The result shows that water quality parameters in Tarapacá River is not so good, especially B, As and Fe. However, information is limited to only this river, supplementary observation on the other rivers was done, as explained in the latter section, for the evaluation of water quality in the whole basin.

3.3.3 Supplementary Observation

1) Objective

The purposes of the observation are to measure flow rate and examine water quality in the whole basin for the estimation of available water resources.

2) Location

Observation points are located as follows:

Location	Code	Latitude	Longitude
1. Aroma	AR-1	19° 37′	69° 31′
2. Tarapaca	TR-1	19° 55′	69° 30′
3. Quipisca	QP-1	20° 00′	69° 11′
4. Sagasca	SG-1	20° 11′	69° 20′

Location of these points are shown in Fig. A, 3.2 and A, 3.3.

3) Observation Method

The measurement was conducted by JICA Study Team & DGA. River conditions during the measurement are shown in Appendix A, 3.3. The items of measurement are as follows;

(1) Flow Rate

Flow velocity was measured by a propeller current meter across the river section at a length interval of about 1/10th of the river width. Flow rate was calculated as the product of average velocity times cross sectional area

$$Q = \sum_{i=1}^{m} V_i \times A_i$$

where Q = flow rate (m^3/s),
V = flow velocity (m/s),

A = cross sectional area of the river (m^2) and
m = number of sub-cross sections.

(2) Water Quality

Samples were taken from the checking points and analyzed mostly in the DGA laboratory following the standard method of water quality analysis. However, pH, EC, Temperature, Turbidity and DO were analyzed in situ. Items of the analysis are classified as follows;

(i) Health Significance : As, Cd, Cr, CN, F, Pb, NO_3

(ii) Aesthetic Quality : Al, Cl^-, Cu, $CaCO_3$, Fe, Mn, Na, SO_4, TDS, Zn, pH

(iii) Others : HCO_3, CO_3, Ca, Mg, K, B, E.C. Temperature, Turbidity, DO

4) Date of Observation

Observation was carried out on 7^{th} - 10^{th} October, 1993

5) Results of Observation

(1) Surface Flow Rate

Flow rate at each points is shown in Table A, 3.5.

Flow rate in Tarapacá River, measured by JICA Study Team is found to be lower than average flow rate obtained from DGA's record during October and November, 199__ probably due to the less precipitation in the upstream than usual.

(2) Water Quality

Results of the examination is shown in Table A, 3.6.

- Aroma is the most contaminated river in the basin in terms of health significance, aesthetic quality and other.

- Sagasca is also a contaminated river in terms of aesthetic quality and other.

- Tarapacá and Quipisca are clean in comparison with Aroma and Sagasca but some items such as B, Ca, Mg, K, etc., are still higher than the standard limit.

Table A, 3.1 Drainage Basin and Sub-Basin Areas in Pampa del Tamarugal Basin
<Cuenca de Drenaje y Area Sub-cuenca en Cuenca del Pampa del Tamarugal>

River/ Quebrada	Sub-Basin (km2)		Total Basin (km2)
Aroma		1,745.6	1,745.6
Tarapaca Upstream of Mina San Juan	1,503.6		
Tarapaca Downstrream of Mina San Juan	212.7	1,716.3	3,461.9
Quipisca		845.6	4,307.5
Juan Morales (or Sagasca)		970.6	5,278.1
Quisma (or Pica)		297.5	5,575.6
Chacarilla		1,221.3	6,796.9
Ramada		244.4	7,041.3
Cahuisa		393.1	7,434.4
Total River Basin			7,434.4
Residual Basin		10,570.6	
Total Pampa del Tamarugal Drainage Basin Area			18,005.0

Table A, 3.2 Average, Maximum and Minimum Surface Flow Rate in Pampa del Tamarugal Basin

<Promedio, Tasa de Flujo de Superficie Maximo y Minimo en la Cuenca del Pampa del Tamarugal>

(Max. and Min. are the maximum and minimum of average values in a month of the recorded years, not instantaneous values)

Unit : m^3 /s

River	Location	Obs. Period	AVG	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG
Tarapaca	Mina San Juan	1984-1990	Max.	0.752	0.933	1.070	0.306	0.460	0.490	0.471	0.417	0.395	0.258	0.202	0.436	0.516
			Avg.	0.316	0.438	0.429	0.245	0.311	0.329	0.363	0.324	0.276	0.212	0.159	0.229	0.303
			Min.	0.145	0.191	0.087	0.148	0.21	0.265	0.257	0.23	0.224	0.185	0.082	0.125	0.179
Coscaya	Saitoco	1985-1990	Max.	0.417	0.230	0.146	0.149	0.148	0.168	0.175	0.157	0.135	0.125	0.127	0.180	0.180
			Avg.	0.192	0.166	0.135	0.123	0.128	0.134	0.145	0.138	0.127	0.104	0.101	0.123	0.135
			Min.	0.116	0.119	0.118	0.109	0.094	0.118	0.12	0.119	0.114	0.076	0.053	0.092	0.104
	Pampa Lirima	1977-1989	Max.	0.544	0.992	0.369	0.253	0.297	0.343	0.290	0.218	0.236	0.168	0.142	0.154	0.334
			Avg.	0.189	0.244	0.199	0.167	0.174	0.171	0.171	0.151	0.158	0.128	0.117	0.111	0.165
			Min.	0.068	0.113	0.108	0.125	0.112	0.045	0.056	0.057	0.106	0.091	0.078	0.029	0.082

Table A, 3.3 Average Runoff Coefficient in Pampa del Tamarugal Basin
<Coeficientes de Escorrentias Promedios en la Cuenca de Pampa del Tamarugal>

Location : **Tarapaca River at Mina San Juan**

Rainfall Range (mm)	Average Rainfall R (mm)	Total River Basin (km2)	Upstream Basin of Mina San Juan A (km2)	Average R*A (mm.km2)	Upstream Avg. Rainfall R (mm) (R*A/A)	Flow Rate at Mina San Juan Q (m3/s)	Runoff Coefficient f (= Q/R*A)	Upstream Average Altitude H (m, msl)
0.0 - 10.0	5.0	354.47	141.79	708.95		0.303		
10.0 - 50.0	30.0	281.74	281.74	8,452.13				
50.0 - 100.0	75.0	199.77	199.77	14,982.41				
100.0 - 150.0	125.0	321.47	321.47	40,183.75				
150.0 - 200.0	175.0	327.14	327.14	57,250.20				
200.0 - 250.0	225.0	166.16	166.16	37,386.00				
250.0 - 300.0	275.0	65.55	65.55	18,026.25				
300.0 - 350.0	325.0	0.00	-	-				
> 350.0	-	-	-	-		(m3/year)		
		1,716.30	1,503.62	176,989.68	117.71	9,555,408	0.054	2,905

Note :
- Average basin rainfall is calculated from Average Annual Precipitation Map (Isohyetal Map) by DGA in 1987
- Flow rate is obtained from monthly data observed by DGA
- Upstream average altitude of the station is obtained by averaging the altitude of the rainfall stations located in the upstream basin of that station

Table A, 3.4 Average Water Quality Observed by DGA in Pampa del Tamarugal Basin

<Calidad Promedio de Agua Observada por DGA en la Cuenca del Pampa del Tamarugal>

River	Location	pH	E.C (mh/cm)	CO_3 (mg/l)	HCO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	B (mg/l)	As (mg/l)	Cu (mg/l)	Fe (mg/l)	$N\text{-}NO_3$ (mg/l)	$N\text{-}NO_2$ (mg/l)	P (mg/l)	$N\text{-}NH_3$ (mg/l)
Quebrada	Mocha	7.68	1,602	3.850	201.3	189	364	93.7	28.3	18.6	224.1	5.07	0.080	0.083	2.89	0.088	6.100		
Tarapaca	Pachica	7.84	1,706	2.633	198.4	199	401	106.9	27.9	21.9	220.1	7.26	0.072	0.025	1.38	0.185	0.002	0.163	0.063
Coscaya	Pampa Lirima	7.51	772	0.000	86.4	81	203	50.4	13.4	15.7	83.6	2.93	0.207	0.023	0.76	0.071	0.003	0.123	0.238
Permissible Value		6.0 - 8.5				250	250		125.0				0.050	1.000	0.30	10.000			

Table A, 3.5 Surface Flow Rate Observed on 10th October 1993 in Pampa del Tamarugal Basin
<Nivel de Flujo de Superficie Observado entre el 10 de Octubre de 1993 en la Cuenca del Pampa del Tamarugal>

