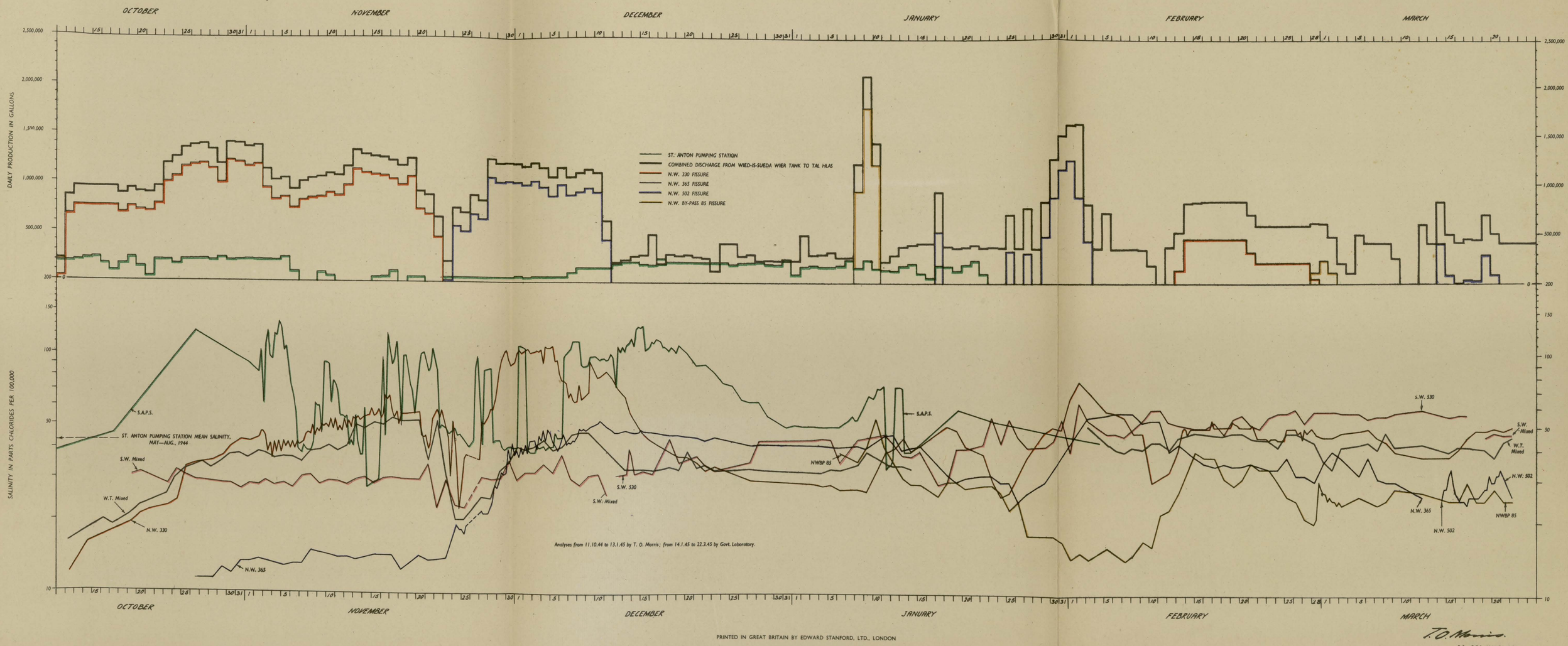

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PLATE 6

VARIATIONS OF WATER LEVEL, LOWER TABLE, WIED IS SUEDA, 11.12.44.–3.2.45.

