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HYDROGEOLOGIC AND AGROCLIMATIC CONSIDERATIONS FOR THE DEVELOPMENT OF A WATER MANAGEMENT MODEL FOR THE TLACOLULA SUBBASIN, OAXACA, MEXICO.

A THESIS
SUBMITTED TO THE FACULTY OF
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BY

ETIENNE PERRATON

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DEPARTMENT OF AGRICULTURAL AND BIOSYSTEMS ENGINEERING
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ABSTRACT

Ph.D **E. Perraton** **Agricultural and Biosystems Engineering.**

HYDROGEOLOGIC AND AGROCLIMATIC CONSIDERATIONS FOR THE DEVELOPMENT OF A WATER MANAGEMENT MODEL FOR THE TLACOLULA SUBBASIN, OAXACA, MEXICO.

The area investigated in this research is the groundwater basin of the valley of Tlacolula de Matamoros, of the central valleys of Oaxaca in Mexico. The objectives of this research were to consider together the causes and symptoms of the technical problems concerned with effective management of ground-water and related land resources in a semi-arid climate.

The preparation of electronic basemaps and their field control is first investigated. A methodology for the preparation of multi-layer base maps is successfully established.

The variability of climatic conditions and climatic trends that may affect the quantification of the design rainfall and the elaboration of long term water management strategies are then investigated.

Historical pumping test data are analyzed. Analytical techniques for the interpretation of single well test data are applied. A trial and adjustment procedure based on the reversibility of the test when the aquifer-well system has stabilized, is proposed for the data analysis of a single well test with declining step drawdown.

In order to determine the suitability of water for irrigation and to obtain an early warning of groundwater salinization, the quality of groundwater is assessed over the area.

Hydrometric measurements are analyzed for accuracy and potential water availability

RESUMÉ

Ph.D **E. Perraton** **Agricultural and Biosystems Engineering.**

CONSIDÉRATIONS HYDROGÉOLOGIQUES ET AGROCLIMATIQUES POUR LE DÉVELOPPEMENT D'UN MODELE DE GESTION DE L'EAU DU BASSIN DE TLACOLULA, DE L'ÉTAT DE OAXACA AU MEXIQUE.

La région étudiée est le bassin de la rivière Rio Salado située dans le versant Est des trois vallées centrales de l'état de Oaxaca au Mexique. Cette recherche vise à un examen des problèmes techniques associés à la gestion des ressources en eau sousterraine en climat-semi aride.

On élabore en premier lieu une méthodologie permettant la préparation et calibration des données cartographiques du système géographique requis par le gestionnaire. On établit sous contrôle géodésique un réseau inventorié de 142 puits domestiques dont on examine la fiabilité pour fins d'observation de l'acuifère libre.

On examine ensuite les données climatiques. On établit la variabilité spatiale et temporelle des conditions agro-climatiques.

On procède alors à une évaluation de l'acuifère par analyse et interprétation des pompages d'essai réalisés dans la région étudiée. Les techniques anlytiques disponibles sont revues. On propose une méthode d'analyse par itération basée sur la réversibilité probable du pompage d'essai qui assure un développement progressif du puits, une stabilité du cône de dépression et une remontée en palier.

On recueille de façon aléatoire des échantillons d'eau afin d'en déterminer la qualité et l'usage potentiel pour fins d'irrigation.

On procède à un examen de la fiabilité des méthodes de mesures et des données hydrométriques disponibles au gestionnaire. On discute des difficultés rencontrées et on identifie les pistes de recherche prioritaires.

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1. Well in construction and furrow system for irrigation 403
2. Molinet, type Price. Weight for carrying the sounding line 403
3. Salt deposited by evaporation of the brackish water of El Brotante 404
4. The planting pace is synchronized with the water front in the furrow 404

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LIST OF SYMBOLS In Appearance Order

Unless otherwise defined in the text the descriptions given below apply to these symbols throughout the text. It is understood that the units applied to a symbol should be consistent in any one equations. Symbols are presented

Symbols	Description
ϕ	Latitude
S_c	Scale at the equator.
S_c'	Scale at any latitude f.
x . y	Coordinates in X-Y local grid system of the topographical map. Z is taken as the elevation of the point.
x_M. y_M	Coordinates in groundwater flow system in which, the reference axes X_M and Y_M define respectively the average orientation of the groundwater flow and the average orientation of the head gradient of the groundwater. The X_M - Y_M reference system lies at 28° clockwise with respect to the X-Y local grid system.
h . k	Define the position of the origin of the X_M - Y_M reference system
x_{Mp} . y_{Mp}	Coordinates of an arbitrary point P in X_M - Y_M groundwater flow system. The same point "p" has coordinates $(x_p;y_p)$ in the X;Y coordinates system.
CB, AD	Control lengths for scale determination.
$\in$	Belongs to. (h ; k) $\in$ Y_M. (h ; k) belongs to Y_M axis line.
α , β	Angle defined by $\alpha = tg^{-1} (y_p / x_p)$. and $\beta = 62.06417° - \alpha$.
σ	Angle that makes the axis X_M with respect to the X axis.
ω	Angle that makes the arctangent of the ratio k to h..
ω_M	Angle that makes the arctangent of the ratio k_M to h_M..
ET-R.	Evapotranspiration - Rainfall
R:ET_0	The Ratio. Rainfall / Potential -Evapotranspiration .
Pr_i	Unknown monthly rainfall in each incomplete year. In [mm].
i	each of the unknown months, (maximum of 11)

$\sum S_i$	Sum of the average rainfall percentages over the historical period for the months for which data are to be generated. [%]
$\sum Pr_k$	Sum of monthly rainfall for the months with known precipitation in the incomplete years. [mm].
S_i	Average monthly Rainfall % calculated as the average of monthly rainfall percentages for historical years with complete data. The S_i % values are then assumed for the months with unknown or missing data.
R^2	Coefficient of determination.
CI	Confidence Interval.
KS	Kolomogorov-Smirnov
H_0	The null hypothesis of a statistical test.
μ_A	The mean of a the population A.
μ_B	The mean of a the population B.
F-test	Test on a population for which F-distribtion is assumed. The F-fistribution was introduced by R.A. Fisher in 1924
t.-test	Test on a sample for which the Student's t-distribution is assumed. The t—distribution was introduced by W.S.Gosset who published under the name of Student (1908, as reported by Kreysig, 1970)
U	Number of runs where a " run " is a cluster of one or more values from the same sample.
$Z_{1-a/2}$	Represents the point on the standard-normal distribution such that the probaility ($Z > Z_{1-\alpha/2}$) = $\alpha/2$
rpm	Rotational Velocity . revolutions per minute
Q	discharge.
Log 10	Logarithm, base 10. When no base is mentioned , base 10 is then understood.
p	the significance probability calculated by the Student "t" table
np	the correct significance ", where *n* is the number of degrees of freedom in the actual error and p the significance probability.
$K(X,\omega)$	a family of sample functions K(X), each having a certain probability of occurrence or a series of random variables $k(X,\omega)$ at each location x_t.

μ_i	Mean values. WHEN NO SUBSCRIPT IS USED μ IS THEN THE absolute or dynamic viscosity. See below.
$[\sigma_{ii}^2]$	Variance matrix.
$[\sigma_{Ij}^2]$.	Autocovariance matrix.
$[\rho_{i,j}]$,	Autocorrelation matrix
l	The distance over which such influences are felt is controlled by the autocorrelation length. It is called the integral scale or range.
K_i	geostatistical description of a the saturated hydraulic ocnductivity in a discretized domain with blocks labeled i = 1,.., n by the specification of a vector of mean values, $[\mu_i]$ and an autocovariance matrix, $[\sigma_{ij}^2]$.
h(Θ)	Capillary head
K(Θ).	Hydraulic conductivity in unsaturated media.
K	Hydraulic conductivity in saturated media. Convenient Units are in (cm/s) and (m/d).
T	Transmissivity. The unit (m^2/d) squared meter per day is prefered to the unit (m^2/s). 1 m^2/ d = 86 400 m^2/s.
S	Storage coefficient. See also S_y the specific yield.
Vn	The "unstructured property variability, called nugget variability. It is the variance not attributable to spatial separation
Vs	The "structured" property variability. It is the variance of fluctuation attributable to spatial separation.
K_p	The specific permeability, intrinsic permeability, physical permeability.
μ	The absolute or dynamic viscosity, (g × s /cm^2) .
γ_w	The unit weight of water, (g/cm^3.)
c_v	Coefficient of consolidation, (cm^2 /s)
m_v	Vertical compressibility of the soil, (cm^2 /g)
P	Pressure applied to the sample in the consolidation test.
n	Total porosity.
β_w	The water compressibility or the reciprocal of its bulk modulus E_w.
D_q	The thickness of the confined aquifer.

