S-42-2

CHAPTER IV

WATER RESOURCES
OF THE
ISLAND OF GRAN CANARIA

WATER RESOURCES OF GRAN CANARIA

A -- GENERAL

1 Previous Investigations and Sources of Information

Up to now, there has been no systematic investigation of the water resources of the island. However several local studies connected with public works specially of dam sites found in various catchments, have resulted in the presentation of official and private consultant reports.

Numerous small-diameter boring investigations and related geophysical prospections have been carried out by the Geological Service of the Ministry of Public Works, which give valuable information on rock-types and aspects of their hydraulic characteristics. The Hydraulic Service of the same ministry in Las Palmas has also many public reports connected with hydrologic characteristics of catchments. Also there exist some consultant reports on geology and geophysical studies in private hands, particularly well -- owners.

In the field of basic geology maps and reports have been published by the Instituto Geológico y Minero with the collaboration of Instituto Lucas Mallada de Investigaciones Geológicas, which form the principal sources of information on surface geology. Also there exist a number of publications on particular themes by local and foreign investigators.

In Climatology, only a few synthetic studies have been published but there is plenty of material, principally in the field of rainfall. The Hydraulic Service for long time had maintained a dense network of raingauges and has published many isohyetal maps with the collaboration of the Centro de Estudios Hidrográficos of Madrid.

As for groundwater, there has been no synthetic studies made but from time to time some statistical informations on the number of wells and galleries as well as some idea of the discharges have been published by the Ministry of Industries. Lately a rather detail inventory of groundwater captations was undertaken by the Hydraulic Service of Las Palmas and this forms our principal source of information on groundwater inventory.

The Project used information from the above sources cited as well as from direct measurement in the field during a 3 to 4 year period. Most of these were facilitated by the public sector and private owners. Part of the information thus obtained specially in the hydrometeorological and hydrochemical fields, was data-processed in the C.E.H. on an I.B.M. 1130 computor for the purpose of the Project.

The present report is thus a synthetic study of the major part of the information available with regard to water resources in the island.

2 Physiography and Geomorphology

The island of Gran Canaria has an approximately circular shape with a diameter of about 45 Km^2 and culminates in Pozo de las Nieves with elevation 1.947 m. The surface area of the island is 1.558,1 Km^2 and the presence of a high peak in the centre results in the existance of high slopes in all directions.

The principal character of the physiography of the island is a very rugged topography resulting from heavy erosion both due to water and rock-weathering.

The median elevation of the island is 445 m. About 25% of the land surface is found above 800 m. and 75% above 200 m. elevation.

There is a fundamental difference in geomorphic features between the north-eastern half of the island with higher rainfall and presence of thick Modern Basalts and the south-western half with arid climatic conditions and existance of older and less permeable rocks such as the Old Basalts, the Trachy-Syenitic complex Ignimbrites and Phonolytes.

The principal "barrancos" in the north-eastern half are curved in the Modern Basalts but the inter-fleuve areas remain rather flat presenting probably declivities of the original surfaces. This gives the impression that the general slope of the northern region is less pronounced.

The resulting valleys have lesser drainage surfaces than in the south. Also the bed materials in the "barrancos" are of little importance and no extensive depositional cones are found.

In the southern half of the island, very large and sharply differentiated drainage basins have developped.

The inter-fleuve areas are generally reduced to sharp-edged, long erosional ridges. Even though the climate is arid very heavy downpours of high intensity occur resulting in heavy floods, carrying much load. Erosión by flood-flow and deposition of load on the mouths of "barrancos" have given rise to canyon-type of river-bottom topography in the upper reaches, and large depositional cones on the coastal zone such as in Tirajana and Maspalomas basins.

The existance of such panoramic views such as the Tejeda valley are probably connected with paleo-erosional surfaces. The presence of terraces in rivers, extensive landslides such as in the upper Tirajana and Fataga basins are indicative of former wetter climates. The terrace deposits of Las Palmas and Arguineguin are of Miocene age.

In the higher parts of the island and in the south active mechanical erosion takes place giving rise to large extends of boulders and unrounded materials. Differential erosion also has taken place following the horizontal lay out or rock bed leaving erosional remnants over large part of the landscape.

One of the most spectacular aspects of the landscape of the island is the great number of volcanic cones and craters as well as the connected lava flows of recent times. Most of these are related to Quaternary and recent volcanic manifestations in the northern and eastern parts, of which we can cite the Caldera de Bandama, Pino de Gáldar, Montaña de Arucas as well as the numerous cones disseminated all over the landscape in this region.

3 Drainage and Slopes

The drainage net is formed principally by radially flowing rivers, with a number of 159 outles to the sea. The total length of stream channels as measured on the topographic map in scale 1: 25 000 is 2628 Km, thus giving an average drainage density of 1.7 Km/Km^2, with variations between 1.2 and 2.3 Km/Km^2 for the various zones of the island, which should still be considered low, indicating that the island has highly permeable subsoil materials.

The island as said earlier is marked by high relief features characterized by abrupt slopes. The mean slopes from the centre of the island varies from 6 to 10% but on short distances values up to 40 and 60% are not uncommon, if we exclude the vertical walls.

4 Vegetations and Soils

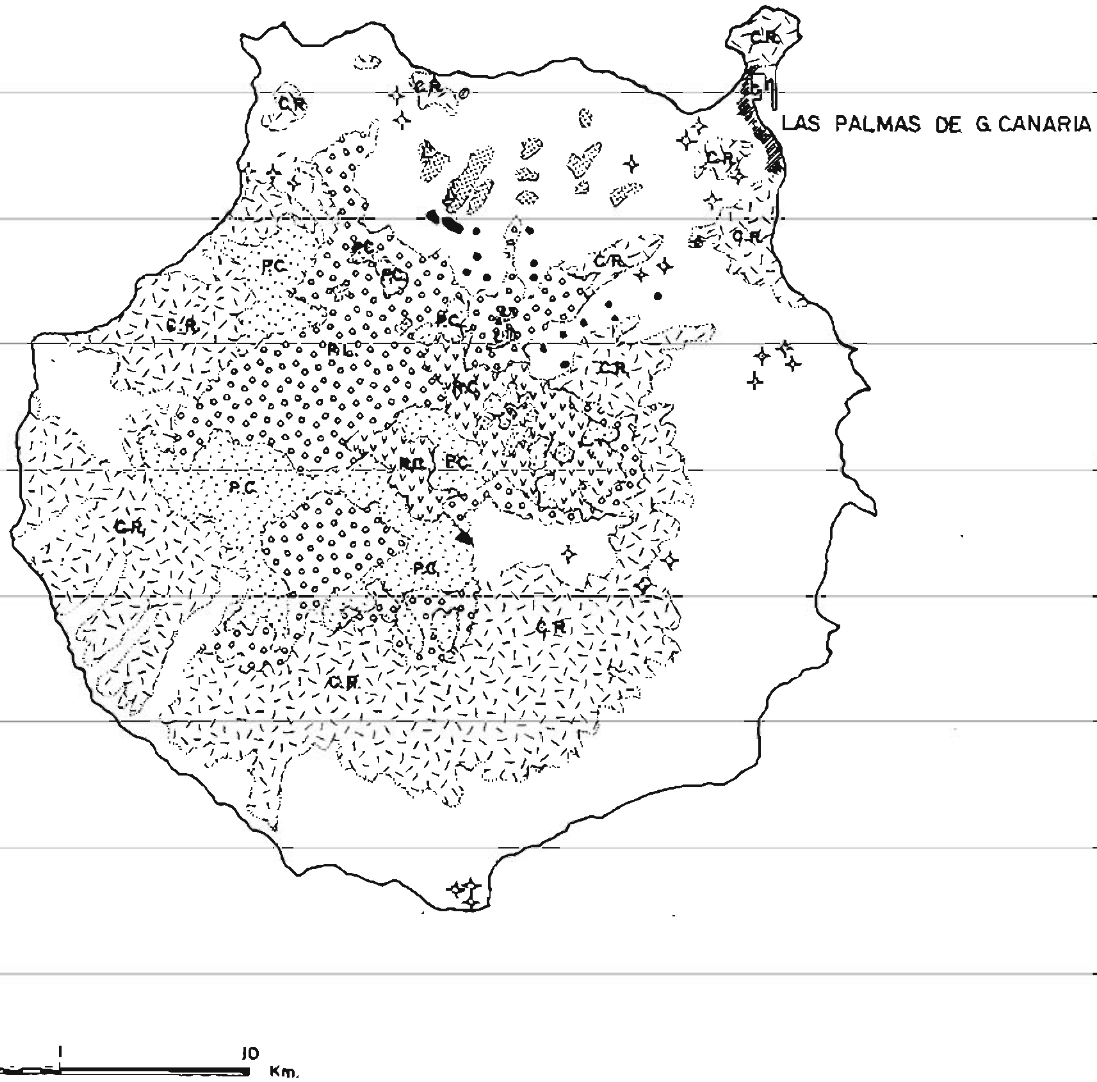
Man has to a large extent changed both the landscape and the vegetation of the island. Very little of the original vegetation remains, as cultivation extended throughout the island and trees were cut down for firewood. In 1972 about 35% of the total area was or had been laboured for agriculture, much of it on man-made terraces on steep slopes. The non-cultivated area is mainly covered with grass and shrubs. Reforestation is taking place and actually some 7 000 ha of mainly pinetrees have been planted.

An idea of the different vegetal zones both natural and man-made can be obtained in Fig. A.1 .

Soil are found better developped in the northern slopes as expected favoured by the higher rainfall and humidity. Most soils found in the northern part are similar to brown soils or latosols with depths varying from 1 to 2 m. They are generally composed of a "A" sandy-loamy horizon of 50 to 75 cms, a "B" horizon with entrained minerals mixed with clayey decomposed rock also of a similar thickness and finally of a "C" horiz

MAP OF VEGETATION

—GRAN CANARIA—



LEGEND

- LAUREL FOREST
- BROOM SHRUBLAND
- PINE WOODLANDS (*Pinus Canariensis mainly*)
- PASTURELAND
- SUCCULENT AND THORNY PLANTS
- PALM GROVES
- EUCALIPTUS PLANTATIONS
- CULTIVATED LAND
- CHESTNUTS

Note: AFTER MINISTERIO-DE-AGRICULTURA—Dirección General de montes, caza y pesca fluvial.

Fig A-1

of decomposed rock either of basaltic Pyroclasts or of Roque Nublo agglome - rates and basalts. The valley walls have little soil but the bottoms often comport clayey and sandy deposits with incipient soils. Paleo-soils simi - lar to latosols with developped sesqui-oxide horizons are also found in the pyroclast beds and may attain a depth of 3 to 4 m in places.

In the southern part of the island only incipient soils are encountered though the depth of decomposition can often attain 2 to 3 m. Generally the "A" horizon is a mixture of loams and clays in a mass of rock debris developped over Phonolytes and loams over Old and Modern Basalts.

The banana cultivations in the north have reconstituted soils with layers of volcanic ash and loams. In the tomatoe region in the east, natural loamy and sandy soils with rock debris are found.

5. Hydrological Zones

The island of Gran Canaria has been divided into 9 major hidrological zones. The regionalization of the island with a certain amount of uniform characteristics both of external and internal features was a prerequisite for systematizing the studies, as a result of the extreme complexity of the physical milieu of the volcanic terrains. Much of the data collection, elaboration and observation network organization both in surface and groundwater, have respected this major hydrological subdivision of the island.

5.I Criteria of subdivision

The criteria used for such a subdivision of the island were as follows: orientation, major topographic and drainage uniformity and certain geological and structural unity significant in groundwater development.

As far as possible the boundaries respected the above conditions but when it was impossible to obtain uniformity, the surface drainage boundary was used as criteria for separation.

5.2 Major units

The principal morphometric and geological features of each of these units is shown in the Table Al.

If we except zones 4, 5 and 6 which are well defined individual basins, the others constitute groups of basins draining however similar morphological and geological areas and generally following the same directions.

Geologically speaking, the porous post-miocene Modern Basalts dominate the surface areas in zones 1, 2, 3 and 5, in the first occupying up to 75% of the area. In zone 6, 7, 8 and 9 the more impermeable formations

Table A.1

MAIN PHYSICAL CHARACTERISTICS OF THE HYDROLOGICAL ZONES

	Surface area (km^2)	Drainage density (km/km^2)	Median elevation (m)	Slope index	Peri-meter (kms)	Major surface geological formations in % (1)					Principal geological structures (2)	
						A	B	C	D	E	Upper Zone	Lower Zone
1	182,2	2,0	360	0,24	62,0	1	16	4	76	3	D/C/B	D/C/B or (B)
2	326,9	1,5	370	0,26	119,0	0	13	25	48	14	D/C/B	D/C/E/B or (B)
3	145,1	1,5	225	0,30	66,0	12	2	1	60	25	D/C/B	E/D/A or (A)
4	88,4	1,2	600	0,28	60,0	1	26	19	10	44	D/C/B or (B)	E/C/B/A
5	49,4	2,1	990	0,29	41,0	13	23	22	42	0	D/C/B	D/A or (A)
6	178,5	1,3	730	0,24	72,0	21	49	18	4	8	C/B	E/B/A or (A)
7	222,0	1,9	380	0,19	80,0	42	54	1	0	3	D/C/B	B/A or (A)
8	323,6	1,9	450	0,13	92,0	2	70	8	3	17	D/C/B	E/B/A
9	42,0	1,5	570	0,32	33,0	47	53	0	0	0	C/B/A	B/A or (A)
Total	1.558,1	--	--	--	--	-	-	-	-	-	--	--

Note: (1) A: Old Basalts; B: Phonolites, Ignimbrites, Trachy-Syenites; C: Roque Nublo Formation;
D: Modern Basalts; E: Miocene Sediments, Landslides, Alluvium.

(2) Upper outcropping member is on left side and lowest on the right side.
Dashed line when the formation is discontinuous, in brackets when large outcrops occur.

such as the Phonolytes, Ignimbrites and the Trachy-Syenitic complex occupy 50 to 70% of the outcropping rocks. The only areas where alluvial deposits occupy an important surface area is in zone 4.

From a structural point of view, the Table in Annex shows that the upper areas of zones 1 to 8 comport a similar situation where the Pho - nolytes-Ignimbrites and Trachy-Syenites constitute a sustratum for both the Roque Nublo formation and the Modern Basalts. This geological structure is common to several areas, because it dominates the higher parts of the island. In the lower areas however there is a big variation as shown in the above table. Large outcrops of the lowest member are often found in the lower zones which are either the Phonolytic-Ignimbritic series in the north and northeast, and the Old Basalts in the south and southwest.

The geological structure in the lower areas of zone 1 is di - fferent from that of zone 2, largely due to the appearence of extensive out-crops of Roque Nublo and also of the Las Palmas Terrace materials overlying the Phonolytic substratum. In both zones, outcrops of Phonolytes are found on the coastal peripherial areas. In zone 3, thick Modern Basalts cover Old Basalts but outcrops of the latter are also found. The lower parts of zone 4 is underlain by Phonolytes and Old Basalts, but on the top of the Phonolytes are also found locally Roque Nublo towards the interior and alluvial deposits in the coastal fan area. In zone 5, only the narrow valley is filled in by Recent Basalts but Old Basalts appear on the sides. Large areas of Old Basalts outcrop in zones 6, 7 and 9 but on the top of them are found generally Ignimbrites, Trachy-Syenites and some Phonolytes. In zone 8 the Old Basalts form probably the substratum with a thick develop-ment of Ignimbrites and Phonolytes on the top, but on the coastal zone there is an alluvial fan possibly overlying the Phonolytes.

5.3 Subzones and minor units

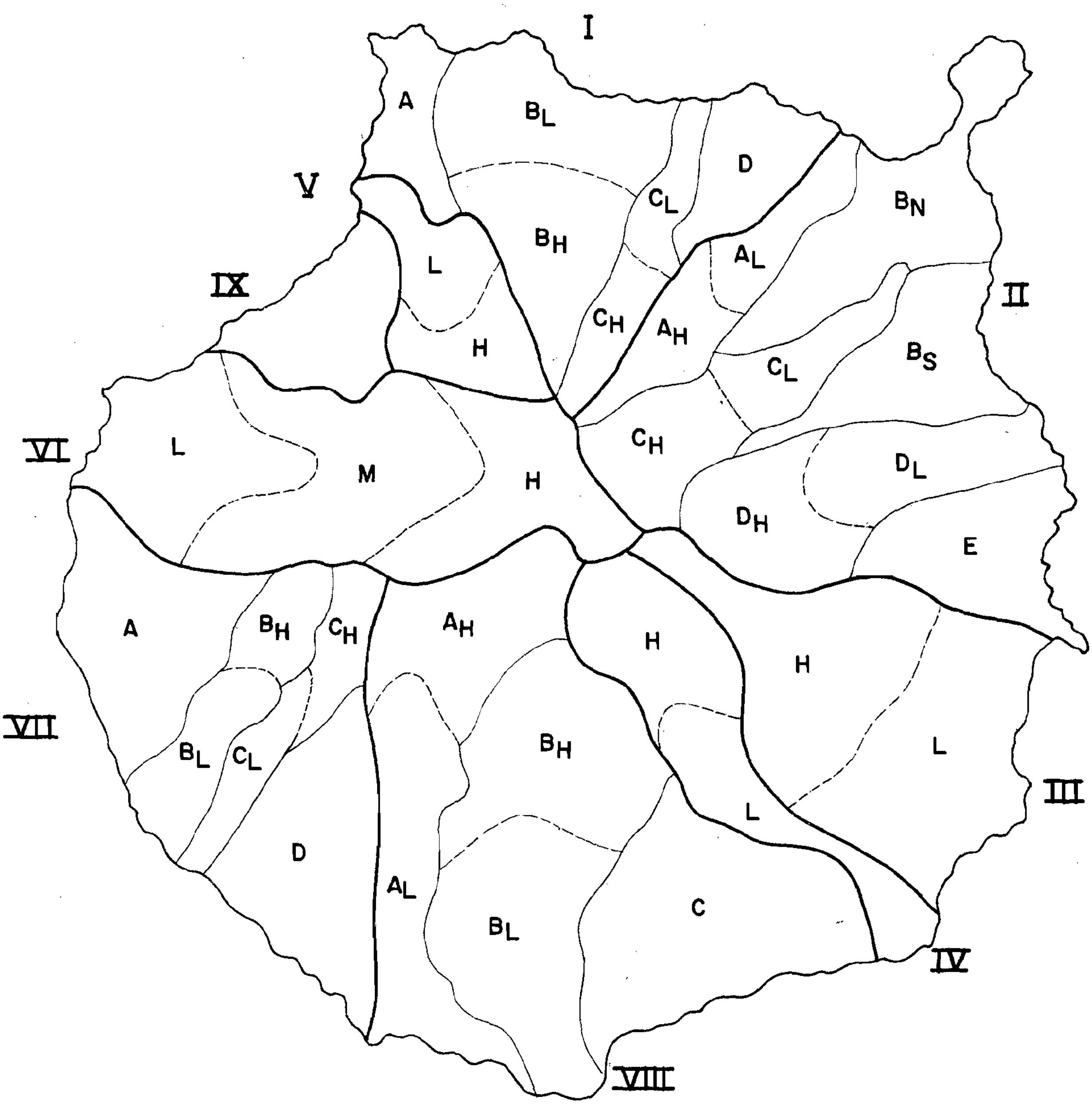
The above mentioned hydrological zones were subdivided into smaller units. The more complex zones 1, 2, 7 and 8, composed of several drainage valleys were separated into the more important individual basins. This subdivision is justified by the fact that water development in the island has a tendency to group around the principal valleys.

In order to facilitate calculations, each of the above subzones (or barrancos) as well as the undivided unitary zones 3, 4, 5 and 6, were again divided into minor hydrological units. A total of 36 minor hydrological units of the island was obtained by a separation of the above zones and subzones into an upper and lower part.

The major hydrological zones, subzones, as well as the minor units are shown in Map A.2.

HYDROLOGICAL ZONES AND SUB-ZONES

GRAN CANARIA



LEGEND

I —— IX MAJOR HYDROLOGICAL ZONES

A_H —— A_L SUB-ZONES HIGHER AND LOWER PARTS

FIGURE A-2

B. HYDROMETEOROLOGY

1. Hydrometreorological Network

Three types of hydrometeorological stations exist in the island, i.e. raingauging stations, meteorological stations and streamgauging stations of which the raingauging stations are the more numerous. Precipitation is measured at about 270 places which results in an extremely high average density of 1 raingauge per 6 square kilometers. Of these 260 stations are either operated by the Servicio Hidráulico de Las Palmas or send data to that organization. Two separate networks are being operated by Jefatura Agronómica (5 stations) and Instituto de Guía (7 stations in the NW part of the island).

Rainfall intensities are recorded at 10 places by recording raingauges, 8 of them installed by this Project and the others by two different organizations, see Table B.1.

There are 26 meteorological stations measuring one or several of the parameters that are interesting from the point of view of Hydrometeorology. These are mainly located in the northern part of the island. The type of measurements taken at the stations and their operating agencies are listed in Table B.2.

The streamgauging network comprises 13 stations, installed and operated by the Project. There are two main types of stations, one located at dams measuring the runoff as the difference in storage in the reservoir, and the other normal rivergauging station measuring the stage of the river. In most cases the latter type of stations is provided with artificial controls. The stations are listed in Table B.3 and the locations of the stations forming part of the hydrometeorological network in the island are shown in Figure B.1.

Table B.1

Recording Raingauges in Gran Canaria

Nº	Name	Coordinates X	Y	Z	Operating Agency	Started in
4	Puerto de la Luz	459.075	3.113.880	20	Junta de Obras del Puerto	
70	Instituto de Guía	438.355	3.112.690	50	Instituto de Guía	
P-1	Lanzarote	443.310	3.101.425	1125	Project SPA-15	Dec.1970
P-3	Los Hornos	441.815	3.093.245	1575	Project SPA-15	Dec.1970
P-4	Las Hoyas	433.885	3.101.385	965	Project SPA-15	Dec.1970
P-6	Tirajana Los Lomillos	441.640	3.089.955	1215	Project SPA-15	Oct.1971
P-7	Chira	437.165	3.086.685	910	Project SPA-15	Dec.1970
P-8	Caidero de La Niña	427.775	3.095.575	245	Project SPA-15	Mar.1971
P-9	Santa Brígida	451.750	3.101.300	450	Project SPA-15	Nov.1970
P-10	Presa Tirajana	447.520	3.084.320	380	Project SPA-15	May 1972

Table B.2

Meteorological Stations in Gran Canaria

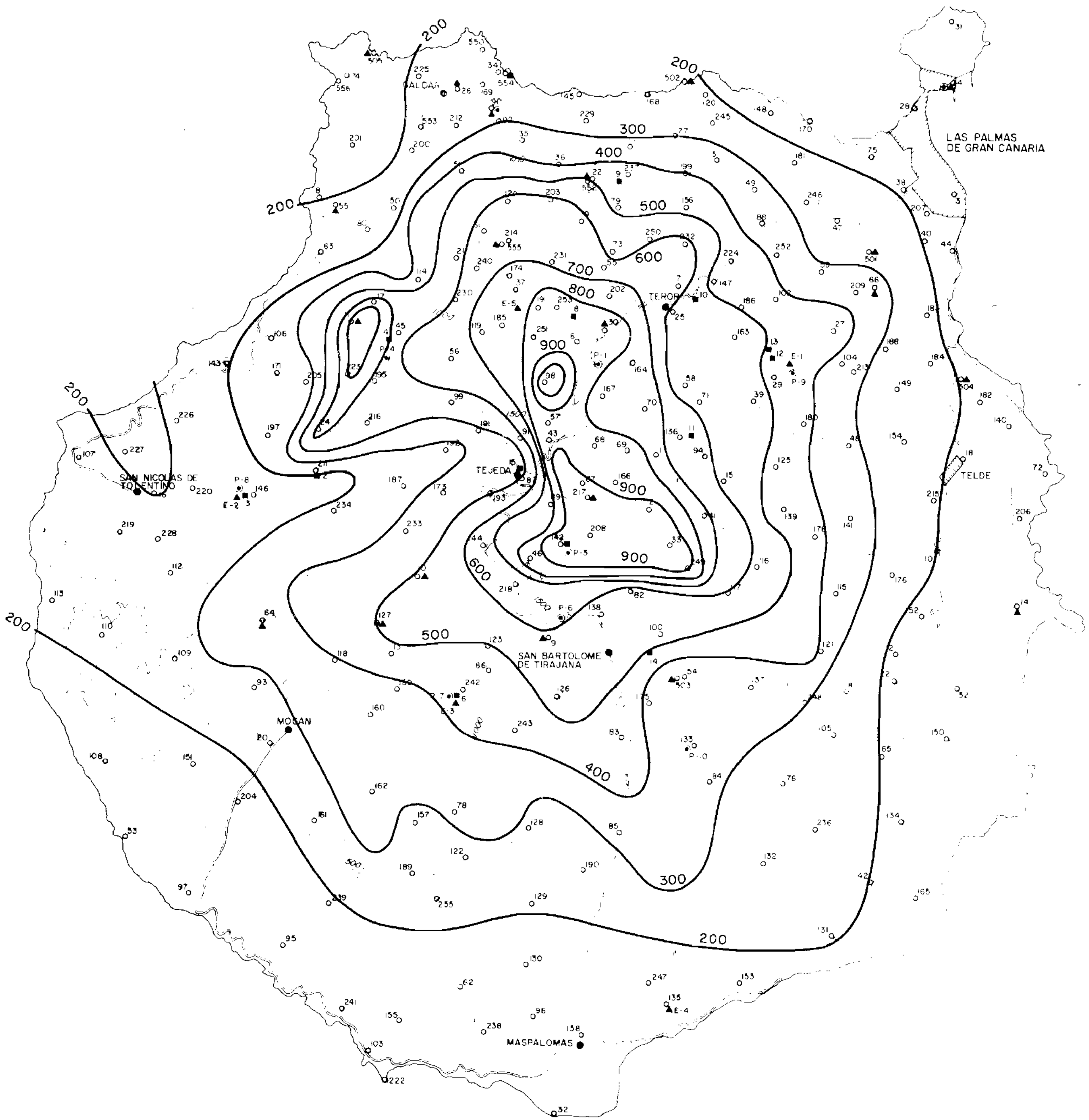
Nº	Name	Started	Coordinates X	Y	Z	Measurements of:	Operating Agency
4	Puerto de la Luz	1940	459075	3113880	19	Temp, Hum., Evap., piche, sunshine, wind, Bar. press.	Junta de Obras del Puerto
9	Cuevas del Pinar	1951	441145	3089115	1215	Temp., Evap., piche	Jefatura de Montes
10	Pajonales Pinar	1951	435315	3091800	1195	Temp., Hum., Evap., piche	Jefatura de Montes
11	Tamadaba Estado	1951	432225	3103210	1260	Temp., Hum., Evap., piche	Jefatura de Montes
14	Gando		462090	3090680	26	Temp., Hum., Sunshine, Wind, Bar. press	Serv. Meteorológico
26	Galdar Esc.Hogar		436985	3113405	145	Temp.	Serv. Meteorológico
30	Valleseco Pueblo		443680	3102730	975	Temp.	Serv. Meteorológico
64	Inagua	1951	428370	3089865	960	Temp., Evap., piche	Jefatura de Montes
66	Tafira Vivero	1950	455520	3104730	335	Temp., Hum., Evap., piche	Jefatura de montes
90	Instituto Guía	1966	438355	3112690	150	Temp., Hum., Evap. piche, Sunshine, Wind, Bar. press.	Serv. Meteorológico
127	Ñameritas	1951	433470	3089755	1005	Temp., Hum., Evap. piche	Jefatura de Montes
217	Las Mesas	1969	442770	3095225	1685	Hum., Wind	Jefatura de Montes
501	Guiniguada	1971	455275	3106350	165	Temp., Hum., Soil temp., Evap. piche	Jefatura Agronómica
502	Bañaderos	1971	447290	3113600	14	Temp., Hum., Soil temp., Evap. piche	Jefatura Agronómica
503	Santa Lucía	1972	446910	3097550	692	Temp., Hum., Evap. piche	Jefatura Agronómica
504	Jinámar	1971	459360	3100820	47	Temp., Hum., Soil temp., Evap. piche, Wind	Jefatura Agronómica
505	Gáldar	1972	433350	3115050	33	Temp., Hum., Soil temp., Evap. piche	Jefatura Agronómica
551	Agaete	1969	431590	3108240	70	Temp.	Instituto de Guía
552	Moya	1970	442880	3109500	480	Temp.	Instituto de Guía
554	Tres Cruces	1970	439015	3109160	625	Temp.	Instituto de Guía
555	Montaña Alta	1970	439080	3106615	875	Temp.	Instituto de Guía
E-1	Santa Brígida	1971	451750	3101300	450	Temp., Hum., Evap. piche and pan, Wind	UNESCO-MOP SPA-15
E-2	Caidero de la Niña	1971	427775	3095575	245	Temp., Hum., Evap. piche and pan, Wind	UNESCO-MOP SPA-15
E-3	Chira	1971	437165	3086685	910	Temp., Hum., Evap. piche and pan, Sunshine, Wind, Dew	UNESCO-MOP SPA-15
E-4	San Agustín	1972	446360	3072750	140	Temp., Hum., Evap. piche and pan, Sunshine, Wind	UNESCO-MOP SPA-15
E-5	Fontanales	1972	438835	3103030	1125	Temp., Hum., Wind, Fog interception	UNESCO-MOP SPA-15

Table B.3

Streamgauging stations in Gran Canaria

Nº	Name	Coordinates X	Coordinates Y	Coordinates Z	Basin km²	Type of Station	Started in
1	Los Hornos	441.650	3.093.450	1590	3.9*	Reservoir	Jan 1971
2	Parralillo	430.670	3.096.520	370	65.1*	Reservoir	Jan 1971
3	Caidero de la Niña	427.850	3.095.350	200	104.0	Reservoir	Jan 1971
4	Lugarejos	434.000	3.102.500	850	10.6	Reservoir	Feb 1971
6	Chira	437.100	3.086.700	875	11.1	Reservoir	Feb 1971
8	Valsendero	442.150	3.103.200	750	8.0*	River	Feb 1971
9	Azuaje	443.950	3.109.050	300	26.5	River	Nov 1970
10	Teror	447.600	3.104.000	450	17.3	River, with canal in 2 levels	Mar 1972
11	San Mateo	447.300	3.098.100	800	7.1*	River, with parshall flume	Jan 1971
12	Santa Brígida	450.950	3.101.380	420	10.8	River, with canal in 2 levels	Nov 1971
13	Guiniguada	450.870	3.101.510	420	36.7	River, with canal in 2 levels	Nov 1971
14	Rosiana	445.500	3.088.500	750	21.3	River, with canal in 2 levels	Feb 1971
15	Tejeda	439.840	3.096.950	1070	1.5*	River, with Thompson weir	Oct 1972
	Total gauged area				238.3		

*Subbasin



UNESCO/ UNDP	WATER RESOURCES OF CANARY ISLANDS	M. O. P

ISOHYETS HYDROLOGIC YEARS
1967-68 — 1971-72
GRAN CANARIA

DATE : FEBRUARY 1974 FIG: D-1

1.1 Data from Raingauging Stations

Raingauging started in Gran Canaria about 1870 at a station in Las Palmas. Its operation ended in the beginning of 1900 and has not been continued. Incomplete records exist at Museo Canario in Las Palmas.

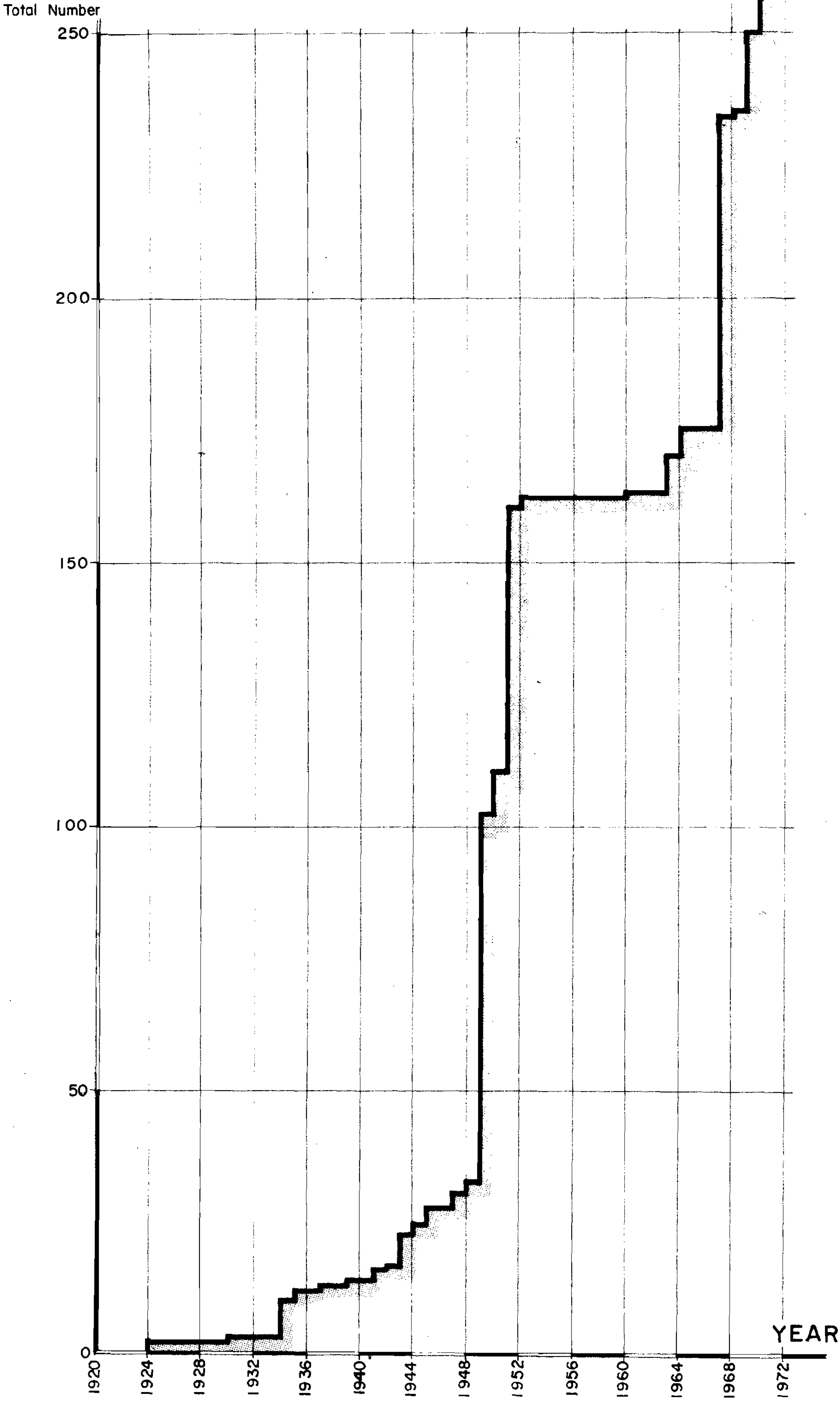
In more recent times precipitation measurements started in 1924 at two stations. The netwotk has been gradually increased to its present size, largely due to private initiatives with a spectacular increase in the number of stations between the years 1949 and 1951, see Figure B.2 (Sección de Hidrología 1973 a).

Over the years many changes in the locations of the raingauges have occurred, which are difficult to follow since new stations have been given the same numbers. Often, relocations of minor significance have taken place or the records and ensure their continuity and consistency.

Rainfall data have been published for part of the recording period i.e. hydrologic years 1949-50 to 1966-67. (Centro de Estudios Hidrográficos 1963, 1964; Servicio Hidraúlico de Las Palmas 1968). About 50% of the approximately 180 raingauges installed in 1951 have continuous records for the period to date. For 132 of the stations the published records have been extended and completed to comprise a common period 1949-50 through 1966-67 and the results have been published (Heras et al, 1971 a). Data from the period before the 1949-50 wateryear and from 1967-68 t date, are not published, but can be obtained from the Servicio Hidráulico of Las Palmas.

Also as said earlier the quality of the stations and the observe

FIGURE B2 NUMBER OF INSTALLED RAINGAUGES
—GRAN CANARIA.—



varies very much, obviously due to the fact that available man-power has not been sufficient for the task of maintaining such a large network. The published data should therefore be used only for general studies, and not for any detailed analysis, until they have been compared with the original fields records and the station history has been consulted for the exact location and the quality of the station.

Most recording raingauges operated by the project were installe in the end of 1970 and the beginning of 1971. From this time up to date total daily and monthly rainfall as well as intensity-duration relationships have been calculated for these stations (Sección de Hidrología,1973 b)

1.2 Data from Meteorological Stations

Three of the meteorological stations, Puerto de La Luz, Guía and Gando, could be classified as the principal meteorological stations of the island. They belong to, or are operated in close collaboration with, the Servicio Meteorológico. They are well equipped and are attended by trained observers. The other stations have been installed in order to supply some complementary information or for a specific purpose. The main objective of the stations operated by Jefatura de Montes is to supply data for determining the incendiary risks in the reforested areas, those operated by Jefatura Agronómica to furnish data for evaluation of plagues affecting crops and the stations installed by this Project especially to gather data on evaporation, and in one case to study the importance of condensation and fog interception.

The period of operation of the various stations is listed in Table B.2 Data are not published but are made available by the operating agencies on request. Some average values have been published, especially for the principal stations (Elías y Jiménez, 1965, Huetz de Lemps,1969

The most common parameter measured is the maximum and minimum temperatures which are recorded with a varying degree of precision depen - ding on the type of thermometer used. Measurements are believed to be re - liable in all stations.

Relative humidity has also been measured at many stations with hygrometers or psycrometers. The former instruments at the stations of the Jefatura de Montes do not seem to have been calibrated regularly and hence these data could not be used but for general indications on the variation of humidity.

Evaporation has been measured with Piche evaporimeters at many stations. The procedures and equipments have not been consistent. The me - thod in itself is not considered as particularly representative for the phenomenon. Therefore, only yearly figures are considered to be indicative of the order of magnitude of evaporation and its variation in space. The Project has installed 4 evaporation pans of the US Weather Bureau Class A type, which is believed to be the best method for measuring this parameter.

At the three principal stations in the island, long term records are also available for sunlight hours and wind, which are believed to be reliable. At the other stations only short periods of observations are available, which could support and complement the information gathered at the principal stations.

Other measured parameters of hydrometeorological interest are soil temperature and barometric pressure. The Project has also investigated condensation and fog interception with a recording dew gauge and other non-standardized equipment.

1.3 Data from Streamgauging Stations

The stream gauging network of Gran Canaria comprises 13 stations situated in 8 different drainage basins. The controlled basin area is 238 Km^2, which is 15% of the total area of the island. The stations are located in the higher parts of the basins where runoff is not regulated by artificial means to the same extent as in the lower parts of the basins. About 30% of the total precipitations falls on the gauged area.

The length of record at the various stations can be seen in Table B.3. Records have not been published, since the collected data should still be considered preliminary.

The conditions for operating streamgauging stations are difficult in Gran Canaria, because of runoff normally torrential which takes place only during very few days of the year, see Fig. B.3. Transportation and depositing of eroded material change the hydraulic characteristics of the gauging stations for each storm.

The river gauging stations are of a type that require a fair amount of streamgauging for their calibration, for lack of which theoretical rating-curves have been used at times. For the stations situated at reservoirs, flow has been calculated as the difference in storage based on waterlevel-storage relationships that may have changed considerably over the years because of sedimentation. Therefore the quality of the gauging stations should be considered low. Further calibration will permit the precision of the calculated runoff to be increased.

2. Other Climatic Features

A certain amount of sporadic data are also available on minor climatic features which complement our understanding of the general

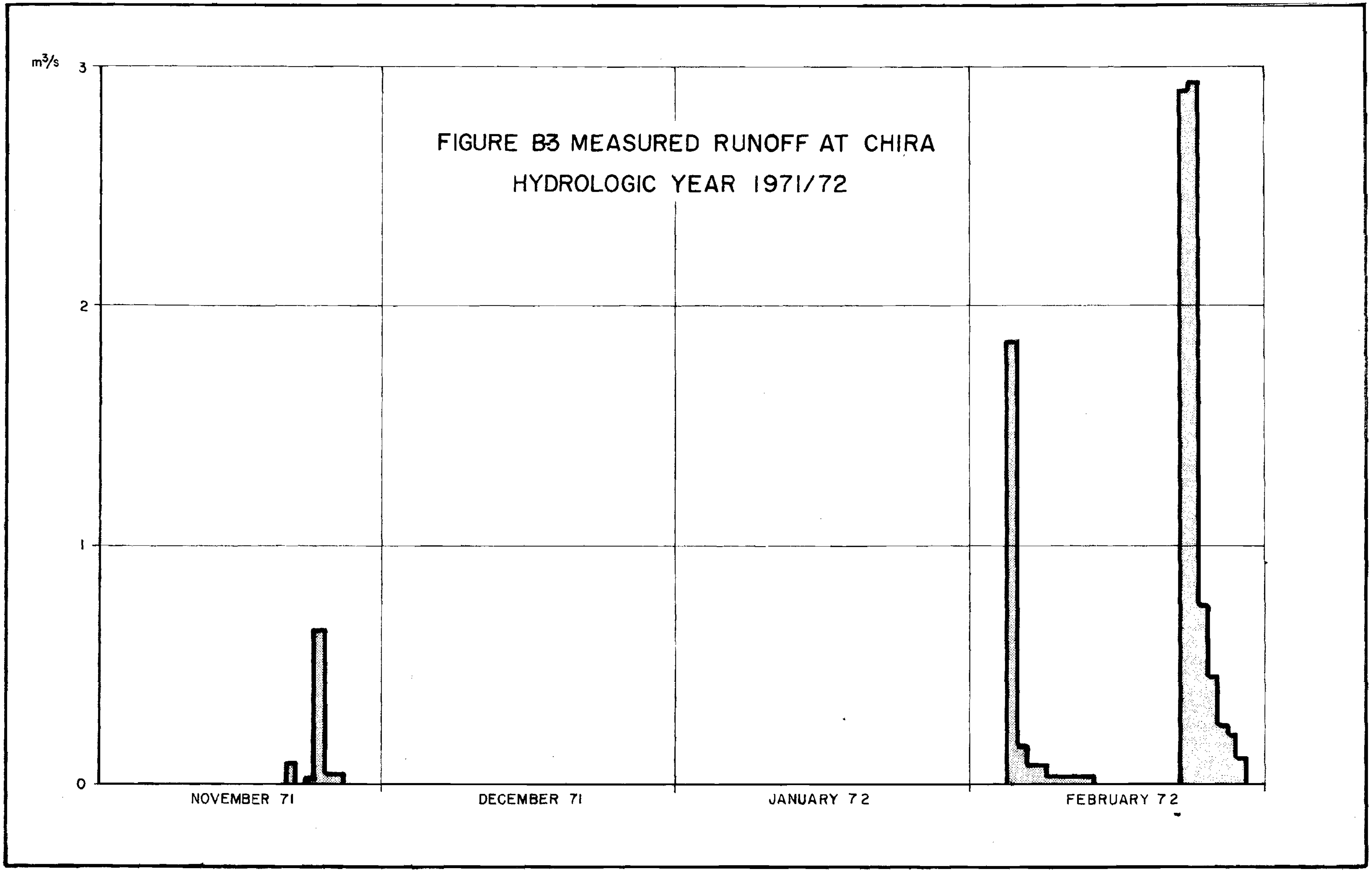


FIGURE B3 MEASURED RUNOFF AT CHIRA
HYDROLOGIC YEAR 1971/72
m³/s
3
2
1
0
NOVEMBER 71
DECEMBER 71
JANUARY 72
FEBRUARY 72

should be considered less representative than the others.

From the studied data it can be concluded that evaporation from a free water surface on the northern slope on the island at lower elevations is about 1000 mm/year and on the southern slope about 1500 mm/year. The high value for the Tamadaba station is caused by very high figures for the months July and August which together account for more than 40% of the yearly total. From the data of this station it is obvious that for these two months the temperature inversion is below the station. It may therefore be concluded that for the northern part above the inversion, evaporation is of the same order of magnitude as for the southern part of the island.

2.3 Condensation

It is a wide-spread belief among the inhabitants of the Canary Islands that condensation plays an important role in the hydrologic cycle, which is also reflected in a recent publication (Huetz de Lemps,1969). The areas indicated as especially favorable are those in the intermediate zone of the northern slope, which are often affected by the clouds. Reference is given to a raingauge installed below a pine tree in Tamadaba which collects about 3 times more water than a normally installed raingauge. However it is clear from the way it is installed, that it collects water from an area much larger than the normal opening of the raingauge and hence no significance can be given to the magnitude of the figures (Michaeli,1973). A likely explanation for the high recorded values is that because of the strong winds, the horizontal component of rainfall is quite large. This component is also captured and is recorded by the raingauge below the tree, whereas the ordinary raingauge only measures the vertical component. Some real fog interception does occur, however, since water has been collected in the raingauge below the tree during rainless days but the quantities of hydrological concept which are dealt with below.

2.1 Winds and Sunshine

The predominant winds are the trade winds blowing throughout the year. In the coastal zones the land and sea breeze phenomenon is also noticeable. Wind speeds are high, especially in the eastern and western low parts of the island, where the air masses are forced to go around the island rather than over it. Wind speeds commonly reach 30 kilometers per hour, with the strongest winds blowing in the summer as can be seen from the values for Gando for the period 1962-1971 in Figure B.4 .

Sunshine is more abundant in the southern than in the northern part of the island. The difference may be illustrated by a comparison between the station Puerto de La Luz in Las Palmas with an average of 2024 hours of sunshine per year for the period 1952-1971, and Gando with 2681 hours for the same period. It should be noted that Gando is not a typical station for the southern part of the island, where sunshine hours are even higher. The monthly distribution of sunlight hours is shown in Figure B.5 . For the southern part of the island, it is believed that this distribution may be approximated fairly well by the theoretical distribution for latitude 28° N.

2.2 Evaporation

The high temperatures and strong winds in the island cause a considerable amount of evaporation. Also because of the higher temperatures and lower humidity, evaporation is larger in the southern than in the northern part of the island as can be seen in Figure B.6 , which shows incidently that variations in evaporation throughout the year are considerable with much lower values in the winter months. A summary of evaporation values for various stations is given in Table B.4 , where the Piché values

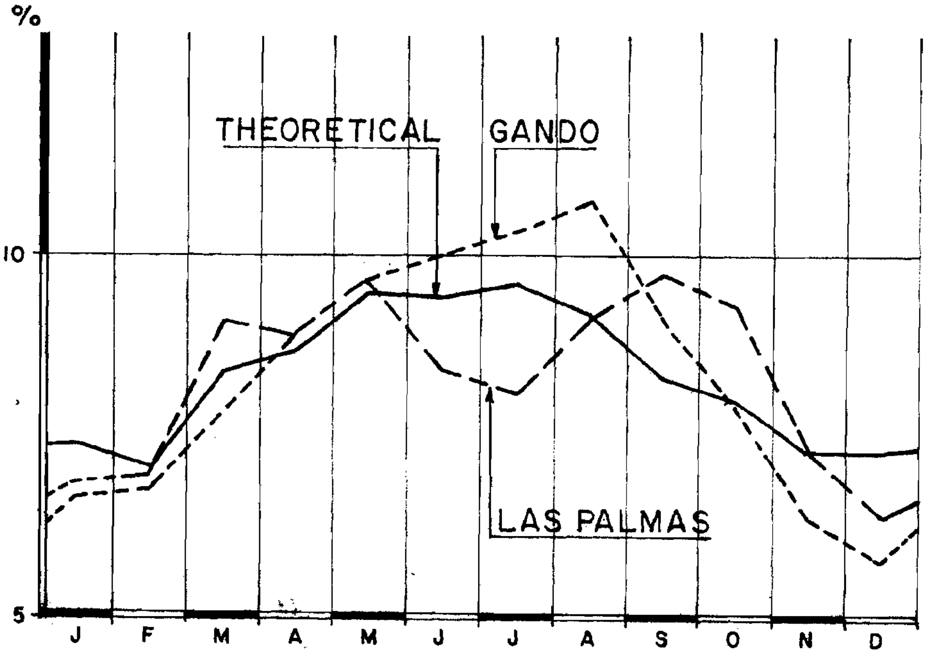
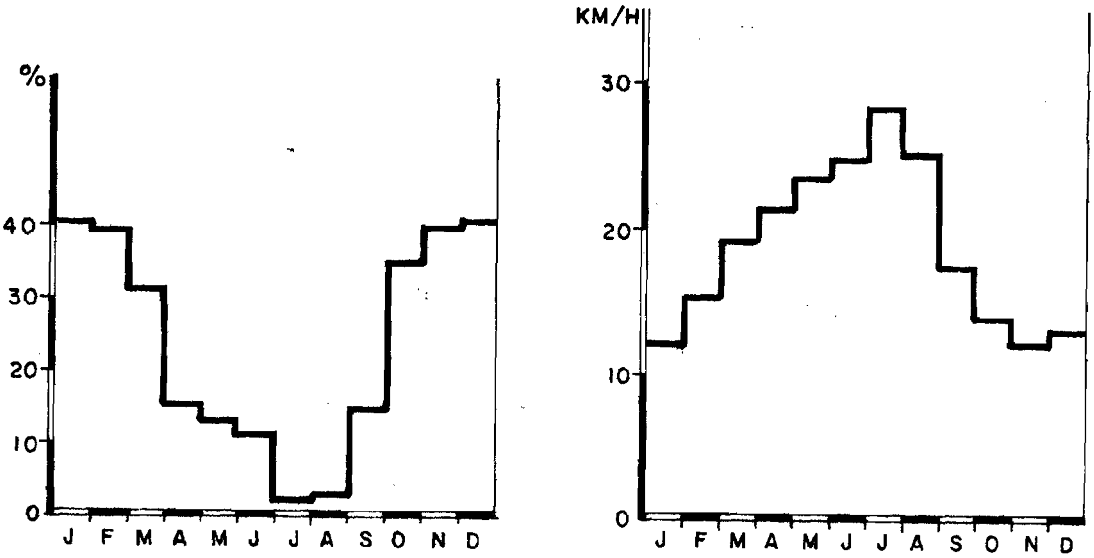


FIGURE B-4 MONTHLY DISTRIBUTION OF SUNLIGHT HOURS FOR 2 STATIONS IN GRAN CANARIA AND THEORETICAL DATA FOR LATITUDE 28° N.

N	55.9%	SW	0.8%
NE	8.5%	W	0.5%
E	0.3%	NW	5.5%
SE	0.5%	CALM	24.0%
S	4.0%		



PERCENT CALM PERIODS

AVERAGE WINDS EXCLUDING CALM PERIODS

FIGURE B-5 WINDS AT GANDO 1962-1971

this real fog interception seem to be of little importance compared with rainfall.

Measurements have been carried out by the Project in Fontanales, where a nylon fog interception net shows the same results. The results from a lysimeter filled with volcanic cinders, "picón", also shows that if any interception takes place on that material, it is less than the evaporation and therefore no influence of fog interception on the water balance should be expected.

Both from theoretical considerations and from actual measurements carried out by the Project, it is clear that dew is an insignificant form of precipitation compared with rainfall (Michaeli, 1973).

3. Climatic Zones

Due to the trade winds and the relief of the island, two different climatic regions can be distinguished, i.e., the northern windward region and the southern leeward region.

3.1 The Northern Region

The northern part of the island can be divided into three climatic zones according to elevation. The coastal and lower zone up to about 600 m elevation, is warm (18-19° C), humid (70-80%) and has low rainfall (200-500 mm/year). It is generally covered during large parts of the day by cloud layers, the "sea of clouds". Typical temperatures are shown in Figure B.7.

The intermediate zone between 600 and 1500 m elevation is situated in the cloudy zone where the air is cool (10-15° C) and very humid (85-95%). Precipitations range between 500 and 900 mm/year. The level of the temperature inversion varys considerably also during short time periods

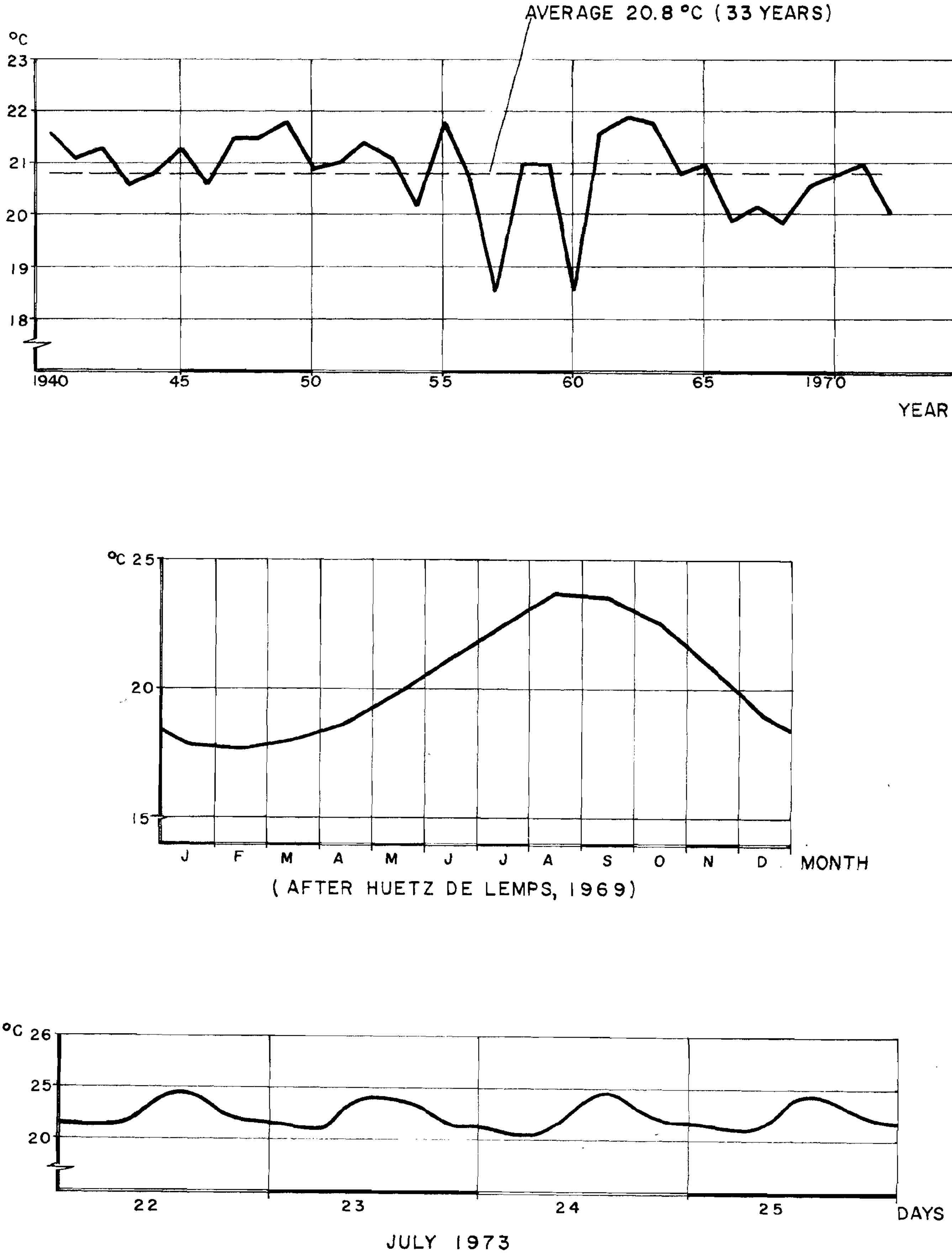


FIGURE B-7 TEMPERATURES IN LAS PALMAS

which causes frequent and rapid changes in temperature and humidity in the upper part of this climatic zone.

The highest zone above 1500 m has a continental type of climate alternating between high temperatures during daytime caused by the insolation and low temperatures during the nights. Relative humidity is low (40%) except during occasional intrusions of polar maritime air. Precipitation in this zone is about 900 to 1100 mm/year and may sometimes also occur as snow.

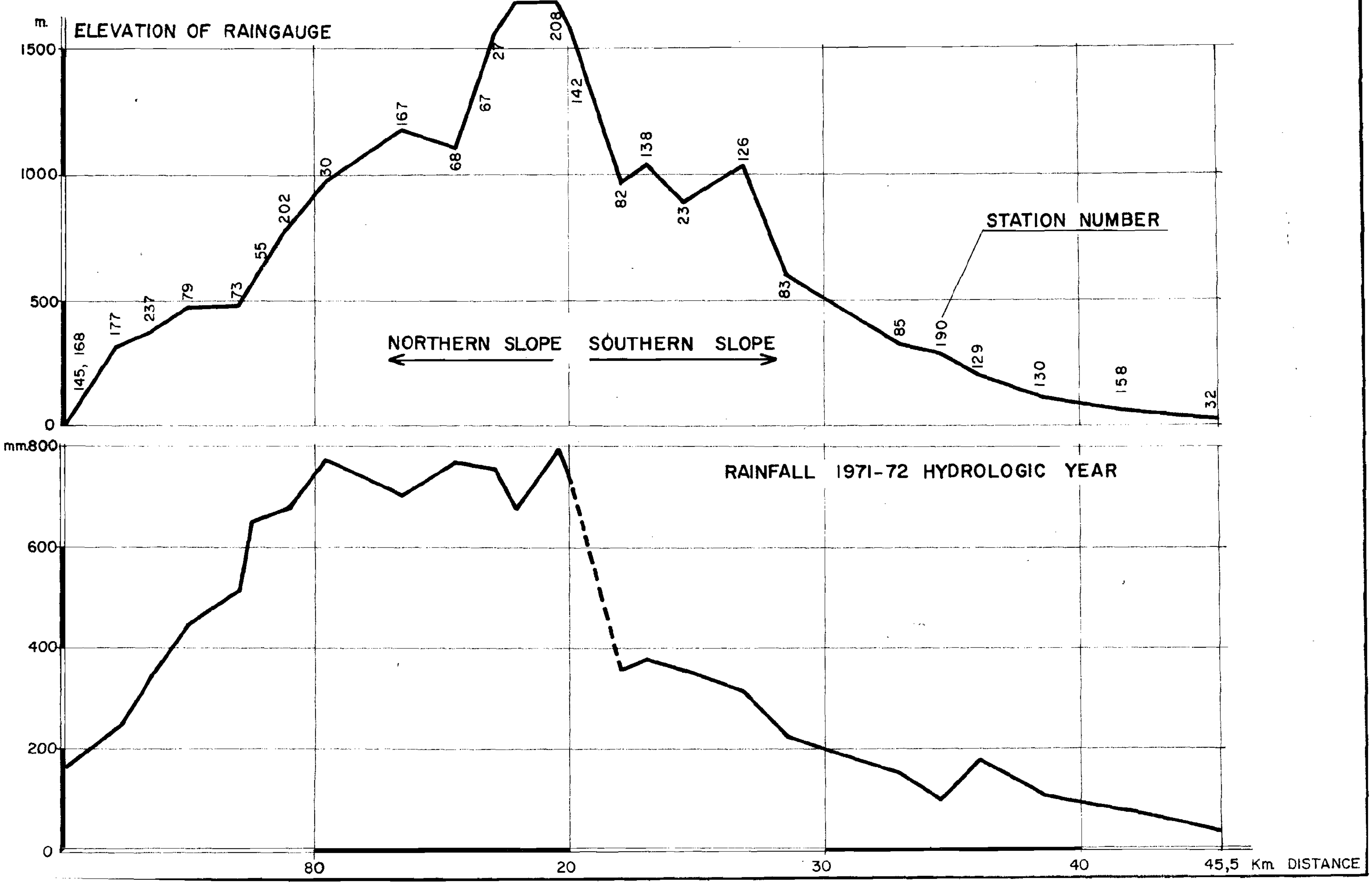
3.2 The Southern Region

On the southern slope of the island two climatic zones could be distinguished. The low zone up to about 800 m elevation is drier and warmer than the corresponding zone on the northern slope. Also rainfall is considerably lower than for the other slope, ranging between 100 to 300 mm/year. The sky is generally cloudless and insolation high. The coastal parts of this zone are practically desertic.

The high zone above about 800 m elevation shows a continental type of climate with large monthly and daily variations of temperature. Also average relative humidity varies considerably with the seasons from about 55% in summer to about 80-85% in the winter. This area receives some precipitation carried over from the northern slope, but the more important rains are due to intrusions of warm humid air from the SW, which cause orographic rains of short durations with high intensities. Average precipitation is between 300-600 mm/year. Insolation is normally high in this zone.

A rainfall profile across the island is shown in Figure B.8

FIGURE B-8 RAINFALL PROFILE FOR GRAN CANARIA YEAR 1971-1972



C GEOLOGICAL BACKGROUND

The surface geology of the island Gran Canaria has been studied in a detail manner in recent years by Prof. Fuster Casas and his co - llaborators.

However the subsurface geology, which is of primary impor - tance in the understanding and definition of groundwater problems was scantily known before the beginning of the Project.

The exploration of subsurface geology was largely facili - tated by the existance of over 2.000 visitable large diameter wells with depths reaching up to 350 m, dug in every type of material found in the island. These investigations have permitted the making of 13 radial cross-sections as can be seen in Fig. C.1,at vertical scale 1: 25.000 and hori - zontal scale 1:10.000, totalling a length of 22 Kms followed by a few transverse sections with a view to correlate geological features.

1 Stratigraphy and lithology

With the exception of limited sedimentary deposits, of local interest only, the island of Gran Canaria is composed of a pile of volcanic materials emitted by a series of eruptive cycles, separated however by in - tense erosive periods.

On the whole, the geology of the island is simple but on a detail scale, there exists a great complexity due to the imbrication of ma - terials proceeding from different centres of emission, the existance of sharp paleotopographic features, the similarity of materials of various ages, etc.

Inspite of these local complications, the salient features of the principal lithological units in their stratigraphic scale can be follo - wed with relative ease. A summary of their characteristics as well as their ages is given in Table C.1.

Table C.1

Summary of the Geology of Gran Canaria

FORMATION	TYPE OF VOLCANIC MATERIAL	COMPOSITION	THICKNESS	AGE	OBSERVATIONS
›dern Basalts Series IV	Single cones and associated 'aa' and 'pahoe-hoe' lavas.	Olivine Basalts	500 m.locally, generally less.	Subrecent and Quaternary.	Mostly in the north-east half of the island.
Series III	idem.				
Series II	'Aa'and 'pahoe-hoe'lavas with intercalated pyro - clasts and abundant buried cinder cones.			Pliocene-Pleisto - cene.	
oque Nublo and re-Roque Nublo Series	Agglomerates with intercalations of tephritic lavas, basalt flows and sediments.	Tephritic in general	600 m.	Lower Pliocene	Originating probably from the centre of the island. Intraformational erosion present. Erosional Discordance
Phonolytic Series	Lava flows, ash-flow levels and pumice.	Phonolytic	Several hundreds of meters.	Upper Pliocene	Many emission centres.
Trachy-Syenitic complex and associated Ignimbrites.	Ignimbrites; trachytic dykes, sills, cone-sheets; syenitic intrusive features.	Ryolitic,panteleritic and trachy-phonolytic.	600 m of ignimbrites.Maximum height up to 1.500 m above sea level.	Miocene	Probably originating from a large caldera in the centre. Local erosional Discordance
Old Basalt Serie I	Subparallel lava flows with intercalated pyroclasts, and buried tuff and cinder cones. A large number of oriented dykes.	Olivine Basalts	1000 m.	Miocene	

As can be seen in the above table, the most ancient formation is composed of the Old Basalts emplaced in the middle Miocene, through large scale fissure eruptions that affected the entire Canarian archipelago. They are formed as can be seen in the western coastal cliffs of the island, of a vary thick tabular series attaining over 1000 m, in which subaerial basaltic flows and pyroclasts are found intercalated.

This cycle of activity was followed probably in late Miocene, by a alkaline episode during which the Trachy-Syenitic Complex associated with an important caldera was formed. The materials are composed of ignimbrite and alkaline lava flows, highly transformed by syenitic intrusive features and oriented trachytic dykes.

The maximum development of this series as can be seen in Fig. C.2 is in western sector of the island specially between Tejeda and San Nícolás de Tolentino.

The following eruptive activity in early Pliocene was a continuation of the alkaline episode, during which a large scale effusion of phonolytic lava from dispersed emission centres took place giving rise to the Phonolytic Series where maximum development however is found in the southern part of the island.

Besides lava flows, they are composed of ash-flow levels, pumice, plugs and other intrusive features.

The Las Palmas Sediments are dated as Miocene according to paleontological evidence, but in all cases stratigraphically speaking they are found on the top of the Phonolytic Series and below the Roque Nublo Series. These materials have a maximum thickness of about 100 m and are principally detritic in nature. In several areas around Las Palmas they are covered by recent lava flows, forming productive aquifers.

The following eruptive cycle was alkaline forming the very extensive Roque Nublo Series in the mid-Pliocene epoch. This series emitted from the centre of the island affected principally the north-eastern sector and was characterised by the "nuée ardente" type of activity.

The lower part of the series called Pre-Roque Nublo is composed of lava flows both of basaltic and tephritic origin, intercalated with some agglomerate layers and sediments. In the upper part called Roque Nublo, the agglomerate materials are dominant. The entire series comports also some associated phonolytic intrusions specially in the central part of the island.

Important from the hydrogeological point of view, this series atta in the centre of the island a maximum thickness of 600-700 m.

In the Quaternary epoch, there was an extraordinary development of volcanic activity affecting mainly the north-eastern half of the island.

In late Pliocene to Pliestocene, the Modern Basalt Series II was formed from numerous emission centres. They are composed of 'aa' and 'pahoe-h lavas flows,associated with cinder cones and pyroclastic layers. This series at times attains thicknesses up to 400 m covering the pre-existing relief features.

The same type of volcanic activity continued up to Sub-recent and Recent times but on a more restricted scale forming important craters, volcanic cones and some lava fields.

Mention must be made of important landslides of varied ages found specially in the upper Tirajana and Fataga valleys. Also in most of the valleys alluvial deposits and terraces have accumulated, the most important being in Tirajana, Maspalomas and San Nicolás de Tolentino.

The stratigraphic development of the island from Miocene up to Recent times shows a gradual migration of volcanic activity from south-west to north-east which explains the sucession of older to more modern forma - tions in the same direction. This factor seems to have an important effect on the occurence of groundwater as will be seen later.

As for lithology the more tabular Old Basalts, compact and highly intruded by dykes in succeded by the even more compact intrusive complexes of the Trachy-Syenitic series as well as of the lava flows of the phonolytic series, all of them without an apparent logical structural layout. The pa - leotopographic surface constituted by these rocks forms in fact an important reference for groundwater flow.

The mateials which piled up later on this surface varied from agglomeratic layers through vast lava fields mostly composed of less compact permeable rocks.The sequential layout of these various formations gives a certain continuity, which has a favourable effect on groundwater.

2 Materials and structural features

The extension of the various aforesaid geological formations can be seen in Fig. C.2.

The Miocene Basalts are composed principally of olivinic types. The lava flows are either massif, vacular or even scoriaceous. The intruding dykes are also generally composed of basaltic materials. The lava layers can vary from 5 to 20 m of thickness and the dykes from less than one to about 5 m.

On the whole the scoriaceous and pyroclastic materials can attain 40 to 60% of an entire area. Also the compactness of these intercalated layers is variable but generally they are tight. As for the basalt layers, they are highly fissured but are closed to a great depth due to alteration and filling in by secondary minerals.

Hence it is believed that the exposed layers are practically im- permeable up to a certain depth. However below this level inspite of the increasing compactness, there is a possibility of water occurence along the fissures. Also the hydraulic characteristics of these materials seem to improve when covered by other formations, possibly explained by the absence of a thick decomposed layer.

The geological study of the surface of the Old Basalts shows, a possible existance of a depression between the outcrops of the western area near Mogan-Arguineguín and the eastern area near Agüimes. This region at present is covered by thick lava flows of the Phonolytic series and Ignimbrites which together can attain up to 700 m of thickness.

The extension of this surface towards the north-eastern part of the island is uncertain but in any case there is a tendency for it to dissappear below the sea-level in the sector found between Montaña Alta and Telde excepting near a point east of Teror.

The Trachy-Syenitic Complex as said earlier is much less uniform. We can distinguish two types of materials, the "intrusive facies" composed of highly dipping dykes (up to 45°) and impermeable syenitic intrusions found west of Tejeda probably representing the rests of an ancient caldera, and the "extrusive facies" found in the southern and south-western regions composed principally of ignimbritic beds which in places can attain up to 600 m of thickness.

As far as groundwater is concerned the intrusive facies constitut an impermeable formation but there is doubt as to the role of the gently dipping ignimbrite beds. It is possible that the materials found at its base which is a mixture of ignimbrites, trachytes and basalts, offer more favorable conditions, as can be noted in the behavior of certain wells. At times they constitute isolated pockets filling ancient topographic inequalites.

The Phonolytic Series as mentioned earlier is a guiding surfac for groundwater movement. An attempt has been made to reconstruet its surface which shows great inequalities as will be explained in section D.

Inspite of the dissemination of the emission centres, a great thickness of coastward dipping lavas acumulated in the southern regions probably originating from the centre of the island. They are composed of alternating lavas and agglomerate beds.

In the region of Las Palmas extensive pumice deposits of ash-flow type are found also belonging to the same series. On the northern coast they form a disconnected barrier probably constituted by outcrops of several individual emission centres.

As a whole they form an impermeable series since the existing primary fissures are rarely interconnected. However locally, large secondary fissures have been found which may explain the occurence of water in restricted zones.

The Roque Nublo Series attain their maximum thickness in the centre of the island, from where the ancient valleys were filled in by a radial flow of the materials. Hence its layout is practically horizontal in the centre but dips in all directions to the sea at lower elevations. However it must be remembered that due to the filling in of ancient valleys, local thicknesses can vary widely.

Also as said earlier the pre-Roque Nublo is much less uniform in characteristic due to the presence of tephritic lavas and sediments. The upper agglomeratic series is composed of angular and subangular fragments found in a matrix. The chemical and petrographic compositions are similar throughout the series.

Mention must be made of the existance of the phonolytic plugs called "roques" in the Tenteniguada-Cuevas Blancas region of the centre, which form an integral part of this series.

The Modern Basalts in the case of Gran Canaria composed principally of Series II, form a continuous cover in the northern region, upper Guiniguada valley and in the south-eastern region. They are like the Old Basalts composed of olivinic lava flows and intercalated scorias and pyroclastic beds. However they dip gently towards the sea and are only rarely tabular.

Also the surface layers are generally pyroclastic and comport developped soil horizons facilitating deep infiltration.

The deeper layers have very porous scoriaceous beds, and the lavas even when compact have a highly developped primary fissure system which obviously favours groundwater circulation.

From a hydrogeological point of view in several areas the Modern Basalts form a protecting layer to the underlying Roque Nublo series through which infiltration occurs continuously and generally both formations constitute a single interconnected hydraulic system.

The structural relationship existing between these various formations have been studied in the several geological cross-sections and their hydrogeological significance has been investigated zone by zone.

Thus the Section I shown in Fig. C.3 depicts the typical situation in the northern zone where the Roque Nublo series attains over 500 m near the centre of the island and is covered in its middle and lower parts by the Modern Basalts. The Phonolytic and the Ignimbritic series form a substratum for groundwater. The latter series outcrops near the coast with the overlying more permeable rocks forming a large basin in the interior.

A similar situation is found in Section 5 which passes through the Valsequillo-Telde valley in the east. However in the upper zone the existance of the intruded phonolytes associated with the Roque Nublo series introduces a certain complexity. These rocks even though fissured, compartimen the Roque Nublo formation, with the consequent result in groundwater occurence.

A change in the structural relationship is seen in Section 6 where the Old Basalt basement appears as a dome beneath the Phonolytic Series, finally outcropping near the coastal zone. However between Old Basalts in the region of Agüimes and the outcropping of the phonolytic basement north of Telde valley, a large basin similar to the one in the northern zone appears, composed principally of Modern Basalts.

From a hydrogeological point of view besides the generally productive Roque Nublo-Modern Basalts, we have also the Old Basalts separated by the Phonolytes, the latter acting as an aquiclude.

The region around the Tirajana Basin shows a similar condition where however the Phonolytes and Ignimbrites form isolated pockets but the Old Basalts are intensively exploited.

The structural relationship typically found in the southern part of the island is shown in Section 9, where the upper parts are composed of large areas of the Ignimbritic-Phonolytic series which can attain up to 700 m of thickness at times. Below this appears the Old Basalt basement generally of low elevation and outcropping near the sea and at the bottom of the deeply eroded valleys. Groundwater production seems to be related to the upper part of this basement, possibly also to the lowest layers of the Ignimbrites.

3 Geophysical Prospection

Up to 1971, several small geophysical prospections were undertaken in connection with dam site investigations by the Geological Service. In that year, it was decided to try out on a larger scale, the feasibility of the electrical and sismic refraction methods for the detection of geological structures significant in groundwater occurrence and flow.

The chosen experimental sector was between Agüimes and Telde in which altogether 89 E.S were effectued aligned on N-S profiles with emission lines generally varying from 1000 to 2000 m.

The great lateral and vertical variation of the contacts and characteristics of the materials made interpretation extremely difficult.

The field of electrical resistivity variation found allowed the definition of a 3-layer system, if we exclude the resistant soil layer which showed variations between 100 and 500 ohms/m. The first corresponded to a low resistant layer generally between 10 and 50 ohms/m, due probably to the existance of pyroclasts and clays. The second layer corresponded generally to high values between 150 and 300 ohms/m. This layer seem to enclose at times the upper part of the Old Basalts or the Phonolytic Series and at other times lavas of the Modern Basalts of Series 2. The third conductive layer found generally below the sea-level shows values less than 40 ohms/m which possibly indicates the interface and the presence of brackish waters.

In the interpretation of the field data, certain structures similar to "fossil valleys" were detected which need however to be confirmed after calibration with boreholes.

A trial was also made with the sismic refraction method however without success, due to strong wind, high noise levels and above all due to the high absorption rate of the sismic waves in the porous materials.

In the first 10 meters the velocity attained 2.000 m/s. Below this level there exists a layer of great thickness with velocity varying from 3.000 to 3.500 m/s., which in turn reposes over a substratum having a velocity of about 4.500 m/s.

As a conclusion we can say that electrical prospection does not permit the separation of the different geological formations but does definitely show certain structures whose nature cannot be yet defined adequately.

D. SURFACE WATER RESOURCES

1. Precipitation

The very large number of raingauging stations in Gran Canaria enables a good interpretation of the rainfall pattern in the island, although there are deficient stations and records of poor quality. Isohyets for the 18-year period 1949/50 - 1966/67 have been published based on 121 stations (Heras, et al 1971 a), which are indicative of the rainfall pattern. This map shows an average annual rainfall of about 325 mm in Gran Canaria for that period. It is obvious from the map that there exists a close relationship between rainfall and elevation in the island, also seen in Figure B.8.

1.1 Isohyetal Maps

In order to improve and bring up to date the previous information on rainfall, an isohyetal map was prepared, using the 5 year period 1967/68 - 1971/72 for 173 stations. Location and quality of the stations have been checked in the field and for this 5-year period the isohyetal map indicates an average annual rainfall of 350 mm for Gran Canaria. Although not entirely free from errors, the records for this additional period are of higher quality than those used for the previous period. The average rainfalls in the island for those two periods seem to be quite similar, since for the 121 stations common for both maps, the arithmetic mean is 453 mm for the 18-year period and 463 for the 5-year period. The isohyetal map shows one rainfall peak in the center of the island and another in the Tamadaba area in the NW part. Most rainfall occurs in the NE part of Gran Canaria, thus clearly indicating the orographic character of the rainfall and the large influence of the trade winds on the rainfall pattern, see Figure D.1.

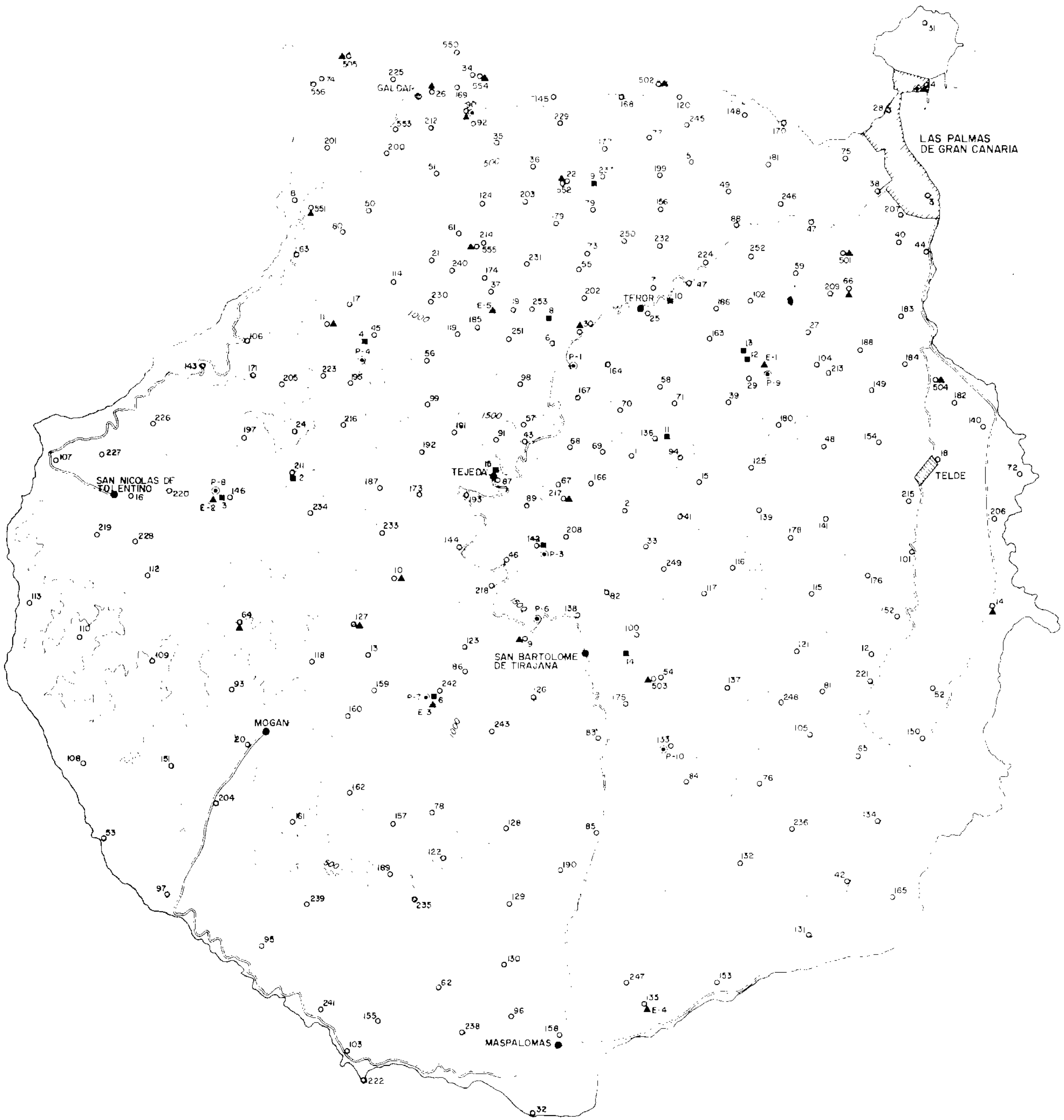
During this period, average annual rainfall has varied from about 200 mm at the northern coast to 900-1000 mm in the center of the island, and in the southern part from about 100 mm at the coast to some 600 mm at the highest parts.

1.2 Definition of the Hydrologic Year

Rainfall in the Canaries shows large monthly variations with one wet and one dry period, each about 6 months long. Since the hydrologic year ought to be defined in such a way that the amount of water fallen in one hydrologic year should have as little influence as possible in the following year and as the wet season stands generally in September, it was decided to use the period September 1st to August 31st ending in the following year. This time period coincides with the so-called agricultural year which is currently used for statistical purposes.

1.3 Annual Variations of Rainfall

The variation of rainfall for a number of stations throughout the island with records for a long period has been studied and the results plotted on probability paper for a normal Gaussian frequency distribution, as shown in Figure D.2. The results are given in Table D.1. The two periods for which isohyets have been prepared and average rainfalls have been calculated are wetter than the average long term conditions. It could further be advocated that the median rainfall is more representative of average conditions as it is the rainfall that will be exceeded during 50% of all years. It will not be distorted in the same way as the mean



LEGEND

- ⊙ Recording raingauge
- ■ Gauging station
- ▲ Meteorological station
- o Raingauge

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HYDROMETEOROLOGICAL NETWORK (OCT. 1972)

GRAN CANARIA

FIGURE D-2-FREQUENCY DISTRIBUTION OF RAINFALL

STA. TAMADABA ESTADO

(1935 – 1971)

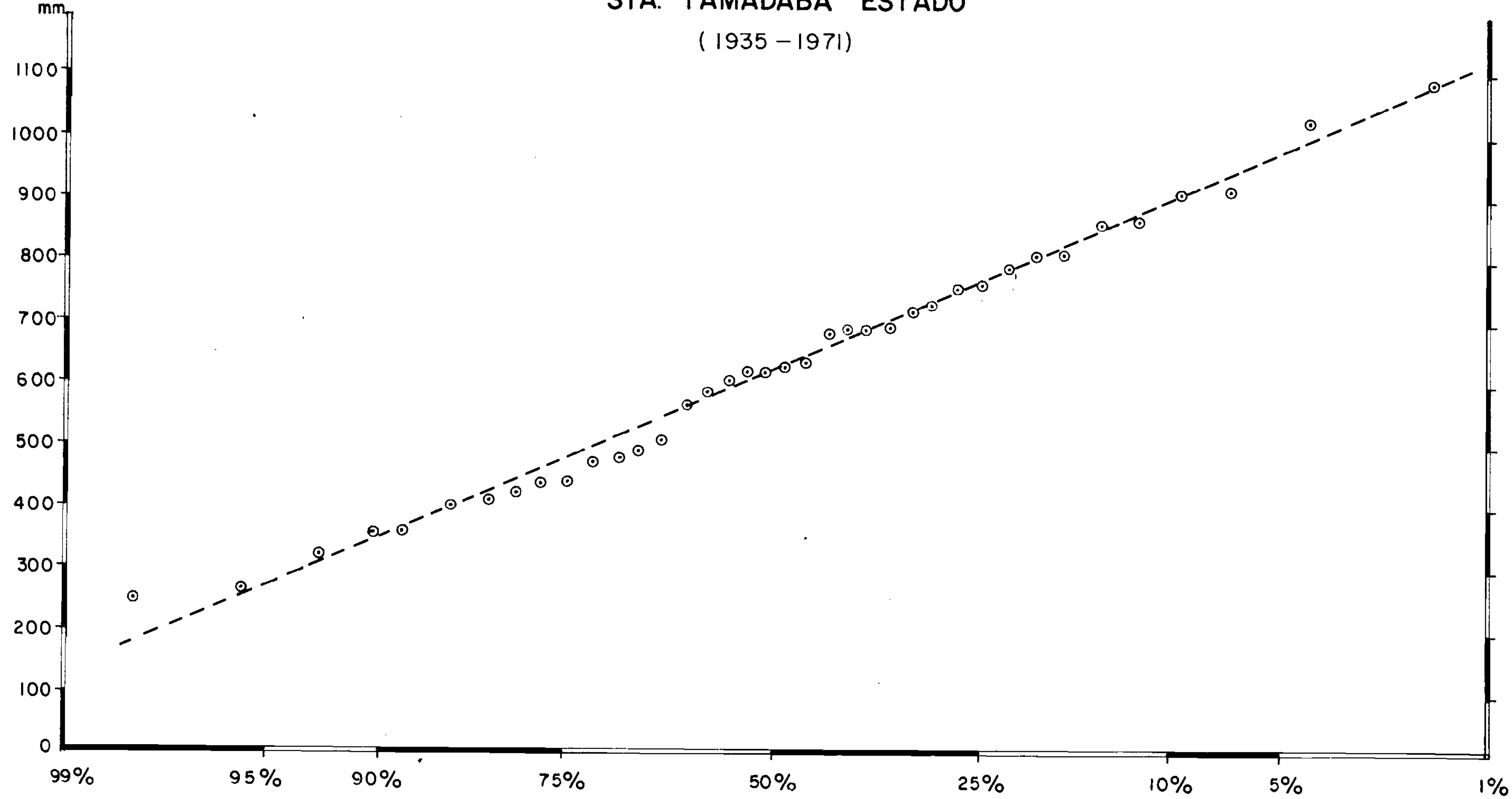


Table D.1 Rainfall variation at 8 selected stations in Gran Canaria

Station		Average	Average	Statistical long term values						
Nº	Name	1949-1966	1967-1971	Nº of years	Aver-age.	exceeded in 10%	25%	50%	75%	90%
1	Lomo Aljorradero	720	729	45	652	890	780	640	510	390
2	Hoya Gamonal	925	955	48	796	1110	940	750	570	400
4	Puerto Junta Obras	138	158	42	138	205	175	140	100	70
5	Arucas	325	336	37	322	495	415	330	240	170
9	Cuevas del Pinar	588	596	37	500	730	605	475	335	220
11	Tamadaba Estado	669	737	38	626	910	775	630	480	350
12	Ingenio	244	198	37	217	350	260	200	140	90
64	Inagua	367	389	23	336	540	440	325	210	110
Average of 8 stations in percent of median		114	117			150	126	100	74	52

value by a few extreme values in a relatively short period. If a long enough period of records were available, the arithmetic mean and the median values would coincide, if the frequency distribution is Gaussian.

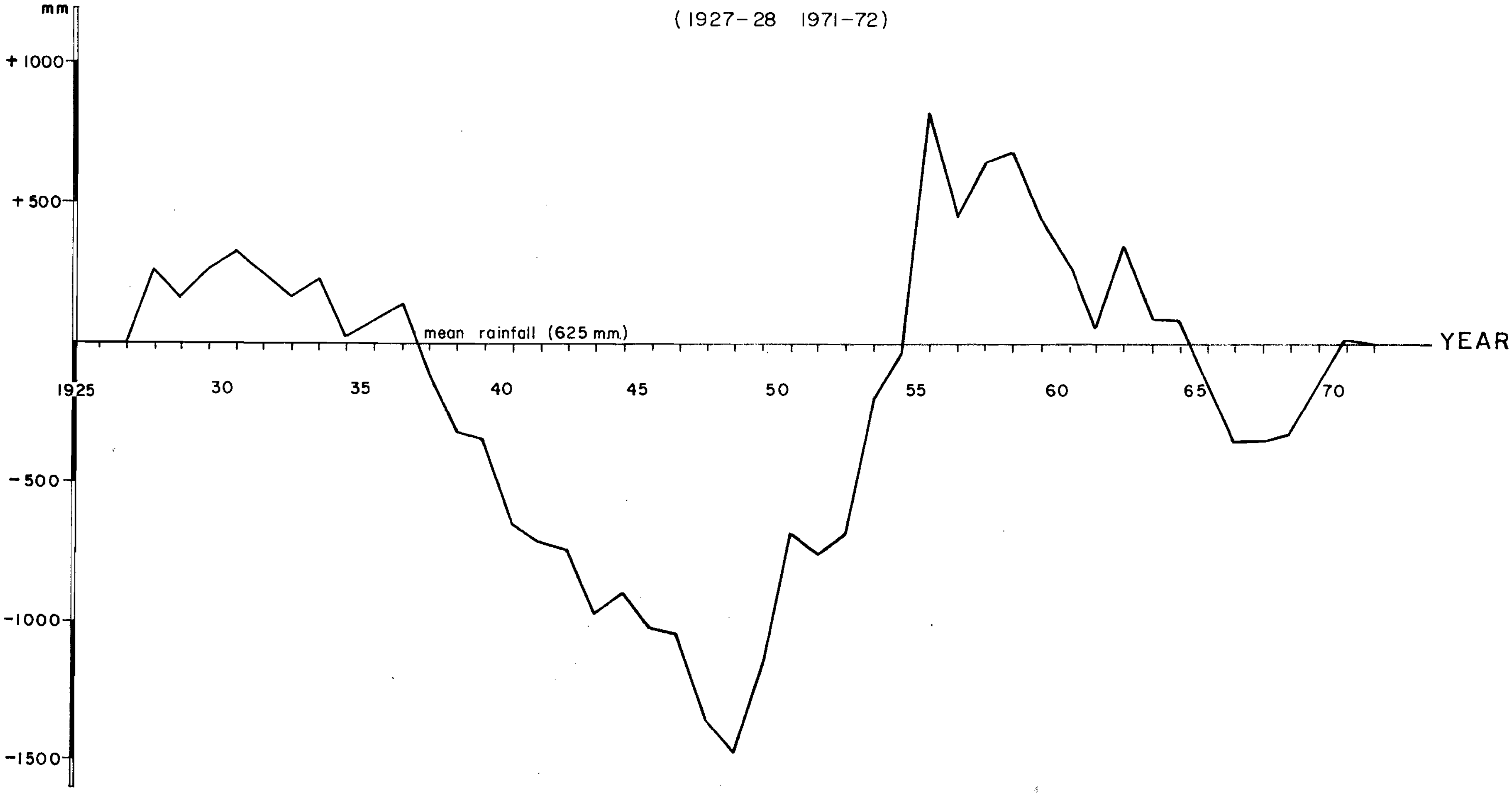
From the calculated values in Table D.1, comparing the periods 1949-66 and 1967-71 with the long term records it may thus be concluded that the true long-term average rainfall in Gran Canaria is about 300 mm/-year. When planning for the utilization of the water resources of the island it should be kept in mind that during 10% of all years, that is 1 year out of 10, total rainfall may be less than 150 mm and in 25% of the time, that is 1 year out of 4, total rainfall may be less than 225 mm. Also, during 1 year out of 10, rainfall may exceed 450 mm and during 1 year out of 4 it may exceed 375 mm. These figures are based on the assumption that the statistical events are occurring simultaneously throughout the island, which according to available data seems to be reasonably valid, at least for the areas that are most interesting from the point of view of runoff and infiltration. Of an average rainfall of 300 mm/year for the whole island about 400 mm/year occurs in the north and 200 mm/year in the southern part.

For the 8 stations with long-term records mentioned above, cyclical variations have been investigated by calculating the accumulated deviation from the mean precipitation, with an example given in Figure D.3. All stations, but particularly those with high precipitation, show a dry period starting about 1930 and ending in 1948, and a wet period starting 1949 and ending in 1955. The period 1956-1971 could be classified as a transition period or a not very pronounced dry period. In the planning it should therefore also be taken into account that a considerable number of consecutive years with extreme precipitation may occur. As an example may be quoted the station Hoya de Gamonal where for the 18 year period 1931-1948 the average rainfall was 604 mm, and for the 7 year period 1949-1955 1221 mm, as compared to the 48 year average value of 796 mm.