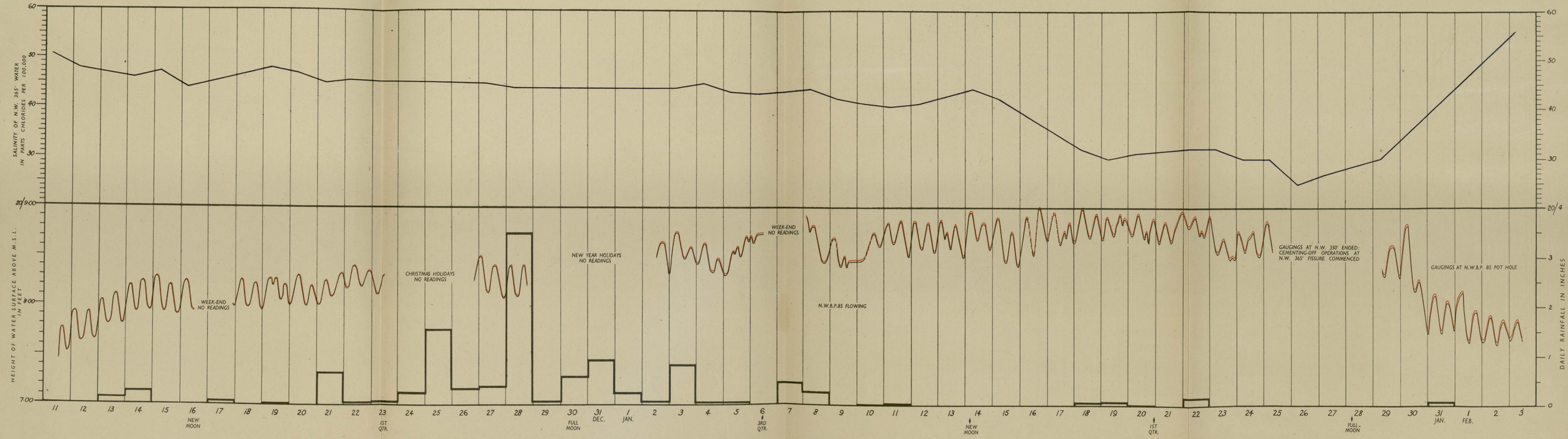

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