River	Location/ Quebrada	Average Velocity (m/s)	Cross-section Area (m2)	Flow Rate (m3/s)	Remarks
Aroma	Aroma	0.42	0.135	0.057	
Tarapaca	Tarapaca	0.52	0.167	0.087	including 2 irrigation canals
Quipisca	Quipisca	0.36	0.017	0.006	
Sagasca	Sagasca	0.10	0.014	0.001	

Table A, 3.6 (1) Water Quality Observed on 10th October 1993 in Pampa del Tamarugal Basin
<Calidad de Agua Observado entre el 10 de Octubre 1993 en la Cuenca del Pampa del Tamarugal>

River	Code	Health Significance						
		As (mg/l)	Cd (mg/l)	Cr (mg/l)	CN (mg/l)	F (mg/l)	Pb (mg/l)	NO3 (mg/l)
Aroma	AR-1	1.764	0.002	0.02	0.00	1.810	0.02	0.200
Tarapaca	TP-1	0.041	0.004	0.01	0.00	1.310	0.02	0.040
Quipisca	QP-1	0.022	0.003	0.01	0.00	1.130	0.02	0.139
Sagasca	SG-1	0.176	0.050	0.07	0.00	5.100	2.00	0.000

Table A, 3.6 (2) Water Quality Observed on 10th October 1993 in Pampa del Tamarugal Basin
<Calidad de Agua Observado entre el 10 de Octubre 1993 en la Cuenca del Pampa del Tamarugal>

River	Code	Aesthetic Quality										
		pH	CaCO3 (mg/l)	Cl (mg/l)	SO4 (mg/l)	Na (mg/l)	Zn (mg/l)	Al (mg/l)	Cu (mg/l)	Fe (mg/l)	Mn (mg/l)	TDS (mg/l)
Aroma	AR-1	8.40	470.5	1,471.6	490.0	772.8	0.025	0.5	0.032	0.33	0.19	3,015
Tarapaca	TP-1	8.15	705.8	391.7	912.6	418.6	0.027	0.6	0.026	0.13	0.04	2,280
Quipisca	QP-1	8.82	213.0	84.0	269.0	174.8	0.035	2.5	0.021	0.10	0.48	818
Sagasca	SG-1	3.90	926.5	277.6	4,034.5	340.4	16.000	190.0	35.800	956.00	727.00	6,835

Table A, 3.6 (3) Water Quality Observed on 10th October 1993 in Pampa del Tamarugal Basin

<Calidad de Agua Observado entre el 10 de Octubre 1993 en la Cuenca del Pampa del Tamarugal>

River	Code	Others									
		Temp (C)	EC (mh/cm)	CO3 (mg/l)	HCO3 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Turbidity (mg/l)	DO (mg/l)	B (mg/l)
Aroma	AR-1	22.4	4,900	0.00	255.00	154.00	21.00	86.00	39	5.80	22.87
Tarapaca	TP-1	17.7	3,170	0.00	298.25	218.50	39.00	35.50	41	6.85	6.60
Quipisca	QP-1	18.1	1,200	8.70	273.30	64.00	13.00	12.00	122	6.10	1.64
Sagasca	SG-1	17.0	5,700	0.00	0.00	218.00	93.00	36.00	999	6.60	4.20

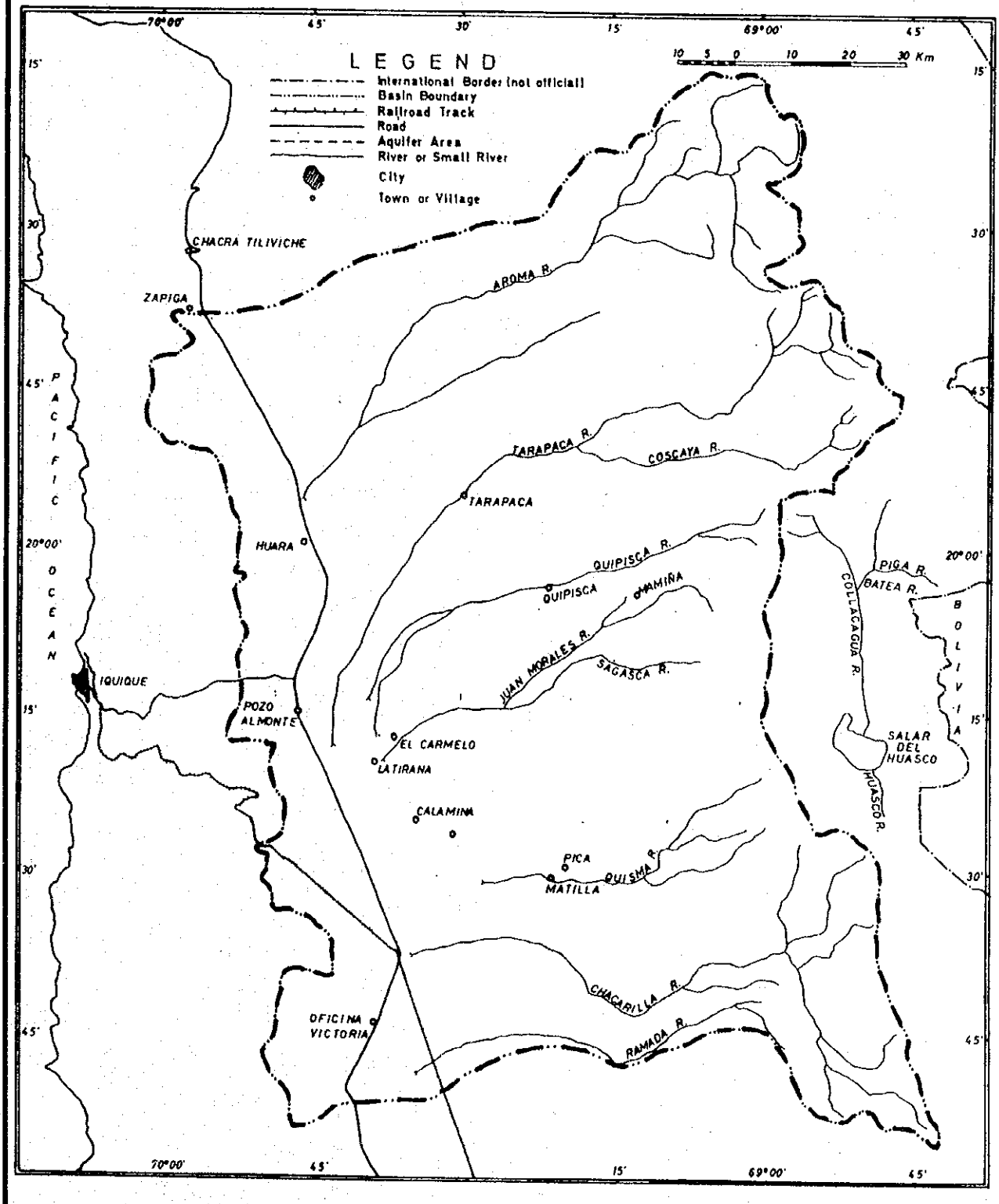
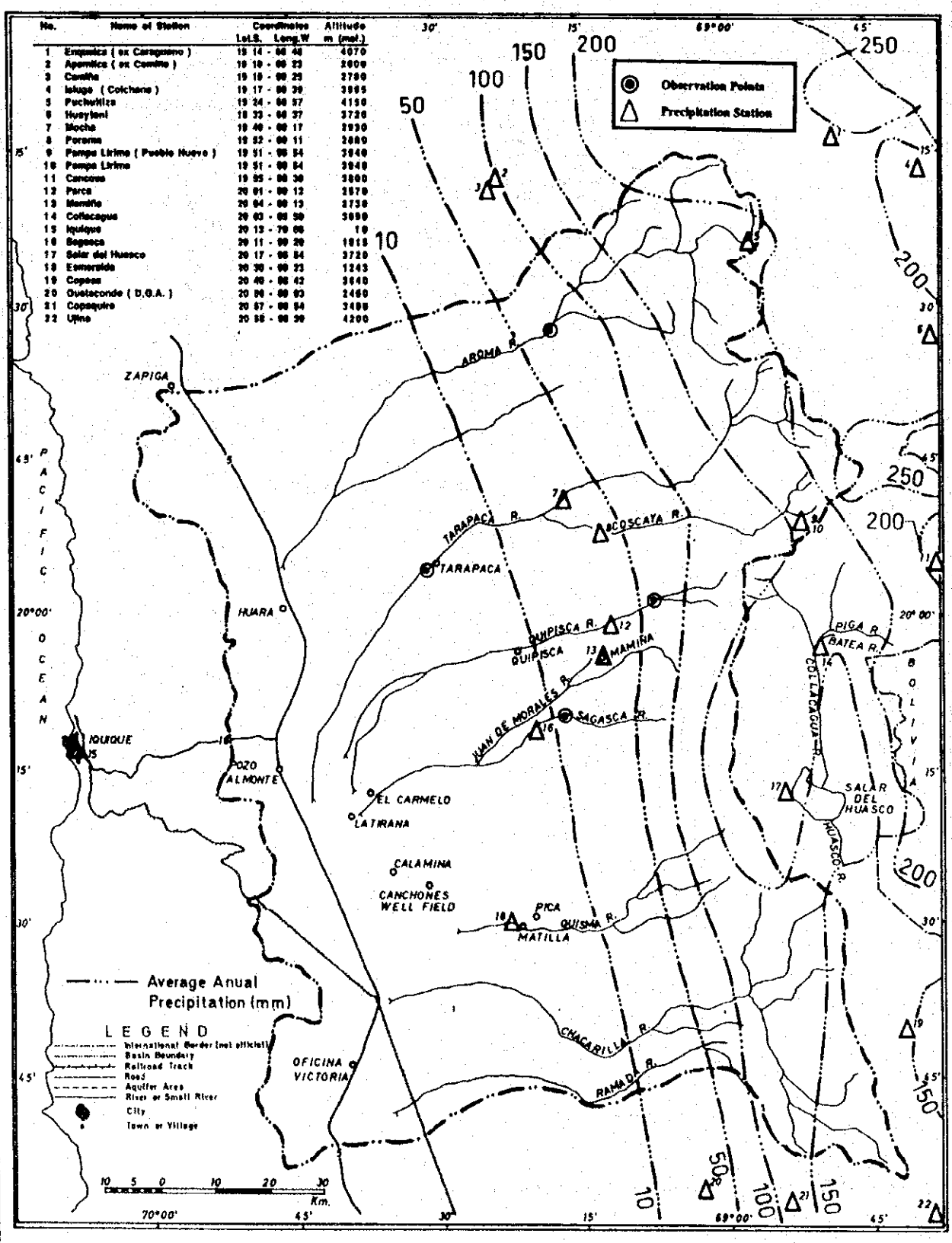