V	The volume of a a vertical prism of height D_q (the thickness of the confined aquifer) and of a unit cross section. , then $D_q = V$.
V_v	The total volume of voids.
Vs	The volume of solids.
V_W	The volume of water.
D, H	Saturated thickness. D_q is used when the aquifer is confined.
S_y	The drainable porosity or specific yield. In unconfined aquifers, the yield capacity increases gradually with time from zero to its maximum value S_y during the drainage process. The intermediate delayed yield S_{ya} is of magnitude less than S_y .
$S_{t,y}$	Storage coefficient. The total amount of water released from storage in unconfined aquifers is $= S_{ya} + S$.
t	A period of pumping.
r_w	The effective radius of the well.
r_e	The radius of influence of the well.
∞	Infinity.
$r_{e,t}$	The radius of influence of the well after a t period of pumping.
$h_{w,t}$	The water head h_w after a t period of pumping.
S_{ini}	The initial yield for an unconfined aquifer corresponds to the yield capacity developed initially at the first inflection in the curve water level drawdowns in observation wells when plotted against time on logarithm paper.
$S_{fin.}$	The final yield obtained after continued pumping.
1/a'	May be regarded as the characteristic thickness of the unsaturated zone. Concept developed by Krozinski and Dagan (1975)
r_c	The radius of the unscreened part of the well.
C	is the well loss coefficient so that CQ2 are well head losses due to entrance high velocity, [m]
P	the power P of the flow rate at which the non linear losses vary according to Rorabough (1953). CQ^P .
s'	The residual drawdowns , [m].

s_{dj}	The adjusted drawdown at radius r. as per $s_{dj} = s_d - (s^2_d / 2 h_u)$
s_d	The measured drawdown in an observation well at a well distance **r** from the pumped well.
h_u	undisturbed height of the water table above the impervious boundary. [m].
t	The time elapsed since pumping started, [1 min = 60s]
t'	The time elapsed since pumping stopped.
B	An empirical constant for the well
s_w	The meadsured drawdown, [m] and
Q	The pumping rate, [1 m^3/min = 1m^3 / 60s]
Δ	The Δ terms represent increments. Example increments of drawdown produced by each increase ΔQ in the rate of pumping is $\Delta s_i / \Delta Q_i$.
e	The void ratio of the soil.
D_s	the diameter of an *ideal* flow medium which consists of spherical grains of equal size and which behaves collectively (with regard to such hydraulic characteristics as head loss) as actual soil under consideration.
i_g	the hydraulic gradient in Darcy's Law.
γ_{sat}	the saturated unit weight
S_r (%)	% degree of saturation.
γ_m	Bulk (mass) unit weight.
γ_d	Dry unit weight.
A	The aquifer loss coefficient.
s_{corr}	The Jacob's corrected drawdown. This is the same as the adjusted drawdown s_{dj} defined above.
s_I / s_{II}	This is the ratio of the corrected drawdown (CASE I / CASE IIB) to be expected when comparing partial (CASE II) to full recovery (CASE I). See Appendix F. for details.
r_i	The radial distance between the pumped WELL and the observation wells.

Chemical Symbols	name	Equivalent Weight (grams)
Ca^{++}	Calcium ion	20.04
Na^{+}	Sodium ion	23.00
K^{+}	Potassium ion	39.10
Mg^{++}	Magnesium ion	12.16
Cl^{-}	Chloride ion	35.46
$SO_4^{=}$	Sulfate ion	48.03
$CO_3^{=}$	Carbonate ion	30.00
HCO_3^{-}	Bicarbonate ion	61.01
NO_3^{-}	Nitrate ion	62.00
$CaCl_2$	Calcium Chloride	55.50
$CaSO_4$	Calcium sulfate	68.07
$CaSO_4$-$2H_2O$	Gypsum	86.09
$CaCO_3$	Calcium carbonate	50.04
Na_2CO_3	Sodium bicarbonate	53.00
NaCl	Sodium chloride	58.45
Na_2SO_4	Sodium sulfate	71.03
KCl	Potassium chloride	74.56
K_2SO_4	Potassium sulfate	87.13
S	Sulfur	16.03
H_2SO_4	Sulfur acid	49.04

name	Units
Electr. Conductivity	mmhos/cm
Reciprocal ohm	mho
Millimho	mmho
Milliequivalent	meq
ppm	parts per million
milligram of solute per liter of solution	mg/l

Basic Units and Symbols

Symbols	Quantity	Units
m	Length.	meter
kg	Mass	kilogram.
s	Time	second

The thermodynamic temperature and its unit [degree Kelvin], the luminus intensity and its unit the [candela] and the Electric current and its unit the [ampere] are not used in this thesis.

Derived Units used in this thesis. (see also units for Chemical analysis)

SI Symbol	Quantity	Unit
m/s^2	Acceleration	meter per second squared
m^2	Area	squared meter
km^2	Area	squared kilometer.
kg/m^3	Density	kilogram per cubic meter. For convenience the density unit gram per cubic centimeter is used. 1 kg / m^3 x 0.001 = g /cm^3 .
m^3 / s	Discharge	cubic meter per second. Unit m^3 / min or cubic meter per minute , lps liter per second are used. 1 m^3/s =1000 lps = 60 m^3/min.
N	Force	newton
mm	Length	milli meter
g	Mass	gram.
N/m^2	Pressure	newton per square meter.
atm	Pressure	The unit atmosphere is also used. 1 atm = a column of 10.33 m water at 4°C .
°C	Temperature .	degree-celcius
m^3	Volume	cubic meter
cm^3	Volume	cubic centimeter. 1 m^3 = $(100)^3$ cm^3
min	Time	minute
d	Time	day
m/s	Velocity	meter/second
rpm	Angular velocity	revolutions per minute. 0.105 rad/s. = 1 rpm.

LIST OF ABREVIATIONS

ADOSAPACO : Administración Directa de Obras y Servicios de Agua Potable y Alcantarillado de la ciudad de Oaxaca.

ASERCA Apoyos y Servicios a la Comercialización Agropecuaria.

BMP BMP is the standard MS-Windows™ bitmap raster format.

CADER[1] Centros de Apoyo al Desarrollo Rural. See PROCAMPO

CEDH Comisión Estatal de Derechos Humanos...

CFE. Comisión Federal de Elctricidad.

CMYK Cyan (C), magenta (M), yellow (Y), and black (K).

C.N.A Comisión Nacional del Agua.

The Comisión Nacional del Agua was created in 1989 with the following duties:

- To supervise the operation and conservation of irrigation units.
- To Plan construct and rehabilitate the Irrigation Units
- To assist water users in formulating irrigation units and to provide them technical assistance .
- To propose policies referring to the use, distribution and abstraction of water.
- To control River Flows and guarantee safety of the hydraulic infrastructure during construction and operation.
- To organize the Financial System of Water.

Background on C.N.A and S.A.R.H

On the first of February 1989, the president of the Republic of Mexico Carlos Salinas de Gortari, proclamed the Act in which the Comisión Nacional del Agua **(C.N.A)** was officially inaugurated. This new organization was given the mandate to ensure that the distribution, use and conservation of water resources would be carried out according to some rigid scientific rules of efficiency and equity. Until that day, the Secretary of Agriculture and Hydraulic Resources (Secretaria de Agricultura y Recursos Hidráulicos **(S.A.R.H)** had been assigned these duties but given the rapid expansion of water infrastructure , these two fundamental objectives of efficiency

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[1] For more details about the role and action of each CADER see Manuales de capacitación . PRODUCTOR. SECRETARIA DE AGRICULTURA Y RECURSOS HIDRAULICOS 1993. Diseñado y Editado por INCA RURAL, A.C en Coordinación con ASERCA

and equity demanded the creation of an organization that would be autonomous and separate from the Federal Government.

Although these two organizations work independently today, they work in very close co-operation. In Oaxaca, the great majority of C.N.A staff was working under S.A.R.H 8 years ago. It is therefore not surprising that today , workers from both organizations still belong to the same Union. S.A.R.H has various functions but its main responsibility is the implementation of Agricultural Policies and the monitoring and promotion of the Agricultural Production.

CI Confidence Interval.

COPLADE Comité de Planeación para el Desarrollo de Oaxaca.

*Cada municipio recibe recursos de los fondos de Solidaridad, de acuerdo con la marginlidad. Todo se realiza mediante un trabajo conjunto entre las tres entidades federativas: el gobierno federal, a través de la Sedesol: el gobierno estatal, por medio del Coplade, y el gobierno municipal, base en sus comunidades. La forma de involucra la participación social es por medio de los consejos municiales de Solidaridad y el comité local de Solidaridad.***ELEXTRA.18Mayo 1994**

DDR Distritos de Desarrollo Rural. See PROCAMPO

DRAINMOD A watertable management model developed by R.W. Skaggs.