FIGURE D-3 ACCUMULATED DEVIATION OF MEAN RAINFALL

STATION LOMO ALJORRADERO

(1927-28 1971-72)



1.4 Rainfall Intensities

As will be shown later in this report, the duration and intensity of rainfall are very important data for the determination of the other hydrologic events which will influence the hydrologic balance. Since only a few data are available for the short-term rainfall intensity from the recording raingauges, the evaluation of such terms as runoff and infiltration has had to be based on recorded daily rainfall. Typical values for the daily rainfall at one station on the northern slope and one at the southern slope are given in Table D.2 - It is clear that although rainfall is much higher on the northern slope , the occurence of high daily rainfall is about the same for the two sides of the island. A typical feature of the rainfall on the northern slope is that there are very many days with low rainfall; approximately 35% of the total precipitation has been falling on days with less than 10mm of rainfall, whereas on the southern slope only about 13% of the total has fallen on such days.

The high intensity rainfall which will provoke runoff will be more or less equal for the whole island , and the northern part in addition will also have a considerable number of days with rainfall less than 10mm/day.

1.5 Condensation

According to what has been stated previously, it would seem logical to disregard the contribution of condensation to the water balance until it has been conclusively proven that such a phenomenon is of importance. This does not preclude that condensation may be an important factor for maintaining the vegetation in the intermediate zone of the northern side of the island.

Table D.2 Range of Daily Rainfall at two stations in Gran Canaria 1949/50 - 1971/72 (23 years)

Daily rainfall mm	Station 55, Madres de Firgas northern slope, elevation average rainfall 662 mm.	Station 83, Fataga southern slope, elevation average rainfall 331 mm.
0,1 - 4,9	1190	140
5,0 - 9,9	355	87
10,0 - 19,9	273	84
20,0 - 29,9	77	56
30,0 - 39,9	33	11
40,0 - 59,9	23	28
60,0 - 79,9	12	8
80,0 - 99,9	6	7
100,0 - 149,9	2	4
150,0 - 199,9	2	1
> 200,0	2	0
Total days of rainfall in 23 years	1975	426

Note: Station 55, elevation 585 m.
" 83, elevation 605 m.

2. Procedure for Study of Hydrological Characteristics

As in every place in the world, rainfall is the term in the hydrologic cycle that governs the magnitude of the other terms. In the Canary Islands it seems , however, that the distribution and intensity of the rainfall plays a much more important role for the understanding of the hydrological cycle than is normal for many other parts of the world. This is especially true for the runoff which previously, for lack of measured data, has been estimated at a constant fraction of the rainfall with different coefficients for the different parts of the island. This procedure may give erroneous results for specific years, since it is quite possible to have considerable amounts of rainfall in one year without any water in the rivers, due to an unfavourable distribution of rainfall in time and it is also quite possible to have a considerable amount of runoff for a low yearly rainfall.

2.1 Methodology for Evaluating Hydrological Events

A suitable procedure for evaluating the terms in the hydrologic balance and the only one that gave reasonable results, is a study of the daily water balance with a bookkeeping procedure to account for the retention of moisture in the upper part of the soil. Available data are still very scarce for an accurate determination, but the method has the enormous advantage of conveying a good understanding of the interaction between the various events and thereby avoiding fundamental mistakes.

For the whole island, hydrologic characteristics have been estimated for the relationship between rainfall and runoff, based mainly on geology. Potential evapotranspiration has been calculated and soil water retention capacity has been estimated.

For each day the rainfall-runoff relation is verified to see if the rainfall of that day would cause any runoff. The amount of precipitation that does not flow out as runoff is considered to replenish the soil moisture. Real evapotranspiration is calculated from the potential value and the actual available soil moisture. Water in excess of the retention capacity is considered to infiltrate and form recharge.

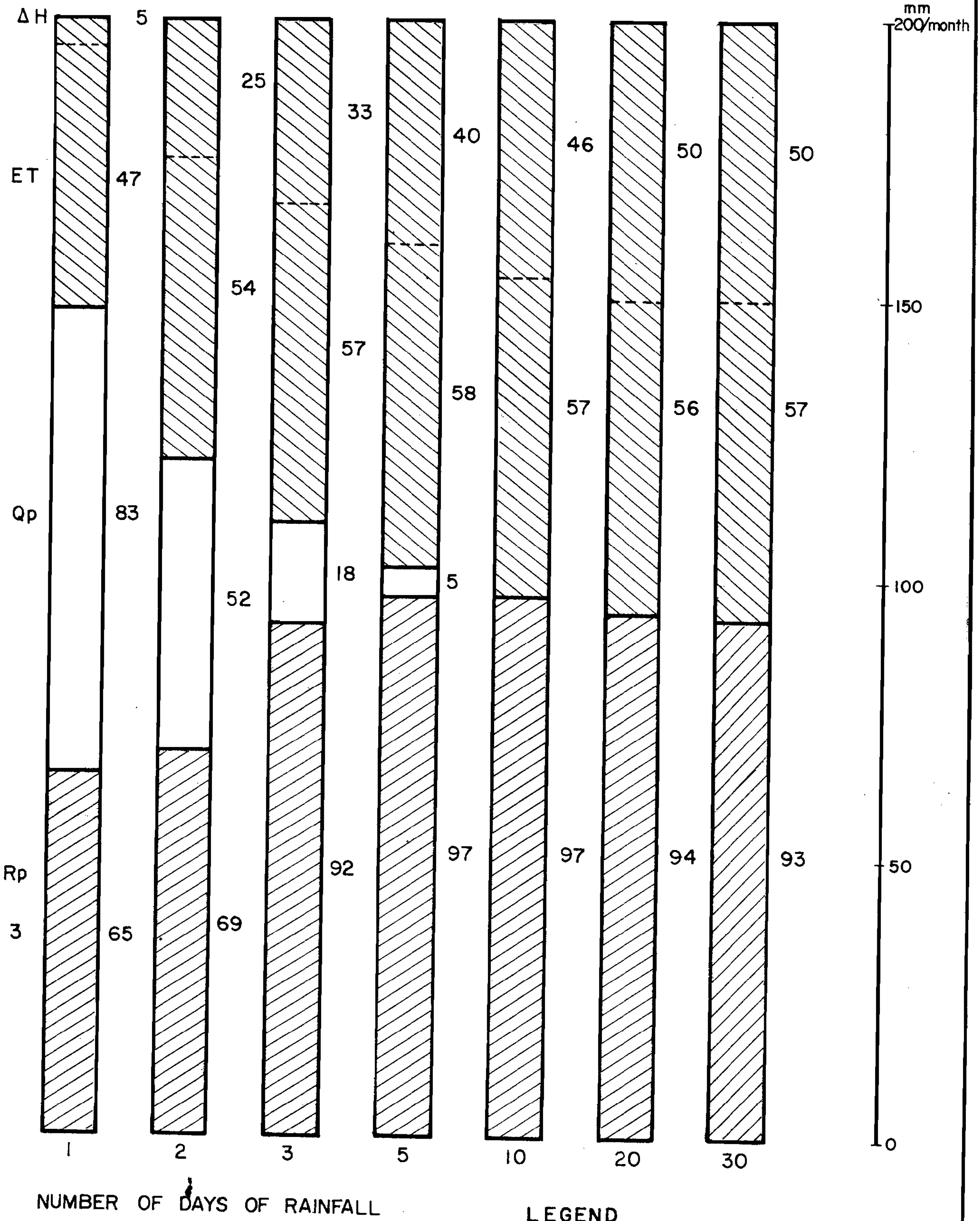
2.2 Importance of the Rainfall Distribution in Time

In order to show the importance of the rainfall intensities and to demonstrate the inadequacy of the concept of a constant runoff coefficient, two examples have been elaborated which are typical for the northern, Figure D.4, and the southern, Figure D.5, parts of the island respectively. For the northern area it has been assumed that 200 mm of precipitation occurs during the month, that retention capacity is 100 mm and that available soil moisture is 50 mm at the beginning of the month. Potential evapotranspiration is assumed to be 60 mm and the rainfall-runoff relationship is assumed to be that of curve number 60, in Figure D.6. If the rain falls on one day runoff will be 83 mm, that is a runoff coefficient of 0,415, and if the rain falls on 5 days runoff will be only 5 mm, equivalent to a runoff coefficient of 0,025. For a 200 mm rain that lasts for 10 days of the month, the runoff coefficient will be zero. For the southern part, a monthly rain of 150 mm has been studied. Retention capacity is estimated at 50 mm and initial available soil moisture is assumed to be 25 mm. Runoff characteristics correspond to curve number 85 and potential evapotranspiration is assumed to be 60 mm. In this case the theoretical runoff coefficient varies between 0,54 and 0.

From Figures D.4 and D.5, it can also be seen that an evenly dis-

FIGURE D-4-VARIATION OF BALANCE ITEMS AND RAINFALL DISTRIBUTION

— NORTHERN ZONE —



LEGEND

Rp = RECHARGE FROM PRECIPITATION

Qp = DIRECT RUNOFF

ET = EVAPOTRANSPIRATION

ΔH = CHANGE IN SOIL MOISTURE STORAGE

tributed rain favours the evapotranspiration which will approach its potential value. The increase of soil moisture storage will of course eventually be consumed as evaporation but as a secondary effect it will also improve the possibilities for recharge during the subsequent months. According to this simplified model, infiltration will reach its maximum value when the rain does not occur on every day of the month, but on every second or third day. This may depend on the assumption that as soon as soil moisture in the root zone exceeds field capacity, the excess immediately penetrates and forms recharge which, of course is not true, but may be a permissible assumption for a water balance model of the kind that is used in this report, taking into account the quality of the basic data.

3. Runoff

There are no perennial rivers in the island, although there are a few gauging stations located downstream of springs where the spring water passes continuously and is diverted below the stations. The rivers, locally called "barrancos" flow only during very few days following heavy rainfall. Runoff is generally torrential with very high velocities due to the steep slopes and often causes damage to bridges and other structures. Erosion is quite large and considerable quantities of sediments and bed materials are carried downstream by the flow. Many rivers do not flow every year, which may depend not only on geological and meteorological factors but also on the existence of dams and diversions in the rivers, in which case flow only occurs when the capacity of these water collecting devices has been exceeded. Base flow in the rivers is nil and the recession process is very rapid generally lasting only about a week.

This is an indication of a lowering of the water table during this century since local residents report that some thirty years ago the rivers were flowing for several months every year. It means that instead of being effluent, which they were, al least during part of the year, before the de - velopment of the water resources, the rivers are now influent which is also obvious from the amount of stream percolation that takes place especially in the lower parts of the island.

3.1 Relationship between Rainfall and Runoff

For all the gauging stations each storm runoff has been plotted against the weighted precipitation for the drainage basin according to the Thiessen method. It has been possible to establish a sufficiently good coincidence between the rainfall-runoff relationships for the gauged basins and the type curves for runoff published by the US Soil Conservation Service (1957), Figure D.6 and this permits the extension of streamflow data. This method is also called the Curve-Number method. For some of the basins only a few storms have been recorded and therefore the calculated runoff characteristics expressed as curve numbers should be revised when more data are available, before using them for detail design purposes. The weighted curve numbers for the gauged basins are shown in Table D.3.

This relationship between rainfall and runoff as defined by the curve-number depends on the infiltration capacity of the soils in the basin and therefore can also be used for establishing some infiltration characteristics in the basin.

A high curve-number means that runoff begins for a smaller amount of rainfall than in a basin with a low curve-number. The high curve numbers thus also indicate that the infiltration capacity is low and viceversa. It has been noticed from both quantitative data collected by this Project and qualitative information obtained from local sources, that runoff occurs for smaller amounts of rainfall in the southern part of the island than in the northern part.

The occurence of reservoirs and the very numerous surface water diversions which still have not been inventoried, has made it very difficult to evaluate the relationship between runoff and rainfall with a sufficient degree of accuracy.

Table D.3

Curve number and Slope Index for the

gauged drainage basins

GRAN CANARIA

Basin	Curve Number	Slope index
Los Hornos	63	0.33
Parralillo	75	0.30
Caidero without Parralillo	84	0.30
Lugarejos	77	0.31
Chira	86	0.35
Valsendero	55	0.47
Azuajo	57	0.38
Teror	64	0.37
San Mateo	40	0.51
Santa Brígida	64	0.35
Guiniguada	56	0.35
Rosiana	86	0.51

3.2 Relationship between Runoff and Geology

Noticing the sometimes considerable differences in runoff characteristics between various drainage basins and the fact that the curve numbers are lower in the northern part where the geological formations are predominanly the Modern Basalts than in the southern part where Phonolites, Trachysyenites and Ancient Basalts are abundant, it was attempted to find a relationship between runoff characteristics and geology. This procedure would provide an objective method for assessing the runoff characteristics of ungauged areas. Since, according to the field investigations carried out by this Project, slope is of minor importance for the water intake capacity of the soils, it is expected that geology is the major factor influencing infiltration and therefore also runoff. This can also be understood from the values in Table D.3 where the curve numbers for the gauged drainage basins are given together with the currently used slope index in Spain as defined by Heras (1972). This reasoning is valid since rainfall intensities usually are below the intake capacity of the soil.

The idea of distinguishing the runoff from each main type of geological formation meant solving a system of equations which had five unknown and a few redundant equations which were used for a final check on the results. Since the curve-number in itself is not a linear quantity, that is a direct physical property of the formations, the potential infiltration capacity associated with the curve number in the described method was used as the unknown to be solved. For those formations where no field data were available, potential infiltration capacities were estimated taking into account hydrogeological factors and the results are given in Table D.4 . The resulting curve numbers for the various hydrological zones are given in Figure D.7 .

Table D.4

Potential Infiltration for the main Geological Formations in Gran Canaria and their equivalent curve numbers

Geological formation	Potential infiltration as defined by the Curve-Number method mm	Equivalent Curve Number	Observations
Ancient Basalts	50	84	Estimated
Phonolites, Ignimbrites and the Trachy-syenite complex	22	92	
Roque Nublo Agglomerates	91	74	
Lower Roque Nublo	151	63	
Modern Basalts, lavaflows	265	49	
Modern Basalts, pyroclasts	175	59	Estimated
Landslide materials	31	89	
Alluvial materials	200-300	56-46	Estimated
Miocene sediments	75	77	Estimated

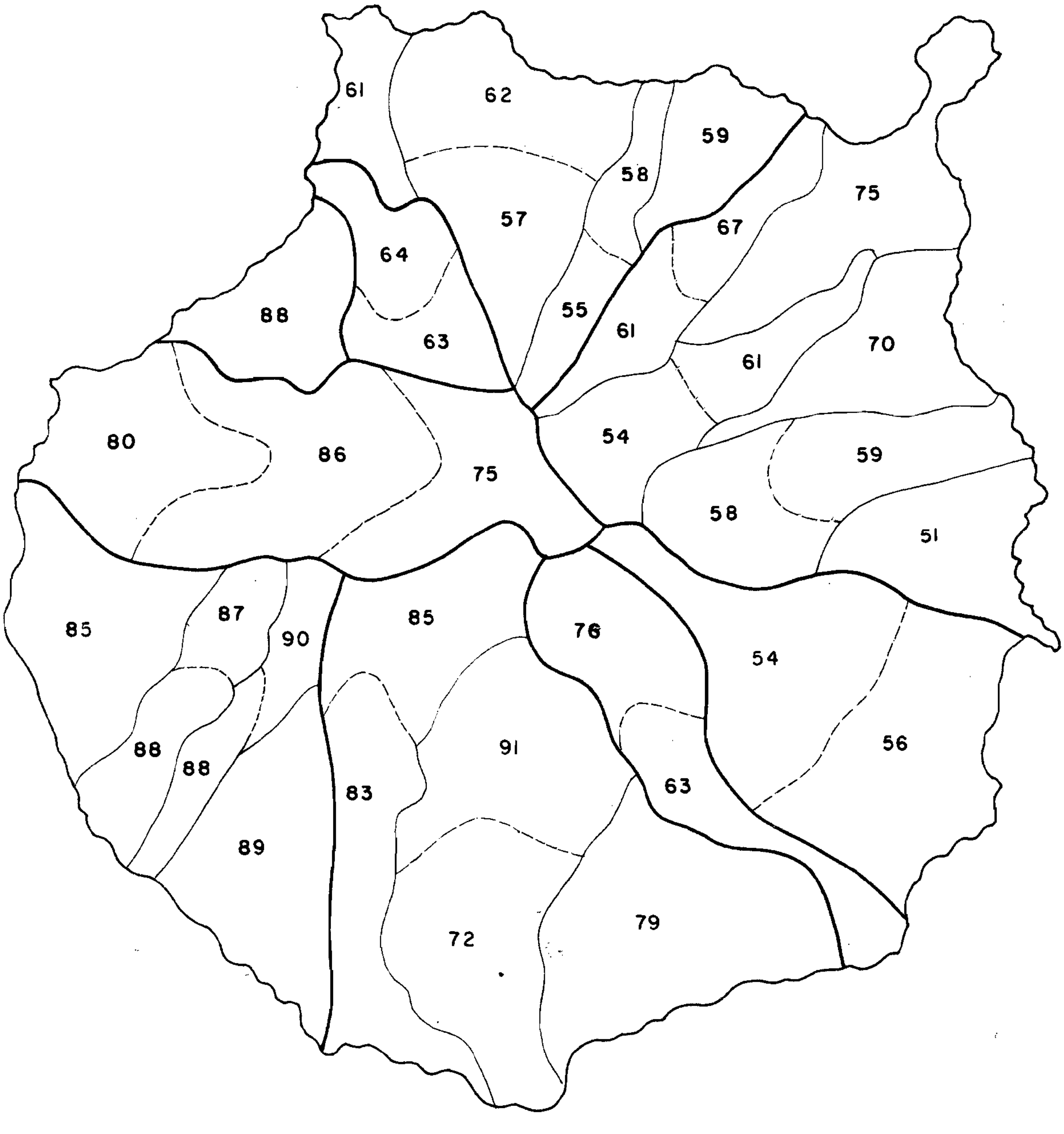


FIGURE D-7 ESTIMATED CURVE NUMBERS FOR
THE HYDROLOGICAL ZONES GRAN CANARIA

From the figures thus derived it can be concluded that as an average direct annual runoff is about 40 mm/year for the whole island. This figure indicates the amount of surface water that could be utilized if the collecting system was perfect. However, in many places, particularly in the lower reaches of the rivers, a considerable amount of stream percolation takes place, which will deduce the amount of available surface water but increase the groundwater resources.

3.4 Distribution and Variation of Runoff

Most runoff is produced in the high parts of the island due to the larger rainfall there. Therefore in the hydrological balance it has been attempted to treat those areas separately. During heavy rains runoff will occur also in the lower areas, but stream percolation will in many basins reduce the runoff in these parts. During normal years only relatively small quantities of runoff will occur in the northern part of the island.

Due to the particular characteristics of the geological formations and the thicker soils in the northern part of the island, direct runoff is normally quite small, about 10 mm for the lower areas and 20-30 mm for the higher areas. These figures apply to the area north of a line across the island from Agaete to Arinaga. To the south of this line the basins show higher runoff figures in spite of the relatively lower precipitation. In the lower zone the direct runoff is in the order of 40 mm for a normal year, and in the higher zone this figure according to the theoretical calculations may amount to 150-175 mm. It should be pointed out that these results are based on estimated values to a larger extent than for other areas in the island. Stream percolation is also quite high in the lower reaches of the southern rivers and hence the difference between the unadjusted values and the actual runoff is large.

3.3 Estimation of the unadjusted Annual Runoff

It should first of all be pointed out that the method used for estimating runoff from geology and daily rainfall figures is very rough. Since the results are derived from very few basic data of reasonable quality, it should be kept in mind that the figures given for runoff in this report are only indicative. The calculated runoff figures have been contrasted with the other terms of the balance and with the real behaviour of the drainage basins, mostly through qualitative data. It is therefore believed that they are reasonably valid as a total for the island, but individual values might differ considerably from reality, especially in areas and geological formations where no gauging stations are available.

The runoff figures refer only to natural conditions, without taking into account water collection in dams and other derivations of surface water, and stream percolation is not considered at this stage since the basic data for the gauged basins do not include those factors.

In the detailed water balance carried out for the three hydrological years 1970/71, 1971/72 and 1972/73, the last two years have had rainfall very close to the estimated median precipitation of 300 mm /year. It would therefore seem reasonable to base the estimate of the median runoff on the results obtained in the detailed water balance for those two years. Furthermore, the quality of the presently available rainfall and runoff records does not justify a detailed calculation of runoff based on the curve number method for the whole island for the total period of records until these records have been verified and corrected. In order to provide a check on the magnitude of the figures for average annual runoff derived from the detailed water balance, a calculation of the runoff has been performed for a number of years for some of the hydrological subzones.

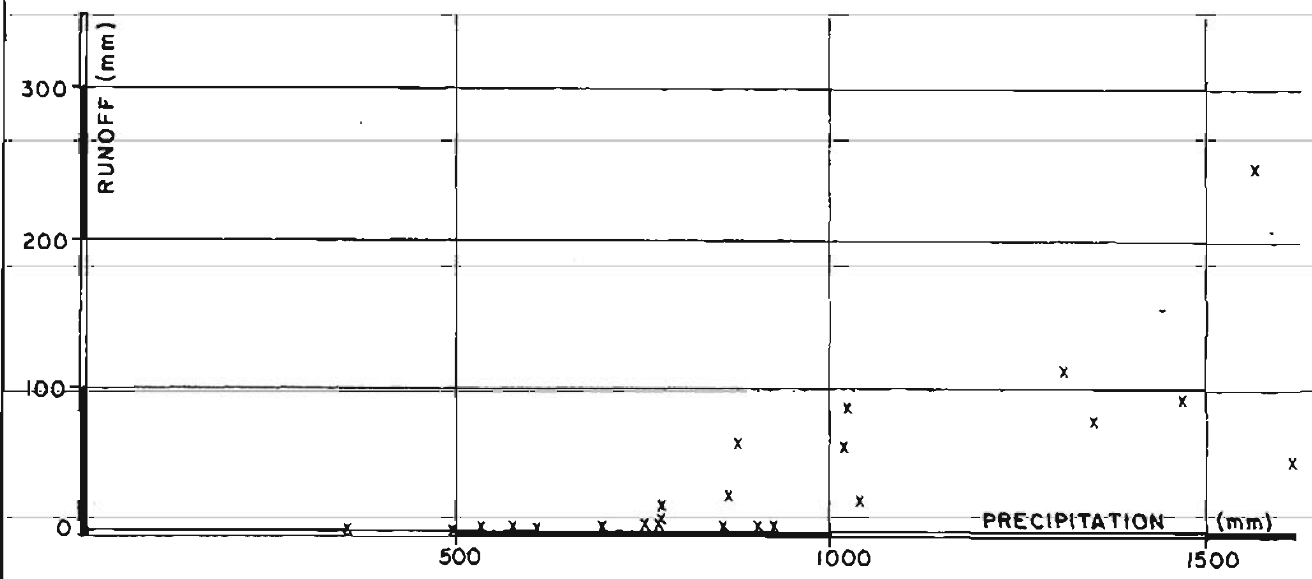
A detailed study of floods falls outside of the scope of this report. It should only be mentioned that because of the heavy rains and the steep slopes of the rivers, runoff is torrential and may cause severe damages. Concentration times are very short and base flow zero, which means that the flow resulting from a rainstorm will occur in a very short time. This will lead to costly designs for structures to be built in the rivers.

The runoff will vary very much between the years and especially in the northern part of the island it would not be uncommon to have years virtually without runoff. For the utilization of the surface-water resources it is imperative to keep this fact in mind so that the water management allows carry-over of water from one year to another. As examples of these variations the runoff in the higher parts of the Azuaje basin and the Tirajana basin in the northern and the southern parts of the island respectively, has been calculated and is shown in Figure D.8 . The poor relationship between the annual figures for rainfall and runoff is more noticeable for the northern basin because of its lower curve-number. The variations of calculated runoff for a 24 year period represented by the accumulated deviation from the mean value, Fig. D.9 are so large that if evaporation is disregarded, the necessary storage capacity would have to be 9 times the average annual runoff in this particular northern basin and 5 times in the southern basin. It can therefore safely be concluded that already for a modest utilization of surface water the necessary storage capacity will be quite large in order to guarantee the desired discharge because of these annual variations in runoff.

3.5 Stream Percolation

For natural conditions stream percolation has been estimated based mainly on qualitative information. From the calculations carried out for the water balance, it can be concluded that the potential stream percolation is between 15 and 20 mm for a normal year: that is, almost half of the average normal runoff. For larger runoff, stream percolation will not

RELATIONSHIP RAINFALL-CALCULATED RUNOFF
AZUAJE BASIN (UPPER PART) 1949/50-1972/73



RELATIONSHIP RAINFALL-CALCULATED RUNOFF
TIRAJANA BASIN (UPPER PART) 1949/50-1972/73

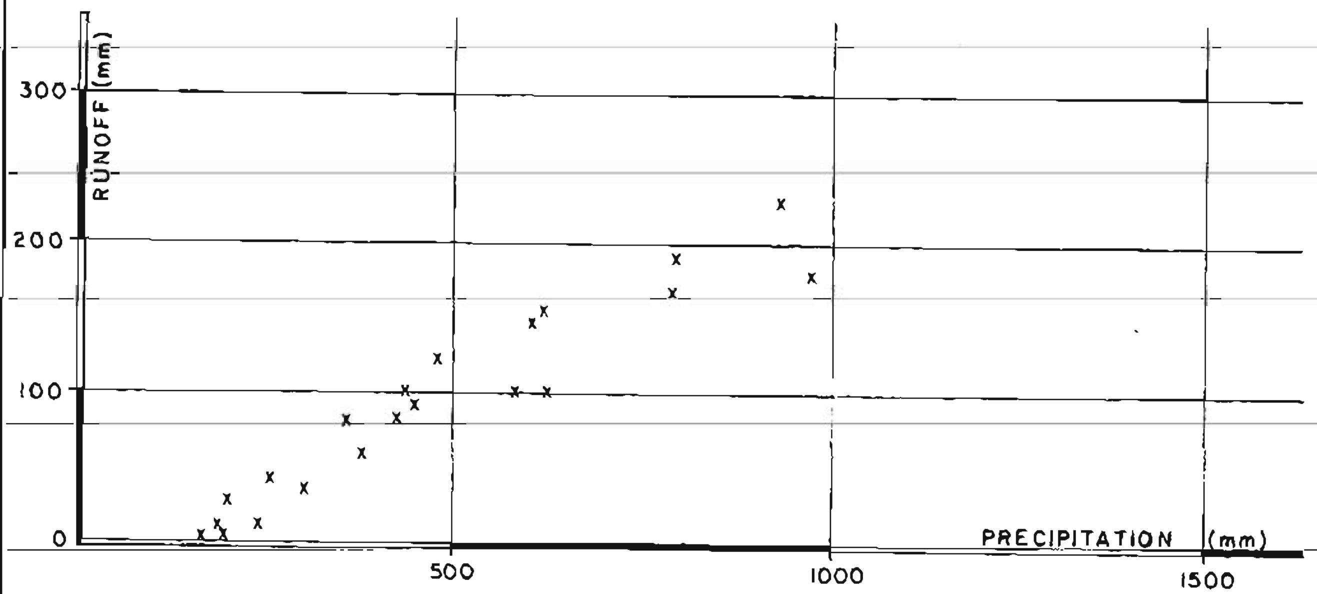


FIGURE D-8 RELATIONSHIP BETWEEN RAINFALL AND CALCULATED RUNOFF FOR 2 BASINS GRAN CANARIA.

increase very much and for smaller annual runoff it will most likely account for a larger part of the annual runoff. Stream percolation occurs mainly in the rivers in the southern part of the island.

Presently a large part of the runoff is collected by surface - water reservoirs and diversion structures before stream percolation occurs, which will to a large extent reduce the figure of actually infiltrated water in the river beds.

4. Evapotranspiration and Evaporation

No direct measurements of evapotranspiration exist in the Canarian archipelago, although irrigated agriculture plays a very important role for the economy of the islands and water is in short supply. Evaporation is measured at a few recently installed stations with the US Weather Bureau Class A pans, and some indication is given at other stations with atmometers of the Piché type.

The potential evapotranspiration is the amount of water that would be lost to the atmosphere by the vegetation and the soil if the demand of water was satisfied at all times. Since this is not the case under the existing climatic conditions, the real evapotranspiration is less than the potential evapotranspiration. Both terms include the water lost through transpiration of the vegetation and evaporation from the soil. These terms, lacking actual measurements, thus have to be estimated, mainly by means of a comparison with evaporation data and from theoretical evapotranspiration formulae based on measurements in other parts of the world.

Three stations have sufficient data to permit the calculation of evaporation according to Penman for a long period of time. The relationship between Penman's open water evaporation and the potential evapotranspiration is not yet established for the Canary Islands. Taking into account the relatively small seasonal changes in the archipelago, it is assumed that a factor of 0.75 should be applied throughout the year to the theoretical evaporation values in order to give the potential evapotranspiration for the vegetation of Gran Canaria.

It has been shown (American Society of Agronomy, 1967) that the correlation of potential evapotranspiration to pan evaporation for monthly values is relatively high. In accordance with measurements in many parts of the world and taking into consideration the type of natural vegetation in the island a factor of 0.75 has been chosen for the adjustment of the pan evaporation.

The potential evaporation for the 6 stations with complete data for the hydrologic year 1971/72 according to the Penman calculations and the Class A pan measurements is shown in Table D.5. This year can be considered as an average year.

4.1 Evaluation of Potential Evapotranspiration for island

In order to determine the potential evapotranspiration for the whole island, it is necessary to extrapolate the data to areas with different characteristics.

The only meteorological parameter that is measured reasonably well over the island is temperature (daily minimum and maximum). It is measured at 25 stations, most of them in the northern and central parts of the island. At 17 stations atmometer observations (Piché) are taken and also at 17 stations relative humidity is measured.

The quality of these data at the 6 main stations is sufficiently reliable but at the other stations the quality is low, and Piché evaporation or relative humidity should not be used for extrapolation of monthly evapotranspiration.

Table.D.5

Evaporation Data for 6 stations

in Gran Canaria 1971-1972

	S	O	N	D	J	F	M	A	M	J	J	A	Total
LAS PALMAS													
Penman	144	124	108	70	80	102	120	135	152	137	149	162	1483
Blaney-Criddle	160	128	128	118	119	111	133	141	156	159	172	175	1728
Thornthwaite	112	115	79	55	54	50	59	67	77	86	106	125	986
GANDO													
Penman	168	168	145	79	96	117	137	177	228	219	266	248	2048
Blaney-Criddle	154	152	125	117	117	110	132	142	157	162	174	170	1712
Thornthwaite	100	110	67	50	48	44	53	63	73	88	106	111	913
GUIA													
Penman	134	125	91	68	61	92	109	131	141	126	158	187	1423
Blaney-Criddle	149	150	128	117	114	114	132	138	157	162	170	170	1701
Thornthwaite	91	98	73	50	44	53	55	58	74	87	100	111	894
SANTA BRIGIDA													
lass-A pan	166	145	71	42	42	54	66	94	109	110	161	142	1152
Blaney-Criddle	144	148	115	103	104	100	117	128	145	148	162	159	1573
Thornthwaite	88	101	65	48	46	46	53	64	78	85	103	106	883
CAIDERO													
Class-A pan	203	238	141	94	100	112	121	182	231	231	252	245	2150
Blaney-Criddle	159	162	129	117	118	112	132	143	160	162	174	170	1738
Thornthwaite	112	130	70	47	46	42	47	61	74	84	106	108	927
CHIRA													
Class-A pan	183	202	104	61	68	87	93	158	223	203	261	240	1883
Blaney-Criddle	142	142	104	93	95	90	108	125	147	146	170	163	1525
Thornthwaite	88	94	43	29	30	28	34	51	74	75	113	111	770

Two commonly used methods for estimating potential evapotranspiration using temperature data are those of Thornthwaite (1948) and Blaney-Criddle (1960). For the year 1971/72, potential evapotranspiration has been calculated with these two methods for the 6 main stations. For Blaney-Criddle a consumptive use factor K = 1 was assumed for the calculations and the results are shown in Table D.5 .

When comparing with the pan and Penman evaporations it is obvious that the Blaney-Criddle method in this case is superior to the Thornthwaite method which is logical since it is based largely on experience in arid or semi-arid areas.

Extrapolation of the potential evapotranspiration was done by comparing the Blaney-Criddle method with the Penman calculation or the pan measurements, as the case might be, for the six main stations and by obtaining for each month a modified consumptive use coefficient F. This will represent for each station all the climatological factors that have influenced evaporation expressed as follows:

$$F = \frac{0.75 \text{ Epan or Penman}}{k.p.\ (0.46\ t + 8.1)}$$

where

F= modified consumptive use coefficient

E= measured or calculated evaporation in mm

k= consumptive use coefficient, in this case k = 1

p= monthly percentage of yearly sunshine hours

t= temperature in °C

For the calculation of the potential evapotranspiration the Blaney-Criddle method was used for each of the 36 studied areas, together with the F-value calculated for the closest main station which has similar climatological characteristics, according to the following formula:

$$ETp = F.p\ (0.46\ t + 8.1)$$

where

ETp = potential evapotranspiration in mm

A generalized map for annual potential evapotranspiration for natural conditions in Gran Canaria is shown in Figure D.10 . These values are based on a very short period of records, but are believed to be representative since the variations in the meteorological parameters between the years are not likely to be of such a magnitude that they will significantly change the results.

Potential evapotranspiration is higher in the southern part of the island than in the northern part, due to the higher temperatures and the more abundant sunshine. In the eastern part of the island the strong winds will also increase the potential evapotranspiration. Generally the potential evapotranspiration is higher than the average annual precipitation , which means that irrigation is necessary for perennial crops and for those annual crops cultivated during dry season.

The monthly variations in potential evapotranspiration are considerable. The class A pan measurements show that evaporation in the 6 months period, November through April, is only about half of the evaporation for the period May through October.

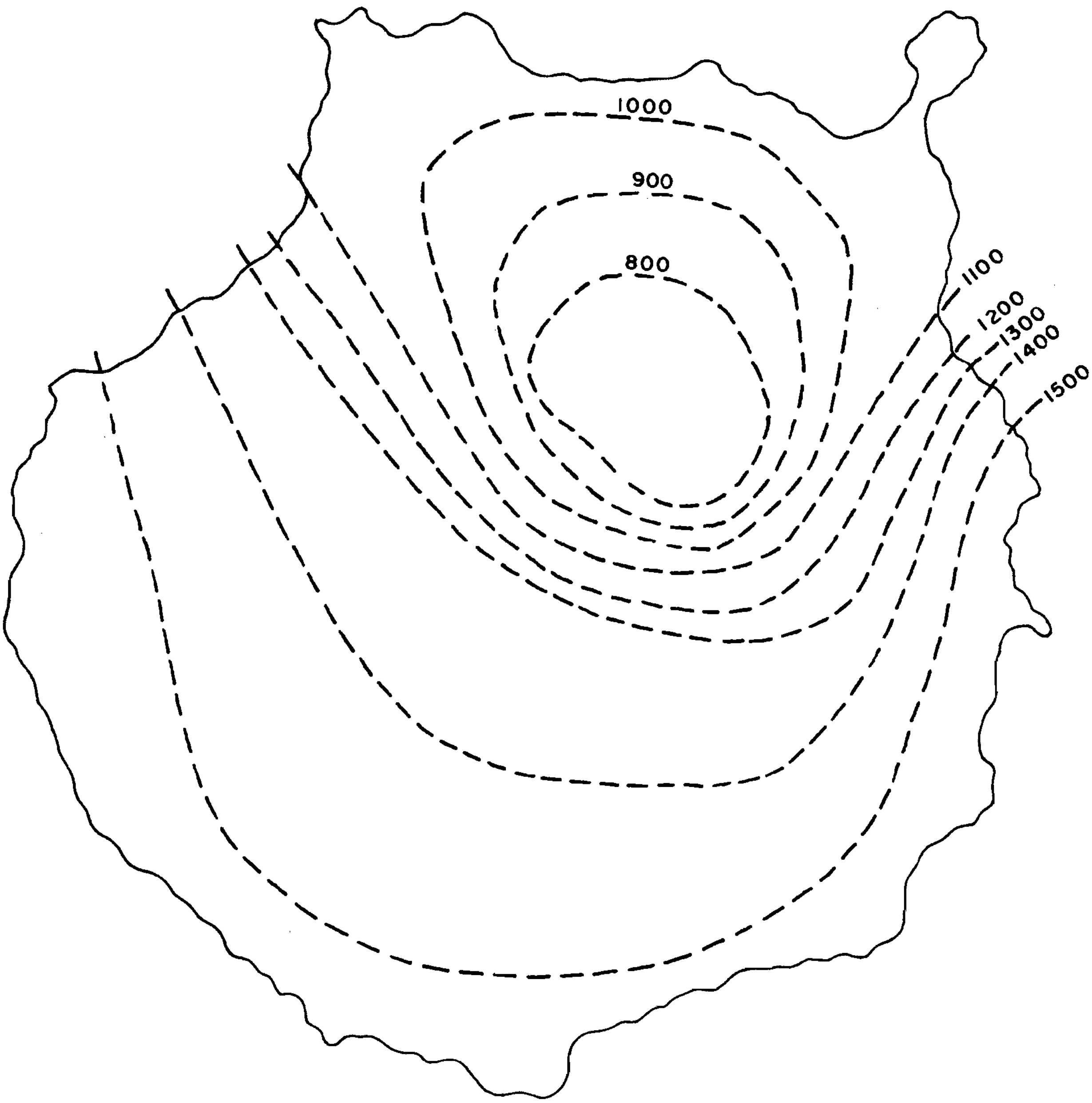


FIGURE D-10 ANNUAL POTENTIAL EVAPOTRANSPIRATION

GRAN CANARIA

Note: values in m/m year

4.2 Soil Moisture Retention Capacity

The real evapotranspiration is smaller than the potential evapotranspiration since the soil moisture is not always high enough to support the full rate of transpiration of the plants and evaporation of the soils. Therefore an evaluation of the real evapotranspiration needs a study of the soils. Since no soil maps and land-use maps are available for Gran Canaria, the water retention capacity for all the hydrological zones in the island was estimated using aerial photographs in scale 1:16000. Vegetation type, root zone, soil depth and soil type were estimated after field check and the retention capacity was calculated based on estimated values available moisture for each soil texture, according to Israelsen and Hansen (1962). The resulting retention capacity is shown in Fig D.11, from which it can be seen that the estimated water holding capacity varies between 40 and 120 mm in Gran Canaria.

4.3 Real Evapotranspiration

Several methods exist that permit an evaluation of real evapotranspiration based on the potential evapotranspiration once the water holding capacity of the soil is known. For this study the method derived by Thornthwaite and Mather (1955) has been used. This method assumes a linear relationship between the rates of the real and the potential evapotranspiration of the type shown in Figure D.12 .

The real evapotranspiration ET has been calculated for each of the hydrologic zones for a three-year period, assuming that the monthly potential evapotranspiration ETp is evenly distributed on the days of the month. For each day it is assumed that the precipitation minus runoff will enter the soil and replenish the soil moisture until the retention capacity is reached. The surplus of soil moisture over field capacity will infiltrate

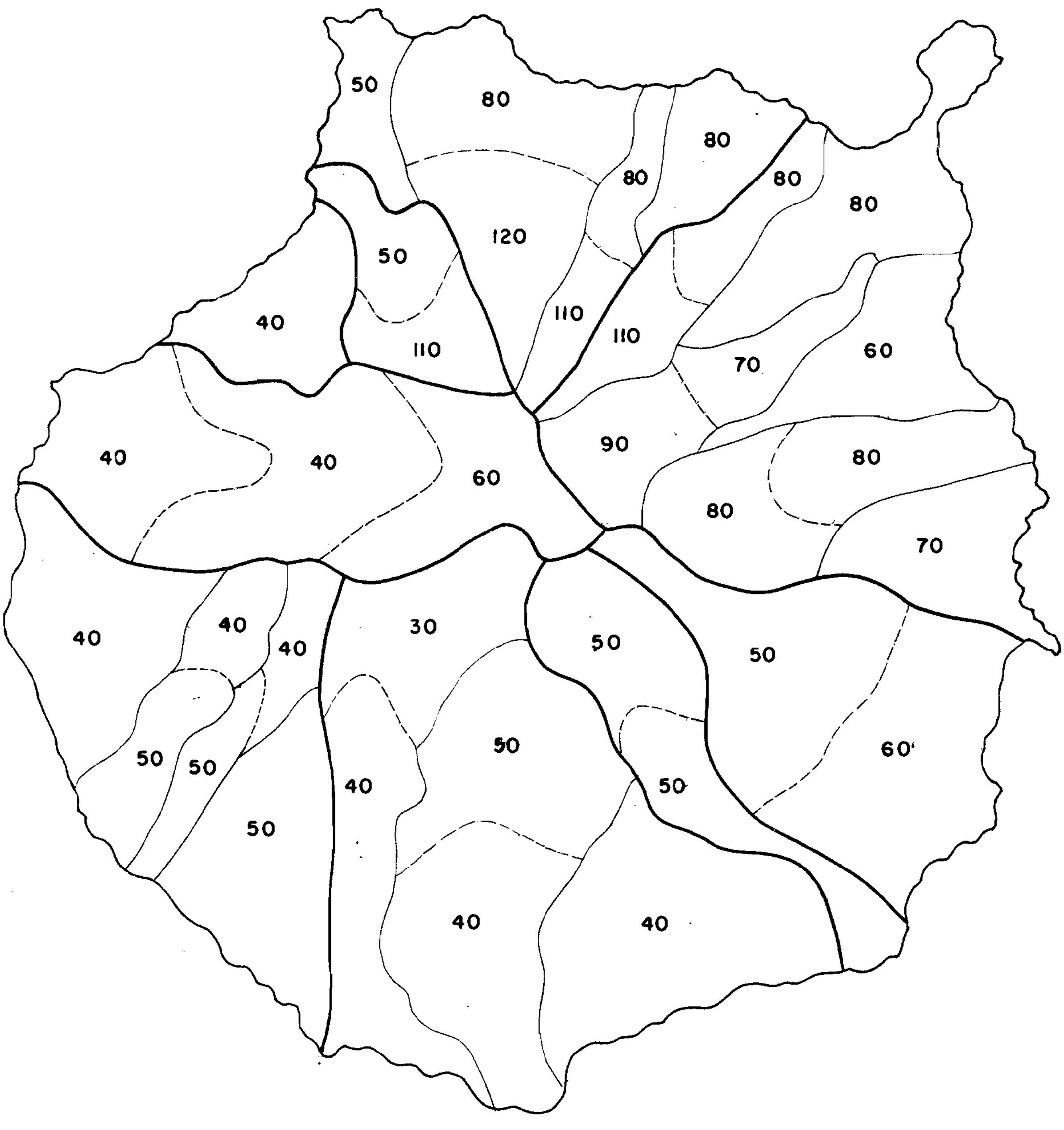
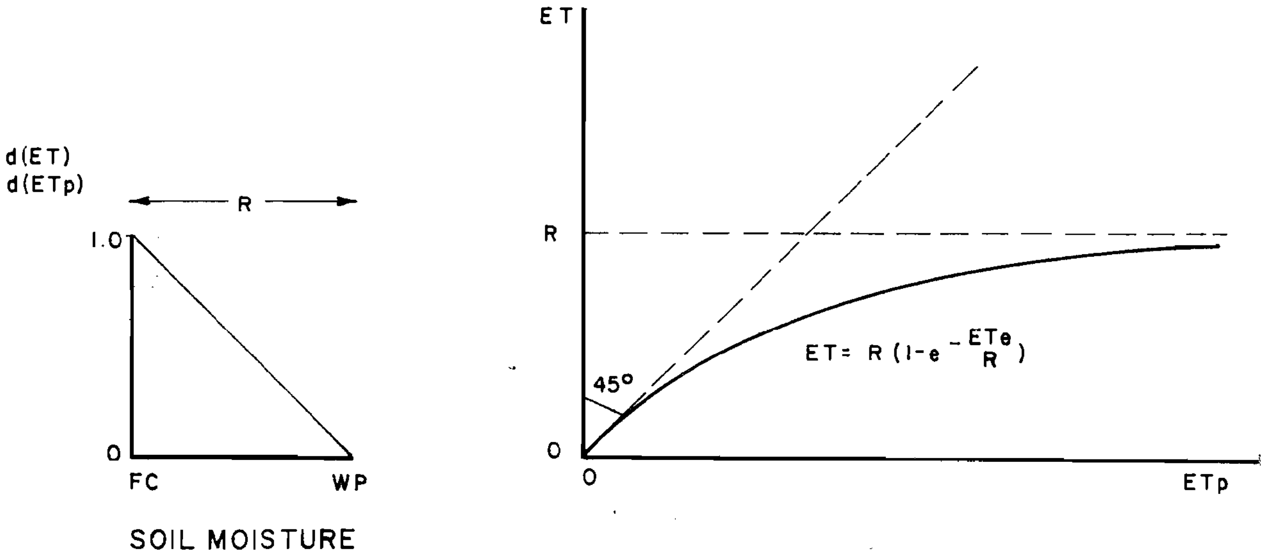


FIGURE D-II ESTIMATED SOIL MOISTURE RETENTION CAPACITY GRAN CANARIA

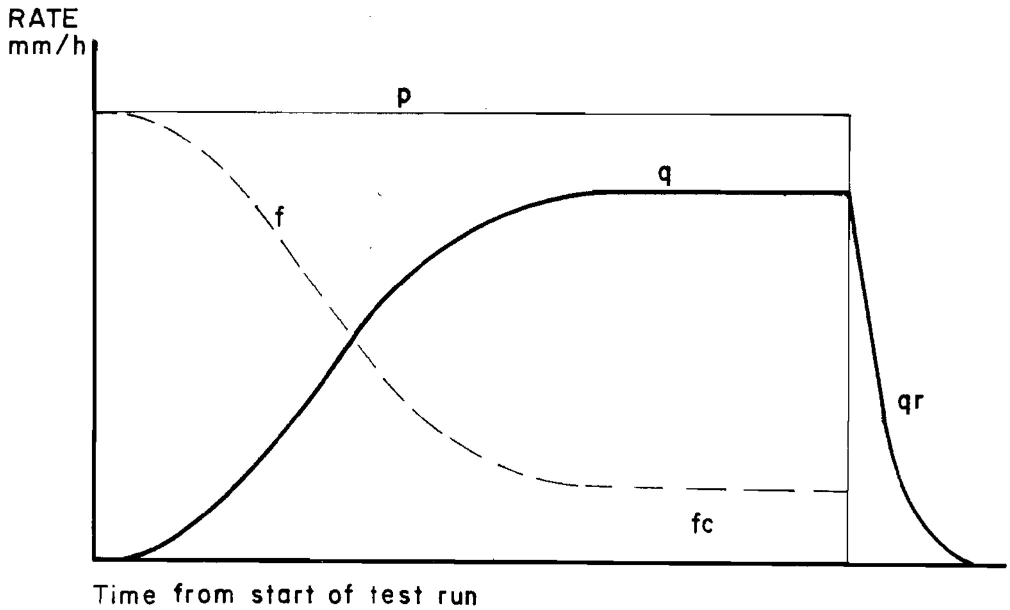
Note: values in m/m.

FIGURE D-12 RELATIONSHIP BETWEEN REAL AND POTENTIAL EVAPOTRANSPIRATION



ET = REAL EVAPOTRANSPIRATION
ETp = POTENTIAL EVAPOTRANSPIRATION
FC = FIELD CAPACITY
WP = WILTING POINT
R = RETENTION CAPACITY = FC-WP

FIGURE D-14 PRINCIPLES FOR MEASUREMENT OF INFILTRATION CAPACITY



p = RAINFALL INTENSITY
q = RUNOFF INTENSITY DURING TEST
qr = RUNOFF INTENSITY DURING RECESSION
f = INFILTRATION RATE
fc = FINAL CONSTANT INFILTRATION RATE

to deeper layers and enter the groundwater system. For each day ET is then calculated based on the relationship demonstrated in Figure D.12.

As an example has been calculated the real evapotranspiration for the year 1971/72 for one area in the northern higher part and another in the southern lower part of the island, with retention capacities of 110 mm and 40 mm respectively. The results are given in Table D.6 , which shows the big difference between the northern and the southern parts of the island and the influence of the dry and wet seasons. From all the cal - culatons it has been noticed that the real evapotranspiration depends more on the amount of rainfall and its distribution than on the potential evapo - transpiration, due to the large difference between potential evapotranspiration and precipitation during a considerable part of the year.

The influence of the retention capacity is not shown in the examples in Table D.6 , but a number of calculations carried out show that an increase of the retention capacity will be accompanied by an approximately equal increase in the real evapotranspiration in the northern area, whereas in the southern lower areas without recharge an increased retention capacity does not have any big influence.

The average real evapotranspiration for the whole island is es - timated at about 200 mm/year, with a maximum in the north central part of the island with 450 mm/year, and a minimum in the southern lower parts wit 100 mm/year. The figures calculated for the water balance, discussed else - where in this report, show that the increase in the real evapotranspiration is not very large even for a very wet year, for which instead runoff and infiltration will increase more notably.

Table T.6

Calculation of Real Evapotranspiration

for two zones Gran Canaria 1971-72

Months	S	O	N	D	J	F	M	A	M	J	J	A	Total
Northern higher zone													
P	10	0	148	53	162	166	129	65	14	9	0	16	772
ETp	82	90	49	33	31	44	52	72	84	80	116	113	846
ET	15	5	33	32	30	44	50	65	53	30	18	13	388
Southern lower zone													
P	11	0	45	0	0	46	3	0	0	0	0	0	105
ETp	122	122	105	58	70	84	99	126	164	158	193	181	1485
ET	4	7	26	11	4	28	16	2	0	0	0	0	98

Note: All values in mm.

4.4 Free Evaporation and Evapotranspiration from Irrigated Crops

Evaporation from a free water surface is approximately equal to the potential evapotranspiration shown in the generalized map , Fig D.10 , and would be about 1400 mm/year and 900 mm/year for the reservoirs in the southern and northern parts of the island, respectively. This high figure means that for a small basin and a big reservoir a considerable part of the average inflow will be lost through evaporation.

The principal irrigated crops in the island are bananas found mainly in the northern part, and tomatoes in the southern and southeastern part. Lately there has been a change in the cropping pattern so that an increased acreage is devoted to greenhouses, where vegetables and flowers are grown. In order to calculate the consumptive use of water for the main field crops, a consumptive use coefficient of 0.9 has been assumed for bananas and 0.7 for tomatoes to be applied to the Penman evaporation at the meteorological stations in Guía and Gando which are believed to be typical for the area where these crops are grown.

Bananas are cultivated throughout the year , whereas tomatoes have a growing season of about 5 months, starting in August for the early tomatoes and March as the end of the irrigation season for the late tomatoes. The consumptive use for tomatoes as an average for the growing season would then be about 370 mm for the northern and 530 mm for the southern areas , and for bananas about 1300 and 1900 mm respectively, see Table D.7.

Very few figures seem to be available for the consumptive use of greenhouse crops, but it is felt that this system of cultivating will considerably reduce the necessary amount of irrigation water. "Consejo Económico Sindical" (1967) indicates that gross demand for peppers, cucumbers and tomatoes in greenhouses is about 450 mm per vegetation cycle, which is about half of the demand for these crops on open fields. The hydroponic system of irrigation in greenhouses reportedly may reduce the consumption of water to about 20 mm/month.

5. Infiltration and Recharge

5.1 Determination of Infiltration Capacity

Two different methods have been used for field determinations of the infiltration capacity of the natural soils in Gran Canaria, i.e. the ordinary infiltrometer method and the artificial rainfall method.

The infiltrometer consisting of two concentric rings can only be used in flat areas or terrains with very little slope. Such terrains are rare under natural conditions and generally occur only as man-made soils on terraces and in the banana plantations.

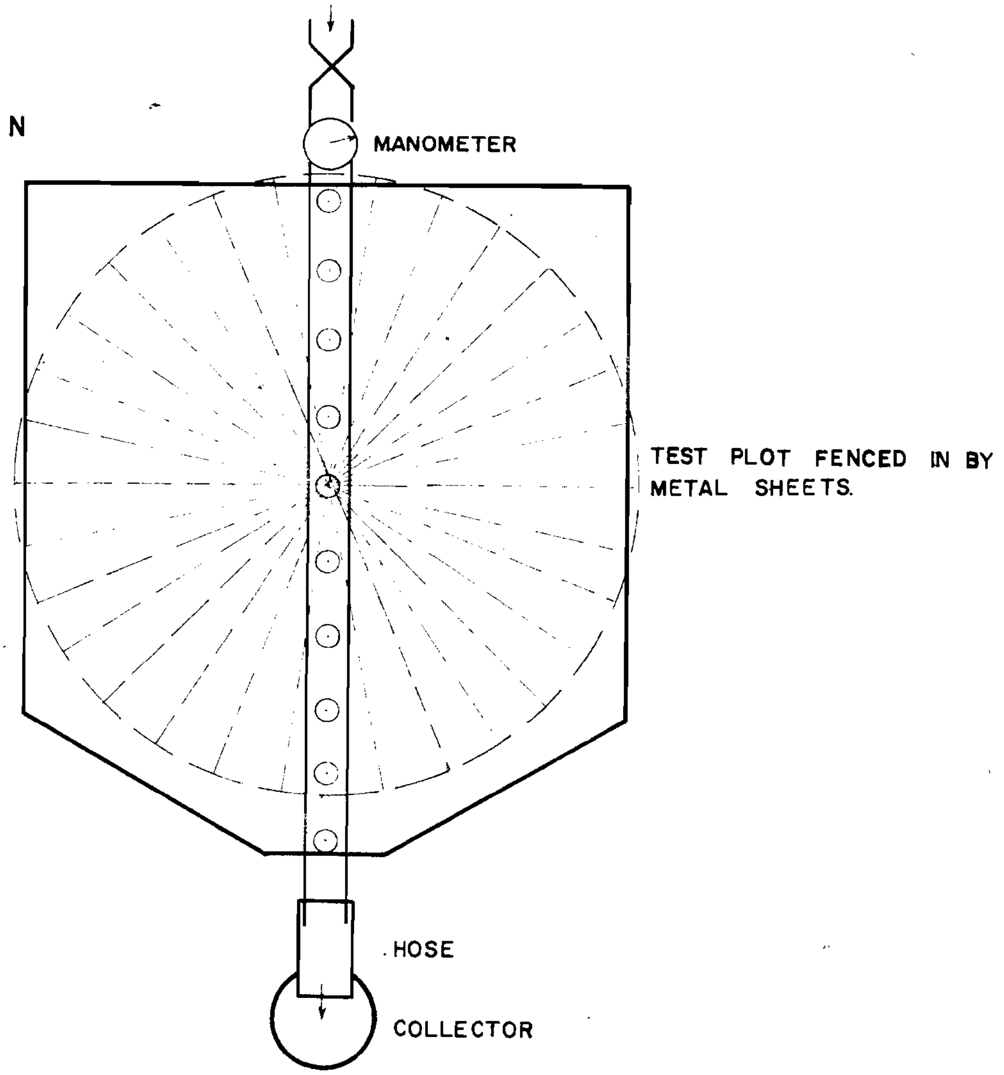
One ring test carried out in a Phonolyte area indicated an infiltration capacity of 30 mm/h. The 5 tests in areas of Modern Basalts gave values between 50 and 160 mm/h.

In order to measure the infiltration of the soil on slopes, a rain simulator was designed that consisted of a row of sprinklers operating at a pressure of 0.2 - 0.5 atm., at a height of 80-100 cm above the soil, as shown in Figure D.13 . The normal size of the test plot was about 1.50 meters wide and 3.00 meters long. The precipitation intensities could vary between 40 and 135 mm/hour, depending on the pressure and the number of sprinklers operating, but was kept constant during each test. The precipitation was measured in 12 points within the plot. Its distribution was reasonably uniform The runoff from the plot was measured volumetrically at time intervals varying from 1 to 5 minutes. The infiltration was calculated as the difference between precipitation and runoff from the test plot as is indicated in Figure D.14 .

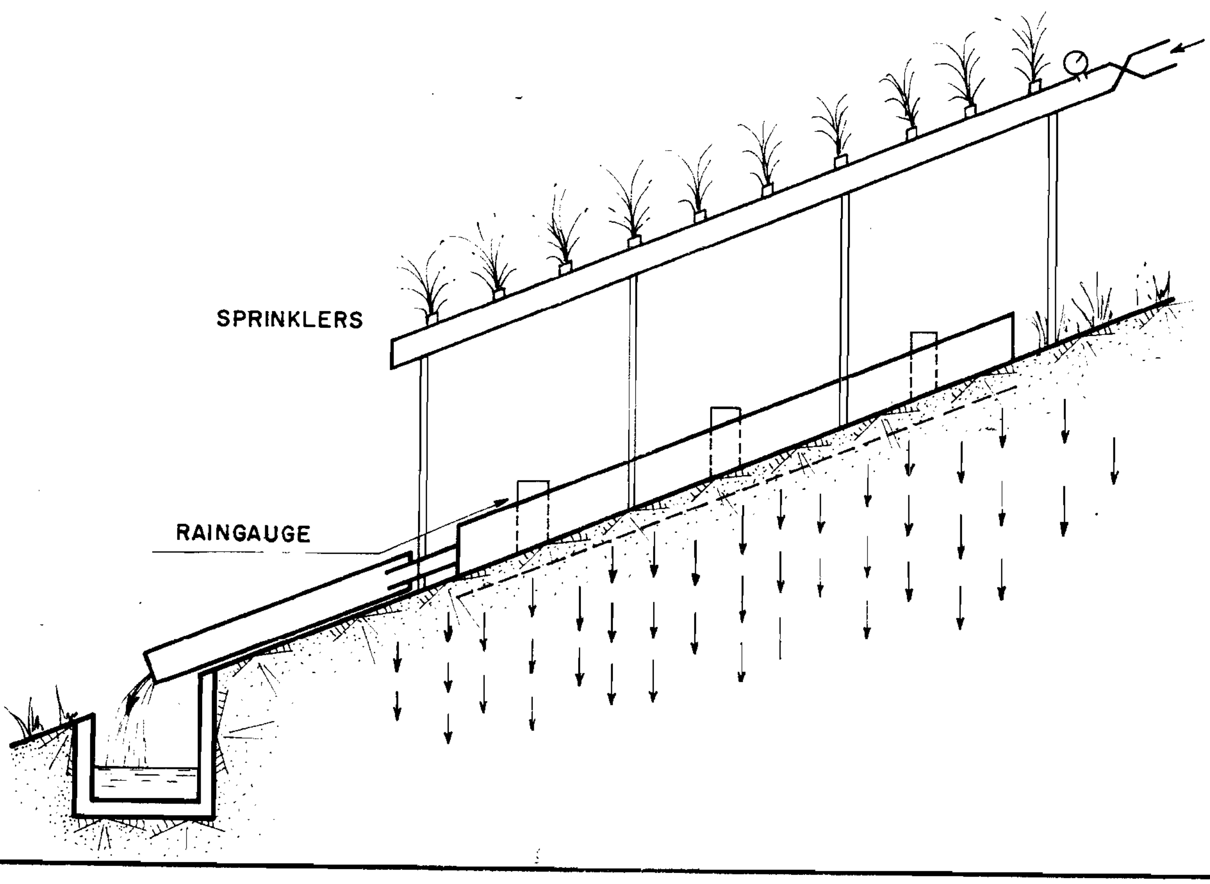
Altogether 16 rain simulator tests were carried out on soils with slopes varying between 20 and 60%, and under natural vegetation consisting of shrubs and grass.

FIGURE D-13 INFILTRATION DEVICES WITH RAIN SIMULATORS

PLAN



SECTION



Soil depths varied between 20 cm and 200 cm. Also these tests showed very high infiltration rates especially in the Modern Basalts varying from 40 mm/hour to more than 100 mm/hour. The tests carried out in the Phonolytes and Trachy-Syenites showed considerably lower infiltration rates in the order of 25 mm/hour. From the results it can be concluded that slope has little influence on the intake infiltration rate of the soils.

Taking into account that the rainfall intensities are normally lower than the measured infiltration rates, it is concluded that generally all precipitation infiltrates and that runoff on terrains with a soil cover occurs as subsurface runoff.

An indirect method of determining the infiltration capacity of different types of soils is available since the curve-number method as discussed previously is based on the infiltration characteristics in the basins. The pertinent results for the potential storm infiltration capacity as indicated by the curve-number method are given in Table D.4. This table shows the same tendency as the field tests, i.e. a high infiltration capacity in the Modern Basalts and considerably lower values in the Phonolytes and similar formations.

5.2 Calculation of Recharge

The recharge of water to the groundwater body, as defined by the surface-water balance, has another significance than the infiltration in the infiltrometer tests and the curve-number method. In the infiltrometer the intake rate of the soil is measured. The sub-surface runoff is included in the infiltration rate. With the curve-number method the difference between rainfall and runoff is calculated, with runoff including the subsurface part. In the water balance, recharge is the difference between the losses on the one hand through evapotranspiration, replenishment of the soil moisture to the field capacity and the other hand the rainfall.

From the water balance it can be concluded that average annual recharge to the groundwater body from precipitation is about 60 mm. In the higher parts of the northern area recharge from precipitation exceeds 400 mm/year, and in the coastal areas it is about zero. In the southern area it varies from about 300 mm, in the higher parts to zero in the coasta belt. A gereralized map of recharge from precipitation is shown in Figure D.15.

5.3 Stream Percolation

Another source of recharge is the stream percolation, which occur in the lower parts of the rivers where the bed consists of alluvial deposit

In the higher parts of the zones used for the water balance strea percolation is not significant and the curve-number for the higher zones can be considered to take into account also the stream percolation of the scarce alluvial deposits found in the river beds.

Because of the absence of measured flow data in the lower parts of the rivers, stream percolation has been estimated based mainly on qualitative data and as such should be considered less accurate and should be subject to revision when measured data are available.

Visual observations as well as verifications in the field if the runoff ever reached the sea for certain storms, have indicated that stream percolation is relatively unimportant in the northern part of the island, but in the southern rivers it is of such magnitude that it will significantly change the relationship between groundwater and surface water. This is also evidenced by the existence of a large number of wells situated along the alluvial valleys in the southern part of the island.

The evaluation of the stream percolation is also distorted by th existence of reservoirs and diversion structures in the rivers, influencing runoff. Based on the results from the water balance it can be esti -

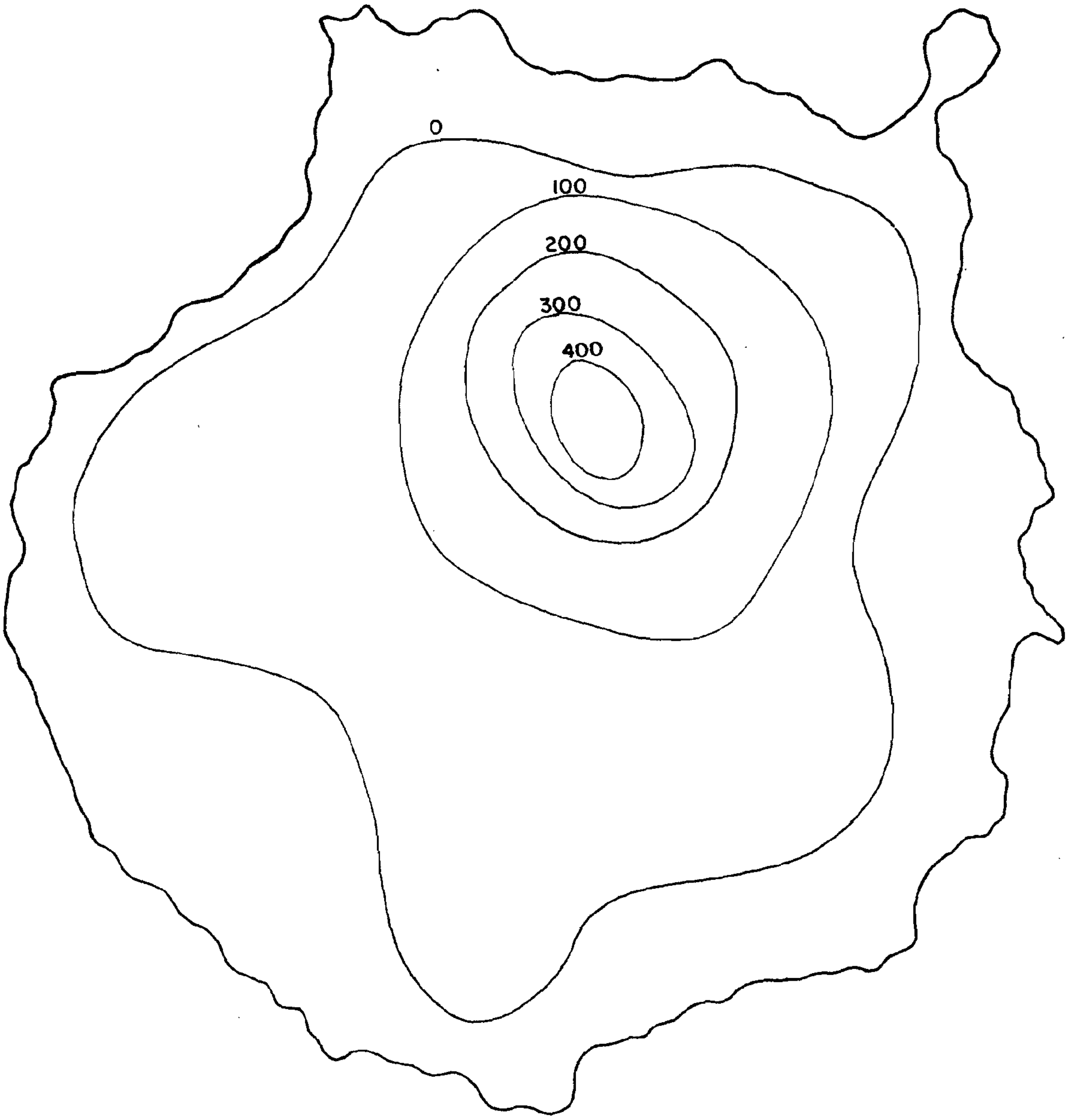


FIGURE D-15 ANNUAL ESTIMATED RECHARGE FROM PRECIPITATION GRAN CANARIA

Note: values in mm.

mated that the potential stream percolation amounts to about 5 mm in the northern part of the island, and about 30 mm in the southern part. Diversions of surface water above the limit of stream percolation will automatically reduce this loss considerably.

If we add the percolation loss to the recharge from precipitation, the total recharge to the groundwater body in a normal year is about 70 mm for the entire island.

5.4 Recharge from Irrigation

From the irrigated areas, some of the water that is not used by the crop will reinfiltrate and recharge the groundwater body. At least in localized areas this quantity of return flow is important as has been evidenced by the study of the chemical composition of the groundwater. Assuming a use of 160 Mm^3/year for irrigation as is stated in the third development plan (Comisaría del Plan de Desarrollo, 1972), a gross delivery efficiency of 65 percent (a value that is probably quite high), and further assuming that two-thirds of the losses return to the groundwater body, recharge from irrigation operations would be about 36 Mm^3/year for the entire island, a volume equivalent to a uniform depth of about 23 mm. The irrigated area is about 12,500 ha which means that in these areas as an average 290 mm/year is recharged. Due to the coastal location of most of the irrigated areas, a large part of this recharge will be rapidly lost to the sea.

6. Development of Additional Supplies

The development of additional surface water supplies would involve both recuperation of existing untapped resources in localized areas, and rationalization of the available resources. At this stage of investigation only general ideas can be advanced, as all future designing needs to be substantiated by more field measurements.

6.1 Surface Storage and Derivations

Present storage capacity in the island in large dams, that is dams with walls higher than 15 m, is about 80 Mm^3, Table D.8, out of which about 12.5 Mm^3 together with about 5 Mm^3 in smaller reservoirs are located in the northern part of the island. Out of the total storage capacity of 67.5 Mm^3, the southern part accounts for 40 Mm^3 and will most likely never be completely filled, but will enable storage of water over many years in order to form a reserve. Considering that for a normal year the runoff of the higher parts of the northern slope is about 20 Mm^3 and the fact that the distribution of the dams and all the small reservoirs in this region makes the water collection relatively more efficient, it might be concluded that only marginal quantities of additional water can be collected there during a normal year. A higher degree of carry-over between years, which is desirable, would make necessary an increased storage capacity.

In the southern part of the island it appears from a comparison between the surface-water balance and present storage capacity that the surface-water resources of about 35 Mm^3 in the higher parts are still underutilized also in a normal year. A programme should therefore be initiated as soon as possible with the objective of studying the southern rivers in more detail. It should be kept in mind that because of the high stream percolation the "excess" water is not necessarily lost to the sea, since much of it will be collected by wells in the lower reaches of the rivers. However, a system of surface-water collection will generally operate with smaller losses than the groundwater collection system, and a comparative

Table D.8

Large Dams in Gran Canaria 1.973

ZONE	NUMBER OF DAMS	CAPACITY Mm^3	OBSERVATIONS
1 a	1	0.168	
1 b	10	2.167	
1 d	9	2.015	
2 a	3	0.871	
2 b north	5	1.846	
2 b south	4	0.525	
2 c	5	0.488	
2 d	2	0.514	
4	1	3.000	
5	5	4.075	
6	4	9.167	
7 c	1	0.100	
8 a	4	49.540	Soria dam 40.289
8 b	4	4.700	
9	1	0.364	
TOTAL	59	79.540	

study could be undertaken. The existing wells would then collect only recharged precipitation and the percolated stream water from the lower parts of the drainage basins.

It should be again emphasized that the conclusion about the southern rivers is mainly based on theoretically derived data and qualitative observations and therefore is subject to revision once quantitative data are available.

In the western part of the island too, there could be possibilities of obtaining additional supplies especially in the basin drained by Bco. Risco, corresponding to hydrological zone 9. It will be difficult to imagine storage in dams as possibilities seem to be inexistent, but diversion devices can be designed for recuperation of quantities lost to sea at present.

6.2 Induced Infiltration

A possible method of gaining additional water would be to infiltrate excess runoff, which otherwise would be lost to the sea, particularly in the southern part of the island. The method may be feasible only during wet years because the high potential stream percolation in the southern rivers will prevent during normal years any water from being lost to the ocean as surface runoff. Before any such scheme is contemplated, an adequate system should be designed and put into operation for collecting the subsurface water that presently is being lost to the sea through the river beds. In areas where such a system works well and little water is being lost, artificial recharge of surface water might be a possible method for increasing the supply.

Infiltration in areas outside of the river beds would, not be feasible due to the disponibility of large quantities of water in a short time. In any case the economic alternative for surface storage should also be considered for every site studied.

6.3 Inhibition of Evaporation

The high values of evaporation indicate that an additional supply of water might be derived from suppressing evaporation from the many surface-water reservoirs. A survey of this problem has been given by Michaeli (1973). In the island many small water reservoirs exist which can be covered with foamed materials in order to reduce evaporation. The possible reduction of evaporation might be in the order of 40% . A small experimental programme should be carried out in order to evaluate the applicability of this method.

In Gran Canaria there are , as pointed out earlier 59 surface-water collecting reservoirs with walls higher than 15 meters. For these, the only known method of suppressing evaporation is a monomolecular film cover. Most of these reservoirs have small surface areas and therefore the small quantities of water that could be saved, would not justify the installation and operation of a system of this kind. For some of the seven biggest reservoirs the monomolecular layer might achieve a 15% reduction in evaporation. Costs for operation and maintenance seem to be in the same order of a magnitude as the cost of the water but no recommendation can be given before trying out the method. Experience in other countries should be followed up and data about winds and evaporation should be collected for these large reservoirs in order to permit a more detailed evaluation.

6.4 Artificial Rainfall

An evaluation of the possibilities of inducing artificial rainfall by Schleusener (1971), shows that most likely it is not feasible to increase rainfall during the summer months by the cloud seeding method. There might be some possibilities of augmenting the rainfall during the winter months by about 10%. This conclusion was based only on indirect evidence and it was suggested that a program of additional investigation be carried out, before t method was used.

Although rainfall occurs on many days in the winter season, the major quantity falls during very few days with high intensities. Under these conditions losses of runoff to the sea may occur and other undesirable effects are that roads are destroyed and the topsoil is washed away. Therefore, it would seem advisable not to start cloud seeding in the island until an adequate surface-water collecting system has been accomplished and sufficient measures are taken to avoid eventual damages due to heavy downpours. The expenditure incurred on protective measures may make cloud seeding processes prohibitive but feasibility studies need to be undertaken before taking a decision. It would be advisable, however, to start collecting the necessary metereological data in order to permit a better evaluation of the possibilities of this method, especially as a last resort to stop prolonged droughts.

6.5 Artificial Condensation

Condensation on trees and artificial interceptors has been observed and has occasionally been used as a source of water supply in the archipelago (Michaeli 1973, Schleusener 1971). The effects have been noticed mainly in the cloudy area of the islands, at elevations between 600 and 1500 meters. It does not seem as if artificial devices for fog interception are economically feasible except in marginal cases. It should be noted that the wide-spread method of "picón" cultivations seems to derive its merits from the fact that it reduces evaporation from the soil rather than increases condensation.

Direct condensation from maritime humid air by use of sea water as a cold source has been suggested as a possible method for increasing the water supply (Schleusener 1971). As a possible power source wind was proposed. A feasibility study for a similar plant in the West Indies (Gerard and Roels, 1970), showed that such a plant would not be economical compared to an ordinary desalinization plant. A preliminary study of available meteorological and oceonographical data and a comparison with the plant in the West Indies showed that the conditions are a priori less favourable in the Canaries, but a feasibility study with an experimental plant has been suggested. (Section of Hydrology, 1972 a).

6.6 Increased Efficiency of Irrigation

It has been shown previously that there are large differences in the water requirements of the two main crops. It would therefore seem appropriate from the water management point of view to substitute greenhouse crops or tomatoes for bananas. It should also be possible to increase the irrigation efficiency using sprinkler or drop irrigation instead of the presently dominant systems of basin, and furrow irrigation. Both the returns and the efficiency of the system might also increase if smaller quantities of water were applied at shorter time intervals if the needs of the plant and the soil are closely followed up.

The figures given in Table D.7 give an idea of the magnitude of the possible savings of irrigation water. It can be seen that if for instance one third of the present banana area of about 3600 ha, mainly situated on the northern side of the island, could be used for greenhouse crops and tomatoes, this would mean a reduction of the gross demand by some 15 Mm^3. Sprinkler irrigation should be preferred to basin irrigation and furrow irrigation. Present experience in the northern part of the island indicates that the decrease in gross demand when changing to sprinkler irrigation is even bigger than is demonstrated in the Table D.6 which may mean that actual irrigation efficiency is even lower than has been assumed.

Table D.7

Estimated Irrigation Requirements of Bananas and Tomatoes

Gran Canaria

	Bananas mm/year	Tomatoes mm/year
Northern Zone		
Potential evapotranspiration	1270	370
-Effective precipitation	-170	-170
Net demand	1100	200
Irrigation efficiency	0.7 (basin)	0.6 (furrows)
Gross demand	1570	330
Sprinkler irrigation efficiency	0.8	0.8
Gross demand for sprinkling	1375	250
Southern Zone		
Potential evapotranspiration	1870	550
-Effective precipitation	-70	-50
Net demand	1800	500
Irrigation efficiency	0.7	0.6
Gross demand	2570	830
Sprinkler irrigation efficiency	0.8	0.8
Gross demand for sprinkling	2250	625

E GROUNDWATER RESOURCES

. Introduction

The island of Gran Canaria has a surface area of 1558 km^2 and is the third in size within the Canarian archipelago.

The major source of water supply is derived from groundwater. The total production obtained mainly from deep wells and some galleries, was about 128 Mm^3 in 1968/69. However, the production has decreased to about 102 Mm^3 in 1973, specially due to some wells going out of production as a result of water level declines.

The groundwater production in 1973 equals a water lamina of 65^{mm} or 22% of the mean annual rainfall, calculated at 300 mm/year.

The principal aquifers producing water are Modern Basalts (Post-Miocene), Roque Nublo Formation, and Old Basalts (Miocene), which together yield over 70% of the total. The Phonolytes, Ignimbrites and Alluvial materials account for the rest.

In this section is attempted a statistical analysis of the well and gallery inventory, a study of the occurence of water in the various geological units as well as their characterization through observed hydrodynamic behaviour and hydraulic properties.

1. Hydrogeological significance of major rock formations

About 90% of the island can be regarded as composed of volcanic rocks and the rest of erosional materials.

The oldest rocks in the island are the Old Basalts of Miocene age. These are composed of a very thick series (max. 800^m) of alternating lava flows and pyroclastic layers. A good idea of their structure can be seen on the western coast between Agaete and Puerto de la Aldea. The entire thickness is crossed by a swarm of dykes oriented generally NW-SE. Weathering has attained great depths on the top, the fissures are normally filled in with secondary minerals. We can consider this formation as the basement of the island from a structural point of view.

The Old Basalts appear below the present sea-level in the southern and eastern coasts spreading from Bco. Tauro to Gando, which indicates that the island probably was dipping in this direction at one time. There is some evidence that a good part of this basement in the north is below the present sea level excepting an area east of Teror.

The Miocene basalts are covered by the Trachy-Syenitic Complex in the central west between Tejeda and San Nicolás. This formation largely composed of trachytic and ignimbritic levels is completely trans - formed by a large-scale intrusion of dykes. The entire complex showing a system of ring dykes is thought to represent an ancient caldeira. Weathering is very deep and this forms an impermeable series compared to the Old Basalts.

The Ignimbrites cover independantly very wide areas both in the south and northern parts of the island, although the maximum develop - ment is seen in the south (max 500^{m}). From groundwater point of view, these form an aquiclude even though at times due to local fissuration, groundwater production can become important specially on the upper zones of the formation.

Phonolytes and pumitic deposits cover in most cases the Ignim - brites but they form at times large intrusive massifs. In the southern part specially the flow levels are very thick and long. Even though they are provided at times with fissures, generally the production of groundwater is low.

The next formation which is also one of the most important aquifers of the island, is the Roque Nublo Series. Product of "nuée ardente" type of explosion, and intermediate periods of calm, this series can attain a total thickness of 800 m in the centre of the island.

The lower member is composed of agglomerate levels mixed with individual lava flows mostly of tephritic origin as well as with intraformational sedimentary deposits. The upper member however is composed of a great thickness of agglomerates. The principal producing level is found in the lower member.

The Modern Basalts are all post-miocene but are composed of several series of which the most important aquifer is constituted by the thick basalts of series 2, found covering the Roque Nublo and the Phonolytes-Ignimbrites substratum in the north between Guía-Fontanales-Arucas and in the east between Las Lagunetas-Telde-Ingenio.

In the north-eastern half of the island the impermeable substratum for groundwater is constituted by the widespread occurence of Phonolytes and Ignimbrites.

Erosional materials specially alluvial deposits can be aquiferous zones locally. This is notably the case for example of the Miocene Terrace of Las Palmas between Telde and Gando underlying the Modern Basalts. Its extension is small, about 30 Km^2 at a maximum but is highly productive being supplied both laterally and horizontally.

The alluvial belt of lower Tirajana basin supplies water to lateral galleries of wells in winter when recharge from surface runoff takes place.

The main outcrops of the principal geological formations of the island are given in Map C.1 and the structural relationship are shown in Sections C2 - C7. The reader is referred to Maps E.23 and E.25 for the basement topography of the Phonolytes-Ignimbrites and the Old Basalts respectively.

2. Groundwater Occurence in a Stratified System

In the island of Gran Canaria groundwater occurs in all altitudinal levels. However, the behaviour of groundwater varies according to certain strata and such a behaviour probably is related to groundwater movement and storage. This implies that in spite of the general geological formations which control the hydraulic characteristics of groundwater occurence in a particular zone, there seems to exist a superimposed system resulting from the complex equilibrium existing between recharge on the one hand and the flow of water towards the sea on the other hand, governed by particular hydraulic laws.

Unlike in normal aquifers, the volcanic aquifer even though comports a water level, has a much greater dispersion of its hydraulic properties. Also the notion of saturation has to be transposed to a system of preferential communication along which the exploitable fraction of the water filters through. If we imagine the volcanic aquifer as a complex system of discontinuous short aquifers composed of confined, semi-confined and unconfined levels cut across by veritable high gradient channels or compartimented by dyke-barriers, we get an explanation why the geological formations do not constitute in this particular case a homogeneous unit as far as water occurence is concerned.

The evidence for such a stratification exists if we study the behaviour of wells, galleries and springs in all levels of water flow, and compare them with hydrogeochemical and isotopic changes.

On the top of the island we find numerous perched water tables in the unsaturated zone, sometimes associated with spring outflow. The wells and galleries traversing this zone have a reasonal flow regime with numerous "hanging levels" characterized by recession of discharge in late summer-autumm. All water in this level is fast moving and have practically the same chemical characteristics as rain water. The total water extraction in the zone is about 3-4 Mm^3/year.

Below this level we have a compact lense associated with a stock of recharge waters. The seasonal fluctuation is much less marked even though it yet exists. Groundwater has a little higher mineralization and its extension is limited to about 60 mg/l of Cl^-; the latter hardly changes with seasons. The entire lense is marked by an $\delta^{18}O$ value of more than 4, characteristics of these waters. Also the tritium values measured are generally more than 10 T.U and often showing up to 25 T.U equal to the present level in rain waters (17,5-31,5 T.U in 1972)

Water is tapped mainly through galleries in this zone and follows vertical contacts and fissures more readily than horizontal ones. Dyke-impounded waters are not absent in this zone due to its location in the centre of the island.

The top of this lense is defined by a water table and hence can be regarded as the top of "saturated zone". The estimated rock volume is around 32.10^9 m^3. If we admit an effective porosity of 2%, the water stock in the lense is estimated at 640.10^6 m^3. At present about 25 Mm^3 are extracted yearly from the recharge water lense.

In the past century the extension of the lense was probably double its present size and this gave rise to permanent flow phenomenon at the head of streams with springs at present non existant. In 1932 there were 285 springs associated with this water lense, which had a total discharge of 1.050 l/s.

The major part of the island's water resources are found however in the core-zone below the recharge water lense. In this unit, water is a slow moving element controlled by the major and minor structural features of the multiple geological formations. The importance of the hydraulic conductivity depends on the hydraulic connections offered by the fissures and interbedded contacts for water movement. The reader is referred to the examples on Figs. E.5 - E.7 for details and to Fig. 1 for the schematic structure of the volcanic aquifers in Chapter 3.

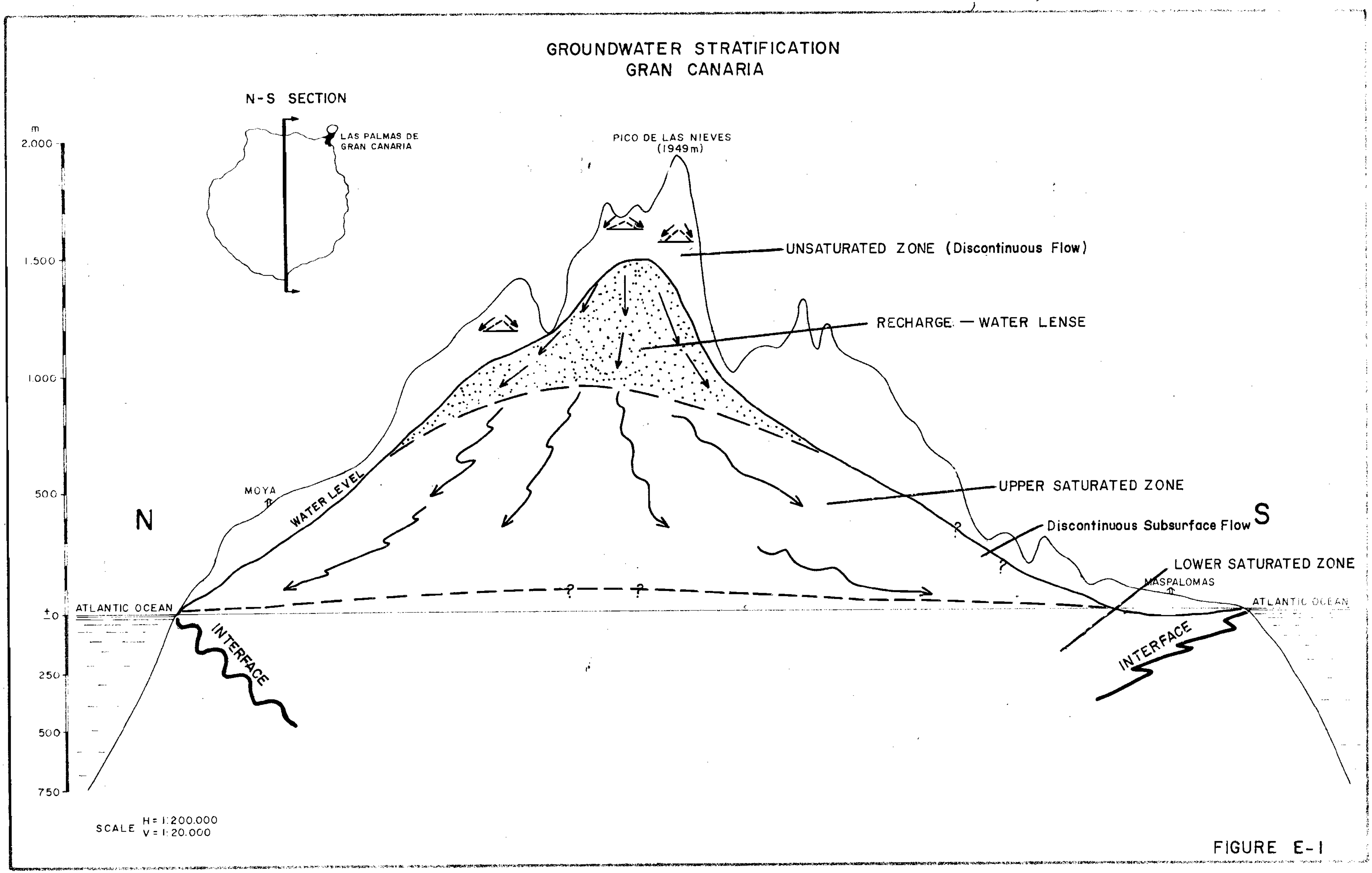
Chemically speaking, we see here a progressive mineralization and the Cl^- content indicates a gradual increase from 60 mg/l on top to about 300 mg/l at the bottom. The evidence offered by $\delta^{18}O$ shows the lack of large values generally varying from 2 to 4 if we except areas of local recharge. As for tritium the core zone shows a variation of 2 to 5, representative of older waters.

The total rock volume of core zone is about 350.10^9 m^3. If we admit an effective porosity of 0,5% (2-3% for Roque Nublo-Modern Basalts; 0,10%and less for Phonolytes-Ignimbrites) we obtain a water stock of $1,7.10^9$ m^3. The present production for the unit is around 60 Mm^3/year.

Nearer the coastal periphery, we observe another type of water stratum, where there seems to exist a relatively higher degree of saturation for the same rock-type. Often we note high water columns in wells showing the influence of alimentation through very large secondary fissures.

This basal water zone is characterized by a sharp increase in total mineralization as well as in Cl^- content, which increases from 300 mg/l to more than 1.500 mg/s over short distances. Tritium values always show less than 2 T.U indicating that these waters are more than 20 years of age. The Cl^- salt balance shows that this water stratum has a turn-over period of about 20-30 years.

The annual groundwater production in this zone obtained from Phonolytes, Ignimbrites and Old Basalts is about 30 Mm^3.



GROUNDWATER STRATIFICATION
GRAN CANARIA
N-S SECTION
LAS PALMAS DE GRAN CANARIA
PICO DE LAS NIEVES (1949m)
UNSATURATED ZONE (Discontinuous Flow)
RECHARGE — WATER LENSE
UPPER SATURATED ZONE
Discontinuous Subsurface Flow
LOWER SATURATED ZONE
MASPALOMAS
MOYA
WATER LEVEL
N
S
ATLANTIC OCEAN
ATLANTIC OCEAN
INTERFACE
INTERFACE
m
2.000
1.500
1.000
500
±0
250
500
750
SCALE H= 1:200.000 V= 1:20.000

FIGURE E-1

A good part of the southern region of the island has an important subsurface flow along the principal "barrancos". As is expected, the period of maximum water level occurs in winter specially after heavy showers.

The amount of water which enters the heterogenous materials in the valley bottoms and thereafter the upper layers of the bedrock, is sufficient to supply the entire year, but the quality of the water deteriorates in summer time due to concentration of salts.

The piezometric levels in these basins, specially in the Mogan-Veneguera region, are disconnected because each barranco has its proper flow pattern.

As is to be expected most of the wells are placed along the barrancos to capture the maximum amount of water from subsurface flow.

The total extraction of subsurface waters from the barrancos in the island is estimated around 10.10^6 m^3/year.

Summarizing the water resources of the island according to the strata we have the following figures:

	Annual Production Mm^3	Estimated Resources Mm^3
Unsaturated Zone:	3	-
Recharge water lense:	25	640
Upper saturated zone: (core-zone)	60	1720
Lower saturated zone: (basal waters)	30	1500*
Discontinuous sub-surface waters: (southern region)	10	-
	128	3.860

The estimated figures for Old Basalts and Phonolytes-Ignimbrites in the basal zone must be considered the maximum since the highest storativity values for these formations have been used for the calculations. The stratification scheme is shown in Fig. E.1. The reader is referred to subsection E.7 for further details.

* 500 Mm^3 in Old Basalts for 500.10^6 m^3 of rock volume at 1,0 % S.
-1000 " in Phonolytes-Ignimbrites for 1000.10^6 m^3 of rock volume at 0,1% S.

3. Groundwater Production

Groundwater flow in the island of Gran Canaria as said earlier, is conditioned both by the hydraulic connections provided by the fracture system and the geological contacts. Groundwater production depends on the water bearing capacity of the rock materials and the rate of flow through the fracture systems.