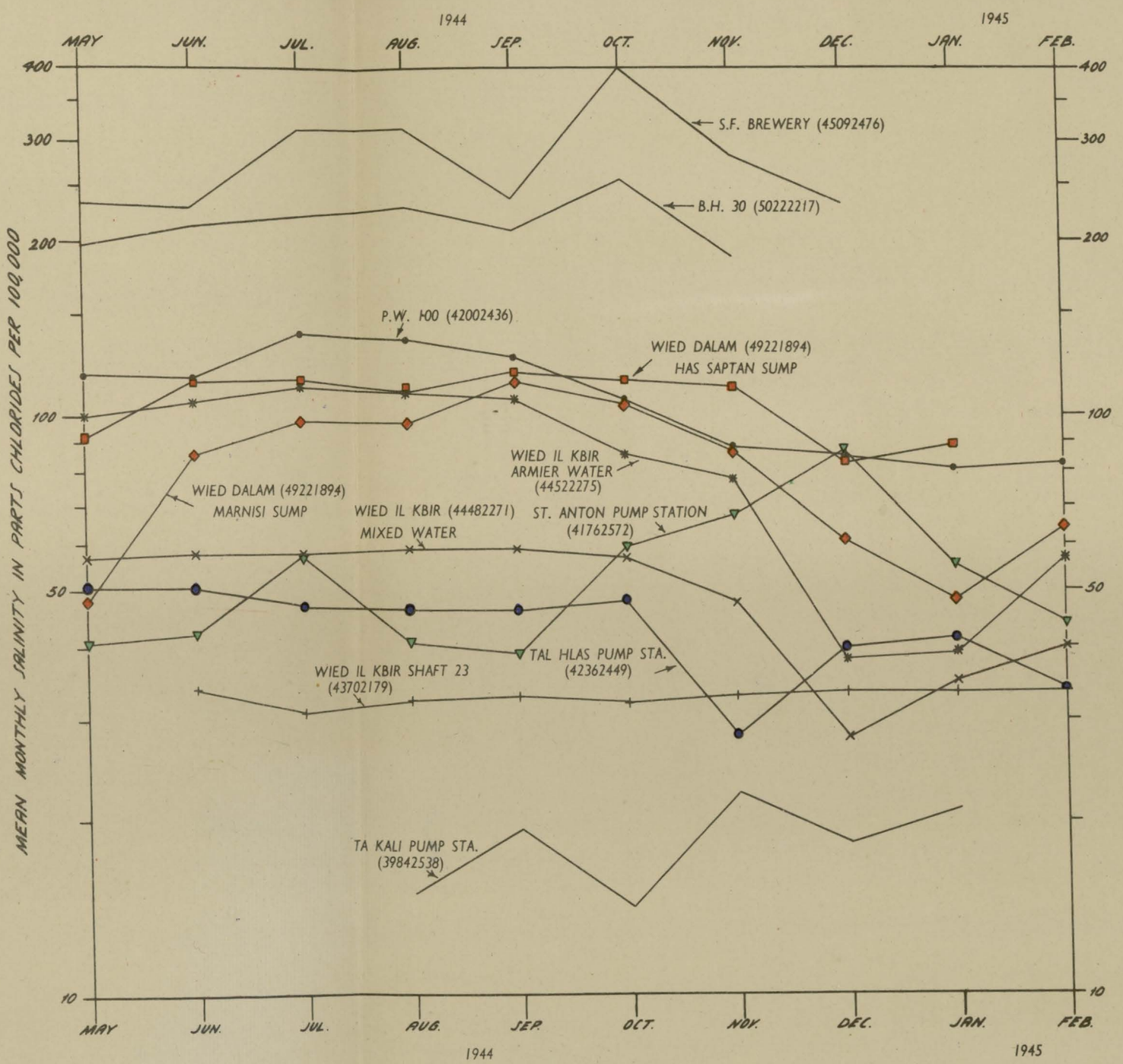
PLATE 7