EC Electrical Conductivity

ET-R. Evapotranspiration - Rainfall

Excel Registered trademark of Microsoft Excel for Windows 95. Version 7.0. Copyright © 1985-1995 Microsoft Corporation, 1987-1993. Use of brand names in this thesis is for identification purposes only and does not constitue endorsement by the author.

FAO Food and Agriculture Organization of the United Nations.

FIRCO Commission to promote and support shared risk investment in integral projects of transfer of technology works of rural infrastructure and projects of technical assistance.

GIS Geographic Information Systems.

ID Irrigation districts. See also IU and WUA.

IDRISI Developed by the Graduate School of Geography at Clark University and introduced on the market in 1987, IDRISI is a popular raster-based microcomputer Geographic Information System (GIS) and image processing on the market. It is for its popularity and because it is used by C.N.A in Mexico that this GIS software was used in this research. It is not by any means suggested here that IDRISI is superior to its competitors. **Use of brand names in this thesis is for identification purposes only and does not constitue endorsement by the author.**

IEA Instituto. Estatal del Agua

ILRI International Institute for Land Reclamation and Improvement.

IMSS Instituto Mexicano del Seguro Social

ITO Intituto Tecnológico de Oaxaca.

Instalaron una estación metereológica en el I.T.O. Inauguración al término de la Jornada Académica de Ingeniería Civil. 5 de mayo 1994.

IU Irrigation units. See also WUA

KS Kolomogorov-Smirnov

lps **Liter per second.**

MLR Multiple Linear Regression

PREFLO PREFLO mode developed by Workman and Skaggs (1992) .

PROCAMPO

Programa de Apoyos Directos al Campo.
El PROCAMPO es un programa con una dureción mínima de 15 años.. PROCAMPO es un esquema bien definido que busca apoyar la productividad y aumentar la calidad de los productos del campo.. EL EXTRA 9 de Mayo 1994. PROCAMPO inició en 1994.

RDM Rational Deductive Method .

R:ET_0 The Ratio. Rainfall / Potential -Evapotranspiration .

REV Representative Elementary Volume

RGB Red Green Blue.

RPM Rotational Velocity ., revolutions per minute.

SAR Sodium Adsorption Ratio

S.A.R.H **Secretaria de Agricultura y Recursos Hidraulicos.**

The Secretaria de Agricultura y Recursos Hidraulicos is responsible for :

- The implementation of Government Agricultural Policies.
- To set standards for Producers Organizations
- To promote Institutional Services.
- To supervise all agricultural aspects of the Irrigation Unites for the rural development.

SCS Soil Conservation Service.

SEDAF Secretaria de Desarrollo Agropecuario y Forestal

Más que saque forestal lo que existe es falta de información..,proque se cuenta con medidas claras de regulación , de control de tráfico de las especies forestales.. 6 de Mayo 1994. EL SUR.

SLR Simple Linear Regression

STD Standard Deviation.

TIFF Tagged-Image File Format .

TIFIDRIS Module of IDRISI™ for MS-Windows™ was used to convert from TIFF to IDRISI for Windows or vice versa

UNORCA Unión Nacional de Organizaciones Campesinas y Forestales.

WUA Water users associations.

Water rights, use rights.

The actual water rights are held by the Comision Nacional de Agua (C.N.A) for the Mexican people and concessions for water use are made for a period of 5 to 50 years. with most of them for 30 to 50 years. The water concessions are made to a variety of entities including water users associations (WUA), irrigation units (IU) individual users, private firms, irrigation districts (ID), and municipalities.

Concession owners must pay a water fee that will help finance C.N.A. The use fee is in two parts, one for the volume extracted, and the other for the volume and quality of the discharge. To maintain ownership of a water concession, the water must be used at least once every three years. This means the owner of the water concession must pay the extraction fee. Easter and Hearne (1995) discuss the difficulties in implementing these three-year limit. The new water law makes it legal to lease or sell water and establishes water concessions or use rights on a volumetric basis separate from land rights. Intersectoral trades are subject to regulation by the C.N.A.

These concessions to use water are registered by the (C.N.A) as are permanent sales of water concessions. The new water law makes it clear that the responsibility for water management is supposed to be decentralized to WUA who assume the responsibility for maintaining the system and allocating the water locally. Easter and Hearne (1995) point out that the idea of water concessions is not new to water users in Mexico since the concept of separating the water right from a use right (concession) was introduced during the Spanish period.

CHAPTER I

INTRODUCTION

The nature and objectives of this research and its contributions to knowledge are the main object of this chapter. These can not be stated and understood without first introducing the environment prevailing in the research region. The field work for this research took place in the Central Valleys of Oaxaca located in the state of the same name in the Republic of Mexico. Much of the analysis and writing was done at Montreal. The background information that follows is needed to assist the reader in understanding the physical and social framework specific to this research. Following this section identified as Background Information, the nature and objectives of this research are discussed. This chapter ends with a list of contributions to knowledge that are provided by this research.

BACKGROUND INFORMATION[1]

The state of Oaxaca is located in the south-east part of the Mexican republic between 15°38' and 18°48' latitude north and between 93°52' and 98°30' longitude west. The state of Oaxaca shares its border with the states of Puebla and Veracruz on the north and north-east, with the state of Chiapas on the east, with the Pacific Ocean on the south and finally with the state of Guerrero on the west. **A Map showing the political division of Mexico is given at the end of this chapter.**

The state of Oaxaca has a total area of 95 364 km^2, which is approximately 4.8% of the total area of Mexico . Oaxaca is the fifth largest state of the republic after the states of Chihuahua (largest), Sonora (2), Caoahuila (3) and Durango (4).

The state of Oaxaca is patently more complex geologically than any other area of Mexico of comparable size. Almost half the state is over 1500 meters in elevation above sea level (Kowalewski et al., 1989). The peak elevations of the highest mountains of the state of Oaxaca range from 3100 to 3900 meters. The peak elevation

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[1] Taken from Programa Estatal de Aprovechamiento del Agua, C.N.A. Oaxaca. December 1992.

of the mountains surrounding the research project area is 3300 meters which is comparable to the peaks in the Canadian Rocky Mountains. The elevation of the valley of Tlacolula de Matamoros (the research area) ranges from 1580 to 1860 meters above sea level.

The state of Oaxaca has been a functional region for at least three millennia (Arbor, 1989). The capital "Oaxaca de Juárez" , founded in 1486 as an Aztec garrison, is practically the centroid point of the state. The name Oaxaca was derived from the Aztec word "Huaxyacac" which means "the location of the guaje". The tree *Guaje* (Leucaena esculenta) is abundant in the central valleys and its fruit is edible (Diskin and Cook, 1975).

The state of Oaxaca was until recently dominated in area and number of speakers by its Mixtec-Zapotec core. Below the level of these groups are many dialects making the area linguistically diverse. Laura Nader (1969, as reported by Kowalewski et al., 1989) maintains in regard to Zapotec, that these nine dialects are in fact languages as different as Spanish and French.

The three central valleys of Oaxaca (Etla, Tlacolula and Zimatlan) are located approximately 530 kilometers to the south of Mexico city. By bus, what used to be a long and painful twelve hours expedition through endless mountains has now become a pleasant seven hours journey, thanks to the new highway completed in December 1994.

The groundwater of the two valleys of Etla and Tlacolula meet at the city of Oaxaca and flow into the groundwater subbasin of the valley of Zimatlan. **Figure K4 in Appendix K shows the three Central Valleys of Oaxaca**. The mountains that surround these three valleys are assumed for the moment to make these groundwater basins hydraulically independent except at their junction point at the city of Oaxaca. The topography and geology of the area are such that no backwater and/or leakage can take place from one groundwater basin of these three valleys to another except via the central region around the city of Oaxaca.

We shall see in light of historical groundwater exploration data that this assumption although valid for the aquifer under present exploitation has also certain

limitations of application. Under these limits however, the groundwater of either the valley of Tlacolula or of Etla can be modeled as an independent aquifer. The junction area of these two groundwaters is well defined and can be practically excluded from the analysis of either groundwater basin.

In other words it is convenient and reasonable to visualize the two upstream central valleys of Oaxaca (Etla and Tlacolula) as two completely independent valleys from which their outflow is collected and serves as inflow to the valley of Zimatlan[2]. The underground of the City of Oaxaca serves then as a large buried conduit to bring these two groundwaters to the groundwater basin of Zimatlan. This illustrates the fragile position of the capital in terms of potential water contamination.

The Research Area

The area investigated in this research is the groundwater basin of the valley of Tlacolula de Matamoros. The Tlacolula valley is the second in importance of the three central valleys of the state of Oaxaca.. Tlacolula de Matamoros is connected to Oaxaca city, the capital of the state of Oaxaca, and the rest of the country by road #190, better known as the Panamerican or "Cristóbal Colón" road.

In the research area (Tlacolula District), the Zapotec civilisation has very well established roots; not only as a spoken language, but also in the people's traditions. Spanish, the official language in Mexico, is however now understood by almost everyone.