3.1 Major Aquifer Units

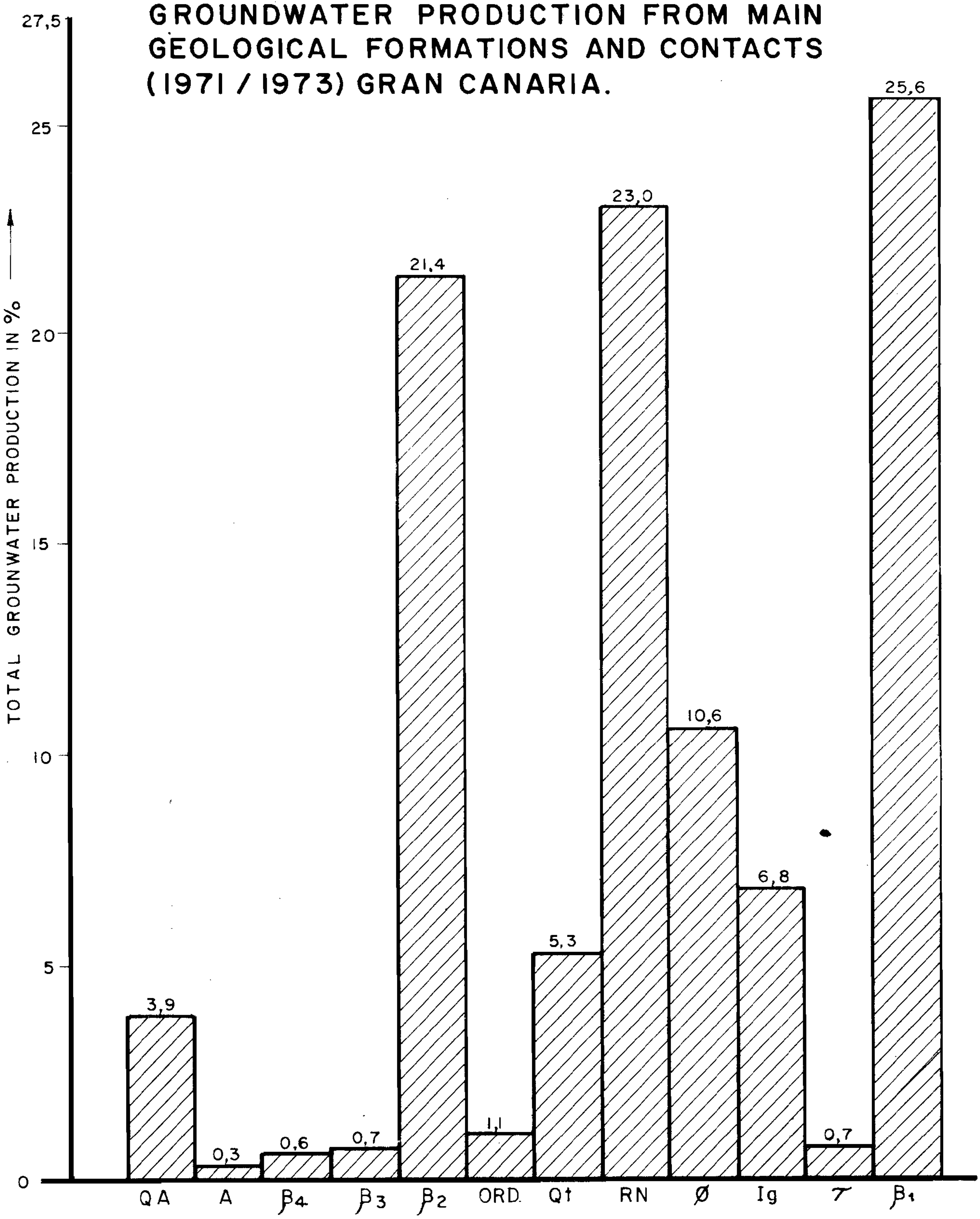
A detail study of the production capacity of each geological formation of the island has been made, the summary of which is shown in Fig. E.2.

This diagrame reveals that 70% of the groundwater production comes from three main geological formations -- Miocene Basalts, Roque Nublo Formation and Post-Miocene Basalts (Bii). If we look at Map C.1 we see that the major outcrops of the Miocene or Old Basalts spread over the western coast and appear in several valley bottoms of the south as well as in the south-east near Agüimes. The total outcropping area is about 170 km^2 but it is a productive aquifer only around Agüimes and in Mogan regions. In addition we can say that a good part of the waters derived from Ayagaures-Arguineguin valleys, covered by thick layers of Phonolytes and Ignimbrites originates from Miocene Basalts.

The Roque Nublo is the principal aquifer in the northern and eastern areas of the island. The productive level is the lower member provided at times with thickness of over 500^m, such for example in the region of Fontanales-Valleseco. The extension of the outcropping area is about 150 km^2 but the covered region can be as big as the outcrops.

The Post-Miocene Basalts specially the Series 2, has a great extension in the northern and eastern zones and probably attain the maximum thickness of over 400^m in the upper valley of Guayadeque. In the northern

GROUNDWATER PRODUCTION FROM MAIN GEOLOGICAL FORMATIONS AND CONTACTS (1971 / 1973) GRAN CANARIA.



LEGEND

QA = Alluvium

A = Landslides

β2 β3 β4 = Post-Miocene Basalts

ORD = Phonolytes (Ordanchites)

Qt = Las Palmas Terrace Materials

RN = Roque Nublo Formation

Ø = Phonolytes

Ig = Ignimbrites

τ = Trachy-Syenitic Complex

β1 = Old Basalts

FIGURE E-2

zone this formed the major aquifer about 20-30 years ago, but presently it is much less important because of the dewatering in the past. In the eastern zone however, it is yet an important aquifer.

It is seen that the Phonolytes and Ignimbrites account for 17% of the production. The latter group produces water only under locally favourable conditions, often with contact of overlying beds.

The alluvial materials represented by Las Palmas Terrace Formation and barranco deposits produce about 9%, specially in the lower reaches of the Telde and Tirajana Valleys.

The rest of the geological formations such as the Trachy-Syenitic Complex due to its impermeable nature and the Recent Basalts (Biii, Biv) due to their extreme porosity, do not offer suitable aquifer conditions.

3.2 Major Aquifers of Hydrological Zones

The production of groundwater from each geological formation within the hydrological zones is shown in Fig. E.3.

The histrogramme shows that 70% of the island's production comes from the NE (zones 1,2,3) with an area of 645 km^2. The principal rock formations contributing to this high production are the Miocene Basalts (Zone 3), Post-Miocene Basalts and Roque Nublo (Zones 1 and 2).

The lower part of Fig. E.3, indicates that these 3 formations continue to be the principal aquifers also in the other zones. However in zones 2 and 8 there is a significant contribution from the Phonolytes and Ignimbrites.

In zone 2, the producing Phonolytes are found in the central part of the island associated with the Roque Nublo Series. Most of the water is derived in contact with the Roque Nublo. In zone 8, only the lowest part of the Ignimbrites in contact with the Old Basalts are productive.

The accompanying map shows the principal producing areas in their geological context, see E.4.

GROUNDWATER PRODUCTION BY ZONES AND FORMATIONS
GRAN CANARIA (1971/73)

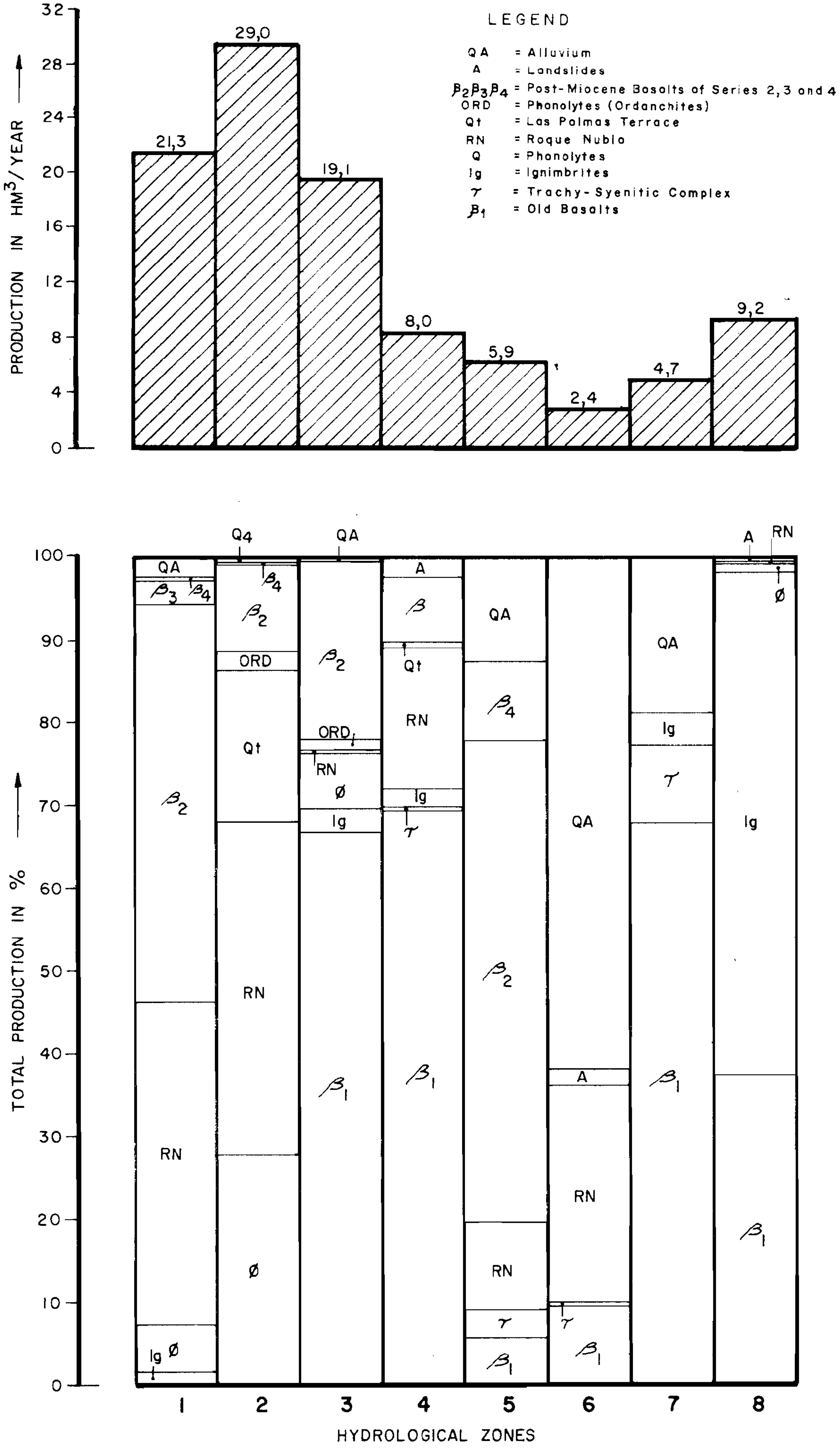
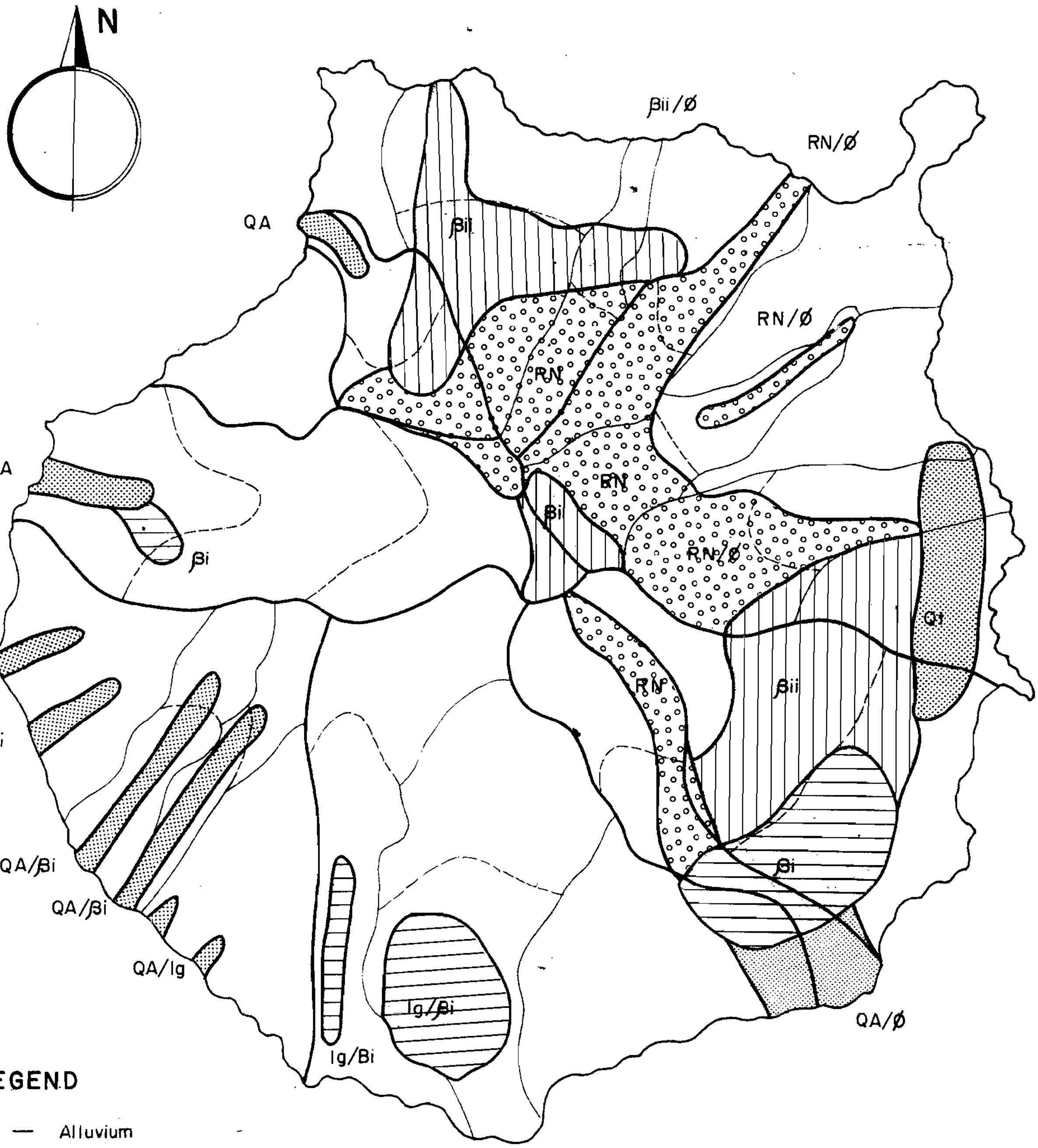


FIGURE E-3

GROUNDWATER PRODUCTION PATTERN

AND AQUIFERS

GRAN CANARIA



LEGEND

QA — Alluvium

QA/Bi — Alluvium with contact βi

QA/Ø — Alluvium with contact Ø

Qt — Las Palmas Terrace formation

βii — Post-Miocene of series 2

βii/Ø — Post-Miocene of series 2 with contact Ø

RN — Roque Nublo serie

RN/Ø — Roque Nublo serie with contact Ø

Ø — Phonolytes

Ig — Ignimbrites

βi Miocene Basalts

0 5 10 15 Km.

ESCALA _ 1: 300.000

FIGURE E-4

3.3 Some examples of groundwater production

A more detailed idea of the occurrence and production of groundwater from the principal geological units is obtained from the examples shown in Figs E5-E7. These examples do not show all the situations favourable for water production but some of them are however typical.

In Fig E.5, , are shown two examples of groundwater production from the Roque Nublo Formation. The well Nº 1023 with continuous pumping at 18 l/s represents a well developed saturated aquifer deriving water mainly from fissures. The diagrame shows a first period where the water level dropped in the Modern Basalts with accompanying decrease in discharge. From 1967 to the present day the fluctuation of discharge within a limit of 18 to 24 l/s has been conditioned by the fortuitous nature of fissure yield during the process of boring.

The well Nº 1060 is also in the Roque Nublo Formation. Here the water is derived from a permeable basaltic bed in contact with a more dense layer below. In this case there exists a preferential contact flow as opposed to the earlier example.

In Fig E6 we have an example of production from the Phonolytic Series. Often, water is produced in contact with this type of rock. Here in this case however water is derived from an agglomeritic layer which is aquiferous. An example of production from Ignimbrites is given by well Nº 2023 in the upper part. The present water is obtained from hard fissured rock through lateral boreholes.

The Fig E7 represents a rather typical example of groundwater production from Old Basalts. In this particular case most of the water is derived from lateral boreholes probably traversing a dyke. In the lower part is represented a case of the occurrence of water on the contact between Old Basalts and Modern Basalts.

GROUNDWATER IN ROQUE NUBLO

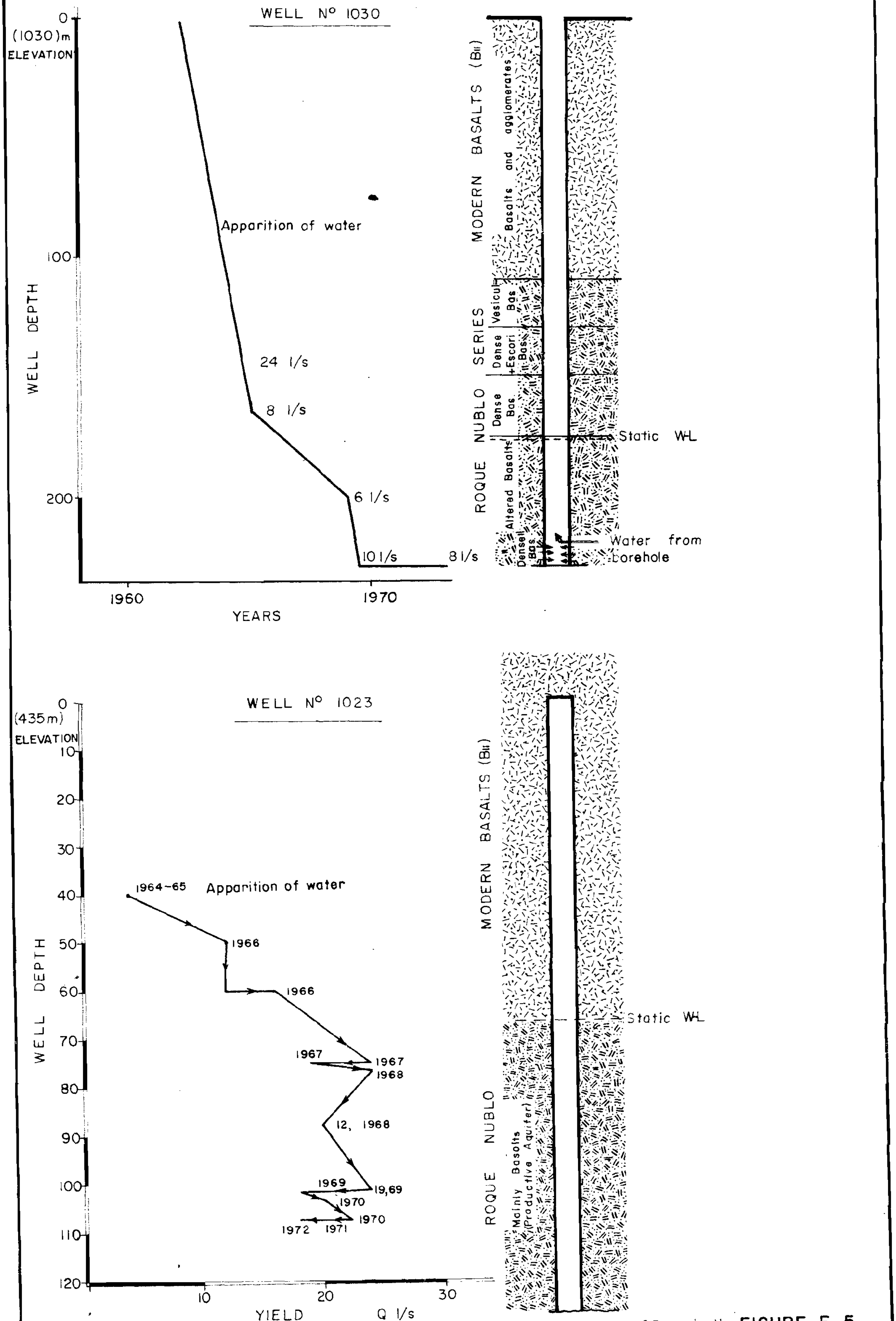


FIGURE E-5

GROUNDWATER IN IGNIMBRITES AND PHONOLYTES

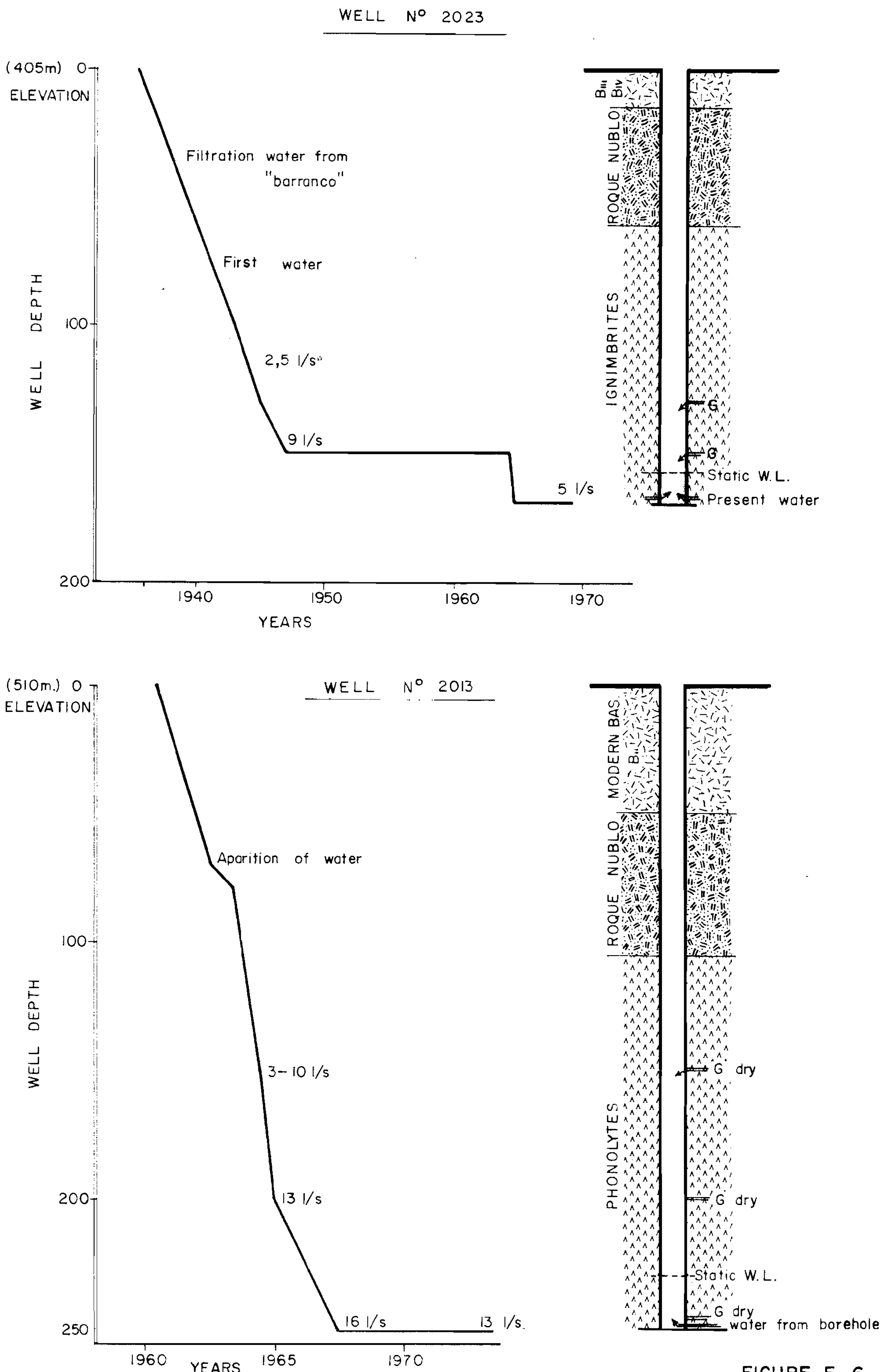


FIGURE E-6

These examples in fact demonstrate the more usual situations favourable for groundwater production -- fissure flow, contact flow, locally saturated water conducting strata and dyke-impoundments.

4. Statistics of captations (1968 and 1972/73)

The inventory of captations was undertaken on the basis of each municipality of which there are 21 in the island. The Table E.1 gives a summary of the essential results of the inventory for the year 1968 on the basis of municipalities.

4.1 Analysis of well and gallery inventories

An analysis of the above table reveals that over 5800 demands for borings have been registered up to 1971 and that only about half the number had been authorized. Also, up to date about 350.000 meters have been bored more or less equally distributed between the wells and galleries. However, in the wells the secondary galleries and small bores called "catas" are not counted which together can be estimated at 50% of the total for wells.

If we compare the production figures for wells and galleries, we have a production of 108 Mm^3/year for a total perforated length including estimation for small galleries and "catas" of about 260.000 meters for wells and only 20 Mm^3/year for a total perforated length of 117.000 meters for galleries. This would give a unit production of 415 m^3/m/year for wells and only 171 m^3/m/year for galleries. The total production for the island amounted to a water depth of 83 mm/year.

This inventory was checked in the field during 1971 through 1973 for about 450 points. During the lapse of 4-5 years, it was found that the total production had dropped by about 22%, which gives us a figure of 102 Mm^3/year valid for 1972/73. Table E2 provides the figures for this year based on the hydrological zones and subzones.

Table E.1

STATISTICS OF CAPTATIONS

Table E.1

Municipality	Surface area km^2	Number of Captations: Solicited Wells	Solicited Gal.	Realized Wells	Realized Gal.	Not author. Wells	Not author. Gal.	Perforated km. Wells	Perforated km. Gal.	Perforated km. Total	Captations Realized (with water). Wells km per.	Wells Mm^3Year	Galleries km per.	Galleries Mm^3Year	Total Production Mm^3/year	Total Production mm/year
Agacte	45,80	40	21	18	12	10	3	0,80	0,89	1,69	0,40	0,9	0,00	0,0	0,9	19,6
Agüimes	76,50	300	36	117	15	98	16	14,70	8,94	23,64	10,80	11,3	7,40	1,2	12,5	163,4
Artenara	49,40	54	17	5	6	38	5	0,58	5,16	5,74	0,36	0,2	4,49	0,3	0,5	11,0
Arucas	35,13	139	16	70	9	38	0	6,29	3,93	10,22	3,09	2,5	1,50	0,1	2,6	74,0
Firgas	16,50	148	16	40	8	65	3	4,72	2,91	8,63	3,01	2,2	1,55	0,1	2,3	143,6
Galdar	67,60	204	38	68	19	95	10	6,95	10,21	17,16	5,25	6,0	7,30	1,8	7,8	116,0
Guía	37,72	306	36	98	23	157	4	12,90	6,27	19,17	9,28	9,5	2,50	0,1	9,6	257,0
Ingenio	37,32	227	21	83	8	75	9	12,84	14,26	27,10	7,94	5,6	10,91	0,4	6,0	162,2
Mogan	164,80	141	10	84	2	25	3	4,14	0,30	4,44	2,84	5,8	0,00	0,05	5,85	35,0
Moya	36,28	228	40	66	24	116	6	8,66	10,17	18,32	6,62	6,0	4,53	0,5	6,5	178,0
Las Palmas	98,86	184	10	87	6	45	1	5,61	1,77	7,38	1,71	0,8	0,88	0,02	0,80	8,0
S.Bartolome	334,70	312	64	78	19	115	17	7,95	8,24	16,19	5,62	12,3	6,11	0,4	12,8	38,0
S. Mateo	34,80	329	87	84	49	165	23	9,69	27,21	36,9	7,69	3,6	13,89	7,7	11,4	328,0
S. Nicolás	139,00	526	12	422	5	31	3	12,42	1,28	13,70	11,92	2,5	0,00	0,0	2,5	18,0
Sta.Brígida	22,60	291	7	110	3	128	4	14,43	1,98	16,41	6,03	2,3	0,00	0,0	2,3	102,3
Sta. Lucía	54,75	246	34	76	10	83	15	9,47	3,11	12,58	6,31	10,3	1,51	2,4	12,7	232,0
Tejeda	100,64	99	18	8	7	21	6	0,23	5,35	5,58	0,05	0,05	3,80	0,2	0,3	2,0
Telde	100,22	444	54	215	24	145	8	21,33	17,49	38,82	17,13	16,2	13,24	1,2	17,4	179,0
Teror	27,40	203	38	31	14	116	10	3,94	6,22	10,16	2,05	1,3	3,86	0,1	1,4	52,0
Valsequillo	32,74	259	85	69	58	137	21	7,19	33,59	40,78	5,49	3,3	28,47	2,5	5,8	177,0
Välleseco	19,74	260	36	59	16	144	12	7,79	6,78	14,77	6,88	5,5	5,54	0,7	6,2	313,0
TOTAL	1532,50	4940	696	1888	337	1847	179	172,63	177,06	349,6	120,47	108,15	117,48	19,77	127,92	83,4

Table E.2 (a)

GRC ..DWATER PRODUCTION AND RESOURCES

ZONE/SUB ZONE		Surface km^2	Precipitation mm	Mean Recharge (R) (71/72-72/73)		Mean Extraction (EXG) (70/71-72/73)		Reserve (estimated) (S)		EXG/R Coeff.	EXG/S %
				M^3	mm	M^3	mm	M^3	mm		
1	A	23,70	153	945	4	-	-	-	-	-	-
	BH	46,30	507	-	134	10.694	231	260.438	5.625	-	4
	BL	46,20	219	-	19	2.552	55	13.860	300	-	18
	B	92,50	363		76	13.246	143	274.298	2.965	1,88	4
	CH	15,90	724		375	4.798	302	95.400	6.000	-	5
	CL	15,80	421		51	634	40	-	-	-	-
	C	31,70	573	7.323	231	5.433	171	95.400	3.009	0,74	5
	D	34,30	272	361	11	2.596	76	-	-	7,19	-
1	Total	182,20	354		81		117		2.029	1,43	5
2	AH	20,10	651	-	318	2.622	130	40.200	2.000	-	6
	AL	20,00	318	-	54	978	49	-	-	-	-
	A	40,20	485	7.458	186	3.600	89	40.200	1.000	0,48	9
	BN	53,90	297	-	37	619	11	-	-	-	-
	BS	54,00	272	-	46	1.685	31	-	-	-	-
	B	107,90	285	4.478	42	2.304	21	-	-	0,51	-
	CH	28,10	779	-	461	5.925	211	84.300	3.000	-	7
	CL	28,00	469	-	219	1.389	50	-	-	-	-
	C	56,10	624	19.075	340	7.314	130	84.300	1.502	0,38	9
	DH	38,00	494	-	171	5.866	150	76.000	2.000	-	8
	DL	37,90	239	-	27	5.700	155	42.637	1.125	-	13
	D	75,90	367	7.476	99	11.567	152	118.637	1.563	1,54	10
	E	46,90	180	94	2	4.218	90	117.250	2.500	44,87	4
2	Total	326,90	371		118		89		1.102	0,75	8
3	H	72,60	296	-	77	12.569	90	190.575	2.625	-	7
	L	72,50	208	-	20	6.529	173	54.375	750	-	12
3	Total	145,10	253		48		132		1.688	2,74	8
4	H	44,20	382	-	94	1.126	25	2.210	50	-	51
	L	44,20	225	-	94	6.874	156	110.500	2.500	-	6
4	Total	88,40	304		94		90		1.275	0,96	7
5	H	24,70	618	-	259	4.489	182	74.100	3.000	-	6
	L	24,70	335	-	53	1.373	56	9.262	1.500	-	15
5	Total	49,40	477		156		119		1.687	0,76	7

Note: With spring 102.10^6 m^3 equal to 6,5 mm/year.
Figures expressed in x 10^3 m^3.

GROUN. .ATER PRODUCTION AND RESOURCES

Table E.2 (b)

ZONE/SUB ZONE		Surface km²	Precipitation mm	Mean Recharge (R) (71/72 - 72/73) M³	Mean Recharge (R) mm	Mean Extraction (EXG) (70/71-72/73) M³	Mean Extraction (EXG) mm	Reserve (estimated) (S) M³	Reserve (estimated) (S) mm	EXG/r Coeff.	EXG/S %
6	H	59,50	580	-	176	634	11	19.813	333	-	3
	M	59,50	293	-	44	-	-		-	-	-
	L	59,50	219	-	85	1.757	30	17.855	300	-	10
6	Total	173,50	364		101		13		210	0,13	6
7	A	68,30	211	1.981	29	621	9	12.294	180	0,31	5
	BH	24,80	242	-	8	167	7	1.537	62	-	11
	BL	24,70	208	-	115	817	33	5.557	225	-	15
	B	49,50	225	2.673	54	983	19	7.094	143	0,37	14
	CH	17,40	281	-	12	289	17	1.078	62	-	27
	CL	17,40	206	-	115	1.783	102	3.915	225	-	46
	C	34,80	238	2.210	64	2.072	59	4.993	143	0,94	41
	D	69,40	132	1.908	28	1.055	15	20.820	300	0,55	5
7	Total	222,00	193		39		22		203	0,54	10
8	AH	53,20	328	-	56	5	0	13.300	250	-	-
	AL	53,10	193	-	86	1.398	26	13.275	250	-	11
	A	106,30	261	7.547	71	1.402	13	26.575	250	0,19	5
	BH	61,20	330	-	11	455	7	15.300	250	-	3
	BL	61,20	237	-	140	4.583	75	91.800	1.500	-	5
	B	122,40	283	9.180	75	5.038	41	107.100	875	0,55	5
	C	94,90	145	1.992	21	2.779	29	8.541	90	1,39	33
8	Total	323,60	233		57		28		435	0,49	6
9		42,00	346	861	21	-	-	-	-	-	-
ISLAND		1558,10	302		79		64		896	0,81	7

Note: With spring 102,10[6] equal to 6,5 mm/year.
Figures expressed in x 10^3 m^3.

The island can also be separated into an upper central part, where infiltration is predominant, with a surface area of 536 km^2 and a lower part with 1022 km^2, where extraction is more intensive. According to the table we obtain a total production of 44 Mm^3 in the upper part equivalent to a water depth of 81^{mm} and in the lower part 56Mm^3equivalent to a water depth of 55^{mm}. The total production of the island amounts to 65^{mm}/year which is equal to 21% of the mean annual rainfall calculated at 300mm.

4.2 Potential yields

The geological analysis of the captations revealed the importance of Miocene Basalts, Post-Miocene Basalts and the Roque Nublo Formation, as the principal volcanic aquifers of the island.

An attempt has been made to study the frequential distribution of their potentiality so that their characteristics could be better known for future exploitation of groundwater.

The two parameters considered in this statistical treatment were well production per unit m^3/24H/meter and saturated depth in meters. A summary of this analysis is given in Table E3. The frequency adjustments fitted with the exception of the Phonolytes in Zone 2, the Frechet distribution a logarithmic form of Gumbel law. As for the Phonolytes, they fitted best, the distribution of Galton.

If we compare the medium production values, we note that Post-Miocene Basalts (Bii) of Zones 1, 2 and 5 have values between 0,13 to 0,16 1/s/meter, that of Roque Nublo around 0,12 1/s/m. The values for Miocene Basalts on the other hand are higher varying between 0,21 and 0,29 1/s/m. The highest value is that of the Ignimbrites -- Miocene Basalts contact in the southern part of the island. Some of the adjusted curves are shown in Figs E.8 to E.11.

Table E.3

POTENTIAL PRODUCTION OF AQUIFER (For Median Values)

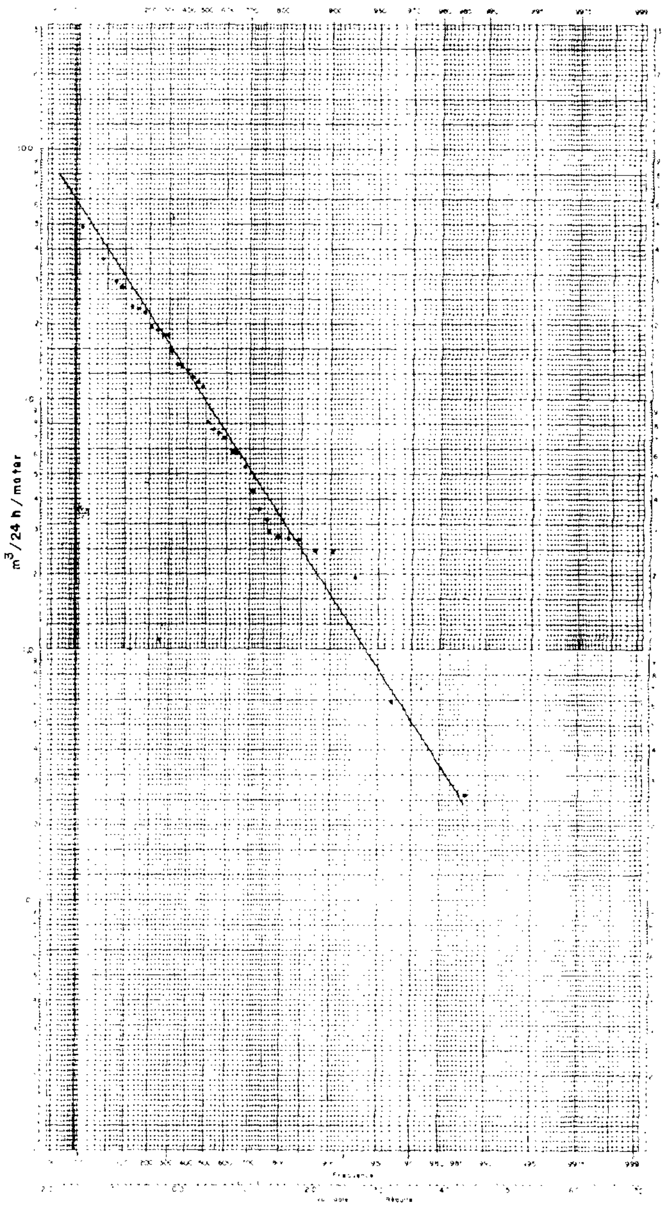
-GRAN CANARIA-

ZONE	FORMATION	Frequency Law	Nº of Points	Mean Production (1/s/m)	Median Production (1/s/m)	POTENTIAL PRODUCTION (for saturated depth)+ in 1/s			
						50m	100m	200m	300m
1	RN	Frechet	36*	0,15	0,12	6,0	12,0	24,0	36,0
"	Bii and Bii/RN	"	37*	0,25	0,16	8,0	16,0	32,0	48,0
2	RN and RN/Ø	"	34	0,37	0,12	6,0	12,0	24,0	36,0
"	Ø (mostly with RN)	Galton	32	0,48	0,15	7,5	15,0	30,0	45,0
2+3	Bii and Bii (various contacts)	Frechet	10	0,36	0,23	-	-	-	-
3+4	Bi	"	30*	0,45	0,29	14,5	29,0	58,0	87,0
5	Bii and Bii/RN	"	8	0,16	0,13	-	-	-	-
7+8	Ig and Ig/Bi	"	8	1,19	0,59	-	-	-	-
7+8	Bi	"	14	0,45	0,21	10,5	21,0	42,0	63,0

Note: +With reference to the water column below Static water level.

*Values used for range analysis

. RECHET DISTRIBUTION OF UNIT AQUIFER PRODUCTION



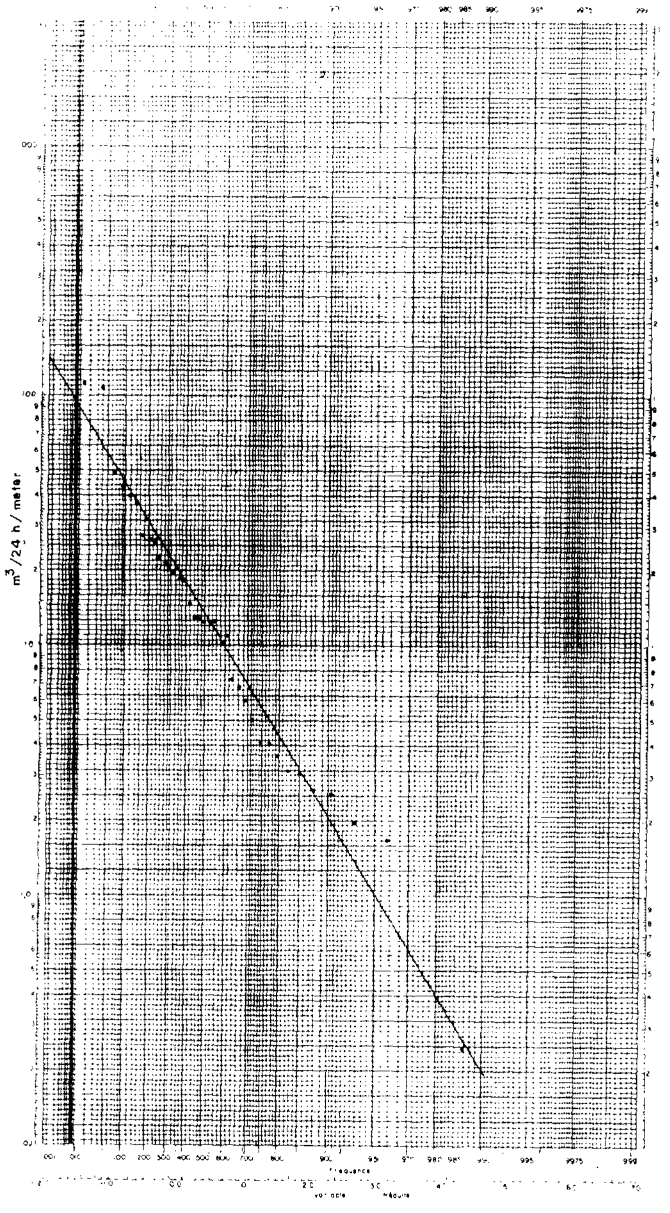


FIGURE E-8

FRECHET DISTRIBUTION OF UNIT AQUIFER PRODUCTION

Modern Basalts (Bii)

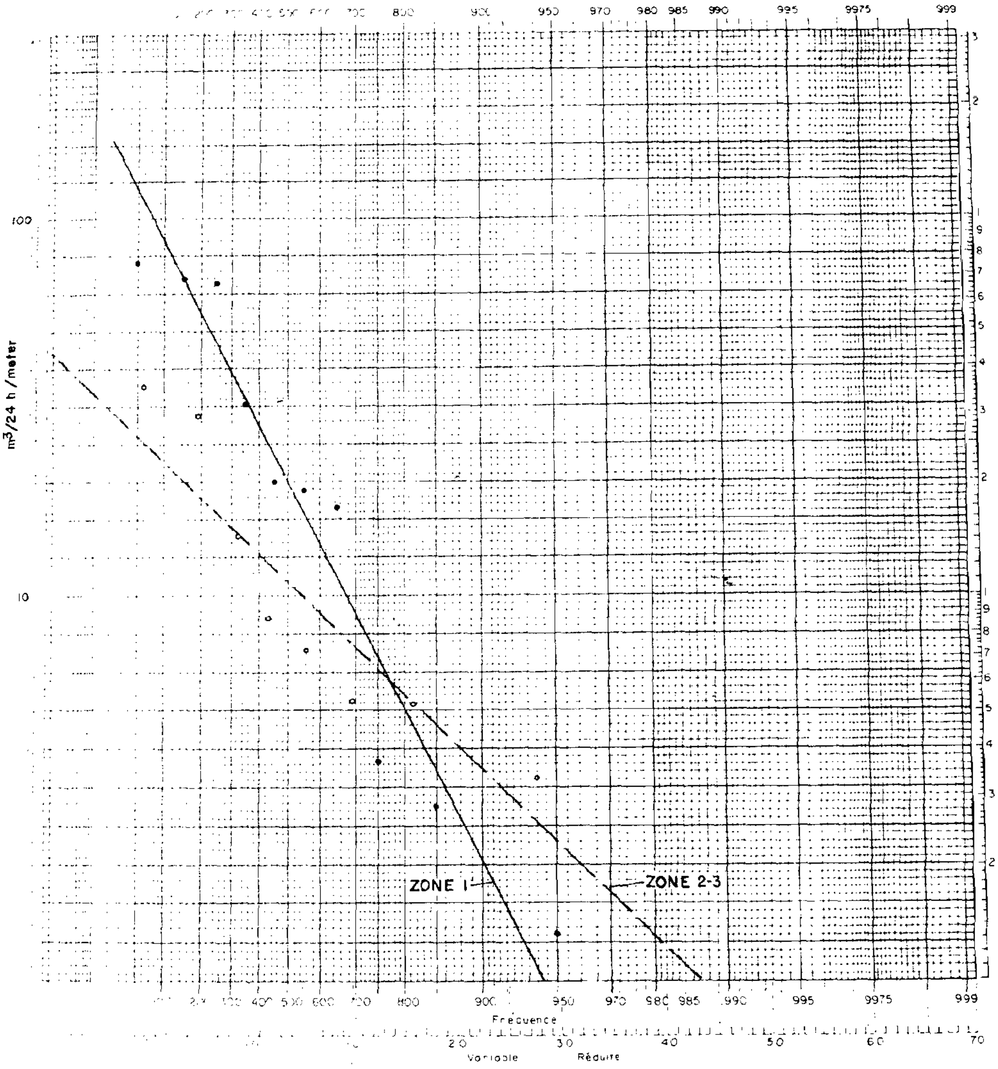


FIGURE E-9

GALTON DISTRIBUTION OF UNIT AQUIFER PRODUCTION

Roque Nublo and Phonolites

ZONE 2

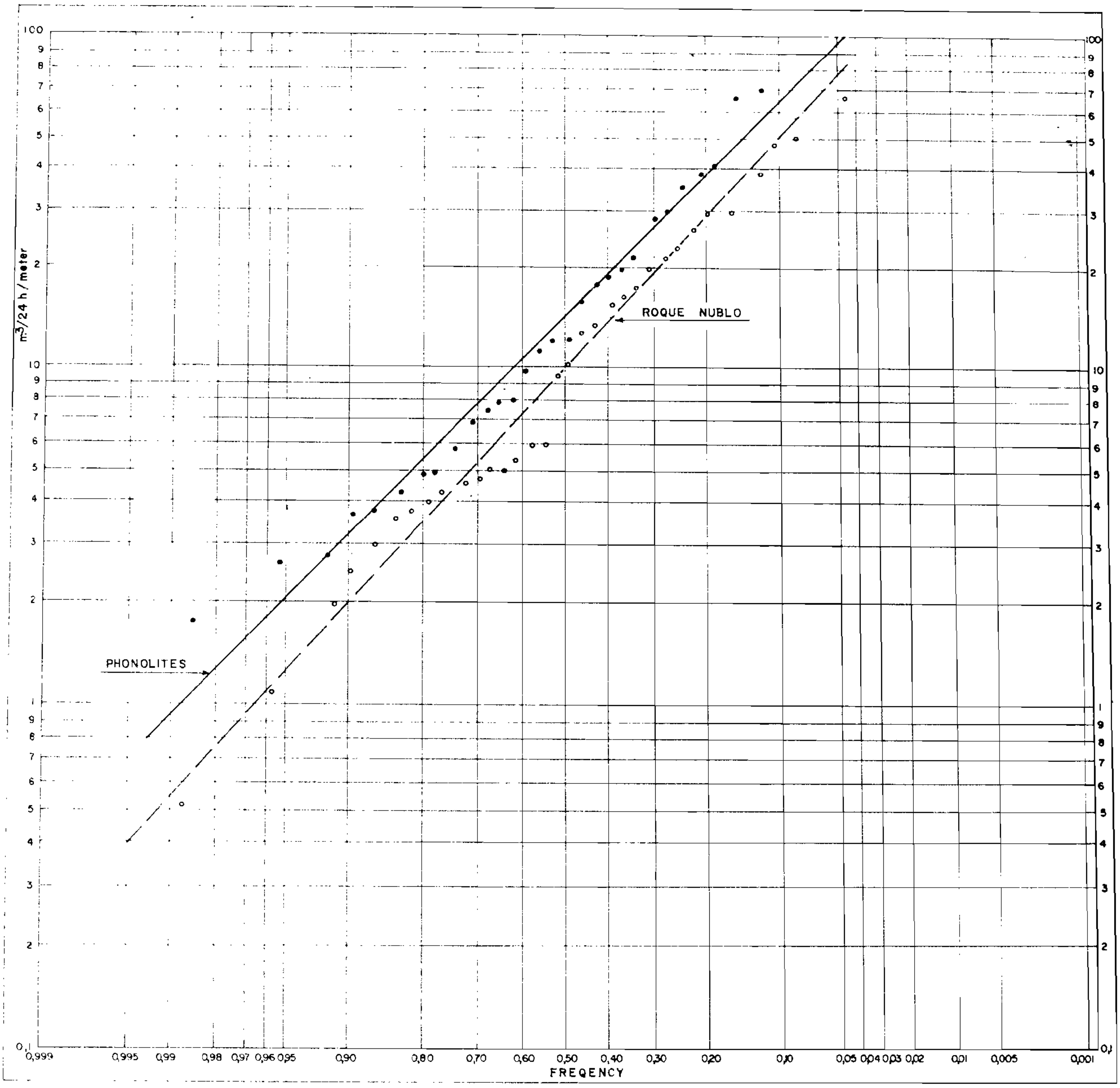


FIGURE E-10

FRECHET DISTRIBUCION OF UNIT AQUIFER PRODUCTION

Old Basalt (Bi) and Ignimbrites (Ig)

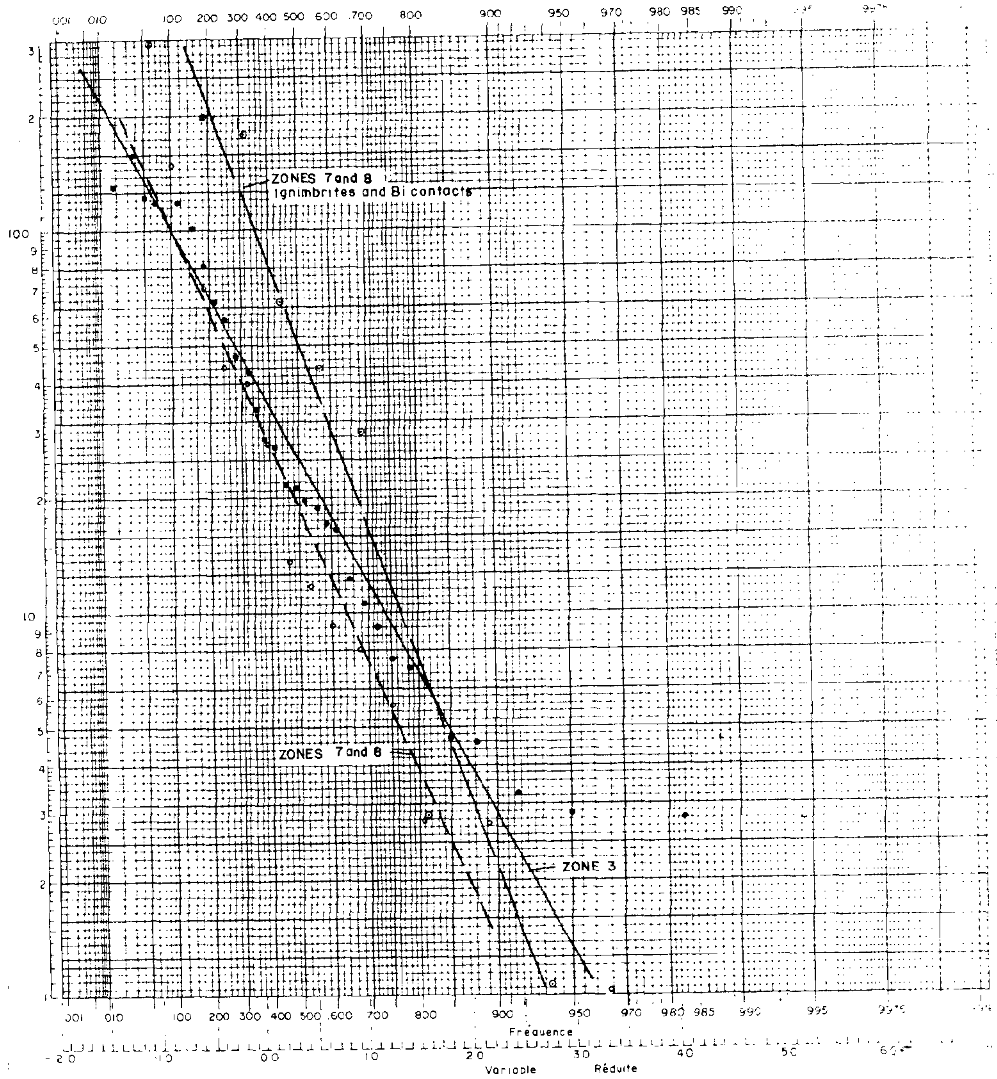


FIGURE E-11

If we exclude the curves with less than 10 points we can estimate the potential production on the basis of median values, for theoretical saturated depths of 50,100,200 and 300^m. The results are shown in Table E3.

It is interesting to note the comportment of the potential production for frequencies of 20% and 10% for example. Only 3 curves corresponding to Post-Miocene Basalts, Miocene Basalts and Roque Nublo Formation were selected for a detail frequential analysis whose results are summarized in Fig E.12.

The following commentaries can be made of the above figure.

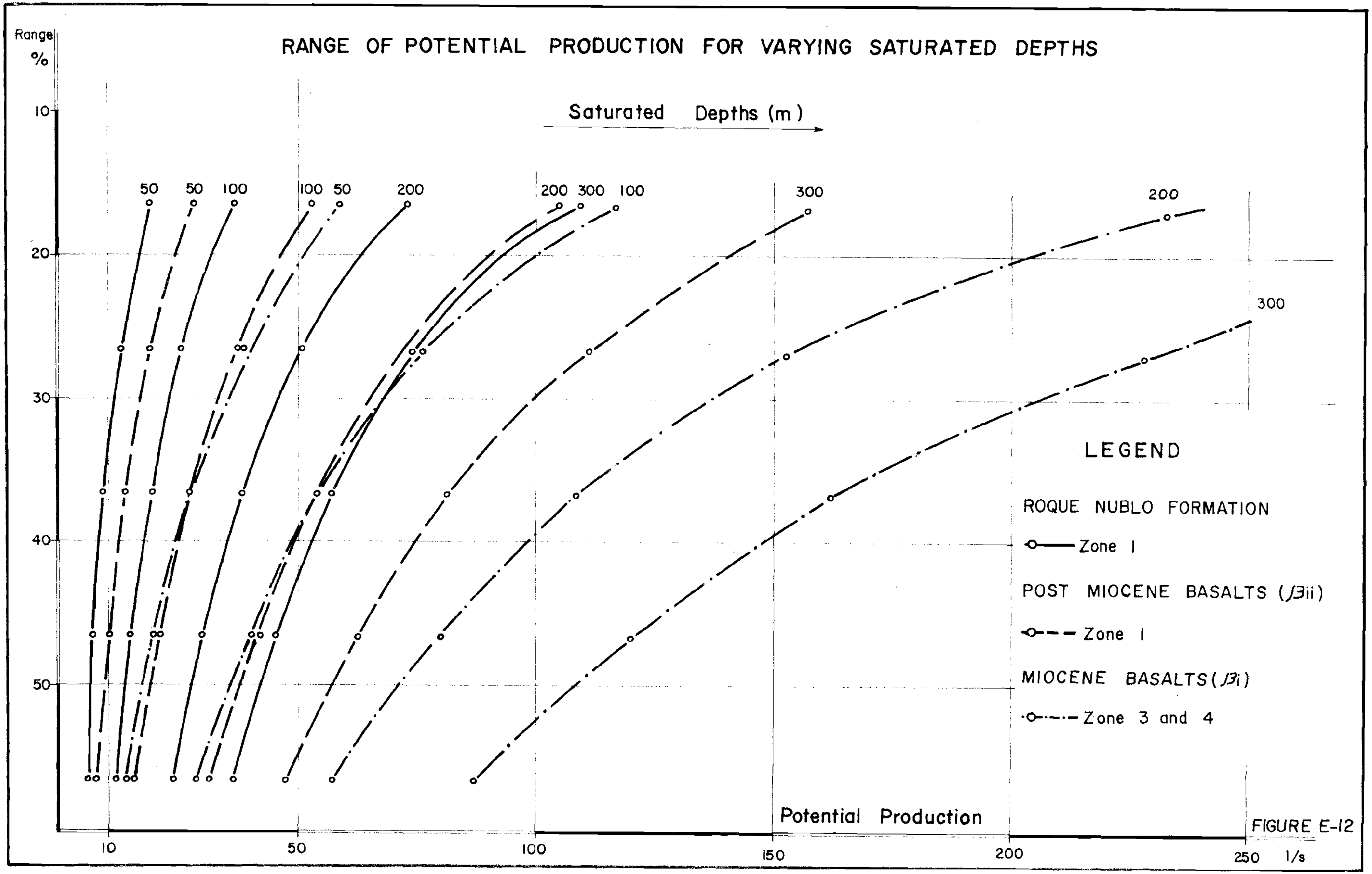
There is general increase of potential production from Roque Nublo through Post-Miocene Basalts (Bii) to Miocene Basalts (Bi) and that, for medium and low frequency values.

The spread of RN and Post-Miocene Basalts is less than for Miocene Basalts in the higher frequencies (40 to 50%) and the difference between RN and Post-Miocene Basalts (Bii) is not significant. This difference however is accentuated in low frequencies to the profit of the Post-Miocene Basalts.

For a frequency of 10% and for 100^m of saturated depth in Bii the potential production is around 50 l/s whereas for Bi it is nearly 60 l/s for only 50^m of saturation. Also, for 30% the potential is the same for 100^m and 50^m of saturation in Bii and Bi, respectively. This would indicate that the Miocene Basalts are provided with higher storage coefficient values or high fissure flow rates distributed unevenly in the rock media on a low frequency level.

The opposite will be true for Miocene Basalts and Roque Nublo Formation where there is a certain uniformity in the hydraulic characteristics of the rock media.

The above observations would indicate that in the search for water in Post-Miocene Basalts and Roque Nublo Series, chances are high in obtaining



RANGE OF POTENTIAL PRODUCTION FOR VARYING SATURATED DEPTHS
Range %
Saturated Depths (m)
50
50
100
100
50
200
200
300
100
300
200
300
LEGEND
ROQUE NUBLO FORMATION
Zone I
POST MIOCENE BASALTS (βii)
Zone I
MIOCENE BASALTS (βi)
Zone 3 and 4
Potential Production
l/s

FIGURE E-12

medium yields probably explained by the existence of well connected hydraulic systems. In the Miocene Basalts generally higher yields are obtained but the spread is very great for low frequencies probably due to a greater dispersion of the hydraulic characteristics of the rock media. The generally higher yielding capacity of the Miocene Basalts should be related to their occurence on the basal parts of the island where a higher degree of saturation generally exists as said earlier in this Chapter.

5. Hydrodynamic behaviour of aquifers

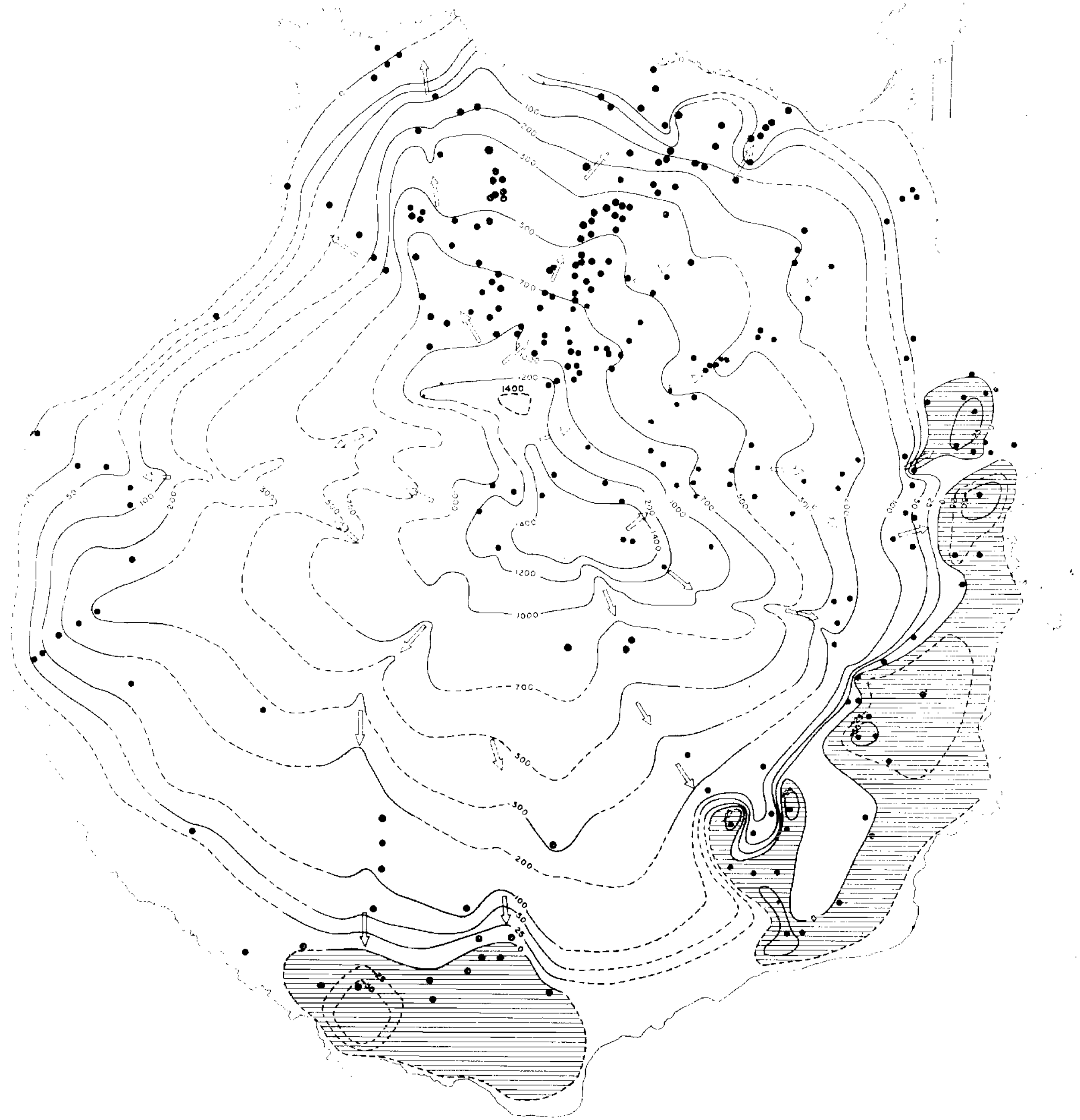
A knowledge of the hydrodynamics of the rock formation of the island was obtained mostly through analysis of the water level behaviour under natural conditions, pump tests as well as through historical records.

5.1 Study of Water Level

Altogether 5 water level maps have been made in the island, 4 of them corresponding to dynamic levels during the summer and winter seasons and 1 map of the static water levels giving a picture over a larger period. The number of points used in the establishment of these maps varied from 350 to 450.

The piezometric surface thus designed shows generally the top of the saturated zone as defined in Section 1 of this Chapter. However, in certain areas specially the summit of the island, several hanging water levels with springs are found. Also in the principal barrancos of the southern part of the island the water levels are related to very individualized flows along valley bottoms. In the western part of the island within the Trachy-Syenite Complex, no groundwater flow has been detected but subsurface flow does occur in the valleys.

Two dynamic water level maps are presented in Figs E13-E14. The Fig E14 represents the winter pumping system when the maximum pumping coincides with the tomatoe season in the southern part of the island. The Fig E14 represents the summer pumping system where maximum pumping takes place in the



Area below o m (pumping cones)

Major directions of groundwater flow.

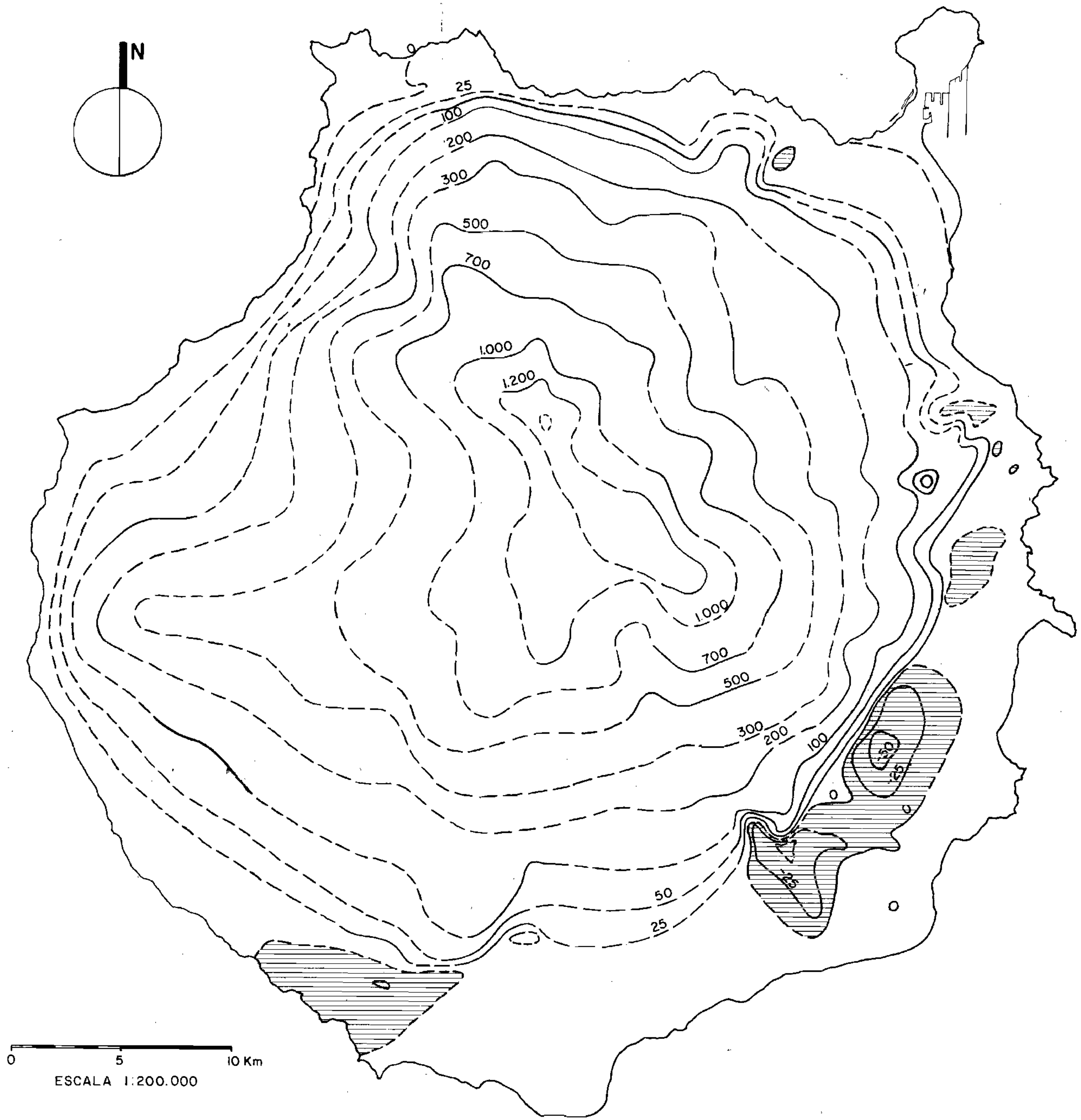
All values expressed in meters

UNESCO/ UNDP	WATER RESOURCES OF CANARY ISLANDS	M. O. P.

WATER LEVEL MAP
(DEC. 1970-JAN-1971)
GRAN CANARIA

DATE: FEBRUARY 1974

FIG: E-13



Area below o[m] (pumping cones)

All values expressed in meters

UNESCO/ UNDP	WATER RESOURCES OF CANARY ISLANDS	M. O. P.

WATER LEVEL MAP
(JUNE AUGUST 1972)
GRAN CANARIA

DATE: FEBRUARY 1974 | FIG: E-14

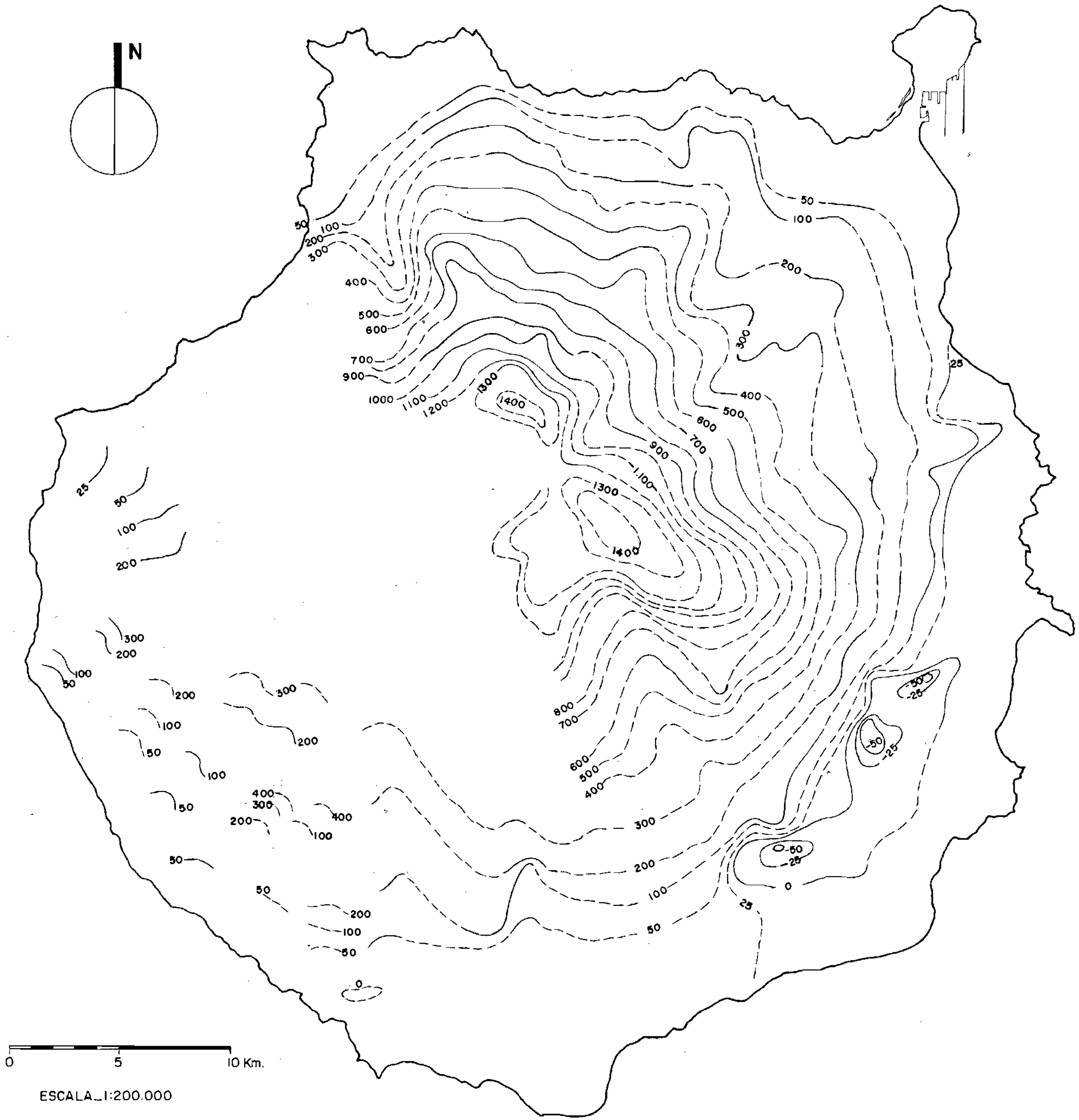
northern part associated with the banana plantations. In winter time the pumping cones in the eastern and southern parts of the island are better defined and accentuated due to intensive pumping in these regions.

The area below sea-level at this season shown by hachures in Fig E13 is about 175 km^2. The area of overdraft represented as a permanent cone in the static water level map in Fig E15 is about 50 km^2 developed in the Miocene Basalts between Agüimes and Tirajana Basin. In both areas the risk of salt water intrusion is great specially so in the overdraft zone where in fact several wells are gradually abandoned due to salinization.

The comparison between the static water level with those of the dynamic water levels indicates that the general pattern remains the same but the curves are less accentuated and that in the eastern and southern areas several seasonal cones in the lower valleys of Telde and in the Arguineguin-Maspalomas region tend to disappear. As mentioned before, only the permanent pumping cones between Agüimes and Tirajana valleys persist. On a detail scale the difference between the dynamic and static levels can vary on the range of 10 to 50^m.

A map of Δ water level values, Fig E16 has been compiled comparing spring and summer state with winter state for the year 1972. There is a clear indication of positive values in spring and summer along the principal barrancos due to recharge deriving from the centre of the island. Also the great variation of levels both in a positive and negative manner is seen in the eastern and southern coastal zones under the heavy pumping impulse.

All maps present a system of flow where the drainage lines are concentrated along the principal barrancos of the island specially in the eastern and southern regions. On the whole, there is a well defined concentric zone in the central area from which water flow diverges in all direct-

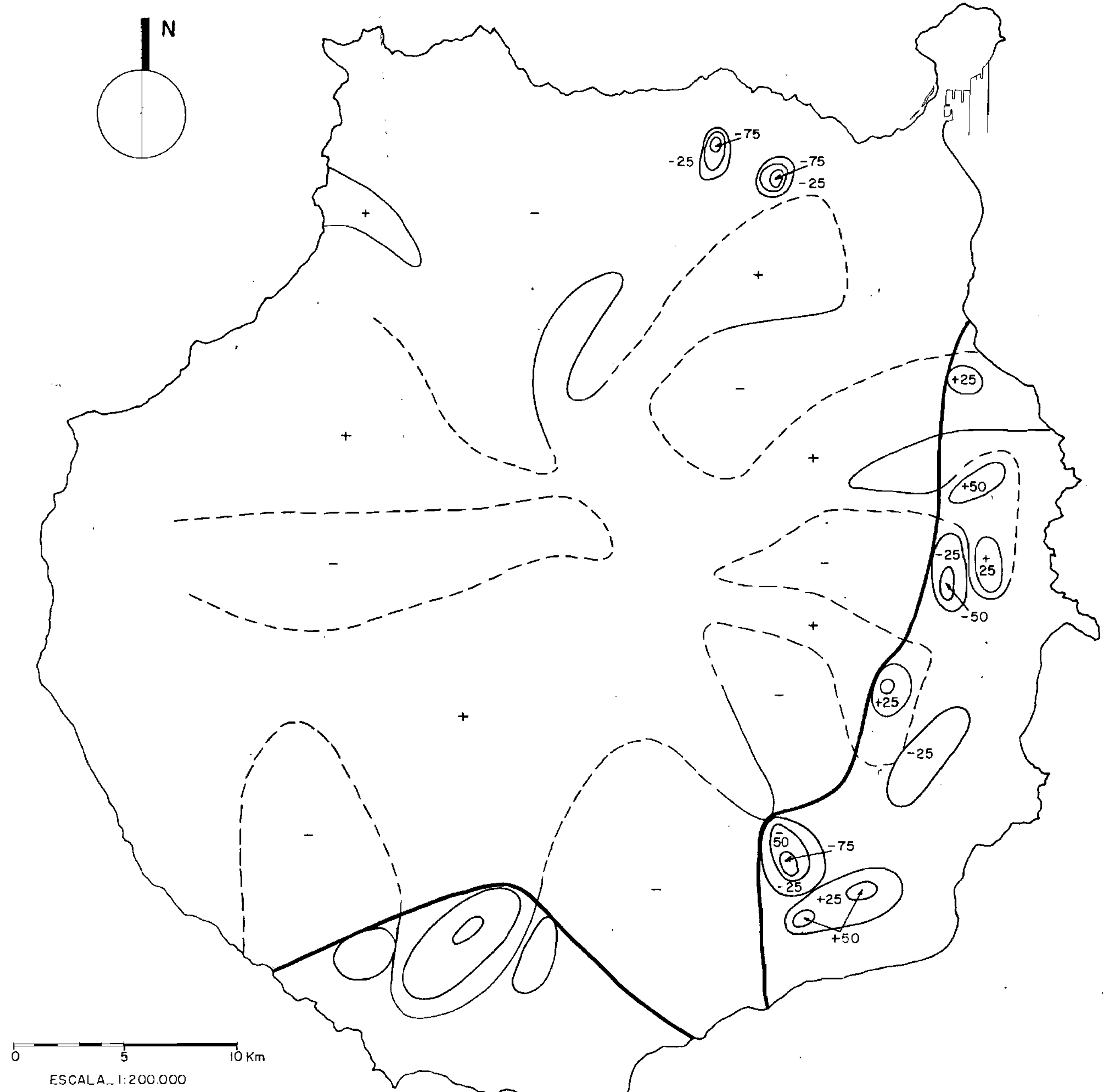


All values expressed in meters

UNESCO/ UNDP	WATER RESOURCES OF CANARY ISLANDS	M. O. P.

STATIC WATER LEVELS
(1971-73)
GRAN CANARIA

DATE: FEBRUARY 1974 | FIG: E-15



Boundary of piezometric variation due to coastal pumping.

Note: July – August 72 compared with Nov. 71 – Jan. 72

UNESCO/ UNDP	WATER RESOURCES OF CANARY ISLANDS	M. O. P.

VARIATION OF WATER LEVELS
(1971-72)
GRAN CANARIA

DATE: FEBRUARY 1974 FIG: E-16

ions. The real water level in the central area originates around 1.400^m above sea level. The general hydraulic gradients from the summit to sea level varies from 10% in the NW and N, 7 to 8% in the NE, 11 to 12% in the E and SE, 7 to 9% in the S and SW. However, along short distance slopes of up to 12% have been found. Nearer the coast the hydraulic gradients vary from 4 to 6%.

These water level maps permit us to define the geometry of the water massif of the island which would have a volume of about 650.10^9 m^3. If we suppose a storativity of 0,5% we have a total stocked volume of about 3250 Mm^3 in the island's water massif.

5.2 Analysis of well hydrographs

Over 35 wells were chosen over the entire island showing practically all types of aquifer conditions and exploitation situations. Of the hydrographs obtained over a period of 18 months about 100 recovery and drawdown curves were analyzed. These well hydrographs were used not only for the study of aquifer characteristics of the different formations but also for the determination of gallery influences and of well storage, the latter of particular importance in the large diameter wells of the island. In the analysis of the pumping tests the nonequilibrium Theis recovery method was largely used even though some examples of steady state, equilibrium flow also were studied.

Typical examples of the drawdown analysis are presented below. In Fig E17 is shown an example of a short pumping test at a constant discharge of 10 l/s during only 3h. Clear separations of well storage, aquifer contribution and a near constant lowering of water level in a less permeable strata are indicated in the figure. A similar example is given in Fig E18, in a well pumping for 7,60h and at 15 l/s, where however the well storage factor is mixed up with the aquifer contribution derived mainly from a gallery. In the same figure in a well pumping for 6,75h at 10 l/s we have an opposite effect where a clear recharge boundary is seen. In fact the trans-

WELL LA CALZADA 2024

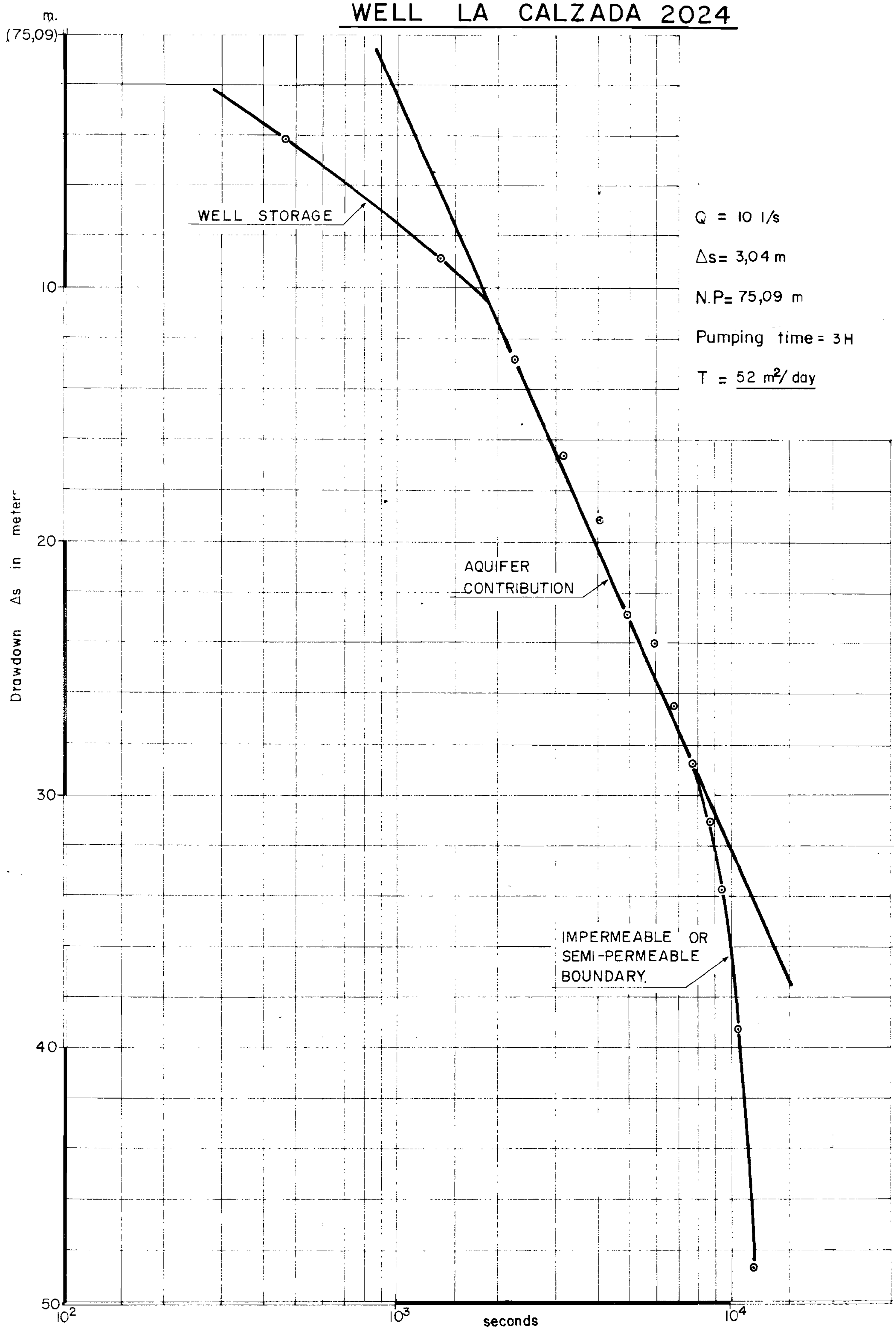
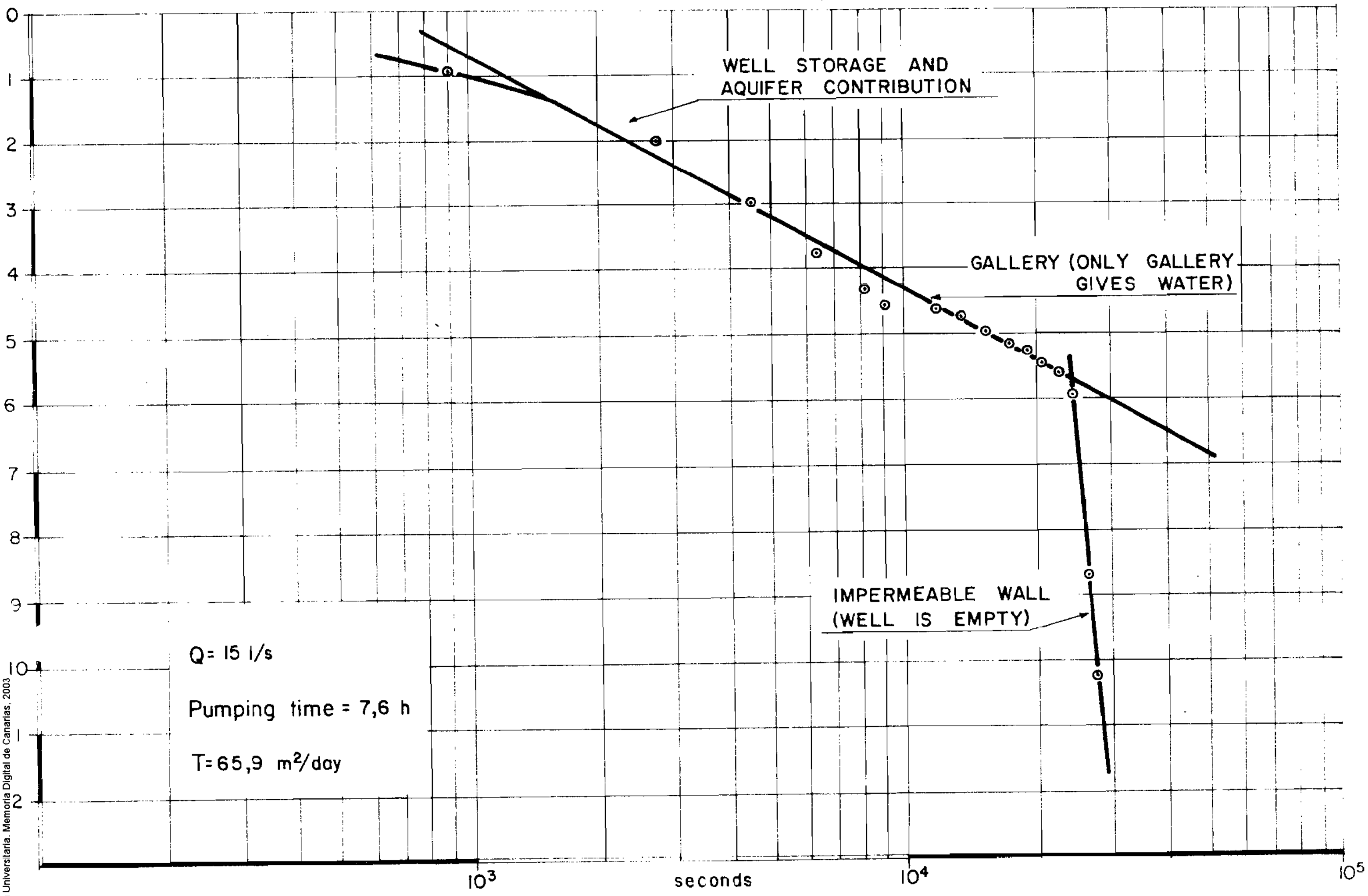


FIGURE E-17

WELL EL COLMENAR 2075



WELL HOYA DEL POZO 2163

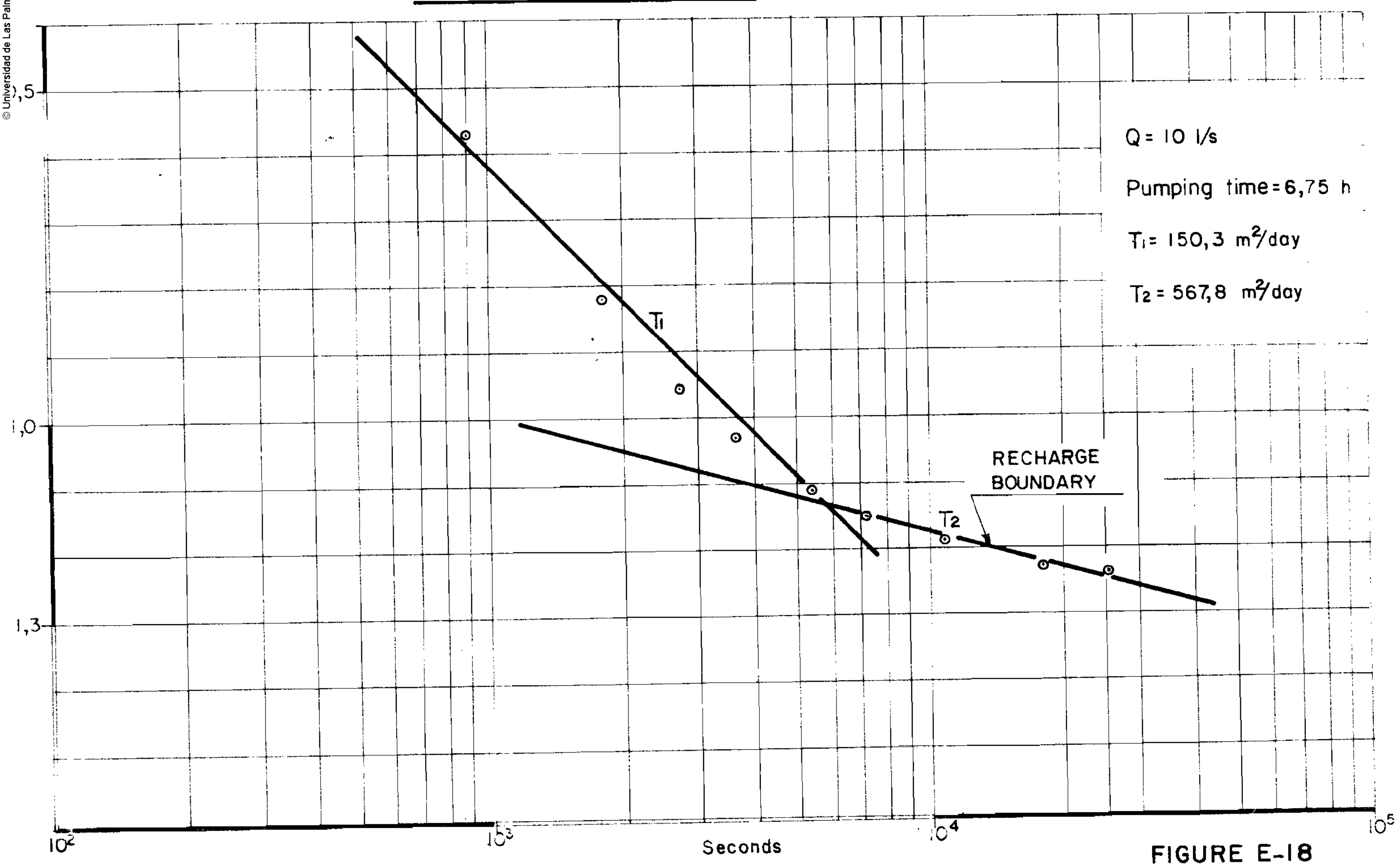


FIGURE E-18

missivity value increases from 150 m /day to 570 m /day due to the inflow from a recharge level. In FigE19 in a well pumping during 14h at 26,6 l/s, the drawdown shows several influences. The well storage comportment is reversed, possibly indicating confined aquifer conditions. Besides, one can note the influence of a small gallery followed by a less permeable layer and finally a recharge boundary with higher transmissivity.

In the analysis of the recovery curves plotting residual drawdowns "s" versus t/t', two types of curves were obtained as seen in Fig E20. The first indicates the normal type curve in a well without gallery where the early part of the recovery shows slow recuperation as in Nº 5021 . The second type shows the opposite tendency with noticeable increase in the rate of recovery at the beginning due to contribution through a gallery. A similar situation occurs when the bottom aquifer level contributes more than the rest or when most of the water is derived from important secondary fissures as is suspected in the case of the well Nº 2082 .. Some wells situated on the coastal zone near the salt water interface demonstrates the same phenomenon where a strong alimentation arrives from the sea front.