LOWER WATER TABLE
SALINITY VARIATIONS, 1944-1945



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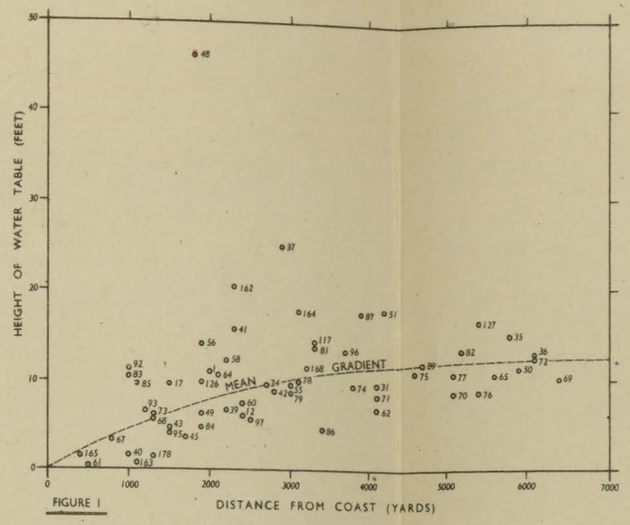

FIGURE 1

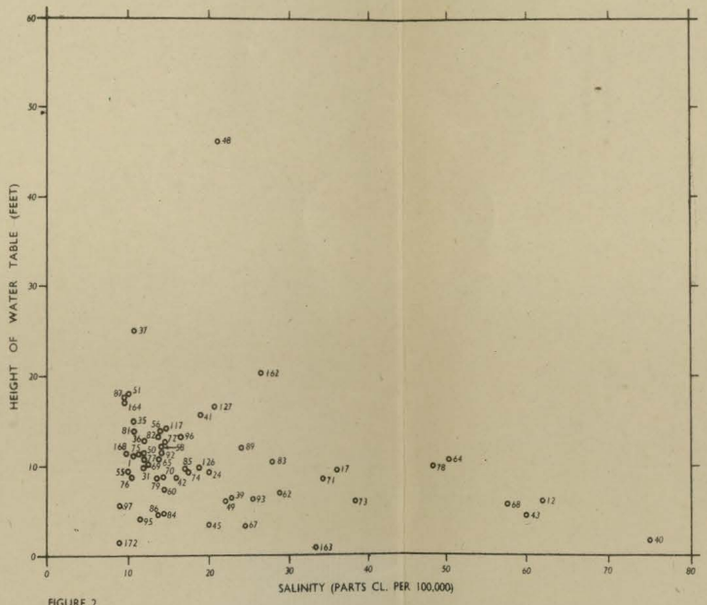

FIGURE 2