Fig. A, 3.1 River System of Pampa del Tamarugal Basin

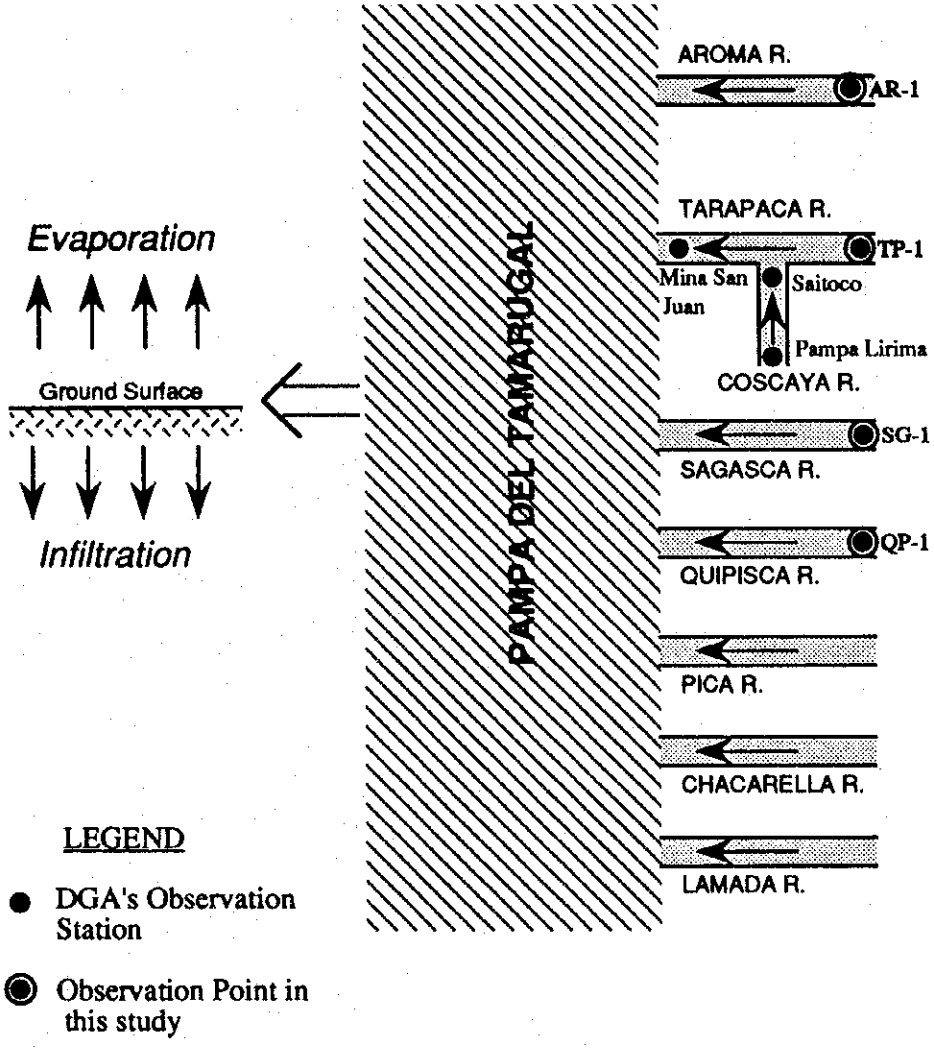
<Systema Fluvial de la Cuenca del Pampa del Tamarugal>



No.	Name of Station	Coordinates Lat.S.	Long.W	Altitude m (msl.)
1	Enquelca (ex Caraguano)	19 14 -	68 46	4070
2	Apamilca (ex Camiña)	19 19 -	68 23	3809
3	Camiña	19 19 -	68 29	2780
4	Ichuga (Colchane)	19 17 -	68 39	3895
5	Pachuntiza	19 24 -	68 57	4150
6	Huaytani	19 33 -	68 37	3720
7	Mocha	19 40 -	68 17	2930
8	Poroma	19 52 -	68 11	2889
9	Pampa Lirima (Pueblo Nuevo)	19 51 -	68 54	3940
10	Pampa Lirima	19 51 -	68 54	3940
11	Cancosa	19 55 -	68 30	3800
12	Parca	20 01 -	68 12	3570
13	Mamiña	20 04 -	68 13	2730
14	Coscacagua	20 03 -	68 50	3890
15	Iquiqua	20 13 -	70 08	10
16	Sagasca	20 11 -	68 20	1815
17	Salar del Huasco	20 17 -	68 54	3720
18	Esmeralda	20 30 -	68 23	1243
19	Copaza	20 40 -	68 42	3640
20	Quetaconde (D.G.A.)	20 56 -	68 03	2460
21	Copaquire	20 57 -	68 54	3480
22	Ujina	20 58 -	68 30	4200