A judicious analysis of well hydrographs both of drawdown and recuperation helps understand the hydraulicsof aquifer comportment, sometimes even in its details.

5.3 Hydraulic properties of geological units

The hydrodynamic properties of the aquifer units of the island have been tested only on selected areas. The principal parameter tested was transmissivity but several areas gave an idea of the storativity of the water bearing rocks by an analysis of historical drawdown.

A detail study of the distribution of transmissivity showed that it was possible to establish a certain scale in the comportment of the aquifers. Also it was found that there was a regional grouping of tested

WELL CRESPO I 1092

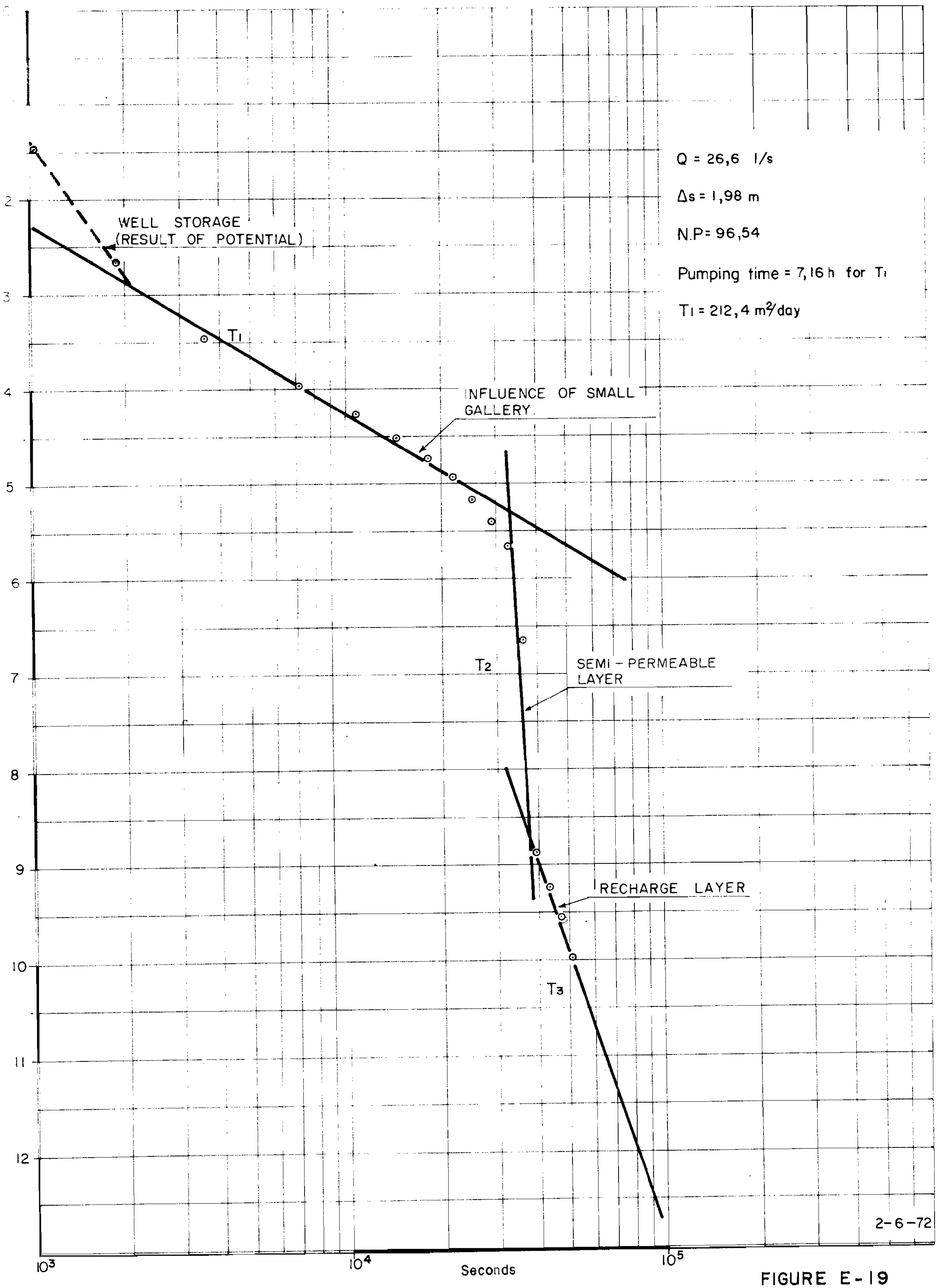
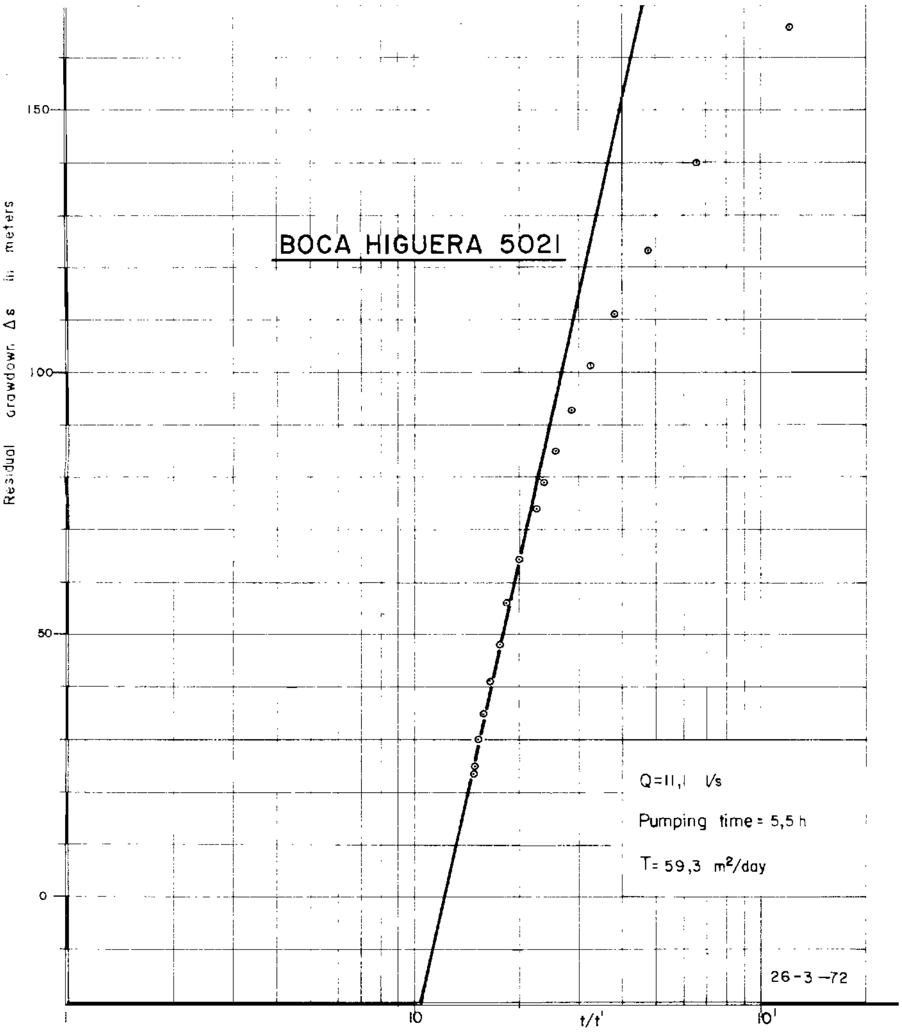


FIGURE E-19


BOCA HIGUERA 5021
Residual drawdown Δs in meters
150
100
50
0
10
t/t'
10'
Q=11,1 l/s
Pumping time = 5,5 h
T= 59,3 m²/day
26-3-72

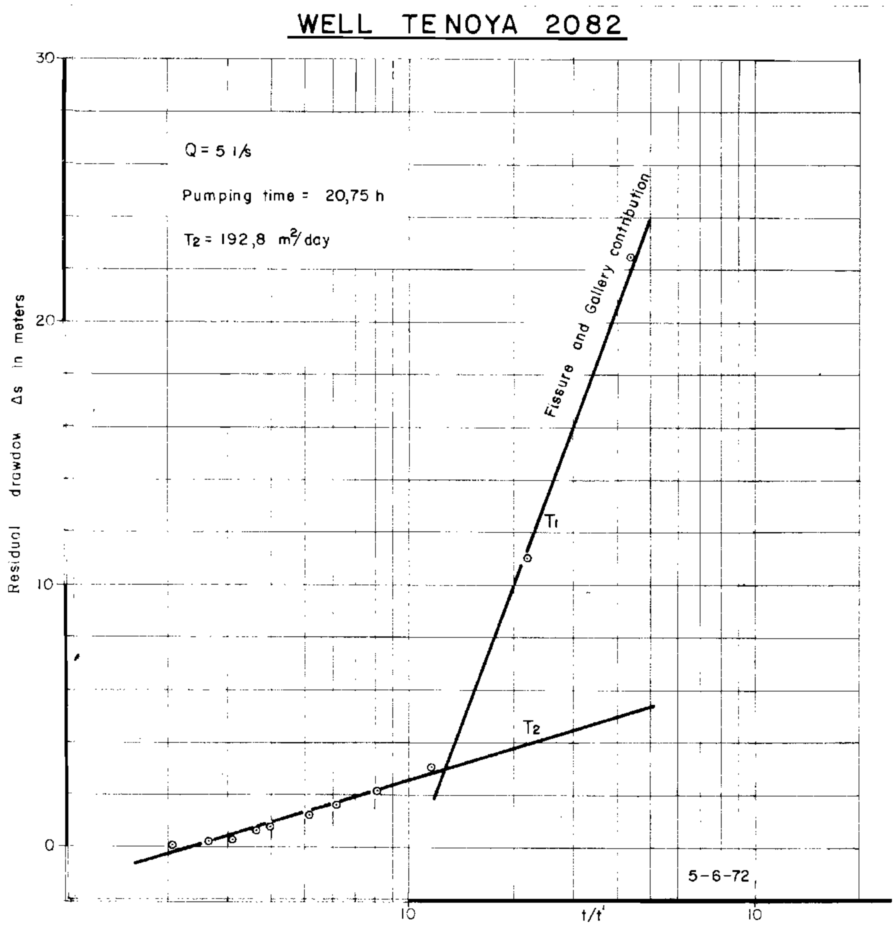

WELL TENOYA 2082
Residual drawdow Δs in meters
30
20
10
0
Q= 5 l/s
Pumping time = 20,75 h
T2 = 192,8 m²/day
Fissure and Gallery contribution
T1
T2
10
t/t'
10
5-6-72

FIGURE E-20

values through which a zonal hydrodynamic behaviour was inferred. Transmissivity values calculated in $m^2/24h$ was correlated with specific drawdown or recovery expressed in m^3/hour/metre. The resulting correlation is shown in Fig E21.

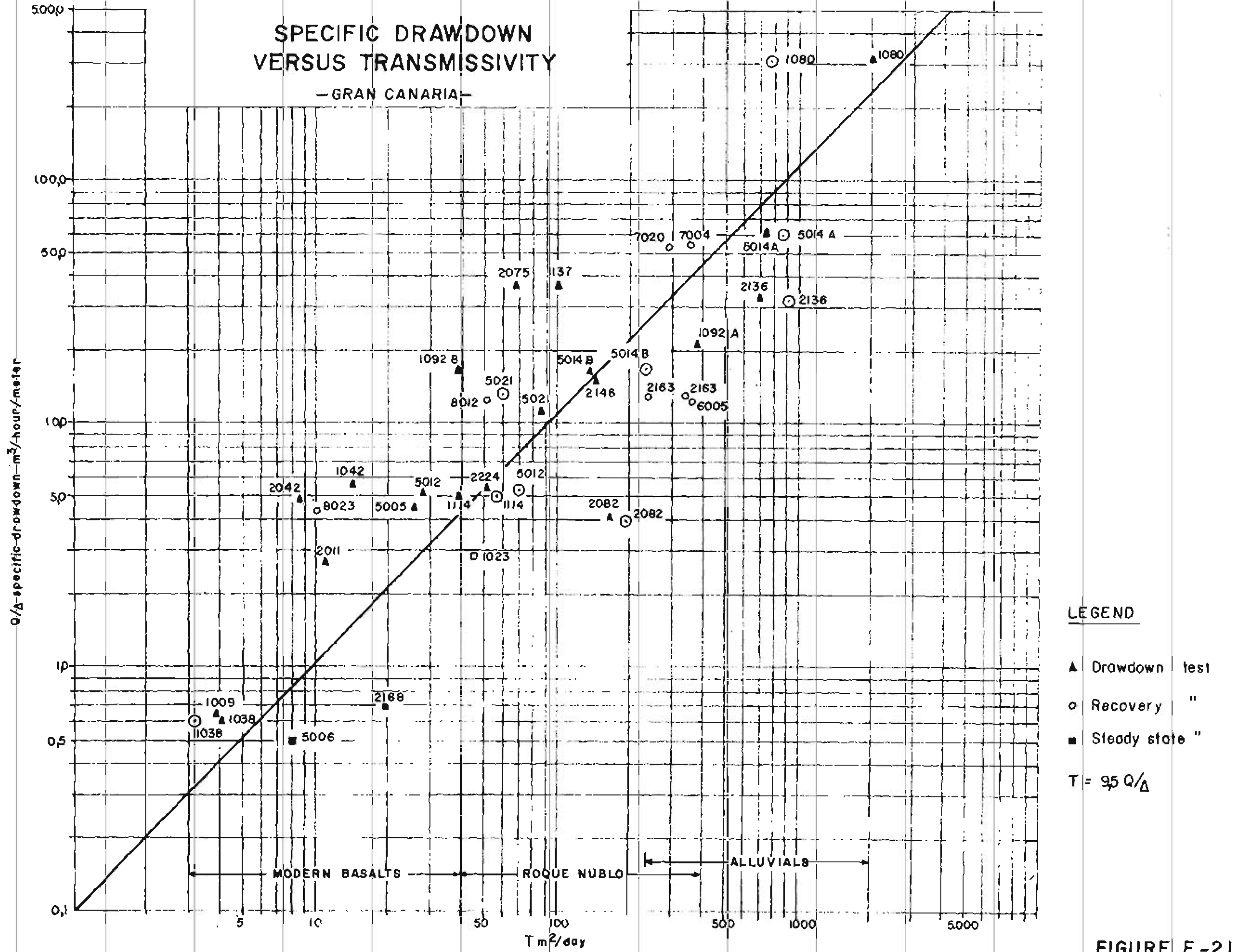
The above curve indicates that in spite of the dispersion there is a clear correlation between the two parameters and also that there is a general increase of T and Q/Δ values from Modern Basalts through Roque Nublo and finally to Alluvial Deposits. No clear example of Old Basalts was found but some marginal cases showed that they behave more like the Modern Basalts but with low values.

As for Phonolytes and Ignimbrites, practically all cases found were on contact zones between two formations but all indications showed that the values were low, with some exceptions.

For the extrapolation of transmissivity values within each aquifer zone, the general relation $T = 9{,}5\ Q/\Delta$ obtained from FigE21 was used. The basic data for the extension was obtained from measurements and inquiry from well owners, of the pumping systems, yield and estimation of drawdown. and recuperation. The resulting map is shown in Fig. E.22.

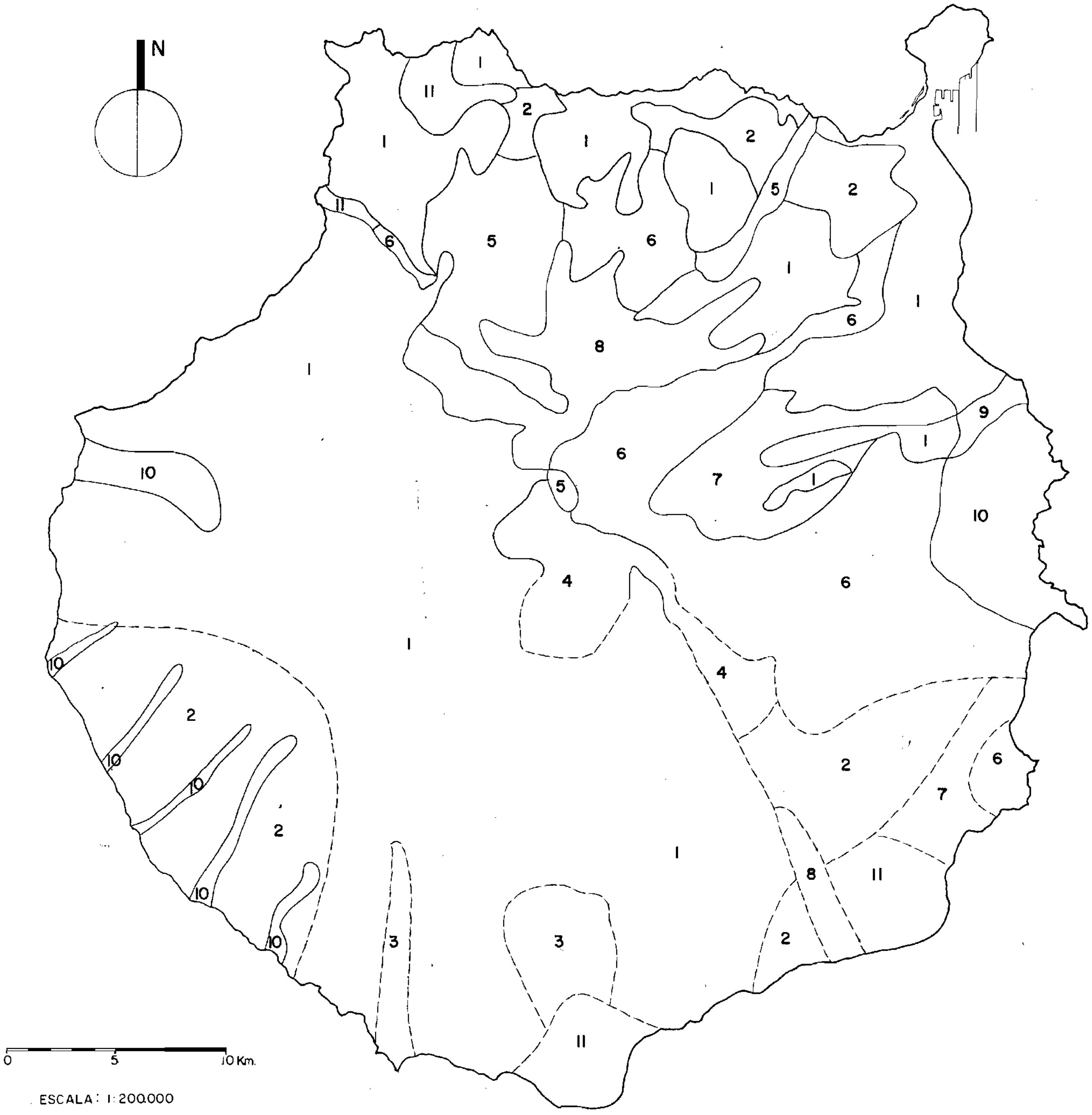
The above map in spite of its inherent imprecision provides a useful tool in the study of the potential yield of aquifers. Based on the principal formations the following limits of transmissivity values are advanced:

Geological Formation	Transmissivity	
- Old Basalts	5-20	$m^2/24h$
- Phonolytes, Trachy-Syenitic Complex and Ignimbrites	5-10	"
" (Exceptional Zones)	10-25	"
- Roque Nublo (dominantly agglomerates)	25-50	"
- Roque Nublo (mixed with basalt layers, tephrites, sediments)	50-200	"



SPECIFIC DRAWDOWN
VERSUS TRANSMISSIVITY
—GRAN CANARIA—
Q/Δ-specific-drawdown-m³/-hour/-meter
T m²/day
0,1
0,5
1,0
5,0
10,0
50,0
100,0
5.000
5
10
50
100
500
1000
5.000
MODERN BASALTS
ROQUE NUBLO
ALLUVIALS
1080
1080
7020
7004
5014 A
5014A
2075
137
2136
2136
1092 A
1092 B
5014 B
5014 B
5021
2146
8012
2163
2163
5021
6005
1042
2224
5012
2042
5012
8023
5005
1114
1114
2082
2082
2011
1023
1009
2168
1038
11038
5006
LEGEND
▲ Drawdown test
o Recovery "
■ Steady state "
T = 95 Q/Δ

FIGURE E-21



LEGEND

1 = 5 to 10 $m^2/24$ hours
2 = 10 to 15 "
3 = 15 to 20 "
4 = 20 to 30 "
5 = 30 to 40 "
6 = 40 to 50 "
7 = 50 to 75 "
8 = 75 to 100 "
9 = 150 to 200 "
10 = 200 to 500 "
11 = 500 to 800 "

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MAP OF TRANSMISSIVITY

GRAN CANARIA

DATE: FEBRUARY 1974 | FIG: E-22

-	Modern Basalts (contact with Phonolytes, Old Basalts, etc.)	10	$m^2/24h$
-	" (Variable conditions)	40-200	"
-	Alluvial deposits (slope deposits, Terrace materials, dejection cones, etc.)	200-800	"

This scale of values indicates that Modern Basalts and the lower member of the Roque Nublo Formation have similar values which would mean that hydraulically the two units behave in a similar manner, a conclusion we already arrived at in Section 3 of this Chapter.

The study of storativity of the aquifers has been made using historical drawdown as well as areas of pumping cones. The formula used was as follows:

$$S = \frac{V - In}{H.A}$$

where

V = Total volume extracted during a time period.

In = Infiltration calculated for the same period.

H = Total historical drawdown or depth of pumping cone.

A = Surface area.

S = Storage coefficient.

In the application of the above formula for a certain area (between 1 to 3 km^2) the values of storativity obtained were checked for several periods.

The result of this analysis showed that the spatial variation of storativity was much less than that of transmissivity. There probably is a closer relationship between the rock formation and storativity than with transmissivity. The following scale of values was proposed according to the different formations:

Geological Formation	Storativity
- Old Basalts	0,50 - 1,0 %
- Phonolytes, Trachy-Syenitic Complex and Ignimbrites	0,01 - 0,10 "
- " (Exceptional zones)	0,10 - 0,50 "
- Roque Nublo	1,50 - 3,50 "
- Modern Basalts	1,00 - 2,00 "
- Alluvial Deposits	3,00 - 5,00 "

These values can be compared with some values of total porosity obtained in laboratory tests: Roque Nublo 15-50%, Modern Basalts 30-60%.

Some indirect idea of storage coefficient was also obtained on individual wells for various values of "r" as supposed limits of pumping influence.

The value of T and S calculated and estimated for the different zones of the island have been used in the simulation of present and future water levels in the R-C model of Gran Canaria. The reproduction of the present piezometric levels have been quite satisfactory, thus imparting a certain confidence to the hydraulic properties thus obtained.

An attempt has been made to get a first idea of the value of permeability of the different formations knowing transmissivity, hydraulic gradient and saturated thickness. It was assumed following the explanations given in Chapter 3, that Darcy's law for volcanic aquifers is applicable if large zones are considered.

A great range in values of K has been found varying between 0,05 to 25 m/24h, probably due to the great variation of saturated thickness. The values obtained for the different geological formations are shown below:

Geological Formation	Permeability (K)
- Old Basalts	0,05 to 0,5 m/24h
- Phonolytes, Ignimbrites	0,10 to 0,5 "
- Roque Nublo	0,30 to 0,75 "
- Modern Basalts	0,20 to 1,0 "
- Las Palmas Terrace Materials	1,5 to 8,0 "
- Alluvial deposits	5,0 to 25,0 "

Some figures obtained in bore-hole tests made by the Geological Service, applying the Lefranc or Lugeon method, are also given below:

Site	Formation	Value of K m/24h
Paralillo	Trachy-Syenites	0,03
Ariñez	Roque Nublo (Agglomerates and with intercalated basalts)	0,10 - 0,80

These results are comparable with those obtained by the application of the Darcy law and can be regarded as representative of the major formations.

The above values computed correspond to mean permeability. Generally speaking the Modern Basalts which often overly the Roque Nublo Formation comport essentially a vertical flow as recharge takes place across this formation whereas in the latter formation, horizontal permeability will be the principal component. In Phonolytes and Ignimbrites, which constitute a substratum for flow in the North and Eastern parts of the island, the movement of water will generally be horizontal and concentrated along a few meters which could explain the relatively high values obtained for the contact zones.

A certain idea of the mean velocity of water movement within the different units can be attempted using the following formula:

$$Ve = \frac{Ki}{S}$$

K = mean permeability
i = hydraulic gradient
S = storage coefficient

Calculations have been made along the principal hydrogeological cross-sections. There is concordance between the type of formation and the value of real velocity found as seen in the figures below:

- Modern Basalts	1,5	m/24h
- Roque Nublo	1,25 - 2,5	"
- Old Basalts	0,75	"
- R.N. or Modern Basalts overlying Phonolytes or Ignimbrites Substratum (contact zones)	2,0 - 5,0	"
- Alluvial deposits (including Las Palmas Terrace Formation)	5,0	"

No figures have been obtained for Ignimbrites, Phonolytes and the Trachy-Syenitic Complex generally considered impermeable excepting where fractures occur locally. The Lefranc tests give values between 0,01 and 0,03 m/24h.

The general conclusions is that groundwater movement in the principal aquifers in the island of Gran Canaria, varies from $8,5.10^{-6}$ m/s in Old Basalts through $1,37.10^{-5}$ m/s in Modern Basalts, $1,4-2,9.10^{-5}$m/s in Roque Nublo to $5,8.10^{-5}$ m/s. in Alluvial Deposits.

The maximum thickness of the Modern Basalts and the Roque Nublo formation in the centre of the island is estimated at about 800^{m}. If we suppose a mean velocity of 1,0 m/24h, recharge water will attain the substratum of the above aquifer units through vertical movement in 2 years. Actually this may be a little longer as the vertical movement of water will be slowed down with depth.

It is supposed that the centre of the island is constituted by Phonolytic and Trachy-Syenitic materials opened up by numerous permeable vents associated with more modern volcanism. Water movement in such a case will be localized along conduits within the massif.

As for horizontal water movement, if we adopt the same mean velocity groundwater from the centre of the island will reach the coastal zones after a 20 kms distance run, in 20 years. This would mean that the "turnover" period of the water massif of the island is around this time period. This conclusion is in agreement with those of tritium analysis of groundwater and salt-balance values established for the island.

6. Estimation of Ground Water Resources and Possibilities

In the earlier section we have studied the hydraulic properties of the different geological formations. Also in the sections 1 and 2 it was pointed out that the most productive aquifers are Modern Basalts, Roque Nublo and Old Basalts.

6.1 Major Underground Structures with Reference to Groundwater

In the North-East half of the island the first two formations constitute also a future potential source of ground water. The substratum composed generally of Phonolytes, Ignimbrites and the Trach-y-Syenitic Complex although can produce water locally, is generally considered impermeable.

The Map E.23 shows the approximate depths of this substratum with reference to surface level. A clear definition of two import underground basins is seen - the more important comprises the upper part of Zone 2 as well as the upper and middle parts of Zone 1. Several individual deeps seem to exist within this basin of which the major one is found around Fontanales-Valleseco.

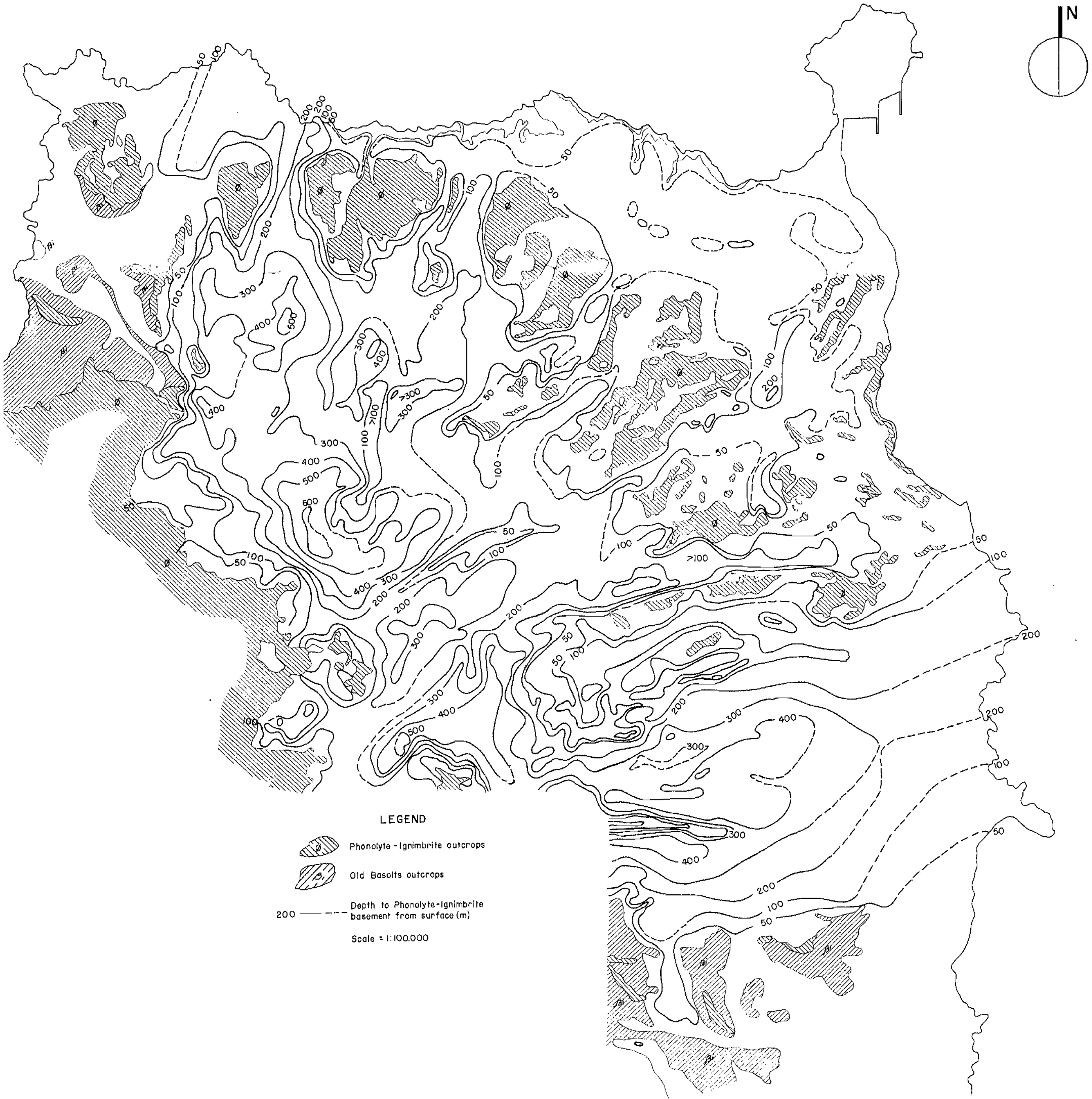
A second basin develops across the borders of Zones 2 and 3 over Phonolytic as well as Old Basalts Substrata. The maximum thickness develops a little north of the upper part of Barranco Guayadeque.

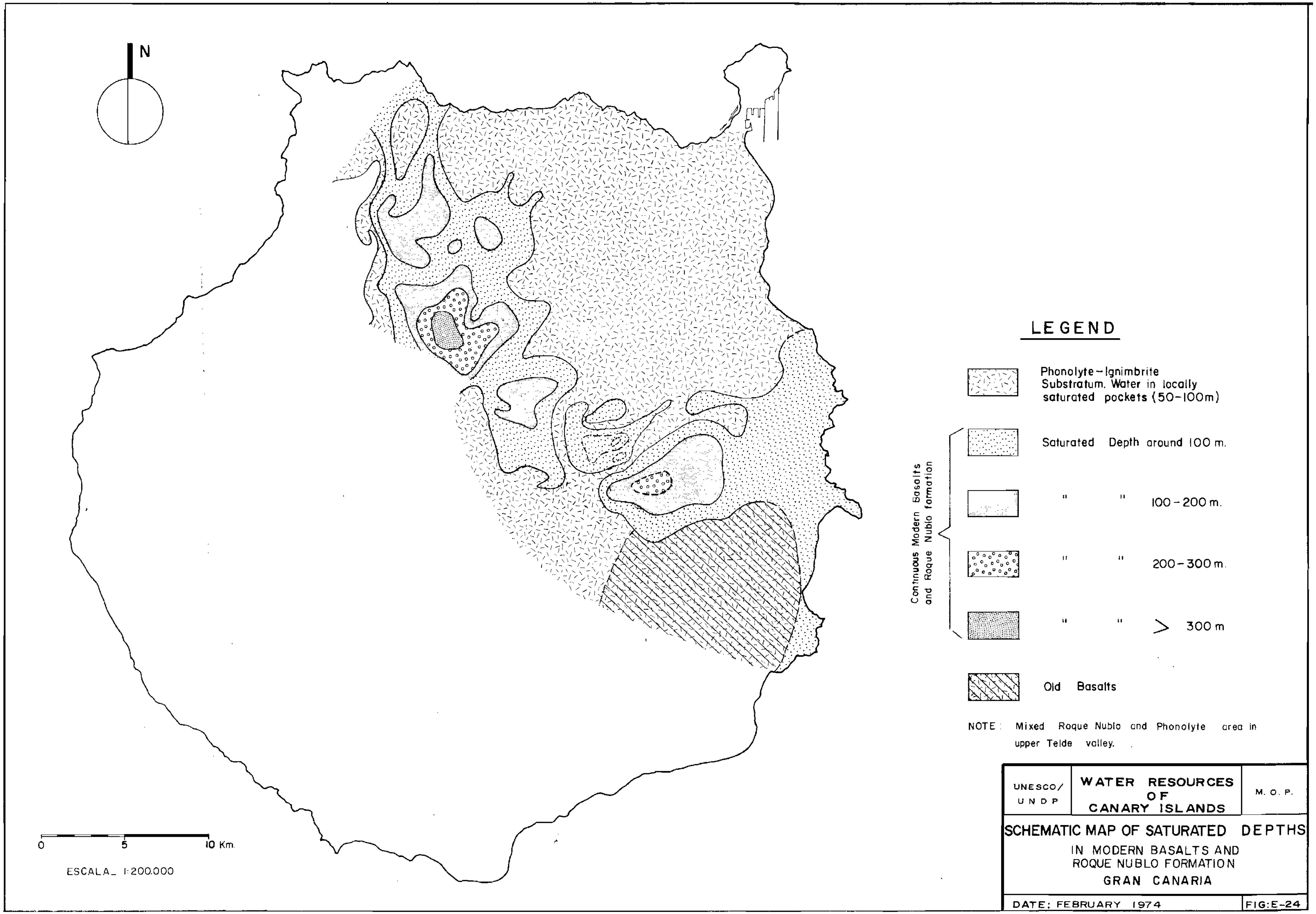
A better idea of the future possibilities of the North East part of the island is obtained from Map E.24 which shows saturated thicknesses obtained from the earlier map with reference to the static water level.

In the first underground basin, the saturated thickness varies from 0 to more than 300 meters. Thus, the upper Guiniguada basin has a saturated thickness of 200 meters, the Fontanales-Valleseco region more

MAP OF PHONOLYTE-IGNIMBRITE BASEMENT

—NORTH—EASTERN HALF OF GRAN CANARIA—




N
LEGEND
Phonolyte–Ignimbrite Substratum. Water in locally saturated pockets (50–100m)
Saturated Depth around 100 m.
" " 100–200 m.
" " 200–300 m.
" " > 300 m
Continuous Modern Basalts and Roque Nublo formation
Old Basalts
NOTE: Mixed Roque Nublo and Phonolyte area in upper Telde valley.
0 5 10 Km.
ESCALA_ 1:200.000
UNESCO/ UNDP
WATER RESOURCES OF CANARY ISLANDS
M. O. P.
SCHEMATIC MAP OF SATURATED DEPTHS
IN MODERN BASALTS AND ROQUE NUBLO FORMATION
GRAN CANARIA
DATE: FEBRUARY 1974
FIG:E-24

than 300 m. and around Montaña Alta up to 200 m. The hydrogeological situations in the ground water basin as well as in the surrounding areas are shown in cross-sections 1,2,3,4 and 13. It is seen that the future potential production lies principally in the lower part of the Roque Nublo formation.

As for the second underground basin there is a gradual thickening of the saturated depth from around 100m in the coastal zone to 200m or more towards the interior. However geological control in the upper part of this zone is poor.

In the southern half of the island the principal aquifer is constituted by the Old Basalts. Water tends to appear in the covered region of Ayagaures-Argineguin when approaching the contact zone or surface of the Old Basalt basement.

An idea of the topography of the Old Basalt basement is given in Map. E.25. In the east, the topography makes various dentations in the coast and the surface plunges slowly towards Telde, but toward the interior it forms a dome. This structure is explained in geological section 6. The eastern dome is separated from the S. western dome in Mogan by a wide valley found in the Fataga-Ayagaures region. Water from this aquifer can be exploited but it is advisable to remain above the 0^{m} line in order to avoid eventual sea water intrusion. The prospective zones are indicated in Map E.25.

6.2 Groundwater Discharge

It was pointed out earlier in this chapter that groundwater investigation was carried out on the basis of hydrogeological units and subunits. The theoretical discharge of each of these units has been calculated using the following formula:

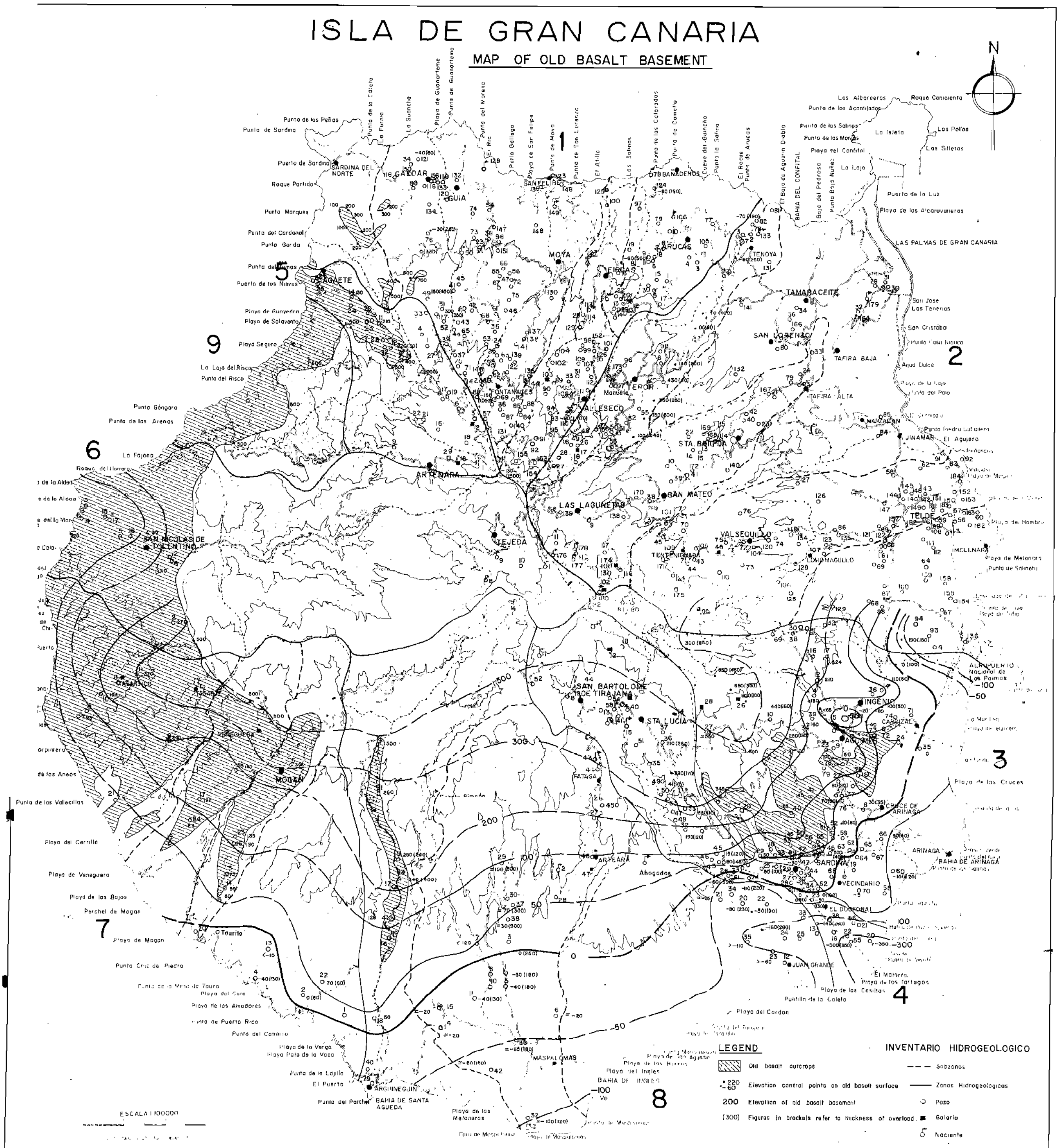

ISLA DE GRAN CANARIA
MAP OF OLD BASALT BASEMENT
N
LAS PALMAS DE GRAN CANARIA
GALDAR
GUIA
AGAETE
MOYA
FIRGAS
ARUCAS
TENOYA
TAMARACEITE
SAN LORENZO
TAFIRA BAJA
TAFIRA ALTA
TEROR
VALLESECO
STA. BRIGIDA
SAN MATEO
LAS LAGUNETAS
ARTENARA
TEJEDA
SAN NICOLAS DE TOLENTINO
VALSEQUILLO
TELDE
JINAMAR
INGENIO
CARRIZAL
AGUIMES
CRUCE DE ARINAGA
ARINAGA
BAHIA DE ARINAGA
VECINDARIO
EL DOCTORAL
JUAN GRANDE
SAN BARTOLOME DE TIRAJANA
STA. LUCIA
FATAGA
ARTEARA
Ahogados
MOGAN
Tourito
MASPALOMAS
BAHIA DE INGLES
ARGUINEGUIN
BAHIA DE SANTA AGUEDA
ESCALA 1:100000
1
2
3
4
5
6
7
8
9
LEGEND
Old basalt outcrops
220 / -60 Elevation control points on old basalt surface
200 Elevation of old basalt basement
(300) Figures in brackets refer to thickness of overload.
INVENTARIO HIDROGEOLOGICO
Subzonas
Zonas Hidrogeologicas
Pozo
Galeria
Naciente

FIGURE E-25

$Q = T L i$ where

Q = discharge m^3 /year

T = transmissivity m^2 /24 h

L = width of the flow cross-section (m)

i = hydraulic gradient

The calculated discharge for each unit refers naturally to the exploited geological level at the present moment, and the computed results are shown in Table E.4. .

The above table also shows the ground water production for 1972. Out of a total calculated discharge of 129 Mm^3 /year, between 100 to 110 Mm^3/year are extracted at present. In 1968-69 the volume extracted totalled 130 Mm^3. The contrast between the two years is shown in Map E.26 and calculated discharge for the different units in Map E.27. .

A closer look at the Table E.4 shows that production equals practically the calculated discharge for Zones 1 and 3. There is a possible surplus principally in Zones 2, 5 and 8 and to a lesser extent in Zones 6 and 7. A clear deficit is seen in Zone 4. However if we study the subunits, surpluses are prevalent in $1 B_H$, 2 E, $3 A_H$ and 5_H and deficits in $2 D_L$, $2 B_S$, $2 A_L$, 4_L and 7 C.

6.3 Potential Reserves

For each zone and subzone, potential reserves are also estimated covering the entire saturated depth in Modern Basalts and Roque Nublo, in the North-East part of the island. As for the reserves in the southern half of the island about 100 m. of saturation in the Old Basalt was assumed. The total reserves thus calculated amounts to 1.300 Mm^3, of which the maximum occurs in subzones $1 B_H$, 2 E, 3_H principally in the Roque Nublo and Modern Basalts. The reserves in the Old Basalts can be under - estimated because of the doubtfulness in the variation of the saturated thickness.

GRONDWATER RESOURCES

Hydrological Units and Sub-units.	Calculated	Production 1.972	Outflow to sea	Surplus/Deficit of annual Extract.	Estimated Potential Reserves
	Mm^3 / Year	Mm^3 / Year	Mm^3/Year	Mm^3 / Year	Mm^3
IA	0,36	-	0,3		
IB_H	14,0	10,70	-	+ 3,3	260
IB_L	2,0	2,55	1,6	- 0,6	14
IC_H	6,6	4,8	-	+ 1,8	95
IC_L	0,6	0,6	0,16	0	-
ID	2,6	2,6	0,66	0	-
TOTAL	26,2	21,3	2,72	+ 4,5	369
IIA_H	4,0	2,6	-	+ 1,4	40
IIA_L	1,0	1,0	0,2	0	-
IIC_H	8,2	5,9	-	+ 2,3	84
IIC_L	1,8	1,4	-	+ 0,4	-
IIB_N	0,5	0,6	0,4	0	-
IIB_S	0,7	1,7	0,4	- 1,0	-
IID_H	8,3	57	-	+ 2,6	76
IID_L	4,9	5,9	1,8	- 1,0	43
IIE	10,9	4,2	4,0	+ 6,7	117
TOTAL	40,3	29,0	6,8	+11,3	360
$IIIA_H$	14,0	6,5	-	+ 7,5	191
$IIIA_L$	7,2	12,6	0,3	- 5,4	54
TOTAL	21,2	19,1	0,3	+ 2,1	245
IV_H	2,2	1,1	-	+ 1,1	-
IV_L	3,2	6,9	0,4	- 3,7	11
TOTAL	5,4	8,0	0,4	- 2,6	11
V_H	7,9	5,0	-	+ 2,9	74
V_M	2,7	1,4	1,6	+ 1,3	9
TOTAL	10,6	6,4	1,6	+ 4,2	83
VI_H	3,5	1,6	-	+ 1,9	20
VI_M	-	-	-	-	-
VI_L	1,9	1,8	0	0	18
TOTAL	5,4	3,4	-	+ 1,9	38

Hydrological Units and Sub-units.	Calculated	Production 1972	Outflow to sea	Surplus/Deficit of annual Extract	Estimated Potential Reserves
	Mm^3 / Year	Mm^3/Year	Mm^3/Year	Mm^3 / Year	Mm^3
VIIA	2,1	0,6	1,5	0	34
VIIB	1,1	1,0	0	0	24
VIIC	1,5	2,2	-	- 0,7	17
VIID	0,6	0,5	0	0	34
TOTAL	5,3	4,3	1,5		109
VIIIA$_H$	0,3	-	-	-	-
VIIIA$_L$	2,3	1,4	0,9	-	26
VIIIB$_H$	1,2	0,5	-	+ 0,7	30
VIIIB$_L$	5,5	4,6	0,9	-	30
VIIIC	4,4	2,8	1,6	-	-
TOTAL	13,7	9,3	3,4	+ 0,7	86
IX	0,5	-	0,5	+ 0,5	-
Total for Island	128,6	100,7	17,2	+22,6	1.300

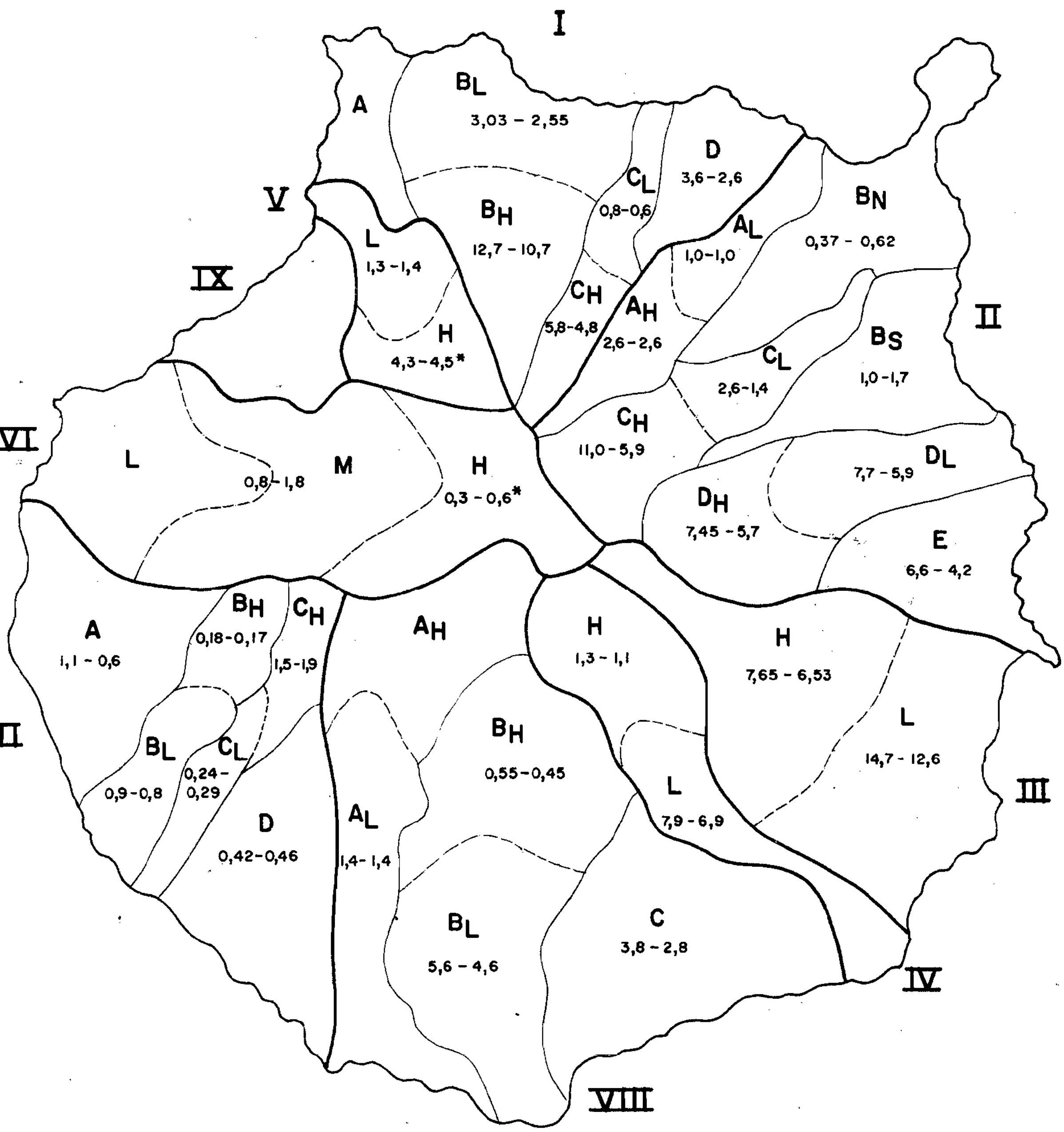
Note:

- All discharges are calculated for Modern Basalts Roque Nublo formation and locally of Old Basalts.
- Subsurface outflow is not included in outflow.
- Potential Reserves are estimated only dor a depth of 300^m of saturation, mostly in Modern Basalts and Roque Nublo. In Old Basalts only about 100^m of saturation was assumed.

GROUNDWATER PRODUCTION Mm^3/year

1968/69 and 1972/73

GRAN CANARIA

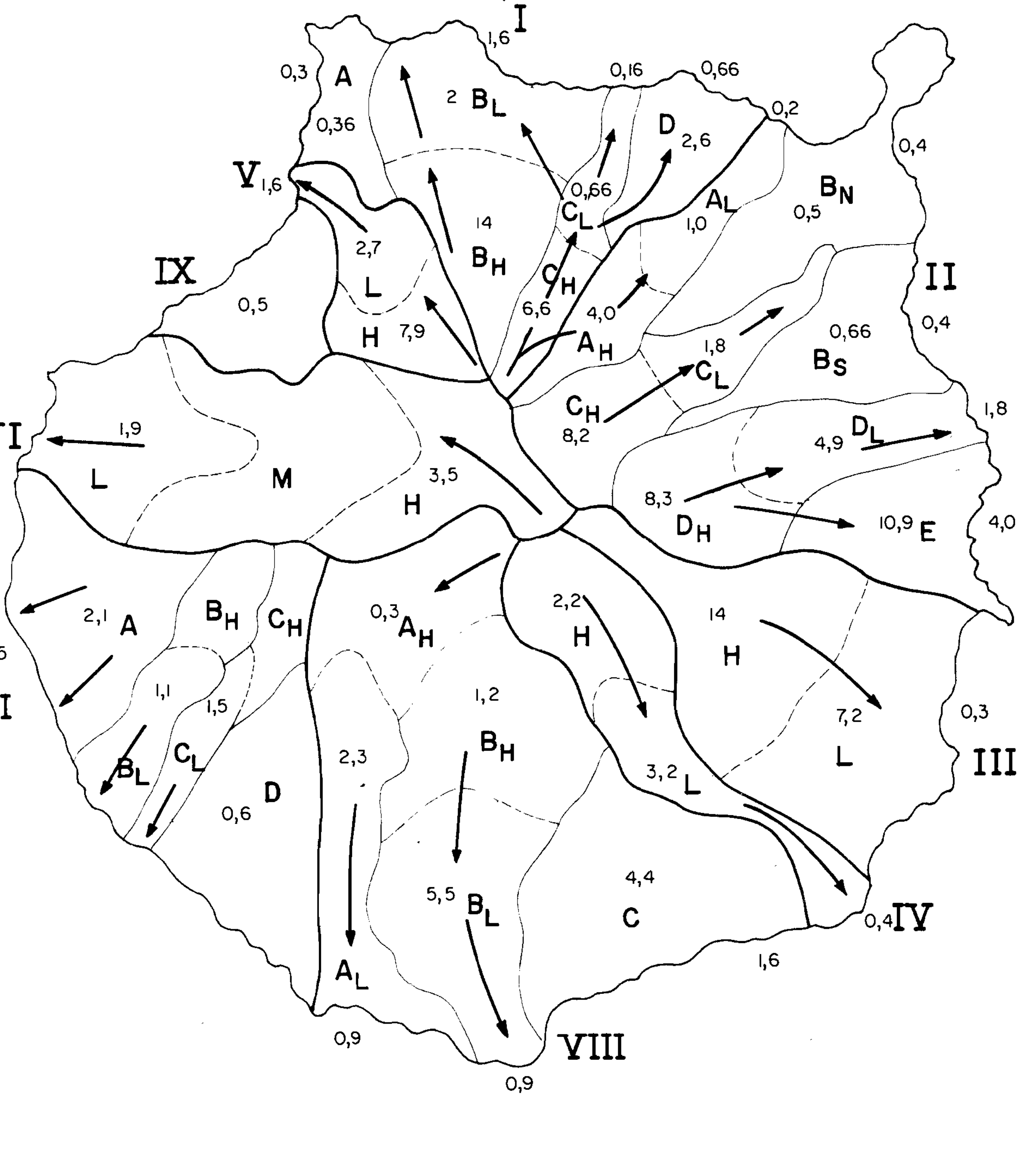


NOTE: Leftside figure for 1968-69 and rightside figure for 1972-73

* With springs 4,5 increases to about 5,0 and 0,6 to 1,6

FIGURE E-26

CALCULATED GROUNDWATER RESOURCES $Mm^3/year$



LEGEND

→ PRINCIPAL FLOW DIRECTION

NOTE: DISCHARGES AND OUT-FLOW ARE CALCULATED FOR EACH ZONE OR SUBZONE

I----IX MAJOR HYDROLOGICAL ZONES

A_H---A_L SUB-ZONES HIGHER AND LOWER PARTS

FIGURE E-27

6.4 Outflow to Sea

In the same table the annual permanent outflow to sea on each coastal strip of the respective subunits has been calculated using the above-mentioned formula.

The total calculated discharge is about 17 Mm^3 /year and the principal coastal areas of outflow are found in 1 B_L , 2 D_L , 2E , 5_L , 7A, 8C, each unit with losses varying between 1,5 and 2M m^3 /year. To these calculated losses should be added temporary subsurface outflow occurring specially in the Southern part of the island. This will be discussed in section H dealing with annual water balance.

Comparison of the aerial thermography of Gran Canaria obtained during the infrared survey in Fig.E.28 with the above computed outflow shows certain correspondence even though the picture is masked by ocean currents. Infrared thermal anomalies due to effluents coincide with outflow calculations in subunits 1 B_L , 2D_L , 2 E , 7 A, 8 A_L, 8 B_L and 8 C. The only significant recuperable outflow seems to occur in subunit 2 D on the coastline South of Telde. This also corresponds to an area with an important surplus of entry into annual storage.

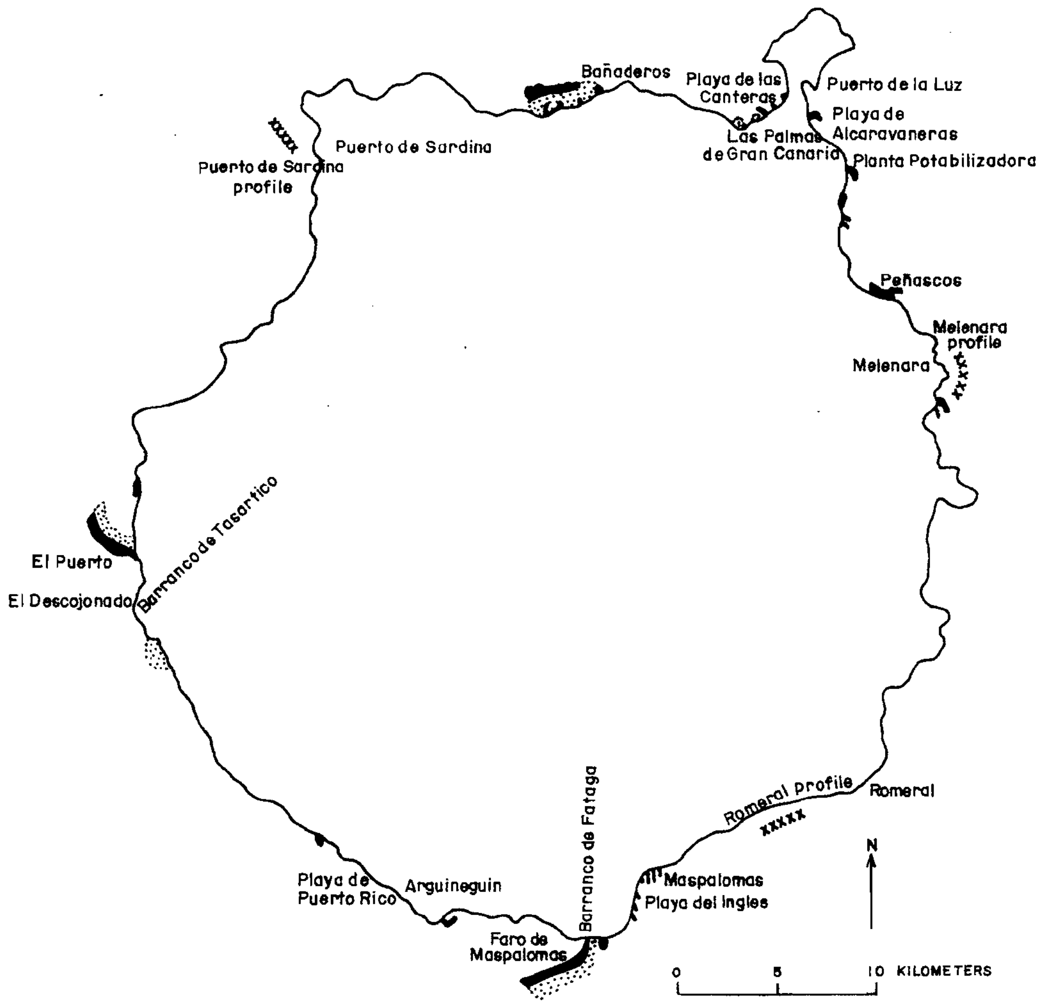
In Map E.27 are shown areas of significant surplus annual storage as well as calculated coastal outflows.

6.5 Exploratory Drilling Possibilities

The drilling program in the island of Gran Canaria up to the present has been limited to very restricted areas. Small diameter boreholes have been made in one of the galleries of Gamonal, in the Tejeda Tunnel both found in Zone 2 C_H in the Roque Nublo formation. Also, a borehole was made in Zone 8 C to test the hydraulic characteristics of the Phonolytes and to

COASTAL OUTFLOW FROM AERIAL THERMOGRAPHY

- GRAN CANARIA -



LEGEND

Cool effluent, discharge, or current

Warm effluent, discharge, or current

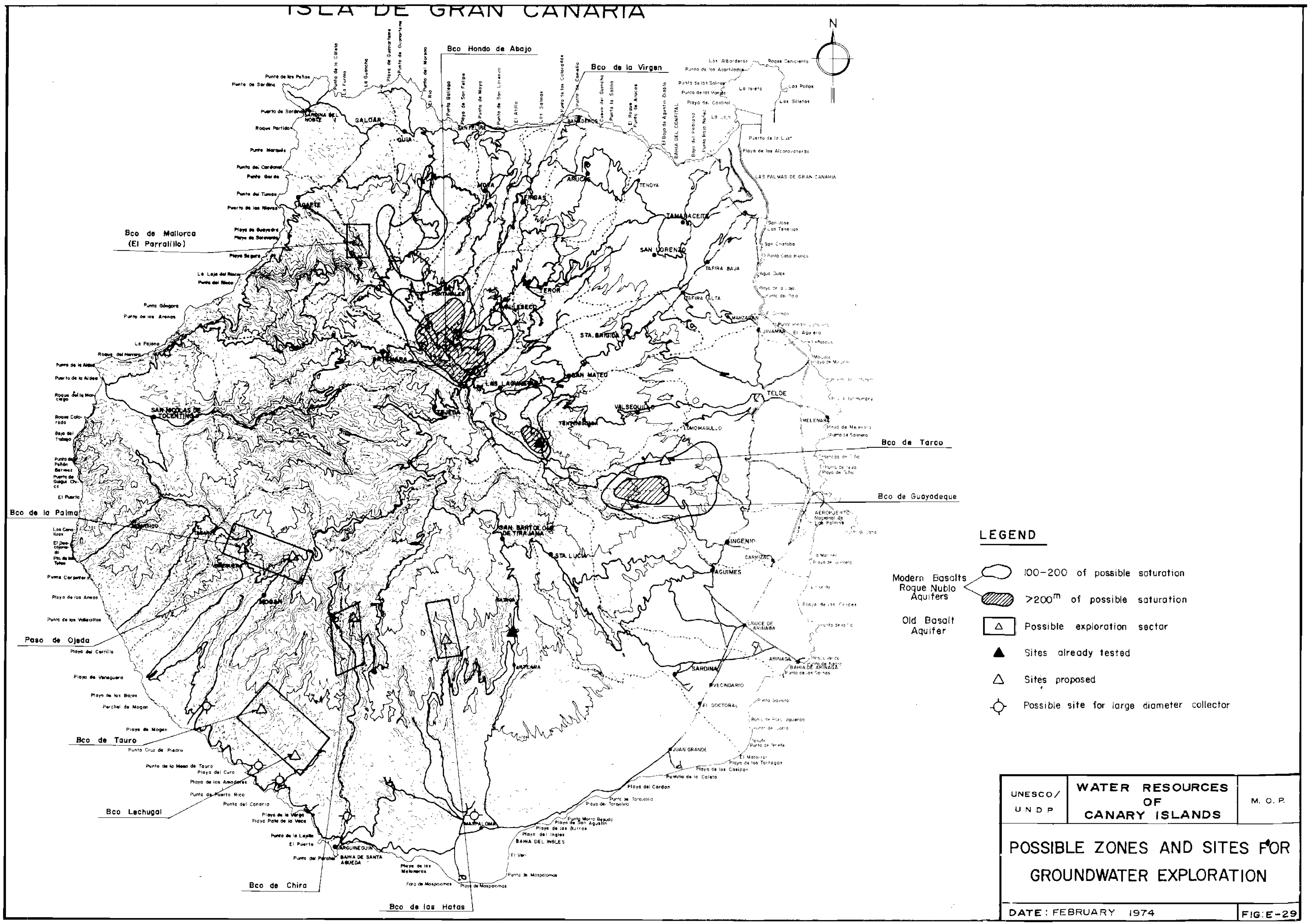
xxxxx Ocean surface temperature profile

FIGURE E-28

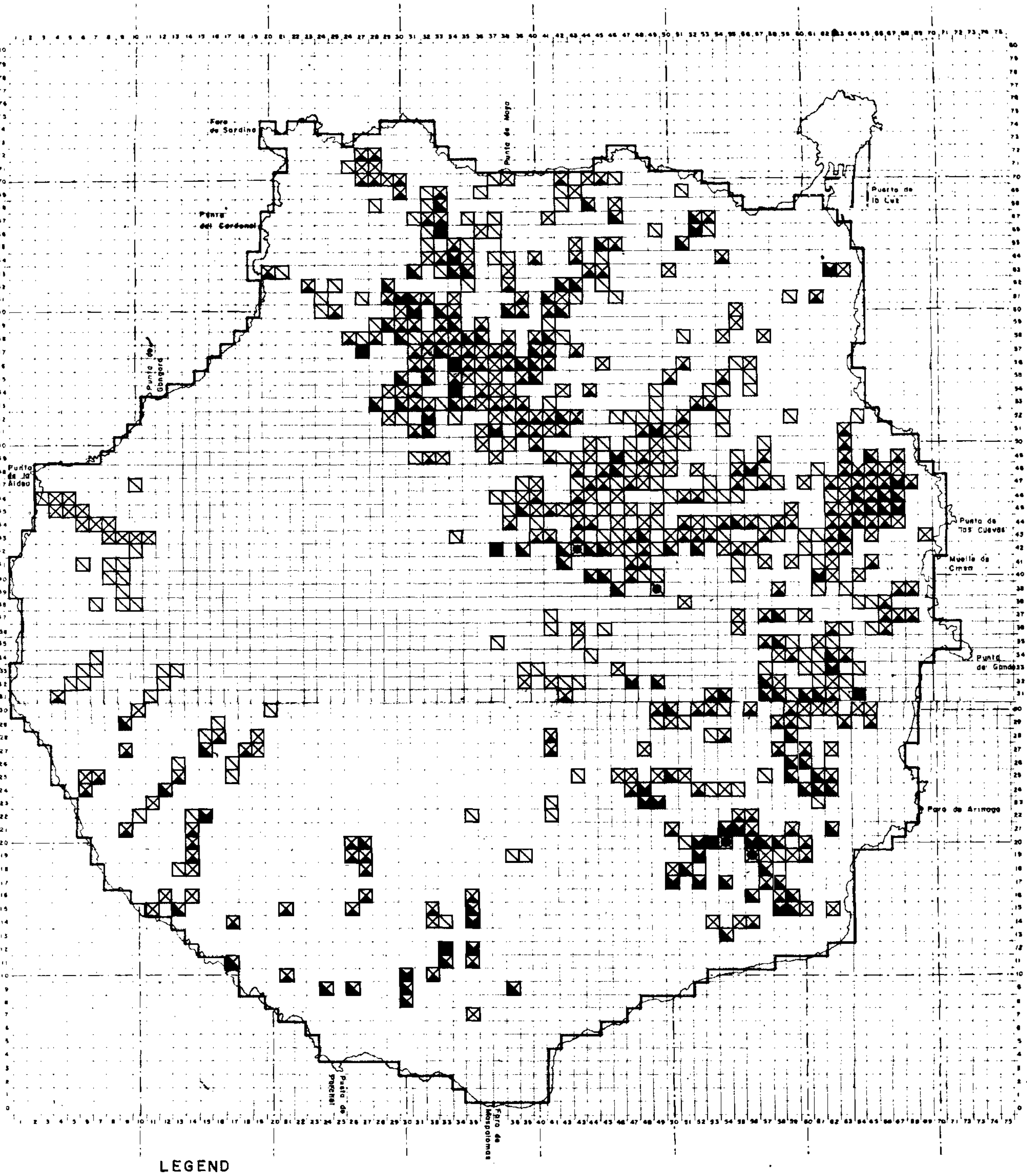
define the top of the Old Basalts in Barranco Hondo. In this particular point the Phonolytes were very thick and impermeable, and the top of the Old Basalts could not be defined due to its great depth. In Zone 2 e a borehole was made to verify the existence of a possible buried valley indicated by the electro-seismic prospection undertaken in this region but without success.

Lately two sites have been selected for larger diameter borings, the first in the Roque Nublo formation on the top of the island near Cuevas Blancas which seem to show the existence of a saturated zone of more than 200m. in this area. The objective of this boring is to test the hydraulic possibilities of the entire thickness of the Roque Nublo formation. The second point chosen for such a boring is found in the lower part of the Fataga valley in hydrogeological unit $8B_L$. The principal objective is to test the water bearing qualities of the contact Ignimbrites -Old Basalts, as well as investigate the hydraulic properties of the Old Basalts in this region.

In addition to this exploratory drilling undertaken up to now, it is recommended to test the hydraulic properties and extraction possibilities of the two zones, firstly in the area Fontanales-Valleseco on the one hand and secondly in the upper part of the Guayadeque Valley. Several possible sites are proposed in Fig.E.29 based on the comparison of the map of water extractions intensity Fig.E.30 with those of saturated depth and trans - missivity. As for the Southern Zone it is advisable to reconstruct the paleotography of the Old Basalts between Fataga and Arguineguin Valleys through a series of small diameter borings.


ISLA DE GRAN CANARIA
N
Bco Hondo de Abajo
Bco de la Virgen
Bco de Mallorca (El Parralillo)
Bco de la Palma
Paso de Ojeda
Bco de Tauro
Bco Lechugal
Bco de Chira
Bco de las Hatas
Bco de Tarco
Bco de Guayadeque
GALDAR
GUIA
MOYA
FIRGAS
ARUCAS
TENOYA
TAMARACEITE
SAN LORENZO
TAFIRA BAJA
TAFIRA ALTA
TEROR
VALLESECO
STA. BRIGIDA
SAN MATEO
LAS LAGUNETAS
VALSEQUILLO
TENTENIGUADA
LOMO MAGULLO
TELDE
MELENARA
JINAMAR
MANZANILLA
LAS PALMAS DE GRAN CANARIA
AGAETE
ARTENARA
TEJEDA
SAN NICOLAS DE TOLENTINO
MOGAN
SAN BARTOLOME DE TIRAJANA
STA. LUCIA
INGENIO
CARRIZAL
AGUIMES
CRUCE DE ARINAGA
ARINAGA
SARDINA
VECINDARIO
EL DOCTORAL
JUAN GRANDE
MASPALOMAS
ARGUINEGUIN
BAHIA DE SANTA AGUEDA
BAHIA DEL INGLES
AEROPUERTO Nacional de Las Palmas
LEGEND
Modern Basalts Roque Nublo Aquifers
100-200 of possible saturation
>200m of possible saturation
Old Basalt Aquifer
Possible exploration sector
Sites already tested
Sites proposed
Possible site for large diameter collector
UNESCO/ UNDP
WATER RESOURCES OF CANARY ISLANDS
M. O. P.
POSSIBLE ZONES AND SITES FOR GROUNDWATER EXPLORATION
DATE: FEBRUARY 1974
FIG: E-29

GROUNDWATER PRODUCTION INTENSITY



LEGEND

- 0-50 x 10^3
- 50-100 "
- 100-250 "
- 250-500 "
- 500-750 x 10^3
- 750-1000 "
- > 1000 "

NOTE: Figures expressed in m^3/year (1969-72). Unit area equals 0,4225 Km^2.

SCALE: 1:200.000

FIGURE E-30

6.6 Conclusions on Resources

The calculated groundwater flow for the entire island is about 4,1 m^3 /s or 130 m^3 /year. This flow would refer to the presently exploited levels comprising principally Modern Basalts and Roque Nublo together reaching on the average 20 to 50 m. of saturation. Based on the known hydraulic characteristics, the potential reserves of the before mentioned two aquifers covering their entire development as well as the Old Basalts up to exploitable depth of 100 m. of saturation have been made giving us a total of 1.300 m^3 . We could call this multi-annual resources as opposed to the reserves calculated for the lower levels. Within the same levels affected actively by recharge phenomena we have estimated an outflow to sea, of about 17Mm^3 /year and an annual entry into storage of about 34 M m^3 / year. However there is a withdrawal from multi-annual resources of about 12 Mm^3 which gives us a real entry into multi-annual storage of only about 22 M m^3 /year.

The deep reserves within the core of the island have been calculated on the basis of a rock volume of 420.10^9 m^3 of which the Phonolytes, Ignimbrites and Trachy-Syenitic Complex together account for about 280.10^9 m^3 and the rest of the Old Basalts. Application of known storativity for the respective areas gives us a total of 280 Mm^3 for the first group and 1.400 Mm^3 for the second, in total a basal water reserve of 1.680 Mm^3.

The total groundwater resources presently exploited and potentially exploitable are resumed below:

- Calculated discharge in Exploited Zone	129 Mm^3 /year
- Outflow to sea	17 Mm^3 /year
- Reserve in exploitable Zone	1.300 Mm^3
- Reserve in core Zone (up to sea level)	1.680 Mm^3
TOTAL..	3.126 Mm^3

These figures are comparable to those advanced in the beginning of the section in the groundwater stratification system.

7. Hydrogeochemistry

The hydrogeochemical investigations carried out in the island were directed towards the definition of the quality and the suitability of groundwaters for agricultural and public use.

Hydrogeochemical parameters were employed as means for the definition of the existing groundwater bodies and for the tracing of masses of subsurface waters flowing through different geological formations.

7.1 Methodology

During 1970-1973 over 600 water samples were collected all over the island. 530 samples were of groundwaters whereas the remaining ones were of runoff and of rainwater. Sampling was carried out at 370 stations of which 43% were resampled. The average sampling density was of 1 sample in every 4 km^2. In the northern and eastern parts of the island in which occur the main groundwater producing zones, the sampling-density was higher, i.e. 1 sample en every 1 km^2. Water samples were collected from every geological formation and under every known condition of groundwater occurrence. The chemical analyses employed in this study were carried out by the Project Chemical Laboratory in the Servicio Hidráulico de Las Palmas. Data processing was made on an IBM 1130 computer at the CEH, Madrid.

The following chemical parameters were studied for all analyses:

Major anions: HCO_3, CO_3, SO_4, Cl, NO_3, NO_2, Br; PO_4

Major cations: Ca, Mg, Na, K (Na+K=Alk), NH_4

Radicals: SiO_2

Ion ratios: rMg/Ca, rNa/K, rCa+rMg/Alk, rCl/$rHCO_3$+CO_3, rSO_4/Cl

Meq %: rCa, rMg, rAlk, rCl, rSO_4, $rHCO_3$

The positive and negative ion-exchange factors, the ionic force, SAR, Total Hardness, Permanent Hardness, Alkalinity and TDS, were also computed. The conductivity, water temperature, pH, O_2, CO_2 were measured in the field as part of the standard procedures of sampling operations.

The study of the various concentrates and parametric values have led to the making of a number of distribution maps and diagrams which will be commented later.

The conclusions of the present study were drawn following three main stages of investigations: a) examination of the distribution pattern of significant physico-chemical and chemical parameters; b) definition of changes occurring in the behaviour of the above parameters, some radicals and ion-ratios along the flow paths. c) ellucidation of the interdependance in the behaviour of major ions as well as of relations existing between the chemical composition of groundwaters and that of aquifer rocks.

7.2 Results of Field Measurements

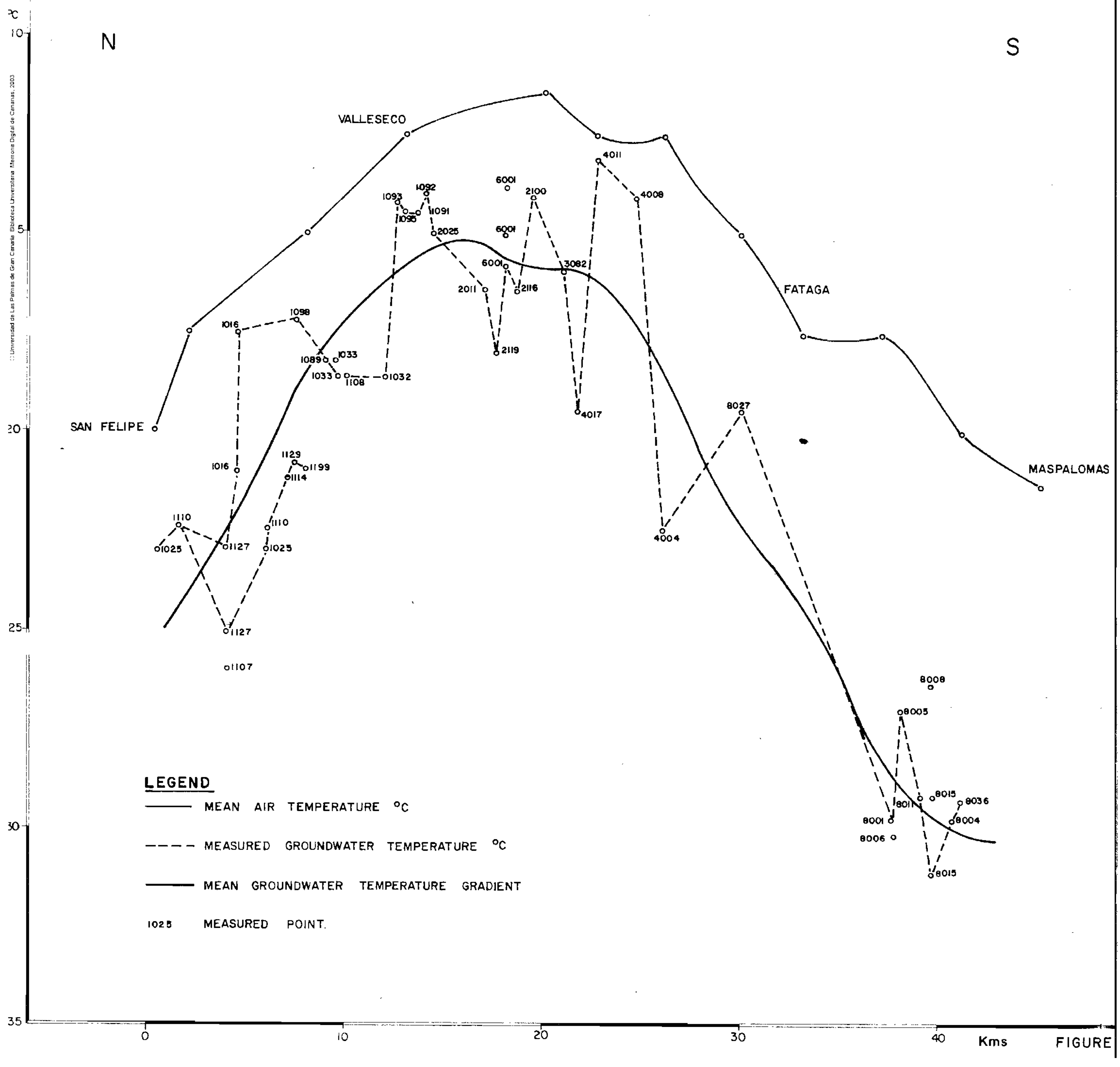
Field measurements of certain chemical as well as physico-chemical parameters were undertaken firstly as a diagnostic method to obtain a preliminary idea of the hydrochemistry of the aquifer under field conditions and to recognize the changes which may intervene after the sampling. Also certain chemical elements like Cl^- were sampled several times to study variations in time.

The principal elements measured in the field were groundwater temperature, O_2, CO_2, pH, electrical conductivity and Cl^-. Alkalinity (TA, TAC) measurements were also done within 12 hours of sampling.

In many of the points where CO_2 played an important part, the samples were stabilized by acidification with H_2SO_4. Besides this general sampling, selected points were also effectuated for fluor and boron.

GROUNDWATER TEMPERATURE PROFILE

— GRAN CANARIA —



All physico-chemical field data gathered were processed and used conjointly with the laboratory chemical analyses for the final interpretations.

A specific study of Cl^- was undertaken as 4 campaigns, each with a total sampling of 300 to 350 points, permitted the making of seasonal maps. The reader is referred to Section H, where this element has been used to study infiltration and derive a salt-balance scheme.

7.2.1 Groundwater Temperature

Generally groundwater temperatures evolves parallely to air temperatures and inversely to topographic conditions if no thermal gradients or deep-circulation anomalies influence groundwater flow.

In the case of Gran Canaria the relationship existing between mean atmospheric and groundwater temperatures is shown in Fig. E.31 which is a cross-section from N to S. While the air temperature has a more regular profile even though sharper in the arid south, the groundwater temperature shows great variation. However, a mean gradient can be drawn which indicates a more or less parallel development to air temperature in the northern zone and anomalous sharp gradient in the south. In the northern zone groundwater temperatures are only a few degrees below air temperatures (2-5°C) whereas in the south the difference is greater (5-12°C).

A separate study of this phenomenon has been made and it was found that in the northern areas groundwater temperatures can be correlated with elevation (1°C for 100 meters) which in turn is related to mean air temperature. This proves that groundwater circulation is closely related to a continuous recharge phenomenon.

On the contrary, in the southern zone groundwater temperatures can be correlated only with the elevation of groundwater level which indicates that continuous infiltration has a lesser influence on groundwater flow. Also the high thermal gradient (1°C for 22 meters) which is practically 5 times greater than in the north may mean that waters are of deeper circulation.

Now if we look at the Map E.32 showing distribution zones of groundwater temperatures, we note the existance of a central area with about 15°C surrounded by successively concentric zones of increasing ground water temperatures.

If we disregard the differences in thermal gradient existing between the northern and southern regions, and against the normal temperature background, there stand out 6 hot spots where the water temperatures exceed 30°C. Five of these are found on a line between Ingenio and Bahía de Sta. Agueda in Arguineguin. The location of these hot spots as well as their alignement, do not coincide with any known tectonical phenomenon but certainly do with the ancient coastline of the Old Basalts, see Fig. E.25.

Also there is an anomalous zone developing around Marzagan and another in the north near Guía, both of which can be related to recent volcanic activity.

The analysis of the limited evidence on groundwater temperature leads to the conclusion that there occur 2 classes, the ones in the N and E related directly to volcanic vents, and others in the S and SE associated possibly to deep structural features associated probably with the Old Basalts, the latter phenomenon possibly influencing groundwater circulation.

7.2.2 Free CO_2

Existance of free CO_2 in large quantities is one of the important factors in the mineralization processes of volcanic terrains. In the island of Gran Canaria, CO_2 emanations are very extensive in the area east of the line Agaete - Juan Grande, corresponding to the more recent geological formations.

MAP OF GROUNDWATER TEMPERATURE

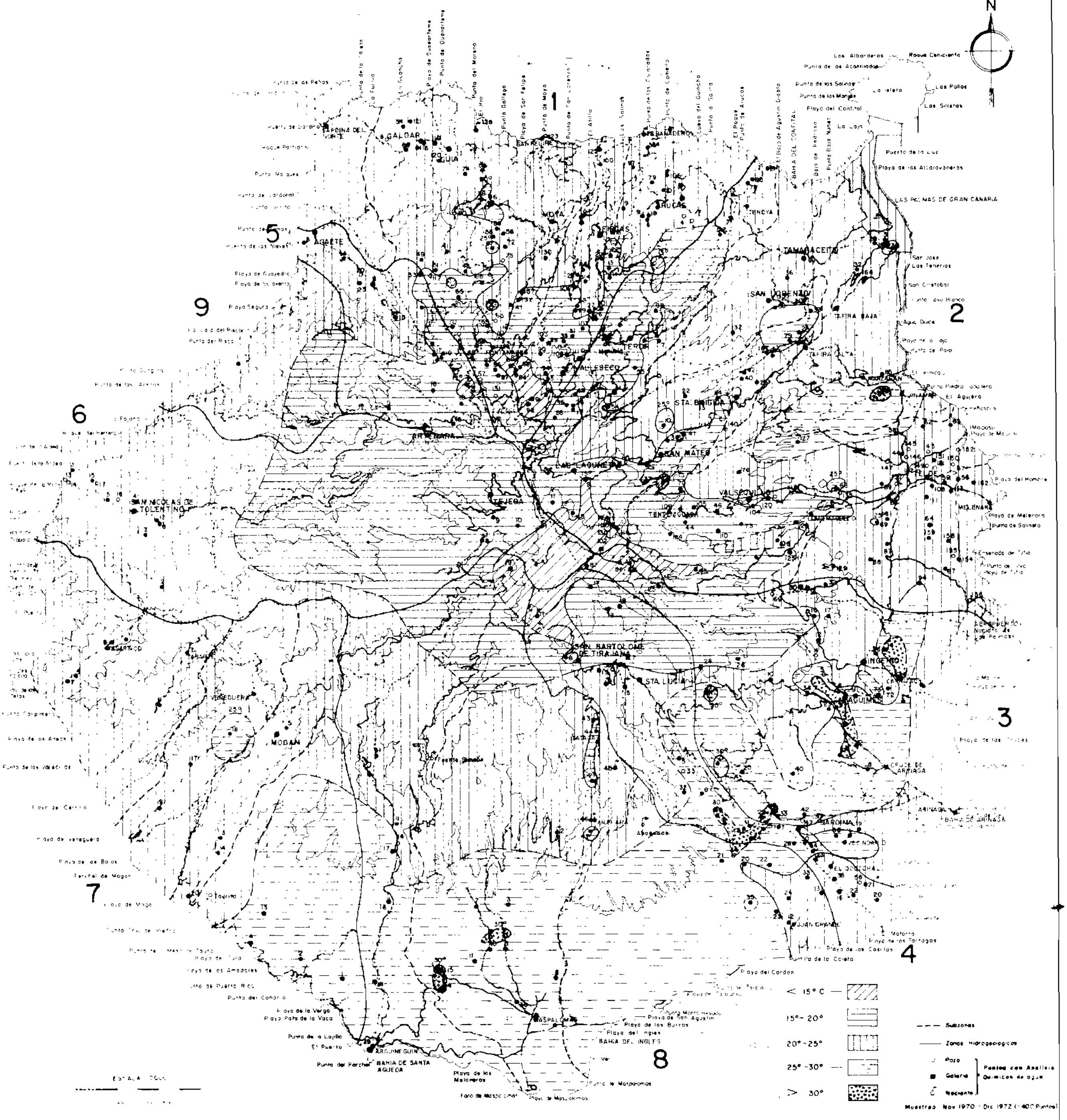


FIGURE E-32

If we look at Map E.33 we notice the existance of 6 large areas with free CO_2 content of above 150 mg/l. Besides these, there exist also many other small spots with content varying from 25 to more than 600 mg/l. The central, the southern, the western zones as well as a large part of middle altitudes are free of volcanic CO_2.

Free CO_2 seems to exist connected to recent volcanic activity as is in the case in Jinamar, Valsequillo, Agaete Valley and possibly Guía and some parts near Firgas. In certain areas, there is no direct relationship with recent volcanics such as in Tenoya, Agüimes, Sta. Lucía and a large zone around Firgas. They consist in a large majority of cases of trapped gas in geological formations specially of porous types. It is also possible that some areas contribute free CO_2 from deep seated origin across fracture zones. Some gas escapes from phonolytic series may have such an origin.

If we compare Maps E.33 and E. 32, we come to the conclusion that free CO_2 emanations coincide with high temperature gradients only in Ingenio-Agüimes, and Jinamar-Valsequillo, which explains the mineralized nature of the water existing in those zones. In the large CO_2 zones of the north around Firgas, Guía-Galdar, Tenoya and Agaete, there are no thermal anomalies.

7.2.3 Field pH, O_2, Conductivity

The above measurements have been made approximately in about 540 field samples. The mean statistical values have been computed in Table E.5 for each hydrological zone.

As can be seen, the mean field pH varies from 6,7 in zone 1 to 7,4 in zone 3, all in the N.E half of the island. In a detail study, variations from 4,0 to 8,5 have been noted, the low figures corresponding to areas of high free CO_2 content.