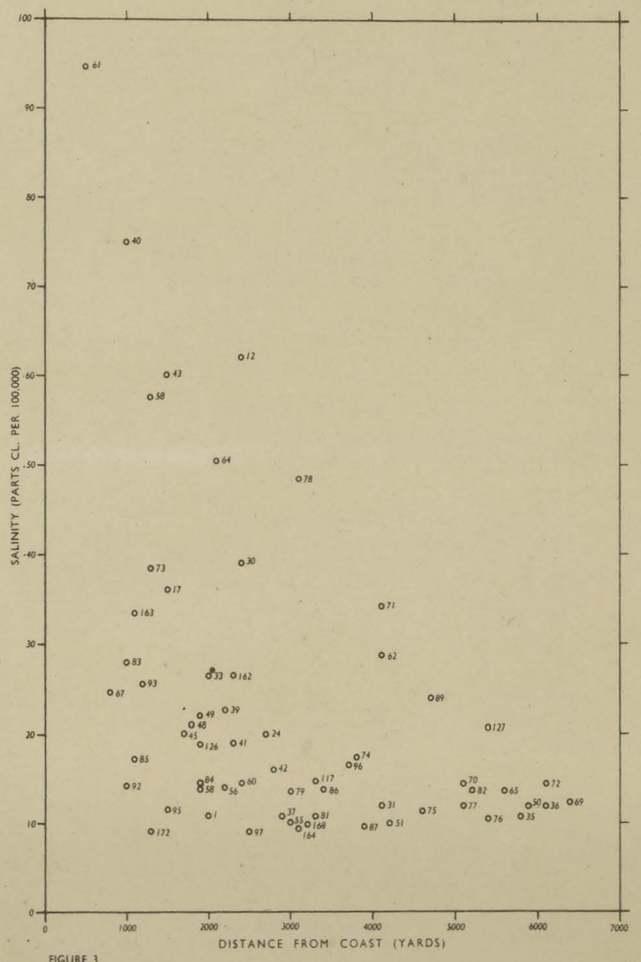

FIGURE 3

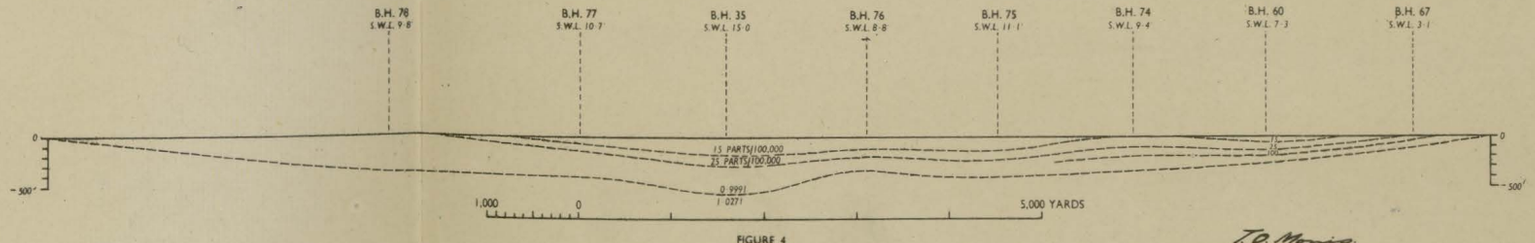

FIGURE 4

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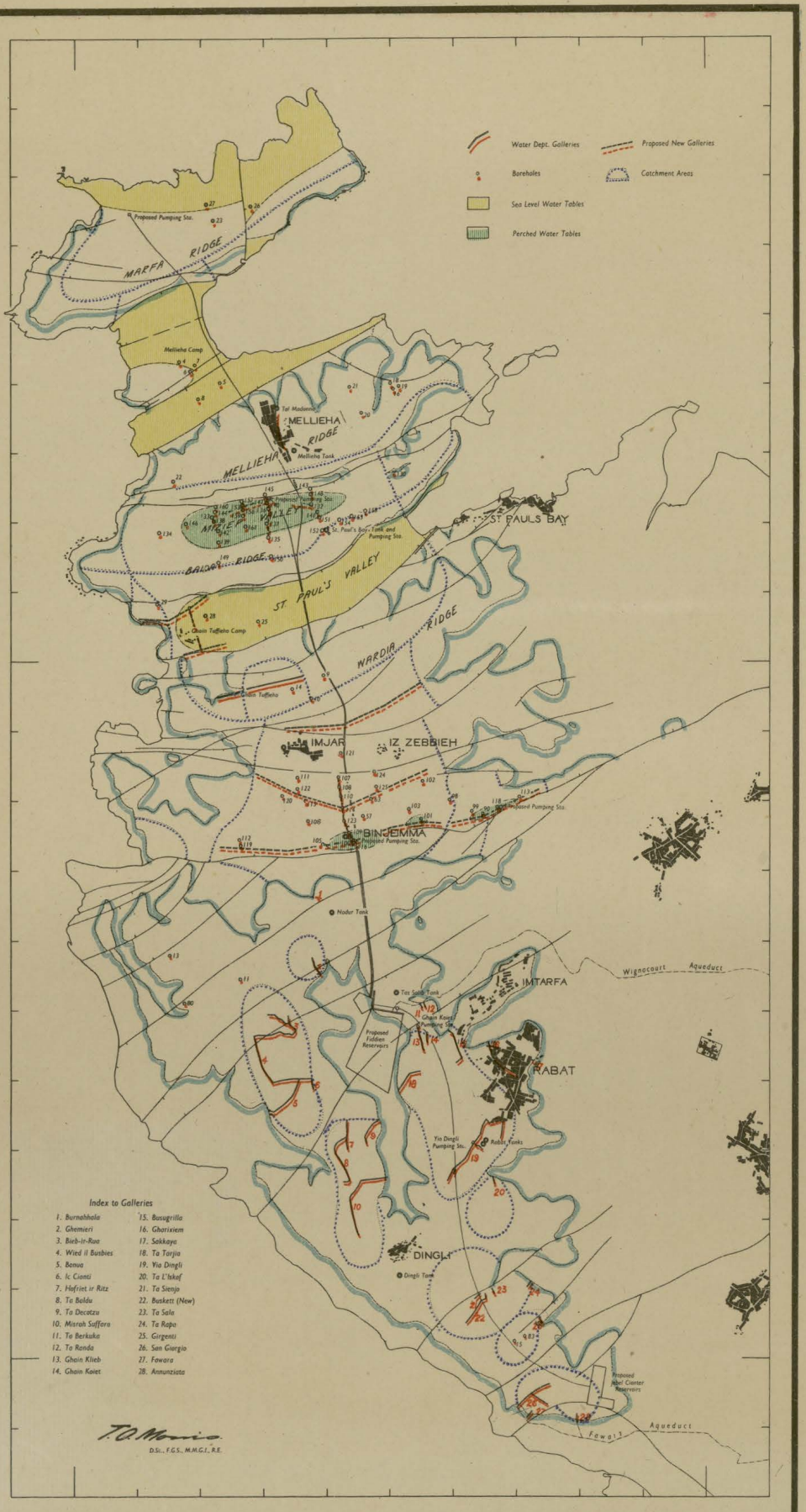
MAIN SEA LEVEL WATER TABLE - BOREHOLE DATA.