Rainfall Pattern

In the summer, masses of tropical air coming from the Gulf of Mexico and from the Caribbean Sea penetrate all the territory up to the mountain range of the "Sierra Madre Occidental". These humid winds called "the trade winds" (Alizés) are the cause for the heavy rains that take place regularly from May to the end of September throughout the country east of the Sierra Madre Occidental.

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[2] Also called Zaachila Valley because of the historical imprtance of Zaachila. The population of Zimatlan (15 315 in 1990) now exceeds the population of Villa de Zaachila (11 861 in 1990).

These rains are also influenced by the displacement of the "thermal equator" to the North in summer, accompanied by a zone of low pressure and convective winds producing abundant rains during their cooling ascent. In most of valleys in Mexico, when such a weak pressure system takes place, a diurnal variation of wind direction occurs. The wind blows upslope in the daytime and downslope at night.

Similarly, the very dry months in winter are the result of the invasion of masses of cold air coming from the North. These dry cold air currents travel at very high altitude and become warmer in their descent while remaining relatively dry. This explains why the air is so dry in January and February almost every where in Mexico with the exception of the North West of Baja California.

In conclusion. the general precipitation pattern in the central valleys of Oaxaca is directly related to the movement of global air masses.

General Topography , General Gradient and Direction of Flow

The topography of the Tlacolula valley follows a continuous slope oriented South-east - North West. At its highest level the ground elevation of the valley is about 1700 meters above sea level. At its lowest point it is approximately 1550 meters above sea level. Mountain peaks in the northern range of the basin reach 2700 to 3300 m above sea level. On the southern range, mountain peaks are less dominant with elevations from 2 200 to 2 800 meters above sea level.

The valley is of irregular shape. Its longest axis slightly exceeds 40 kilometres. The middle section of the valley approaches 17 kilometres wide. The valley gets relatively narrow at the outlet of the aquifer.

The general groundwater flow follows the topography of the valley. At the extreme south-east where the river "Salado" makes its first appearance, the groundwater flow has an approximate hydraulic gradient of 8.6×10^{-3} . As the river reaches the middle of the valley the hydraulic gradient of the groundwater seeping towards the river has then decreased to 5.7×10^{-3}. Along its journey, meandering along the South-East - North-west axis of the valley, the river receives much water from the mountains.

When the river "Salado" crosses the project area, the gradient of the groundwater varies then from 8.0×10^{-3} to 13.0×10^{-3}.

According to Kirkby(1973), the most important criteria for distinguishing land for agriculture are gradient, altitude and soil. On the basis of these criteria, the valley is divided into four physiographic zones: mountain, piedmont, high alluvium, and low alluvium. A summary of Kirkby's (1973) description of the four physiographic zones in the research area is given in Appendix K.

Demographic And Social Aspects [3]

In 1990 [4], the total population of the state of Oaxaca was 3 019 560 people distributed in 7210 localities and 570 townships [5] with 39.5% of the population living in 134 urban municipalities and 60.5% living in rural communities. We note in Table 1 a growth rate of 2.2% for the state population between 1980 and 1990. This state ranks tenth at the national level in terms of growth rate. The total population of the central valleys of Oaxaca was, in 1990, 718 942 people (density of 82.05 people/km^2) which represented 23.8% of the total population of the state of Oaxaca.

There are seven districts in the central valleys of Oaxaca. The capital, Oaxaca city, is the most populated district of the central valleys. Its population was, in 1990, 342 338 people. This research project is concentrated in the Tlacolula district which is

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[3] Taken from **OAXACA STATISTICS YEARBOOK.**
These yearbooks are divided into four chapters.
Chapter 1: Data relative to geographical situation and conditions of the environment.
Chapter 2: Conditions of the infrastructures.
Chapter 3: Demographic data.
Chapter 4: Economic activities.
Yearbooks of 1985, 1987, 1989, 1990 , 1991 and 1992 were consulted. These yearbooks are all published by INEGI. See References under INEGI "Anuario Estadistico Del Estado De Oaxaca"

[4] Statistics of 1990 are chosen because of the extensive socio-economic survey of all townships that took place in that year.

[5] *Municipios* is translated here as townships as suggested by (Kowalewski et al, 1989).

the second most populated district of the central valleys of Oaxaca. Its population was 99 915 people in 1990.

The group of people between 0-19 years old represented then 50% of the population and the group between 20 - 49 years old, 36.4%. Approximately 13% of the population was older than 50 years.

Active Population

Refering to Table 2 and Figure 1, we note a clear shift in the break down of the active population. This is characterized by a significant increase of the active population working in the industrial sector and the sector of services. In 1980, the industrial sector and the sector of services attracted 7.1% and 13.5% respectively. Ten years later the industrial sector and the sector of services attract 16.4% and 28.3% respectively. The number of people working in the primary [6] sector significantly increased in the decade 1970-1980 but one can speak of a continuous decline in terms of percentage of active population since 1970. It is not clear however why in 1980 there is such a high percentage (24.1%) of active population who was reported as involved in "not specified activities".

The primary sector was responsible for providing work to 72% of the active population in 1970, 55% in 1980 and 53% in 1990. This social trend towards industrialization and an economy growing steadily in the sector of services are not unusual in North America. Agriculture practiced in Oaxaca is however very different from Canada.

When expressed in constant 1980 Pesos, the agricultural production went down 18% from 1980 to 1990 whereas the decrease in the active population working in the primary sector was 16%. Production of the industrial sector during the same decade went up 32%. The economic crisis of the 1980's had a major negative impact on the injection of money in agriculture. This is explained by C.N.A (1992 Report) as a

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[6] *Primary* relates to agriculture and forestry and the extractive industries or their products.

return to traditional methods of farming resulting in a significant decline in production yields.

National versus Oaxaca State

Table 3 shows some perturbing demographic statistics for the state of Oaxaca when compared with the same for the Republic of Mexico. These statistics are given for the period 1940-1990 in the case of the Republic of Mexico and for the period of 1970-1990 in the case of the state of Oaxaca. These statistics are: the percentage of the population living in rural and urban areas and the percentage of the population employed or economically active. Out of this active population a breakdown is also given to examine the proportions of the active population working in each of the three major sectors of the economy. These are; the primary sector, the industrial sector and the services sector.

In 1970 the relative population of the state of Oaxaca expressed in terms of the total Mexican population was 4.9% about the same as its 4.8% of the area. Oaxaca did not lose any territory but its relative population decreased continuously to reach a minimum of 3.5% in 1980. People were leaving Oaxaca for better conditions elsewhere. In 1990, 3.7% of the entire mexican population was in Oaxaca state.

Given this relatively small population of the state of Oaxaca, we can reasonably position Oaxaca state demographic statistics (denoted here Oax. State) with respect to the statistics of the country (denoted Country) without having to correct the statistics of the Country (Country) for the contribution of Oax. State within the Country . This is done in Table 3.

It can be seen that Oaxaca demographic distribution and the breakdown of its active population in 1990 compare relatively well with the 1960 distribution of the national demography and the break down of its active population . Mexico has a greater percentage of active population. This has always been and most likely will remain the same for a long time. A fact remains, the state of Oaxaca is facing today a demograhic distribution somehow similar to what the rest of the Country was facing some twenty to thirty years ago.

The demographic distribution gap between Oaxaca and the rest of the country is expected to decrease since the migration to the urban areas is slowing down at the national level and so is the growth of the sector of sevices.

It is logical therefore to conclude that this demographic time warp is at its peak now and so must be the self regulating social pressure if any for demographic movements towards zones of greater perceived benefits.

Importance Of Agriculture

The economy of Oaxaca is dominated by tourism and agriculture. In 1992, approximately 31% of the economically active population was involved directly in agricultural activities. The agricultural production however is far below its actual capacity. Still today, less than 65% of the cultivable land can be found under cultivation at any time of the year, whereas the rest of the time the land is abandoned.

The agricultural productivity of the Central Valleys consists almost entirely of peasant agriculturalists who use traditional methods of cultivation and irrigation and have small scattered holdings (the great majority have less than 2.5 ha) , low capital resources, and strong social and economic ties within the village.

Peasant is generally understood to mean an agricultural producer with a low level of technology and little land or capital resources, who grows food for his family and provides produce for sale in markets which support large centres of population.

In Oaxaca, peasant means a small-scale agricultural producer who grows some food for direct consumption by his family and also works to earn cash income by producing cash crops or other goods and services. A peasant household in Oaxaca is an economic unit for production and consumption.

By an agriculture of subsistence, Kirkby (1973) does not mean an economy which produces the bare minimum required to keep people alive or that all the needs of a household are provided directly by subsistence agriculture. Kirkby (1973) refers to Nash (1966) who pointed out that in any human society subsistence includes a biological minimum requirement and an additional cultural component which can include the supplies for large feasts and elaborate ceremonies.