Fig. A, 3.2 Average Precipitation (Isohyetal Map) in Pampa del Tamarugal Basin

<Precipitacion Promedio en Mapa de Isoyeta en la Cuenca del Pampa del Tamarugal>



Flow Model in Pampa del Tamarugal Basin

Fig. A, 3.3 Flow Model in Pampa del Tamarugal Basin

<Modelo de Flujo en la Cuenca del Pampa del Tamarugal>

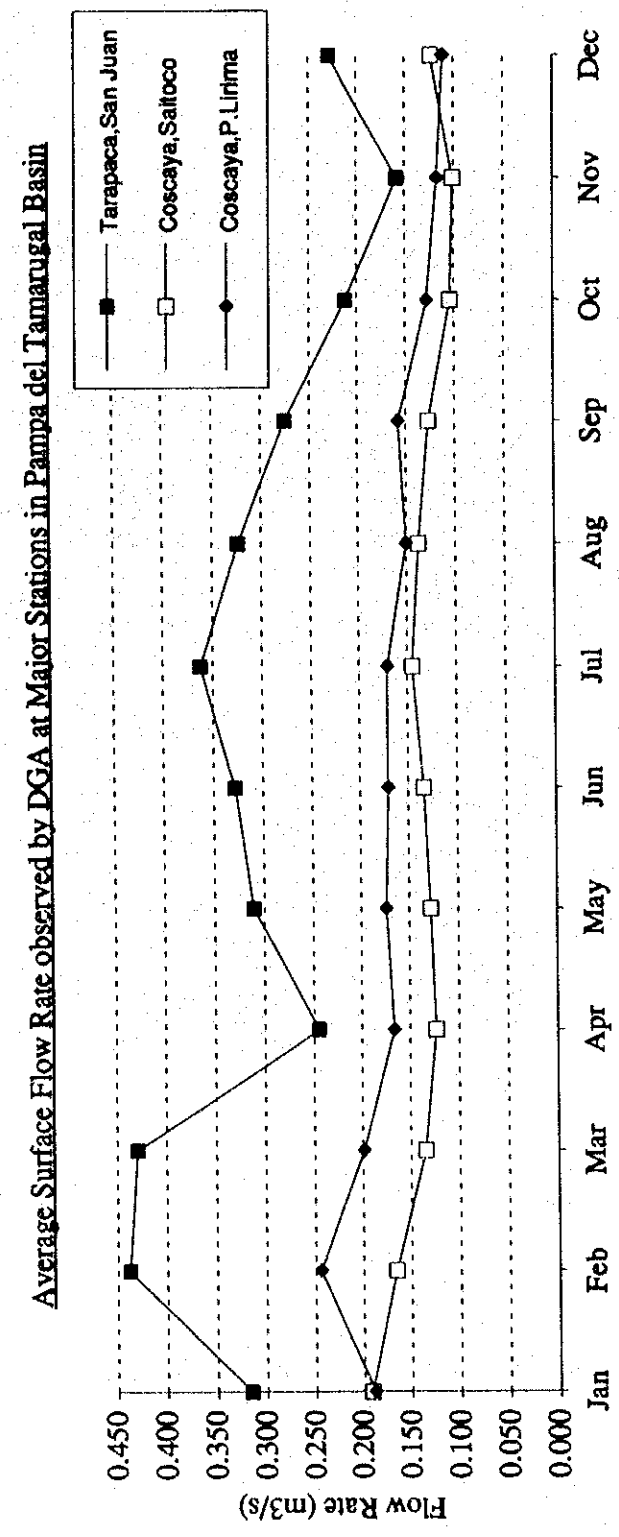


Fig. A, 3.4 Average Surface Flow Rate in Pampa del Tamarugal Basin

<Nivel de Flujo de Superficie Premedio Meansual de la Cuenca del Pampa del Tamarugal>

Chapter IV SURFACE WATER OF SALAR DE HUASCO BASIN

4.1 General

Salar de Huasco basin, located in the Region I in northern Chile has a total drainage basin area of 1,712 km^2 and covers the river basin of 1,112 km^2 and residual basin of 600 km^2. Drainage basin area is shown in Fig. A, 4.1 and Table A, 4.1.

4.1.1 Climate and Precipitation

Information on climate in the basin is obtained from Collacagua weather station at Collacagua village and Salar de Huasco weather station at Vertiente Laguna. Maximum monthly average temperature is in December at 20.3 °C and minimum one is in July at -15.0 °C. Humidity is not observed in the basin.

Precipitation is observed regularly by DGA and Meteorological Department. The stations are shown in Fig. A, 4.2.

Average annual precipitation regionally varies from 150 mm in Huasco lagoon area to 250 mm in the highest mountain areas as shown in Fig. 4.2.

4.1.2 River System

Collacagua River, the main river, flows southwards from the north, meets its tributaries, Batea and Piga, at Pampa Batea and flows down to Salar de Huasco lake, which is a closed lake. Flow model is shown in Fig., A, 4.3.

4.2 Surface Flow Rate

4.2.1 Flow Rate at Major Stations

Daily water levels are observed at DGA's observation stations by automatic recorders. Flow rate at each station is generally calculated by the so called "Discharge Rating Curve" or "H-Q Curve" which is a

calibration curve of water level and flow rate. Major observation stations are as follows;

River	Location	Observation Period
Piga	Ojos de Agua	1947 - 1990
	Confluencia	1959 - 1967
	Collacagua	1980 - 1990
Collacagua	Peñablanca	1981 - 1990

Average, maximum and minimum surface flow rates of these stations in the recorded years are shown in Table A, 4.2. Monthly fluctuation of flow rates throughout the year are shown in Fig. A.4.4 and recorded monthly flow rates are shown in Appendix A, 4.1.

The average flow rates of the above stations are as follows.

Stations	Average Flow Rate (m^3/s)
Ojos de Agua	0.072
Confluencia	0.023
Collacagua	0.139
Peña Blanca	0.197

The whole surface run-off of the basin finally infiltrates into underground to recharge the groundwater of the basin.

4.2.2 Calculation of Runoff Coefficient

Average yearly rainfall contour map prepared by DGA in 1987, as shown in Fig. A, 4.2, is used to calculate the surface runoff coefficient which in this case is the ratio of the average indigenous flow rate in Collacagua River at Peñablanca, to average annual precipitation in its upstream basin. Runoff coefficient is found to be 0.042 at Peñablanca as shown in Table A, 4.3. This can be interpreted that about 4.2 % of rainfall runs off through Collacagua River as surface flow.

4.3 Surface Water Quality at Major Stations

Water quality is observed by DGA. Water quality samples are taken from the river and analyzed in the laboratory. Observation stations are as follows;

River	Location	Observation Period
Collacagua	Peñablanca	1983 - 1989

The items of the analysis are classified as follows;

(1) Health Significance : As, $N\text{-}NO_3$, $N\text{-}NO_2$, $N\text{-}NH_3$

(2) Aesthetic Quality : Cl^-, Cu, Fe, Na, P, SO_4, pH

(3) Others : HCO_3, CO_3, Ca, Mg, K, B, E.C.

Results of the examination are shown in Table A, 4.4.

Table A, 4.1 Drainage Basin and Sub-Basins Area in Salar de Huasco Basin
<Cuenca de Drenaje y Area Sub-cuenca en Cuenca del Salar de Huasco>

River/ Quebrada	Sub-Basin (km2)	Total Basin (km2)
Upstream of Collacagua	307.1	307.1
Piga	244.0	551.1
Upstream of Pegnablanca	273.7	824.8
Downstream of Pegnablanca	287.7	1,112.4
Total River Basin		1,112.4
Residual Basin	599.6	
Total Salar de Huasco Drainage Basin Area		1,712.0

Table A, 4.2 Average, Maximum and Minimum Surface Flow Rate in Salar de Huasco Basin

<Promedio, Tasa de Flujo de Superficie Maximo y Minimo en la Cuenca del Salar de Huasco>

(Max. and Min. are the maximum and minimum of average values in a month of the recorded years, not instantaneous values)

Unit : m^3 /s

River	Location	Obs. Period	AVG	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG
Qda. Piga	Ojos de Agua	1959-1967	Max.	0.077	0.086	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.081	0.072	0.079	0.082
			Avg.	0.068	0.073	0.068	0.066	0.070	0.078	0.076	0.078	0.078	0.075	0.066	0.067	0.072
			Min.	0.060	0.060	0.060	0.052	0.060	0.072	0.072	0.072	0.072	0.069	0.060	0.060	0.064
Qda. Piga	Confluencia	1980-1990	Max.	0.029	0.047	0.027	0.028	0.035	0.037	0.031	0.033	0.029	0.037	0.029	0.033	0.033
			Avg.	0.023	0.025	0.022	0.021	0.024	0.025	0.024	0.025	0.023	0.023	0.022	0.023	0.023
			Min.	0.018	0.019	0.017	0.013	0.014	0.018	0.020	0.021	0.020	0.017	0.018	0.016	0.018
Qda. Piga	Collacagua	1947-1990	Max.	0.462	0.369	0.562	0.472	0.289	0.239	0.245	0.197	0.167	0.167	0.169	0.201	0.295
			Avg.	0.147	0.153	0.151	0.143	0.146	0.162	0.157	0.141	0.127	0.117	0.108	0.116	0.139
			Min.	0.084	0.083	0.085	0.085	0.100	0.118	0.075	0.079	0.071	0.067	0.075	0.079	0.083
Collacagua	Pegnablanca	1981-1990	Max.	0.281	0.490	0.499	0.259	0.254	0.329	0.459	0.442	0.823	1.070	0.172	1.020	0.508
			Avg.	0.159	0.180	0.186	0.147	0.170	0.203	0.219	0.232	0.244	0.276	0.124	0.229	0.197
			Min.	0.078	0.092	0.050	0.094	0.091	0.125	0.127	0.123	0.094	0.081	0.075	0.076	0.092