MAP OF FREE CO_2

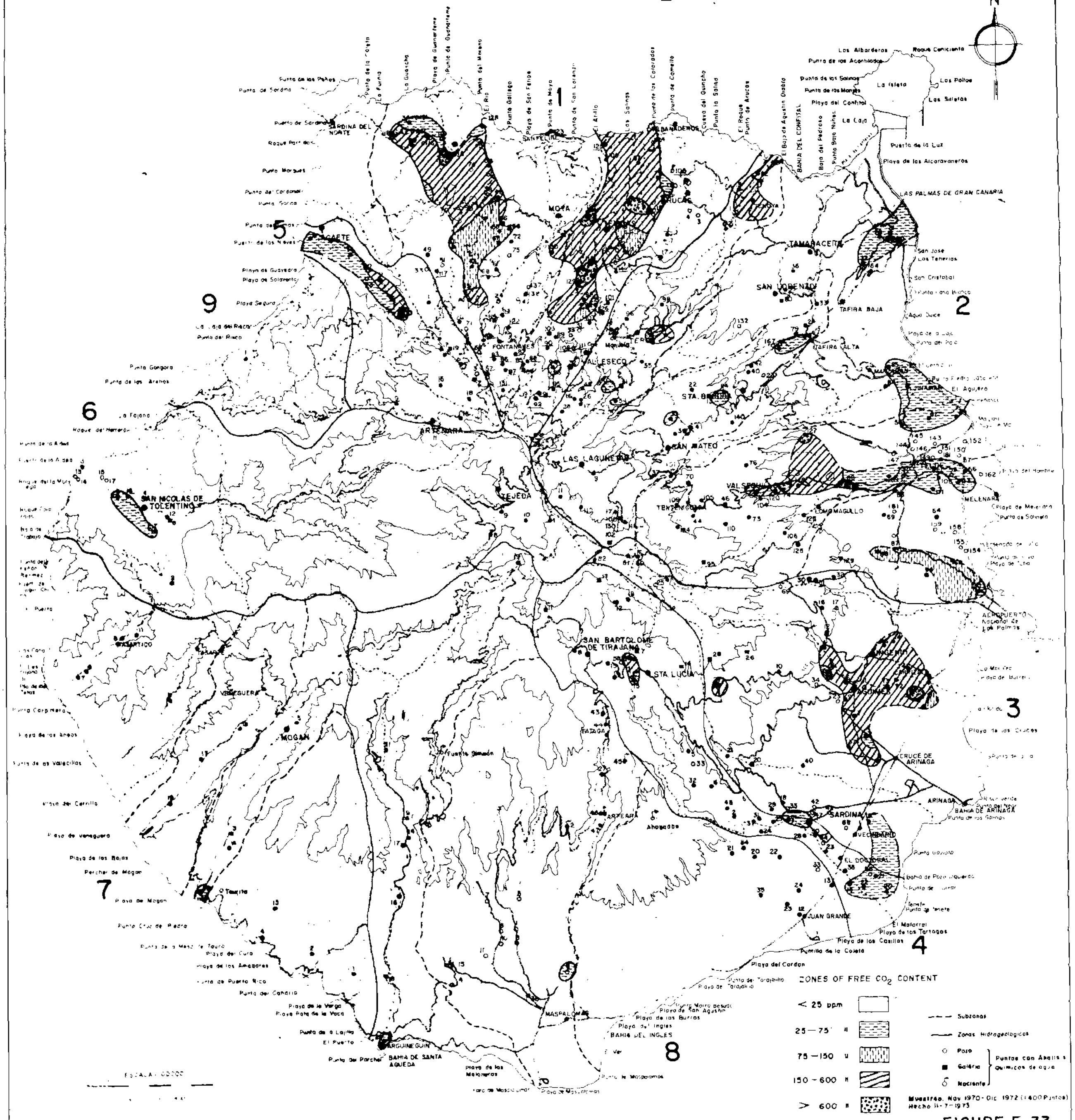


FIGURE E-33

Table E·5

STATISTICS OF GROUNDWATER QUALITY - GRAN CANARIA

ZONE	Area km²	Nº of samples (approx)	°C field	CO_2	O_2	pH field	SiO_2	Conduct. 20°field	Dry residue	TH oF	Perm. hard. oF	TAC oF	TA oF	Ca	Mg	Na	K	NH_4	Σ cations	Cl	CO_3	HCO_3	SO_4	NO_3	PO_4	Σ Anions
1	182,2	109	19,9	160,9	6,1	6,7	42,8	341	601	20,0	1,3	31,2	0,1	27,8	32,6	118,7	11,4	0,1	190,6	99,0	12,8	281,6	70,7	14,7	1,7	479,8
2	326,9	165	20,4	71,8	8,0	7,4	28,4	412	1037	29,4	12,4	31,2	0,3	44,1	44,6	244,8	14,8	0,1	348,5	264,8	10,7	280,9	183,1	40,1	1,3	771,9
3	145,1	54	25,0	129,0	5,8	7,4	52,4	422	1003	43,4	12,7	41,3	0,1	63,5	68,2	166,6	12,0	0,1	310,4	270,4	5,3	481,2	74,5	3,4	1,4	836,2
4	88,4	55	24,4	24,6	8,4	7,7	32,0	591	1909	63,0	49,1	20,2	0,0	90,1	99,1	313,6	15,9	0,0	518,7	663,7	3,2	320,9	137,9	4,2	1,0	1130,9
5	49,4	33	20,7	138,0	5,9	7,0	43,0	432	517	22,3	4,3	31,3	0,0	37,0	31,9	89,4	10,1	0,4	168,8	74,6	5,9	275,3	69,7	16,9	1,7	444,1
6	178,5	31	18,9	16,5	8,7	7,8	25,1	444	1552	66,9	51,2	17,1	0,0	107,2	92,7	229,0	8,8	0,1	437,7	431,8	1,5	174,2	347,2	48,1	1,1	1003,9
7	222,0	28	24,1	18,6	8,5	7,8	35,0	1192	1144	36,9	19,2	19,6	0,0	66,8	49,2	238,1	9,0	0,1	363,2	392,4	3,0	209,6	147,1	23,9	1,1	777,1
8	323,6	61	25,2	18,0	8,8	7,7	32,0	1030	1083	31,6	14,5	19,8	0,0	59,4	40,6	241,7	12,0	0,1	353,8	377,5	1,0	221,7	132,4	11,4	1,2	745,2
9	42,0	2	20,9	17,5	9,0	8,0	14,9	905	1691	61,0	42,2	22,6	0,0	131,6	68,5	309,5	6,8	0,5	516,9	440,2	0,0	229,5	388,2	85,9	1,1	1144,9
Total	1558,1	538	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weighted Mean Value for the island	-	-	-	-	-	-	33,9	-	1115	-	-	-	-	59,1	54,0	220,0	11,7	-	348,3	327,9	5,4	265,6	162,2	24,8	1,2	785,5
meq/l	-	-	-	-	-	-	-	-	-	-	-	-	-	2,95	4,44	9,57	0,30	-	17,26	9,25	0,18	4,35	3,38	0,40	0,04	17,60
%meq/l	-	-	-	-	-	-	-	-	-	-	-	-	-	17,1	25,7	55,5	1,7	-	-	52,6	1,0	24,7	19,2	2,3	0,2	-

Note: Cations, Anions, CO_2, O_2 dry residue and SiO_2 are expressed in mg/l.
Conductivity is expressed in micro-mhos.

The mean pH in the S.W half of the island varies from 7,7 in zone 4 to 8,0 in zone 9. In this sector of the island the variations are between 7,0 and 9,0 and very low values are absent.

As for O_2 practically all the waters seem to be well provided with, but very locally there exist areas of oxygen depletion. The variations occur between 6,0 and 12 mg/l. An inverse but complex relation between oxygen content and carbonate alkalinity TAC is noted. Hence in zones of oxygen depletion, very high TAC values are generally noted and vice-versa.

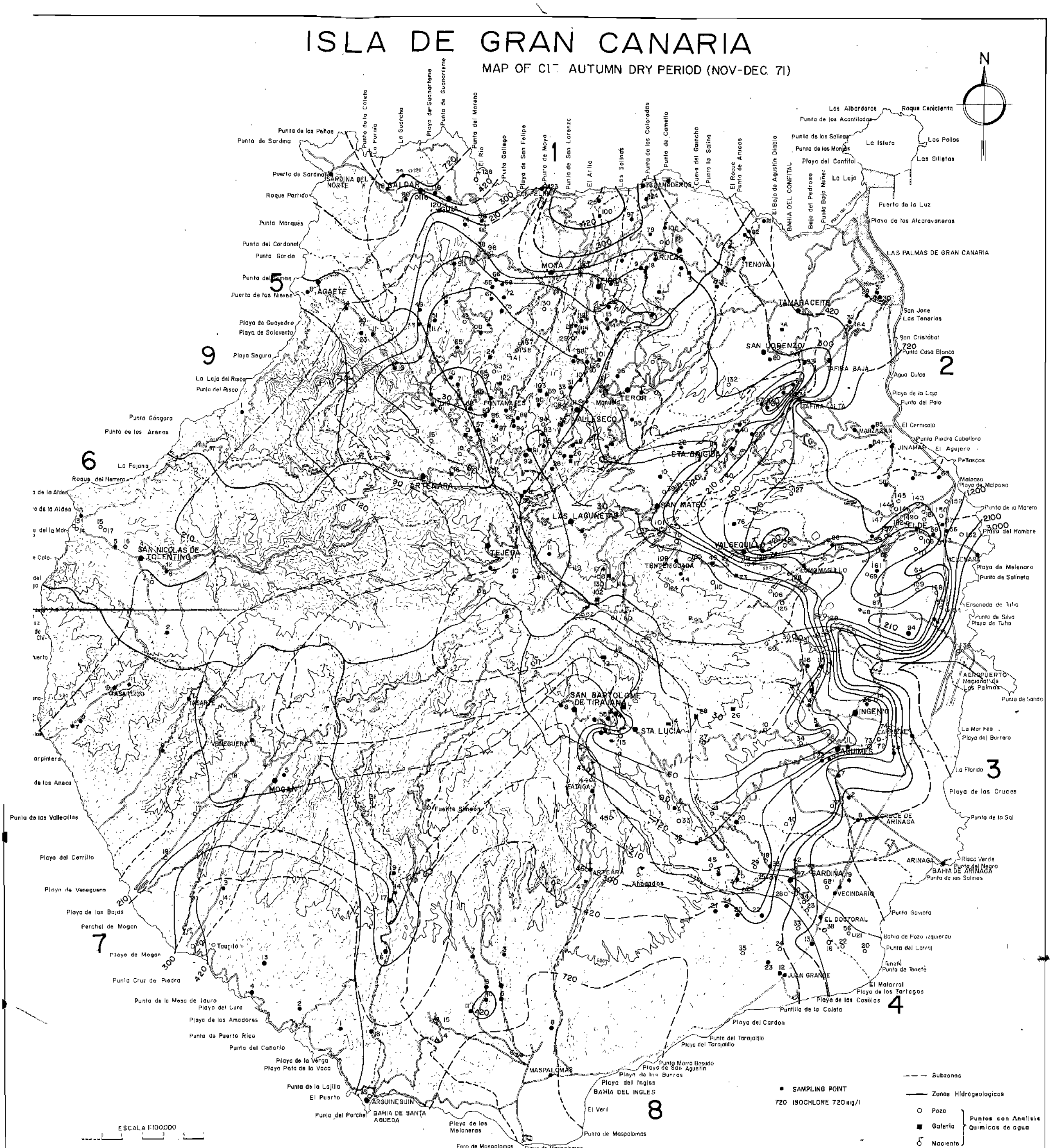
Field conductivity has been expressed in micro-mhos for 20°C. The variations are 341 to 342 micro-mhos in the N.E. half and from 444 to 1192 in the S.W. half of the island. Thus with aridity there is an increase of field conductivity as is normal.

7.2.4 Cl^- content and Variations

As said earlier a detail study of Cl^- has been done with reference to its role in water balance in Section H.

When examining the Cl-content in the groundwaters of Gran Canaria, it is necessary to refer to two different sets of isochlore maps, one representing Cl-concentration at the end of the annual recharge period (end of the rain season) and to another set, drawn at the end of the dry summer season. The pattern of both sets of isochlores resembles that of isopiezometric lines, which is roughly concentric in shape.

Examples of the contrasted situation of the autumm dry period and spring recharge are given in Maps E.34 and E. 35, respectively. The autumm early winter Map E. 34, shows a concentration range of 30 mg/l in the center of the island, and 700 to 3.000 mg/l in the coastal zones, the latter in the eastern Telde-Arinaga area where sea water intrusion is prevalent. On the contrary the recharge Map E. 35 shows a clear dilution



ISLA DE GRAN CANARIA
MAP OF Cl⁻ AUTUMN DRY PERIOD (NOV-DEC 71)
N
LAS PALMAS DE GRAN CANARIA
AEROPUERTO Nacional de Las Palmas
SAN BARTOLOME DE TIRAJANA
SAN NICOLAS DE TOLENTINO
ARGUINEGUIN
MASPALOMAS
BAHIA DEL INGLES
AGAETE
ARTENARA
TEJEDA
MOGAN
INGENIO
AGUIMES
TELDE
TERO R
MOYA
FIRGAS
ARUCAS
GUIA
GALDAR
TAMARACEITE
SAN LORENZO
TAFIRA BAJA
TAFIRA ALTA
JINAMAR
STA BRIGIDA
SAN MATEO
VALSEQUILLO
STA LUCIA
FATAGA
VECINDARIO
JUAN GRANDE
CRUCE DE ARINAGA
Subzonas
Zonas Hidrogeologicas
SAMPLING POINT
720 ISOCHLORE 720 mg/l
Pozo
Galeria
Naciente
Puntos con Analisis Quimicos de agua
ESCALA 1:100000

FIGURE E-34

MAP OF Cl⁻
SPRING RECHARGE PERIOD (JULY AUGUST 1972)

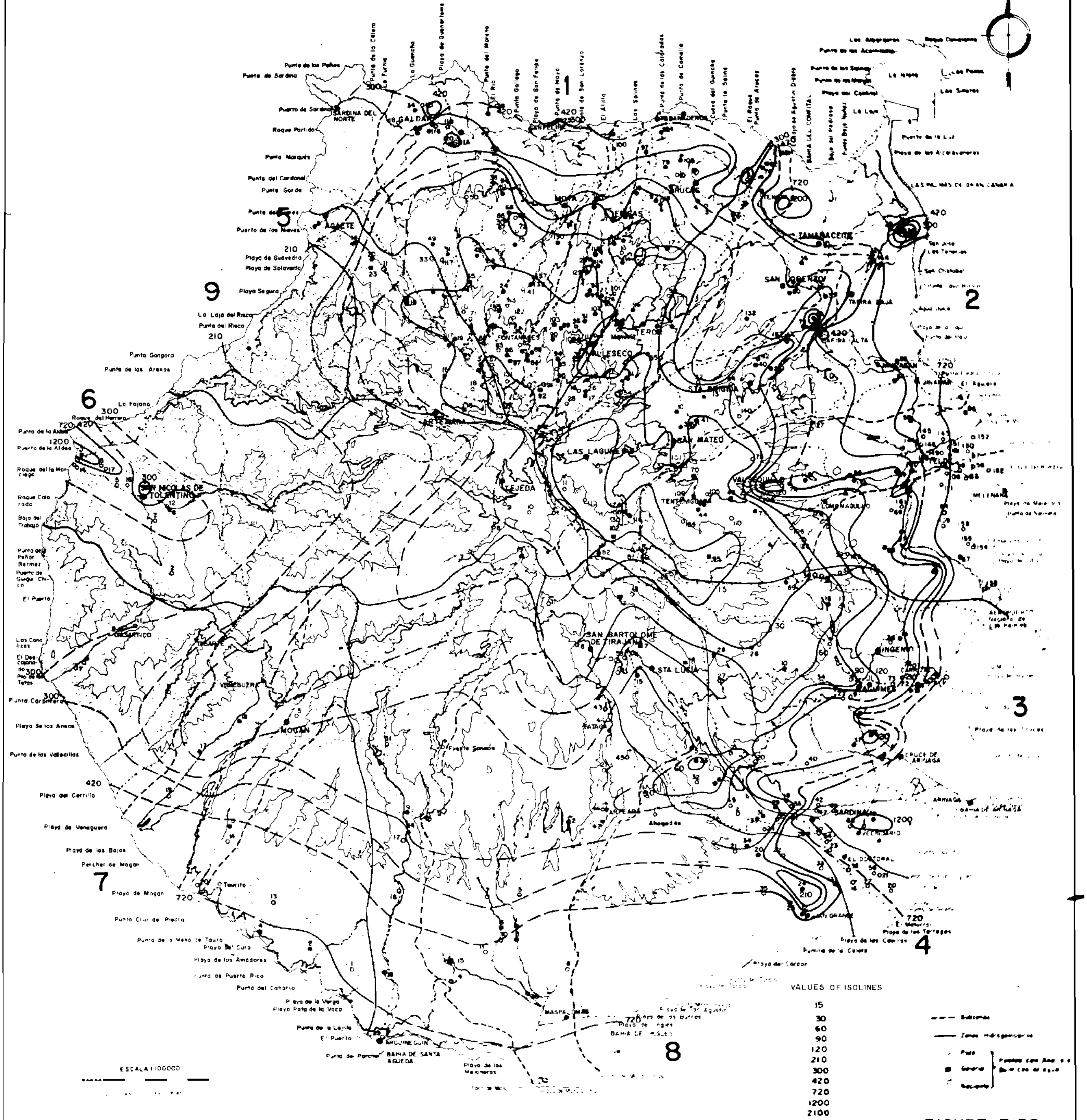


FIGURE E-35

effect with concentration range varying from 15 mg/l in the centre of the island to 720 mg/l in the coastal areas.

The chlorinity gradient in mg/l/km, along various sections for the two contrasting seasons were as follows:

	Dry Autumn	Spring Recharge
Tejeda - Las Palmas	46	13
" - San Felipe (Moya)	23	15
" - Agaete	10	11
" - Arinaga	125	20
" - Maspalomas	28	12
" - Mogan	6	16

The ratio autumn/spring varies from 1 to more than 6, the sharpest gradients are found in the eastern coast between Telde and Tirajana. The only reversal of gradient is found in the Mogan region, explained in this case by autumm rains and dilution from runoff waters in wells found along the valleys. There is concentration in Cl^- in summer following the dry epoch. In Agaete valley a similar phenomenon has taken place this year.

The different protrusions of isochlores are found along Guiniguada, Firgas-Arucas, Guía, Agaete valley, Veneguera-Mogan, Maspalomas and Telde, which probably represent preferential flow lines of groundwater.

It is interesting to remark that these protrusions are found both in the autumn and spring maps. Also we note that the position of isochlores, 30 to 60, hardly suffers change.

In order to appreciate the phenomenon of variability several ΔCl maps have been compiled. As an example we can see in Map E.36 the change in Cl comparing the recharge period with that ot the dry autumn. The nega-

MAP OF Δ Cl
WATER YEAR 1971-72

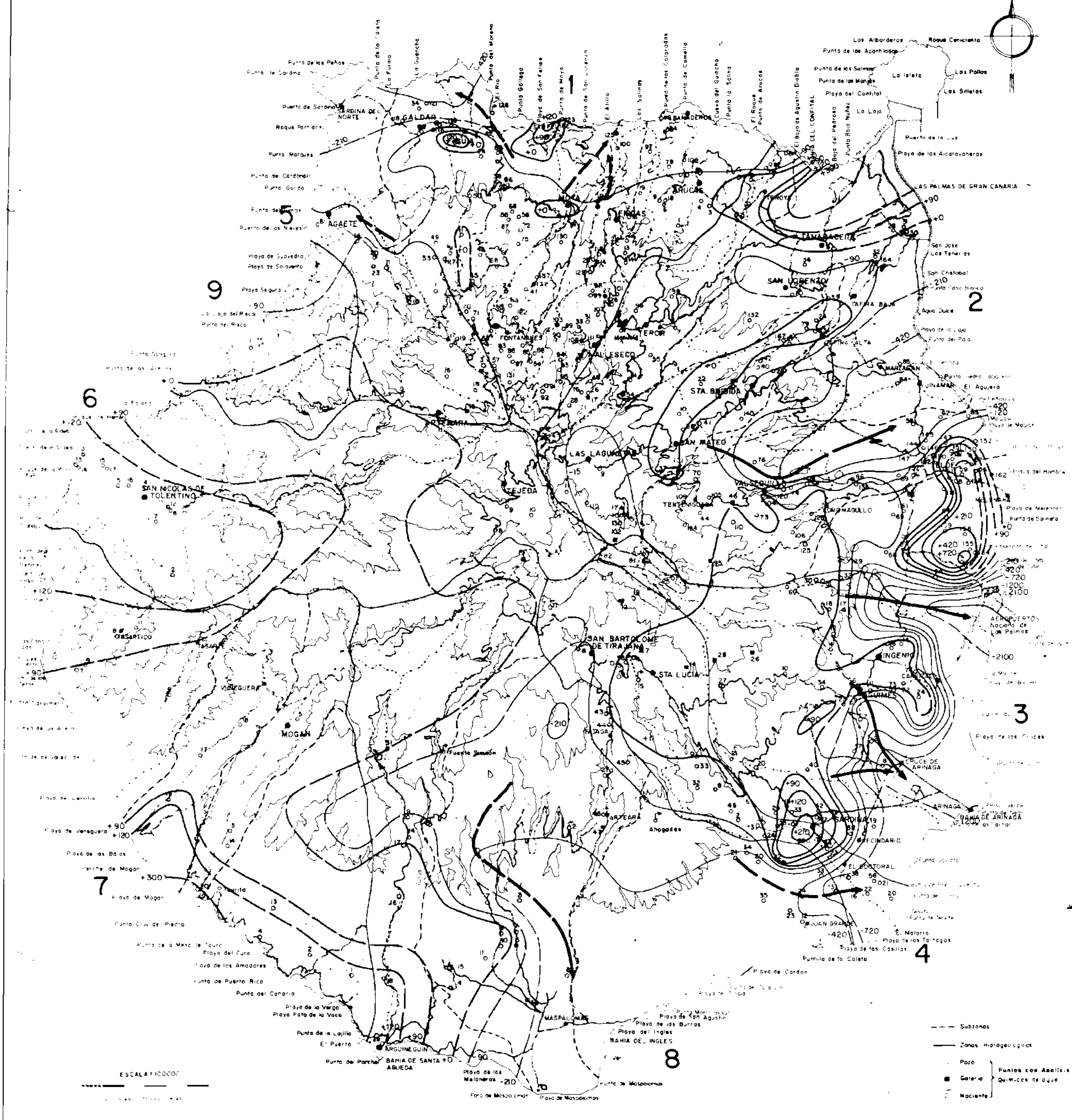


FIGURE E-36

tive Δ values correspond to dilution and the positive Δ values to concentration. During this particular water year, dilution occured in the central areas, in the northern coast, Agaete, San Mateo-Marzagan area, Fataga-Maspalomas as well as a wide coastal belt stretching from Gando to Maspalomas, the latter precisely corresponding to the heavy pumped Old Basalt aquifer in the coastal zone.

The principal dilution lines are shown in the same map. The very sharp dilution affecting the coast may be a secondary effect of pumping. In fact in summer time there is less pumping in the coastal zones of the eastern and south parts of the island, where the water is for tomatoe cropping and the subsequent spring dilution is possibly due to shutting off of pumping.

The principal concentration zones are of two types, the first found in the western, south-western parts and east of Sta. Lucía, explained by the lack of effective infiltration this year and the second found in Tenoya, Telde-Melenara and Sardina-Agüimes, all due to heavy coastal pumping.

An attempt has been made to correlate Cl^- content with groundwater and a correlation between Cl^- concent and elevation of water table exists as seen in Fig. E.37. The dispersion is due to chlorinity changes according to season.

We have remarked earlier that 30-60 mg/l isochlore suffers little change and this possibly indicates the limit of fresh infiltrated water due to direct recharge. In Fig. E.37 we also see that 60 mg/l of Cl^- content corresponds to a mean water table elevation of 300^m or about 500 to 700^m of altitude. This value is considered in this report as the lower limit of the recharge lense existing on the top of the island and from which water is transmitted gradually to the lower water strata of the island.

Cl⁻ CONTENT OF GROUNDWATER VERSUS WATER TABLE ELEVATION

GRAN CANARIA

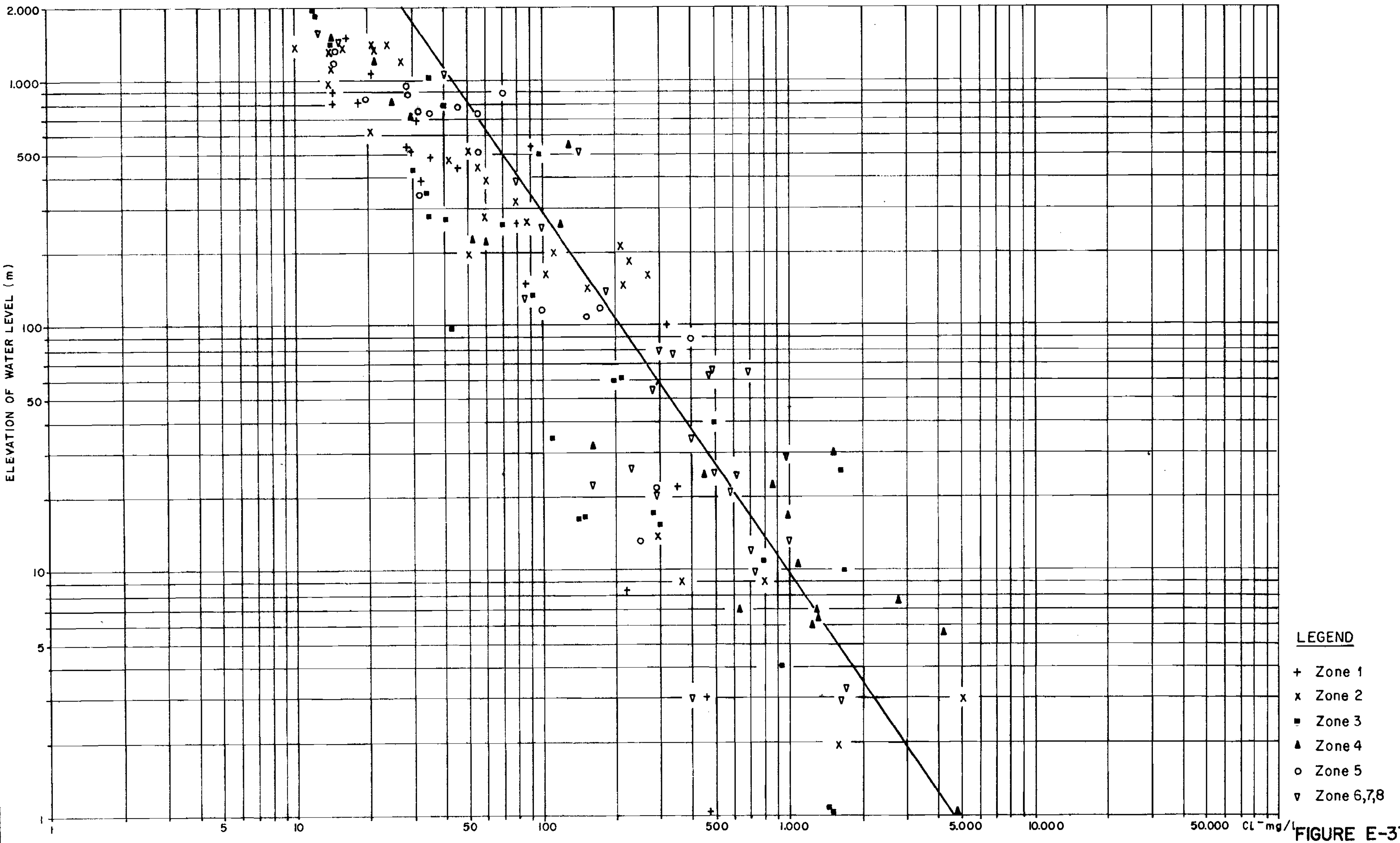


FIGURE E-37

Also we note that most of abrupt changes in the coastal zones occur for concentrations higher than 600 mg/l of Cl. This corresponds to a water table elevation of about 20^m or 100 - 200^m of height above sea level. In fact 80% of the irrigated tracts in the island are found below elevation 200^m and the effect of return water as well as the influence of brackish water are felt in this zone, which also explains the extreme dispersion in the chlorinity of this belt.

Taking into consideration the foregoing observations, a Cl^- stratification scheme for the island, analogous to the groundwater stratification scheme already proposed in Section E.1, is given in Fig. E.38.

Following this scheme, the recent waters from recharge have a Cl^- content varying from 15 mg/l on the top to about 60 mg/l on the bottom limit. Below this level groundwater flow follows a slow movement across the water massif gradually increasing in concentration from 60 to 600 mg/l to the coast. The basal water zone has a variation from 600 to more than 1.000 mg/l. Sea water has around 20.000 mg/l of Cl^- and hence the diffusion zone probably is very large.

7.3 Results of Laboratory Measurements

The laboratory of the Servicio Hidráulico de Obras Públicas, performs routine chemical determinations, and is also equipped by the Project with a Perkin-Elmer 403 model atomic absorption unit for the analyses of micro-elements. Only the reliable analyses were used for computations and the results of this study are discussed below.

7.3.1 Cations, Anions and Total Mineralization

The mean values of the cations and anions are summarized in Table E.5, according to each hydrological zone. The weighted mean values expressed in mg/l for the island in the cation group are 59,0 of Ca, 54,0 of Mg, 220,0 of Na and 11,7 of K. The waters are thus predominantly sodic and are equally rich in Ca and Mg.

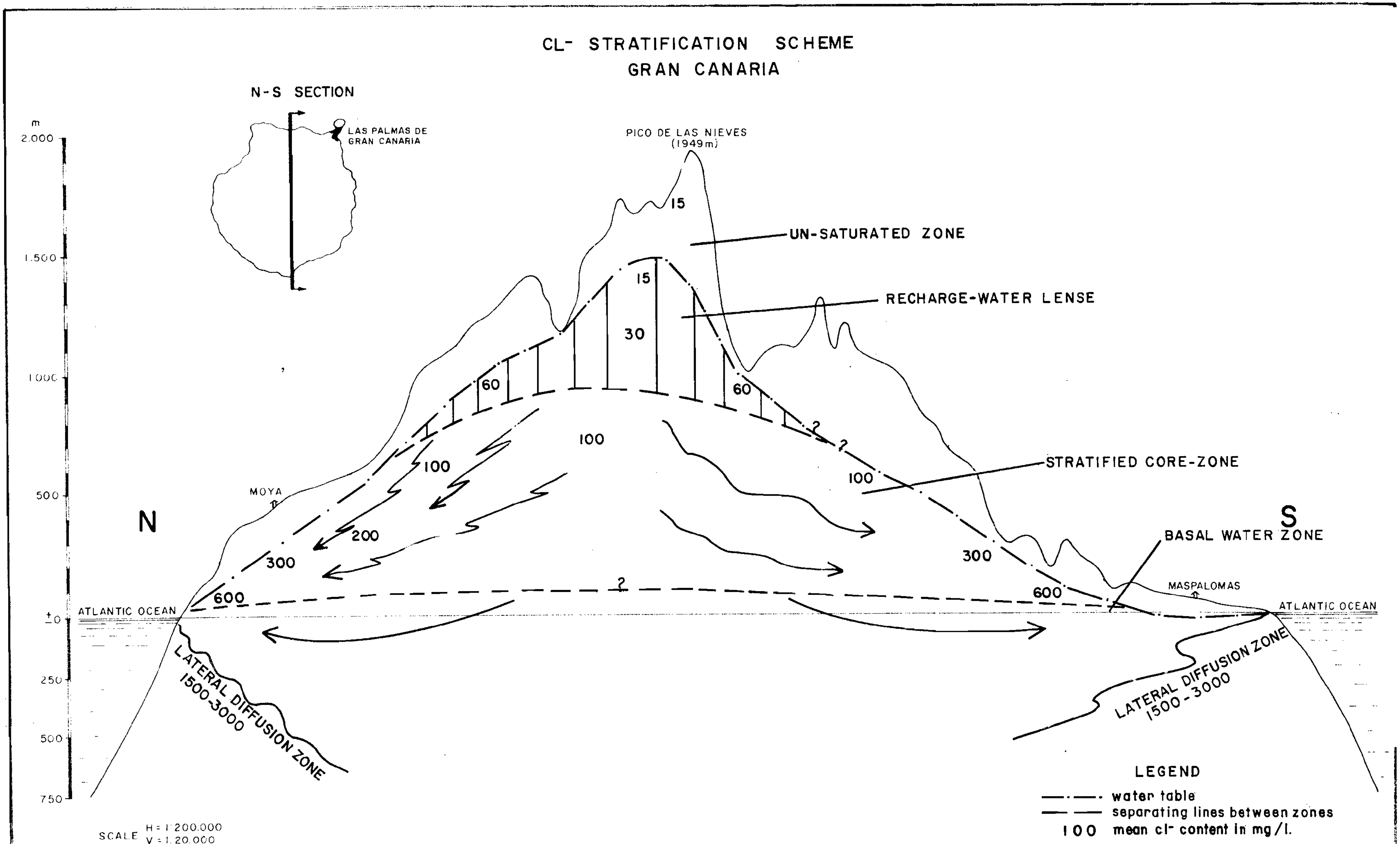

CL- STRATIFICATION SCHEME
GRAN CANARIA
N-S SECTION
LAS PALMAS DE GRAN CANARIA
PICO DE LAS NIEVES (1949m)
m
2.000
1.500
1.000
500
±0
250
500
750
N
S
MOYA
MASPALOMAS
ATLANTIC OCEAN
ATLANTIC OCEAN
UN-SATURATED ZONE
RECHARGE-WATER LENSE
STRATIFIED CORE-ZONE
BASAL WATER ZONE
LATERAL DIFFUSION ZONE 1500-3000
LATERAL DIFFUSION ZONE 1500-3000
15
15
30
60
60
100
100
100
200
300
300
600
600
?
LEGEND
water table
separating lines between zones
100 mean cl- content in mg/l.
SCALE H = 1:200.000 V = 1:20.000

FIGURE E-38

If we study the anionic group we see the values obtained are 328 of Cl, 5,4 of CO_3, 265,6 of HCO_3, 162,2 of SO_4, 24,8 of NO_3 and 1,2 of PO_4. The waters are subsequently rich in Cl and HCO_3, but the content of SO_4 and NO_3 are not negligeable.

The total mineralization T.D.S is less in zones 1 and 5 (671 to 613 mg/l) due to continual flushing by infiltrating and probably fast flowing ground waters, and high in the rest of the island, the highest being in zone 4 with 1650 mg/l, possibly due to the slow moving mineralized waters of Old Basalts. However in the entire southern zone, the T.D.S content is generally high probably due to the longer contact times of groundwaters as well as possibly due to small permeability and aridity of climatic conditions.

A better idea of the total mineralization of groundwater in the island is obtained from the map of T.D.S, E.39. The values of T.D.S gradients expressed in mg/l/km and corresponding electrical conductivity in micro-mhos/km are as follows:

Tejeda	-	Las Palmas	86	(86 micro/mhos/km)
"	-	San Felipe	112	(170 ")
"	-	Agaete	88	(112 ")
"	-	Arinaga	412	(412 ")
"	-	Maspalomas	103	(144 ")
"	-	Mogan	30	(32 ")

A similar tendency as for Cl^- during recharge is noted, which may be because total mineralization of groundwater follows a similar fluctuation corresponding to that of Cl^- due to recharge phenomenon. Also it is to be noted that the principal protuberances of Cl^- explained as possible permanent preferential groundwater flow paths, are reproduced here.

MAP OF TOTAL DISSOLUED SALTS (T.D.S.)

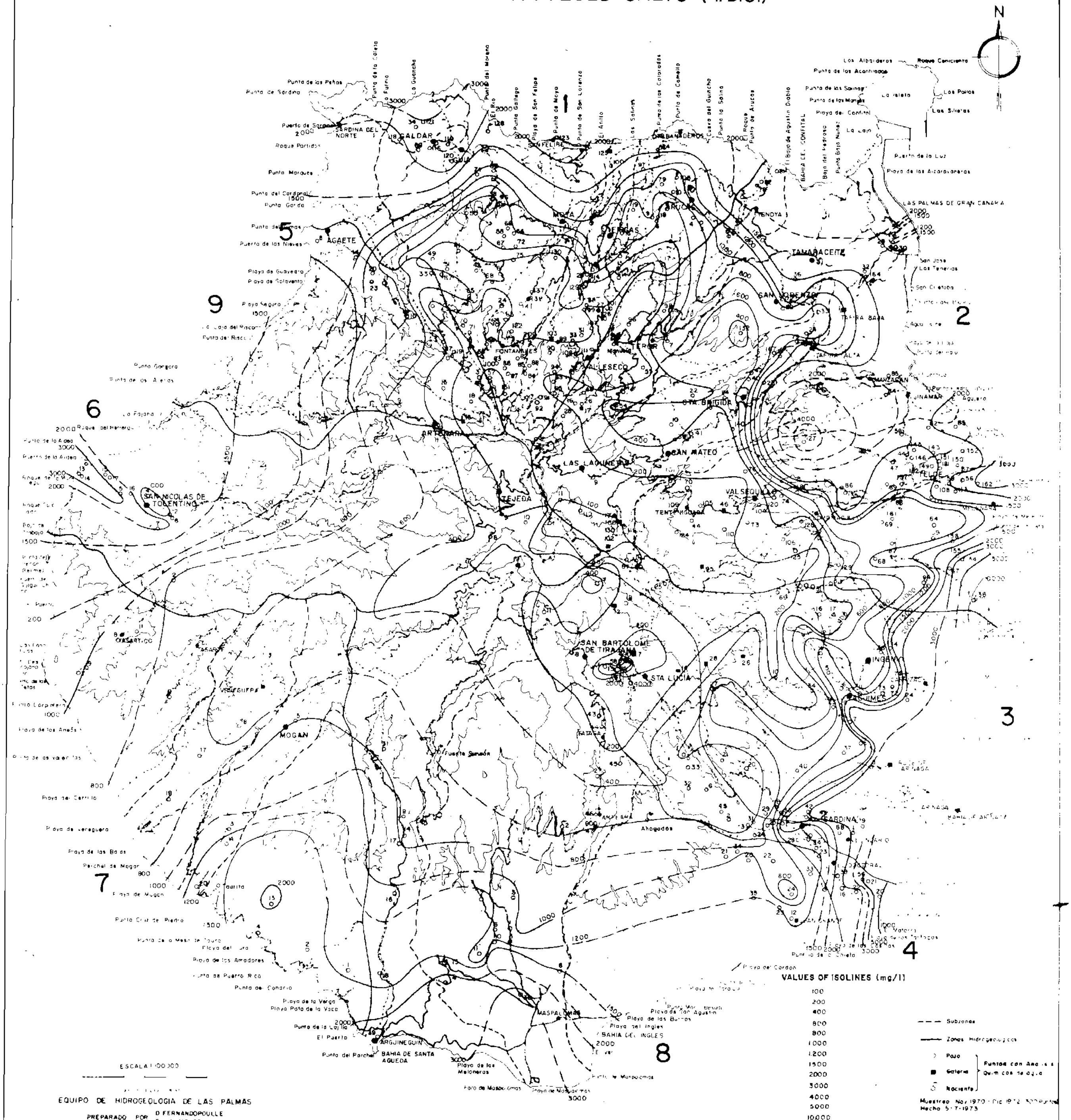


FIGURE E-39

7.3.2 Distribution of SiO_2

The average concentration of SiO_2 in groundwaters of the island is in the 20-40 mg/l range and thus does not differ from the world average values established for groundwaters flowing through carbonaceous and igneous rock-formations (White). For Gran Canaria, the 20-40 mg/l concentration range may be regarded as a background.

The higher values are found all within the NE half of the island where the younger rocks occur. However within this region, there are localized concentration areas practically all of which coincide with the previously mentioned high CO_2 focuses. The SiO_2 value varies from 40 to 112 mg/l and 6 of such areas stand out against the background values:

- Guía-Galdar	40 to 50 mg/l
- Moya-Firgas-Fontanales	50 to 80 mg/l
- Tenoya	about 80 mg/l
- Upper valley of Agaete	50 to 75 mg/l
- Agüimes-Ingenio	70 to 112 mg/l
- Lower Tirajana	(west of Sardina) 50 to 90 mg/l

The small focuses in Tafira, near Sta. Brígida and Teror, also can be related to recent volcanic vents characterized by high CO_2 content.

This coincidence between CO_2 emanation zones and high SiO_2 values is related to the rising of the solubility point by the lowering of the pH. Later we will see how the comportment of the earth-alkalis follow a similar pattern in these areas.

7.4 Study of Hydrogeochemical Ratios and Parameters

The study of the various hydrochemical ratios is of particular interest in the diagnosis of hydrogeological problems. Several ratios were examined but only 5 of them were found to be significant in the analysis of the groundwater system of the island. Through these ratios as we will see in the following pages, an attempt is made to study the behaviour of the earth alkalis with relation to alkalis, indicative of the ion-exchanges taking place within the rock system, and also examine the metamorphism of Cl^- with relation to bicarbonate along the flow paths of groundwater. Also attention is paid to the study of the mecanism in the development of Ca with relation to Mg and Na with relation to K.

7.4.1 The rCa+rMg/rAlk ratio

The spatial variation of this ratio is shown in Map E. 40. Two types of values can be seen, 0,25 to 1,00 considered to be alkali dominant and 1,0 to 4,0 which are earth-alkali dominant.

The north-eastern half of the island stands out by a predominance of zones with high values. These are, Montaña Alta (south of Guía), upper valley of Agaete, and between Fontanales-Moya-Firgas, Tenoya, small area W of Telde, a large zone between Ingenio-Agüimes and lower Tirajana valley. Also there are local points near Tafira, Teror and San Mateo-Lagunetas.

In this particular sector the earth-alkali rich zones coincide with high values of CO_2 and SiO_2 and are concordant with Modern Basalts principally pyroclasts, and volcanic vents. The intermediate areas with low values and therefore richer in alkalis are concordant with the Phonolytic and Ignimbritic rock formations, such for example in the northern coastal periphery, upper Tenoya valley, near Las Palmas and also near Marzagan. It is to be noted the upper Telde Valley, where Ordanchites ? occur intercalated with Roque Nublo around Tenteniguada, also has low values.

If we now look at the south-western half of the island, the only high values found are in Mogan-Veneguera region corresponding to the Old Basalt outcrops.

MAP OF RATIO rCa + rMg/rALC

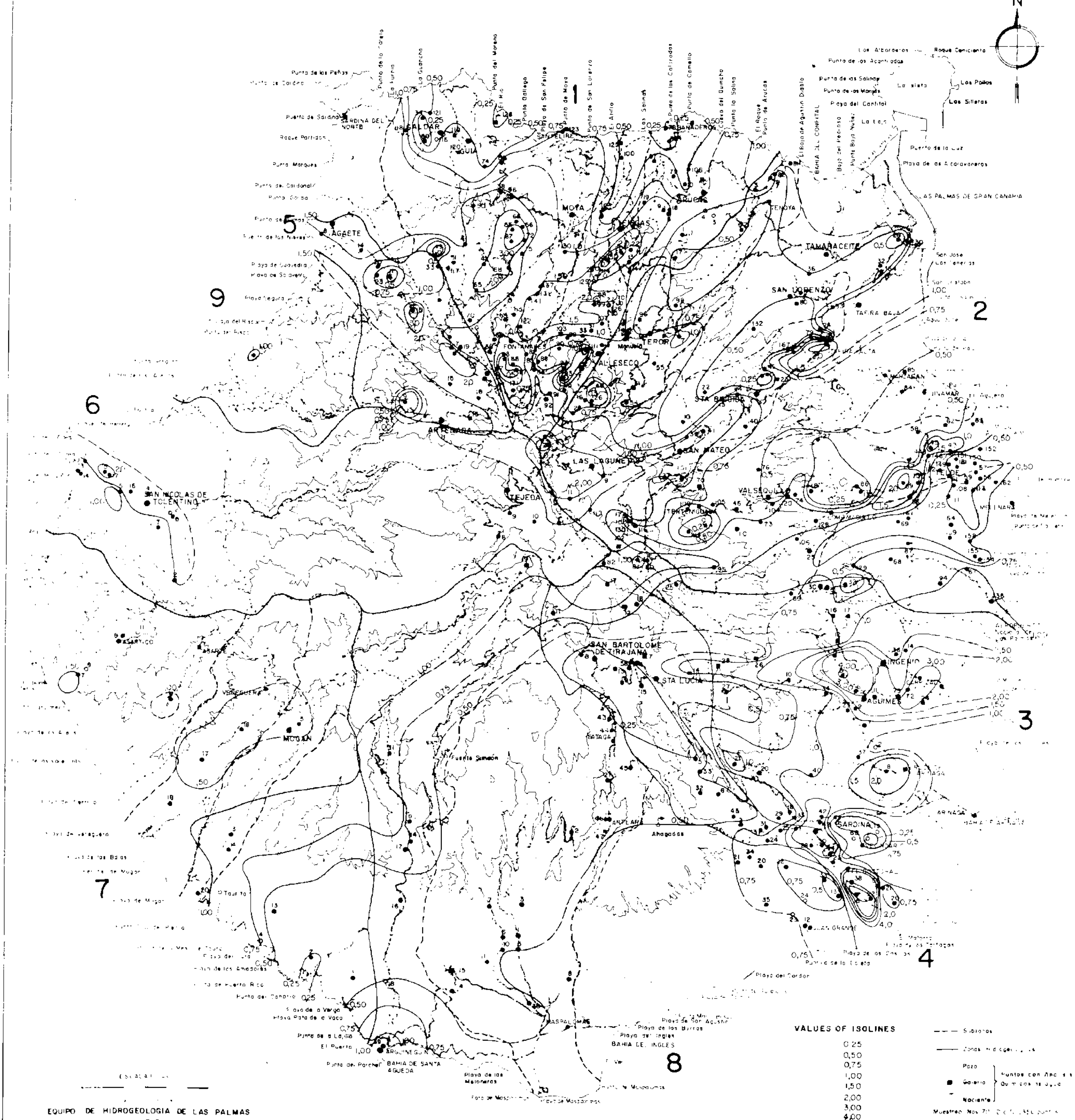


FIGURE E-40

This analysis reveals that the dominance of earth-alkalis and alkalis are correlated to the nature of the rock formations, through which water is flowing. Hence there is a concordance between the lithological provinces of the island and the variation of this ratio.

The inversion of the ratio along the coastal belt of Gando-Doctoral is probably due to the existance of brackish water from heavy pumping.

These field investigations are confirmed by an absolute correlation existing between this ratio in water and the chemical composition of the rocks as seen in Fig. E. 46. A further explanation of the relation between rock types and waters will be made later in this sub-section.

7.4.2 The rMg/rCa ratio

The variation in this ratio is shown in Map E. 41. The distribution pattern shows a clear development of the ratio 0,5 near the centre of the island. This belt stretches from Artenara-Tejeda to San Bartolome de Tirajana. Another belt spreads from Tenteniguada to the upper part of the Guayadeque valley. Two small zones seem to develop near Teror and Valleseco. No clear correlation with either rock types or climatic conditions exists. However, these areas do not coincide with the higher rainfall areas and specially the Tejeda-San Bartolome belt is found frankly on the leeward slopes of the central area.

The ratio values 0,5 to 1,0 extends through the central zone and the south central region. Protrusions towards Teror and Valsequillo as well as large detached areas between Valleseco-Fontanales-Moya and W of Montaña Alta are also noted.

Over the rest of the island, the coastal areas in the south generally have values between 1,0 and 2,0 which locally like in Tirajana can go up to 5 and 6. The areas from 1,0 to 2,0 spread all over the eastern and north-eastern section. The only exception is found in the northern

MAP OF RATIO rMg/rCa

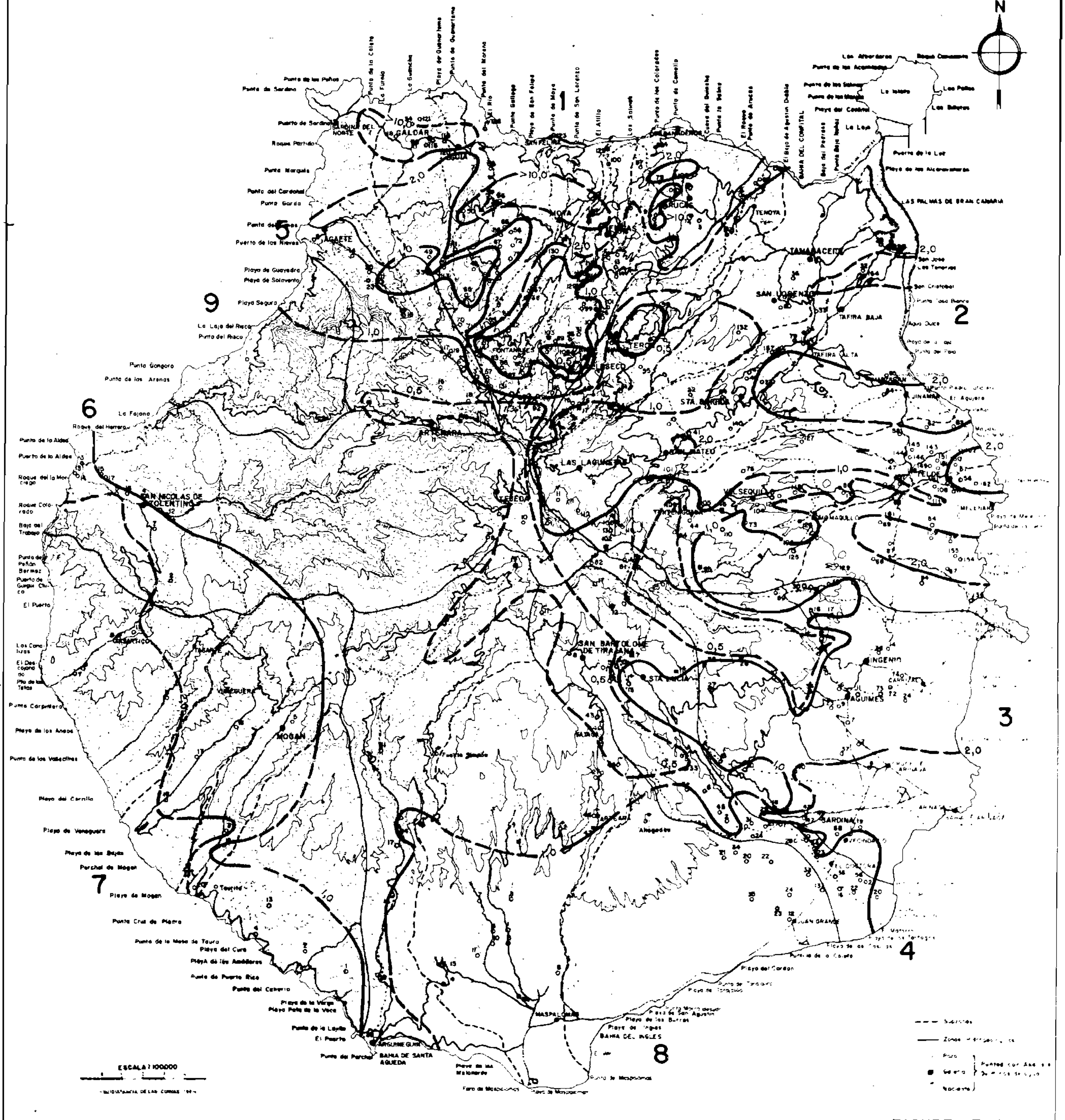


FIGURE E-41

zone where within an area of over 2,0. there exist nuclei of over 10,0. These latter one localized W of Arucas, between Moya-Guía and around Galdar. There is no clear correlation between this distribution pattern and CO_2 emanations or temperature anomalies, even though all areas with such anomalies have values between 1,0 and 2,0.

The explanation for the behaviour of the rMg/rCa ratio may be a combination of both geological and climatic factors, where phenomena of preferential leaching and dissolution may be the dominant factors.

7.4.3 The $rCl/rHCO_3+rCO_3$ ratio

The outlines of the map portraying the distribution of this ratio resembles those of the isochlorinity and water level maps. The distribution pattern is shown in Map E. 42. The increase in the ratio values in the groundwaters of Gran Canaria, is gradual and is caused by bicarbonate saturation and by the increase in the Cl^- content towards the geological strata nearer the sea level.

Ratio values of less than 0,5 englobes large parts of the central zone as well as extensive areas in the south-east between Sta. Lucía and Ingenio. The values increase gradually up to 1,0 or 2,0 around the coast excepting between Telde and Playa de Mogan. The maximum values of over 10,0 found between Gando and Juan Grande on the one side and around Maspalomas and Playa del Cura in the south confirms the presence of sea-water intrusion in this area.

An inverse relationship has also been noted when this ratio was compared with that of rCa+rMg/rAlk. When this ratio increases which is normally the case when passing from Basalts and Roque Nublo to Phonolytes and Ignimbrites, the rCa+rMg/rAlk ratio decreases and that for the same arrangement of rock types. This indicates that when chlorinity increases there is a parallel increase in alkalinity. Also earth-alkali enrichment

MAP OF RATIO $rCl/rHCO_3+rCO_3$

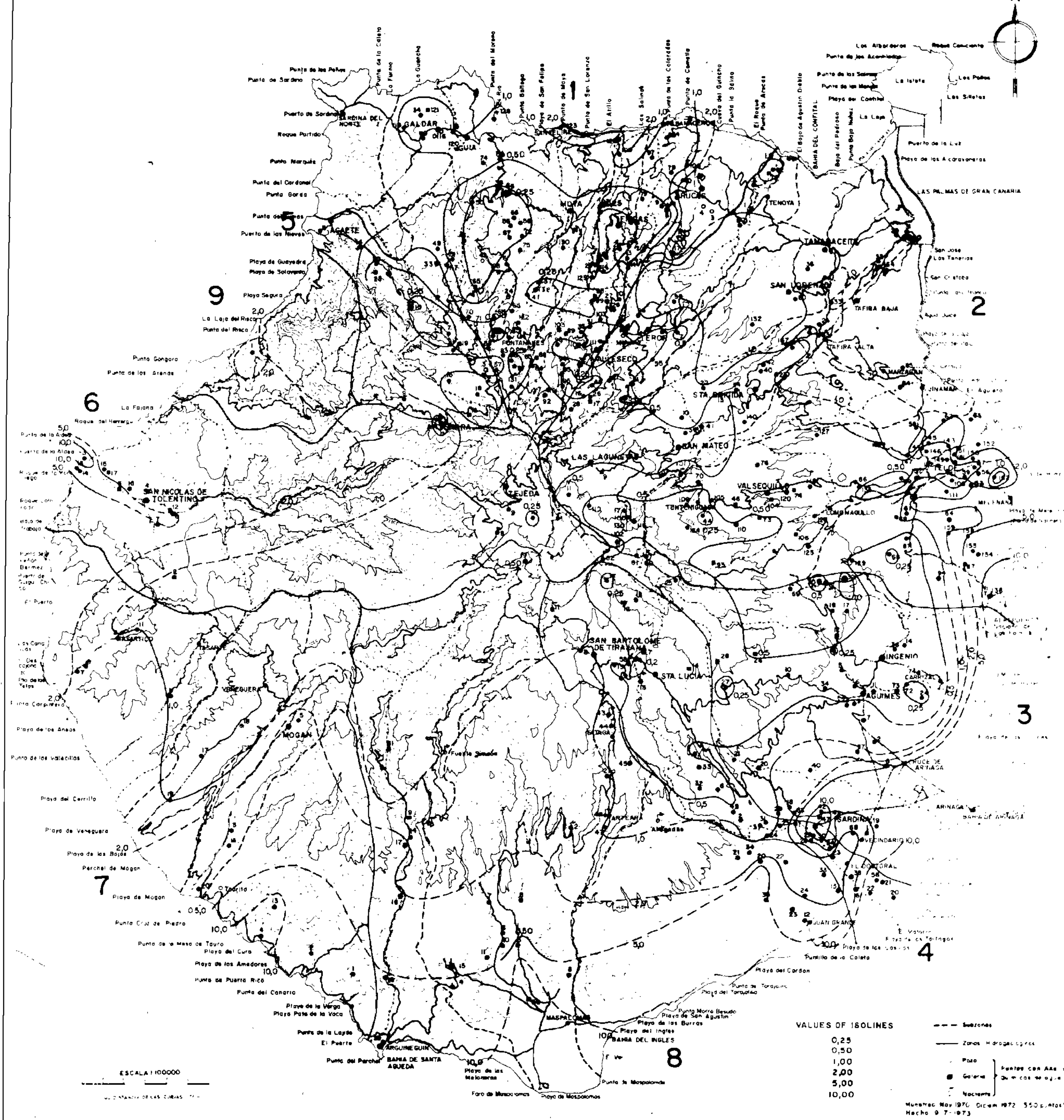


FIGURE E-42

goes parallel with carbonate enrichment.

7.4.4 The rNa/rK ratio

The distribution of this ratio varies from around 1,0 in the centre of the island to about 40 in the eastern and northern coasts and to about 60-70 in the western coast. The ratio above 40 is related to sea water encroachment as is the case in the eastern and southern coasts and also to aridity of climate as is probably the case in the west of the island.

It is noted that the rate of concentration of rNa along sections is always higher than that of rK. This may be attributed in the latter case to the absorption of K in clays and to the initial lower concentrations of this ion in the surrounding rocks.

Hence increase in this ratio shows the growing concentration of Na, when K remains relatively constant. The ratio 20 practically coincides with basalts of all types and Roque Nublo. Above this limit, the values englobe the Phonolytes, Ignimbrites, the Las Palmas Terrace and the Trachy-Syenitic complex.

7.4.5 The rAlk/rCl ratio

All through the island this ratio attains positive values which means that the amount of alkalis is always superior to the amount necessary to counterbalance the chlorides. The ratio values increase seawards along the flow-lines. This stands in good agreement with the hydrochemical data from other volcanic terrains and is due to the extensive negative ion-exchange processes through which alkali ions, abundantly supplied by volcanic aquifer rocks, are exchange against alkaline-earth ions in the water and thus take the leading place in the cation-sequence. This process is confirmed by the preponderance of negative exchange values found specially in the middle and lower altitudes.

7.4.6 Study of Hydrogeochemical Sections 2, 5, 6 and 9

A better understanding of the mecanism of the hydrogeochemical processes in groundwater mineralization can be obtained by a detail study of cross-sections. For this purpose 4 of these have been selected for analysis in the following pages.

Cross section N. 2 traverses the northern region starting from the near centre of the island (Mirador de Moriscos) and can be considered representative of the structures of the entire northern part of Gran Canaria, see Fig. E. 43.

Geologically speaking, it consists of a great thickness of the Roque Nublo Series in the upper part, composed of agglomerates, intercalated lava flows (specially of tephritic type) and sediments. This is the main aquifer of the region. In the middle section, Ignimbrites and Trachy-Syenites underly the Roque Nublo series and most wells draw water from the contact. Some modern volcanic vents pierce the ignimbritic substratum. In the lower zone the thinning out Roque Nublo Series is overlain by Modern Basalts and underlain by Phonolites. Water is drawn from the lower contact with the Phonolytes or partly from fissured zones of the latter formation.

If we examine the hydrogeochemical section we note that in the upper zone the temperature and pH values are rather constant, characteristic of the recharge zone and Cl content increases only gradually.

Excepting for one point (1095) the ratios rCa+rMg/rAlk, rNa/rK and the value of SiO_2 remain constant which is opposed to the behaviour of ratio $rCl/rHCO_3+rCO_3$ making a deep downward curve between 1095 and 1032. This indicates a bicarbonate enrichment which probably is in relation with an increase in CO_2 at a volcanic vent near 1095-1032. In the same section at the same point there is a sudden decrease in ratio rCa+rMg/rAlk which is indicative of an alkali enrichment related to a CO_2 high. The ratio rMg/rCa

CONCENTRATIONS VARIATIONS OF PRINCIPAL IONS

CROSS - SECTION 2

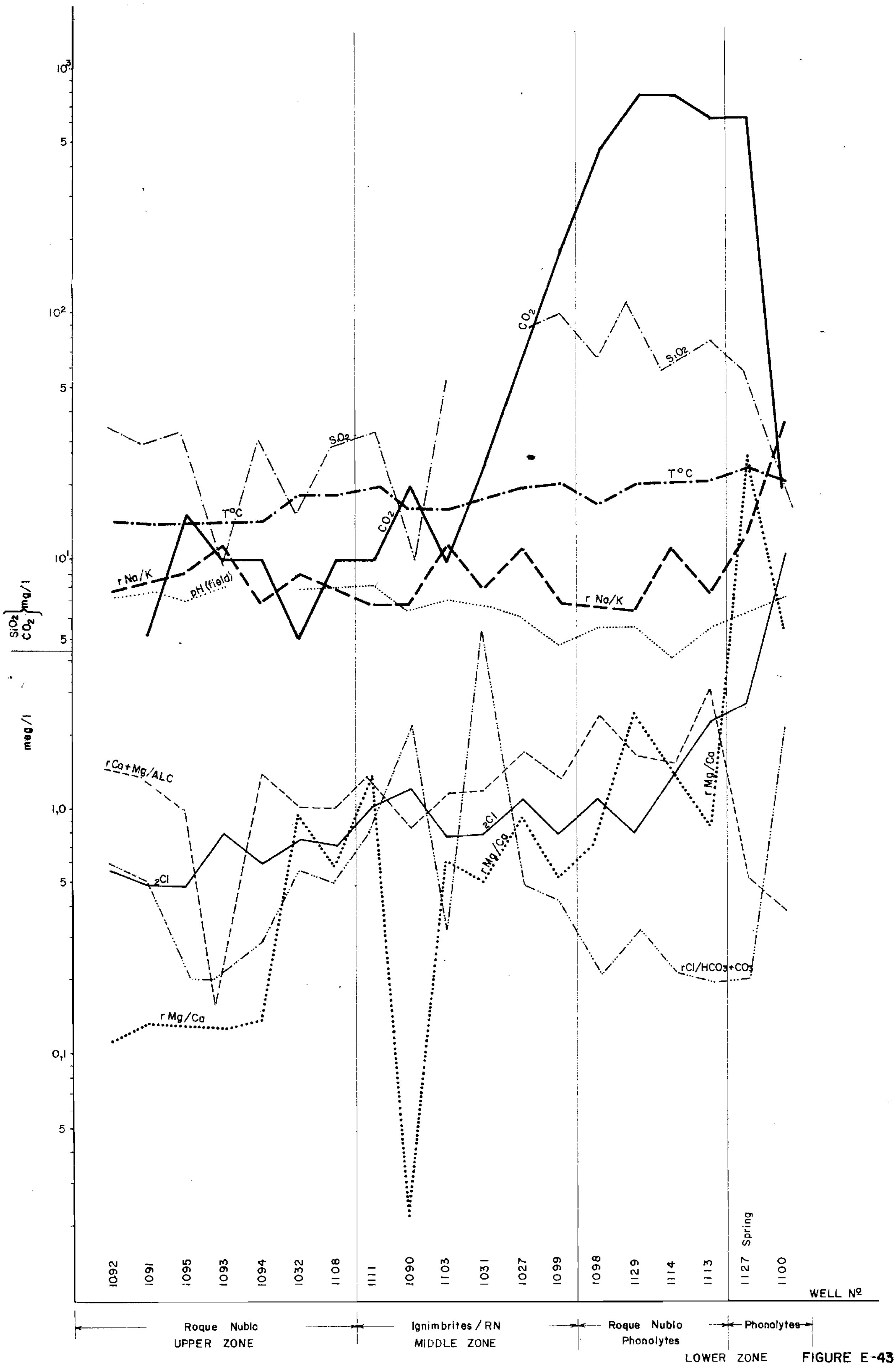


FIGURE E-43

remains constant excepting towards the lower section of this zone where it rises suddenly, explained by an enrichment in Mg.

In the middle zone, we note a gradual increase of temperature and Cl, also a gradual decline of the pH but a sudden increase of CO_2 towards the lower part. As for the other ratios, rNa/rK fluctuates, rMg/rCa generally decreases with a depresion around 1090 agreeing with a CO_2 high, $rCl/rHCO_3+rCO_3$ accuses a general high with fluctuations corresponding to the high chlorinity also related to CO_2 emanations and finally rCa+rMg/rAlk increases gradually following very much the tendency of rCl. The value of SiO_2 increases following the curve of CO_2. In this middle section we see notably the predominance of CO_2 in the hydrogeochemistry of waters.

In the lower zone, the earlier tendencies are accentuated excepting at the end when the waters touch the phonolytic substratum.

As expected, there is a general rise of CO_2, Cl, SiO_2 contents following a decline in pH. Also the ratios rNa/rK, rMg/rCa and rCa+rMg/rAlk tend to rise with the increase in the solubility of the medium. Although rCl rises, the $rCl/rHCO_3+rCO_3$ ratio lowers which indicates that carbonate solution rate is greater. When we arrive at well 1100, the CO_2 mecanism ceases with the incurving of the majority of the chemical ratios mentioned.

The cross-section Nº 5 can be divided like the earlier into 3 zones. The aquifer in the upper zone consists of Roque Nublo, but in the middle zone this formation thins out and water is derived at times also from Phonolytes. In the lower zone the thin Roque Nublo reposes over Phonolytes and is covered by Modern Basalts. Towards the sea however, the main aquifer is the Las Palmas Terrace composed of alluvial and colluvial materials.

As can be seen in Fig. E. 44 temperature and pH remain rather constant but there is an important high in free CO_2 and rCl in the lower part of the middle zone. The fluctuations in SiO_2 also follow those of CO_2 but in a less accentuated manner.

CONCENTRATION VARIATIONS OF PRINCIPAL IONS

CROSS SECTION 5

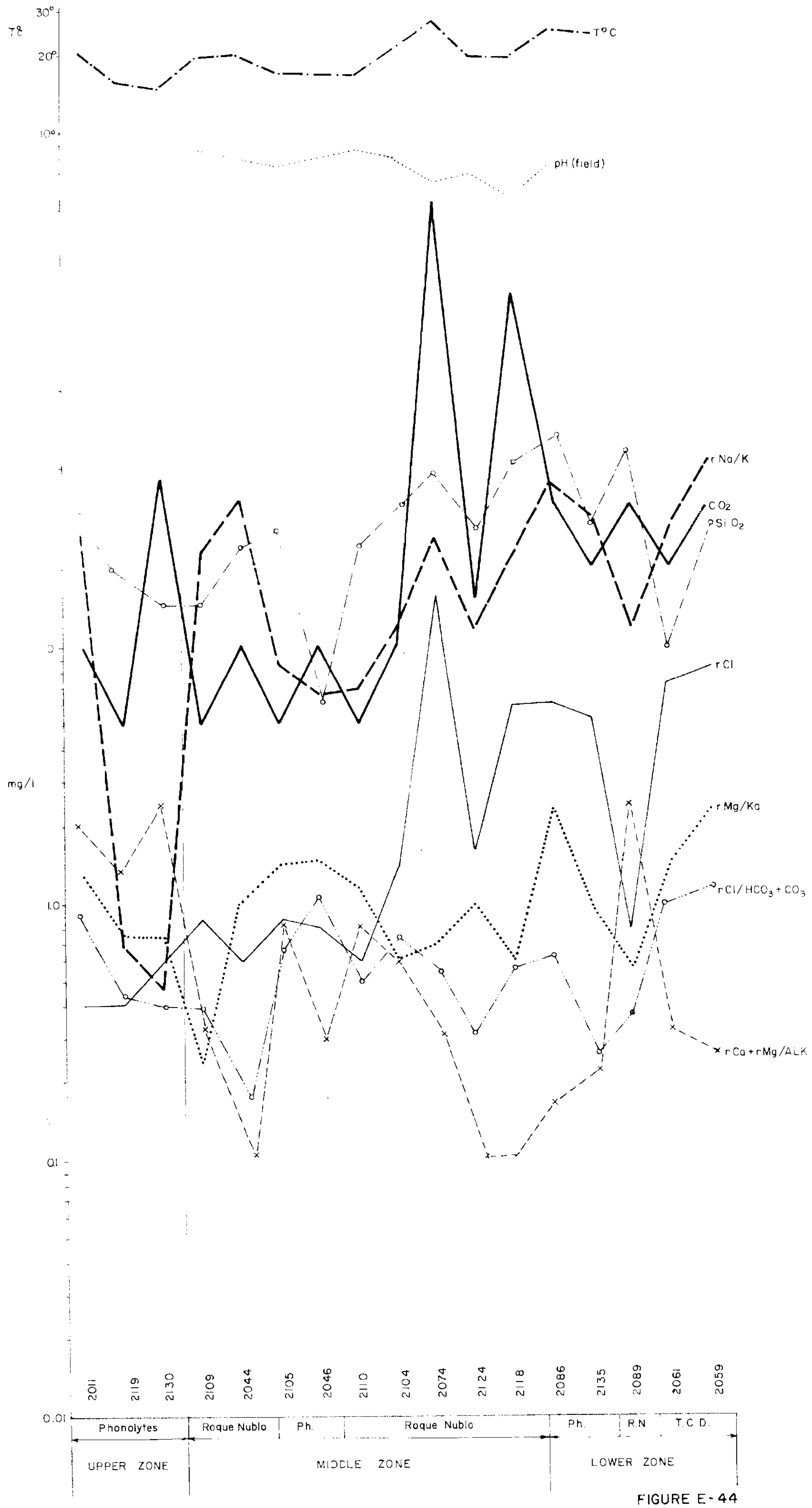


FIGURE E-44

With regard to the chemical ratio, $rCl/rHCO_3+rCO_3$ it follows an opposite tendency to rCl and CO_2 which indicates a relative bicarbonate enrichment process. The rCa+rMg/rAlk ratio also seems to behave similar to the earlier ratio, which indicates a general alkali-enrichment to the detriment of the earth-alkalis. The general increase of rNa/rK along the section confirms this hydrochemical process.

Summarizing, we see again here the important role of CO_2 as a hydrochemical agent responsible for the major mineralization process of groundwater in the north and eastern regions of Gran Canaria.

When we examine cross-sections 6 and 9 in Fig. E. 45, we see certain other patterns. Section 6 is rather representative of the south-eastern part of the island and traverses principally in the upper part, the Roque Nublo and Modern Basalts and in the lower part the Old Basalts. The section referring to Roque Nublo has been left out.

In section 9 we see the typical situation in the south-western part of the island. The upper part is composed of Modern Basalts and Roque Nublo (agglomeritic beds of upper levels) and in the lower area, of Old Basalts. The middle zone composed of Phonolytes and Trachy-Syenites do not seem to confirm the existance of any important groundwater circulation.

In section 6, the upper part is marked by normal temperatures, low CO_2 and high pH values. In the lower part corresponding to the Old Basalts the temperatures are high and the pH goes down with a rise in CO_2 content. This is in fact one of the major temperature anomaly zones in the island coinciding with CO_2 emanations. Both rCl and SiO_2 comportment follows that of CO_2 but with a still higher total mineralization characteristic of these rocks. As for the ratios we note an increase in rMg content as well as rNa. The $rCl/rHCO_3+rCO_3$ ratio as well as that of rCa+rMg/rAlk develop parallely showing a general enrichment in Cl and earth-alkalis.

CONCENTRATION VARIATIONS OF PRINCIPAL IONS

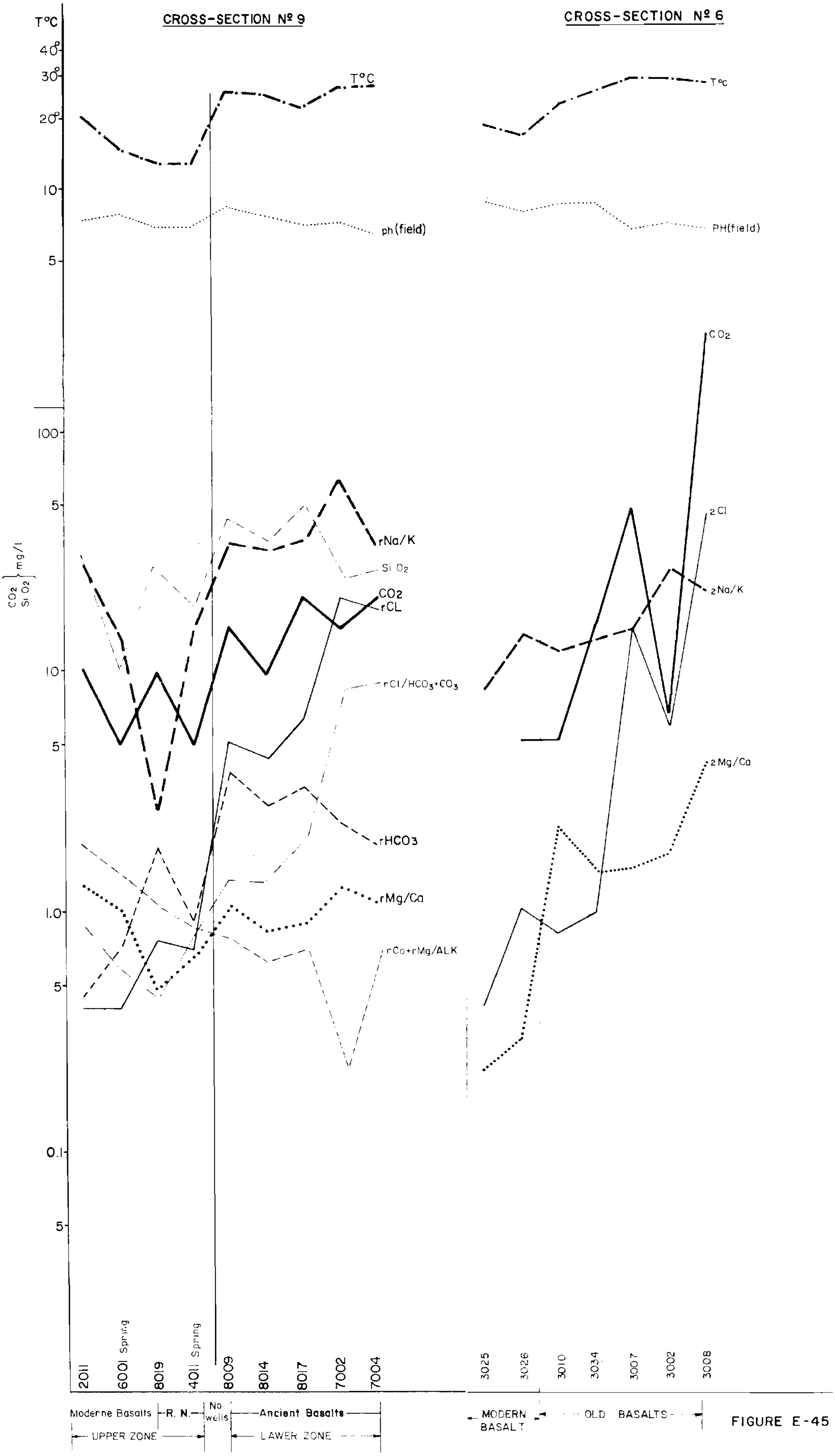


FIGURE E-45

In this section we find that CO_2 is related to a general all round mineralization process rather typical of the Old Basalts.

In section 9, the development of the hydrogeochemical process towards the coast is somewhat similar to that found in section 6. However, the CO_2 content even though rises gradually cannot be considered abnormal. In spite of this, the SiO_2 content follows closely the CO_2 fluctuation. A tremendous increase in Cl is seen and this can be noted in the ratio $rCl/rHCO_3+rCO_3$, where $rHCO_3$ tends to decrease. The rCa+rMg/rAlk ratio decreases from the upper zone to the coast indicating an alkali enrichment, also seen clearly in ratio rNa/rK. In this section, the principal hydrogeochemical process involved seems to be an alkali enrichment as against earth-alkali (Mg) enrichment in section 9.

In the analysis of the 4 sections undertaken, we note that the principal agent of groundwater mineralization is CO_2. We have also seen that the main processes intervening in the metamorphism of groundwater are bicarbonate, chloride, alkali and earth-alkali enrichments whose interrelationships are tied down by ion-exchange phenomenon as mentioned earlier.

7.4.7 Rock-water relationship

An attempt has been made to relate the principal geological formation of the island to salient hydrogeochemical characteristics studied before.

For this purpose, uncontaminated water samples from the various formations as well as associated rocks, were analyzed. In fact, a clear correlation does exist between rock types and "formational waters" as shown by the ratio rCa+rMg/rAlk of water plotted against $CaO+MgO/Na_2O+K_2O$ of rock on a logarithmic paper as seen in Fig. E. 46.

We see clearly the increasing tendency for alkalinization when water flows through Phonolytes, Ignimbrites, and the Trachy-Syenitic Complex.

CORRELATION ROCK-TYPES AND WATERS

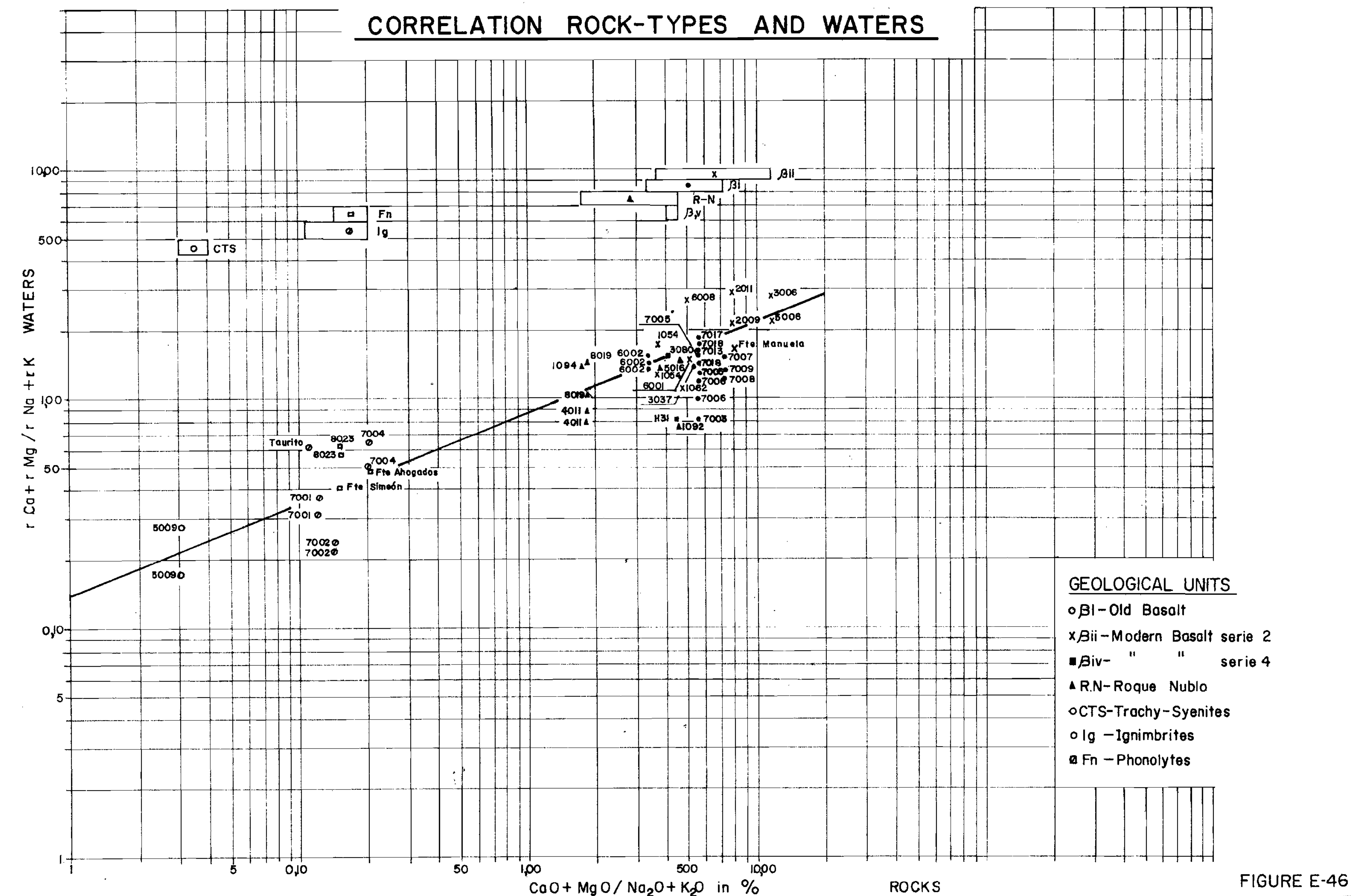


FIGURE E-46

The Roque Nublo formation occupies an intermediate position between the former types and the basalts. As for the latter, their richness in earth-alkalis in clearly seen.

The rock-water relationship of the same water samples have been also studied with relation to their total cationic and anionic assemblages and their dispersion shown in Fig. E. 47.

In Table E. 5 are presented the defining characteristics of the rock waters. It can be noted there is little difference between Modern and Old Basalts in their alkali and earth-alkali %, but the latter are richer in chloride and poorer in bicarbonates. The Phonolytes and Ignimbrites have a similar comportment with regard to alkalis and earth-alkalis, being always richer in the latter than the basalts. However, the Phonolytes are poorer in chlorides and richer in bicarbonates than the Ignimbrites. In this system the Roque Nublo series occupies an intermediate position.

This clear relationship between rock types and "formational waters" can be tied up to the distribution pattern of hydrogeochemical ratios specially rCa+rMg/rAlk.

7.5 Classification of Groundwater

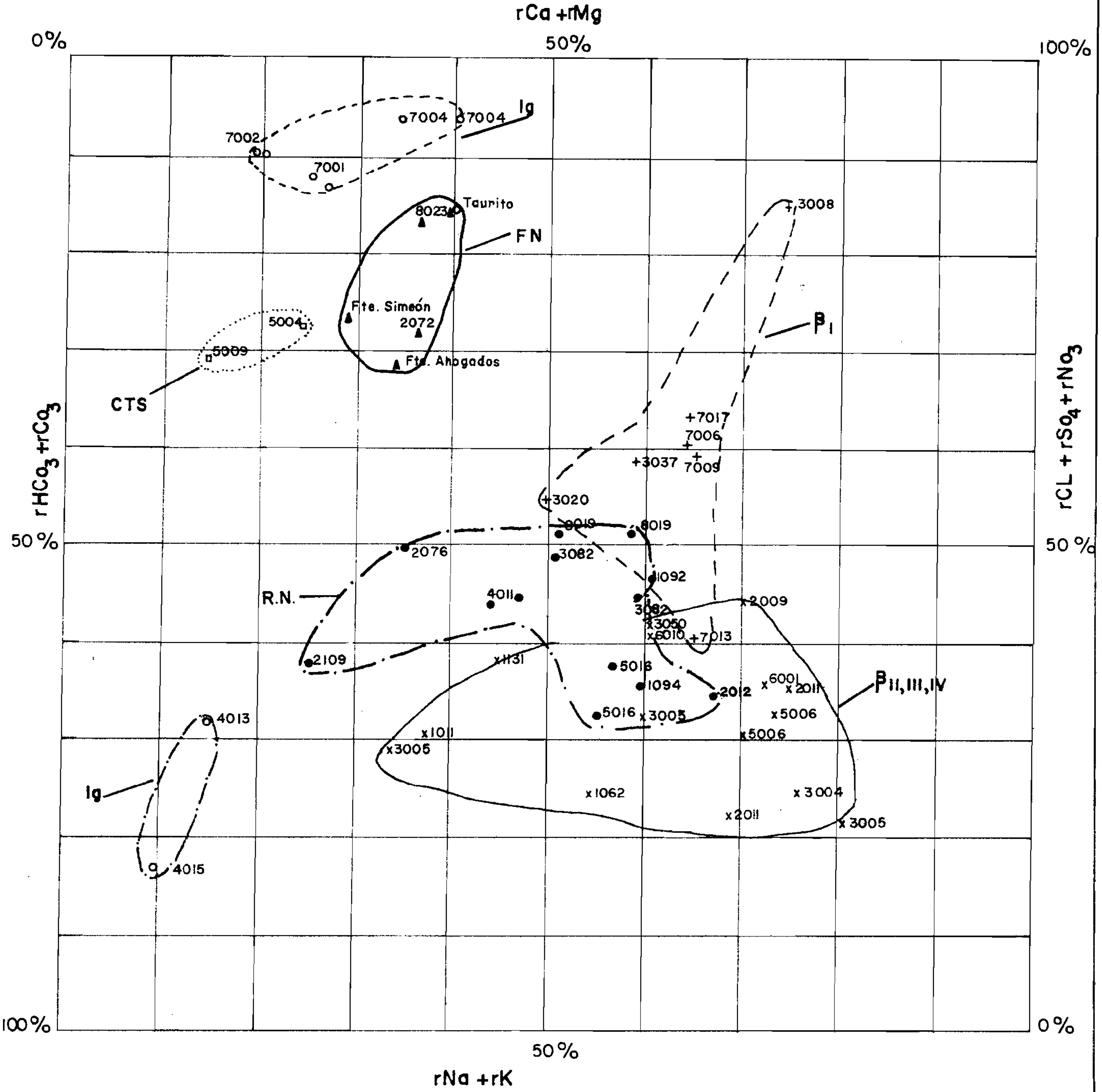
The groundwaters of Gran Canaria are classified into 3 families and 7 types, taking into account of the leading cations, anions and the subsequent changes in their hydrochemical assemblages which indicate the principal mineralization tendencies.

7.5.1 Major Families

The families are named after the 3 major anions present, as follows:

Family I - Carbonate-Bicarbonate Family: The dominant anion is bicarbonate and only in specific cases (15%) when the pH exceeds 9,3 the leading role is played by carbonates. This family occurs in the centre

ROCK-WATER RELATIONSHIP



+ β_I OLD BASALTS
x $\beta_{II,III,IV}$ MODERN BASALTS
• RN ROQUE NUBLO SERIES
▲ FN PHONOLYTES
o Ig IGNIMBRITES
□ CTS TRACHY-SYENITIC COMPLEX

FIGURE E-47

Table E.5

Rock-water Relationship

	Modern Basalts	Roque Nublo Series	Phonolytes	Ignimbrites	Old Basalts
rAlk %	20-40	50-65	60-70	60-80	25-50
rCa+rMg %	55-80	20-70	30-40	20-40	50-75
$rCl+rSO_4+rNO_3$ %	20-45	30-50	70-85	85-95	40-85
$rHCO_3+rCO_3$ %	55-80	50-70	15-30	5-15	15-60
rCa+rMg/rAlk	1,5-3,0	0,8-1,4	0,4-0,7	0,2-0,7	0,8-2,0

of the island related to Modern Basalts and Roque Nublo. This area coincides with high rainfall and the central recharge zone.

Family II - Chloride Family: The major distribution is found in the southern region as well as around the coasts. Its occurrence generally coincides with Phonolytes, Ignimbrites, the Trachy-Syenitic complex and the Las Palmas Terrace. The waters of this family are confined to areas of little recharge and increasing aridity of climate.

Family III - Sulphate Family: The distribution pattern is highly localized to the lower reaches of the "barrancos". Its occurrence corresponds to intensively cultivated zones where return irrigation waters occur and also to drainage outlets of the main populated areas.

7.5.2 Water types and principal sub-types

The three families are subdivided into 7 major water types and 13 subtypes. The characteristic mineral assemblages and hydrochemical parametric limits are given in Table E. 6. The principal types and subtypes found in hydrological zones 1, and 3, , which would correspond to the areas described by hydrogeochemical cross-sections 2 and 6, are found in Figs. E.48 and E. 49. The distribution of the water types and principal subtypes are shown in Map E. 50. A description of the main characteristics of these are given below:

- T.1 Mg Dominant Bicarbonate waters:

They occur in the Ca-Mg rich olivine Modern Basalt zones found in the upper Guinguada valley, Ingenio-Agüimes, Firgas and Guía.

Subtype T.1.1 is associated with Modern Basalt aquifers where CO_2 emanations and occasional high temperatures exist, such for example around Firgas and Ingenio.

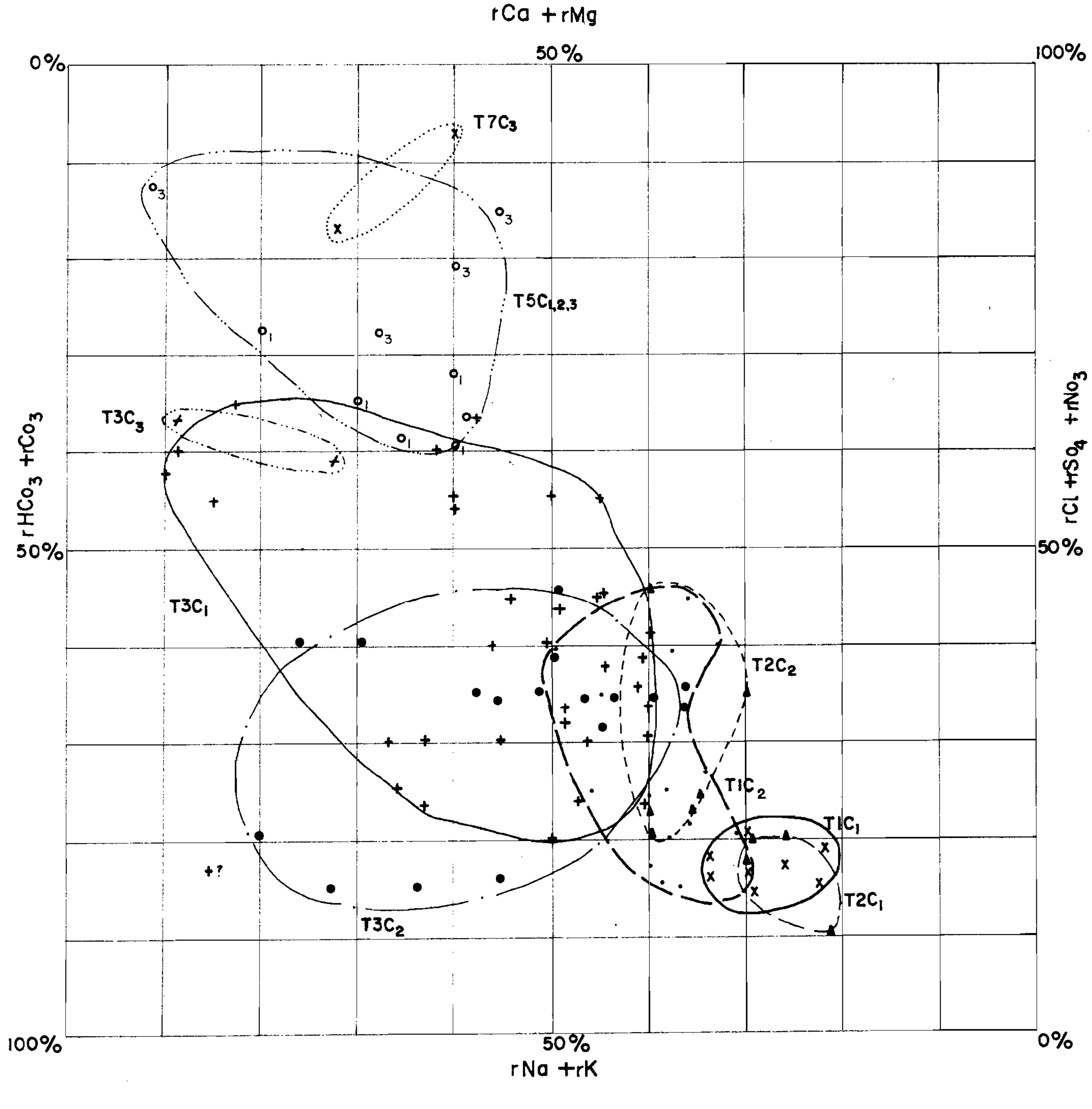
Subtype T.1.2 shows a gradual enrichment in Na, although Mg is yet dominant.