According to Nash (1966), subsistence agriculture in Oaxaca means an agriculture in which production and consumption are more or less direct without intervening acts of exchange among producing units although some exchange will exist.

In the Valley of Oaxaca, subsistence agriculture must be combined with other sources of income because, by definition, it cannot provide cash for the household's other needs. When corn is grown in addition to the food needs of the producer and is aimed at the cash market, it becomes a cash crop.

Table 4 shows the land uses, areas and percentage for the state of Oaxaca. It can be seen that the area of cultivated dry land is about eight times the area of irrigated land. This ratio amounts to sixteen within the research area. Irrigated land generally constitutes the best land in the Valley and is more or less synonymous with cash-crop production. Irrigated land is not, however, separated from dry land farming for subsistence crops because everywhere irrigated fields are interspersed with dry-land corn fields.

Satisfaction strategies [7] are predominant not only in unirrigated subsistence agriculture but also where production for a market is concerned. Indeed, Kirkby (1973) shows evidence that even where cash-crop production is in the hands of individual households, peasant agriculturists appear to achieve satisfaction in a similar manner to the way in which they achieved it in their subsistence agriculture - by under-utilising their labour resources rather than their land resources.

Kirkby (1972) recognizes that the increasing commercialism of some irrigators indicates that these attitudes are undergoing changes.

The Level Of Margination Of The Target Population

In 1990 in order to fight poverty, an extensive survey of all Mexican municipalities was conducted in order to elaborate a diagnostic tool that would indicate

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[7] Strategies where crop production is aimed at a satisfaction level. A satisfaction level in corn production is understod as an amount grown by a cultivator which is defined not by the limit of his landholding or his labour, or even of his family's needs, but is a response to the amount he wants to grow and the time he wishes to expend in relation to his other work and leisure activities.

the level of social margination[8] of each township. This national survey was conducted jointly by the Consejo Nacional de Poblacion (CONAPO) and the C.N.A.[9]

This level of margination is based on nine indicators that were selected to reflect the conditions and processes of social deficit. These indicators are the following:

1. Percentage of illiteracy.
2. Percentage of population over 15 years old and without primary education.
3. Percentage of dwellings with no sewage system.
4. Percentage of dwellings with no electric power.
5. Percentage of dwellings not served by an urban water pipe distribution system.
6. Percentage of dwellings with more than 2.5 people per room (high level of occupancy).
7. Percentage of dwellings with an earthen floor.
8. Percentage of population living in townships with less than 5000 people
9. Percentage of working population with an income smaller than twice the minimum salary.

The overall index of margination (IM) that is calculated from these nine indicators reflects the social deficit of the township. The more positive the IM value the more marginate is the township and therefore the higher is the deficit of the township. Five levels of margination are proposed as a margination classification tool by CONAPO, those are:

VERY LOW Level of Margination	$-2.6 < IM < -1.6$
LOW Level of Margination	$-1.6 < IM < -0.5$
AVERAGE Level of Margination	$-0.5 < IM < 0.0$
HIGH Level of Margination	$0.0 < IM < 1.1$
VERY HIGH Level of Margination	$1.1 < IM < 2.8$

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[8] In spanish the word *marginación* is used. The english word margination is the action or process that leads to a margin distinct in appearance or structure (here understood as social structure).

[9] For further details see the reference under CONAPO-CNA: Indicatores Socioeconómicos e Índice de Marginación Municipal 1990.

Table 5 gives for each state of Mexico, the number of townships belonging to each of these five levels of margination. The Index of Margination for each state is also estimated in order to rank the state of Oaxaca in terms of social deficit with respect to the rest of the Country. The method for calculating this State IM value is explained at the bottom of the Table.

It can be seen from Table 5 that Oaxaca in 1990 was the third most marginate state of the country. What is even more alarming is the fact that out of the only six other states of the country that have a high level of margination, four of them are states neighbouring the state of Oaxaca (Chiapas, Guerrero, Puebla, and Veracruz). This suggests there has been an important geo-political feature contributing to the drawback in the social development of the south-east region.

The same Table also shows that Oaxaca is the state with the highest level of fragmentation, with 570 townships. This is 23.7% of the total number of townships in Mexico whereas the population of the state of Oaxaca is only 3.7% of the total Mexican population.

Table 6 shows the total population and the index of margination with detailed calculations for all the townships located in the research area. It can be seen that out of the twenty-two townships that were surveyed in 1990 within the research area, one had a very high level of margination (Magdalena Teitipac), thirteen had a high level of margination, six had an average level of margination and only two had a low level of margination. It becomes evident why the capital, Oaxaca de Juarez, with a very low level of margination, is attracting so many people. This social deficit with respect to the capital is true not only for the Tlacolula district but CONAPO - C.N.A (1993) concludes it also applies to all rural districts of the state of Oaxaca when compared with the capital .

Figure 2 and Table 8 may be analyzed as a direct consequence of this social deficit in rural areas. The population growth between 1940 and 1990 for the state of Oaxaca is far less rapid than the population growth in the district of Oaxaca city. This is

not due to a greater birth rate in the capital but rather to a clear migration of the state population towards the capital.

While it is true that an effort is being made to reduce these social deficits in Mexico and tangible success is being achieved [10], one must recognize that the research area is one with a high level of social deficit, an important consideration that must be taken into account in this research.

Reform of Article 27 of The Constitution.

The main objective of this reform is to increase food production and to bring abandoned or marginally exploited farm lands under cultivation. To achieve this goal , the government encourages farm users to enter into partnerships (with the commercial or private sector) with the aim of receiving financial support that would allow them to complete infrastructures required for full and profitable exploitation of their land. For example S.A.R.H through FIRCO and CONASUPO signed an agreement to make available 63.4 millions Nuevos Pesos (in 1994, 1CAN$ = 4.0 N$) for works in soil and water conservation and for the distribution of 22 500 metric tons of corn and 3 000 metric tons of beans. For each N$ coming from the government the same must be invested by the beneficiaries generally in form of manpower. Agricultural programs aimed at increasing crop yields are also put in place[11]. This agricultural development plan is called "El plano de desarrollo parcelario".

Urgent Need For A Water Management System.

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[10] Maybe the most impressive success C.N.A had was with the control of cholera. This was achieved with the creation of special brigades that would visit each dwelling to guarantee chloration of water in rural areas after heavy rains that cause river overflow. Out of the 15 cases of cholera registered in the first months of 1994, 14 were actually contracted outside of Oaxaca, one only was contracted locally.

[11] Programs such as the following in 1994 for the state of Oaxaca: Programasde Maiz de Alta Producitividad in 20 000 hectares, Programa de Trigo de Alta Productividad in 3 500 has, programs in elaboration for rice , 2000 has for a target yield of 5 tons-ha and programs for beans production in the region of Mixteca for a target production of 12 000 tons. NOTICIAS 9 May 1994. Detailed money investments can be obtained from S.A.R.H/Oaxaca.

Schneider (1982) classifies the following main forms of land tenure currently recognized in Mexico by the Federal Agrarian Reform Law, 1971:

Communal _ *Ejidos*, i.e., communal holdings where land is owned by a community of peasants, and cropland is allotted individually to each family. Each family is then an *ejidatario*. In collective ejidos, land , tools , animal and commerical activities might be shared.

Private properties. 1) Minifundia, small properties generally less than 5 ha. ii) " Pequeños proprietarios ". This sector includes rural properties from just above the minifundio level up to several thousand hectares. The English translation "small proprietors" is, for this reason misleading.

Oaxaca is particularly sensitive to the threat of chaotic development of their aquifers, following the reform of Article 27. The state of Oaxaca has indeed the greatest number of *ejidatarios* that is 329 986 or almost 11% of the entire number in the country. Oaxaca also has the third highest amount of agricultural land of federal government ownership.

Therefore, there is an urgent need for the C.N.A. to develop a water management system that will be able to respond quickly to the demands of the water users while ensuring that exploitation of the water resources does not jeopardize a sustainable development of the valley.

The situation is further complicated by the fact that the bulk of the population of the Central Valleys of Oaxaca is concentrated in the semi-arid areas. The productive potential of these areas depends primarily upon the use of water. The development of the central valleys of Oaxaca will demand from the managers an optimal use of the surface and subsurface water.

This research study is limited to the human and physical management of the groundwater while keeping in view a conjunctive use of the surface and subsurface water. While this research study is limited to the scope of groundwater management, the analysis of groundwater recharge demands a global approach in quantifying the hydrologic cycle.

Because of the agricultural vocation of the Central Valleys of Oaxaca, the water management system required must include an Agricultural Production Function so as to optimize the use of the water resources. It must also include a permanent groundwater and surface water observation network and take into account the cultural particularities of the users.

The need for including cultural constraints arises from Kirkby (1973) who rather than resorting to environmental imperatives, concludes that Oaxacan agriculture has probably always been under-productive for reasons which are directly related to the "satisfying" world view of the Valley Zapotec.