Table A, 4.3 Average Runoff Coefficient in Salar de Huasco Basin
<Coeficientes de Escorrentias Promedios en la Cuenca de Salar de Huasco>

Location : **Collacagua River at Pegnablanca**

Rainfall Range (mm)	Average Rainfall R (mm)	Total River Basin (km2)	Upstream Basin of Pegnablanca A (km2)	Average R*A (mm.km2)	Upstream Avg. Rainfall R (mm) (R*A/A)	Flow Rate at Pegnablanca Q (m3/s)	Runoff Coefficient f (= Q/R*A)	Upstream Average Altitude H (m, msl)
0.0 - 10.0	-	-	-	-		0.197		
10.0 - 50.0	30.0	-	-	-				
50.0 - 100.0	75.0	-	-	-				
100.0 - 150.0	125.0	76.37	-	-				
150.0 - 200.0	175.0	945.90	734.62	128,557.85				
200.0 - 250.0	225.0	90.13	90.13	20,280.27				
250.0 - 300.0	275.0	-	-	-				
300.0 - 350.0	325.0	-	-	-				
> 350.0	-	-	-	-		(m3/year)		
		1,112.40	824.75	148,838.12	180.46	6,212,592	0.042	-

Note : - Average basin rainfall is calculated from Average Annual Precipitation Map (Isohyetal Map) by DGA in 1987
- Flow rate is obtained from monthly data observed by DGA
- Upstream average altitude of the station is obtained by averaging the altitude of the rainfall stations located in the upstream basin of that station

Table A, 4.4 Water Quality Observed by DGA in Salar de Huasco Basin

<Calidad de Agua Observada por DGA en la Cuenca del Salar de Huasco>

YEAR	PH	EC mhos/cm	CO3 mg/l	HCO3 mg/l	CL mg/l	SO4 mg/l	Ca mg/l	Mg mg/l	K mg/l	Na mg/l	B mg/l	As mg/l	Cu mg/l	Fe mg/l	N-NO3 mg/l	N-NO2 mg/l	P mg/l	N-NH3 mg/l
ST: Collacagua River in Penablanca																		
1983	7.67	628	0.000	278.0	26	80	38.9	22.4	8.0	60.4	1.74	0.085	0.035	0.735				
1984	7.73	544	0.000	249.5		79	40.3	22.3	9.0	61.9	0.83	0.101	0.000	6.500	5.540			
1985	7.70	611	0.000	278.0		68	40.0	21.0	15.3	68.3	1.68	0.104						
1986	7.70	582	0.000	269.5		62	40.3	19.8	10.0	56.8	1.12	0.078	0.080	3.280	0.221			
1987	7.73	636	0.000	273.3		73			9.5	68.5	1.16	0.107		0.910				
1989	7.90	700	0.000	293.0		90			9.9	68.1	1.04	0.143			0.162			
Average	7.74	617	0.000	273.6	26	75	39.9	21.4	10.3	64.0	1.26	0.103	0.038	2.856	1.974			