Table E.6

Water types and Principal Sub-types

Ionic assemblage	Significant Parametric limits: T.D.S. mg/l	rCa+rMg/Alk	rCl/HCO$_3$+CO$_3$	rMg/Ca	%rMg+rCa	%rHCO$_3$+CO$_3$	%rAlk	%rCl	%rSO$_4$	Observations
T.1 $rHCO_3+rCO_3, rCl, rSO_4$.....rMg,rCa,rAlk										Mod.Bas.
T.1.1 $rHCO_3+rCO_3$ rCl.....rMg rCa	500-2000	2 4,5	0,15 0,5	1,0 2,0	60-80	70-80	30-40	10-20	2-10	CO_2
T.1.2 $rHCO_3+rCO_3$ rCl.....rMg rAlk	500-2000	1,0 2,0	0,20 0,7	1,5 5,0	50-60	70	50-60	20	2-10	
T.2 $rHCO_3+rCO_3, rCl, rSO_4$.....rCa,rAlk,rMg										
T.2.1 $rHCO_3+rCO_3$ rCl.....rCa rMg	500-1000	2,5	0,08 0,2	0,07 1,0	70-80	60-80	20-30	5-15	2-10	"Volcanic
T.2.2 $rHCO_3+rCO_3$ rCl.....rCa rAlk	100-500	1,5 2,0	0,2 0,5	0,10 0,80	60	50-60	40	15-30	2-10	waters"
T.3 $rHCO_3+rCO_3, rCl, rSO_4$.....rAlk,rMg,rCa										R.Nublo
T.3.1 $rHCO_3+rCO_3$ rCl.....rAlk rMg	100-1200	0,4 1,5	0,2 1,0	1,5 3,0	10-40	40-50	50-90	30-40	10-15	
T.3.2 $rHCO_3+rCO_3$ rCl.....rAlk rCa	150-1200	0,8 1,5	0,2 0,8	0,5 1,0	30-60	50-70	40-70	20-40	10	
T.3.3 $rHCO_3+rCO_3$ rSO_4.....rAlk rCa	1200-5000	0,10 0,50	0,5 1,0	0,6 4,0	10-20	40-70	80-90	15-30	30-40	"Volc.
T.4 $rCl, rHCO_3+rCO_3, rSO_4$.....rMg,rCa,rAlk										therm. waters"
T.4.1 rCl $rHCO_3+rCO_3$.....rMg rCa										Old.Bas.
T.4.2 rCl $rHCO_3+rCO_3$.....rMg rAlk	2000-3000	1,5 2,0	4,5 8,0	1,5 2,5	60-70	10-20	30-40	70-85	5-15	
T.4.3 rCl rSO_4 .....rMg rAlk,rCa	2000-8000	2,0 5,5	1,0 4,0	1,0 2,0	65-80	2-10	15-35	80-90	10-15	
T.5 $rCl, rHCO_3+rCO_3, rSO_4$.....rAlk,rMg,rCa										Phonol.
T.5.1 rCl $rHCO_3+rCO_3$.....rAlk rMg	1000-2500	0,1 1,0	1,0 5,0	1,0 4,0	10-45	15-40	55-90	40-70	10-30	Ignimb.
T.5.2 rCl $rHCO_3+rCO_3$.....rAlk rCa	800-1500	0,3 0,7	1,5 5,5	0,7 1,0	20-40	20-40	60-80	50-60	10-20	
T.5.3 rCl rSO_4 .....rAlk rMg,rCa	1500-10000	0,4 0,7	2,5 20,0	0,9 3,0	30-40	5-15	60-70	40-80	10-30	Brackish
T.6 $rSO_4, rHCO_3+rCO_3, rCl$.....rMg,rCa,rAlk	1000-3500	1,7 2,3	1,5 3,0	0,5 2,0	60-70	10-15	30-40	20-40	54-70	waters.
T.7 $rSO_4, rHCO_3+rCO_3, rCl$.....rAlk,rMg,rCa	1000-2000	0,4 1,6	2,4 4,5	0,5 5,0	30-50	10-30	40-70	30-50	40-60	Derived waters.

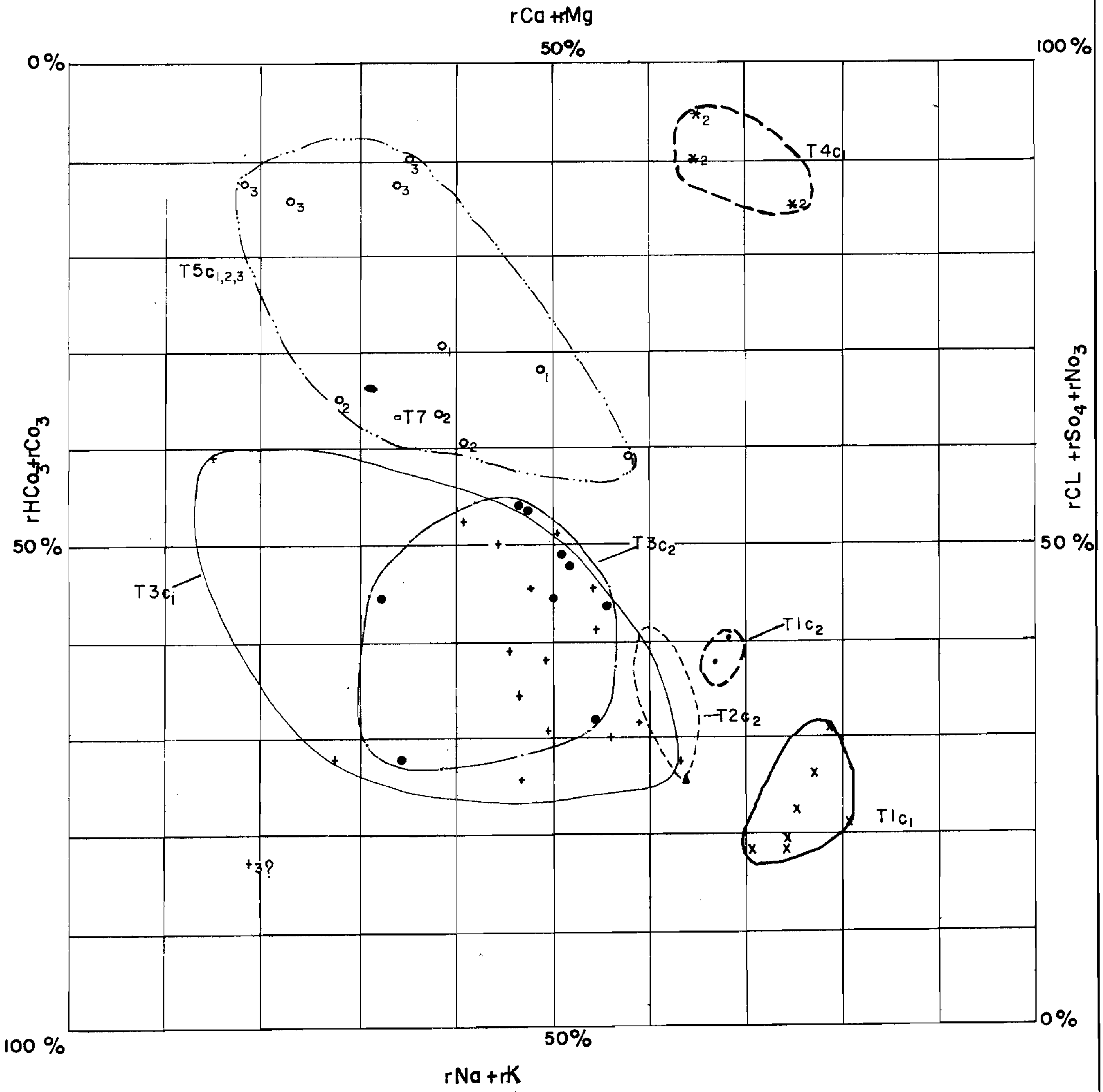
GROUNDWATER TYPES - ZONE 1
-GRAN CANARIA-



N.B. TYPES 4, 6 ARE ABSENT IN THIS ZONE

FIGURE E-48

GROUNDWATER TYPES - ZONE 3
-GRAN CANARIA-



N.B TYPE 6 IS ABSENT IN THIS ZONE

FIGURE E-49

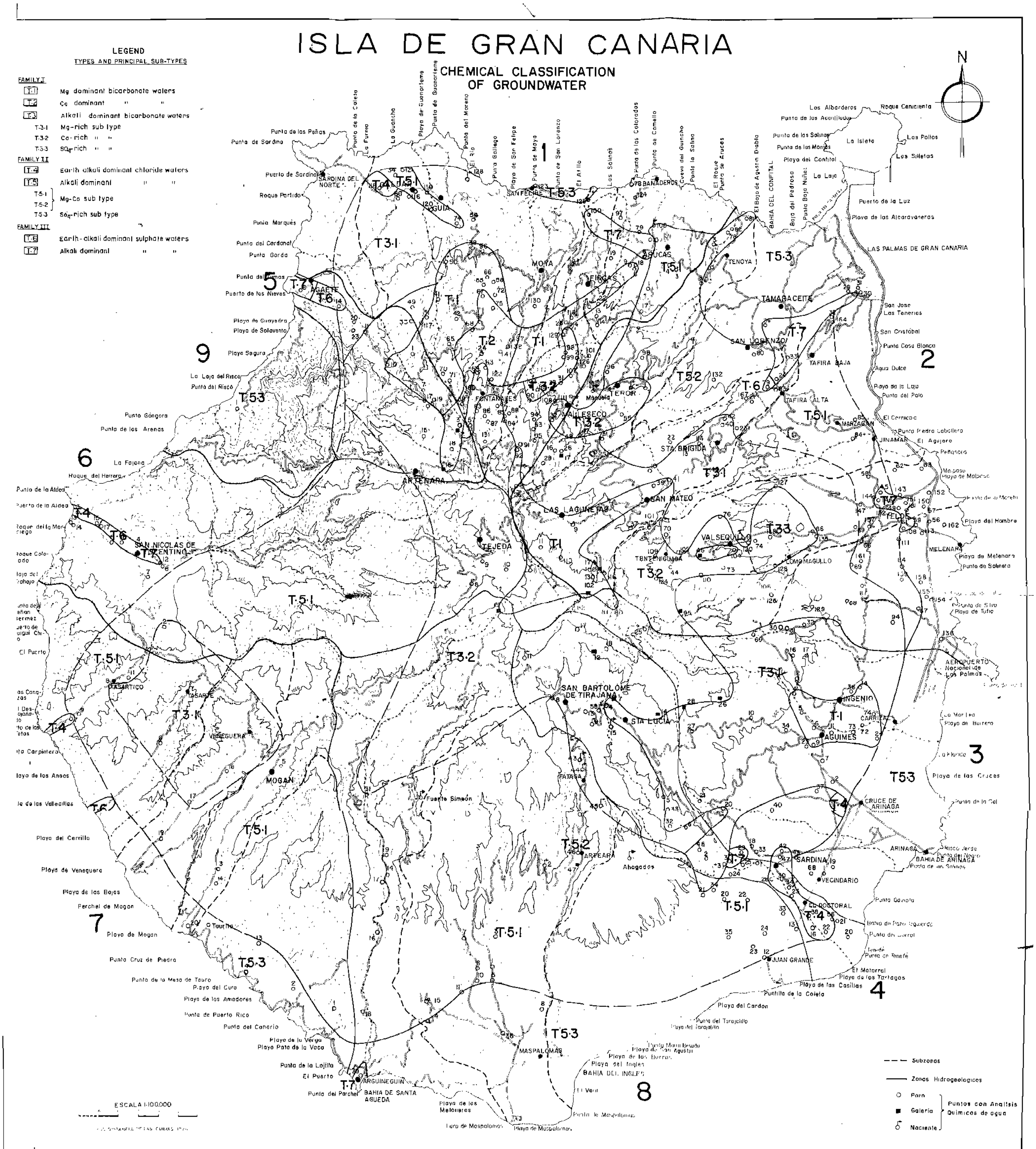

ISLA DE GRAN CANARIA
CHEMICAL CLASSIFICATION OF GROUNDWATER
LEGEND
TYPES AND PRINCIPAL SUB-TYPES
FAMILY I
T-1 Mg dominant bicarbonate waters
T-2 Ca dominant " "
T-3 Alkali dominant bicarbonate waters
T-3-1 Mg-rich sub type
T-3-2 Ca-rich " "
T-3-3 SO_4-rich " "
FAMILY II
T-4 Earth-alkali dominant chloride waters
T-5 Alkali dominant " "
T-5-1 Mg-Ca sub type
T-5-2
T-5-3 SO_4-rich sub type
FAMILY III
T-6 Earth-alkali dominant sulphate waters
T-7 Alkali dominant " "
N
Subzonas
Zonas Hidrogeologicas
Pozo
Galeria
Naciente
Puntos con Analisis Quimicos de agua
ESCALA 1:100.000
LAS PALMAS DE GRAN CANARIA
AEROPUERTO Nacional de Las Palmas
TELDE
INGENIO
AGUIMES
SAN BARTOLOME DE TIRAJANA
MASPALOMAS
ARGUINEGUIN
MOGAN
TEJEDA
ARTENARA
AGAETE
GALDAR
SAN NICOLAS DE TOLENTINO
TEROR
SAN MATEO
STA BRIGIDA
MOYA
FIRGAS
ARUCAS
VALSEQUILLO
STA LUCIA
TASARTICO
VENEGUERA
JUAN GRANDE
SARDINA
VECINDARIO
CRUCE DE ARINAGA
BAHIA DE ARINAGA
BAHIA DEL INGLES
BAHIA DE SANTA AGUEDA

FIGURE E-50

- T.2 Ca Dominant Bicarbonate waters:

In this type Na forms the second important cation. They coincide with T.1 type and are related to pyroclasts of Modern Basalts.

Subtype T.2.1 has a higher mineralization due to CO_2 association. It exists around Firgas and Montaña Alta and can be classes as "volcanic waters".

Subtype T.2.2 represents a transition to waters in the Roque Nublo Series.

- T.3 Alk Dominant Bicarbonate waters:

This is the most widespread type occurring in the middle altitudes and associated with the Roque Nublo Series, as is indicated by the alkali enrichment. It spreads over Fontanales-Valleseco, Teror, Valsequillo, all having Roque Nublo outcrops. The exception is the area W of Agüimes where Modern Basalt outcrops are found.

Subtype T.3.1 accounts for about 50% of the areal distribution of this type in association with Ordanchites and Phonolytes of high areas. It also occurs in the upper part of zone 7 in Old Basalts.

Subtype T.3.2 is found in Ca-rich rock type enriched by Na brought from higher lying areas by leaching process.

Subtype T.3.3 is localized around San Roque-Valsequillo in association with CO_2 and higher temperatures and thus can be classed as "volcanic thermal waters". It is characterized by high alkali and SO_4 content.

- T.4 Earth-Alkali Dominant Chloride waters:

This is largely found in the lower reaches of the Tirajana valley associated with Old Basalts even though mixing is suspected. All subtypes show a predominance in Mg (50 to 60%) in the cation group, of Cl (70 to 80%) in the anion group.

- T.5 Alk-Dominant chloride waters:

This is one of the most widespread types of waters covering the entire Phonolyte and Ignimbrite outcrops of the southern part of the island. In the north it covers the Tenoya and Moya basins as well as the Tafira-Jinamar region, all of phonolytic or pumitic composition. The major source of Na-mineralization is derived from these rocks (5-10% of Na in rock analyses).

Subtypes 5.3.1 and 5.3.2 are found towards the interior. Subtype 5.3.3 is marked by high T.D.S. and Cl values and is confined to the coastal belt, which can be classed as "brackish waters".

- T.6 Earth-Alkali Dominant sulphate waters:

This type along with T.7 can be classed as "non-formational" waters since their occurrence has little relationship to rock types but rather to mixing of waters of different origins.

- T.7 Alk Dominant sulphate waters:

The extension of this type coincides with T.6 and is found specially in the Arucas valley, and the lower reaches of Guiniguada-Telde valleys.

The principal relationships existing between the rock formations and the mineralization tendencies seen in the development of the various water types are illustrated in Fig. E. 51.

7.6 Principal factors influencing hydrochemical porcesses

We have seen in Fig. E. 47 the rock-water relationship of the "formational waters" and in Fig. E. 51 the principal mineralization tendencies of through-flowing water in various rock media.

Leaching processes dominate in the "cumbres" region, particularly in the Modern Basalts where water types T.1 and T.2 are found. In the middle

MINERALIZATION TENDENCIES
AND
ROCK-FORMATIONS
- GRAN CANARIA -

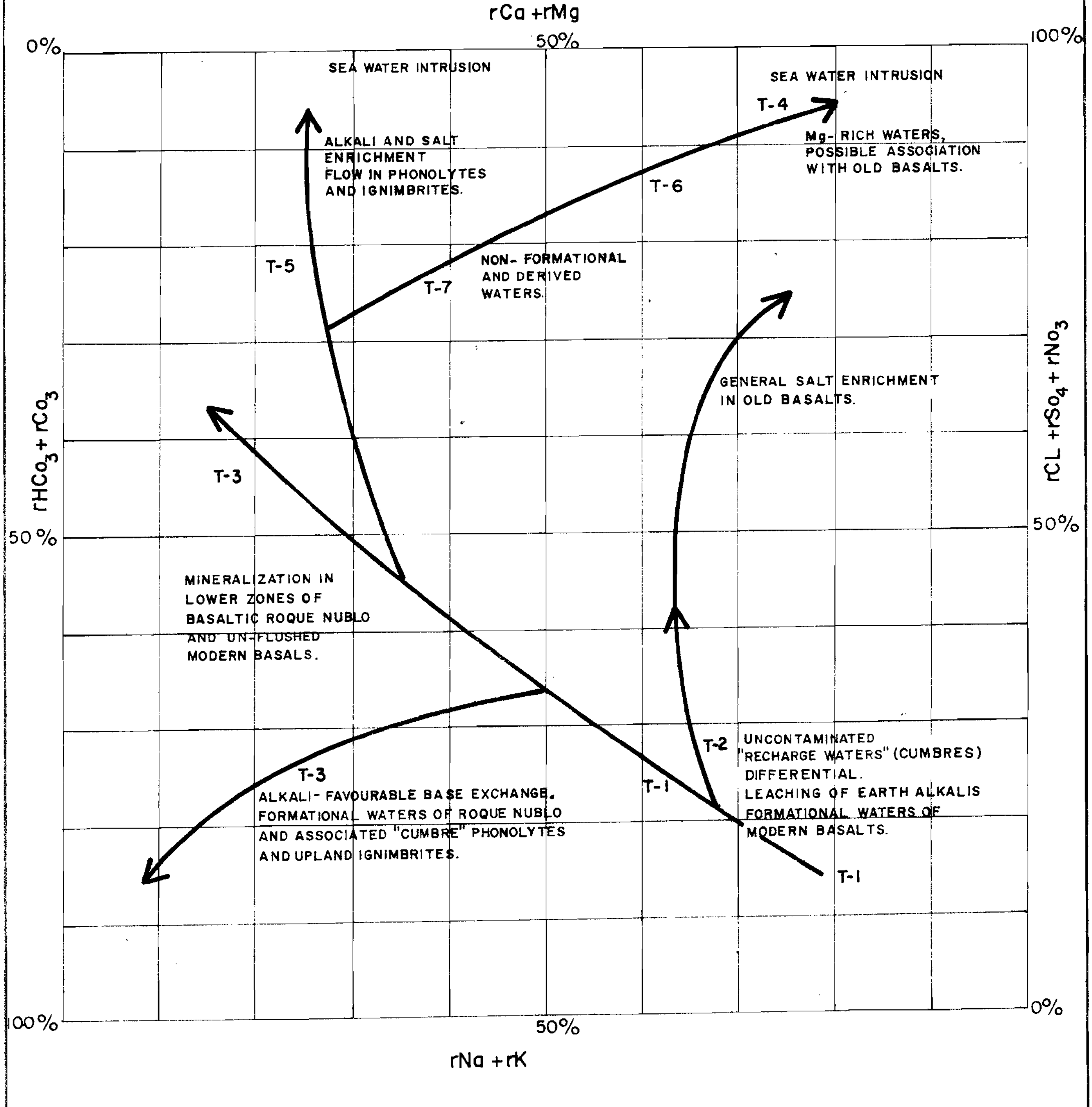


FIGURE E-51

altitudes, where the lower member of a Roque Nublo series outcrops, subtype T.3.1 develops, the tendency being for NaCl enrichment. However, in the Roque Nublo series of higher areas and in the associated Ordanchites (phonolytes) the tendency is for an alkali-favourable base exchange. The T.5 type associated with the Phonolytes and Ignimbrites is characterized by a general alkali-enrichment process.

The types T.4, T.6 and T.7 can be classed as "non-formational waters", resulting from artificial mixing of waters of different origins, secondary derived waters, return flow from irrigation and drainage, and salt water intrusion, as mentioned earlier.

7.6.1 Role of weathering and the leaching process

Several detail laboratory tests were made to study the contribution of rock types in mineralization of water using both fresh and weathered samples. A first idea of the importance of weathering was obtained through the study of "synthetic waters" obtained from rock samples collected in Basalts and Roque Nublo in the north of Gran Canaria. This was followed up by more detail analyses of rocks, lapilli, dust and soils.

The latter undertaken for a number of horizones showed specially the mecanism of the behaviour of cations and anions during the leaching process in rock types Roque Nublo and Modern Basalts. Thus it is found that there occurs a faster leaching of alkalis over Roque Nublo and of earth-alkalis over Modern Basalts. As for the anions, a clear idea was obtained of their entrainment through the soil profile derived from the top-soil. Also it was seen that a greater contribution of minerals took place from pyroclast, paleo-soils and the weathered zones. The total mineral content for 100 grs of soil or weathered material varied from 83 to 173 mg/l.

7.6.2 Volcanic phenomenon

The study of lapilli both fresh and steam-affected, was made of the recent volcano of Teneguía in La Palma island. The total soluble constituents in fresh samples were about 90 mg/l for 100 grs of sample, but in steam and gas impregnated lapilli, the soluable constituents increased by 2 to 4 times. The lapilli and pyroclastic materials specially if influenced by gases such as CO_2, release large quantities of soluable minerals and thus constitute an important factor in the mineralization of throughflowing waters. We have already dealt with the important role of CO_2 in mineralization. The presence of volcanic phenomenon gives rise to subtypes of water as was seen earlier.

7.6.3 Dust fall out

Analyses of Saharan dust fallout revealed the presence of high soluable constituents varying from 1,220 to 4.150 mg/l for 100 grs of sample. A large variation of the T.D.S. as well as the cationic and anionic assemblages from storm to storm may be atributed to variability of origin and local contamination. In all samples, the preponderance of Ca, Na, HCO_3, Cl and SO_4 were noted, the latter representing 20 to 30% of the total salts.

Most of the dust storms last 4 to 10 days per year. At a rate of 12 kilograms/km^2/year or 12 mg/m^2 and at the rate of 2,4% soluable mineral content, the total amount available for dissolution in groundwater can be estimated at 300 - 500 kilograms of salts for the entire island which is negligeable. We can hence conclude that dust fallout is a minor agent of mineralization. It is suspected that the input of brine and aerosol even though not measured, can be an important factor in the coastal areas.

7.7 Sea water intrusion

We have seen in Subsection E.4 the nature of coastal pumping in the island of Gran Canaria. The pumping zone found below sea-level occupies as we said earlier 50 km^2, representing a permanent cone. Also in the eastern coastal belt between south of Telde and Tirajana there is a variation of the dynamic water level due to seasonal pumping and the limit of the variation is marked in Fig. E. 13.

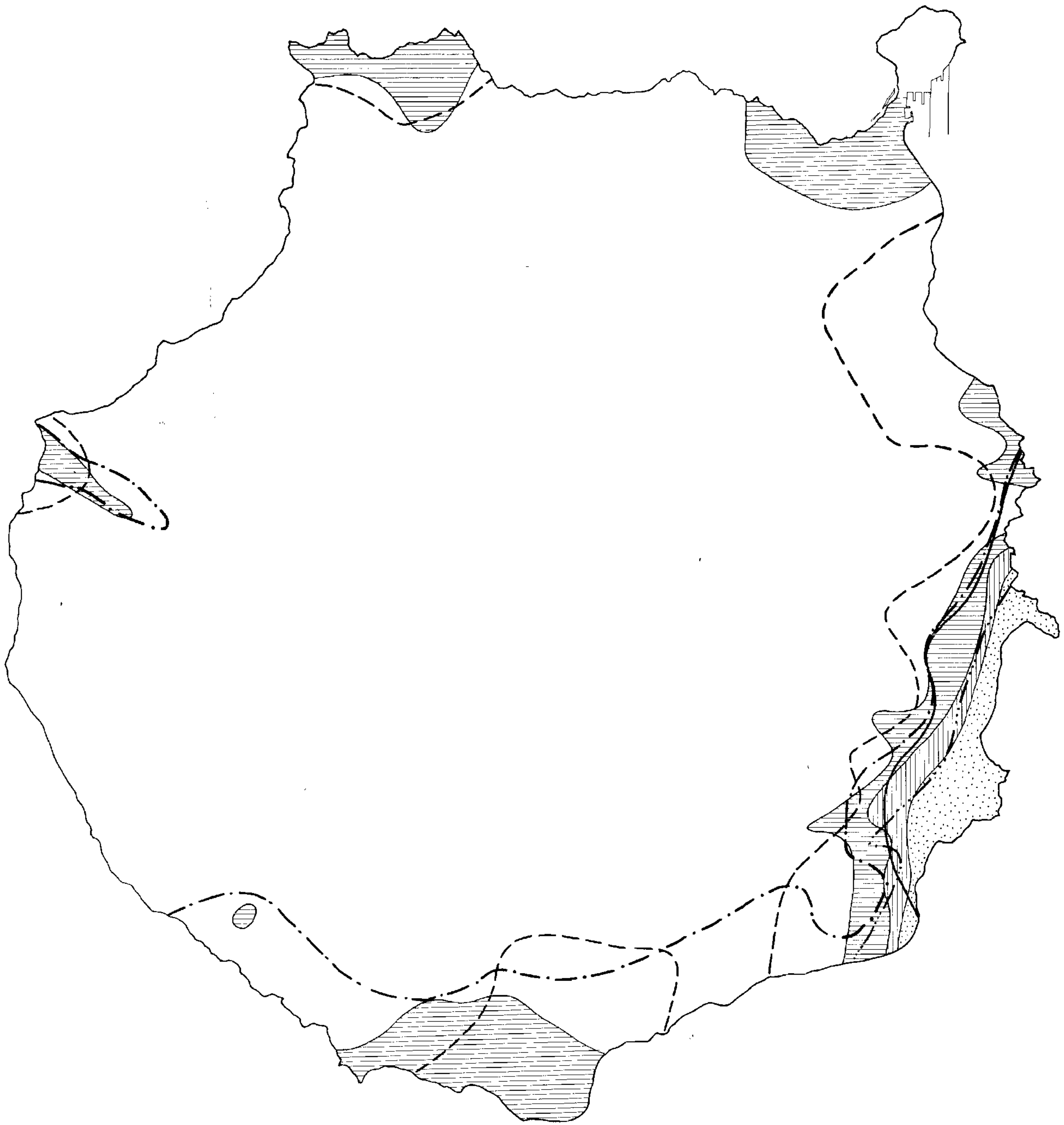
There is substantial hydrochemical evidence for the presence of brackish water in this coastal zone through pumping. Thus if we superimpose the T.D.S. and ΔCl values and study the results, we see a good fit with the information obtained from water levels and also with the hydrochemical ratios investigated in the foregoing pages.

Sea water in this particular coast was analysed and the hydrochemical characteristics were compared with those of the groundwater. The approximate limit of coastal pumping coincides with a T.D.S. value of 3.500 mg/l and a Cl^- content of about 700 mg/l which is about 1/10 and 1/30 respectively of sea water concentration, shown in Fig. E. 52. The reader is referred to Map E. 25 showing Old Basalt basement. The brackish water areas are found mainly below 0^m level. Heavy pumping in zones below this elevation should be regulated if future intrusion is to be avoided.

7.8 Micro-elements

The principal micro-elements studied are Co, Cr, Pb, Ni, Cu, Zn, Fe, Mn, Sr, Li, Fl and Bo. The sensitivity characteristics and limits used in the 403 Perkin Elmer atomic absorption unit are shown in Table E. 6.

The variation of concentrations was not found to be significative and no correlations between themselves or with the macro-elements could be established. However their very presence in groundwater and the pattern of distribution we found to be interesting. Out of over 350 points analysed



LEGEND

Total Dissolved Salts T.D.S.

- 2– 5 grs/l
- 5–10 "
- > 10 "

- Ratio $rCl/rHCO_3 + rCO_3 > 5,0$
- Ratio $rCl/rHCO_3 + rCO_3 > 10,0$
- 700 mg/l Isochlore } Autum dry period (1971)
- ⩾2.000 mg/l Isochlore } Autum dry period (1971)

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LIMIT OF SEAWATER INTRUSION

GRAN CANARIA

DATE: FEBRUARY 1974 | FIG: E-52

Table E. 7

SENSITIVITY CHARACTERISTICS AND LIMITS FOR MICROELEMENTS

Model Perkin Elmer 403

Micro-Element	Fe	Li	Sr	Zn	Mn	Cr	Ni	Cu	Co
Radiation	UV	VIS	VIS	UV	UV	UV	UV	UV	UV
Wavelength	248	336	230	214	279	358	232	325	241
Aperture	3(0,3^{mm}-2A)	4(1,0^{mm}-13A)	4(1,0^{mm}-13A)	4-5(3^{mm}-20A)	4(1^{mm}-7A)	3(0,3^{mm}-2A)	3(0,3^{mm}-2A)	4(1^{mm}-7A)	3(0,3^{mm}-2A)
Lamp	Hollow Cathode	H.C	H.C	H.C	H.C	H.C	H.C	H.C	H.C
Optimum concentration	2-20 ppm	0,5-5,0 ppm	2-20 ppm	0,2-3,0ppm	2-20ppm	2-20 ppm	2-25 ppm	2-20 ppm	4-40 ppm
Sensitivity limit	0,01ppm	0,005 ppm	0,01ppm	0,002 ppm	0,005ppm	0,1 ppm	0,005ppm	0,005ppm	0,01 ppm
Filter	No	Yes	No	No	No	No	No	No	No
Flame	Air-Acetyl	Air-Acetyl	Air-Acetyl	Air-Acetyl	Air-Acetyl	Air-Acetyl	Air-Acetyl	Air-Acetyl	Air-Acetyl

only 241 points showed the presence of the above micro-elements as seen in Fig. E. 53. A study of their distribution is attempted in the following pages.

7.8.1 Occurence of Co, Cr, Pb and Ni

Their distribution pattern is shown in Fig. E. 54. As can be appreciated from this figure, Co, Cr and Pb are principally concentrated in the Telde-Gando areas. Ni too is found in the same area but its distribution spreads towards the interior. The presence of this group of micro-elements could be mainly duc to industrial contamination. However, it is to be noted that basalts are richer than other rocks in these micro-elements as is indicated in rock analyses but their rather localized occurence do not show any strict relationship with basalts.

7.8.2 Occurence of Cu, Zn, Fe (total), Mn

No occurence of Cu was noted in the water analyses even though the basalts contain between 20 and 100 ppm, which phenomenon could be explained by the position that Cu occupies in the scale of tension.

The distribution patterns of Zn, Fe and Mn are shown in Fig. E.55 in which we see that while Zn has a large distribution, the latter are found in the north-east half of the island.

In rock analyses, Zn predominates in basalts and Roque Nublo (up to 200 ppm), and the same can be said of Fe (20-30%), but Mn is found in greater quantities in Phonolites and Ignimbrites (3000-5000 ppm) and in lesser quantities in Modern Basalts (1500-3000 ppm) and Old Basalts (_ 1000 ppm).

The wide distribution of Zn in groundwater can be attributed to metallic contamination specially of galvanized pipes found in wells. As for total iron, there is a clear correlation with the richness of the rock

OCCURENCE OF MICROELEMENTS IN GROUND WATER

GRAN CANARIA

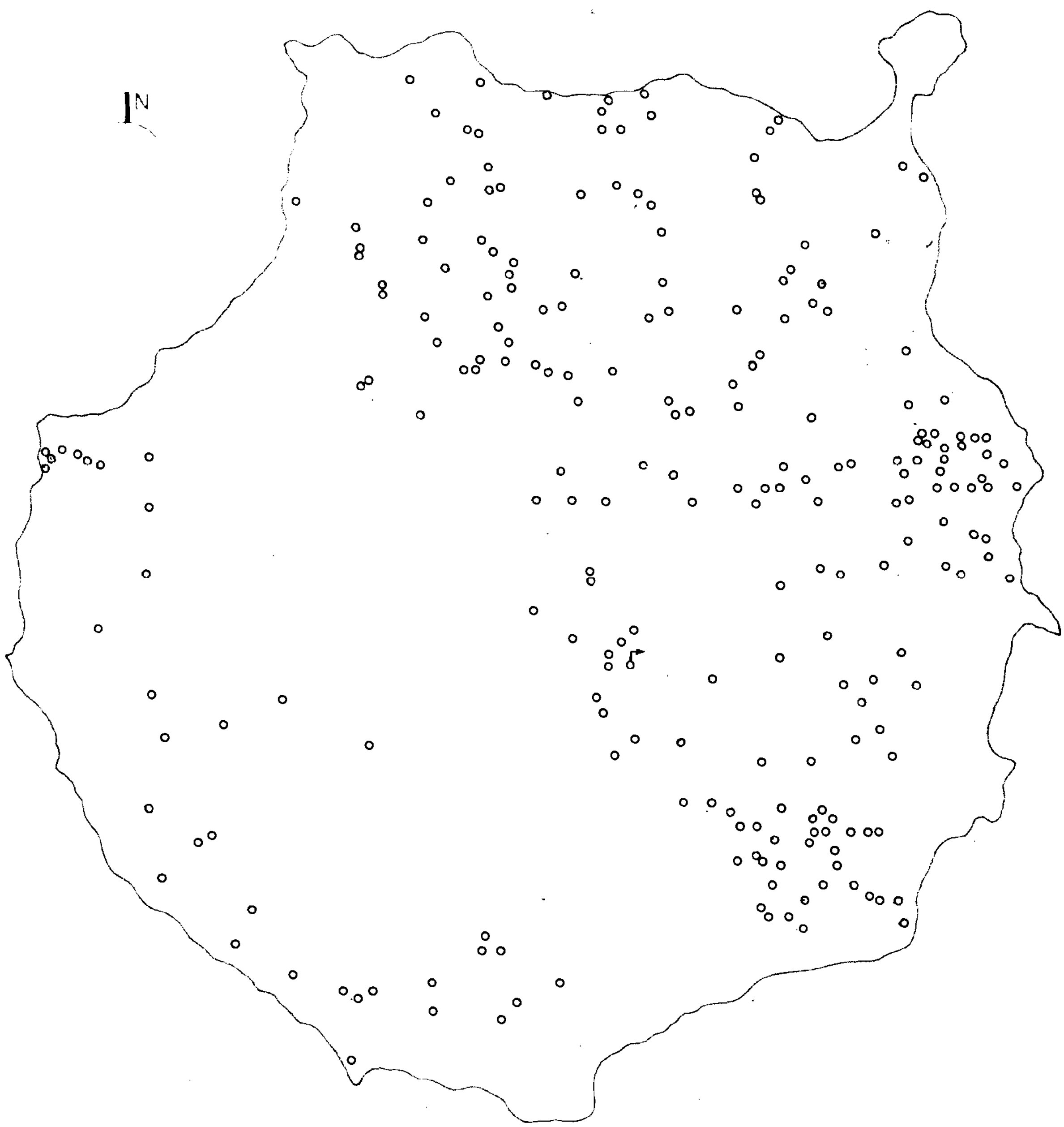


FIGURE E-53

OCCURENCE OF Co, Cr, Pb and Ni
-GRAN CANARIA-

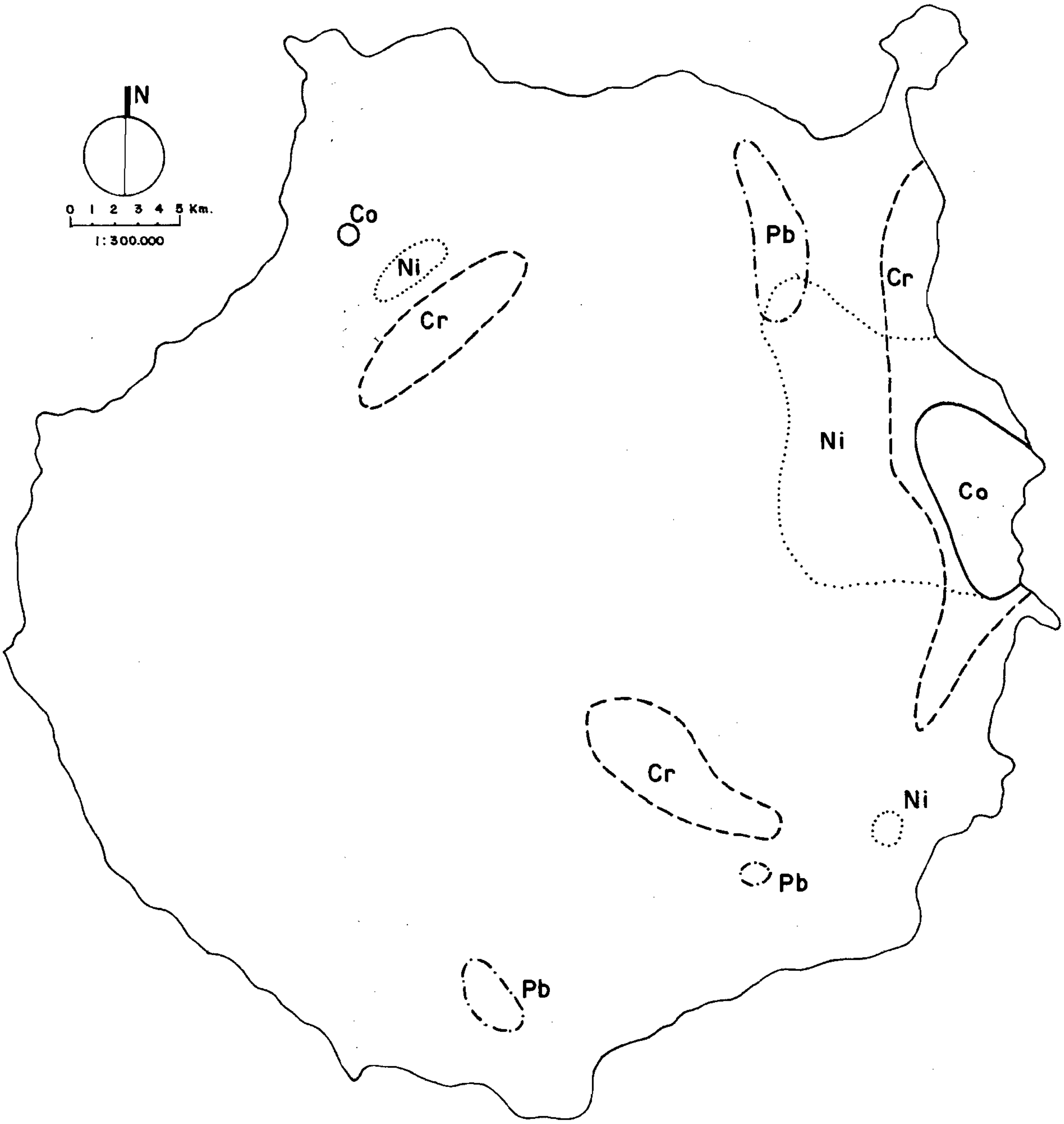


FIGURE E-54

formations. In certain points however, bacterial contamination and specially dissolution due to CO_2 emanations cannot be underestimated. As an example of the latter phenomenon we can cite the upper Agaete valley with more than 1,0 mg/l of Fe (total) and particularly of Berrazales spring where it attain exceptionally 19 mg/l of Fe for 800 mg/l of free CO_2.

As for Mn its distribution coincides with basalt rocks poor in this element and total absence in Phonolytes, Ignimbrites and Trachy-Syenites, all richer in this element which may be explained by the lack of leaching and consequent infiltration in these rock formations.

7.8.3 Occurence of Sr, Li

Strontium is a very widely distributed micro-element in groundwaters even though the basalts and Roque Nublo found in the north-east show a higher content in rock analysis (700-2000 ppm). A particularity of this distribution is the tendency for concentration in the coastal periphery as seen in Fig. E. 56. This may be explained by their dissolution in runoff waters from dust fallout rich in this element and re-infiltration in the coastal belts.

Distribution of Li, at first seems similar to Sr, but it is noted that there is a greater spread towards the interior. All rock analyses show very low content of Li, about 0,001 ppm and in dust fallout it is insignificant. Hence we may have to atribute its presence and absence to alkali-favourable ion-exchange and leaching phenomenon.

7.8.4 Occurence of Fl, Bo

A special study was made of these two micro-elements, the first due to its great importance in dental conservation. The limits of Fl are chosen according to admitted safe limits and its distribution is shown in Fig. E. 57.

OCCURENCE OF Sr AND Li

GRAN CANARIA

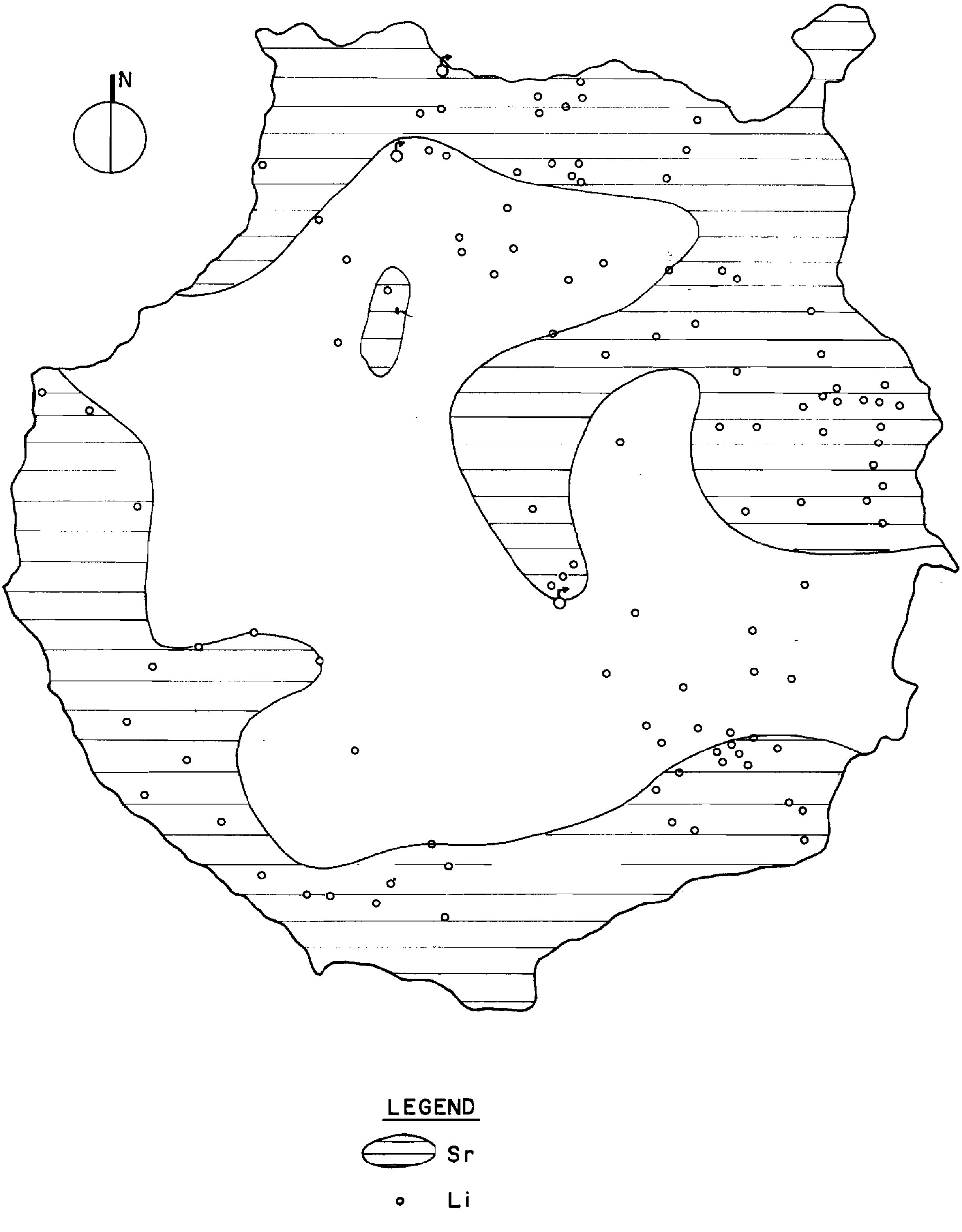


FIGURE E-56

OCCURENCE OF FL AND Bo IN GROUNDWATER

— GRAN CANARIA —

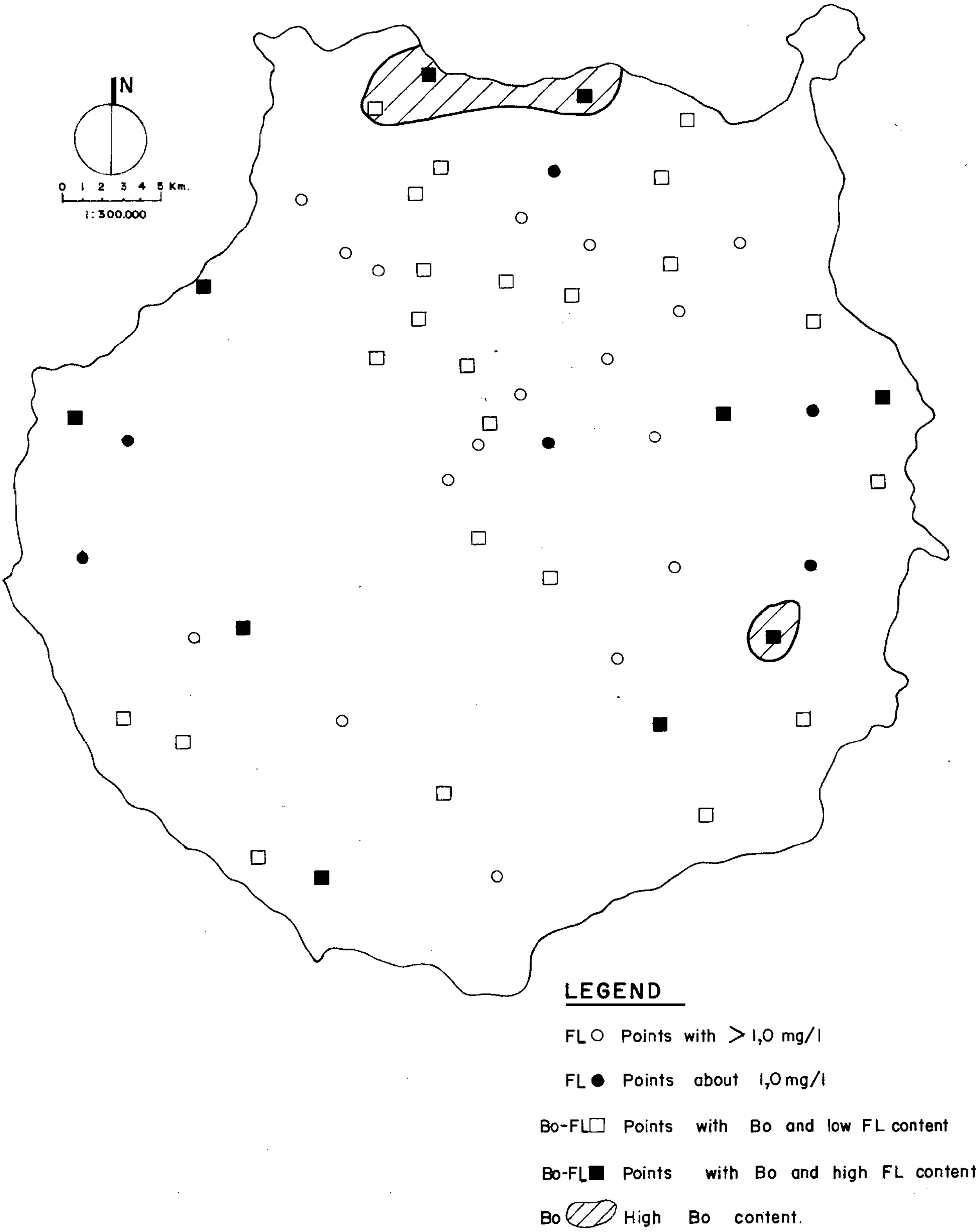


FIGURE – 57

As is seen in the above figure, the zone between Tejeda-Teror-Firgas and Agaete is specially poor and can be named the "deficient zone". This region coincides with the presence of Modern Basalts and Roque Nublo; also it is one of the zones of heavy rainfall and leaching.

In the eastern zone starting from Telde and comprising also the entire southern region, excepting the coastal belts and coinciding with the phonolytic rocks and Old Basalts, there are a number of points with high content of Fl.

The above distribution in fact corresponds to the Ca-Mg dominant bicarbonate waters in the "deficient zone" and Na-dominant chloride waters in the richer zone.

As for Bo, there is a relation with Fl in its distribution but not in its localization. Only a thin zone in the northern coast and a point near Agüimes have a content $>$ 1,0 mg/l. The absence of boron in the central zone seems to correspond to the Roque Nublo aquifer principally.

7.9 Suitability for use

One of the objectives of the hydrochemical investigations was the definition of water quality for public and agricultural uses.

7.9.1 Water for Public use

There are no standard legalized limits for drinking water in Spain yet, but the international standards are currently accepted and used.

In Gran Canaria if we go by the international standards, in the cation group specially of Ca and Mg, several zones have mean values superior to maximum acceptable limits.

If we refer to Table E. 5, we see that zones 6 and 9 have mean concentrations of Ca superior to the 75 mg/l which is the acceptable maximum limit for drinking water. As for Mg, the zones 3, 4, 6 and 9 have concentration superior to 50 mg/l. However, in both cases they do not surpass the maximum tolerance limits which are 200 mg/l for Ca and 150 mg/l for Mg.

In the anion group, the zones 2, 3, 6, 7, 8 and 9 have mean values superior to 200 mg/l of Cl^- which is the maximum acceptable and the zone 4 has a mean value superior than 600 mg/l, the tolerable limit. As for SO_4^{--} zones 6 and 9 surpass the acceptable limit 200 mg/l. We can therefore conclude that only in zone 4 in the lower reaches of Tirajana, the water derived from the Old Basalt aquifer is unaccepted for drinking as far as Cl^- is concerned.

In Map E. 58, we see the 200 mg/l line of isochlore as well as the 1.500 mg/l limit of T.D.S., the latter being the tolerable limit for total salts. A good part of the coastal zone starting from south of Telde going down to lower Tirajana valley on the one hand, the lower reaches of "barrancos" Arguineguin, Maspalomas, Tauro and the valley of San Nicolas de Tolentino and the coastal belt of a north and north-east of the island on the other hand, have concentrations above tolerable limits.

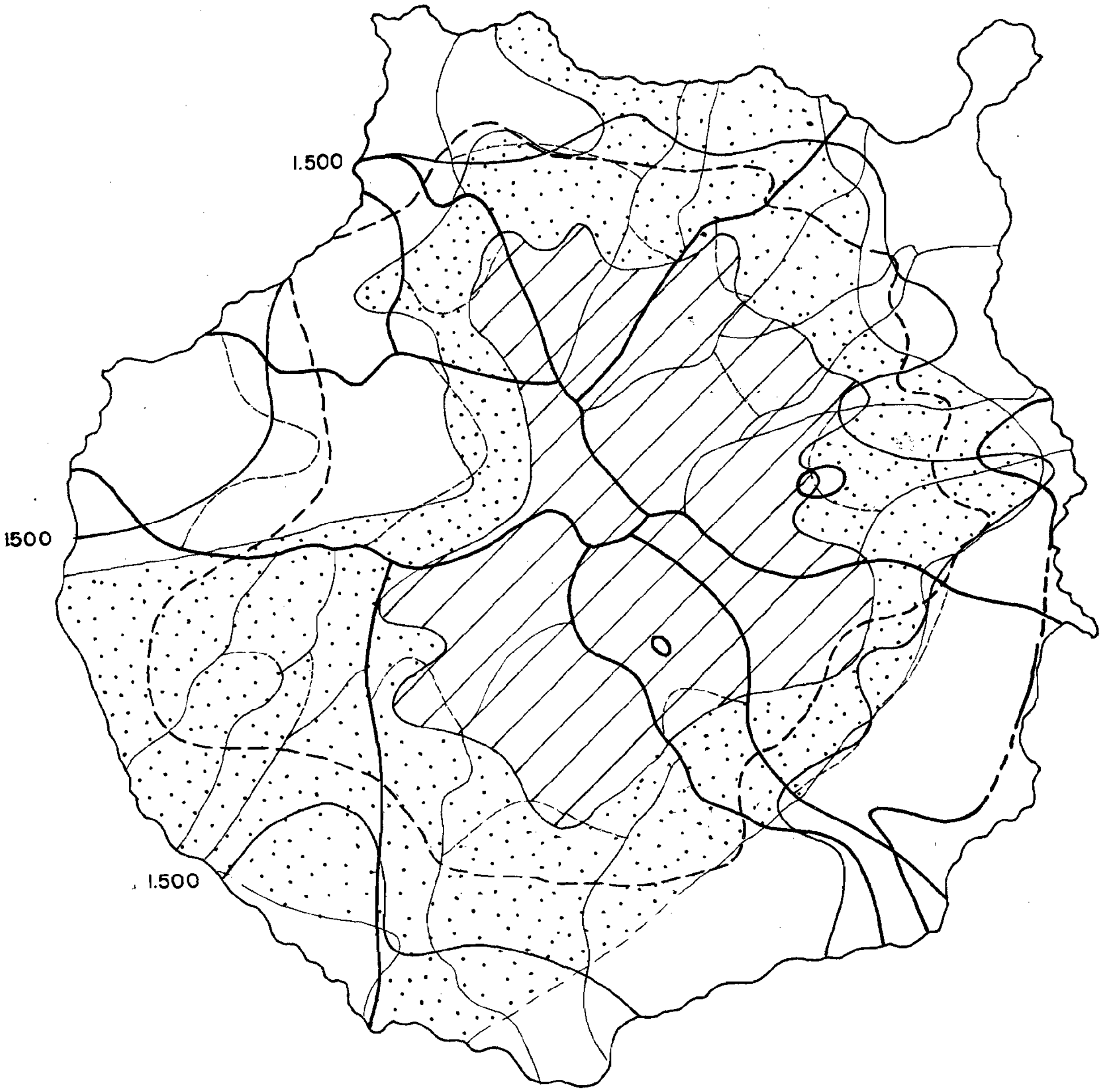
The same map shows 3 significant limits of the total hardness of water. The presence of soft water with less than 15°F of total hardness is confined to the central zone and very hard water superior to 50°F coincides roughly with the T.D.S. values of 1.500 mg/l.

With regard to the organic contaminants, the presence of nitrates, nitrites and ammoniac at the same time, can be an index. The study of this factor revealed that the coastal periphery with a T.D.S. value of over 1.500 mg/l corresponds to the occurence of nitrates between 30 and 100 mg/l accompanied at times by the presence of nitrites and ammonia.

The reader is referred to figures E. 55 to E. 57 for the occurence of micro-elements in groundwater. The presence of Cr, Co and Ni in the eastern coast can be a sign of contamination. As for Zn it is probably

WATER QUALITY LIMITS

—GRAN CANARIA—



TOTAL HARDNESS °F

< 15° soft water

15–50° Hard water

>50° Very hard water

1.500 mg/l T.D.S.

200 mg/l Cl

S.A.R. (18–26)

FIGURE E-58

related to existance of galvanized metal in wells. The concentration of iron is normal excepting in 3 points. Comments have been already made of the occurence and concentration of Fl and also of a specially "deficient zone" existing in the northern region.

No bacteriological analyses have been effectuated in the Project. However, a certain number of such analyses have been carried out by the Laboratorio del Servicio Hidráulico of Las Palmas specially in the areas found between Las Palmas-Tejeda and Agüimes which supply water to the city. Tests made on samples not subjected to chloration, showed the presence at several points mainly Coliformes and sometimes of Escherichia Coli.

7.9.2 Agricultural use

Banana, which is the principal crop in the island has a tolerable limit of 200 mg/l of Cl^-. If we consult the Map E. 58 we see that this limit corresponds to a very large area in the central and middle altitudes.

Tomatoe cultivation has a limit of 1.500 mg/l of Cl which explains the fact that mediocre water derived from the coastal periphery can be successfully used for this crop.

Alfalfa is the only crop which admits a limit of 3.000 mg/l of Cl^- and is widely grown in the eastern coastal plain utilizing practically brackish water.

A study of the sodium absorption ratio has also been done for all the points analysed. It was found that the major part of water produced has values below 1 and 4 (S_1) all in the central and middle altitudes. However, medium values (S_2), 10-18 were found in the north coastal strip between Galdar and Bañaderos, in the east between Marzagan and Tirajana, in the south between Maspalomas and Bco. Tauro as well as in the alluvial belt of San Nicolas. High values of S.A.R (18-26) were found spreading from the mouth of Telde valley to Tirajana valley as seen in Fig. E. 58.

7 Investigations through study of Environmental Isotopes

The initial plan drawn up for the isotopic study of Gran Canaria island in December 1971, defined two stages of investigations: a reconnaissance study of groundwater through analysis of stable isotopes ^{18}O and D, as well as of tritium as a first step; a detail study of particular problems following the results of the first stage.

Only the first phase was realized during the Project period and the main results are discussed below.

7.1 Methodology of sampling

In the island altogether 49 sites were sampled for the isotopic study of groundwater: 36 wells, 12 springs and 1 gallery. The principal sampling points were placed on radial lines starting from the centre of the island and reaching the coast, but some intermediate points were included to get better coverage.

Even though the large majority of points were concentrated in the north eastern half of the island some points were also sampled in the more important groundwater producing areas found in the south.

The springs placed in the centre of the island were sampled every month for stable isotopes, wheareas the wells along the principal sections were visited every 4-5 months including for tritium sampling.

During winter, rain samples were also gathered every month on 7 points in the upper and middle altitudes and some runoff samples too were collected in the different reaches of the "barrancos" on which were placed the groundwater sampling points.

Out of the samples collected, only a selected number was analysed , 147 for stable isotopes and 43 for tritium, due to financial and logistic reasons. The samples were analysed by I.A.E.A. in Vienna, but some tritium determinations were also made by GANOP in Madrid.

7.2 Results of Stable Isotopes

The variations of the stable isotope composition in groundwater samples collected from the same site at different times usually do not exceed the experimental error of the measurements. The average $\delta^{18}O$ values of the points analysed are shown in Map E.59.

7.2.1 Distribution and differences between Nand S slopes

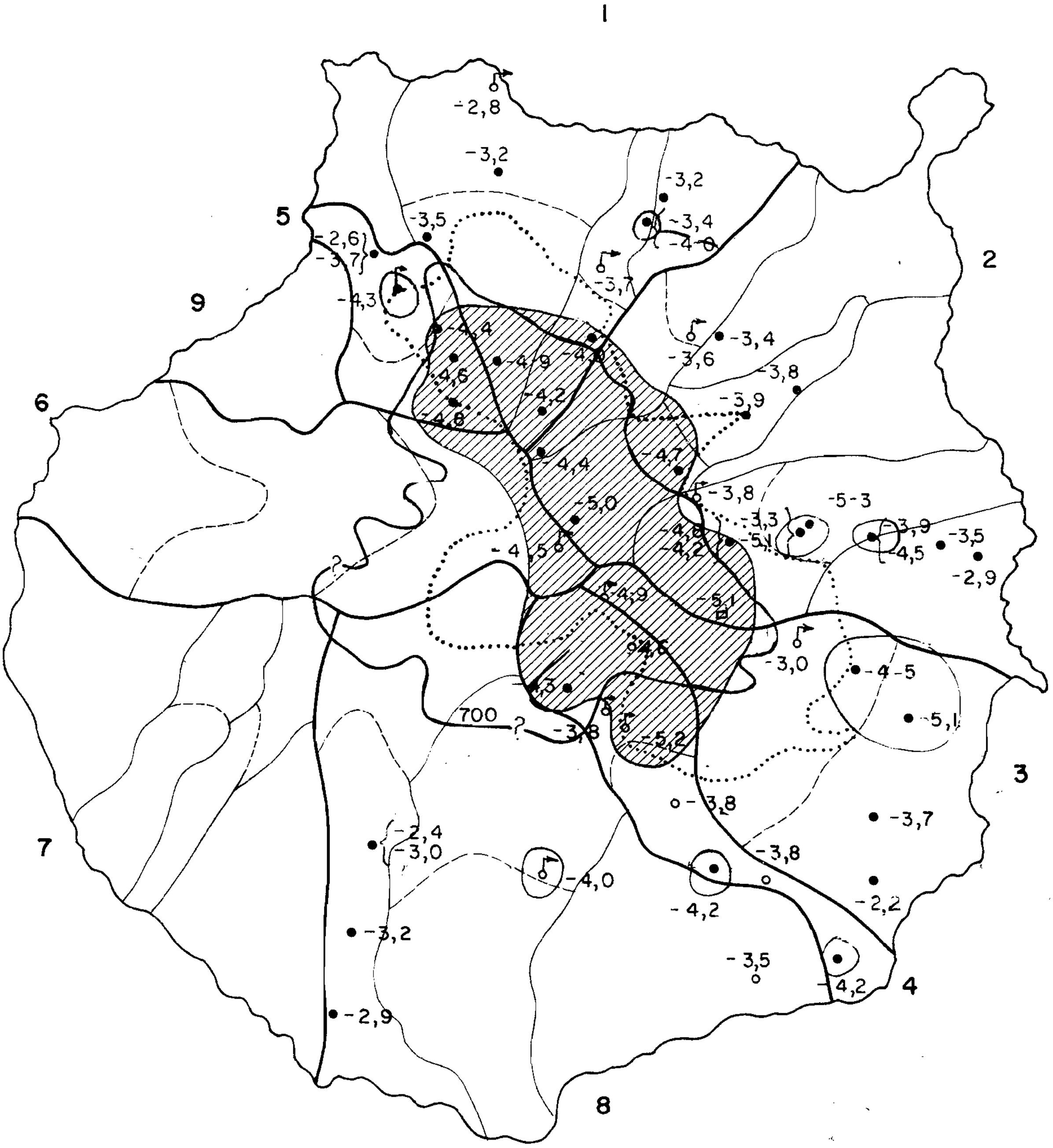
This map indicates the characteristic decrease of $\delta^{18}O$ with altitude, the values between - 4and- 5 indicating zones of effective recharge. Such a zone cover the entire top of the island coinciding with the probable main recharge area. Also a number of isolated points were found in the peripheral area, practically all located near the "barrancos" Azuaje, Agaete, Valsequillo, Guayadeque and Tirajana indicating recharge from surface runoff.

On the same map are shown the mean water table elevation of 700 m and the 60 mg/l line of isochlore both of which largely coincide with the defined recharge zone. Also it is interesting to note that the 100 mm annual isoinfiltration line englobes this same area.

A few points show some variation in stable isotope values, which may be explained in principle by the existance of several water bearing levels with different supply regimes which can be seasonal.

An attempt was made to find out, if the stable isotopes suffered evaporation during rainfall. For this reason a $\delta^{18}O$ versus δD correlation for groundwater was done. As a result, it was found that all samples for the Northern slope have at equal $\delta^{18}O$ a higher δD value, which would mean that groundwater in the southern slope has undergone a partial evaporation. The same difference was noted in the surface water samples analysed.

VALUES OF δ ^{18}O IN GROUNDWATER
(POSSIBLE LIMITS OF CENTRAL RECHARGE ZONE)
GRAN CANARIA



LEGEND

Sampling points: • well, spring, ▭ gallery.

———	700^{m} Water level (1970-71)
....	60 mg/l Limit of Cl^- (1971)
(hatched area)	$\delta^{18}O$ < -4,0 (Possible central recharge zone)
(ellipse)	Local recharge areas
1-9	Hydrological zones

FIGURE E-59

The altitude effect in the northern region is essentially due to a Releigh type equilibrium condensation when clouds are forced over the slope, while in the south this process is much less important, since the moisture comes mostly as an overflow from the north and the altitudinal effect is mainly due to evaporation and re-equilibrium during the fall of raindrops.

7.2.2. Evaluation of the altitude of recharge

In the study of the relation between altitude and ^{18}O, only samples with higher tritium content for which the area of recharge is probably nearer the sampling sites, were considered. It was seen that the samples in the northern and southern slopes had two distinct linear relationship with altitude which can be expressed as follows:

Northern slope - $\delta^{18}O$ ‰ = $-(0,00125 \pm 0,0009)\,h - (2,54 \pm 0,11)$

Southern slope - $\delta^{18}O$ ‰ = $-(0,00239 \pm 0,00023)\,h - (2,06 \pm 0,16)$

h, being the altitude in m.

The equation for the northern slope is similar to that found for the precipitation of February 1972 for Gran Canaria and Tenerife together.

These two equations have been used for the evaluation of the mean altitude of the recharge area of each sampling point. A section across the island from N to S, taking into account of the feeder zones is shown in Fig E.60. On the top of the island, as expected the feeder zones are near the sampling points but on the middle and lower altitudes, recharge is derived often from long distances. However it must be remembered that there are several points in the lower zone, specially along "barrancos" which are recharged locally by percolation, as mentioned earlier.

A certain correlation also exists between $\delta^{18}O$ and Cl^- content of the different samples studied as seen in Fig E.61. It was seen in subsection E.6, that we can regard the 60 mg/l $^-$ isochlore as

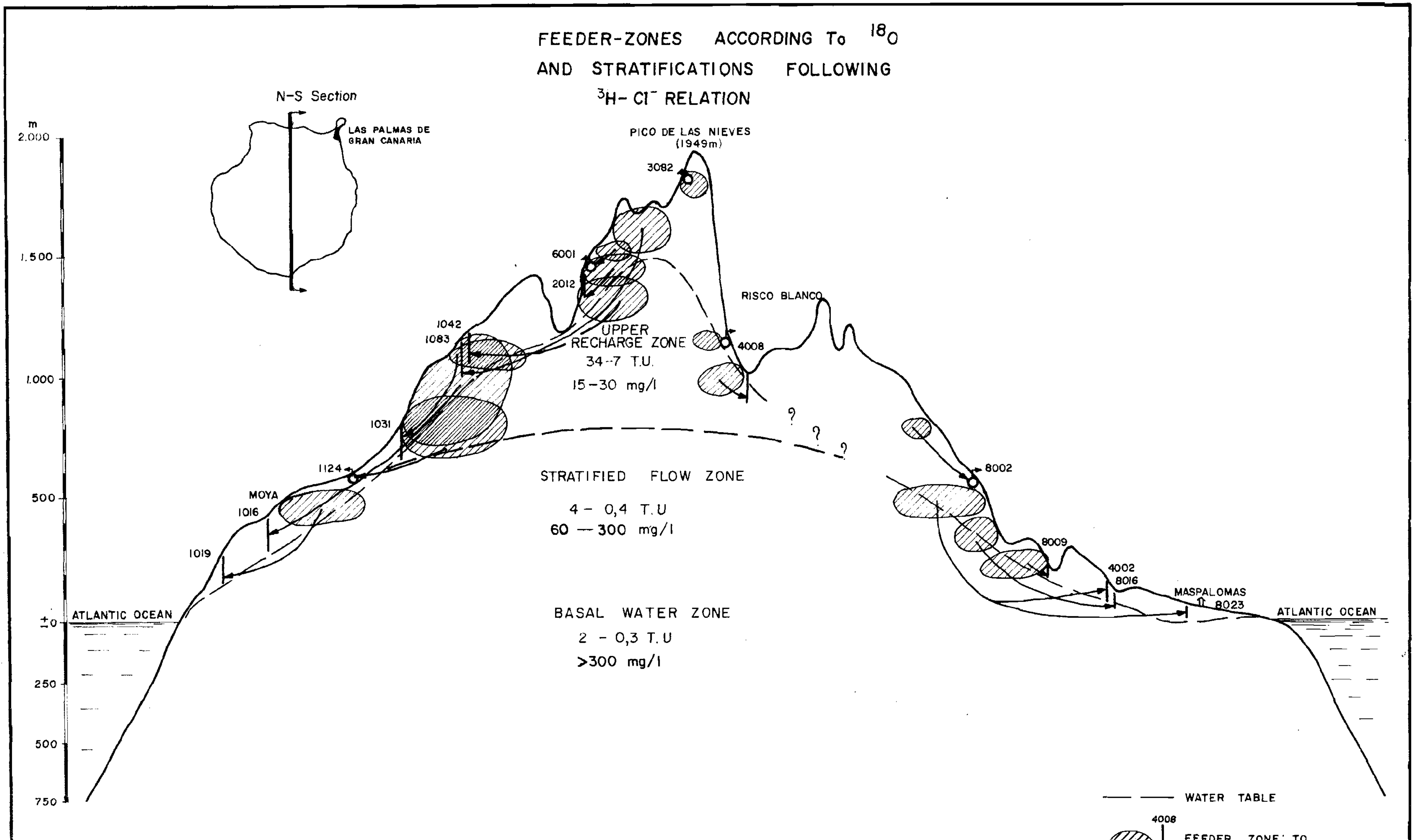
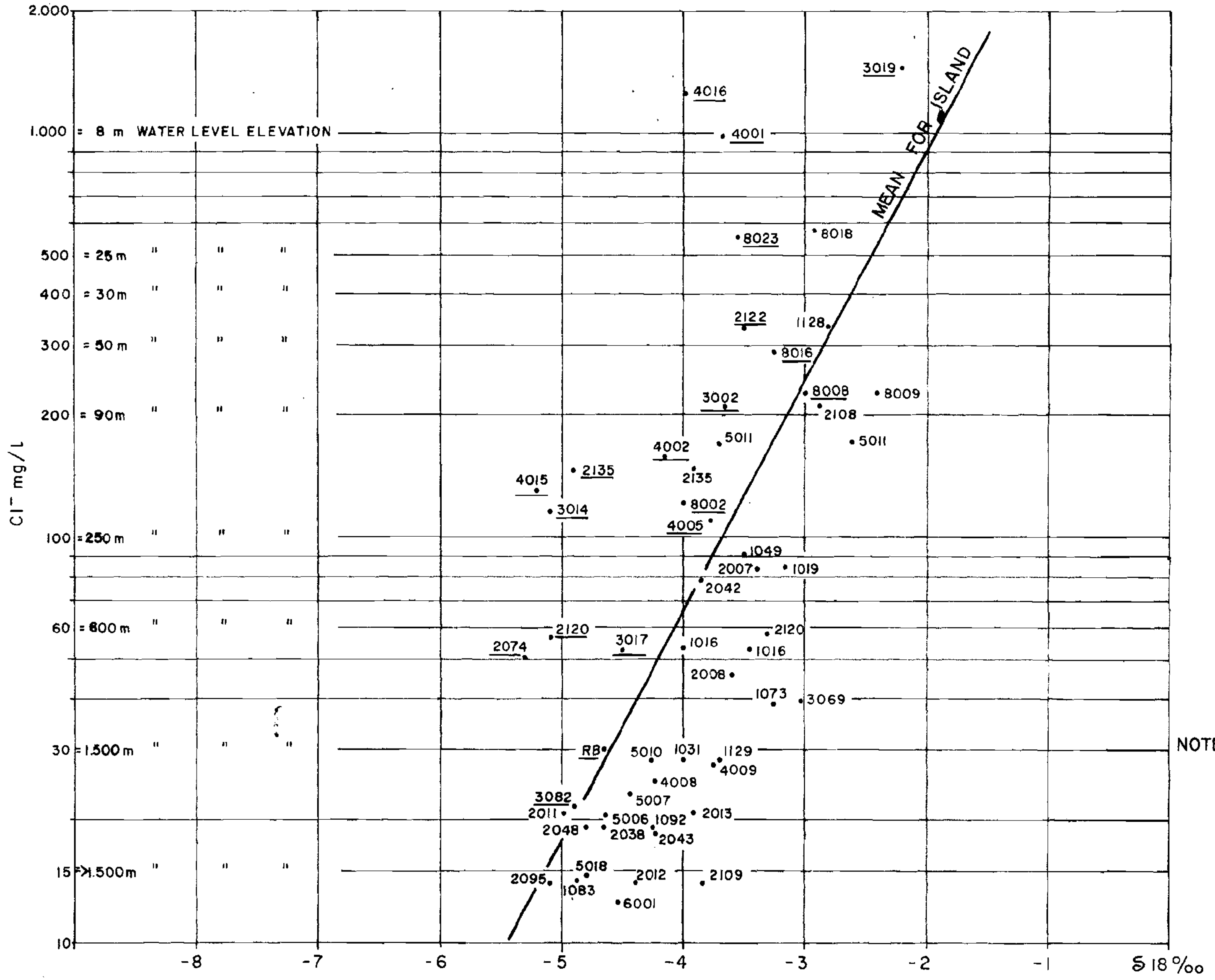

FEEDER-ZONES ACCORDING To ^{18}O
AND STRATIFICATIONS FOLLOWING
$^{3}H-Cl^{-}$ RELATION
N-S Section
LAS PALMAS DE GRAN CANARIA
m
2.000
1.500
1.000
500
±0
250
500
750
PICO DE LAS NIEVES (1949m)
3082
6001
2012
RISCO BLANCO
4008
1042
1083
UPPER RECHARGE ZONE
34-7 T.U.
15-30 mg/l
1031
1124
MOYA
1016
1019
STRATIFIED FLOW ZONE
4 - 0,4 T.U
60 — 300 mg/l
BASAL WATER ZONE
2 - 0,3 T.U
>300 mg/l
8002
8009
4002
8016
MASPALOMAS
8023
ATLANTIC OCEAN
ATLANTIC OCEAN
WATER TABLE
4008
FEEDER ZONE TO WELL OR SPRING

FIGURE E-60

OXYGEN 18 VERSUS CL^- CONTENT

GRAN CANARIA



NOTE: Figures underlined are found on southern slope.

FIGURE E-61

the lower limit of recharge which correspond here to the $\delta^{18}O$ value of -4 if we consider only the mean slope of the island.

The above figure also reflets the difference existing between the northern and southern slopes, even though the scantiness of the measurements does not permit its definition.

7.3. Results of Tritium measurements

Although some tritium sampling was done as early as 1966 by GANOP in Madrid, no measurements of its content in precipitation was undertaken. Therefore no attempt is made to establish the input function in groundwater and reconstruct the history of tritium in the Canary Islands.

However, E. Baonza del Prado and A. Plata Bedmar of GANOP after having reconstructed theoretically the tritium level in precipitation of Gran Canaria with reference to Gibraltar, and comparing values of the few points measured, came to the conclusion that the waters analysed at that time (1966) could have originated in 1956-57 (minimum age). The contents varied from 3,1 to 7,0 T.U.

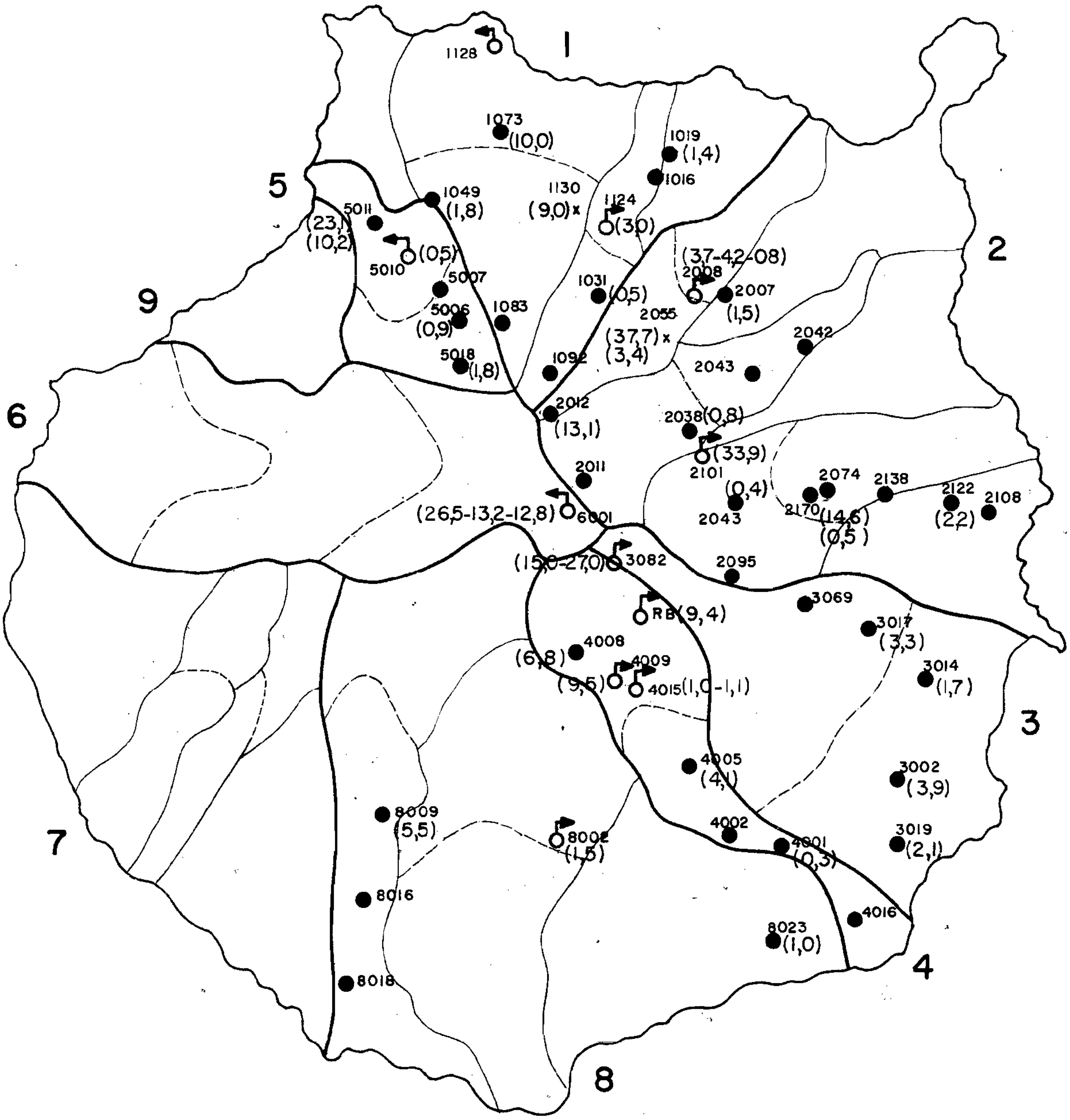
7.3.1 Tritium Content in Waters

The measurements carried out on samples collected from 1970-72, permit us to obtain the approximate age of groundwater. The distribution of the sampling sites and the corresponding values are given in Fig. E. 62.

The level of tritium in precipitation during the rainy season of 1972 varied between 20 and 30 T.U. The content in groundwater for the period 1970-72 (most samples in 71 and 72) varied from 0,3 to 37,7 T.U. It is noted that there is an increase in tritium content with altitude, the higher values corresponding to the recharge zone on the top of the island. The above map also shows that on the coastal zone the values drop to very low levels (generally below 2 T.U).

TRITIUM CONTENT OF GROUNDWATER

GRAN CANARIA



NOTE: x ANALYED BY GANOP(MADRID)1968/69
1–9 HYDROLOGICAL ZONES

FIGURE E-62

The upper recharge zone shows very recent waters, the few low values of tritium referring to older waters may be explained by the complex geological structure of the zone with dyke-injected zones. The stock in the recharge zone may not be more than 2-5 years old.

The middle core zone with values ranging from 3 to 5 T.U may correspond to ages between 15 and 20 years. Water then takes about 10 to 15 years to traverse this water-massif of about 600^{m} of thickness with a rock volume of about 350.10^{9} m^{3}, composed mainly of Roque Nublo, Phonolytes, Ignimbrites and Old Basalts. The core of the island as can be imagined would comport very many intrusive features, dykes, volcanic vents, etc., traversing the above formations. Hence water movement will be a slow process, which would explain the low tritium content and its greater variation. Local recharge is limited to areas of surface water flow.

The basal water zone has generally values of less than 2 T.U but most of the wells in this zone indicate feeder-zones following ^{18}O investigations, in the upper part of the island as is logical. If we judge by the tritium content, the basal waters will be older than 20 years.

The general conclusion is that the turn-over period of the water massif of Gran Canaria is over 20 years. If we compare it with the calculated velocity of groundwater, the north-eastern half of the island in Modern basalts and Roque Nublo, the groundwater flow will attain the coast in about 20 years, In the south-western half on Old Basalts, it will be around 40 years. As for the more compact formations of Phonolytes and Ignimbrites, flow takes place only along large secondary fissures and it will be difficult to estimate flow velocities correctly.

Certain points show wide variation of tritium, which can be explained like for stable isotopes by the existance of several sources of supply.

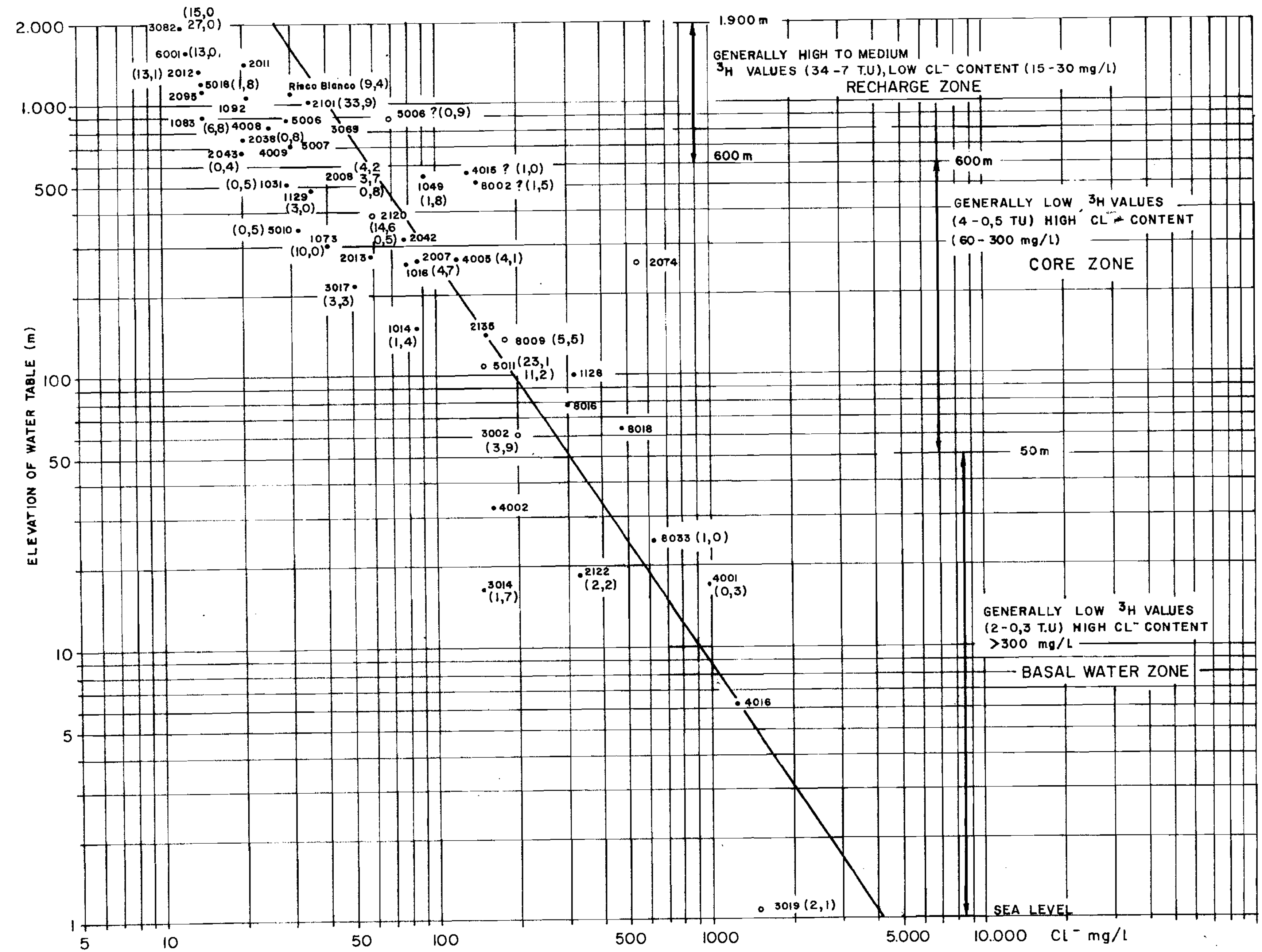
7.3.2 Tritium versus Cl^- and Water Table elevation

The relationship existing between tritium, Cl^- on the one hand, and water table elevation on the other hand, is shown in Fig. E. 63. We can in fact group them into 3 water strata having the following characteristics:

- Upper Recharge Zone: (up to $\simeq$ 600^m water level from top of island)	High tritium content, generally $>$10 T.U. Some over 20 T.U similar to content in rainwater. Low Cl^- from 15 mg/l in the non-saturated zone (1900- to 1500^m) to 60 mg/l in the lower limit. The T.D.S content is around 200-300 mg/l.
- Middle Core Zone: (lowest level about 50^m water level)	Medium tritium content, generally between 3-5 T.U, but higher values found locally. The Cl^- content varies from 60 mg/l on top of zone to 300 mg/l on the lowest limit. The T.D.S values vary from 200-300 to 1000-1500 mg/l from top to bottom of the zone.
- Basal Water Zone: (below 50^m water level)	Very low tritium content, usually below 3 T.U and high Cl^- values varying from 300 through 1000 mg/l. The T.D.S content is always more than 1000 mg/l.

If we are to judge the approximate age of the waters in the different water strata from the range of tritium content, we may draw the following conclusions:

TRITIUM OCCURENCE VERSUS WATER TABLE / CL⁻ RELATION



NOTE:

o POINTS INFLUENCED BY LOCAL CONDITIONS

4005 (4,1) WELL / SPRING NO. WITH T.U IN BRACKETS

FIGURE E-63

The upper recharge zone shows very recent waters, the few low values of tritium referring to older waters may be explained by the complex geological structure of the zone with dyke-injected zones. The stock in the recharge zone may not be more than 2-5 years old.

The middle core zone with values ranging from 3 to 5 T.U may correspond to ages between 15 and 20 years. Water then takes about 10 to 15 years to traverse this water-massif of about 600^m of thickness with a rock volume of about 350.10^9 m^3, composed mainly of Roque Nublo, Phonolytes, Ignimbrites and Old Basalts. The core of the island as can be imagined would comport very many intrusive features, dykes, volcanic vents, etc., traversing the above formations. Hence water movement will be a slow process, which would explain the low tritium content and its greater variation. Local recharge is limited to areas of surface water flow.

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8. Simulation of the aquifer by Analog Modelling

8.1 Introduction

Analog techniques are extensively used throughout the world and are a well known hydrological tool. A hydrologic system can be analysed using the mathematical relations which describe the potential field within a diffusive medium and the representation of the continuous medium of the groundwater by a finite difference method.

Simulation is the use of this tool for the heuristic appraisal of the system. In hydrologic simulation a prototype description of the system which is the desired result, should sufficiently account for the response of that system to applied stresses. The elements of the hydrological system are fitted together and synthesized, duplicating some known historical stress-response relationship and which if sucessfull can be used as the system des - cription, from which the future response to new stresses may be predicted.

In the case of the complex volcanic hydrologic system of Gran Canaria, a necessary simplification has been accepted in the quantifi - cation of the system parameters, even though all available data were used in the formulation of the conceptual model of this system. Only pertinent data were therefore used in the electric analog model of the island, but those unused data are implicit in the functionning of the system, to the degree that the model does not violate conclusions drawn from them.

It would be rare to attain a veracity of the hydrologic re - presentation due to the above mentioned simplifications and the heuristic nature of the system analysis, but in most cases it would be sufficient to demonstrate that there is a consistency with available facts.

The analog model of Gran Canaria can be considered to offer a certain guarantee in this field which implies the usefullness of the method for future stress-response investigations.

The modelling process of the Gran Canaria aquifer system has followed the steps illustrated in the following chart, see Fig. E ____.

The present status of analog simulation is on its last step: the input of strategies of exploitation and appraisal of results for a definitive selection.

8.2 R.C Model of the whole island

The preliminary works executed before the end of 1972 have been already described in Chapter II. Here only the final phase which involves the modelling of the entire island will be studied in detail.

8.2.1 Proceedure and basic assumptions

The final phase of analog simulation was undertaken keeping in mind that:

- the simulation study should include zones of present and potential groundwater production consisting of 1.200 km^2 of productive area in the N.E. and E. An additional 370 km^2 of unproductive area in the W. was incorporated in the ultimate stage.
- nodal density should result in lumping few wells at every node and that the grid spacing between 500 and 800 m would be appropiate.
- an orthogonal square grid pattern would be the most convenient which would result in a model with about 800 to 2.000 nodes.
- validation was expected without resorting to drastic changes of the values adapted for the formation constants, but taking into account the influence of historical uncertainties.

The similarity between the characteristics of the two-dimensional flow field of the proposed model for the entire island and the complex flow field of the prototype could not be complete. The internal hydraulic system of volcanic rock media as described in Fig. ____ had to be simplified according to the following basic assumptions:

- the primary and secondary fissures of the whole stratigraphic column transmit and store water according to two parameters (transmissivity and storage coefficient) averaged for the entire depth of the column; the two-dimensional electrical network could be designed accordingly by computing the values of resistors and capacitors proportional, respectively to the reciprocal of averaged <u>T</u> and to the averaged <u>S</u> .

- one consequence from the regional water level decline caused by pumping has been the almost complete depletion of spring discharge; no matter the uncertain connection existing between "hanging" water levels and regional water table, the capture of spring discharge could be simulated feeding electrical current to the net through diodes (current limiters) connected to the nodes which correspond to the spring locations in the prototype.

- natural discharge to sea has also been reduced; this source of salvaged discharge could be incorporated in the simulation by the current through the ground bar which connects the terminal nodes equivalent to the coastal line location in the prototype. Thus, the analogy here implies zero head change along the aquifer coastal line and, of course, no differentiation between fresh and salt waters.

The validation proceedure lies on the comparison between model and field water-level changes through some historical period. To the usual scarcity of historical water-level records is added here the uncertainty in the interpretation of the past position of the regional water table. Most often it is not clear if the first level of water found some years ago, as it has been reported by the owner or user of the well, belonged to an isolated water pocket or was a hanging level without any further relationship with the true regional water table reached afterwards, as the deepening of the well progressed.

The figure of ∓ 20 m. has been the assumed range of error in the interpretation of water-level change data for the period 1960 - 1971. This range is wide enough to overshadow the errors strictly due to the sim - plifying assumptions. For example, + 14 m. has been the maximum difference from simulations of water-level change, for the above period, when an overall reduction of transmissivity values (to the 80%) was tested in the model. Consequently, unless more confidence can be gained from further investigation of the past behavior of the aquifer, the refinement of the model will have to wait for the data collection (pumpage and water-levels) obtainable from now on, from a scheduled program of measurements in carefully selected wells.

8.2.2 Hydraulic parameters

Values of transmissivity and storage coefficients were obtained evaluating data from limnigrams and pumping tests made in about 50 selected points scattered through the aquifer and located in different geo - logical environments.

The reader is referred to subsection E.4 of this chapter where a tentative correlation has been established between the hydraulic parameter transmissivity and storage coefficient according to the principal rock formations.

The figure E ___ shows the areal distribution of these parameters as they were set in the model; in this figure are also illustrated the small changes made in T and S to get the best possible agreement between the simulation results and the historical data available at this time.

8.2.3 Steady state analysis

The simulation of steady state conditions made over this field of transmissivity distribution pointed that a closer approach to the latest estimates of average steady water balance could be attained if an overall reduction of T was made. With a reduction factor of 0.8, that is decreasing all T's by 20%, the simulated steady state water balance results in:

	Mm^3/year
Net recharge	125
Springs discharges	42
Discharge to sea	83

The water level distribution associated to this balance is suspected of having its maximum error (of about 100 m.) spread over the area between model coordinates x = 30 to 45 and y = 55 to 68, being the simulated water levels in excess of the probable historical ones that existed in the aquifer before its development. This consideration points out to the convenience of a more detailed research for transmissivity distribution, mainly in that area. However, the significant hydrological factor on which the steady state simulation has laid stress on has been the spring discharge. Consequently, the future investigation will have to pay special attention to any data will allow to rebuild the historical evolution of spring depletion.