UPPER CORALLINE AREAS DEVELOPMENT PLAN

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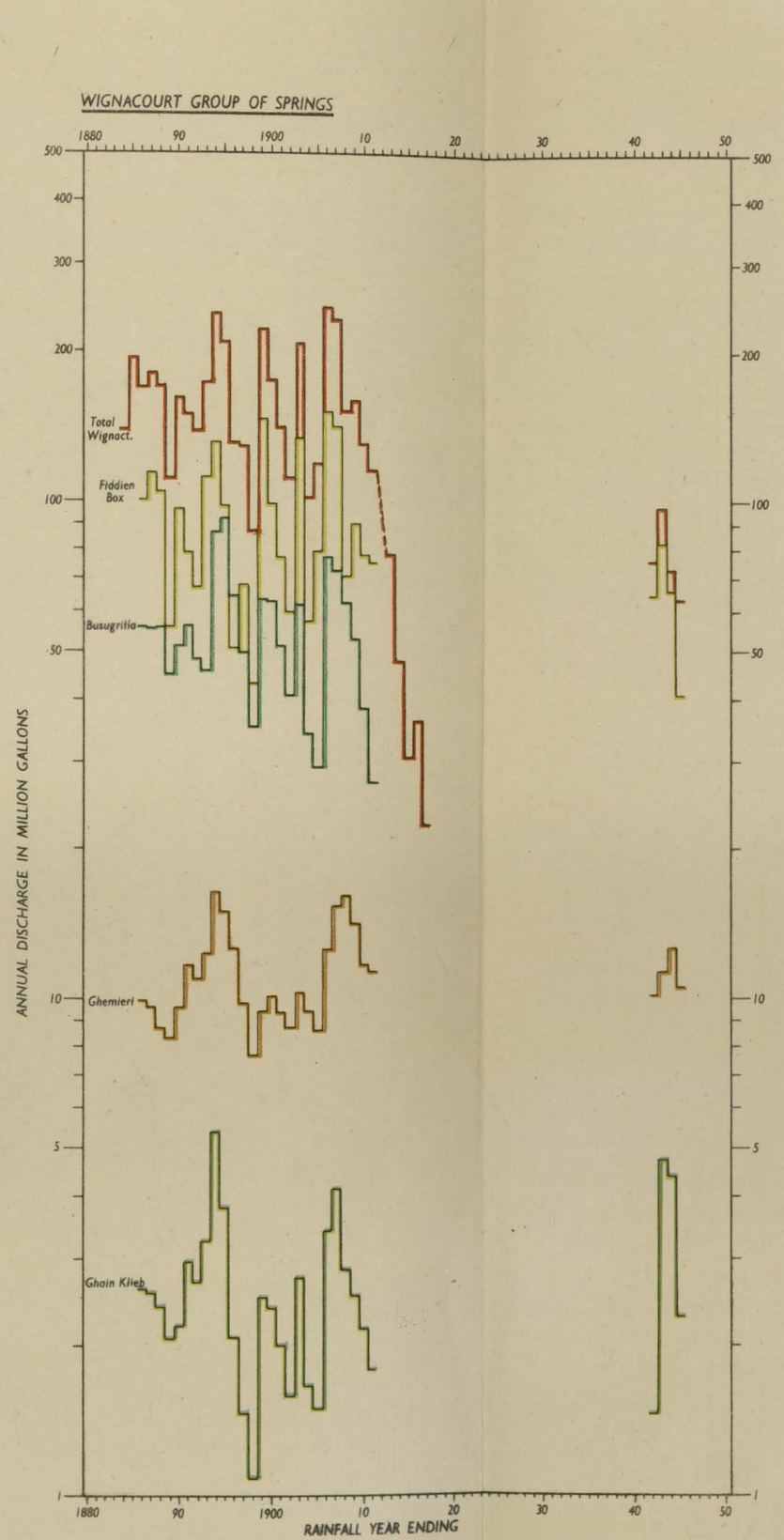