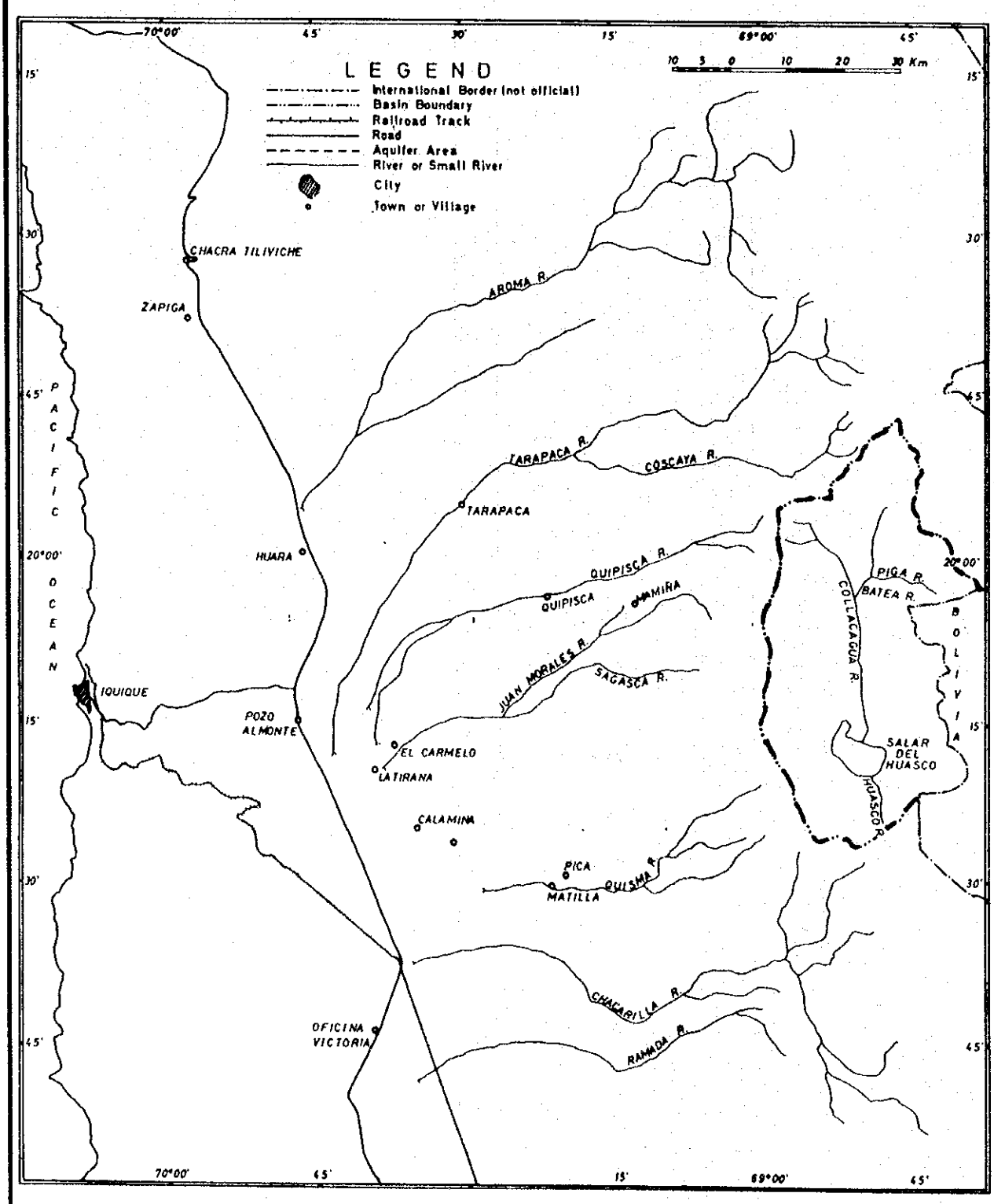


Fig. A, 4.1 River System of Salar de Huasco Basin

<Systema Fluvial de la Cuenca del Salar de Huasco>

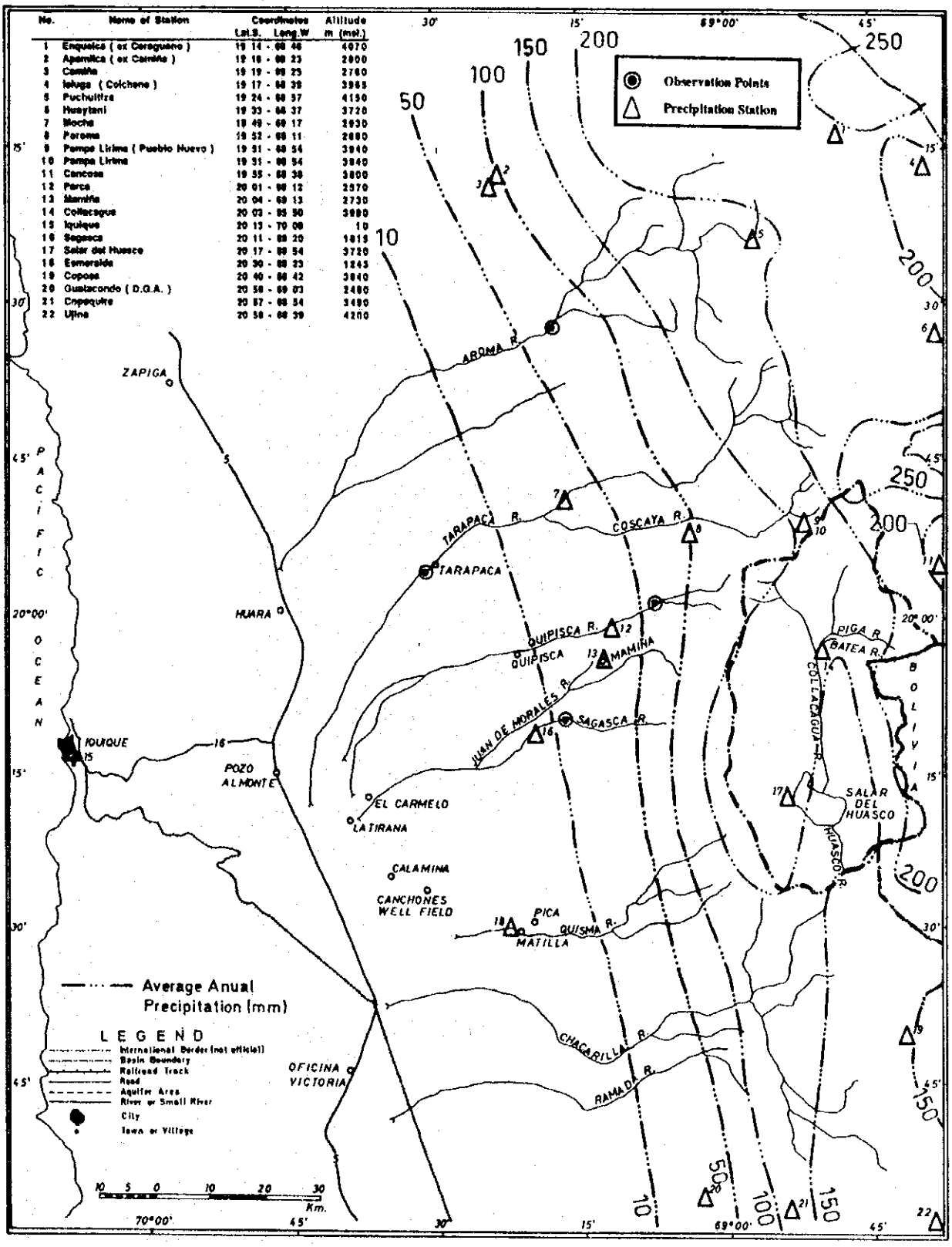
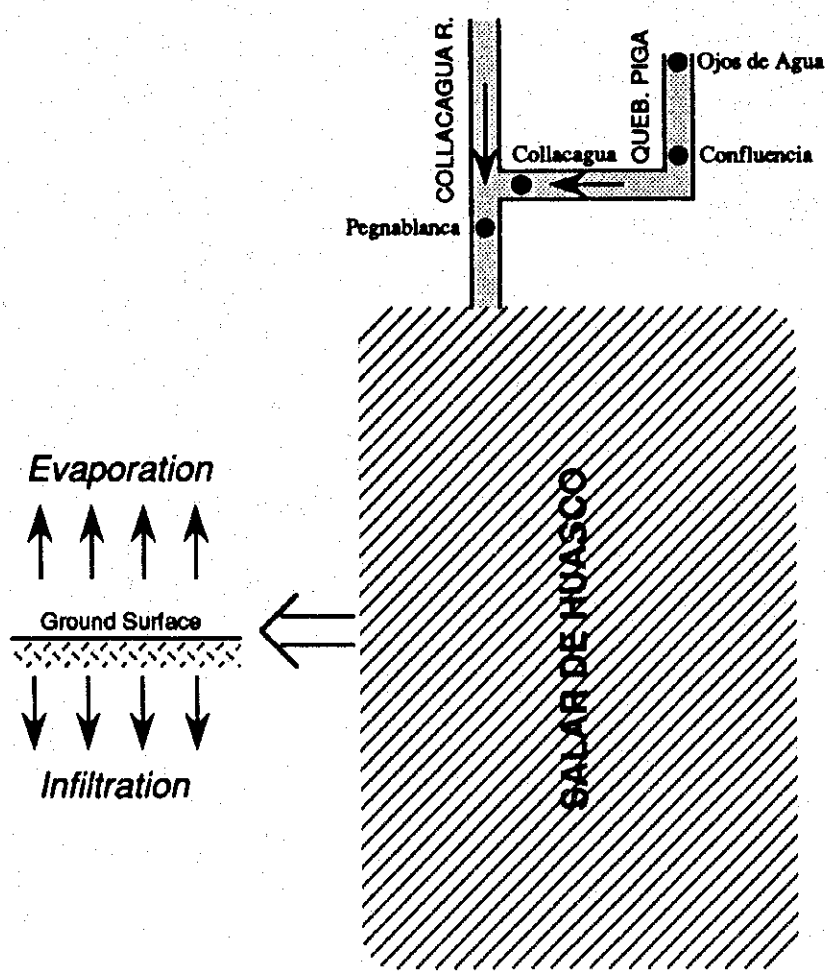


Fig. A, 4.2 Average Precipitation (Isohyetal Map) in Salar de Huasco Basin

<Precipitacion Promedio en Mapa de Isoyeta en la Cuenca del Salar de Huasco>



LEGEND

● DGA's Observation Station

Flow Model in Salar de Huasco

Fig. A, 4.3 Flow Model in Salar de Huasco Basin

<Modelo de Flujo en la Cuenca del Salar de Huasco>

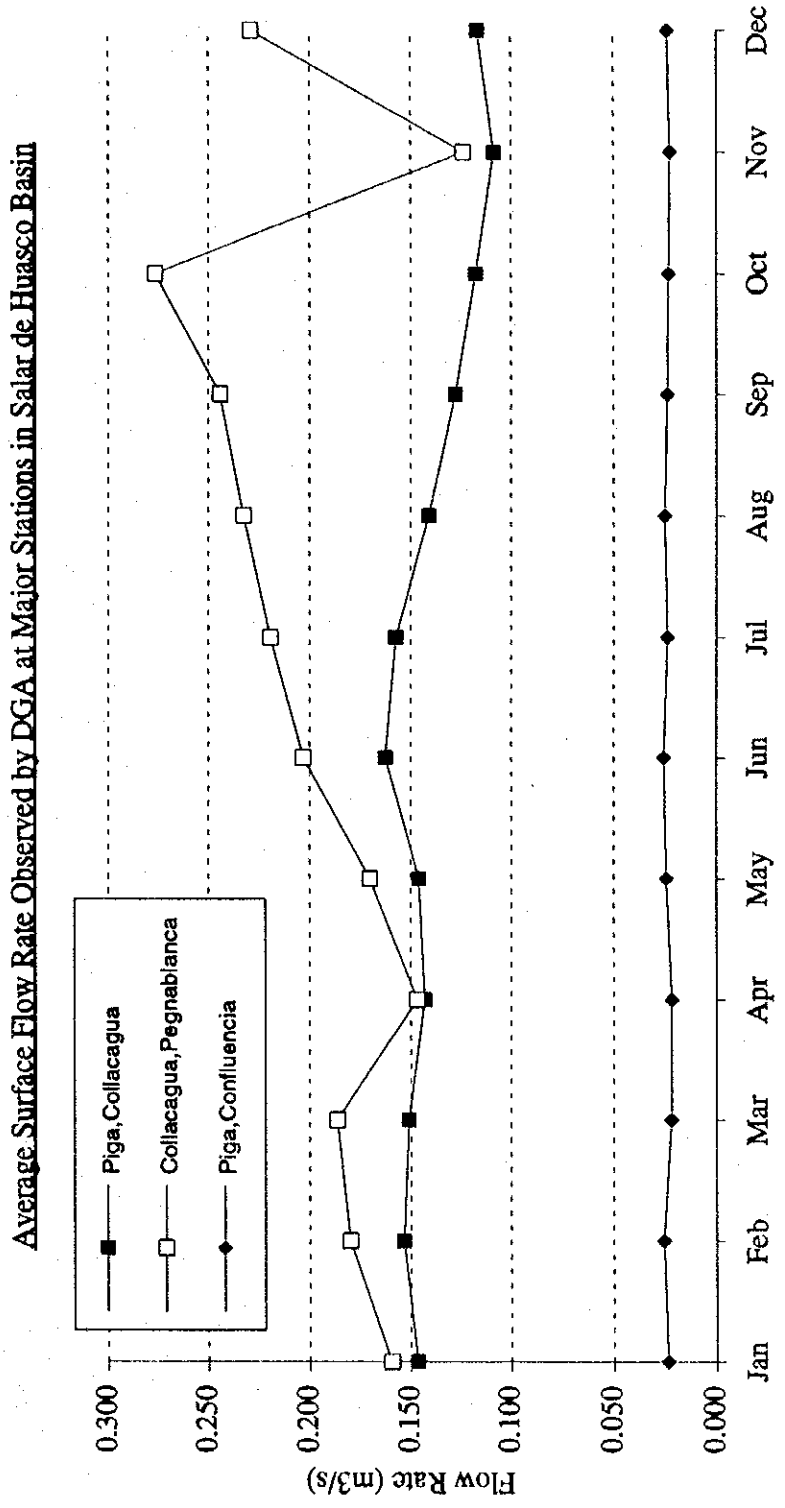


Fig. A, 4.4 Average Surface Flow Rate in Salar de Huasco Basin

<Nivel de Flujo de Superficie Premedio Meansual de la Cuenca del Salar de Huasco>

Chapter V EVALUATION OF RUNOFF IN PAMPA DEL TAMARUGAL AND SALAR DEL HUASCO BASIN

5.1 General

In Pampa del Tamarugal Basin, existing data of the surface flow rate are limited to the Tarapacá River. No data is available in the other rivers.