One aspect no less important is the social implication related to the implementation of a water management system . This aspect is fundamental. Wolf (1966) has argued that it is not simply the existence of potential surpluses that stimulates development but also the presence of institutional means and imperatives within the organisational structure of society to mobilise them.

Wolf's argument according to Kirkby (1973) holds important implications as to how cultural development has proceeded in the past and how far resources are exploited today in the Central Valleys of Oaxaca. This suggests that it is most likely the social constraints that will dictate how far planned agricultural and economic development can succeed in the future if it is not accompanied or preceded by fundamental changes in society. This topic is not tackled in this research but will be discussed briefly in the last chapter with the objective of setting some guidelines that revealed themselves in the process of this research and that may prove useful for future research in this field.

Long Term Objective

The Long Term Objective goes beyond the scope of this work but it is discussed here for a better understanding of the need for this research. The long term objective is to provide C.N.A-Oaxaca, the manager of the water resources of the state of Oaxaca, with a complete groundwater management system. A priori, such a system will include a groundwater flow model that describes the physical behavior of the groundwater system, an agricultural production function that reflects the seasonal life cycle of the

crops and the effect of changing hydrological conditions on the latter and an aquifer-depletion function to assist regulatory officials in implementing well drilling and operating controls.

The goal of this management system is to ensure sustainable economic growth while still protecting the natural environment and cultural particularities of the water users. The groundwater flow model will demand the establishment and monitoring of an observation network for continuous calibration of the model. Similarly, agricultural production should be monitored closely. Social constraints and social response to the implementation of these managment practices will be key parameters in the equation. This social-technical-economic triangular foundation is intrinsic to the duties of the C.N.A and was expressed by the president of the Mexican Republic at the time of creation of the C.N.A in the following terms:

"En suma , la C.N.A habrá de incorporar la visión del ingeniero. la lógica económica pero todo ello con un profundo sentido social". "In a nutshell, the C.N.A will have to incorporate the vision of the engineer. the logic of economics but all this with a profound sense of social values." Carlos Salinas de Gortari. President of the U. S of Mexico..Feb/01/1989 .

In agreement with Freeze's concern (1988) for an analysis of data worth prior to any data collection program, it was decided to first proceed with an analysis of the worth of the data available. From the above simple considerations the following specific objectives were set for this research.

Objectives Of This Research.

The objectives of this research reflect the common urgent need for the C.N.A and for S.A.R.H to develop a water management package that can simulate the response of the groundwater to the stimuli induced by realistic agricultural production strategies and from which optimal water management practices can be established.

In this research, our attention will be focused on the first steps required for the elaboration of such an agro-water model.

The specific objectives of this research are:

1) To derive a scientific methodology for the preparation of basemaps and for data collection required in the development of the groundwater flow model. This methodology will be reproducible and compatible with functions and responsibilities of the Comisión Nacional del Agua (C.N.A).

2) To review, analyse and investigate scientific methods of analysis and to propose methods of interpretation of data of historical single well tests conducted in the research area .

3) To investigate the climatic and hydrologic conditions prevailing in the Central Valleys of Oaxaca that are needed for the future evaluation of the recharge of the aquifers and for the determination of the potential area of irrigable land.

4) To assess the quality of groundwater over the area in order to determine the suitability of water for irrigation and/or to obtain an early warning of groundwater salinization or pollution.

5) To establish a convenient groundwater monitoring network. A convenient network is one where the observation wells are readily accessible, while being representative of the hydrogeology of the area and meeting the basic hydraulic requirements of accuracy and reliability for monitoring the aquifer.

6) To establish basic guidelines for further research required for the elaboration of the proposed groundwater management scheme.

Contributions To Knowledge.

This research study will benefit water managers of Oaxaca and similar semi-arid areas by providing scientific analytical considerations for the groundwater basin geology, water quality, basin precipitation, and surface streams hydrology.

This research study will benefit the scientific community involved in groundwater management by providing researchers with feedback regarding practical requirements and needed extensions of existing methods.

This research study will also benefit the scientific community involved in archaeologically-related geo-cultural geography by providing researchers with a low cost and accurate mapping procedure.

Contributions to knowledge are in:

1) Establishing a methodology for the preparation of multi-layer electronic basemaps (topography, geology, soil, agricultural production, water quality).
2) Development of a scientific method of analysis and interpretation of single well tests data for determination of aquifer parameters in an unconfined aquifer.
3) The analysis of temperature and rainfall data for the period 1950- 1980 and the demonstration of a significant increase of the minimum monthly temperature in time.
4) The frequency analysis of the rainfall data in the dry months and the presentation and comparison of three methods of analysis for overcoming statistical analysis limitations in dealing with recurrence of zero rain.
5) The review of sustainable water management practices in a dry farming peasant type agriculture and a view on the social implications associated with in promoting irrigation in the dry season.

TABLE 1. POPULATION GROWTH BETWEEN 1970 and 1990. BY SIZE OF MUNICIPALITIES

	------- 1970 ----		------- 1980 ----		GROWTH	------- 1990 ----		GROWTH
Township Size	Population	%	Population	%	1970-80 %	Population	%	1980-90 (%)
Upto 2500 people	1470685	73.0%	1611205	68.0%	0.8%	1828257	60.5%	1.2%
Upto 10 000 people	302252	15.0%	374024	15.8%	2.0%	544339	18.0%	3.5%
Upto 50 000 people	142952	7.1%	229624	9.7%	4.4%	256036	8.5%	1.0%
Upto 500 000 people	99535	4.9%	154223	6.5%	4.4%	390928	12.9%	8.8%
More than 500 000	0	0.0%	0	0.0%	0.0%	0	0.0%	0.0%
TOTAL	2015424	100.0%	2369076	100.0%	1.5%	3019560	100.0%	2.2%

Source: Censos Generales de Poblacion y Vivienda . 1970, 1980,1990. (INEGI)

POPULAT.xls

TABLE 2 POPULATION ECONOMICALLY ACTIVE.

(in thousand of people)	1970		1980		1990	
Activity Sector	**Active Population Sector wise 1970.**	**Sectorial Percent of Active Popul. 1970**	**Active Population Sector wise 1980.**	**Sectorial Percent of Active Popul. 1980.**	**Active Population Sector wise 1990.**	**Sectorial Percent of Active Popul. 1990.**
Agropecuarian (Primary)	372950	71.5%	474793	55.3%	398848	52.9%
Industrial	56952	10.9%	60899	7.1%	123805	16.4%
Services	63402	12.2%	115786	13.5%	213819	28.3%
Not specified	28081	5.4%	206805	24.1%	17833	2.4%
T O T A L Active	521385		858283		754305	
Entire Population	2015424		2369076		3019580	
Active Population in %	25.9%		36.2%		25.0%	

Source: Censos Generales de Población y Vivienda 1970, 1980, y 1990. (INEGI).

Figure 1 Active Population in Oaxaca State 1970-1990. Sector Wise.

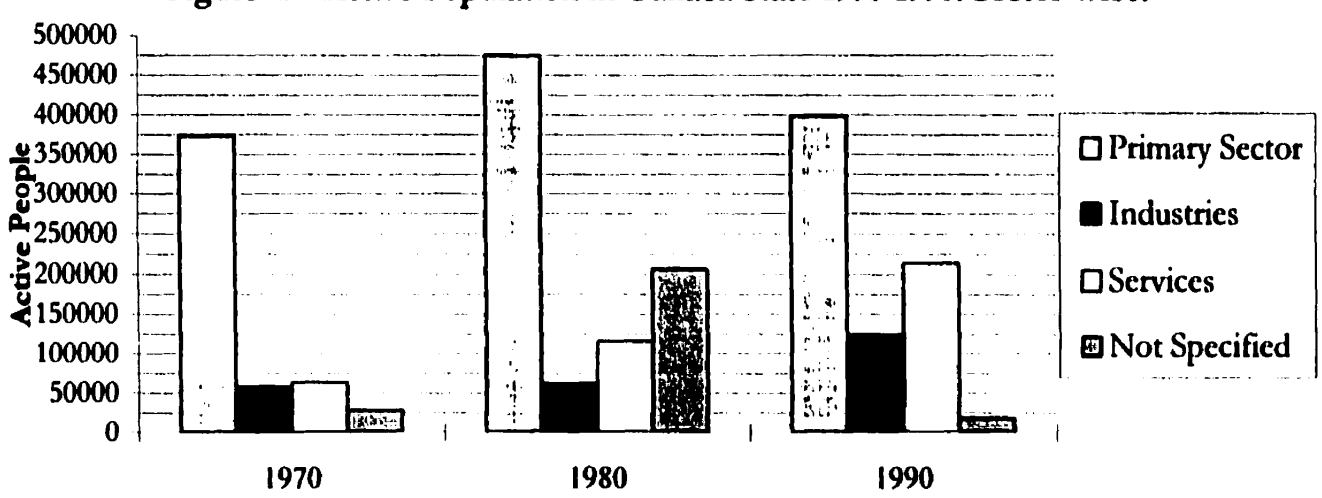


TABLE 3 OAXACA STATE versus MEXICO (national). DEMOGRAPHY

	COLUMN A		COLUMN B		B/A
	MEXICO Country (in thousands)		**Oaxaca State** (in thousands)		
Year	Total Popul.	Active pop.	Total Popul.	Active pop.	%
1930	16553	5151			
1940	19654	5858	1193		6.1%
1950	25791	8272	1421		5.5%
1960	34990	11274	**1727**		4.9%
1970	48996	13343	**2015**	**521**	4.1%
1980	67576	19951	2369	858	3.5%
1990	81250	28416	**3020**	**754**	3.7%