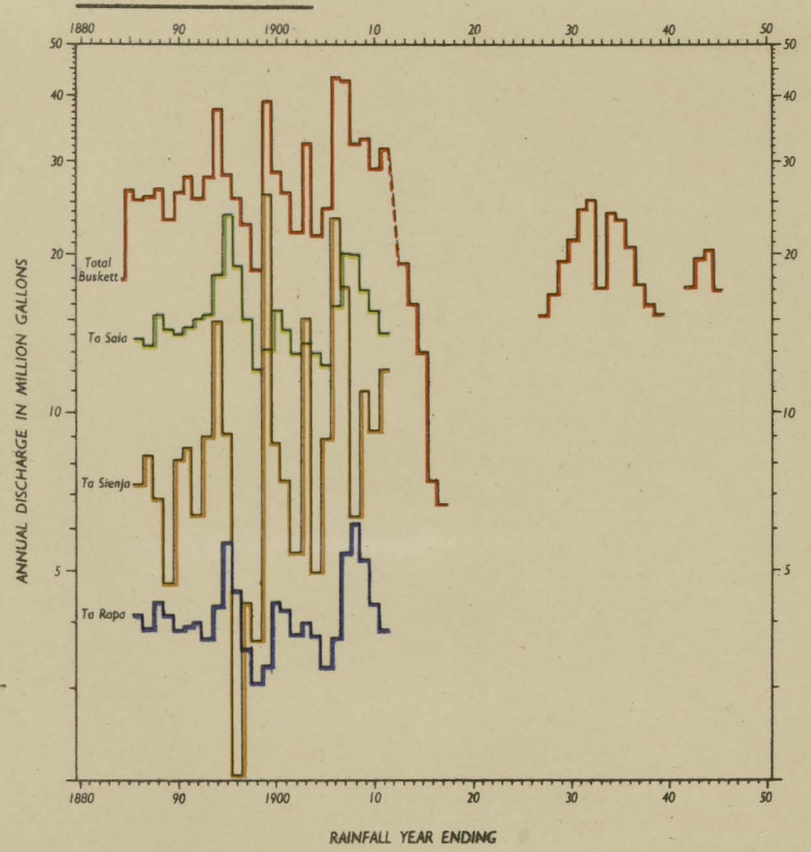
ANNUAL PRODUCTION OF UPPER CORALLINE SPRINGS. PLATE 10
RABAT PLATEAU. 1886 - 1944.