In Salar del Huasco Basin, the surface flow rate has been observed by DGA at Peñablanca of Collacagua River, and at Ojos de Agua, Confluencia and Collacagua of Quebrada Piga River.

However, the Peñablanca station does not catch the whole run-off of its upstream basin. Because some portion of the river flow infiltrates into underground before reaching the station since the station is located on the alluvial deposits. Furthermore, some river water bypasses the station at a flood time.

On the other hand, the drainage areas of the other three (3) stations are so small that it is difficult to directly estimate the total discharge of Collacagua River from the discharge records at the three (3) stations.

Considering the above situations, the surface water run-off of Pampa del Tamarugal and Salar del Huasco is estimated from the rainfall records of the basins.

In the above estimation, the basin average rainfall is to be calculated by weighting the point rainfall records distributed in the basin. In this study, the basin average rainfall was calculated by using the rainfall isohyetal map prepared by DGA in 1987.

5.2 Relationship of Rainfall and Run-off Coefficient

The relationship between rainfall and run-off coefficient in the Study Area was obtained from the observed discharge data at the following stations within and near the Study Area.

River	Quebrada	Station
1 Lluta		Alcerreca
2 Lluta		Tocontasi
3 San José		Antes Bocatoma
4 Vitor	Qda. Vitor	Qda. Vitor
5 Camarones		Camarones
6 Tana	Qda. Camiña	Qda. Camiña
7 Tana	Qda. Camiña	Altusa
8 Tarapacá		Mina San Juan
9 Chacarilla		Salado
10 Loa	San Pedro	San Pedro
11 Loa	San Pedro	San Pedro (Inacaliri)
12 Loa		Desp. Junta
13 Loa		Lequena

However, the data at Peñablanca of Collacagua River were not used in this analysis. Because some portion of the river flow infiltrates into underground before reaching Peñablanca station since the station is located on the alluvial deposits. Furthermore, some river water bypasses the station at a flood time. The station does not catch the whole run-off of the upstream basin. The calculated run-off coefficient is considered not correct, too small compared to the corresponding rainfall depth.

The relationship between rainfall and run-off coefficient is established as shown in Fig. A, 5.1. It is expressed by a linear equation as follows.

$$R = af + b$$

where R = Average total rainfall in a year (mm/year),
f = Runoff coefficient,
a, b = constant

Parameter a and b are calculated by Least Square Method using rainfall and runoff coefficient as values of samples. The result is shown below.

$$R = 1{,}192.39\, f + 38.960$$

where Correlation coefficient (r) = 0.9778

From this equation, average yearly flow rate in seven (7) tributaries in Pampa del Tamarugal including Aroma, Tarapacá, Quipisca, Sagasca (Juan Morales), Quisma (Pica), Chacarilla and Ramada Rivers can be estimated as shown in Table A, 5.1.

Calculated yearly average flow rate of the rivers in Pampa del Tamarugal are as follow;

River	Flow Rate (m^3/s)
Aroma	0.310
Quipisca	0.089
Sagasca	0.072
Quisma	0.021
Chacarilla	0.159
Ramada	0.007
Tarapaca	0.318
Total	0.976

The total flow rate of the basin was estimated by Chile University as well in 1988 (Refer to Modelo de Simulacion Hidrogeologico de la Pampa del Tamarugal Informe, 1988, Universidad de Chile). It is 1.002 m^3/s, about 2.6 % different from the calculation of this study.

The surface run-off from the whole area of Salar del Huasco Basin is also estimated by using the above equation as shown in Table A, 5.1. The yearly average run-off is calculated at 0.809 m^3/s.

Table A, 5.1 (1) Calculated Runoff in Pampa del Tamarugal and Salar de Huasco Basin

<Escorrentias Calculadas en la Cuenca de la Cuenca del Pampa del Tamarugal y Salar de Huasco>

(Liner Equation of Average Rainfall and Runoff Coefficient : R = 1,192.39 f + 38.960)

River : **Aroma River (Pampa del Tamarugal Basin)**

Rainfall Range (mm)	Average Rainfall R (mm)	Total River Basin (km2)	R*A (mm.km2)	Average Rainfall (mm (R*A/A)	Runoff Coefficient f	Estimated Runoff Q (Q =fRA) (m3/year)	(m3/s)
0.0 - 10.0	5.0	595.14	2975.688				
10.0 - 50.0	30.0	312.00	9,360.00				
50.0 - 100.0	75.0	301.47	22,610.25				
100.0 - 150.0	125.0	298.34	37,292.50				
150.0 - 200.0	175.0	451.34	78,985.20				
200.0 -250.0	225.0	130.45	29,351.70				
250.0 - 300.0	275.0	0.00	0.00		(from Linear		
300.0 - 350.0	325.0	0.00	0.00		Equation of		
> 350.0	-	-	-		R and f)		
Total		1,745.60	177,599.65	101.74	0.055	9,761,363	0.310

River : **Tarapaca River (Pampa del Tamarugal Basin)**

Rainfall Range (mm)	Average Rainfall R (mm)	Total River Basin (km2)	R*A (mm.km2)	Average Rainfall (mm (R*A/A)	Runoff Coefficient f	Estimated Runoff Q (Q =fRA) (m3/year)	(m3/s)
0.0 - 10.0	5.0	354.47	1,772.37				
10.0 - 50.0	30.0	281.74	8,452.13				
50.0 - 100.0	75.0	199.77	14,982.41				
100.0 - 150.0	125.0	321.47	40,183.75				
150.0 - 200.0	175.0	327.14	57,250.20				
200.0 -250.0	225.0	166.16	37,386.00				
250.0 - 300.0	275.0	65.55	18,026.25		(from Linear		
300.0 - 350.0	325.0	0.00	0.00		Equation of		
> 350.0	-	-	-		R and f)		
Total		1,716.30	178,053.10	103.74	0.056	10,036,643	0.318

River : **Quipisca River (Pampa del Tamarugal Basin)**

Rainfall Range (mm)	Average Rainfall R (mm)	Total River Basin (km2)	R*A (mm.km2)	Average Rainfall (mm (R*A/A)	Runoff Coefficient f	Estimated Runoff Q (Q =fRA) (m3/year)	(m3/s)
0.0 - 10.0	5.0	70.14	350.70				
10.0 - 50.0	30.0	284.82	8,544.69				
50.0 - 100.0	75.0	146.81	11,010.83				
100.0 - 150.0	125.0	221.20	27,650.00				
150.0 - 200.0	175.0	122.63	21,459.38				
200.0 -250.0	225.0	0.00	0.00				
250.0 - 300.0	275.0	0.00	0.00		(from Linear		
300.0 - 350.0	325.0	0.00	0.00		Equation of		
> 350.0	-	-	-		R and f)		
Total		845.60	69,015.60	81.62	0.041	2,817,387	0.089

River : **Sagasca River (or Juan Morales) (Pampa del Tamarugal Basin)**

Rainfall Range (mm)	Average Rainfall R (mm)	Total River Basin (km2)	R*A (mm.km2)	Average Rainfall (mm (R*A/A)	Runoff Coefficient f	Estimated Runoff Q (Q =fRA) (m3/year)	(m3/s)
0.0 - 10.0	5.0	237.23	1,186.13				
10.0 - 50.0	30.0	258.78	7,763.28				
50.0 - 100.0	75.0	152.52	11,439.00				
100.0 - 150.0	125.0	164.82	20,601.88				
150.0 - 200.0	175.0	157.26	27,520.94				
200.0 -250.0	225.0	0.00	0.00				
250.0 - 300.0	275.0	0.00	0.00		(from Linear		
300.0 - 350.0	325.0	0.00	0.00		Equation of		
> 350.0	-	-	-		R and f)		
Total		970.60	68,511.23	70.59	0.033	2,265,774	0.072