Country : Refers to Mexico, the country
Oax.State : Refers to the State of OAXACA.
B/A : is the ratio of Column B/Column A
B/A : Total popul Oaxaca/ Total popul MEXICO

	Total Population		Active	BREAK DOWN OF ACTIVE POPULATION			
	%Urban	% Rural	% Active	Primary	Industries	Services	Not Speci.
Year	%	%	%	%	%	%	%
1930 Country	19.8	80.2	31.1	70.4	15	14.6	
1940 Country	21.9	78.1	29.8	65.4	15.5	19.1	
1950 Country	28.9	71.1	32.1	58.3	15.9	25.7	
1970 **Oax.State**	**27**	**73**	**25.9**	**71.5**	**10.9**	**12.2**	**5.4**
1980 **Oax.State**	**32**	**68**	**36.2**	**55.3**	**7.1**	**13.5**	**24.1**
1960 Country	39.3	60.7	32.2	54.1	19.2	26.9	
1990 **Oax.State**	**39.5**	**60.5**	**25**	**52.9**	**16.4**	**28.3**	**2.4**
1970 Country	**58.7**	**41.3**	**27.23**	**37.5**	**23.11**	**39.3**	
1980 Country	66.3	33.7	29.5	32	26	42	
1990 Country	73	27	34.97	25	28	47	
2005 **Oax.State**	**52**	**48**	**28**	**44**	**18**	**36**	**2**

TABLE 4 LAND USE Area and Percentage. State of Oaxaca

Land use	**Present Area**		**Potential Area**	
	ha	%	ha	%
Irrigated land	106944	1.1%	372740	3.9%
Dry land	844364	8.9%	739904	7.8%
Pasture	2588305	27.1%	2550239	26.7%
Forest area	4089227	42.9%	3939227	41.3%
Water bodies	225600	2.4%	225600	2.4%
Others	1681960	17.6%	1708690	17.9%
TOTAL	9536400	100.0%	9536400	100.0%

Source: Comision Nacional del Agua. Gerencia Estatal en Oaxaca. Programa Estatal De Aprovechamiento del Agua. Dic. 1992.

Sources

1) Gallardo Navarro et al. (1982). La industria de Alimentos Procesados en Mexico. Ana-lisis y Tendencias.
2) La Economía Nacional en Cifras. Nacional Financiera, S.A. México,D.F. 1981.
3) NAFINSA. La Economía Mexicana por Cifras. 1984.
4)T. Ayllon Torres and Jose Chavez Flores (1992). México: Sus recursos naturales y Poblacion
5) Censos Generales de Población y Vivienda 1940-1990. (INEGI).

Primary Sector relates to the population employed for Agricultural production/ distribution and Forestry Extraction industries.
Industries relate to population employed in manufacturing activty as a whole.
"Services" relates to the active population offering some type of skill (manual or mental) or services raher than producing goods for sale.

TABLE 5	LEVEL OF MARGINATION of Mexican Townships in 1990. Estimated States Margination Level								
STATE	Very Low	Low	Average	High	Very High	Total	Estimated State IM[1]	State Level of Margination	National[2] Rank
TABLE									
OAXACA	4	52	83	263	168	570	0.68	HIGH	30
Puebla	1	22	53	105	36	217	0.41	HIGH	29
Queretaro Arteaga	1	4	3	9	1	18	-0.01	AVERAGE	24
Quintana Roo	1	3	2	1		7	-0.74	LOW	13
San Luis potosí	2	8	13	28	5	56	0.17	HIGH	26
Sinaloa	1	10	4	3		18	-0.66	LOW	15
Sonora	15	50	5			70	-1.22	LOW	5
Tabasco	1	6	9	1		17	-0.59	LOW	18
Tamaulipas	8	12	12	11		43	-0.61	LOW	17
Tlaxcala	3	29	11	1		44	-0.89	LOW	9
Veracruz	7	29	41	89	41	207	0.36	HIGH	28
Yucatán	1	11	24	68	2	106	0.20	HIGH	27
Zacatecas	1	23	21	11		56	-0.45	AVERAGE	20

Notes 1: Estimated State IM = Number of Municpalities of each level of margination times the median IM value of corresponding level of margination

Example: Estimated IM Oaxaca= ((4* -2.1)+(52*-1.05)+(83*-0.23)+(263*0.55)+(168*1.95))/570 = 0.68

Margination Level	Median	LB		HB
VERY LOW	-2.1	-2.6	< IM <	-1.6
LOW	-1.05	-1.6	< IM <	-0.5
AVERAGE	-0.25	-0.5	< IM <	0
HIGH	0.55	0	< IM <	1.1
VERY HIGH	1.95	1.1	< IM <	2.8

LB is the Low boundary IM value
HB is the High boundary IM value

Notes 2: Estimated Rank of margination index. Ascending order that is Rank = 1 is the least marginate state

TABLE 6 TOTAL POPULATION. SOCIO-ECONOMIC INDICATORS. INDEX AND LEVEL OF MUNICIPAL MARGINATION.
Townships surveyed in 1990 by CONAPO in the Tlacolula District .

Municipality	Population	% of analpha-betism	% of people >15 yrs with no primary school	% of dwellings with no sewers.	% of dwellings with no electricity	% of dwellings with no water pipe dis-tribution .	% of dwellings with high level of occu-pancy	% of dwellings with earthen floors	% of people in locality < 5000 people.	% of people with income < 2x min. salary.	Index of margina-tion. IM	Margina-tion LEVEL
Magdalena Teitipac	2986	53.8	92.4	55.3	9.7	41.3	78.4	80.6	100.0	94.6	1.33	Very High
Rojas de Cuaauhtemoc	993	9.9	40.8	25.9	2.3	93.4	59.1	27.8	100.0	81.1	-0.26	Average
San Bartolome Quialana	2510	32.7	73.0	68.9	9.7	50.5	87.5	73.5	100.0	72.3	0.88	High
San Dionisio Ocotepec	8380	36.4	66.9	62.8	25.5	31.5	85.1	58.1	100.0	93.6	0.91	High
San Francisco Lachigolo	1282	14.7	39.1	22.5	5.8	41.7	66.9	31.1	100.0	78.0	-0.42	Average
San Juan Guelavia	2992	30.4	71.2	56.6	7.3	98.3	71.1	45.8	100.0	82.3	0.75	High
San Juan Teitipac	2970	33.3	73.1	54.1	7.1	98.7	66.0	78.6	100.0	75.8	0.84	High
San Lucas Quiavini	2156	41.3	71.8	50.6	9.7	9.0	83.7	58.8	100.0	71.0	0.49	High
San Pablo Villa de Mitla	10373	17.8	53.2	38.9	2.8	37.9	72.8	37.6	32.3	84.4	-0.26	Average
San Sebastian Abasolo	2030	12.2	37.2	24.6	2.8	23.2	79.0	74.4	100.0	88.2	-0.06	Average
San Sebastian Tetipac	2175	21.5	63.0	63.5	9.3	70.7	79.8	65.2	100.0	72.0	0.59	High
Santa Ana del Valle	2220	14.2	61.0	79.4	1.2	67.0	76.2	49.7	100.0	89.8	0.57	High
Santa Cruz Papalutla	1735	21.6	63.0	31.8	7.6	18.6	74.9	68.0	100.0	91.2	0.28	High
Santa Maria del Tule	6398	6.7	22.1	11.3	0.6	35.6	49.5	9.7	5.8	65.3	-1.59	Low
Santa Maria Guelace	656	11.6	48.3	38.9	3.5	20.1	72.3	46.1	100.0	92.1	-0.09	Average
Santiago Matatlan	7910	38.8	65.3	56.0	28.3	45.5	74.9	62.2	100.0	84.5	0.78	High
Santo Domingo Tomaltepec	2353	14.6	61.9	53.4	2.7	28.8	79.3	58.2	100.0	83.2	0.26	High
Teotilan del Valle	5083	21.6	58.0	63.3	1.2	13.2	74.5	64.4	100.0	85.8	0.28	High
San Jeronimo Tlacochahuaya	4491	20.0	53.4	46.0	4.3	53.3	69.6	42.9	100.0	78.9	0.08	High
Tlacolula de Matamoros.	12255	19.3	48.9	24.4	2.0	29.5	57.0	29.1	20.6	74.6	-0.79	Low
Tlalixtac de Cabrera.	5121	18.5	48.5	36.8	6.1	42.3	74.8	44.0	100.0	66.9	-0.14	Average
Villa Diaz Ordaz	5901	18.0	64.7	47.2	5.7	6.4	73.1	56.5	100.0	91.3	0.19	High
TOTAL Tlacolula District	92970	23.8	51.0	38.9	5.9	36.2	63.7	43.7	66.5	72.9	0.01	Avg-High
Oaxaca de Juarez	213985	7.4	22.4	7.6	2.0	13.7	50.0	14.1	0.6	61.4	-1.73	Very Low
State of Oaxaca	3019560	27.5	56.7	45.5	23.8	42.2	69.9	52.5	69.6	78.7	0.65	High