8.2.4 Transient state analysis

In figure E___ is shown a scheme of the electrical components used in the simulation of the transient state. The stimulus to the passive net of resistors and capacitors is provided by electrical pulses applied through "well" resistors connected to the nodes which represent pumping centres in the prototype.

The hydrologic parameters were converted directly into their electrical equivalents in accordance with the basic assumptions made to support the conceptual simplification of the system. The conversion is made through the use of constants of proportionality or scale factors, whose selection is made after evaluating the range of hydraulic variables and confronting it with the operating range of the electronic equipment.

The four basic scale factors are defined as follows:

Length : a_o = prototype "cell" length/nodal "unit" (m/m).

Potential: a_2 = hydraulic head/voltage (m/v).

Flow : a_3 = discharge/current (m^3/day.amp.)

Time : a_4 = real time/electrical time (days/sec.).

The following table lists the values used in this model and a computed set of values for R and C in correspondence with T and S.

a_o =	650 m/m	$a_o^2 = .4225 \times 10^6\ m^2/m^2$
a_2 =	20 m/volt.	
a_3 =	$2.32 \times 10^7\ m^3$/day.amp. =	8.45 Hm^3/year.miliamp.
a_4 =	$.365 \times 10^6$ days/sec. =	1 year/milisec.

T (m^2/day)	R (Kilohms)
200	5.8
100	11.6
50	23.2
20	58.
10	115.
1	1.2×10^3

S(%)	C(μ F)
1	.01
5	.05
etc.	

$$R = \frac{a_3}{a_2} \frac{1}{T}$$

$$R(k\Omega) = 1160/T\ (m^2/day)$$

$$C = \frac{a_2\ (a_o)^2}{a_3\ a_4}\ S$$

$$C(\mu F) = S$$

The basic steps followed in the excitation of the model were as follows:

- A total groundwater extraction of 113 Mm^3/year obtained from 760 points producing over 1 l/s. in 1971 was distributed over 410 nodes.
- The historical pumping was known only for 60% of the points inventoried in 1971. This programme was imposed on the model by the usual step-change function. A small fraction (8 Mm^3/year) from older wells was accumulated to the origin of this programme.
- The water level changes from 1960 to 1970 were obtained from 200 wells with a possible error of ± 20 m as inventoried earlier. A close fit between field and model results was obtained as seen in Fig ____ but some local changes were made, using scattered data available for period 1950-1960.

The flow rate balance obtained from oscillograms for 1971 gave the following results:

	Mm^3/year	
Pumping (increment since 1935)	113	
Rate of change in storage		58
Change in discharge rate to sea		43
" " to spring		12

If we assume that in 1935 prior to intensive groundwater development that spring discharge depletion equalled production, a certain semi-equilibrium state can be formulated for that year:

	Mm^3/year	
Net recharge	125	
Pumping (assumed equal to spring discharge depletion)		16
Spring Discharge		26 (42-16)
Discharge to sea		83

The transient water balance for 1971, as a result of combining this with the flow-rate balance is as follows:

	Mm^3/year
Net Recharge	125
Rate of change in storage	58
Pumping (increment since 1935)	113
Pumping (before 1935, not simulated)	16
Discharge to sea	40 (83-43)
Spring discharge	14 (26-12)

These results show that about 45% of the extraction in 1971 came from reserves and that discharge to the sea accounted for 32% of recharge. A comparison with the inflow-outflow balance in Fig____ shows a similar evolution from 1935 to the present day.

8.2.5 Forcasting Programmes

The first programme imposed on the R-C model of the island consisted of an extension of the extraction rates in 1971 up to 1980, on the assumption that no substantial changes in the pumping pattern would take place during this period.

The resulting water level change map was superimposed on the map of saturated thickness made for the principal aquifers of the north-eastern part of the island. This superimposition revealed the possible formation of a "critical" zone where a total depletion of the presently exploted aquifer could take place before 1980 as seen in Fig_____. This area extending from Moya to Sta. Brígida, with it maximum development around Teror accounts for about 20% of the total extraction.

The reliability of these results, excluding the SW zone, is estimated to be within a range of + 30% and - 20% of the Δh values shown, the optimistic margin being considered less, because with the effect of progressive reduction in "T" as the regional decline occurs, there will be an increase in the drawdown rates.

An analysis of the repercussion of regional drawdown on cost of pumping is attempted later.

A second programme has been imposed to analyse the effect of simultaneous increase and decrease of regional pumping. Thus from 1975 onwards, pumping was supposed to increase in 4 zones up to a total increment of 35 Mm^3/year and diminish in 5 zones by 50% of the present extraction, for a total of 22 Mm^3/year. This simulation was made for periods 1971-80 and 1971-1991 and results for the first period are shown in Fig ____.

This forcasting programme shows that for 1980 in the zones of pumping reduction sea water intrusion might be stopped or delayed in the coastal region between Telde and Tirajana valleys; that in the northern zone S of Guía and Moya the rate of present decline can be aliviated.

In the region of pumping increment, the levels may be maintained in areas (a) and (c), partly in (b) but not in (d), the latter being doubtfull as it is found in the zone "without sufficient field data".

Further simulations are planned in the near future for varies hypotheses of groundwater extraction, but regional calibration is necessary as more data become available on aquifer characteristics.

AGRO-ECONOMY

1 - Land Use

The total area of Gran Canaria island is 155.306 ha. For the purpose of the study of water availability, the island has been divided into two parts, named hereafter respectively Northern and Southern parts; each part includes the territory of the following "municipios".

Southern part	Northern part
Agaete	Arucas
Aguimes	Firgas
Artenara	Gáldar
Ingenio	Moya
Mogán	Las Palmas
San Bartolomé	Santa Brígida
San Nicolás	Santa María de Guía
Santa Lucía	Telde
Tejeda	Teror
	Valleseco
	Valsequillo
	Vega de San Mateo

Using the data of the 1971 - 1972 agricultural year gathered at the "municipio" level by the "Organization Sindical" and the "Ministerio de Agricultura", it is possible to give the following figures on the total distribution of land shown in Table F.1.

The percentage of arable land is much greater in the Northern part than is the Southern part; whereas fallow is much more developped in the South and on the whole cultivated land is two times greater in the Northern part of the island. On the contrary, the total amount of land under permanent vegetation (meadows, pastures, forests ...) is much greater in the South than in the North. Finally, only about 12% of the total area was really cultivated in 1971-1972.

If we consider now the distribution of arable land by main crops under dry farming or under irrigation, we have the following figures as shown in Table F.2.

Table F.1 - Land distribution of Gran Canaria (1971-1972)

	Southern part		Northern part		Total island	
	ha	%	ha	%	ha	%
Arable land	31.164	30,5	22.587	42,6	53.751	34,7
Cultivated	6.012	5,9	12.360	23,3	18.372	11,9
Fallow	25.152	24,6	10.227	19,3	35.379	22,8
Land with permanent vegetation.	47.861	46,7	15.558	29,4	63.449	40,8
Unproductive land.	23.314	22,8	14.792	28,0	38.106	24,5
Total	102,339	100,0	52.967	100,0	155.306	100,0

Table F.2 - Distribution of arable land by main crops for dry farming and irrigation (1) (1971-1972).

Main crops	Southern part		Northern part		Total	
	Dry farming	Irrigation	Dry farming	Irrigation	Dry farming	Irrigation
Cereals	295	176	1,072	218	1,367	394
Legumes	102	59	216	84	318	143
Potatoes	19	608	480	1,844	499	2,452
Vegetables	-	2.633	1	1.542	1	4.175
Forages	304	356	1.711	368	2,015	724
Other	-	12	-	97	-	109
Sub total	720	3,844	3,480	4,153	4.200	7,997
Fruit plantations.	774	674	688	4,039	1,462	4,713
Sub total	1,494	4.518	4,168	8,192	5,662	12,710
Fallow	16.290	8.862	6.813	3,414	23,103	12,276
Total	17,784	13.380	10.981	11,506	28,765	24,986

(1) The figures refer to the main crops grown during the agricultural year not including secondary or associated crops.

Dry farming is not very important in the South of the island due to scanty and unreliability of rainfall and the products are mainly cereals, forage crops and legumes. On the other hand it is much more important in the Northern part; where the crops are however the same except for potatoes which are grown in higher elevation farms with more rainfall.

Irrigation farming is by for the more important, since high yields cannot be obtained without water under the climatic conditions of Gran Canaria. With a total area of about 13;000 ha, irrigation is devoted mainly to annual crops but one third of the area is under permanent crops principally banana as we will see later on. In fact, fruit production is much more important in reality and the statistics in Table. F.2 do not show it as they refer only to regular plantations.

As annual irrigated crops, two main products are grown (tomatoe and potatoe) and represent more than 80% of total area in both sections of the island but potatoes are more important in the North than in the South.

It is now possible to give a more detailed analysis of these crops. In fact, the total area physically irrigated is not a good indicator for a study of water consumption since several crops can be grown during the same year on the same field.

The distribution of total area of various products grown on the 12;710 ha under irrigation is shown in Table F.3.

Table F.3- Distribution of the area with various irrigated crops for the 1971 - 1972 agricultural year.

Main commodity groups	Southern part ha	Southern part %	Northern part ha	Northern part %	Total island ha	Total island %
Cereals	831	13,9	307	3,5	1.138	7,6
Maize	773	12,9	277	3,1	1.050	7,0
Legumes	95	1,5	97	1,1	192	1,3
Vegetables	2.934	48,9	1.627	18,3	4.561	30,6
Tomato	2.236	37,2	850	9,6	3.086	20,7
Potatoes	661	11,0	2.181	24,5	2.842	19,1
Forages	798	13.3	550	6,2	1.348	9,0
Others crops	12	0,2	100	1,1	112	0,7
Total annual crops.	5.331	88,8	4.862	54,7	10.193	68,3
Fruits	674	11,2	4.039	45,3	4.713	31,7
Banana	436	7,3	3.629	40,8	4.065	27,4
Total	6.005	100,0	8.901	100,0	14.906	100,0

By comparaison with Table F2 we see that in the Southern part 1,4 crop is grown as an average on one hectare of irrigated land devoted to annual crops and in the Northern part the corresponding figure is less than 1,2.

We see now that the main irrigated crops in the Southern part are tomatoes, corn, forages and banana; in the northern part, banana, potatoes and tomatoes.

To have a complete picture one should add that in 1973, an inventory was made of the area under hot-houses which are developping rather rapidly and the results are given below:

Cucumbers:	320 ha
Peppers:	75 ha
Green beans:	80 ha
Tomatoes:	30 ha
Total:	505 ha

2 - Farm Sizes

In 1972, a census of agriculture was made in the Canary islands and we will use its results to present the characteristics of farm holdings in Gran Canaria.

As we can see from Table F4 total number of farm units has considerably decreased over the last ten years but especially in the Southern area of the island. This is a consequence of the rapid evolution of the economy of the island and especially of the large increase of activity in the building and tourist industries. During the period 1960-1970, the total population of Gran Canaria increased by nearly 30%, from 400.837 to 519.606 inhabitants.

Most of the farms are small, as can be observed in Table F.5.

Table F.4- Evolution of the number of farm holdings 1962-1972.

	Southern part	Northern part	Total island
Farm units in 1962	12.485	23.642	36.127
Farm units in 1972	5.630	16.452	22.082
% of decrease	54,8	30,5	38,8

Table F.5- Distribution of farm holdings by size in 1972.

Farm size ha	Southern part Number	%	Northern part Number	%	Total island Number	%
0,1 - 1,9	3.414	60,6	12.760	77,6	16.174	73,2
2 - 4,9	1.125	20,0	2.269	13,8	3.394	15,4
5 - 9,9	447	8,0	597	3,6	1.044	4,7
10 -19,9	264	4,7	281	1,7	545	2,5
20 -49,9	180	3,2	133	0,8	313	1,4
50 -99,9	70	1,2	34	0,4	104	0,5
100 -499,9	76	1,3	31		107	0,6
500 -999,9	11	0,2	1		12	
> 1000	11	0,2	-		11	
Sub total	5.598	99,4	16.106	97,9	21.704	98,3
Farms without land.	32	0,6	346	2,1	378	1,7
Total	5.630	100,0	16.452	100,0	22.082	100,0

Source: Primeros resultados - Censo Agrario de España - 1.972.

In the Northern part, 91,4% of all farm units have less than five hectares, as against 80,6 % in the Southern part. The distribution of farms according to size is not yet available but it would show a con - centration of the area in the large size farms.

The age distribution of farm holders is interesting to study because we can infer from it a possible evolution of farm production in the future.

Table F.6 - Age distribution of farm holders and importance of part-time agriculture.

	Southern part		Northern part		Total	
	Number	%	Number	%	Number	%
Total number of farms	5.630	100,0	16.452	100,0	22.082	100,0
Number of farms owned by non physical persons.	916	16,3	1.788	10,0	2.704	12,2
Farms owned by physical persons.	4.714	100,0	14.664	100,0	19.378	100,0
Farm holders working:						
. Mainly in agriculture	1.857	39,4	5.411	37,0	7.268	37,5
. Mainly in other sectors.	2.857	60,6	9.253	63,0	12.110	62,5
Age group of the farm holders .						
34 years	153	3,2	562	3,8	715	3,7
35 - 54 years	1.415	30,0	4.992	34,1	6.407	33,0
55 - 65 years	1.277	27,1	4.293	29,2	5.570	28,8
over 65 years	1.869	39,7	4.817	32,9	6.686	34,5
Total	4.714	100,0	14.664	100,0	19.378	100,0

First, we notice that 12% of all farm units are not owned or run by individual persons which is a high figure. Second, we see that only about 40% of the farm holders are working mainly in agriculture. Hence part-time agriculture is predominant in Gran Canaria probably in the small farms. Although we have no data on this phenomenon it would be very interesting to be investigated because of its consequences in the future.

Also we note that the majority of farm holders are on a high age group since more than 60% of them (even 67 % in the Southern part), are older than 55 years.

Hence, we can conclude that in ten years from now 35 % of the present farm holders (40% in the Southern area) will most probably disa - ppear (dying or retiring); this could be true also of a part of the farm holders in the 55-64 years age group.

Then, the problem is: will younger people take over all these farms or not? This is not obvious at all, since less than 4 % of all farm holders are less than 34 years old. To have a better idea about the fundamental change that will occur in the next ten years, one should study very carefully the structure of the family of farm holders and from the present activities of the adult members (mainly men) deduce how many people could stay in agriculture in the future.

From the present characteristics of the farm holdings, one can find a good explanation of the problems encountered now. With a majority of old people running the farms and the existance of part-time agriculture, we can infer that gains in productivity will be difficult to obtain in the near future. But in the long term, the present characteristics allow for a much better farm size distribution. If regrouping in larger farms occurs modernization and new crop patterns will be easier to achieve.

The main problem will be however to find the necessary farm hands. A special study of the movements of the active population within the various sectors of activities would enable the Canarian authorities to see if a sufficient amount of hired labor will be available.

Thus a detail study of the present farm activity is needed to have a better knowledge of the future trends and possibilities. This is very important for the future of irrigation, since dry farming will probably decrease because of low yields. Also for irrigation, the total water demand will depend mainly on the total area under irrigation as well as on the distribution pattern of the main crops.

3 - Crop Patterns

We have seen earlier the existing crop pattern for the land under irrigation. It is interesting to obtain an idea of the general evo - lution in the recent past and try to forecast possible future tendencies.

In the last thirty years irrigation has known a very large development as a result of groundwater extraction. This resulted in a large development of the banana plantation as well as of the vegetable production. In the last ten years, the area devoted to banana in Gran Ca - naria seems to be relatively stable varying between 3.800 hectares and 4.100 hectares a situation which contrasts with what happened in Tenerife which has seen a further development of the area under banana cultivation. One of the main reasons for the stabilization in Gran Canaria appears to be the shortage of water.

During the same period of time the area devoted to potatoes decreased from about 7.000 hectares to 3.600 hectares. This crop is no more profitable since it appears that the value of the crop does not pay the total cost of production.

Tomato production has a greater fluctuation depending on the climatic conditions in the island and also on the evolution of prices in the main foreign markets since most of the production is exported. Another reason for the stabilization of production could be a poor marketing organization.

The most interesting recent change in crop pattern is the rapid development of the cucumber production in hot houses (320 hectares in 1973) which has the advantage of being highly productive using only a small quantity of water.

Speaking of the future evolution of agriculture in Gran Canaria, one should be cautious because of the lack of real knowledge of the present situation. It appears however clear that due to the present shortage of water and its increasing price only high productive crops will remain competitive in the future. These are mainly export crops in the winter season such as cucumbers, green beans, flowers, tomatoes, ..., either with a very great yield per hectare or a high value per unit. The advantage of winter crops would also be to to reduce the total amount of water needed per hectare.

As for the future of banana plantations it will depend mainly on two factors:

- firstly change in the irrigation system that could reduce the total amount of water used by shifting to sprinkler irrigation. This would allow banana to remain competitive for a while;
- secondly the future government policy with regard to price support

and of the amount of the subsidy paid by the Spanish consumers. This factor is the more important since until now the price of banana , has been guaranteed by the spanish government so that it is higher than on the world market.

Most probably in the next future, the price support will go on but the technical changes in the plantations will not be made in time everywhere. This would mean that the marginal plantations, with low yields, will probably disappear when they are too old. Will they be replaced by modern banana plantations or will another crop, like cucumber or tomato take over the land ? Most probably, new crops will be practiced. But this variable depends on a government decision.

4 - Crop Yields and Cost of Production

4.1 - Crop Yields

It is difficult to get a good idea of the yields in the different sectors because most of the time the available statistics agregate the data of dry farming and irrigation.

It is however possible to illustrate the level of the various yields obtained in the province of Gran Canaria through the "Anuario estadístico de la producción agrícola" for the 1970-1971 agricultural year, for the main crops:

- Hard wheat in dry farming	1,7 Ql/ha
- Barley in dry farming	2,1 Ql/ha
- Potatoes (dry farming and irrigation)	89,0 Ql/ha
- Tomatoes irrigated	283,0 Ql/ha
- Banana	365,0 Ql/ha

Another source, the "Organization Sindical", gives the following figures for average yields in Gran Canaria:

- Banana:
  - under 150 m elevation 480 Ql/ha
  - from 150 to 250 m 350 Ql/ha
- Tomato for export in open fields 260 Ql/ha
- Potatoes:
  - for export 125 Ql/ha
  - for local consumption from 150 to 210 Ql/ha
- Irrigated corn 35 Ql/ha
- Cucumbers grown in hot houses 750 Ql/ha
- Tomatoes grown in hot houses 600 Ql/ha
- Peppers grown in hot houses 350 Ql/ha

4.2 - Costs of Production

Few informations are available on this subject and further - more they are difficult to compare. Sometimes also they are too old to match the present situation.

Two examples can be given for banana and tomato for 1972 or the beginning of 1973:

- Banana:

. Water 14.000 m^3/ha x 8 pesetas =	112.000	pesetas/ha
. Manure and fertilizers:	33.820	"
. Chemicals for pest and deseases:	13.350	"
. Labour 257 days x 320 pesetas:	94.528	"
Total Direct Costs:	253.698	pesetas/ha

Total Direct Costs	253;698	pesetas/ha
. Amortization:	9.000	"
. Taxes:	15.196	"
. Interests of capital invested and of the value of land:	104.553(1)	"
Total costs	373.427	pesetas/ha
Production: 45.000 kg/ha x 9,5 pesetas :	427.500	"
Profit:	54.073	"

From this example, we can see that water costs are greater than the cost of labour; they represented 44% of direct costs and 30 % of total costs, when labour represents 37 % and 25%. Few products are in a situation similar to banana. The benefits depend mainly on two factors: water and labour. If both factors see their prices go up at the same time, no profits can be attained. This example shows also that benefit could be maintained by reducing the water consumption which is very high. New irrigation techniques could perhaps reduce this consumption by 10 or 20%. The economy on water thus obtained has to be compared with the cost of the needed equipment.

- Tomato

. Water: 5.938 m^3/ha x 4,17 pesetas :	24.759	pesetas/ha	
. Chemicals for pests and deseases:	37.741	"	"
. Fertilizers and manure:	25.661	"	"
. Various inputs and preparation of the soil:	26.734	"	"
. Labour 432 days at 200 or 250 pesetas	90.250	"	"
Total direct costs	205.145	"	"
Indirect costs	23.000	"	"
Total costs	228.145	"	"
Production: 30.000 kg x 10 pesetas:	300.000	"	"
Profit:	71.855	"	"

(1) High value due to the very high price of the land in the banana area.

Here, water costs are only 12% of direct costs and only 11% of total costs whereas labour costs represents 44 % of direct costs and 40% of total costs. Therefore, we see that the profits in tomatoe cultivation depend much more on the variations in the price of labour than in the changes in the price of water, assuming that other costs do not rise too quickly.

Some remarks can be made on the above examples.

1º - If we compare the cost of labour in both examples we note an appreciable difference in wages. We see thus the cost of labour is 320 pesetas per day in banana plantations and only 200 pesetas in tomato field for an ordinary worked and 250 pesetas for a qualified worker.

2º - In the case of tomatoes, the cost of water is only 4,17 pesetas/m^3 wheareas for banana it is 8 pesetas/m^3. Since tomatoes are mainly grown in fall when prices are highest, this value appears to be low.

One explanation possible is that in the case of banana we are dealing with average prices on the water market whereas in the case of tomatoes, it probably refers to the average cost of production of water when the farmer owns his supply of water.

Inspite of these descrepencies the conclusions already deduced from the above examples will not change much since, in physical terms benefit in banana cultivation depend much on water and labour whereas in tomatoe cultivation they depend more on labour and to a lesser extent on water.

No example of costs of production is available for cucumber cropping in hot houses. As a consequence of the great amount of labour needed per hectare and of the very high cost of investment, water is a minor factor in total costs. Like for tomato , the increase in the wage rates should be much more important than an increase in the price of water.

5 - Prices of Water

As seen very often, there is only rare coincidence betweeen areas under irrigation and water production points. Also since groundwater is privately owned, there exists in Gran Canaria, as in the other islands, a water market. This market follows the normal rules of adjustment between supply and demand. Nevertheless it has the characteristics of an oligopolistic market as there are only few owners and many buyers of water.

5.1 - Water Market Tendencies

The price on the market includes all costs of production and distribution of the water as well as the profit margins of the owners and of the intermediaries.

In general when the demand is high and according to the physical possibilities of shifting from one place to another through pipes and canals, the price on the market will tend to rise up to a level accepted by the more productive sectors.

But the most important thing to notice is the fact that in agriculture the price of water can change very quickly from one week to another, which makes agriculture a highly speculative operation, when water is an important input as in the case of banana cropping.

These facts can be illustrated on Fig. F.1, which shows the price fluctuations during several years for the water market on San Mateo in the Northern part of Gran Canaria.

Firstly, we notice that there is a close correlation between the amount of rainfall and the price of water, as a result price of water is at its lowest level during the December-March rainy period, but it goes up very quickly after the end of the rain . The maximum price is attained during October and November, which enregisters the combined demand for banana and tomato crops.

If we wish to analyse the various factors behind the price variations during the 3 year-period under study, one should also know the quantity of water used by the different crops each month in order to get a weighted price for every crop.

Now, if we compute the average price for the unit period 1st August to 31 July of the following year we obtain an evolutive tenden - cie as seen below.

1970 - 1971	average price	4,5 pesetas/m^3
1971 - 1972	" "	5,7 " "
1972 - 1973	" "	6,6 " "

The price increase from 1970-1971 to 1971-1972 was 27% and from 1971-1972 to 1972-1973 was 16%.

After June 1973 water demand was so high that the normal market mechanism disappeared. Price was about 12,7 pesetas/m^3 until Sep - tember, and the local authorities fixed a maximum price of 10.2 pesetas/m^3 but it appears that this decision had little effect and effective prices were much higher.

The referred prices on Fig. F.1 are those paid by the more important consumers. At the small farm level, they are higher because of extra costs of distribution and of profit margins for the intermediaries; these extra costs in the San Mateo area range from 0.5 to 1,5 pesetas/m^3.

As a conclusion we can say that in three years, the price of water in this area rose by nearly 47%, which is extremely high. If one adds also the increase of the cost of labour, we can infer that the economic results of farm production must have been sharply reduced. The main crops of the island will not be able to support new increases in the price of water if the present tendency goes on.

5.2 - Prices of Water in Other Activities

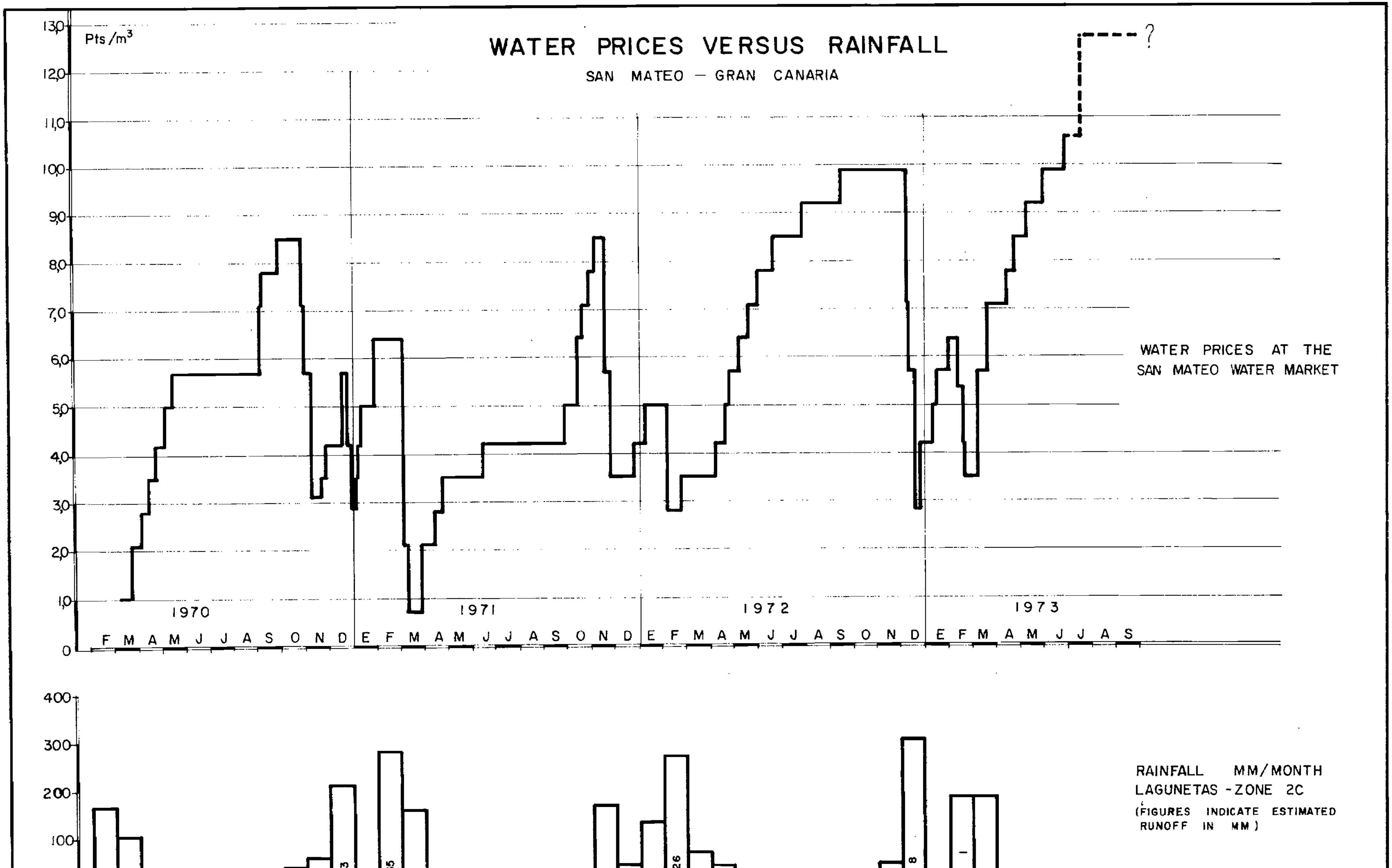
We reproduce here the 1972 structure of prices charged on consumers depending on the public distribution system in Las Palmas municipality and are detailed as follows:

- Private users: households and tourist activities:

. minimum fees charge consumption = 4 m^3	33 pesetas
. below 10 m^3	8,8 pesetas/m^3
. from 10 to 15 m^3	11,1 " "
. from 15 to 100 m^3	16,5 " "
. above 100 m^3	22,0 " "

- Industry:

. minimum fee: 10 m^3	88,0 pesetas
. below 100 m^3	8,0 pesetas/m^3
. above 100 m^3	11,0 " "



WATER PRICES VERSUS RAINFALL
SAN MATEO — GRAN CANARIA
Pts/m³
13,0
12,0
11,0
10,0
9,0
8,0
7,0
6,0
5,0
4,0
3,0
2,0
1,0
0
?
1970
1971
1972
1973
F M A M J J A S O N D E F M A M J J A S O N D E F M A M J J A S O N D E F M A M J J A S
WATER PRICES AT THE
SAN MATEO WATER MARKET
400
300
200
100
0
13
65
26
8
1
RAINFALL MM/MONTH
LAGUNETAS - ZONE 2C
(FIGURES INDICATE ESTIMATED
RUNOFF IN MM)

FIGURE F-1

Here we see clearly that the price increases with total consumption except for municipal uses. This price structure intends to prevent users from wasting water.

We can try to see now the incidence of this price structure on the budget of a normal family of six persons, using two hypothesis of daily consumption: 50 l and 100 l per head. The total annual consumption of the family amounts to 109,5 m^3 and 219 m^3 respectively. Using the prices for the different amounts of water, the total expenses are respectively 1.755 pesetas/year and 4.164 pesetas/year.

Assuming now a total revenue of 10.000 pesetas/month for the household, i.e.: 120.000 pesetas/year, water expenses would represent from 1,5% to 3,5% of total gains which are high figures.

G. WATER USE AND REQUIREMENTS

Introduction

The rights and conventions for the use of water resources in the island have their origin in the Spanish conquest of the Canarian Archipelago in the 16th Century.

The constitution of different regional bodies with water rights coming down even to modern times is related to the original settlement of the Spanish speaking population.

Up to the First World War, most of the water used in the island was supplied by springs and associated stream-bed derivations controlled principally by the "Heredades de Agua". The total production at that period could have been around 1,5 m^3/s. With the expansion of irrigated plantation agriculture and with the growing demand for water, there took place a gradual development of groundwater resources. Before the Second World War, the production can be estimated about 2 m^3/s. With the tremendous expansion of irrigated agriculture around 1940's, there was a corresponding increase in groundwater captations and dam building activities.

1. Surface Water

The utilization of surface water resources comprises storage dams and river-bed derivations. In earlier times river-bed captations and small capacity dams of less than 15 meters of height as well as stocking ponds, furnished the major part of the surface water resources. However with the development of extensive irrigated tracts and the ever-growing need for large and permanent supplies of water, the construction of large capacity dams was undertaken. For a normal year a total of about 25 Mm^3 can be estimated as collected from runoff, either stocked in reservoirs or diverted from river-beds.

1.1 Storage Capacity

The larger part of the storage of surface water is achieved at present by 59 large dams with walls higher than 15 meters, which together have a capacity of about 80 Mm^3 as indicated in Table D.8 . A few more dams under construction will add about 5 Mm^3 within a few years. The dams with small storage capacity operate on an annual basis so that they generally are empty towards the end of the dry season. The bigger reservoirs, however, are pluriannual in operation which permit a carry-over of water to dry years. A special case is the large Soria dam with a storage capacity of 40 Mm^3 in a basin of 32 km^2. Average runoff in the basin can be estimated at about 3-4 Mm^3, which means that this reservoir will permit storage over a very long period and in the future could act as a "despatch dam".

Also a considerable storage capacity exists in the form of small dams, cisterns and tanks, mainly located in the northern part of the island. The capacity of these tanks and small reservoirs varies between 20 and 500.000 m^3, and their total storage capacity, failing an inventory, could be estimated at 5-10 Mm^3. Many of the tanks are not used entirely for collecting surface water but are also stocking reservoirs for extracted groundwater.

1.2 Distribution Systems and Practices

The island is covered by a very complex network of water conduits, where water from wells and dams sometimes is mixed. Due to the complexity of the system it has only been possible to make an inventory of the main canals and pipelines.

The transportation of water from the source to the point of utilization takes place by means of covered and open channels, ditches, tunnels and pipelines, with frequent changes in the mode of conveyance depending on the terrain. The system operates almost entirely by gravity.

Water is sold at several places in the network of canals before it is distributed to the ultimate buyers. The total distribution system can be considered as covering four independent zones in the western, northern, north-eastern and the southern parts of the island, respectively. Presently the northeastern part of the island is being connected to the southern part by means of a big canal which will enable water to be carried from the large dams in the south to the important agricultural areas around Agüimes, Ingenio, Telde, as well as for public water supply in these places and in the city of Las Palmas.

1.3 Historical Development

After the Spanish conquest of the Canary Islands irrigated agriculture was developed in the coastal areas and a system of tunnels, irrigation ditches and aqueducts was built in order to convey the water from the springs and the perennial streams to the irrigated fields. The irrigated agriculture expanded slowly and in the year 1900 only two dams existed in the island with a total storage capacity of about 1 Mm^3.

After the First World War with the expansion of agriculture the available quantities of water from springs and streams were not sufficient to satisfy the demands, and therefore the construction of many smaller dams was undertaken in the 1920's. The reservoirs built in this period were generally small and construction of the large dams in the southern part of the island started after the Second World War. The storage capacity is still being expanded.

1.4 Costs and Prices

The cost of surface water involves two items, the cost of the storage of water and the cost of distribution. For both items the cost can be split up into the amortization of the original investment and the cost for operation and maintenance of the installations.

The investment cost for storage of water is obviously dependent on the size of the reservoir and the characteristics of the site for the dam. Most likely the best sites have now been exploited. The investment cost for storing 1 m^3 of water could be estimated at about 60 pts for a dam of 0.5 Mm^3, and about 40 pts for a dam of 2.5 Mm^3 (Toran, 1968). The cost of the water from the dam will also depend on the average quantity of available water. If it is assumed that as an average the storage capacity is twice the annual inflow and the interest rate is 8%, the total yearly cost per m^3 at the dam is about 8 Pts for the larger dams and 11 Pts for the smaller dams now under construction, whereas the cost of water from the existing dams in many cases could be lower.

The distribution cost depends on many factors that can vary so much between the areas that an estimate is somewhat futile, but the order of magnitude may be about 2Pts/m^3.

2. Groundwater

The development of groundwater in Gran Canaria can be traced to the beginning of the present century. Up to 1924 no authorization was necessary for the boring of wells and galleries. However from this year onwards, there has been a steady increase in demands for opening up of wells as seen in Fig. G.1 . The maximum amount of demands correspond to a period between 1940 to 1950, but there has been a recrudescence of activity between 1960 and 1963. At the present moment boring of new wells has practically stopped but bore-holes and lateral galleries continue to be opened.

2.1 Historical Development of Ground Water

Before 1924, there were 50 to 100 wells equiped with machinery and about 200 to 300 wells with windmills. Most of the wells were concentrated in the zone of Telde-Ingenio and the wind mills in San Nicolas de Tolentino. Up to this period, the main water supply of the island came from the springs found at the head waters of the "barrancos" together yielding about 1,5 m^3/s. In the same figure is presented the historical development of groundwater extraction in the island. There has been a notable increase in the production capacity from wells and galleries from 1945 to about 1963 corresponding to the heaviest demand for opening up of wells as seen before. As the production capacity increases, the yield of springs fell as expected.

The earliest available information on the inventory of captations is in the year 1933 given in Table G.1 . If these informations can be taken as reliable, the total production was around 67 Mm^3, of which 50% came from springs, 39% from wells and 11% from galleries. In the same year there were about 285 springs with a mean yield of 3,7 l/s, 303 wells with a

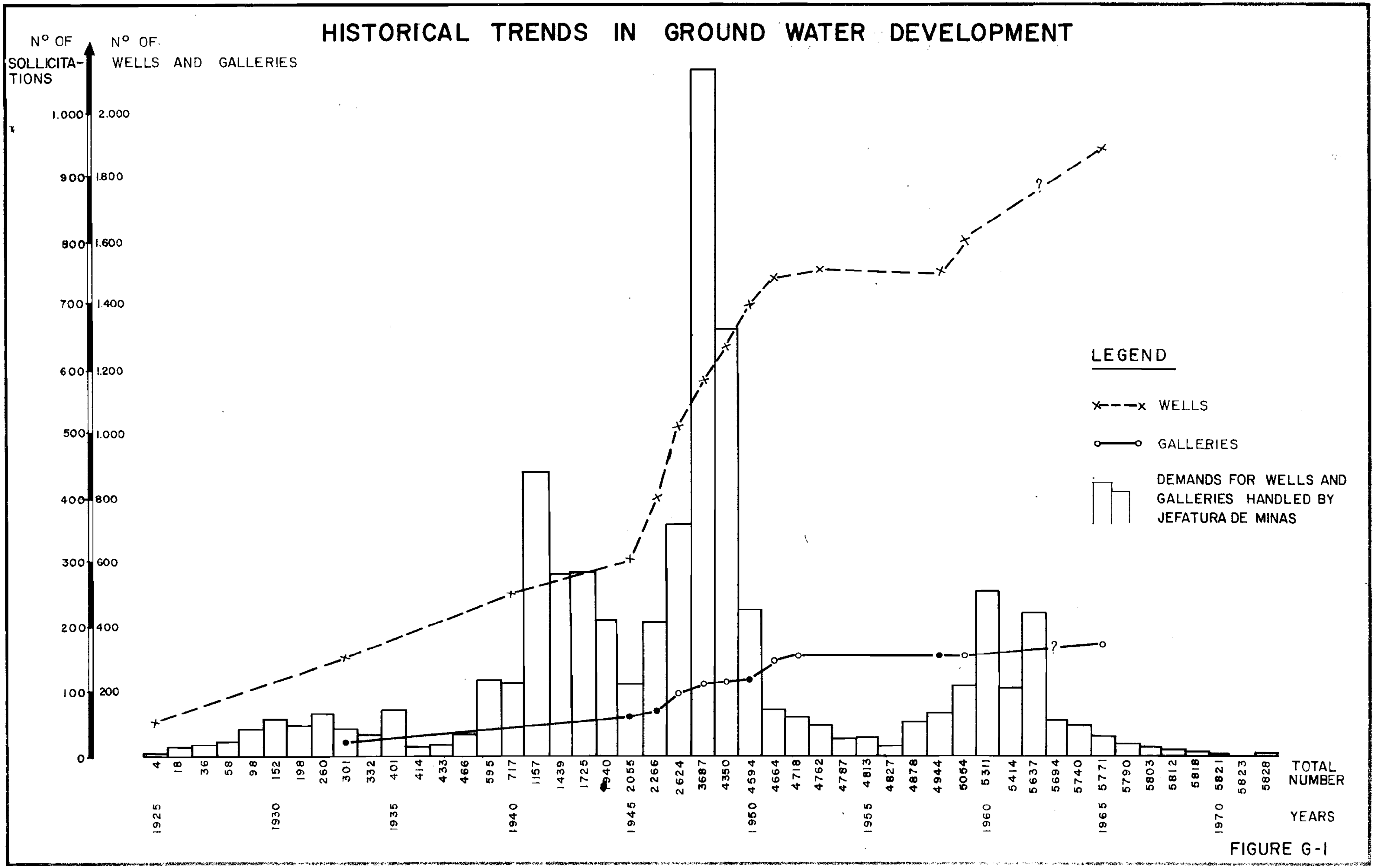

HISTORICAL TRENDS IN GROUND WATER DEVELOPMENT
Nº OF SOLLICITA-TIONS
Nº OF WELLS AND GALLERIES
1.000 2.000
900 1.800
800 1.600
700 1.400
600 1.200
500 1.000
400 800
300 600
200 400
100 200
0
LEGEND
WELLS
GALLERIES
DEMANDS FOR WELLS AND GALLERIES HANDLED BY JEFATURA DE MINAS
4 18 36 58 98 152 198 260 301 332 401 414 433 466 595 717 1157 1439 1725 1940 2055 2266 2624 3687 4350 4594 4664 4718 4762 4787 4813 4827 4878 4944 5054 5311 5414 5637 5694 5740 5771 5790 5803 5812 5818 5821 5823 5828
TOTAL NUMBER
1925 1930 1935 1940 1945 1950 1955 1960 1965 1970
YEARS

FIGURE G-1

Inventory of Groundwater
1932

Municipality	Springs	Wells	Galleries
Agaete	3,784 (4)	1,356 (6)	-
Agüimes	1,892 (5)	8,060 (28)	0,599 (5)
Artenara	0,032 (10)	-	-
Arucas	1,186 (3)	0,482 (20)	0,159 (2)
Firgas	3,376 (14)	-	-
Galdar	3,521 (16)	0,367 (8)	0,034 (2)
Guía	3,274 (12)	0,205 (1)	-
Ingenio	-	0,667 (67)	-
Mogán	0,383 (39)	1,921 (29)	Insig. (1)
Moya	1,497 (5)	0,022 (1)	-
Las Palmas (+San Lorenzo)	- 0,093 (10)	1,577 (20 1,984 (19)	- 0,512 (4)
S. Bartolomé	0,360 (32)	-	-
San Mateo	2,688 (32)	-	4,336 (15)
S. Nicolas	0,158 (10)	1,577 (20)	-
Sta. Brigida	1,198 (7)	-	0,820 (2)
Sta. Lucía	2,278 (30)	5,990 (30)	-
Tejeda	1,703 (8)	-	-
Telde	-	1,887 (53)	-
Teror	1,104 (22)	-	0,473 (2)
Valsequillo	2,160 (6)	0,165 (1)	0,473 (4)
Valleseco	2,365 (20)	-	0,788 (5)
Total for island Mm3/year = 67,506 or 43,3mm/year.	33,052 (285)	26,260 (303)	8,194 (42)
1/s = 2,141 l/s	1048	833	260

Note: All figures expressed in Mm^3.
In brackets are number of captations.
Source: Estadística Minera y Metalúrgiga de España, 1933.

mean production of 2,8 l/s. and 42 galleries with a mean production of 6,2 l/s. The total production of that year amounted to a water lamina of 43 ^{mm} which compared to the mean rainfall of 300^{mm}/year accounted for 14% of the total.

A closer look at the same table indicates that most of the yielding springs were concentrated in the "municipios" of Agaete, Firgas, Gáldar, Guía, Valsequillo and San Mateo, and most of the high production wells were found in Agüimes, Sta. Lucía and Las Palmas wheareas the "municipio" of San Mateo alone produced half the yield of galleries.

From this year onward only partial statistics are available on the development of groundwater in the island. However it must be said that these figures correspond except for 1933, to production capacity and not to real production. The maximum production capacity coincides with the period 1952 to 1960 after which no statistical figures were available even though the tendency was a drop in the production capacity.

It is interesting to note however the increase in wells from about 600 in 1945 to 1400 in 1950 and to about 1900 in 1970. Galleries augmented from about 115 in 1945 to 240 in 1950 to about 340 in 1970.

As for the total perforated length it increased for 57 km for wells and 50 kms for galleries in 1945, to 90 kms. for wells (bore-holes and lateral galleries excluded) and 80 kms. for galleries in 1950, and 172 kms. for wells and 177 kms. for galleries in 1970.

During these 3 years the unit production in l/s/m in wells and galleries varied probably as follows:

	Total perforated (meters)	Total production (l/s)	Unit product. (l/s/m)
1945	107.000	3.800	0,036
1950	170.000	4.800	0,028
1970	350.000	4.060	0,011

The above figures demonstrate that during the last 25 years the unit production has decreased gradually but sharply to about one-third of the original value.

Also from 1940 up to 1970 the mean depth of the well has remained around 100^m, excepting between 1950 and 1955 where it dropped to around 60^m, explained possibly by a proliferation of wells along the coastal areas.

The historical trends in ground water development are given in Fig. G.1.

2.2 Perforation and Equipment of Wells

Construction of wells is a costly operation in Gran Canaria due largely to the hardness of the rocks and the great depths to water. Most of the coastal wells attain a medium depth of 100^m but in the interior the mean depth to water is around 150^m and occasionally wells attain a little over 300^m of depth. The price of boring varies from 5.000 to 10.000 pts/-meter according to the terrain and depth.

In Fig. G.2 is presented the general aspect and equiptment of a typical well in the island which normally has a diameter of 3 meters. The development of ground water has been closely related to the improvement in the techniques of well-making.

In early times wells were hand dug using simple tools and without explosives. The extraction of rock debris was effectuated by winches. Sections of loose materials on the wall were consolidated with lime at earlier times and with ciment at present.

The use of explosives and air-compressors in relative recent times has greatly accelerated perforation activities.

Once the water level is reached, lateral galleries and boreholes, the latter named "catas", are effectuated to increase the yield.

TYPICAL LARGE- DIAMETER WELL

— GRAN CANARIA —

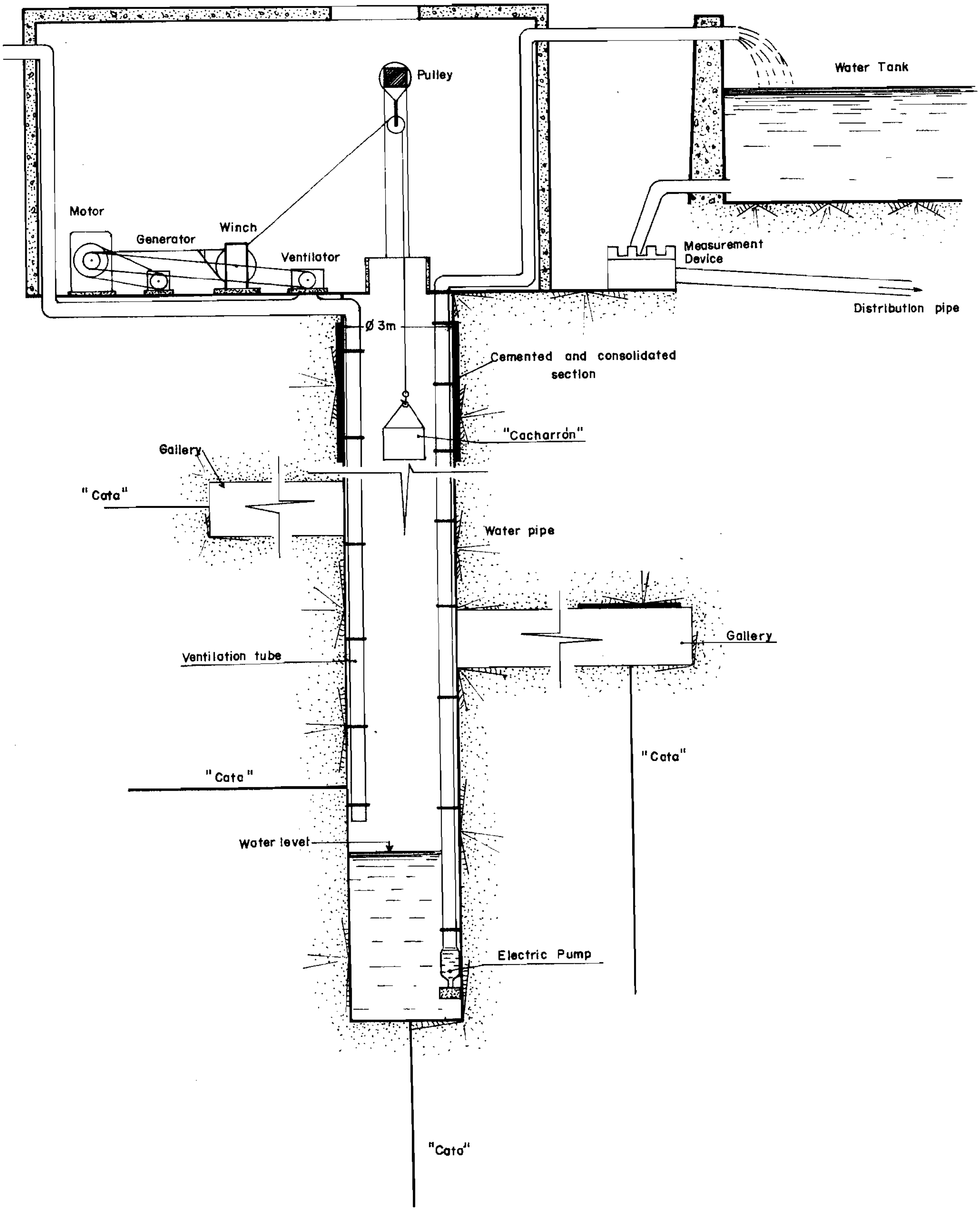


FIGURE G-2

The bore-holes are either vertical or horizontal and are effectuated by small diameter rotative machines.

At earlier times the withdrawal of water was done by fuel oil piston engines of 50 to 100 H.P., now substituted by electric pumps and motors of higher performance. A second elevation pipe is sometimes placed for the elimination of dirty water during perforation periods. If the well produces toxic gases (CO_2 etc.) ventilators are also installed.

2.3 Well and Gallery Inventory System

An inventory of existing wells and galleries was undertaken for the need of the Project through 1968 to 1970. In this inventory the principal data obtained were ownership, well or gallery location, depths or length of well or gallery, annual production, state of construction and installed H.P. The data were grouped by "municipios" and the numbering system was the same as that used by the Jefatura de Minas of the Ministry of Industries. This system which is the one currently used for administrative purposes has been retained in the enclosed Hydrogeological Maps in this report.

With the undertaking of field investigations through 1970 to 1973, each well or gallery visited was also given a study number based on the division of the island into 9 major hydrological zones. This system adopted for ulterior data processing is composed of 4 digits, the last identifying the point visited within the zone. In this system springs as well as borings have been included.

The analysis of the official and field inventories has been done in Section E-3. The statistical summaries are presented in Tables E.1 and E.2.

2.4 Historic Withdrawals and Variations of Discharge

Only sporadic data are available on historic withdrawals and discharge variations. Data published by the Jefatura de Minas gives perforated lengths and corresponding installed extraction capacities but no real productions are available as said earlier excepting some rare statistical summaries like for 1933 and 1945.

The historical trends in production could be correlated to several factors of which the increasing demand for irrigation and variation of rainfall seem to be the most important. In Table G1 is given historic yields of certain points with relation to the total precipitations of the island. The spring "La Mina" as well as the gallery Gamonal Nº 36 seem to follow the rainfall tendency although the carry-over effect in dry years is clearly seen. There is however some doubt with regard to the behaviour of the gallery which could be also explained as a recesion of a subterranean water pocket.

There is also a correlation between the rainfall and the perforation of wells. For example between 1945 to 1950 a total of 98.000 meters were perforated whereas between 1950 and 1955 only 37.000 meters were bored. If we consult the Fig H.9 showing the mean annual rainfall tendency of the island, we conclude that intense water searching activity coincides with a previous dry period. The dropping of the boring activity between 1950 and 1955 coincides on the other hand with a wet period, as is also seen in the above mentioned Table.

The relatively dry period 1959-69 is also marked by a recrudescence of the search for water specially by deepening of wells and over exploitation in the northern and eastern parts of the island. Study of historical records in these zones from 1960 to the present day shows very sharp water level declines varying between 1 to 4 meters/year. Reconstruction of the historic piezometric levels has been attempted in sub-section E.8 based on simulation of aquifers and a separate analysis of this problem will be made later.

An approximate idea of the total volume withdrawn between the

Table G.1

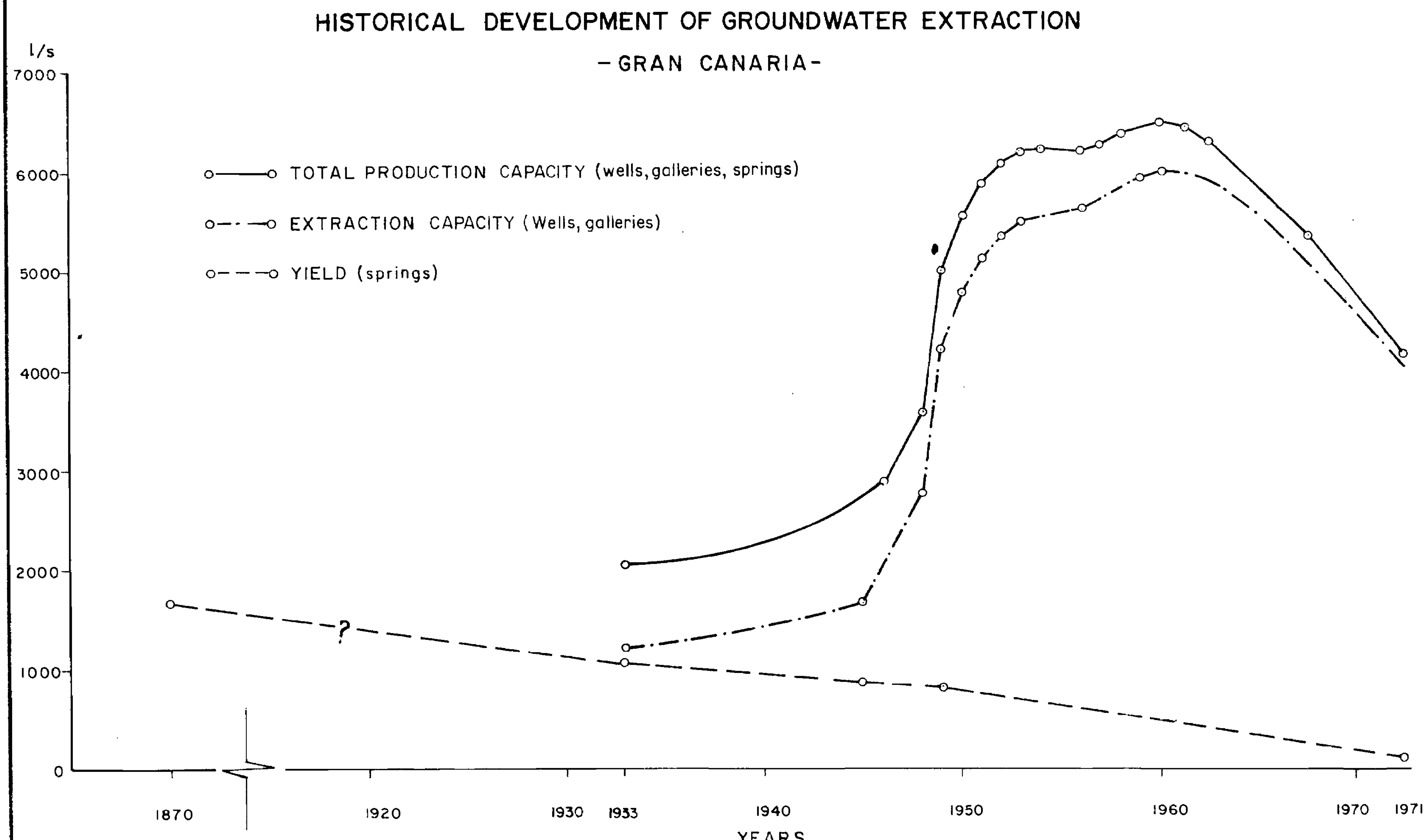
Precipitation versus Historical Yields

Year	Total Precipitation of Island (Mm3)	Gallery Gamonal Nº 36 (l/s)	Springs "La Mina" (l/s)
1949/50	570,1	-	22,0
50/51	663,5	-	24,0
51/52	456,0	-	28,0
52/53	524,4	-	30,0
53/54	881,4	7,0	35,0
54/55	595,7	8,0	30,0
55/56	1.100,5	12,0	45,0
56/57	225,1	7,0	40,0
57/58	600,9	5,0	32,0
58/59	416,4	4,0	34,0
59/60	313,6	3,0	28,0
60/61	290,8	3,0	23,0
61/62	245,7	2,0	21,0
62/63	861,2	-	-
63/64	212,9	-	31,0
64/65	390,6	-	34,0
65/66	313,7	-	-
66/67	257,9	-	19,0
67/68	-	-	19,0
68/69	-	-	20,0
69/70	483,0	-	19,0
70/71	677,8	-	22,0
71/72	467,4	-	22,0
72/73	473,6	-	22,0

last 50 years can be obtained using Fig G3 and on the supposition that the actual production was one-third less than the indicated production capacity. This seems to be in agreement with the present system of ground water production. The volume variations are as follows:

Period	Discharge (m^3/s)	Total Volume (Mm^3)	Water Lamina (mm/year)
1923-1933	1,3	41x10 = 410	26
1933-1947	2,5	79x14 = 1106	51
1947-1950	4,0	126x3 = 378	81
1950-1970	4,3	136x20 = 2723	87
1970-1973	4,0	126x3 = 378	81
Total.........................		4992	

The above figures even though approximative indicate that maximum extraction took place between 1950 and 1970, more precisely between about 1955 and 1965 and this coincides with the period of maximum decline of water tables specially in the northern part of the island.


HISTORICAL DEVELOPMENT OF GROUNDWATER EXTRACTION
- GRAN CANARIA -
l/s
7000
6000
5000
4000
3000
2000
1000
0
TOTAL PRODUCTION CAPACITY (wells, galleries, springs)
EXTRACTION CAPACITY (Wells, galleries)
YIELD (springs)
?
1870
1920
1930
1933
1940
1950
1960
1970
1971
YEARS
FIGURE G-3

3. Crop-Water Requirements

No scientifically established data exists in the Canary Islands on this subject. But one could use the figures most commonly admitted in published works on Canarian agriculture. The difficulty with these figures is that they vary from one source to another, the reason being that the climatic, technical and production characteristics of each example cited were not clearly explained.

The figures cited below constitute only a broad basis which could be used to draw out certain conclusions.

We shall retain the mean unitary needs obtained after study of the figures found in various publications and the mean level of crop productivity.

TABLE G 2 Unitary water needs of crops

Banana	15;000 m^3/ha/year	Cereals (other)	4;000 m^3/ha/year
Potato	4;000 m^3/ha "	Vegetables	8;000 m^3/ha "
Tomato	8;500 m^3/ha "	Forage crops(1)	4;800 m^3/ha "
Corn	4;000 m^3/ha "	Others annual Crops	4;500 m^3/ha "
Cucumber hot houses	4;500 to 5;000 m^3/ha "	Others fruit trees	12;000 m^3/ha "

(1) Weighted average between maize for forage 4.000 m^3/ha and alfalfa 19.000 m^3/ha.

With these figures we could estimate the water demands for agriculture in the two agro-climatic zones of the island, with the help of landuse statistics.

Two thirds of the total consumption is found in the north and southeast of the island and this is due to the banana cultivation which in itself uses up to 55 Mm^3. In the south, tomato cultivation accounts for almost half the total demand of the region.

On the whole, three crops use up 75% of the water in the island: banana, tomato and potato. However, the rest, mainly vegetables, together consume a little more than that of potato.

TABLE G 3 Annual Water Consumption in Agriculture

(Estimated in Mm^3 - 1970/71)

Crops	Southern part Mm^3.	%	Northern part Mm^3	%	Total Mm^3	%
Cereals	3,32	7,5	1,23	1,4	4,55	3,5
Legumes	0,35	0,8	0,39	0,4	0,74	0,6
Tomatoes	19,01	43,0	7,22	8,4	26,23	20,1
Other vegetables	5,58	12,6	6,25	7,2	11,83	9,1
Potatoes	2,64	6,0	8,72	10,1	11,36	8,7
Forage crops	3,83	8,7	2,64	3,1	6,47	5,0
Other crops	0,05	0,1	0,45	0,5	0,50	0,4
Total annual crops	34,78	78,7	26,90	31,1	61,68	47,4
Banana	6,54	14,8	54,44	63,2	60,98	46,8
Other fruit trees	2,86	6,5	4,92	5,7	7,78	5,8
Total Hm^3	44,18	100	86,26	100	130,44	100
%	34		66		100	

It is thus on these three crops that future technical and eco - nomic investigations should be focused in oder to determine their real regional needs as well as the irrigation methods most suited to reduce the total water consummation.

In Section D of this Chapter certain theoretical calculations have been made on evapotranspiration potential and the need of plants depending of rainfall and the soil moisture situation. Two examples were retained: banana in the north and tomato in the south. Thus for banana the need would be 11.000 m^3 and for tomato 5.000 m^3.

An efficient irrigation system must be able to supply the necessary quantities for the crops. The methods presently used have low efficiencies: 0,7 for banana (flood irrigation) and 0,6 for tomato (furrow irrigation).

The consumptions vary between 15.000 m^3 and 8.300 m^3, respectively for the two crops, and approach those given in the above table.

The efficiency can reach 0,8 if sprinkler irrigation was practised which should represent a water economy of 12,5 % and 25,0 % for banana and tomato respectively. It sprinklers irrigation is practiced for both crops, it is possible to economise 14 Mm^3 of water per year. But this is a theoretical conjecture since only large modern farms are in a position to practice it. In addition, it is necessary first to verify the preceeding figures by concrete experiments and then study the cost-benefit margins since sprinkler irrigation will automatically increase investment costs.

One should also note the small volume of water necessary for hot-house cultivation. According to the "Organizacion Sindical", one cubic meter of water permits a harvest of 3 to 4 kg. using classical methods and 8 to 15 kg. in hot-house cultivation. Hence an important change will occur if present open-field cultivation (banana and other fruits) was partially replaced by hot-houses.

As an example let us suppose that half of the actual area under banana cultivation, those that give the worst harvests were replaced by hot-house cultivation. This would give a cultivable area of 2.000 ha or 1/6 of the existing irrigated land. In this eventuality the water economy realized will be 21 Mm^3/year. Also,, if the remaining areas under banana plantations used sprinkler irrigation as well as half of the area under tomato, a total economy of 28 Mm^3 per year could be achieved, which represents a volume economized, sufficient to supply other activities during a number of years.

Such a change however needs time, and meanwhile it is probable that there will occur reduction in agricultural consumption due to progressive abandonning of the less productive cultivations, which leaves intact the problem of supply in the entire field of activity. Hence, one reckons the urgent need of finding a solution to this problem.

4 Municipal Water Supply and Other Requirements

Besides the agriculture the sector we have water requirements in the following sectors of activity:

- Tourist Industry
- Industrial needs
- Port water supply in Puerto de La Luz for international ocean traffic.

In 1967, according to the document "El Plan de Abastecimientos y Saneamientos Hidráulicos" the following data have been published:

- Domestic and municipal uses	-	27,40 Mm^3
- Tourism	-	0,41 "
- Industries	-	3,50 "
- Harbour (International sea traffic)	-	0,74 "
	Total:	32,05 "

The domestic, municipal and touristic requirement were calculated at a mean unitary consumption of 150 litres per day per inhabitant.

4.1 Consumption Needs of the city of Las Palmas

According to the data for "Término Municipal de Las Palmas" the city consumption in 1971 was as follows:

Volume of water entering pipe-system:	14,37 Mm^3
Volume of water paid by consumers:	12,52 "

These volumes were distributed in the following manner:

- Domestic and touristic consumption	-	0,93 Mm^3
- Municipal requirements	-	0,56 "
- Industries	-	0,72 "

- Public and Official Buildings	-	0,75	Mm^3
- International port requirements	-	1,06	"
	Total:	12,52	"

The total supply of 14,37 Mm^3 (455 l/s) was derived mainly from ground water complemented in 1971 by 2,36 Mm^3 (75 l/s.) from the de - salinization plant. When we compare the volume entering the pipe system and the volume sold to consumers, we note a loss of 1,75 Mm^3 in the pipe network which is about 12% of the water provided. This figure is not too high considering the multiplicity and the age of the network.

A comparison of the data, estimated for 1967 with those for 1971 helps to draw certain interesting conclusions:

- Industrial needs continue to be of little importance; the figures cannot be compared as the consumption in the first case is for the entire island and in the second for the municipality of Las Palmas. But most of the industries are in this zone. The port requirement has risen on the contrary sharply.

- The comparison is instructive only when seen from the point of view of consumption per head.

The population of Las Palmas during the 1970 census was 263.000 inhabitants to which one must add 24.000 tourists present at that time giving a total of 287.000. The resident population was estimated as 283.000 in 1972, and 273.000 in 1971. We could estimate a total of 30.000 tourists in 1971 having stayed on the average 7,5 days in the capital equal to 225.000 night stopovers.

Admitting a net average consumption of 120 litres a day per head the corresponding requirements would be 270.000 m^3 net and 307.000 m^3 gross.

The consumption of the inhabitants of the city was established as follows:

	Net	Gross
Domestic consumption	92 l/day	104 l/day
Collective	13 l/day	15 l/day
	105 l/day	119 l/day

These figures seem to coincide with total gross consumption obtained for Arucas in 1972 which was about 96 litres a day per head.

4.2 Consumption Needs of the island

It is then possible to estimate the global consumption for the entire island using a few supplementary hypotheses. We could assume that:

- In the other regions of the island the gross consumption per head is on the average 80 litres/day per head.
- All the tourists consume 135 litres/day per head.
- The total industrial consumption for the island is 2,0 Mm^3.

With a population of 520.000 in 1970 in the island of Gran Canaria in which we include 40.000 tourists and taking into consideration the rate of increase already formulated, one can use as a base of calculation for 1971 a total population of about 500.000 inhabitants of which 273.000 in Las Palmas and 227.000 in the other municipalities.

In 1971 the tourist population was about 595.000 with an average stay of 7,5 days equal to 4,5 million night stopovers.

The total consumption for the entire island can be established as follows:

- Consumption need of the islands population (domestic and collective uses)			-	17,07 Mm^3
- Las Palmas	-	10,44 Mm^3		
- Other regions	-	6,63 "		
- Touristic consumption			-	0,60 "
- Industrial "			-	2,00 "
- Port "			-	1,06 "
			Total:	20,73 "

One notices that the requirements of the population are by for the most important, tourism requiring only a feeble quantity. However this could increase in the future when the urbanistic plans in the south of the island are fully developped.

As a conclusion we can say the total consumption of water in the island of Gran Canaria for 1971 was as follows:

Agriculture	-	130 Mm^3
Other uses	-	21 "
	Total:	151 "

Irrigation used up to 86% of this total.

4.3 Future Perspectives

In "El Plan de Abastecimientos y Saneamientos Hidráulicos" one finds the following future consumption estimates for 1985:

- Domestic and municipal uses	-	47,08 Mm^3
- Tourism	-	1,58 "
- Industry	-	8,75 "
- International sea traffic	-	0,60 "
	Total:	58,01 "

These previsions seem very high considering the actual si - tuation. In fact it corresponds to a gros consumption of 180 litres/day per person for a total population of 700.000 inhabitants and a forecast of 600.000 tourists.

Actually in Las Palmas according to earlier studies, the increase in unitary consumption was about 4% per year per person, as a result of the rise in living standards and the housing development scheme. It is probable that an increase will manifest also in the villages and in less important towns with a certain time delay (+ 5% a year ?).

It seems that one could retain the following unitary con - sumption norms:

Urban population of Las Palmas (individual and collective needs)	-	200 litres/day per person
Population of other areas	-	140 " " "

In the tourist sector on the contrary, it seems that the area of Las Palmas is beginning to show a decline in growth while in the south it is developping rapidly. In these regions where irrigated lawns and gardens have to be created and maintained, the unitary demand also would be high. For this reason it is proposed to retain a gross consumption of 250 litres/day per head.

For the industrial (and port) sector where development programmes do not seem to keep to the scheduled rythm, we will nevertheless admit the double of the present requirements. Furthemore for industries, if development takes place as planned, it would be best desirable to insist that all new installations adapt systems for reuse of water.

In 1985 according to different sources of information the islands total population would be between 650.000 and 700.000 inhabitants whether or not the actual immigration continues. For Las Palmas the corresponding estimates are 390.000 to 430.000 inhabitants.

It is difficult to forcast the number of future tourists as one could question the saturation point which would one day manifest itself in the south, similar to what is happening in Las Palmas presently.

However in 1973 about 800.000 tourists are expected to visit Gran Canaria. In 1985 it would be possible to predict 1.500.000 tourists with an average stay of 10 days although since 1965 the 7,5 days average was constant.

With these hypotheses, bearing in mind the average figures for the population the following consumption needs can be proposed:

- Population Requirement (domestic and collective)		-	40,5 Mm^3
Las Palmas:	30,0		
Other regions:	10,5		
- Tourism		-	3,75
- Industry		-	4,00
- Port		-	2,00
		Total:	50,25

This represents about 30 Mm^3 more than the present consumption.

Of this about 5 Mm^3 could be provided by the desaliniza - tion plant which is not yet functionning at full capacity. Hence there will be a deficit of 25 Mm^3.

We saw in the subsection G.3 relative to crop requirements that by switching on to sprinkler irrigation 21 Mm^3 could be saved with no loss of the irrigated agricultural surface but cutting out marginal and improductive banana crops and growing more productive crops instead.

The remaining 4 Mm^3 can be probably obtained by a further development of surface water resources and possibly by improving the system of distribution.or by a second desalinization plant.

Nevertheless the main problems remains, the capacity of the groundwater aquifers to support the present rate of production. It is po - ssible that the presently used aquifers provide the volume of water soli - cited on condition that a rationalization of the captations is realized so that no serious water level decline is registered in the future and hence the cost of unitary production does not go up. The present effort to simulate future levels and possibles costs, through the Gran Canaria R-C model will give the answer and will be dealt with later.

It is also possible that the effort to preserve the dispo - nible more easily exploitable groundwater resources and the desire to avoid water level decline could diminish groundwater extraction in the future. In this case the problem of the maintenance of the present agri - culture system with the big water demand will remain unsolved since it is out of question that desalinization can ever supply the need.

5. Desalinisation

Since 1970 a desalinisation plant has been functioning in Gran Canaria installed a little south of the city of Las Palmas.

5.1 Characteristics

The process used is multiflashing and it serves a double purpose: production of potable water and electricity.

Some technical characteristics of this plant are given below:

- nominal water production capacity: 20.000 m^3/day
- nominal electricity production capacity: 24.200 Kw at 13.000 V
  18.000 Kw at 66.000 V (max. to net)
- number of stages: 22
- performance ratio: Quantity of water/Quantity of vapour, 6,35
- recirculation performance: cooling discharge/freshwater discharge 6,67
- temperature range sea water (20^o) - soft water (33^o) = 13^oC
- production vapor: 148 T/h (reheated vapour)
  28 T/h (max. saturated vapour)
- pre-treatment by poly-phosphates
- materials used: soft steel and epoxy for parts in contact with water; copper-nicker for evaporation and condensors.

In 1971 the plant produced 2,36 Mm^3 of fresh water with less than 2 ppm of total salt content and 61,6 millions Kwh. In 1972 the production increased to 3,43 Mm^3. It is used at present to satisfy peak-hour consumption of drinking water and mainly for electricity production.

In the face of the penury of water in Las Palmas, its hours of production should increase. In fact in 1971 it was used to 1/3 its capacity. In 1972 the percentage reached 47%. It seems that certain technical problems have not yet been totally solved, principally corrosion.

5.2 Costs

The functioning costs of this installation figures in the following publication: "Problemática de la Desalinización y la Reutilización en España", presented by the Dirección General de Obras Hidráulicas at the International Symposium on the planification of Hydraulic Resources (Mexico, December 1972).

The initial investment was 570 millions pesetas. Amortization is calculated at the rate of 4% for a period of 20 years with 75% of the investment, and 15 years for the remaining 25%, which gives us an annuity of 44,5 million pesetas.

In 1971 the costs were as follows:

Exploitation costs	-	76,1	million pesetas
Amortization	-	44,5	" "
Insurance costs	-	5,7	" "
Total		126,3	million pesetas

Deducting the selling price of electricity at the rate of 0,72 pts. per Kwh or 44,4 million pesetas, we have a rest of 81,9 million pesetas for a production of 2,36 Mm^3 of fresh water equal to a unitary cost of 34,68 pts/m^3.

For the first semester of 1972 the corresponding costs were established as follows:

Exploitation costs	-	51,0	million pesetas
Amortization	-	22,2	" "
Insurance costs	-	2,8	" "
Total:		76,0	
Sale of electricity	-	31,3	
Remaining:		44,7	million pesetas

Production of water: 1,17 Mm^3
Cost price of 1 m^3: 38,22 pts.

The cost price was thus very high. However we see that the cost price is not based on an analytic study of investment costs of water and electricity and corresponding functioning costs, thereby falsify the estimation to an extent.

It is also evident that the more capacity of the plant is used, the more the role of investment costs in the cost price will diminish (in 1971 and 1972 it was 35% and 29%, respectively).

6. Treatment of Waste Water

A waste water treatment plant has been functionning in Las Palmas for some years.

Planned to treat 300 l/s. of used water with 575 ppm of BOD and 700 ppm of matter in suspension, it renders treated water back with 15 ppm of BOD and 60 ppm of suspension matter. At the present moment it treats 200 l/s., equal to 6,3 Mm^3 per year of the 10,4 Mm^3 consumed by the population if we except industrial uses. The rest of the used water is sent out directly to the sea.

This station is a classical biological station made up of:

- a pre-treatment unit.
- a primary treatment (decantation)
- a biological treatment (activated slugs)
- a tertiary treatment (floculation)
- a treatment of muds

The product of the last stage unfortunately is lost to agriculture as there is no interest for this type of organic matter and consequently almost everything is incinerated.

As for the treated residual waters, 3.000 to 6.000 m^3/per day are used for agriculture in Tafira and Almatriche. This corresponds to an annual volume of 1,1 to 2,2 Mm^3 and the rest flows out to the sea.

Utilization of these treated waters, however, poses certain problems. In order to transport it, prior pumping to a height of 200 - 300 m is needed. Also, the treated water has an NaCl content of 700 to 800 mg/l and is not suitable for banana cultivation, which is sensitive after a limit of 200 mg/l. It is however used for tomato cultivation or for vegetables after mixing with less salted water.

Farmers pay 4 pts a cubic meter which is insufficient to cover overall costs.

The future sewage treatment programme provides for the functionning of the plant at full capacity. The ulterior stages forseen are only at a pre-project level.

Hence we see that the hope of using these waters in the near future is not to be exaggerated. Here again apart from the economic factors of transport costs and rendering it readly available for agriculture, one finds the same problems posed by banana monocultivation as in the Northern part of the island.

However, this supplementary source of irrigation water should not be neglected as in the long run it could provide many millions of meter cubes which would otherwise be lost to the sea. Its future utilization can be also considered for artificial recharge of aquifers in areas of salt water encroachment for example (South of Telde and North of Tirajana), and where medium quality water is actually in use for crops such as tomatoes and alfalfa.

7. Cost of Groundwater Pumping

Quantitative data have been studied for 15 wells, the depth of which varied between 40 and 212 m. These are summarized in Table G.4. . They come from a private source and one notices immediately the current booking keeping method for expenses incurred in well pumping and management. When one questions people, about the cost of 1 m^3 of water produced, we obtain the usual answer, 2 to 3 pts. In fact, as seen in the above Table, only real annual costs are registered as expenses, disregarding all notions of amortization of initial investment costs which is very high, or even the short term investment on the pump which does not last more than 5 years.

Amortization costs do not seem to be taken into account except at the level of selling price. It must be stated that the initial investment has a long life-span, the well itself, the shed, the winch, the generator, the ventilators, etc., last indefinitely.

7.1 Current method of calculating water price

This method of accounting for costs has its inconveniences, because a big reparation intervening on a generating plant for a particular year is listed for that year and not for a 5 or 10 year amortization period, which raises very much cost price.

After these preliminary remarks, one can make the following observations for the 15 cases studied:

a) Annual extraction from wells oscillates between 72.000 and 540.000 m^3 or by a factor of 1 to 7,5.

b) If the installed power of the generating plant follows the variation in the depth of wells, the pump on the contrary remains relatively constant.

Table G.4

Analysis of 15 Wells (Cost-Price for 1 m^3)

Nº of wells	Depth m	Motor in H.P.	Pump in H.P.	Pump discharge l/s	Actual yield 10^3 m^3	Potential yield 10^3 m^3	Utilization coefficient	Yearly Expenditure: Maintenance (estimated)	Yearly Expenditure: Power	Yearly Expenditure: Labour	Yearly Expenditure: Total	Cost price of 1 m^3 in Pts.: Maintenance	Cost price of 1 m^3 in Pts.: Power	Cost price of 1 m^3 in Pts.: Labour	Cost price of 1 m^3 in Pts.: Total	Nº OF LABOURERS
1(1)	39	46	a piston	15	144	223	0,65	75	130	218	423	0,39	0,68	1,14	2,21	2
2	35	50	"	20	176	278	0,63	50	72	95	217	0,28	0,41	0,54	1,23	1
3	68	50	"	20	144	315	0,46	75	54	138	267	0,51	0,38	0,96	1,85	1
4	70	120	100	30	540	788	0,69	150	248	308	706	0,27	0,47	0,57	1,31	3
5	86	150	100	35	306	472	0,65	100	208	110	418	0,33	0,68	0,36	1,37	1
6	94	120	120	?	246	472	0,52	150	137	101	388	0,60	0,56	0,41	1,57	2 half-time
7	135	175	50	20	248	372	0,67	75	395	314	784	0,30	1,59	1,27	3,16	3
8	143	135	80	15	540	630	0,86	75	479	329	883	0,13	0,89	0,61	1,63	2
9	176	135	100	25	396	616	0,64	125	427	328	880	0,33	1,08	0,81	2,22	2 salary equals 3
10	178	150	90	20	180	278	0,65	150	257	207	614	0,83	1,43	1,15	3,41	2
11	180	185	100	?	360	540	0,67	175	504	435	1114	0,50	1,40	1,20	3,10	2 salary equal 4
12	186	184	150	?	540	790	0,69	175	543	340	1028	0,33	0,95	0,63	1,91	3
13	186	150	100	25	92	158	0,58	100	94	101	295	1,08	1,02	1,10	3,20	1
14	200	184	?	?	432	720	0,60	175	513	314	1002	0,40	1,19	0,73	2,32	2 salary equal 3
15	215	125	100	20	72	315	0,23	75	130	126	331	1,04	1,81	1,75	4,60	2 half-time

(1) These wells produce electricity 25% of their utilization time and this is taken into account in the cost price of a m^3.

(2) 10^3 pesetas

c) The total maintenance costs are estimated forfeitavily but seem to be established in the following manner:

- Wells with piston pumps - 65.000 to 70.000 pts/year
- Wells of 80m to 150m deep - 90.000 to 100.000 pts/year
- Wells of 150m to 215m deep - 130.000 to 150.000 pts/year

d) Examination of energy costs per m^3 extracted should show a clear relation with price.. But one notices large variations going up to 0,5 pts. per m^3 for identical depths.

e) Labour costs also vary per m^3 extracted. It seems however that when the annual output in less than 200.000 m^3, there is usually only one labourer. On the contrary when production is over 400.000 m^3 there are three workers for each well.

In fact things are more complex. One would suppose that a well which functions only a few hours a day could be looked after by 1 worker visiting several wells. But in reality a single worker permanently looks after one well no matter how many hours the well is pumping. If pumping last long hours and the unitary production is high, he is helped by one or two more men.

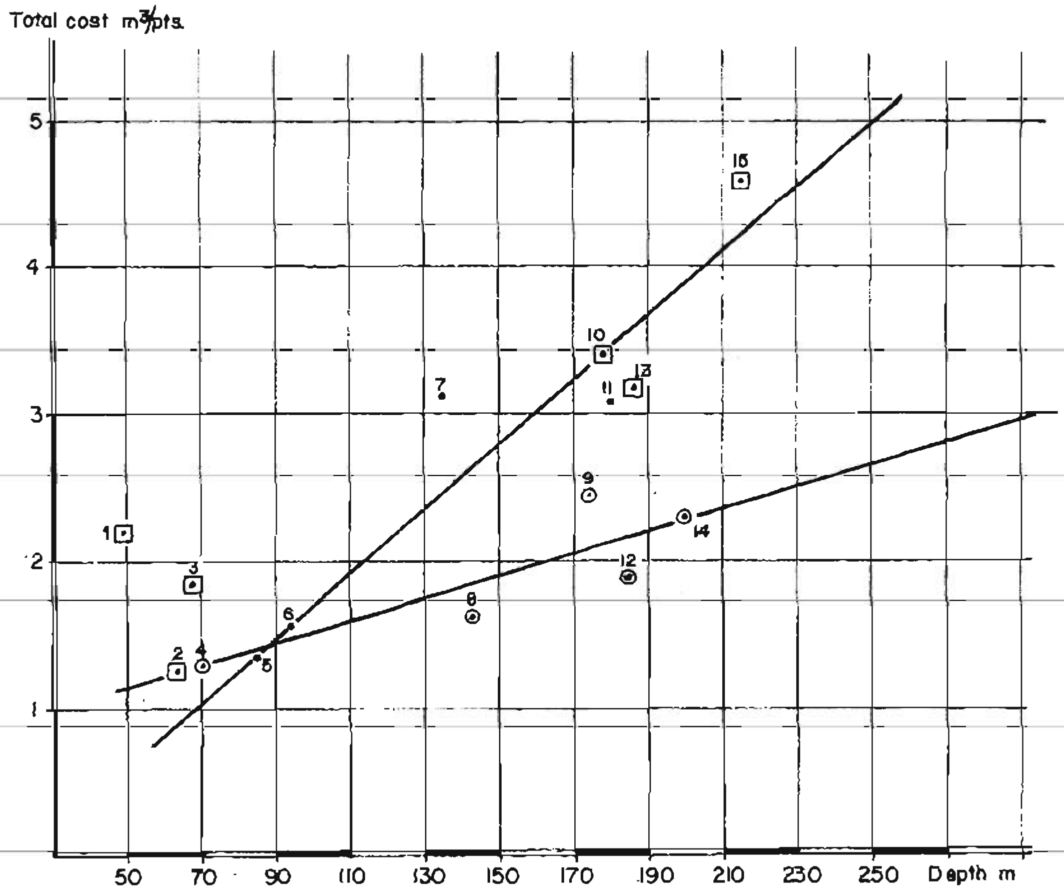
Following the above considerations, we should find at the level of the cost price of 1 m^3, a relation between itself, the depth of well (due to extra power used) and the annual production (because labour costs become fixed according to certain extraction limits).

In Fig. G.4 is shown the cost price of a m^3 considering the depth of a well; in the first graph the total cost price is used and in the second, the cost of energy is used distinguishing the following types of wells:

- Wells with an extraction of 200.000 m^3/year

  Nº 1, 2, 3, 10, 13, 15: 6 Wells

TOTAL PRODUCTION VERSUS DEPTH OF WELL



WELL PRODUCTION

⊡ < 200.000 m³/year

• > 200.000 < 400.000 m³/year

⊙ > 400.000 m³/year

1,2 = well numbering

UNIT COST OF ENERGY VERSUS DEPH OF WELL

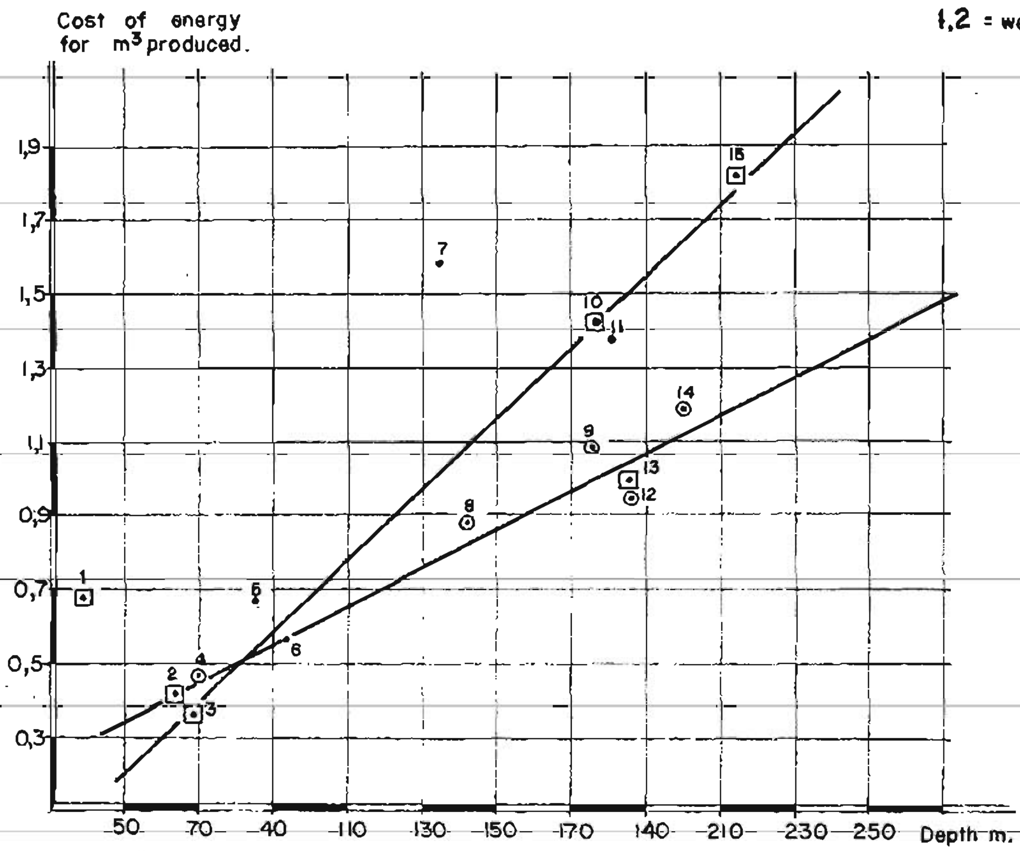


FIGURE G-4

Wells with an extraction between 200.000 and 400.00 m^3/year

Nº 5, 6, 7 and 11: 4 Wells

Wells with an annual extraction superior to 400.000 m^3/year

Nº 4, 8, 9, 12 and 14: 5 Wells

No clear conclusions can be drawn from these graphs but one can notice 2 classes of curves:

1) The first composed of high yielding wells with an extraction above 400.000 m^3/year which in both cases are found below the other points when the depths increase.

The total cost price for 1 m^3 would increase by about 0,75 pts. per 100 m of depth, while the energy costs would increase by 0,52 pts. per m^3, representing thus 2/3 of the increase.

2) The second class is less clear. One must first disregard the three wells with piston pumps which do not represent the same characteristics as the others. This family will include all the other wells with an extraction of less than 400.000 m^3/year.

Without being able to guarantee the validity of the following figures the total cost price of 1 m^3 would increase by 1,75 to 2,15 pts. for 100 m of depth while the price of energy would increase by 0,80 to 0,90 pts/m^3, representing 40 to 45% of the total increase.

These figures should be used with extreme precaution as we do not understand why the cost of energy should increase with depth in a way so diverse in both types although the pumps installed in wells 8 and 9 are more feeble than those in other wells of the same depth. It is the contrary for wells 4, 12 and 14.

Does it mean that the material is more modern with better performance, or must one question the basic data?

Besides one does not know if this could be extrapolated to depths over 200 m. following a linear or exponential curve in the absence of reference points.

Also it must be said that the wells examined are particularly productive, since the well the least used (Nº 15) produces 72.000 m^3/year, equivalent of 2,3 l/s.

The total extraction in the island amounts to 108 Mm^3/year for about 1.200 producing wells equal to an average yield of about 2,85 l/s per well (case of Nº 13). For the 15 wells the average is about 9,35 l/s or 3,3 times the mean for the island.

Even if we accept as a base for calculation the cost of energy for per m^3 pumped with relation to depth, it is necessary to multiply the cost of labour, maintenance costs and reparations by the volume of m^3 pumped by the coefficient 3,3 in order to have an idea of real average.

It is thus materially impossible to extend the results obtained for these wells in one and the same region (1,25% of all the wells of the island) without committing serious errors. Only a selective study of about 10% of the wells, chosen in a way to be representative of the various depths and the total volume pumped could enable a valid extrapolation.

Also it should be noted that it is necessary to add to the cost price calculated in the example, the cost of amortization of the pump.

Taking an average of 125.000 pesetas as cost of pump, an interest of 8% per year for a life-span of 5 years. (This has yet to be verified in the field). Amortization costs per m^3 taking into account the annual extraction well, would be as follows:

50.000	0,62 pesetas/m^3
100.000	0,31 " "
150.000	0,21 " "

200.000	0,156	pesetas/m^3	
250.000	0,125	"	"
300.000	0,104	"	"
400.000	0,078	"	"
500.000	0,063	"	"
550.000	0,057	"	"

If the cost is negligeable for wells with large production it is certainly not for the average wells in the island, of which the production is less than 100.000 m^3 per year.

7.2 Influence of progressive deepening of wells on cost price

The above examples referred to recent years without reference as to whether the wells more deepened or not. Also the cost of upkeep of the pumps would be about 8% or 10.000 pesetas per year. The corresponding charges for a generator valued new at 600.000 to 800.000 pesetas according to its capacity, would be about 10% including big reparations done every 5-6 years. It is thus seen that the average cost of maintenance of a single well would be 70.000 to 90.000 pesetas/year for pump and motor, which constitutes the major expenditure item in maintenance.

Of these figures out of the 15 examples one should leave out a certain number of posteriorily deepened wells (Nº 4, 5, 6, 9, 10, 12, 14).

In order to utilize the simulation results of the analog model it is interesting to estimate the importance of posterior deepening on price levels.

The cost of deepening of wells is about 16.000 pesetas per meter. The complementary costs (lowering of pump, pipes, etc.) are negligeable for which we will use a forfeitary sum of 1.000 pesetas per year. Thus subsequent deepening of 5 meters would cost 17.000 x 5 = 85.000 pesetas.

We know that the water table is declining constantly in certain zones of the island and therefore we can consider that this operation becomes an annual expenditure, although in reality deepening takes place every 2, 3, 5 years following the rythm of decline of the water table.

One can thus calculate the incidence of deepening on the cost-price of 1 m^3, according to the amount of water extracted. One should also add the increase in energy costs retaining an average amount of 0,72 pesetas for 100 m, or 0,036 pesetas/m^3 for 5 m. We have the following price elevations for a 5 m deepening:

Volume extracted per year in m^3	Effect on cost-price per 1 m^3 (5 m of deepening) in pesetas		
	Cost of deepening	Extra energy cost	Total
50.000	1,70	0,036	1,736
100.000	0,85	0,036	0,886
150.000	0,576	0,036	0,612
200.000	0,425	0,036	0,461
300.000	0,284	0,036	0,320
400.000	0,212	0,086	0,248
500.000	0,170	0,036	0,206

Here again, the effect is particularly great in wells of small output, being about 0,9 pesetas/m^3 for an average well in the island.

As decline of 2 to 4 m/year in the water table is not rare, in 10 years this would signify for wells of feeble discharge (100.000 m^3/year) an increase in the cost price of water from 3,6 to 7,2 pesetas/m^3.

For productive wells of 300.000 m^3 for example, the increase in cost in 10 years would be from 1,3 to 2,6 pesetas/m^3 which is already quite high.

Remarks

1) Because of the general rise in the standard of living and the difficulty of working at the bottom of deep wells, this operation becomes more and more costly.