Table A, 5.1 (2) Calculated Runoff in Pampa del Tamarugal and Salar de Huasco Basin
<Escorrentias Calculadas en la Cuenca de la Cuenca del Pampa del Tamarugal y Salar de Huasco>
(Liner Equation of Average Rainfall and Runoff Coefficient : R = 1,192.39 f + 38.960)

River : **Quisma River (or Pica) (Pampa del Tamarugal Basin)**

Rainfall Range (mm)	Average Rainfall R (mm)	Total River Basin (km2)	R*A (mm.km2)	Average Rainfall (mm (R*A/A)	Runoff Coefficient f	Estimated Runoff Q (Q =fRA) (m3/year)	(m3/s)
0.0 - 10.0	5.0	64.57	322.84				
10.0 - 50.0	30.0	84.46	2,533.74				
50.0 - 100.0	75.0	54.89	4,117.05				
100.0 - 150.0	125.0	53.31	6,664.13				
150.0 - 200.0	175.0	40.27	7,046.64				
200.0 -250.0	225.0	0.00	0.00				
250.0 - 300.0	275.0	0.00	0.00		(from Linear		
300.0 - 350.0	325.0	0.00	0.00		Equation of		
> 350.0	-	-	-		R and f)		
Total		297.50	20,684.40	69.53	0.032	668,673	0.021

River : **Chacarilla River (Pampa del Tamarugal Basin)**

Rainfall Range (mm)	Average Rainfall R (mm)	Total River Basin (km2)	R*A (mm.km2)	Average Rainfall (mm (R*A/A)	Runoff Coefficient f	Estimated Runoff Q (Q =fRA) (m3/year)	(m3/s)
0.0 - 10.0	5.0	313.36	1,566.82				
10.0 - 50.0	30.0	141.24	4,237.20				
50.0 - 100.0	75.0	109.93	8,244.90				
100.0 - 150.0	125.0	401.13	50,141.00				
150.0 - 200.0	175.0	255.64	44,736.30				
200.0 -250.0	225.0	0.00	0.00				
250.0 - 300.0	275.0	0.00	0.00		(from Linear		
300.0 - 350.0	325.0	0.00	0.00		Equation of		
> 350.0	-	-	-		R and f)		
Total		1,221.30	108,926.22	89.19	0.046	5,026,138	0.159

River : **Ramada River (Pampa del Tamarugal Basin)**

Rainfall Range (mm)	Average Rainfall R (mm)	Total River Basin (km2)	R*A (mm.km2)	Average Rainfall (mm (R*A/A)	Runoff Coefficient f	Estimated Runoff Q (Q =fRA) (m3/year)	(m3/s)
0.0 - 10.0	5.0	80.85	404.26				
10.0 - 50.0	30.0	66.32	1,989.54				
50.0 - 100.0	75.0	49.41	3,705.75				
100.0 - 150.0	125.0	47.82	5,977.50				
150.0 - 200.0	175.0	0.00	0.00				
200.0 -250.0	225.0	0.00	0.00				
250.0 - 300.0	275.0	0.00	0.00		(from Linear		
300.0 - 350.0	325.0	0.00	0.00		Equation of		
> 350.0	-	-	-		R and f)	(Q = fIA)	
Total		244.40	12,077.05	49.42	0.018	219,746	0.007

Salar de Huasco Basin

Rainfall Range (mm)	Average Rainfall R (mm)	Total River Basin (km2)	R*A (mm.km2)	Average Rainfall (mm (R*A/A)	Runoff Coefficient f	Estimated Runoff Q (Q =fRA) (m3/year)	(m3/s)
0.0 - 10.0	5.0	-	-				
10.0 - 50.0	30.0	-	-				
50.0 - 100.0	75.0	-	-				
100.0 - 150.0	125.0	676.87	84,608.75				
150.0 - 200.0	175.0	945.00	165,375.00				
200.0 -250.0	225.0	90.13	20,279.25				
250.0 - 300.0	275.0	-	-		(from Linear		
300.0 - 350.0	325.0	-	-		Equation of		
> 350.0	-	-	-		R and f)	(Q = fIA)	
Total		1,712.00	270,263.00	157.86	0.094	25,512,192	0.809

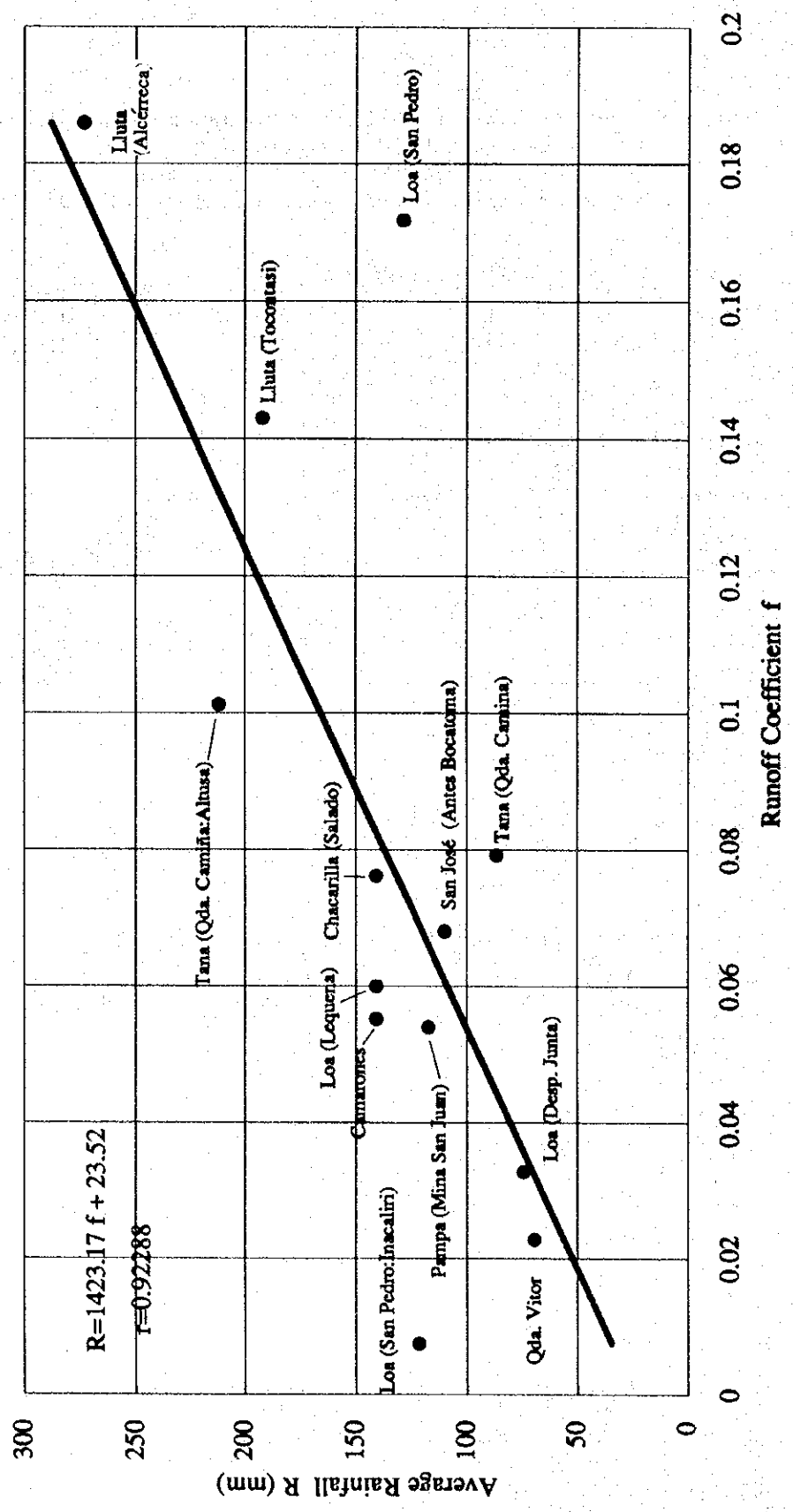


Fig. A, 5.1 Relationship of Average Rainfall and Runoff Coefficient in the Study Area

<Relacion Promedio de las Lluvias y Coeficiente de Escorrentias en el Area Estudiada>