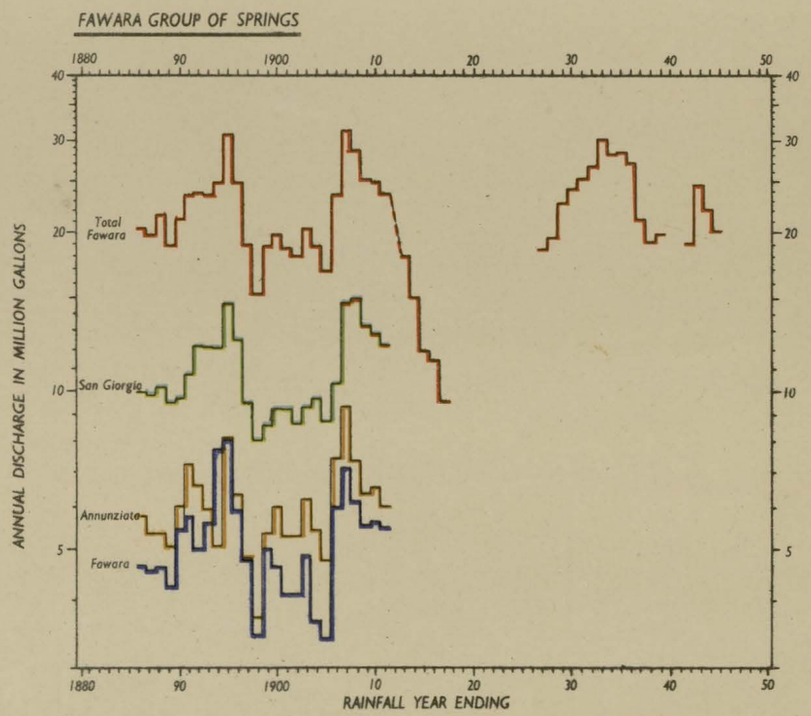


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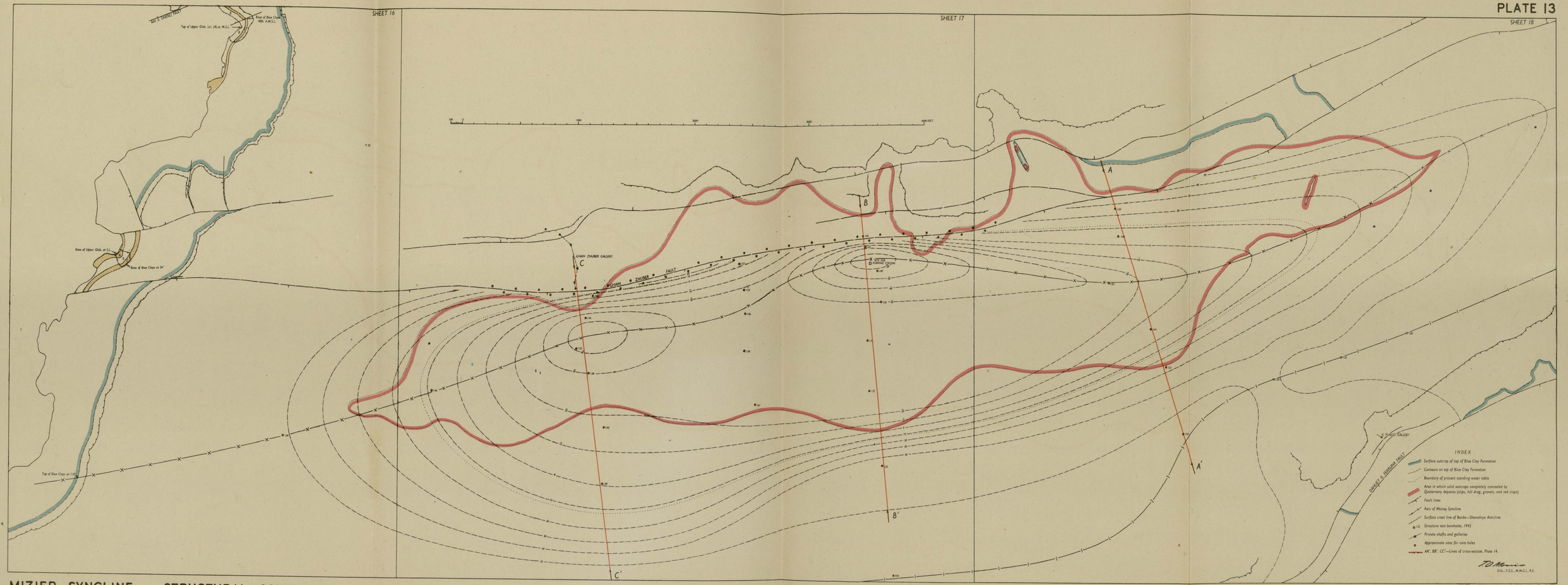
PLATE 13



MIZIEP SYNCLINE - STRUCTURAL CONTOURS.

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