The current tarif for deepening is 16.000 pesetas/meter but 4 years ago it was only 10.000 pesetas. If the actual tendency continues, the increase in price calculated above constitutes a minimum.

2) It will be the same with the salaries of the labourers which would have increased about 10% between 1972 and 1973. Taking into account of the importance of labour in the cost price calculated for the 15 wells studied, we can forsee the role of this factor.

3) As seen before, amortization was not included in the calculations and this is a weak-point. According to the current prices of equipment, it will cost about 5 millions pesetas to make a well of 200 m deep, of which 4 millions for the digging operation and 1 million for the generator. (Pump, reservoir and shed not included).

Even if we base our calculations on a well with a life-span of 30 years (which seems to be a reality for the major investment units) the effect on the price of 1 m^3 is important: annuity of 444.000 pesetas at 8% varies from 4,44 pesetas/m^3 to 0,82 pesetas/m^3 for wells having production of 100.000 to 540.000 m^3/year.

Such prices make the digging of new wells a financially risky operation as the production cannot be forseen.

But for the wells already existing, such values are not applicable. A large majority of these have been dug after the war, and in the 50's when the labour costs were low, compared to other expenses. However, we have no data on this point.

H. WATER BALANCE

1. Surface-water Balance

As discussed above, the island has been divided into 9 hydrological zones, some of which in turn have been divided into subzones. In order to be able to take into account special features such as differences in precipitation or geology, some of these have been divided once more into smaller parts which are the basic units. The water balance of Gran Canaria will be evaluated using 36 such units considering only natural conditions. Natural conditions in this context signify that all direct manipulation of water by man has been disregarded.

When two or more units form part of a hydrologic zone or subzone they have been divided into areas of equal size in order to facilitate the calculations since all quantities can be expressed as laminas of water instead of volumes. After the balance for natural conditions has been established for the hydrologic years 1970/71, 1971/72 and 1972/73, an attempt is made to superimpose the effects of man.

1.1 Terms of the Balance Equation

The terms considered in the surface-water balance are defined in Figure H.1 . With these notations the surface-water balance equation for the basic unit under natural conditions can be written as follows:

$$P + Qi = ET + R + Qo \pm \Delta H; \qquad \text{...(1)}$$

with the following relationships between terms:

$$P = ET + Qp + Rp \pm \Delta H; \qquad \text{...(2)}$$

$$R = Rp + Rq; \qquad \text{...(3)}$$

$$Qo = Qi + Qp - Rq; \qquad \text{...(4)}$$

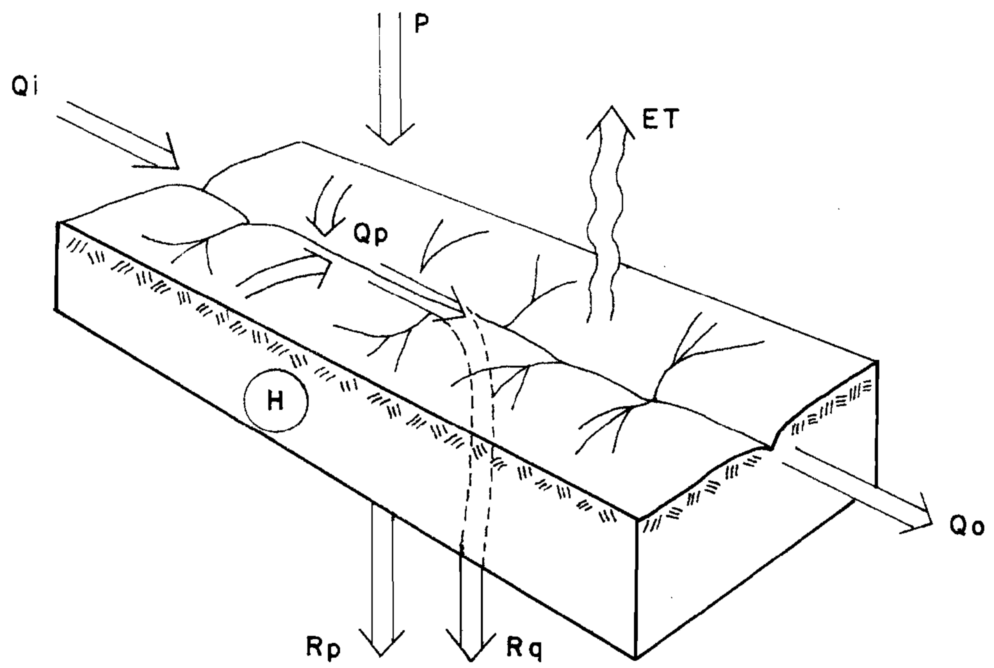


Figure H-1 The unit used for the surface water balance where

P = Precipitation

Qi = Surface water inflow

Qp = Surface runoff from the unit

Qo = Surface water outflow

ET = Evapotranspiration

Rp = Recharge from precipitation

Rq = Recharge from stream percolation

R = Total recharge

ΔH = Change in soil moisture storage

The local hydrological relations existing between rainfall and the other terms of the balance obliges the evaluation of these terms on a daily basis in order to obtain values reasonably close to reality. The determination of the daily values of recharge from precipitation will be made using equation (2) after which the effects of stream percolation will be assessed and superimposed according to equations (3) and (4).

1.2 Calculation of the Parameters

The calculation procedures for precipitation, runoff, real evapotransporation, recharge and stream percolation are discussed below.

For each zone and subzone a linear relationship between yearly rainfall and elevation has been established, which has made it possible to simplify the calculation of daily rainfall on the studied area. For each studied area one or two representative stations were selected and the rainfall for the total area was assumed to be equal to that of the representative stations. These stations were selected in such a way that their elevations were as close as possible to the median elevation of the studied area, obtained from the hypsometric curve.

From the gauged basins a relationship has been established between rainfall and runoff which has been expressed as the curve-number CN, for which type-curves have been published by the US Soil Conservation Service (1957), Figure D.6 The relationship has the following mathematical expression in metric units:

$$Q = \frac{25.4\left(\left(\frac{P}{25.4} - \frac{200}{CN} + 2\right)^2\right)}{\frac{P}{25.4} + \frac{800}{CN} - 8} \qquad \ldots(5)$$

where

Q = Storm runoff in mm.

P = Storm precipitation in mm.

CN = Curve-number (varying between 0 and 100)

The curve-number is related to the infiltration characteristics of the basin according to the following formula:

$$S = \frac{2540}{CN} - 254 \qquad \ldots(6)$$

where

S = Potential infiltration capacity in mm.

The curve-numbers depend on the infiltration characteristics of the basin, and in this case principally on geology. Also it has been possible to establish a relationship between runoff and rock types for the gauged basins so that for each main geological formation a corresponding potential infiltration capacity has been established. This procedure has enabled an extrapolation of runoff characteristics to ungauged areas, whereby each studied area has been assigned a curve-number, see Figure D.7 .

For each studied area daily runoff has been calculated from the daily rainfall using the curves in Figure D.6 , based on equation (5).

The real evapotranspiration depends on the potential evapotranspiration and the soil moisture conditions. For each zone, monthly potential evapotranspiration was calculated using a modified Blaney-Criddle formula written as follows:

$$ET_p = F_p\ (0.46\ t + 8.1); \qquad \ldots(7)$$

where

ET_p = Potential evapotranspiration in mm.

F = Modified consumptive use coefficient taking into account climatic factors.

P = Monthly percentage of yearly sunshine hours

t = Average temperature of the month in ºC

The coefficient F has been established for each month of the studied period for the six main meteorogical stations where the existence of more complete data have permitted a good evaluation of the potential evapotranspiration, as has been previously discussed. To each studied area has been assigned the same F value as for the closest main station with similar climatic conditions. The calculated monthly potential evapotranspiration has been assumed to be evenly distributed on all the days of the month.

For each studied area the soil moisture retention capacity has been estimated, see Figure D.11. For each day, available soil moisture in the area has been calculated utilizing a bookkeeping method, where the differences between daily rainfall and runoff is considered to enter the soil moisture storage. The real evapotranspiration was then calculated for each period between rainy days utilizing the Thornthwaite-Mather hypothesis discussed previously. In order to facilitate the calculations, tables for the soil moisture depletion derived by Thornthwaite and Mather (1955) were used.

In the bookkeeping method of calculation, actual available soil moisture is calculated for each day or each period between rainfalls as the available soil moisture at the beginning of the period, augmented by the excess of rainfall over runoff and diminished by the real evapotranspiration for the period. As soon as the actual available soil moisture exceeds the retention capacity, the excess is considered to form recharge to the ground-water body.

As has been discussed previously in this report, stream percolation is quite noticeable in the southern rivers. Therefore for each day with runoff in the river derived from the calculations, the part of the runoff that would percolate in the riverbeds has been estimated with an ad hoc method taking into account observations made by the Project, qualitative information obtained from local inhabitants, the relative magnitude of the alluvial deposits, the existence of wells in the alluvial areas for exploitation of the infiltrated water and the previous moisture conditions. The result has been superimposed on the balance, using equations (3) and (4).

1.3 Results of the Surface-water Balance

For the 3-year period defined by the hydrologic years 1970/71, 1971/72 and 1972/73 , a water balance has been carried out on a daily basis for the 36 areas defined above. Yearly summaries for each zone and subzones are presented in Tables H.1 - H.3 . Data for the last few months, that is the dry season, of the final year have not been available, and hence they have been estimated. However this will have no important influence on the result since that period has had no significant rainfall.

It can be seen that the year, 1970/71, was very wet with a recurrence interval of about once every ten years. The two subsequent years 1971/72 and 1972/73 have both been normal. This is favourable for the present study since estimates for the median conditions can be based

Table H.1

Surface-water balance for Gran Canaria

1970/71

Zone	Surface area	P	Qp		Qo		ET	H	Rp		Rq	
		mm	mm	Mm^3	mm	Mm^3	mm	mm	mm	Mm^3	mm	Mm^3
1 A	23,7	161	0	0	0	0	161	0	0	0	0	0
1 B	92,5	539	37	3,423	53	2,868	367	+ 6	129	11,932	6	0,555
1 C	31,7	789	54	1,719	47	1,490	426	+ 8	426	9,542	7	0,222
1 D	34,3	393	31	1,063	24	0,823	286	+ 1	75	2,573	7	0,240
2 A	40,1	674	73	2,927	60	2,406	357	+ 9	235	9,424	13	0,521
2 B	107,9	422	47	5,071	33	3,561	291	0	84	9,064	14	1,510
2 C	56,1	765	80	4,488	70	3,927	325	+ 2	358	20,084	10	0,561
2 D	75,9	557	59	4,478	20	1,518	294	0	204	15,484	39	2,960
2 E	46,9	284	2	0,094	0	0	194	0	88	4,127	2	0,094
3	145,1	366	11	1,596	4	0,580	208	0	147	21,330	7	1,016
4	88,4	512	95	8,398	45	3,978	212	0	205	18,122	50	4,420
5	49,4	464	11	0,543	5	0,247	359	0	94	4,644	6	0,296
6	178,5	397	55	9,818	32	5,712	279	0	63	11,246	23	4,106
7 A	68,3	305	61	4,166	40	2,732	198	0	46	3,142	21	1,434
7 B	49,5	358	100	4,950	44	2,178	210	0	48	2,376	56	2,772
7 C	34,8	340	148	5,150	95	3,306	180	0	12	0,418	53	1,844
7 D	69,4	305	119	8,259	84	5,830	185	0	1	0,069	35	2,429
8 A	106,3	357	144	15,307	100	10,630	181	0	132	14,032	44	4,677
8 B	122,4	496	193	23,623	140	17,136	188	0	115	14,076	53	6,487
8 C	94,9	298	71	6,738	30	2,847	170	0	57	5,409	41	3,891
9	42,0	306	71	2,982	71	2,982	227	0	8	0,336	0	0
Total	1158,1	435	74	114,793	48	74,751	246	+ 1	114	177,430	26	40,035

Table H.2

Surface-water balance for Gran Canaria

1971/72

Zone	Surface area	P	Qp		Qo		ET	H	Rp		Rq	
		mm	mm	Mm^3	mm	Mm^3	mm	mm	mm	Mm^3	mm	Mm^3
1 A	23,7	159	2	0,047	0	0	157	0	0	0	2	0,047
1 B	92,5	394	3	0,278	2	0,185	325	- 2	68	6,290	1	0,093
1 C	31,7	611	4	0,127	1	0,032	387	- 2	222	7,037	3	0,095
1 D	34,3	278	0	0	0	0	279	- 1	0	0	0	0
2 A	40,1	486	4	0,160	0	0	323	- 5	164	6,576	4	0,160
2 B	107,9	289	9	0,971	4	0,432	247	0	33	3,561	5	0,539
2 C	56,1	625	16	0,898	10	0,561	303	0	306	17,167	6	0,337
2 D	75,9	352	2	0,152	0	0	284	0	66	5,009	2	0,152
2 E	46,9	167	0	0	0	0	167	0	0	0	0	0
3	145,1	221	0	0	0	0	199	0	22	3,192	22	0
4	88,4	272	35	3,094	5	0,442	188	0	49	4,332	30	2,652
5	49,4	501	33	1,630	22	1,087	341	0	127	6,274	11	0,543
6	178,5	408	101	18,029	75	13,388	238	0	69	12,327	26	4,641
7 A	68,3	200	56	3,825	36	2,459	144	0	0	0	0	1,366
7 B	49,5	204	64	3,168	25	1,238	139	0	1	0,050	39	1,930
7 C	34,8	206	81	2,819	38	1,322	125	0	0	0	43	1,497
7 D	69,4	131	37	2,568	7	0,486	94	0	0	0	30	2,082
8 A	106,3	268	100	10,630	59	6,272	148	0	20	2,126	41	4,358
8 B	122,4	220	63	7,711	23	2,815	155	0	2	0,245	40	4,896
8 C	94,9	105	7	0,664	0	0	98	0	0	0	7	0,664
9	42,0	471	220	9,240	220	9,240	226	0	25	1,050	0	0
Total	1558,1	300	42	66,011	25	39,959	210	0	48	75,226	17	26,052

directly on the calculated results for the last two years. For these years it is obvious that stream percolation in the lower parts of the rivers has been less than was indicated for the natural conditions since much water has been retained in the reservoirs , the capacities of which are listed in Table D.8 . The stream percolation therefore has been adjusted so that the surface-water balance for Gran Canaria for the three hydrologic years 1970/71, 1971/72 and 1972/73 will be the one that is shown in Table H.4 .

A preliminary idea of where additional surface water resources might be exploited can be obtained from a comparison between the detailed water balance of the two normal years 1971/72 and 1972/73, Tables H.2 and H.3 , and the list of present storage capacity of 5-10 Mm^3 in smaller reservoirs is situated in the northern part of the island. However the results for certain areas have been based only on estimates which should preferably be verified the soonest possible.

The following coefficients have been derived for the period 1970/73:

	R/P	R_p/P	Q_r/P
1970-71	0,32	0,26	0,17
1971-72	0,20	0,16	0,14
1972-73	0,29	0,24	0,11
Mean for 1971-73 (Mean years)	0,24	0,20	0,12

Adjusted surface-water balance for Gran Canaria

Year	1970/71		1971/72		1972/73	
Item	mm	Mm^3	mm	Mm^3	mm	Mm^3
P	435	677	300	468	304	474
Qp	74	115	42	66	32	49
Qo	48	75	30	48	18	28
ET	246	348	210	327	200	312
H	+ 1	+ 1	± 0	± 0	- 1	- 1
Rp	114	117	48	75	73	114
Rq	26	40	12	18	14	21
R	140	214	60	93	87	135

2. Groundwater Balance

An exhaustive study of the state of surface water balance has been made in the preceding subsection for the period 1970-1973. In this subsection an attempt is made to diagnose the variation of the annual storage factor in the different hydrological subunits taking into account of the groundwater extraction.

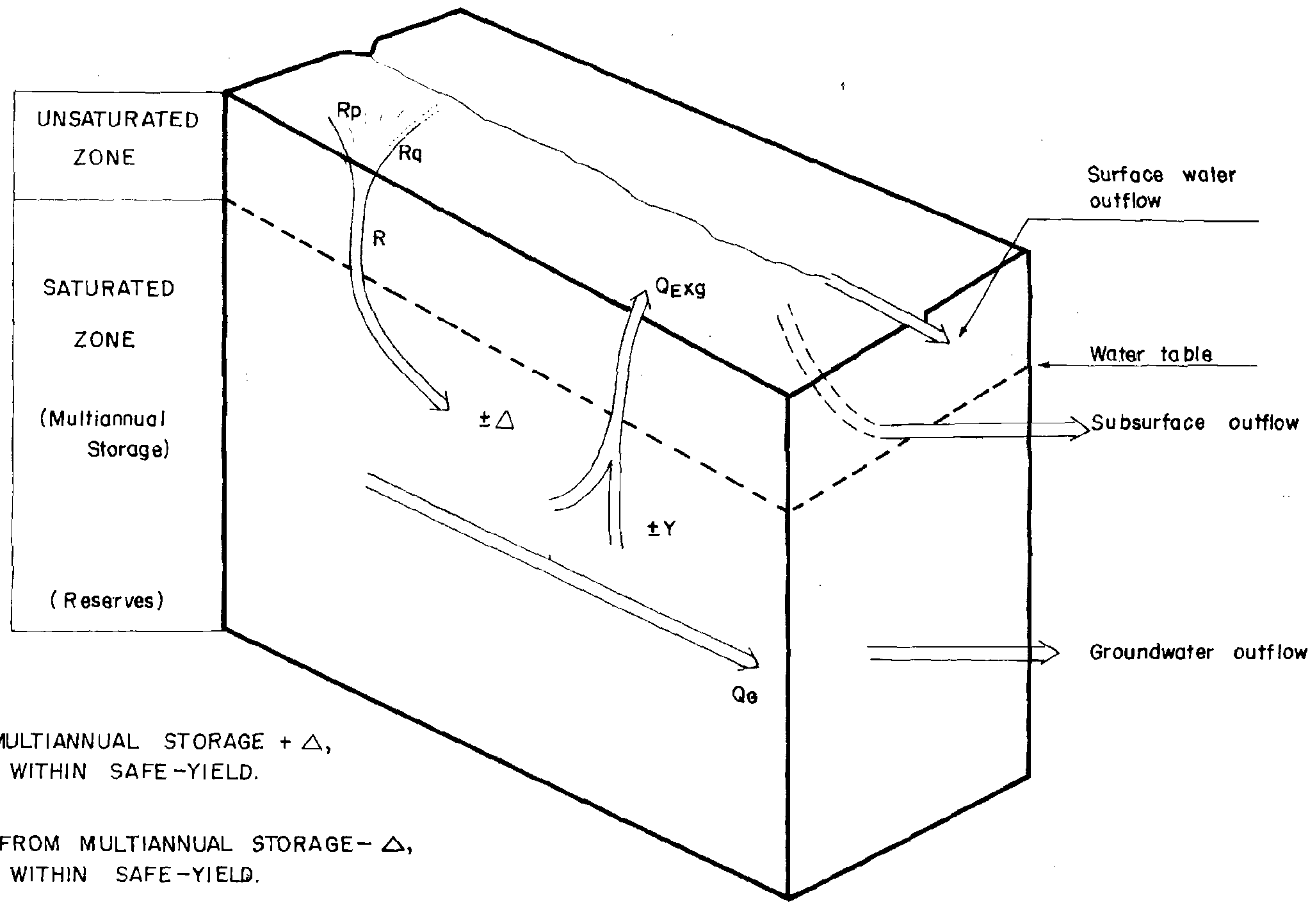
2.1 State of Annual Water Balance

A state of the annual water balance has been studied for the three water years 1970-71, 1971-72 and 1972-3. In fact the year 1970-71 has been similar to a tenth wet year whereas the two latter years were nearer to mean years as far as rainfall was concerned.

The state of the groundwater balance has been investigated following the scheme presented in Fig. H.2. The results according to the hydrological units, for the wet as well as for the average years are presented in Tables H.4, H-5. For the wet year figures of groundwater extraction obtained for 1968-69 were used whereas for the mean years the extraction figures were obtained from field data for 1971-1973.

For the mean year the calculated total recharge R was 79 mm equal to 123 Mm^3. Comparison with groundwater extraction shows that in zones 1 and 3 about 18,7 Mm^3 have been taken out of storage. In the case of zone 3 the deficit is entirely due to extraction from deep reserves confined to lower areas in Old Basalts. The detailed situation of the balance for the subunits is given in Fig. H.3 . In zone 4 the lower part also has an important deficit but probably is compensated by recharge in the upper part. In zone I, also subunit Ie around Arucas has an important deficit probably compensated by surplus in the neighbouring areas.

SCHEME FOR GROUNDWATER BALANCE



$+Y = R > Q_{Exg} < Q_G$ .... ENTRY INTO MULTIANNUAL STORAGE + Δ, EXPLOITATION WITHIN SAFE-YIELD.

$+Y = R < Q_{Exg} < Q_G$ .... WITHDRAWAL FROM MULTIANNUAL STORAGE − Δ, EXPLOITATION WITHIN SAFE-YIELD.

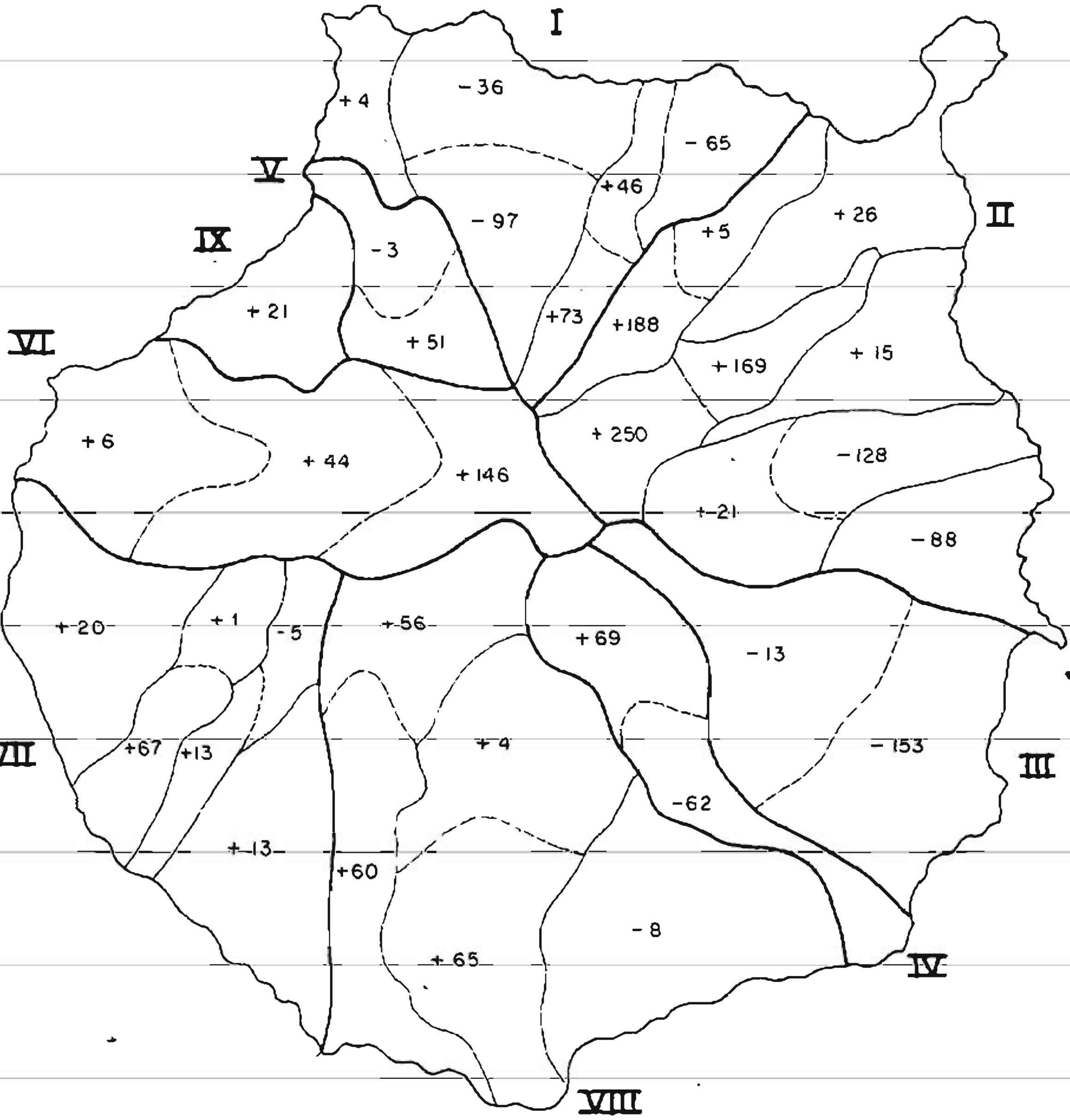
$-Y = R > Q_{Exg} > Q_G$ .... ENTRY INTO MULTIANNUAL STORAGE + Δ, EXPLOITATION DESEQUILIBRIUM.

$-Y = R < Q_{Exg} > Q_G$ .... WITHDRAWAL FROM STORAGE AND RESERVES, EXPLOITATION DESEQUILIBRIUM.

FIGURE H-2

WATER BALANCE

1971-72 and 1972-73 (Average years)



NOTE: All figures expressed in mm.

Deficit ares for period 1971-73

I - IX Hydrological zones

FIGURE H-3

GROUNDWATER
VOLUME VARIATIONS IN ANNUAL CYCLES
(Cl^- Balance)
GRAN CANARIA

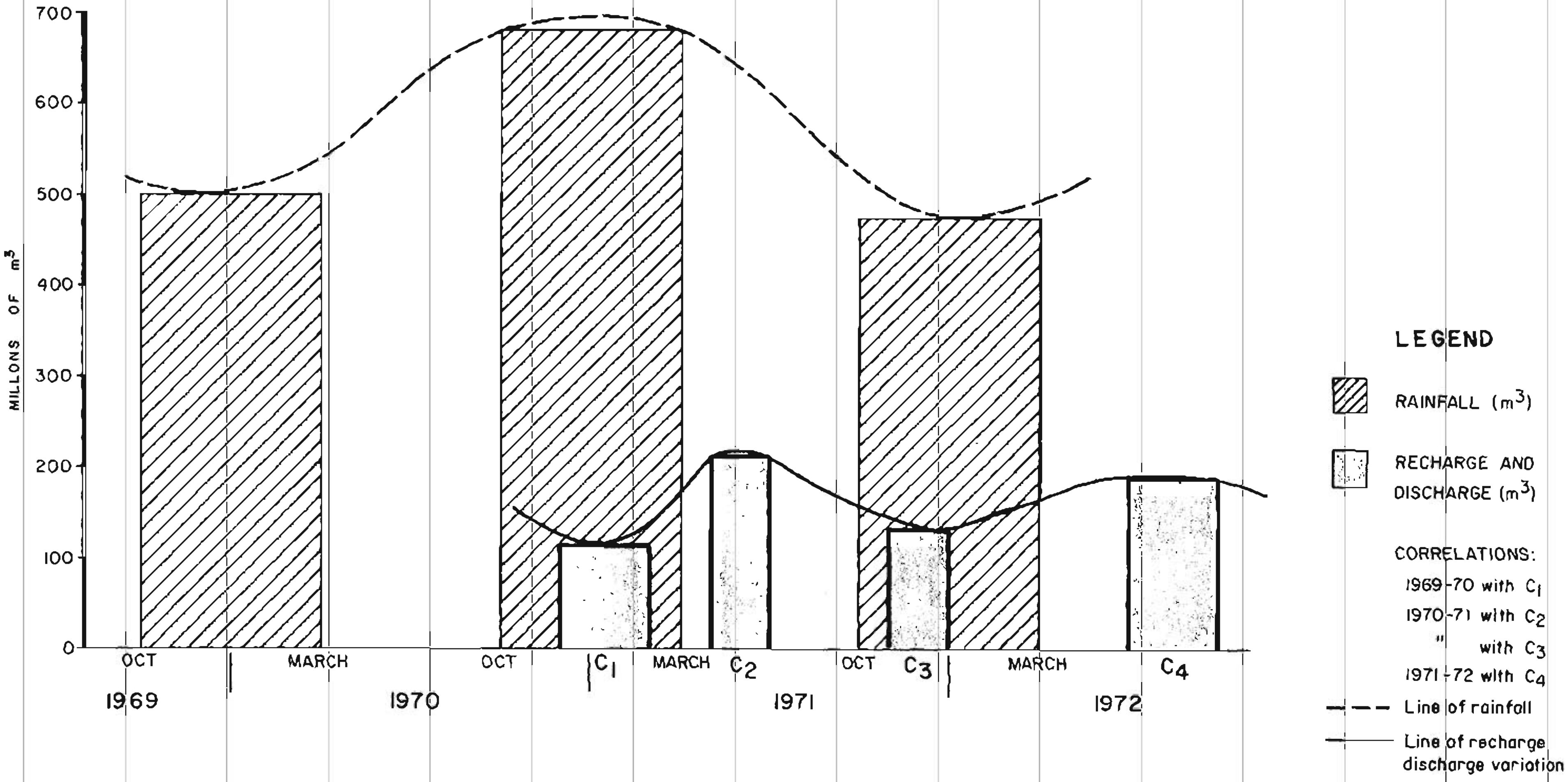


FIGURE H-5

If we consider the entire island there has been an entry into multi-annual storage of 39,2 Mm^3 , a withdrawal of 6,6 Mm^3 from storage and an overdraft of 12,2 Mm^3 from deep reserves, resulting in a net entry into storage of 20,4 Mm^3. During the mean water years 1971- 73 , the major part of the net entry into storage occurred in the southern part of the island in zones 6,7,8 and 9 accounting for a total of over 30 Mm^3/year. In this part of the island due to the existence of low permeable rocks, it is reasonable to formulate that large quantities of this volume returned to stream beds and were lost to sea through subsurface flow.

For the wet year 1970-71 the situation changes radically. Out of a total recharge of 218 Mm^3 the extraction was 121 Mm^3. The total entry into multi-annual storage was about 98 Mm^3 and only about 1,2 Mm^3 were withdrawn from storage giving a net entry of 96,6 Mm^3. Slight deficits were found in zones 1 and 5. However the situation in zone 3 has not changed , where in fact persists the large permanent deficit in the lower part,due to extraction from reserves. The subsurface outflow principally from the southern region can be estimated at about 50 Mm^3 which gives an entry into multi-annual storage of about 47 Mm^3 for the entire island.

The above analysis demonstrates that several dry years can generally be compensated by the high recharge occurring in wet years. However it must be born in mind that a mean year for the entire island may not necessarily represent average conditions for individual zones. If more rain falls in the southern sector, a good part of it will be lost by underflow as deep recharge will be very limited. It will be the opposite case in the North-East sector where deep infiltration and voluminous storage can occur.

2.2 Water Balance versus Groundwater Flow and Extraction

The Fig. H.2 presents a scheme of groundwater equilibrium conditions with reference to recharge, extraction and groundwater flow. In fact the groundwater level in any area will reflect the equilibrium situation attained between these three factors.

We can represent the changes in the multi-annual storage levels in the upper part of the saturated zone as follows:

$\pm \Delta = R - Q\ Ex$ where R= Annual recharge in Mm^3

$Q\ Ex$= Annual groundwater extraction in Mm^3

The equilibrium in extraction can be represented by:

$\pm Y = Q_G - Q\ Ex$ where Q_G = Groundwater flow rate Mm^3/year

$Q\ Ex$ = Annual groundwater extraction in Mm^3.

The combination of the two conditions will give us a number of favourable and unfavourable exploitable situations of which four are cited below:

(1) $+ Y = R > Q\ Ex < Q_G$

This will indicate a + Δ situation with entry into multi-annual storage of recharge waters and extraction of groundwater occurring within "safe yield" conditions defined for the present exploitation zone.

(2) $+ Y = R < Q_{Ex} < Q_G$

This indicates a $- \Delta$ situation and hence withdrawal from the annual storage system but groundwater extraction occurs within defined "safe yield" limits.

(3) $- Y = R < Q_{Ex} > Q_G$

Such a condition would indicate a $- \Delta$ situation and withdrawal from storage and reserves. This also implies that groundwater loss to sea along the exploited aquifer thickness is negligeable.

(4) - $Y = R > Q_{Ex} > Q_G$

This situation can occur in certain areas especially in coastal zones. If the captations extract only reserves, there is a possibility of loss to sea as a result of flow from multi-annual storage levels, but if the captations are well disposed in the upper levels this would constitute an ideal situation with little loss to sea.

The optimal exploitation situation is attained when extraction equals annual recharge, maintaining thereby the water levels and when the recharge of wet years enter integrally the multi-annual storage system and when outflow to sea is reduced to a minimum.

3. General Scheme of the Water Cycle

A complete picture of the water cycle, obtained through the study of surface and groundwater parameters as well as of water use is presented in Fig.H.4.

3.1 Interrelationship of the Principal Parameters

The situation as presented in the above figure depicts only average conditions represented by the last two water years. In arid zones, annual rainfall variation is a climatic characteristic and ground water recharge follows up very closely changes in the interannual rainfall regime.

There is an increase of evapotranspiration with higher rainfall but it is not proportional. Runoff depends mostly as said before on the intensity of the rainfall and the state of moisture in the soil. An important fraction of the increasing total rainfall in wet years profits groundwater recharge.

As for example the hydrologic year 1970-71 which had 44% higher rainfall (435 mm.) than mean years, had the following increases: 21% of evapotranspiration (246 mm.), 100% of runoff, (74 mm.) and 87% of direct recharge (114 mm.) from rainfall.

Compared to the mean water year, an appreciable increase in both surface and groundwater resources is noted for the wet years. It would be the opposite for dry years. This phenomenon must be taken into account in the future planning of water resources.

3.2 Estimation of Error Margins

In the utilization of various components of the water cycle it is necessary to consider the possible error margins of each of the main items.

Considering the high density of raingauges in the island, the error margin in the calculation of precipitations is estimated at ± 10%. However in the definition of the mean year it is necessary to admit an extra ± 5% since only 8 stations with long term records (30-45 years) were used for this purpose.

Runoff is a weak point due to the paucity of data and uncertainty of rating curves. An error margin of ± 20% is estimated for this parameter.

Evapotranspiration calculations are more reliable but the soil water retention capacity which form the basis of these calculations can carry large errors locally. About - 10% error is advanced for this parameter.

Recharge is calculated as a daily difference of the terms of the balance and about ± 20% of error is estimated in these calculations.

As for groundwater extraction, water consumption quantities for irrigation and domestic use, an estimated error of ± 10% is included.

3.3 Comments on Water Resources

One of the items to be studied in detail for optimal use of water resources as indicated earlier in this section is outflow. In the water cycle scheme, Q_L refers to surface water outflow and Q_G indicates groundwater outflow. Every year about 25 Mm^3 is stored in dams or diverted from stream beds. For a mean water year the loss to sea by direct runoff is about 18 Mm^3 occurring principally in the southern part of the island. This figure needs to be verified by measurement devices at present lacking.

With regard to groundwater, losses can occur both as subsurface outflow and aquifer outflow, the latter originating probably from multi-annual storage levels . From the water balance for an average year a groundwater loss of 20 Mm^3 was estimated. This possibly corresponds to the 17 Mm^3 of coastal outflow calculated earlier using groundwater hydraulic parameters. However in this volume is included a return flow component from irrigated zones of low quality water estimated at 8 to 10 Mm^3/year. Groundwater losses from deeper zones are difficult to estimate but 20 Mm^3/year of entry into storage perhaps would mean also outflow of an equal quantity from the multi-annual system. In the southern zone a major part of the infiltrated water seems to be lost by subsurface flow. For a mean year this can be estimated at about 20-30 Mm^3 and in a tenth wet year it could be double that amount.

The water cycle also shows an estimated reserve of about 3000 Mm^3 in the entire water massif of the island. Of this quantity about half seems to occur in the principal aquifers as multi-annual storage and the rest as deep reserves. The total figure has been obtained by several methods and would seem to indicate a stock of 20-25 years which would imply that the turnover period of the groundwater body of Gran Canaria could be around this period.

4. Water Balance with Cl^-

Starting from December 1970 up to September 1972, four chlorine measurement campaigns were carried out in the island of Gran Canaria, two during the winter season and two during the spring-summer season. On each occasion about 300 to 350 points covering the entire island, were sampled. Besides the Cl^- measurement "in situ", the conductivity, water temperature, water depth, were determined and general information on pumping was also obtained.

The main objective of these campaigns was to determine the possible variation of Cl^- with time and thereby obtain a dynamic salt balance if that was possible. It was also believed that an idea of annual infiltration could be obtained by the study of the dilution factor.

4.1 Cl^- change in annual cycles

The four Cl^- campaigns permitted a comparative study of the two water years 1970/71 and 1971/72. In order to facilitate such a comparison, two Δ Cl maps were prepared for each water year, see Maps H.5 and E.36.

Lines of maximum dilution in each water year coincided with the principal "barrancos" and maximum concentration with heavy pumping areas. These two pehnomena seem to occur mostly in the peripheral zones. In the central region of the island, there seems to occur a certain equilibrium as extreme Cl values are not found. The eastern coastal belt from south of Las Palmas going down to Tirajana alluvial fan is the most sensitive as far as chlorine change is concerned. In wet years, like in the case of 1970/71, the northern and southern coastal areas also show high dilution.

The study of the two annual cycles in our posession indicates firstly that maximum dilution occurs in spring-summer time and the minimum in winter, specially early winter. This would indicate that the infiltration occurring in autumn-winter seasons has a lag of 6-8 months. In fact, a corresponding effect, even though masked by pumping, seems to occur in the recuperation of measured water levels.

4.2 Methodology for Calculation of Infiltration

Taking into consideration the effect of the lag on chlorine dilution, it is possible to calculate the volume of water infiltrated during each water year.

In fact, the total infiltration in the case of the Canary Islands, would be the result of direct infiltration from rainfall and loss of run-off along water courses due to percolation phenomenon. The frequency and dilution lines along the major "barrancos" would indicate not only the preferential drainage of infiltrated water from high altitutes but also percolation on their lower courses.

The amount of Cl^- entering the soil can be expressed as follows:

(1) $$Cl_{In} = (1-Q)\, P . Cl_p$$

Cl_{In} = Cl^- entering soil

$(1-Q)$ = Infiltration coefficient (with Q runoff coefficient)

P = Rainfall in mm (1 cycle)

Cl_p = Cl^- concentration rainwater in mg/l.

And the recharge can be calculated by:

(2) $$R = (1-Q)\frac{Cl_p}{Cl_n} + \frac{r}{P \times Cl_n}$$

R = Recharge coefficient

r = Cl^- dissolved from soil and rock by water flowing to saturated zone.

Cl_n = Cl^- concentration in groundwater.

The term "r" would integrate effects of dust fallout and Cl^- content of rocks.

The total input in the case of Gran Canaria is around 0,6% equal to about 5 mg/l yearly input.

The term $\frac{r}{P \times Cl_n}$ is the negligeable and the formula becomes:

(3) $$R = (1-Q)\frac{Cl_p}{Cl_n}$$

In a pumping area exploiting principally the upper part of the aquifer and where infiltration is taking place continuously, the calculated volume increment R will give only a partial picture of the volume transfers if the extraction is not taken into account. If we admit this principle, the total infiltration calculated by this method can be expressed by :

(4) $$I = R.P + W$$

I = Infiltration in mm/year.
R = Recharge coefficient.
W = Water extraction due to pumping during the period.
P = Rainfall in mm/year.

The above formulas have been used for the calculation of total infiltration using the following correlations as shown in Fig. H.6 :

1. Correlation of Cl^- values of May-June 71 (C2) with annual rainfall of 1970/71.
2. Correlation of Cl^- values of July-September 72 (C4) with annual rainfall of 1971/72.
3. Correlation of Cl^- values of Dec. 70/Feb. 71 (C1) with annual rainfall of 1970/71.
4. Correlation of Cl^- values of Nov-Dec. 71 (C3) with annual rainfall of 1970/71.

The first two correlations would reflect the effect of infiltration at its maximum point and the latter two correlations the amount of water discharged out of the system with reference to the peak dilution periods.

4.3. Annual Infiltration Results

Information on annual rainfall , annual runoff, Cl^- contents of rainwater and groundwater as well as the computed values of infiltration for the 4 Cl^- campaigns are shown in Tables H.7 to H.10.

The following volume increments were obtained for the peak dilution periods for campaigns C2 and C4:

C2---------- 57^{mm} ($88,7.10^{6}m^{3}$) ..... Volume increase by dilution
77^{mm} ($120.10^{6}m^{3}$) ..... Volume of groundwater extracted during the period.
134^{mm} ($208,7.10^{6}m^{3}$) ----- Total volume increment.

Cl⁻ CYCLE AND SALT BALANCE - GRAN CANARIA

(Idealized section representing situation in the entire island)

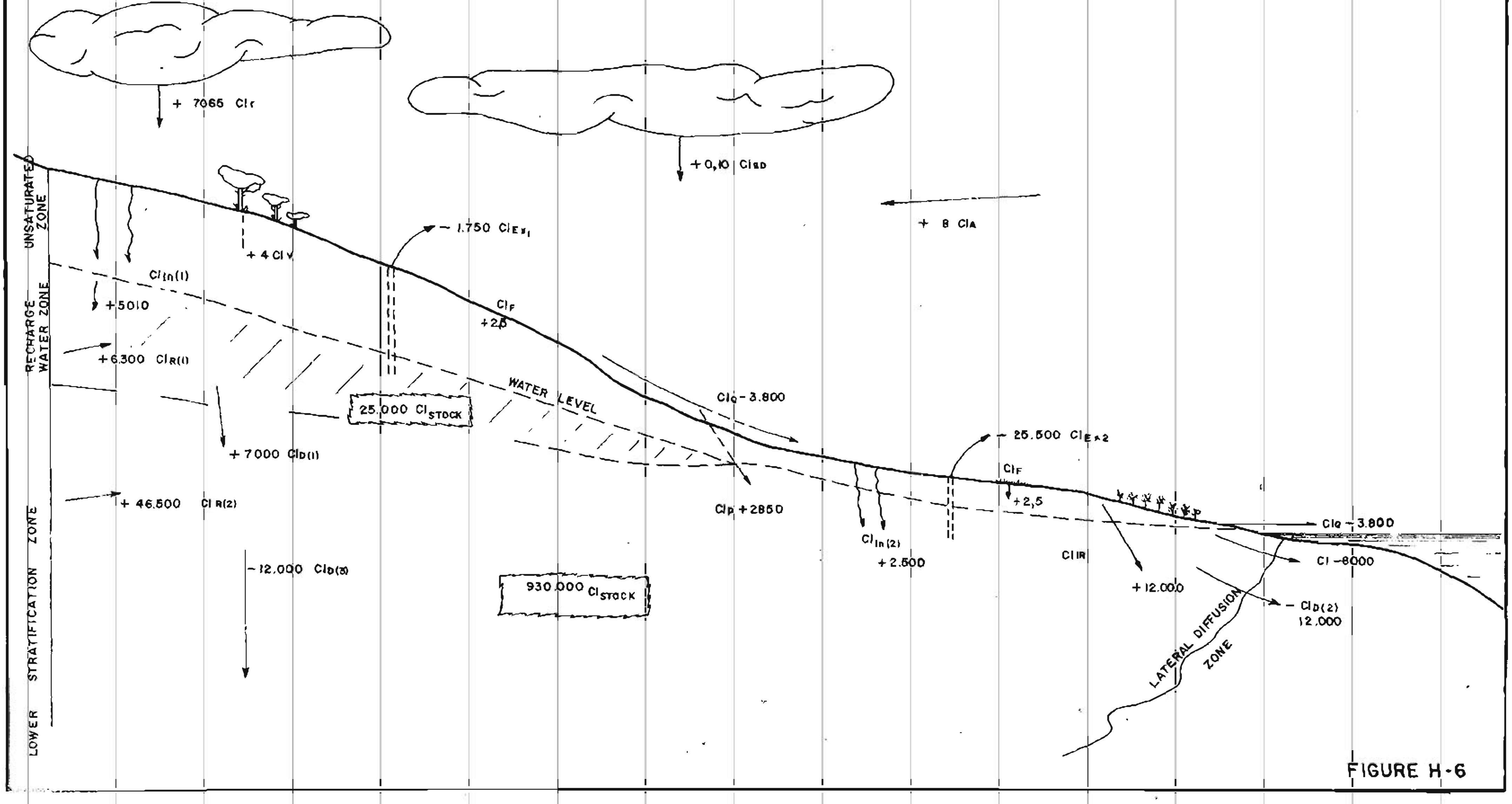


FIGURE H-6

Results of Cl^- balance C-1

Hydrogeological zone/sub-zone	Annual rainfall P(mm)	Annual runoff Q (mm)	Cl^- content in groundwater mg/l	Cl^- content rainwater mg/l	Value of total infiltration (without extraction. mm	m^3
1 a	175	0	495	13	4,6	109.000
1 b_L	350	0	427	13	10,6	492.000
1 b_H	650	0	109	13	77,5	3.586.500
1 C_L	475	0	157	13	39,3	623.400
1 C_H	855	0	45	13	247	3.915.000
1 d	375	0	276	13	17,7	605.800
ZONE 1	463	0	270	13	51	9.332.000
2 a_L	400	0	226	13	23	461.000
2 a_H	750	0	78	13	125	2.507.000
2 b_N	300	0	382	13	10,2	510.000
2 b_S	300	0	470	13	8,3	415.500
2 C_L	450	0	133	13	44	1.233.000
2 C_H	875	0	46	13	247,3	6.436.000
2 d_L	275	0	380	13	9,4	357.000
2 d_H	600	0	63	13	123,8	4.697.500
2 e	225	0	775	13	3,8	177.000
ZONE 2	417	0	337	13	53	17.294.000
3 L	150	0	1230	13	1,6	115.000
3 H	400	0	111	11	46,8	3.398.000
ZONE 3	275	0	670	13	24	3.514.000
4 L	175	0	368	13	6,2	273.000
4 H	570	103	66	13	92	2.066.000
ZONE 4	372	51	217	13	49	4.339.000

Results of Cl^- balance (cont.)

Hydrogeological zone/subzone	Annual rainfall P (mm)	Annual runoff Q (mm)	Cl^- content in groundwater mg/l	Cl^- content rainwater mg/l	Value of total infiltration (without extraction) mm	m^3
5 L	490	8	165	13	38	938.000
5 H	770	40	96	13	99	2.442.000
ZONE 5	630	24	130	13	68	3.380.000
6 L	225	22	805	13	3,3	195.500
6 M	300	90	398	13	6,9	409.000
6 H	550	55	90	13	71,5	4.254.000
ZONE 6	358	56	431	13	27	4.858.000
7 a	225	56	412	13	5,3	364.000
7 b_L	150	45	230	13	5,9	147.000
7 b_H	300	75	404	13	7,2	179.000
7 c_L	175	61	420	13	3,5	61.500
7 c_H	275	184	260	13	4,5	79.000
7 d	200	60	597	13	3	211.000
ZONE 7	217	69	437	13	5	1.042.000
8 a_L	250	35	647	13	4,3	230.000
8 a_H	430	120	124	13	32,5	1.728.000
8 b_L	150	22	702	13	2,8	170.000
8 b_H	325	130	120	13	21,1	1.293.000
8 c	225	45	500	13	4,7	444.000
ZONE 8	268	67	429	13	12	3.865.000
ZONE 9	375	130	436	13	11,2	469.000
Total for island	402	44	394	13	31	48.093.000
				Total for island with extraction	73	113.000.000

N.B. Averages are all weighted.

Table H.8

Results of Cl^- balance C-2

Hydrogeological zone/subzone	Annual rainfall P(mm)	Annual runoff Q(mm)	Cl^- content in groundwater mg/l	Cl^- content rainwater mg/l	Value of total infiltration (without extraction) mm	m³
1 a	161	0	249	13	8	199.179
1 b_L	345	21	241	13	17	808.980
1 b_H	733	53	51	13	173	8.017.646
1 C_L	549	27	101	13	67	1.065.080
1 C_H	1.028	81	30	13	410	6.504.485
1 d	393	31	139	13	34	1.160.600
ZONE 1	506	34	144	13	97	17.756.000
2 a_L	461	57	209	13	25	503.750
2 a_H	886	89	39	13	266	5.325.700
2 b_N	380	55	373	13	11	566.200
2 b_S	463	40	235	13	23	1.169.000
2 C_L	705	83	76	13	106	2.984.000
2 C_H	824	78	27	13	359	10.073.000
2 d_L	398	16	193	13	26	975.700
2 d_H	716	102	31	13	257	9.771.000
2 e	284	2	155	13	24	1.109.500
ZONE 2	523	52	161	13	101,5	32.480.000
3 L	285	8	488	13	7,4	535.500
3 H	447	15	82	13	68,5	4.968.300
ZONE 3	366	11	285	13	38	5.503.800
4 L	382	30	348	13	13	580.800
4 H	641	161	55	13	113,5	5.015.000
ZONE 4	511	95	201,5	13	63,3	5.600.00

Results of Cl^- balance (cont.)

Hydrogeological zone/sub-zone	Annual rainfall P(mm)	Annual runoff Q(mm)	Cl^- content in ground-water mg/l	Cl^- content rainwater mg/l	Value of total infiltration (without extraction) mm	m^3
5 L	361	4	88	13	52,7	1.303.000
5 H	567	19	64	13	111,3	2.749.000
ZONE 5	464	11	76	13	82	4.050.000
6 L	210	20	142	13	17,4	1.035.000
6 M	370	103	85	13	41	2.430.400
ZONE 6	397	55	95	13	62	11.065.000
7 a	305	61	305	13	25,6	1.748.000
7 b_L	334	105	334	13	30,4	751.000
7 b_H	382	95	382	13	41,5	1.026.000
7 C_L	308	118	308	13	10,4	181.000
7 C_H	371	177	371	13	13,5	235.600
7 d	305	119	305	13	9,7	671.000
ZONE 7	322	101	322	13	24	5.280.000
8 a_L	345	73	345	13	15	810.500
8 a_H	569	214	569	13	32	1.974.400
8 b_L	410	67	410	13	12,4	758.000
8 b_H	581	319	581	13	18,3	1.120.000
8 c	298	71	298	13	8,7	823.000
ZONE 8	425	141	425	13	19,5	6.310.000
ZONE 9	306	71	306	13	15,5	650.000
Total for island	435	74	244	13	57	88.700.00
Total for island with extraction					134	208.700.000

N.B. Averages are all weighted

Results of Cl^- balance C-3

Hydrogeological zone/sub-zone	Annual rainfall P(mm)	Annual runoff Q (mm)	Cl^- content in groundwater mg/l	Cl^- content rainwater mg/l	Value of total infiltration (without extraction) mm	m^3
1 a	161	0	304	13	6,9	163.300
1 b_L	345	21	368	13	11,5	529.700
1 b_H	733	53	65	13	136	6.289.000
1 c_L	549	27	174	13	39	618.000
1 c_H	1.028	81	47	13	262	4.152.000
1 d	393	31	259	13	18,2	623.000
ZONE 1	506	34	217	13	68	12.374.000
2 a_L	461	57	229	13	23	460.300
2 a_H	886	89	77	13	134,6	2.698.400
2 b_N	380	55	386	13	11	547.200
2 b_S	403	40	542	13	10	507.000
2 c_L	705	83	88	13	91	2.557.000
2 c_H	824	78	40	13	242,4	6.800.000
2 d_L	396	16	668	13	7,4	282.400
2 d_H	716	102	63	13	126,7	4.806.800
2 e	284	2	860	13	4,3	199.800
ZONE 2	523	52	391	13	58	18.858.000
3 L	285	8	1722	13	2,1	151.000
3 H	447	15	120	13	43,5	3.158.700
ZONE 3	366	11	920	13	23	3.309.600
4 L	382	30	457	13	10	442.000
4 H	641	161	78	13	80	3.536.000
ZONE 4	511	95	268	13	45	3.978.000

Results of Cl⁻ balance (cont.)

Hydrogeological zone/subzone	Annual rainfall P (mm)	Annual runoff Q (mm)	Cl^- content in groundwater mg/l	Cl^- content rainwater mg/l	Value of total infiltration (without extraction) mm	m³
5 L	361	4	130	13	35,7	881.900
5 H	367	19	66	13	108	2.666.500
ZONE 5	464	11	98	13	72	3.548.400
6 L	210	20	189	13	13	777.200
6 M	370	103	120	13	29	1.721.600
6 H	610	42	66	13	112	6.656.500
ZONE 6	397	55	125	13	51	9.155.000
7 a	305	61	210	13	15	1.031.000
7 b_L	334	105	218	13	13,7	338.000
7 b_H	382	95	105	13	35,5	879.300
7 C_L	308	118	284	13	8,7	151.000
7 C_H	371	177	84	13	30	522.000
7 d	305	119	487	13	5,0	345.000
ZONE 7	322	101	282	13	15	3.267.000
8 a_L	345	73	337	13	10,5	557.400
8 a_H	564	214	75	13	61,5	3.209.200
8 b_L	410	67	599	13	7,5	456.700
8 b_H	581	319	299	13	11,4	700.000
8 c	298	71	596	13	5	469.500
ZONE 8	425	141	412	13	17	5.452.000
ZONE 9	306	71	174	13	17,6	738.000
Total for island	435	74	356	13	39	60.680.000
Total for island with extraction					81	125.000.000

N.B. Averages are all weighted

Results of Cl^- balance C-4

Hydrogeological zone/subzone	Annual rainfall P (mm)	Annual runoff Q (mm)	Cl^- content in groundwater mg/l	Cl^- content rainwater mg/l	Value of total infiltration (without extraction) mm	m³
1 a	159	2	223	15	9	217.000
1 b_L	212	4	219	15	14	659.000
1 b_H	576	2	37	15	232,7	10.762.600
1 c_L	449	0	134	15	50	796.400
1 c_H	772	8	25	15	458,4	7.266.000
1 d	278	0	164	15	25,4	873.000
ZONE 1	349	2	139	15	113	20.573.000
2 a_L	318	2	215	15	22	442.000
2 a_H	654	5	42	15	232	4.647.000
2 b_N	282	10	367	15	11	555.000
2 b_S	295	8	367	15	11,7	587.000
2 c_L	483	5	98	15	73,2	2.053.000
2 c_H	767	26	24	15	463	12.990.000
2 d_L	210	0	364	15	8,7	328.300
2 d_H	493	3	32	15	229,7	8.716.700
2 e	167	0	537	15	4,7	218.500
ZONE 2	394	18	210	15	93	30.538.000
3 L	167	0	718	15	3,5	253.000
3 H	274	0	70	15	58,7	4.260.000
ZONE 3	221	0	394	15	31	4.513.000
4 L	180	16	390	15	6,3	278.500
4 H	364	64	76	15	59	2.618.000
ZONE 4	272	35	233	15	33	2.896.000

Results of Cl^- balance (cont.)

Hydrogeological zone/sub-zone	Annual rainfall P (mm)	Annual runoff Q (mm)	Cl^- content in groundwater mg/l	Cl^- content rainwater mg/l	Value of total infiltration (without extraction) mm	m^3
5 L	394	17	80	15	70,7	1.746.000
5 H	607	49	47	15	178	4.399.000
ZONE 5	500	33	64	15	124	6.145.000
6 L	247	39	424	15	7,4	438.000
6 M	363	137	210	15	16,2	961.000
6 H	616	128	50	15	146,4	8.712.000
ZONE 6	408	101	228	15	57	10.111.000
7 a	200	56	417	15	5,2	354.000
7 b_L	192	68	300	15	6,2	153.500
7 b_H	215	60	115	15	20,2	500.200
7 c_L	188	62	366	15	5,2	90.000
7 c_H	244	100	88	15	21	368.000
7 d	131	37	476	15	3,0	205.500
ZONE 7	180	56	359	15	8	1.671.000
8 a_L	210	47	383	15	6,4	339.300
8 a_H	326	153	87	15	29,8	1.585.400
8 b_L	164	9	482	15	4,8	295.000
8 b_H	276	117	120	15	19,9	1.216.000
8 c	105	7	451	15	3,3	309.000
ZONE 8	202	54	323	15	13	4.054.000
ZONE 9	471	220	163	15	13	963.300
Total for island	306	45	261	15	52,3	81.471.000
			Total for island with extraction		121	188.500.000

N.B. Averages are all weighted.

C4 ---------- 52^{mm} ($81,5.10^6 m^3$) ..... Volume increase by dilution
69^{mm} ($107.10^6 m^3$) ..... Volume of groundwater extracted during the period.
121^{mm} ($188,5.10^6 m^3$) ----- Total volume increment

If we compare the above results, with the respective rainfall figures, 1970/71 (435 mm) had an infiltration coefficient of 0,30 and 1971/72 (306 mm) 0,39. Thus, in spite of the lesser rainfall, there has been an increase in infiltration coefficient during the latter year. Also, it is possible that the effects of the wet year 70/71 were prolonged into the following year.

As said earlier the campaigns C3 and C1 were used to study the recession periods between peak dilutions. The following volume decreases were calculated for the campaigns C3 and C1:

C3 ---------- 39^{mm} ($60,9.10^6 m^3$) ..... Volume decrease by recession
42^{mm} ($65,0.10^6 m^3$) ..... Volume of groundwater extracted during the period.
81^{mm} ($125.10^6 m^3$) ----- Total Volume

C1 ---------- 31^{mm} ($48,1.10^6 m^3$) ..... Volume decrease by recession.
42^{mm} ($65.10^6 m^3$) ..... Volume of groundwater extracted during the period.
73^{mm} ($113.10^6 m^3$) ----- Total volume

These figures, in fact very similar for increment on the one hand and discharge periods on the other hand, show that there exists a certain annual equilibrium. However, the wet year 1970/71 indicates a higher carry-over. See Fig. H.6 for volume variations between 1969 and 1972.

Summing up we have the following comparative results:

1969-70 Decrease C1 (from origine) ---- $-77.10^6 m^3$?? with extraction ?

1970-71 Increase C1 to C2 -------------- $+96.10^6 m^3$ "

1971-72 Decrease C2 to C3 -------------- $-84.10^6 m^3$ "

1971-72 Increase C3 to C4 -------------- $+64.10^6 m^3$ "

($190.10^6 m^3$ increment assumed for 1969/70 summer)

Comparing these results we note that there is a certain tendency for attaining equilibrium in the discharge figures but a greater variation is found in the recharge figures. During the water year 1970/71, wetter than 1971/72, more recharge occured as is expected. The equilibrium tendency in the discharge figures is probably due to a constant underground diffusive discharge to the sea and a possible regulating capacity of the groundwater system in the upper areas.

Conclusions

A dynamic water balance with Cl^- shows large volume exchanges within the aquifer system. There is a tendency to even out rainfall differences by a regulating phenomena in groundwater flow, probably originated in the "cumbres" region of the island.

The actual mecanism of the volume variation may be due to a displacement effect originating in the "cumbres" zone even though direct infiltration in lower altitudes cannot be excluded. The infiltration coefficient calculated by this method for the period 1969-72 vary from 0,30 to 0,40.

5 Cl^- Cycle and salt balance

Introduction

Solute balance with Cl^- has the advantage over other chemical elements, of being influenced only to a lesser degree by ion exchange phenomena. This in fact permits the study of groundwater bodies using Cl^- as a pulse and estimate not only immediate changes due to infiltration but also study the turn over period of the system.

The solute balance for any chemical element can be written in the form of an inflow-outflow equation. In the case of the island of Gran Canaria, this equation takes the following form:

$$\Delta Cl_{stock} = Cl_{In} + Cl_{SD} + Cl_{A} + Cl_{V} + Cl_{R} + Cl_{p} + Cl_{F} - (Cl_{D}+Cl_{L}+Cl_{Ex}+Cl_{Q})$$

Cl_{In} = Cl^- brought into the system by infiltration from rainfall.

Cl_{SD} = Cl^- fallout from Sahara dust.

Cl_{A} = Cl^- content of aerosol.

Cl_{V} = Cl^- inflow from vegetation decay.

Cl_{R} = Cl^- input from rock decomposition.

Cl_{p} = Cl^- inflow through percolation.

Cl_{F} = Cl^- release from fertilizers.

Cl_{Q} = Cl^- outflow from runoff.

Cl_{D} = Cl^- outflow by diffusion to sea and to lower strata.

Cl_{L} = Cl^- outflow to sea through underflow.

Cl_{Ex} = Cl^- output from groundwater extraction.

The main items of the balance have been measured during a 2-year study period. As is seen from Table H.10 , the principal contributing

ESTIMATION OF SALT BALANCE ITEMS

Cl_R ... 15 mg/l Cl^- in rainwater for mean annual volume of $471.10^6 m^3$. Total - 7065 MT/year.

$Cl_{In(1)}$ ... 20mg/l Cl^- in infiltrating water for a volume of $250,5.10^6 m^3$. Total - 5010 MT/year.

$Cl_{In(2)}$ ... 20mg/l Cl^- in infiltrating water for a volume of $125.10^6 m^3$. Total - 2500 MT/year.

Cl_A ... 20 kilos/year/Km^2 of aerosol over 25% of the islands surface. Total - 8 MT/year.

Cl_{SD} ... 90 kilos/year of Cl^- measured in Sahara dust fallout.

Cl_V ... 100 grams/year/hectare from vegetation cover . Total 4 MT/ year.

Cl_R ... 15 mg/l of Cl^- release per year from weathered rocks to circu - lating waters. Total - 6.300 MT/year. Recharge Zone (R_i)
" - 46.500 " . Stratified Zone (R_2)

Cl_Q ... 40 mg/l of Cl^- for total runoff volume $95.10^6 m^3$/year. Total - 3500 MT/year.

Cl_p ... 50mg/l of Cl^- in percolation water for $57.10^6 m^3$/year. Total - 2850 MT/year.

Cl_F ... Total release from fertilizers estimated at 5 MT/year.

Cl_D ... $D_{(1)}$ Diffusion to lower zone with Cl^- 100 mg/l for volume $70.10^6 m^3$.
Total - 7000 MT/year.

$D_{(2)}$ Diffusion loss to sea estimated with 600 mg/l for $20.10^6 m^3$.
Total - 12.000 MT/ year.

$D_{(3)}$ Diffusion to lowest strata estimated with 600 mg/l for $20.10^6 m^3$.
Total - 12.000 MT/year.

Cl_L ... Subsurface loss to sea with 300 mg/l Cl^- for volume $20.10^6 m^3$.
Total - 6.000 MT/year.

Cl_{Ex} ... Ex(1) Extraction in Recharge Zone with 50 mg/l Cl^- for $35.10^6 m^3$.
Total - 1750 MT/year.

Ex(2) Extraction in lower Stratified Zone with 300 mg/l Cl^- for $40.10^6 m^3$. Total - 12.000 MT/year.

Extraction in lower Stratified Zone with 450 mg/l Cl^- for $30.10^6 m^3$. Total - 13.500 MT/year.

factors in the solute balance are rainfall, release from rock decomposition, extraction and outflow to sea. The principal items of the Cl^- cycle are shown in Fig. H.6.

Of the large quantities of Cl^- taken out of the ground annually through groundwater extraction, 50% is estimated as entrained by return water in the peripheral coastal irrigated areas, and 50% as retention in soil. The presence of return water, in fact explains the high Cl^- content of some areas even though sea water contamination is absent. It is assumed that 25% of the Cl^- extracted from groundwater is lost to the sea. In Fig. H.6, Cl_{IR} represents 50% of the total extraction Cl_{ex}.

For the sake of clarity, the consequent comportment of Cl^- of the extracted water is excluded from the solute balance.

5.1 Balance for Vertically Stratified Zones

In chapter 4, section E, a groundwater stratification scheme was suggested for the island of Gran Canaria. A parallel stratification also exists for Cl^- as shown in Fig. E.38.

In fact, the Recharge Water Lense corresponds to the top of the island with Cl^- content varying generally from 15 to 60 mg/l but some extreme values up to 100 mg/l are also found. The Stratified Core - zone found below the above level has a greater variation in Cl^- content, from 60 to 500 mg/l. The lowest part of the saturated zone, in the so called Basal Water zone found only about 50 to 100 m. above sea level, the Cl^- content varies from 500 to 1.500 mg/l or more. The fresh water - sea water interface is marked by a large diffusion zone with concentration varying 1.500 mg/l to 3000 mg/l and more of Cl^-.

If we accept this simplified scheme of stratification, the salt balance can be applied successively to each stratified level. Only the mean Cl^- content will be used for the salt balance and this will be limited to sea level, what occurs below this level being difficult to predict.

5.2 Recharge Water Lense

The Cl^- balance of the recharge zone expressed in tons per year can be written as follows:

$$\pm \Delta Cl = \left(Cl_{In(i)} + Cl_{SD} + Cl_A + Cl_V + Cl_F + Cl_{R(i)}\right) - \left(Cl_{D(i)} + Cl_{Ex(i)} + Cl_Q\right)$$

$$- 1225 = 11.325 \qquad -12.550$$

The existence of this deficit is due to extraction and hence the system can be considered at equilibrium state.

The rock volume of the water body in the recharge water lense is estimated at $32.10^9\ m^3$. If we assume a storativity of 2% for the circulating fraction of the stocked water, we have an equivalent volume of $640.10^6 m^3$. The mean concentration of Cl^- in this water body is about 45 mg/l which gives us a mobile Cl^- volume of 29.000 MT/year.

If we compare the inflow of 11.000 MT/year with the mobile volume we arrive at the conclusion that the water stocked in the recharge zone may comport a chemical equilibrium cycle of about 3 years only.

5.3 Lower Stratified Zone

This, in fact constitutes the principal water body of the island and a stratified system is developed with less mineralized waters on the top and more mineralized waters in the basal water zone near the sea level.

The Cl^- balance of this water body is influenced to a less extent by direct inflow from rainfall unlike in the recharge water lense above. In fact the main inflow will be by vertical diffusion from the above zone, percolation from runoff in the peripherical zones, deposition from aerosol and dust fallout, and release from rock decomposition. The outflow is mainly through lateral diffusion to sea or to lower levels, runoff, underflow and extraction.

The balance in this zone is limited to a water level of about 50m. above sea level, below which non-equilibrium chemical conditions due to mixing and contamination are bound to occur.

The total balance for this zone can be written as follows:

$$\pm \Delta Cl = \left(Cl_{In(2)} + Cl_{D(i)} + Cl_{p} + Cl_{F} + Cl_{R(2)}\right) - \left(Cl_{D(2)} + Cl_{D(3)} + Cl_{Q} + Cl_{L} + Cl_{Ex(2)}\right)$$

$$-450 = 58.850 \qquad -59.300$$

If we neglect the residual value, we can conclude that outflows equals inflow. But this pseudo-equilibrium is attained due to a high extraction figure, which makes us suspect that a larger amount is transferred by vertical diffusion than supposed.

The rock volume in this water massif is calculated at $620.10^9 m^3$. and the circulating volume of water at storativity 0,5% is about $3,1.10^9 m^3$. The mean Cl^- content of the zone is about 300 mg/l.

If we compare the inflow of 59.000 MT/year with the annual mobilized volume of 930.000 MT/year, we arrive at the conclusion that the chemical equilibrium cycle in this zone may be around 15 years. For areas around the coastal belt at 600-700 mg/l of Cl^- where equilibrium conditions exist, the chemical turnover period may be between 20-30 years or more.

5.4 Conclusion

The analysis of groundwater body of the island of Gran Canaria through Cl^- solute balance reveals a state of equilibrium in the recharge water zone and of desequilibrium in the lower stratified zone, the latter probably due to the lack of a precise idea of outflow through vertical diffusion.

The comparison of annual input of Cl^- with the mobile annual volume indicates that the waters in the recharge zone represent a stock of only 3 years whereas in the main water body the lowest zone indicates a 15-year equilibrium cycle for a mean concetration of 300 mg/ l and perhaps 20-30 years for the coastal periphery.

Several maps of Cl^- concentration made for the island show a re-establishment of stable conditions in winter months, dilution effect occurring only in summer time. This would indicate that the different concentrations under normal conditions are acquired by equilibrium flow.

Under such a case, infiltration water from the top of the island, flowing through the aquifer system under undisturbed conditions, will acquire corresponding concentrations in a time-scale similar to ones calculated by the solute balance.

If this conclusion is valid, the "turn-over" period of the entire water massif of the island of G. Canaria is about 20-30 years. This is in agreement with the dating of groundwater realized through tritium analyses where the major part of the groundwater body of the island has very low values corresponding to injection a few years before 1953.

CORRELATION TOTAL ISLAND RAINFALL VERSUS STATION HOYA DEL GAMONAL

(1949/50 – 1972/73)

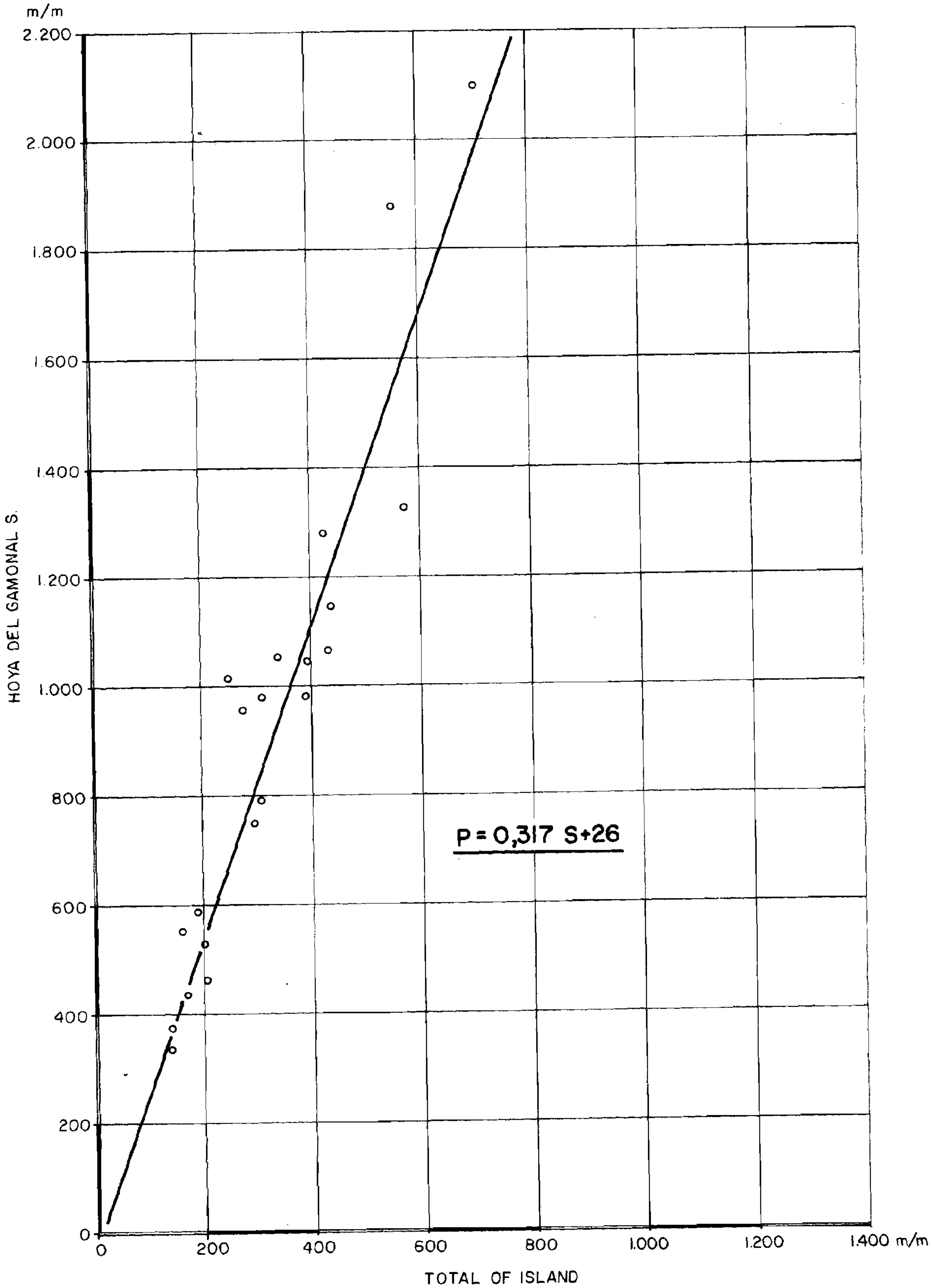


FIGURE H-7

6 Multiannual Groundwater Balance

The study of the groundwater balance for a short period gives only an appreciation of a particular situation referring to the period. A better understanding of the aquifer comportment can be obtained, if the historical evolution can be traced.

The lack of longterm basic data makes this task very hazardous. However some do exist and using certain refinements and assumptions, a diagnosis of historical aquifer behaviour can be obtained.

Methodology for Total Recharge Estimation

The only long-term source of information available for such an investigation is rainfall of a few stations with available data from 1924 up to now. For a large number of stations data are available for 1949/50 up to now, permitting the calculation of the islands rainfall by isohyetal maps.

Several correlations were done between the few longterm stations and the islands rainfall for the period 1.949/50 to 1.971/72 and finally station Hoya del Gamonal was chosen to extend backwards the island's rainfall since the guaranty offered by a correlation coefficient of 0,95 was judged adequate. The islands rainfall can be expressed by:

$$P = 0,317\ S + 29$$ (see Fir. H.8 and Table H.12)

where P = islands rainfall in mm/year
S = rainfall of station Hoya del Gamonal in mm/year.

The extension and extrapolation of the islands rainfall for the entire period 1924/25 up to 1972/73 are shown in Fig. H.8.

VARIATION OF ISLANDS RAINFALL

(1924-25 to 1972-73)

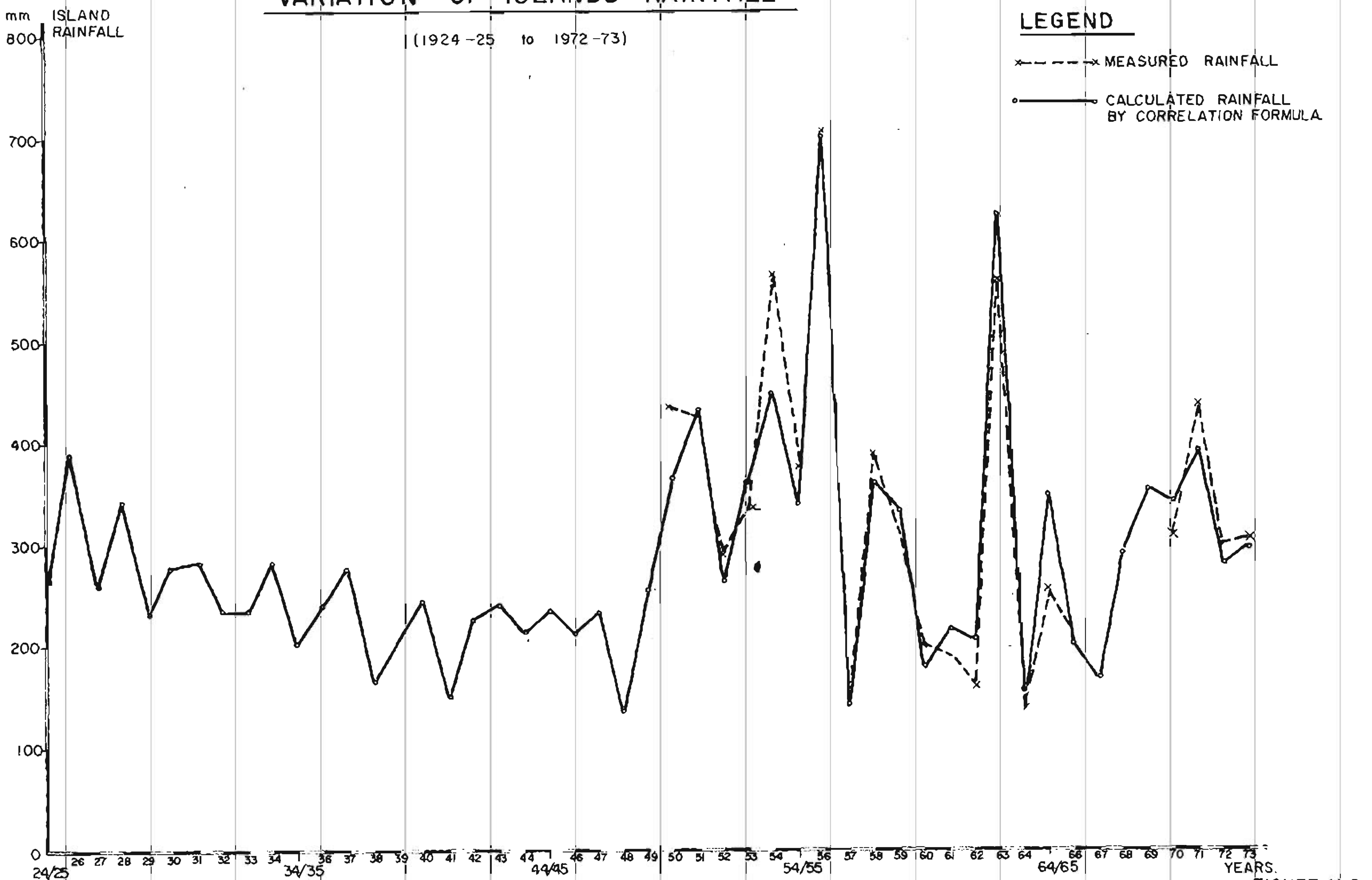


FIGURE H-8

Table H.12

CORRE TION RAINFALL OF ISLAND VERSUS RA ALL STATION HOYA GAMONAL

YEAR	Rainfall Island P mm	Rainfall Hoya Gamonal S mm	P - P_o	S - S_o	$(P-P_o)^2$	$(S - S_o)^2$	$(P-P_o) \times (S-S_o)$
1949/50	430	1.058	+ 104,3	+ 121,6	10.878,49	14.786,56	12.682,88
50/51	426	1.285	+ 100,3	+ 348,6	10.060,09	121.521,96	34.964,58
51/52	293	752	- 32,7	- 184,4	1.069,29	34.003,36	6.029,88
52/53	337	1.057	+ 11,3	+ 120,6	127,69	14.544,36	1.362,78
53/54	566	1.325	+ 240,3	+ 388,6	57.744,09	151.009,96	93.380,58
54/55	382	969	+ 56,3	+ 32,6	3.169,69	1.062,76	1.835,38
55/56	706	2.104	+ 380,3	+1167,6	144.628,09	1.363.284,70	444.038,28
56/57	145	343	- 180,7	- 593,4	32.652,49	352.123,56	107.227,38
57/58	386	1.050	+ 60,3	+ 113,6	3.636,09	12.904.96	6.850,08
58/59	267	962	- 58,7	+ 25,6	3.445,69	655,36	1.502,72
59/60	201	461	- 124,7	- 475,4	15.550,09	226.005,16	59.282,38
60/61	189	586	- 136,7	- 350,4	18.686,89	122.780,16	47.899,68
61/62	158	556	- 167,7	- 380,4	28.123,29	144.704,16	63.793,08
62/63	553	1.879	+ 227,7	+ 942,6	51.847,29	888.494,76	214.630,02
63/64	137	375	- 188,7	- 561,4	35.607,69	315.169,96	105.936,18
64/65	251	1.017	- 74,7	+ 80,6	5.580,09	6.496,36	6.020,82
65/66	201	533	- 124,7	- 403,4	15.550,09	162.731,56	50.303,98
66/67	166	439	- 159,7	- 497,4	25.504,09	247.406,76	79.434,78
69/70	310	980	- 15,7	+ 43,4	246,49	1.883,56	681,38
70/71	435	1.147	+ 109,3	+ 210,6	11.946,49	44.352,36	23.018,58
71/72	300	787	- 25,7	- 149,4	660,49	22.320,36	3.839,58
	6.839 Po=325,7	19.665 So=936,4	o	o	476.714.69	4248.247,70	1.364.715,00

$$R = r \times \frac{\sigma Po}{\sigma} = 0,3349$$

$$(P-Po) = (S-So)\ R$$

$$P = 0,317\ S + 29$$

$$r = \frac{\Sigma (P-Po)(S-So)}{\sqrt{\Sigma (P-Po)^2\ \Sigma (S-So)^2}} = \frac{1.346.715}{1.423.100} = 0,946$$

$$\frac{\sigma Po}{\sigma} = \sqrt{\frac{\Sigma (P-Po)^2}{\Sigma (S-So)^2}} = 0,33495$$

The adjusted rainfall series was found to fit a Galton's distribution frequency law which permits us to calculate the rainfall frequency for the entire island.

Total recharge (R), which is the sum of the infiltration fraction from rainfall and percolation of runoff, has been calculated from observed data for the last 3 water years. The frequential comparison of these 3 years and the relation R/P showed that recharge behaves similar to rainfall. A check has been made on calculated runoff and recharge as seen in section D for one basin in the north and another in the south, and the results showed that a certain correlation exists between total recharge, and rainfall but recharge is a little less for wet years and a little more for dry years. The estimated frequential curve for recharge is seen in Fig. H.10 .

With the aid of this curve the reconstitution of historical recharge has been made for the entire period 1924/25 to the present day and the cumulative values are shown in Fig. H.11 .

Estimation of Historical Extraction

The main source of information on historical discharge of springs and captations is obtained from statistical figures of extraction capacity published by the Ministry of Industries .

The curve as represented in Fig. G.3 has been corrected for the maximum extraction period by a factor of 75% to obtain figures which seem nearer the truth. The estimated cumulative extraction is also shown in Fig. H.11 .

Variation of Inflow-Outflow Balance

The comparison of inflow from total recharge and outflow from extraction and spring discharge gives us the state of the residual

GALTON DISTRIBUTION OF THE ISLAND'S RAINFALL AND ESTIMATED TOTAL RECHARGE

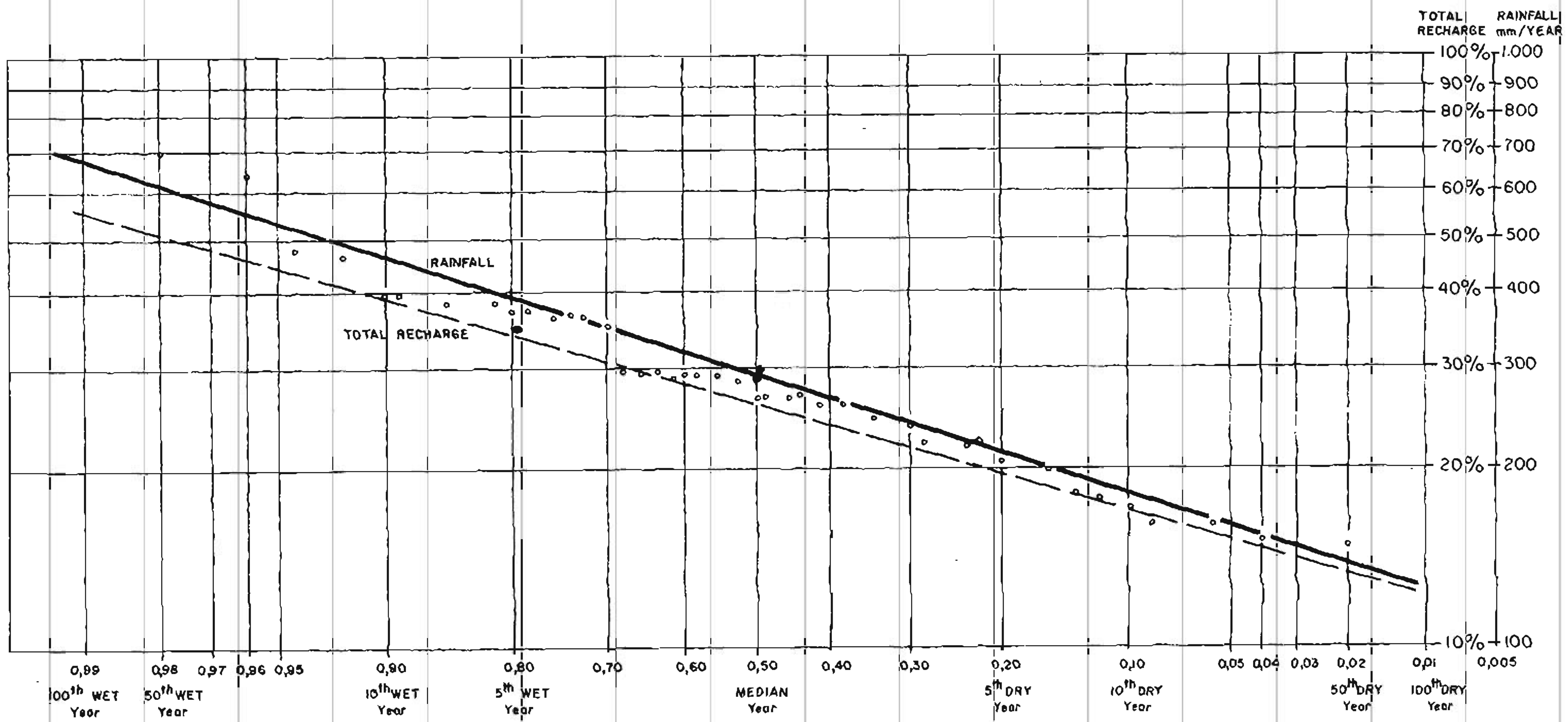
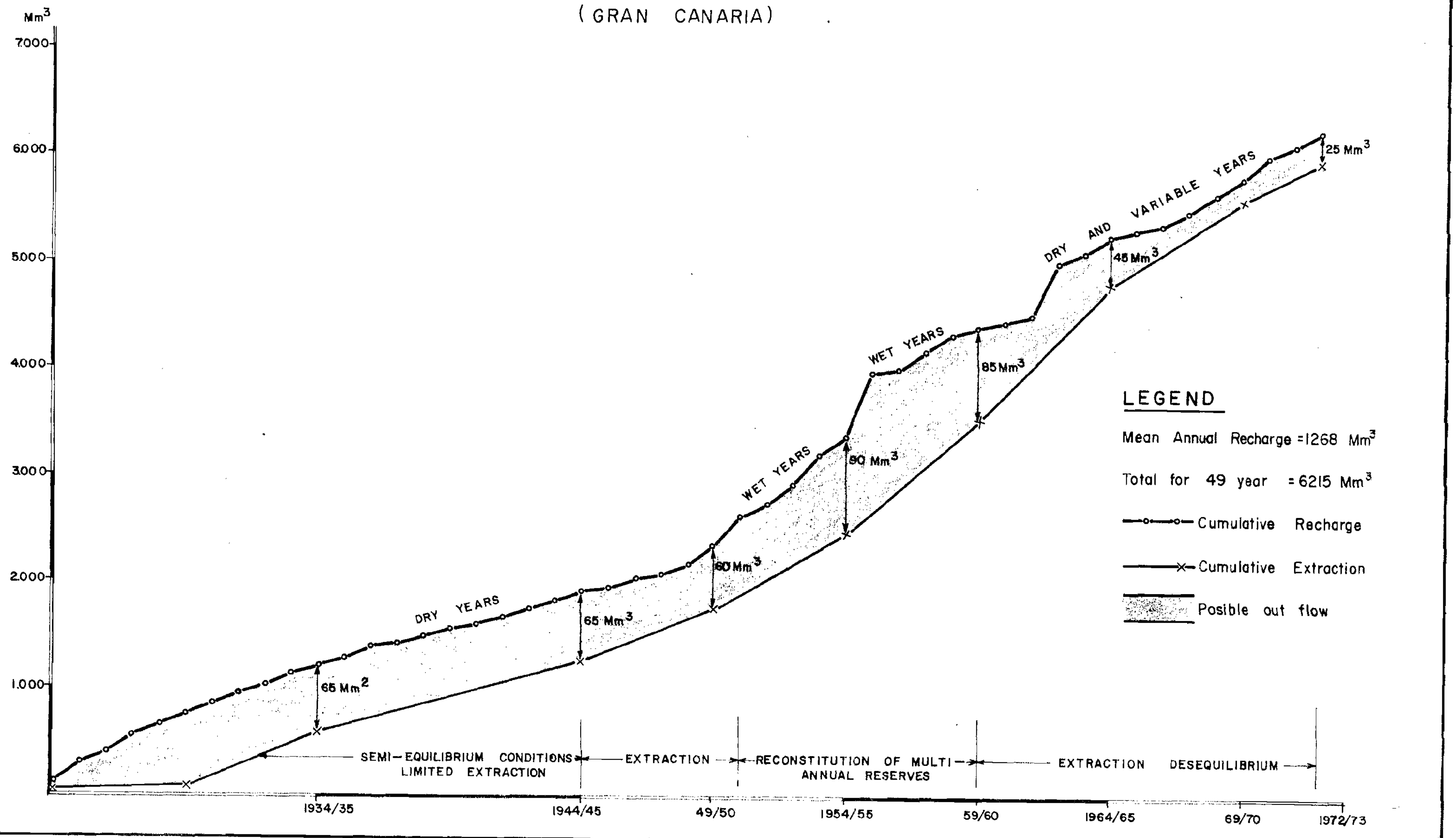


FIGURE H-9

FIGURE H-10

MULTIANNUAL VARIATIONS OF GROUND WATER INFLOW - OUTFLOW BALANCE

(GRAN CANARIA)



volume, of which the larger part is assumed to represent outflow to sea. The Fig. H.10 gives us precisely a notion of the variation of this outflow component to the sea.

The correct interpretation of the historical tendencies of this outflow, needs a knowledge of the original equilibrium conditions before the starting of wells or galleries. We know however that by 1924, there existed in the island around 50 to 100 motor-driven wells, 200 to 300 wind-powered wells and 10 to 20 galleries. Also it was noted that the total spring discharge in 1924 was only about 65% of that registered in 1870.

The outflow to sea up to about 1944/45 maintained at a level of about 65 Mm^3/year, which would represent a semi-equilibrium state of the island's aquifer. From 1944/45 to 1950/51 there has been a very heavy extraction represented in the latter year by 1430 wells and 237 galleries. The subsequent wet period reconstituted the multiannual resources, and that inspite of the high groundwater production. From 1959/60 up to the present the accumulated reserves have been used up with a gradual decrease of outflow from 85 Mm^3 to about 25 Mm^3 to the present day. The last 2 years have also seen a sharp drop in the production of groundwater by about 15%. The latter figure is comparable to the 18 Mm^3 calculated with hydraulic parameters as outflow in coastal zones at the present moment.

An attempt to check on the hypothetical equilibrium-state has been made by the construction of a steady-state model using theoretical recharge figures of about 175 Mm^3/year and known spring yield of 59 Mm^3 (for 1870) which gives us an outflow to sea of 116 Mm^3. These results even though rough confirm that in 1924/25 the aquifer system was under semi-equilibrium conditions and that on the whole, the discharge to sea has gradually diminished to the present station.

Incidently the total recharge entering the system for a period of 49 years has been 6.215 Mm^3 which gives us 126 Mm^3/year or 81 mm/year.