Reported total population of Tlacolula District : 99915 % of Population of Tlacolula District non reported/surveyed in above list : 7.0%

Statistics from: Indicatores Socio - económicos e Índice de Marginación Municipal 1990.
CONAPO- C.N.A. Primer informe técnico del proyecto "Desigualidad regional y marginación municipal en México".
México, D.F., enero de 1993. ISBN - 968 - 805 - 927 - 7. pp304

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TABLE **7** Oaxaca State versus The Mexican Republic in 1991.

		Oaxaca State	Mexico	
		A	B	A/B
Population	People	3021513	81140922	3.7%
Area	km^2	95364	1972547	4.8%
Density	$people/km^2$	31.7	41.1	77.0%

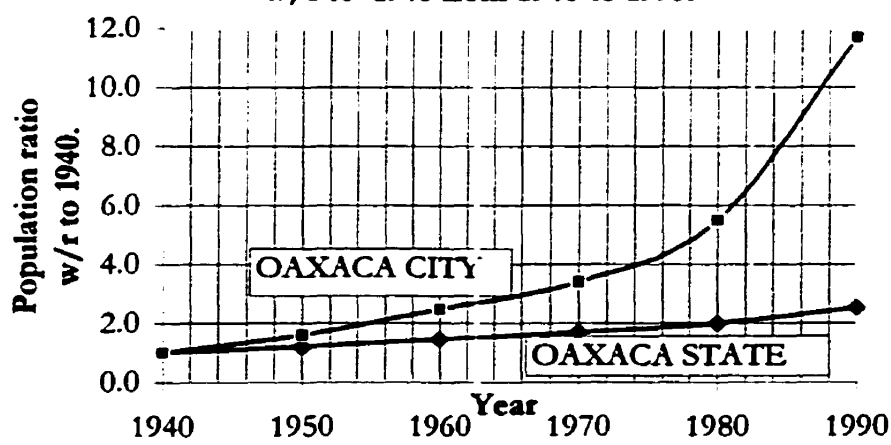
Source: INEGI 1991.

TABLE **8** Migration towards the Capital. 1940-1990.

	POPULATION		OAXACA		
Year	OAXACA CITY	OAXACA STATE	Ratio w/r to 1940 CITY	Ratio w/r to 1940 STATE	City/State
1940	29300	1192794	1.00	1.00	2.5%
1950	46600	1421313	1.59	1.19	3.3%
1960	72400	1727266	2.47	1.45	4.2%
1970	99500	2015424	3.40	1.69	4.9%
1980	161100	2369076	5.50	1.99	6.8%
1990	342338	3019580	11.68	2.53	11.3%

Censos Generales de Población y Vivienda 1940-1990. (INEGI).
Compiled by E. Perraton.

Figure 2. Oaxaca Population ratio w/r to 1940 from 1940 to 1990.



w/r 1940: with respect to the Population in 1940.
Censos Generales de Población y Vivienda 1940-1990. (INEGI).

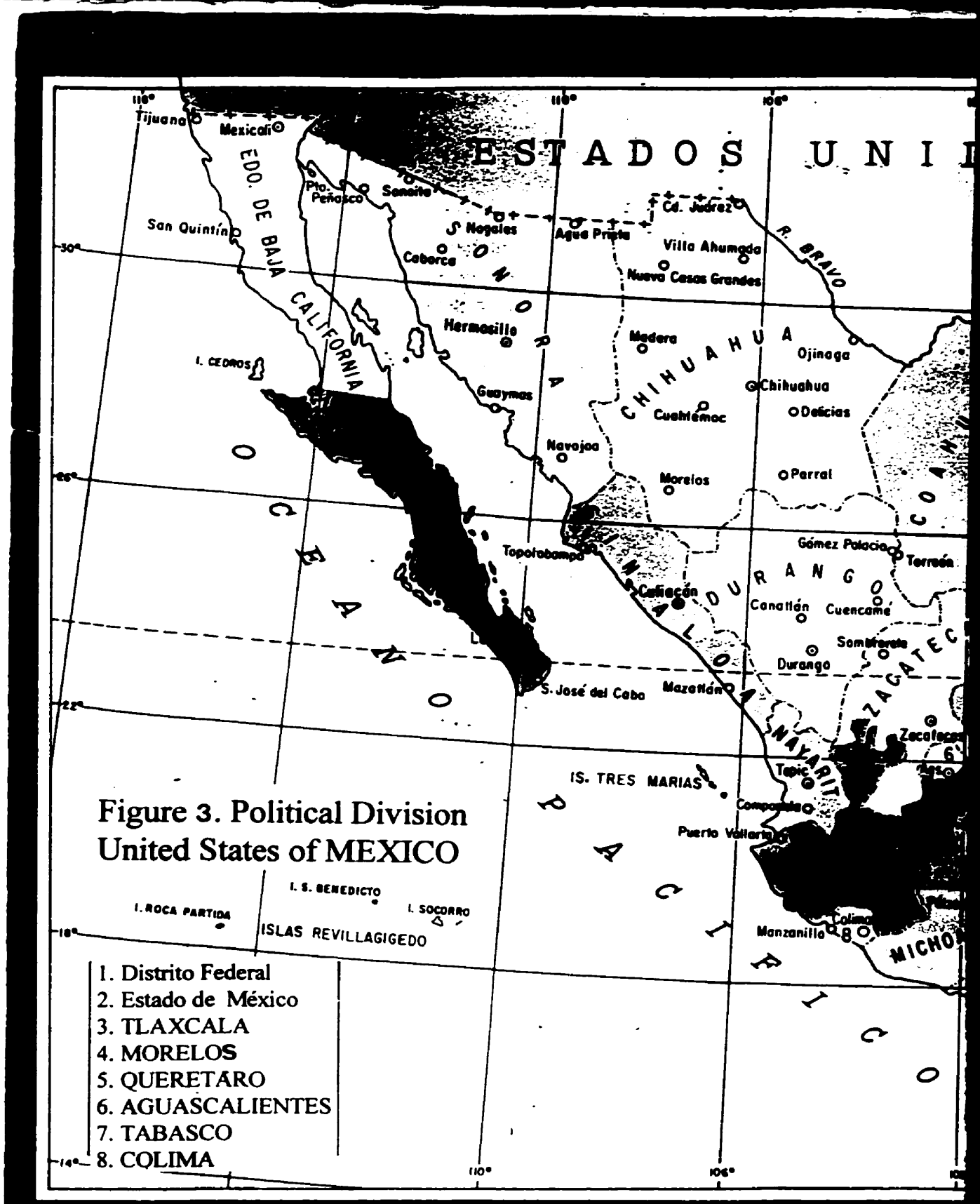


Figure 3. Political Division
United States of MEXICO

1. Distrito Federal
2. Estado de México
3. TLAXCALA
4. MORELOS
5. QUERETARO
6. AGUASCALIENTES
7. TABASCO
8. COLIMA


UNIDOS DE AMERICA
R. BRAVO
Ojinaga
Villa Acuña
Piedras Negras
Nuevo Laredo
Parral
COAHUILA
NUEVO
Reinosa
GOLFO
DE
MEXICO
Gómez Palacio
Torreón
Saltillo
Monterrey
LEON
Matamoros
Cuencame
Sombrerete
Trópico de Cáncer
ZACATECAS
Zacatecas
Tampico
San Luis Potosí
Cd. Valles
Tuxpan
GUANAJUATO
HIDALGO
Pachuca
Jalapa
Veracruz
Toluca
Puebla
Alvarado
Coatzacoalcos
Frontera
Villahermosa
Progreso
Mérida
Valladolid
Puerto Juárez
YUCATAN
Campeche
Champotón
CAMPECHE
QUINTANA ROO
Chetumal
Colima
MICHOACAN
Cuernavaca
Iguala
PUEBLA
VERACRUZ
Chilpancingo
GUERRERO
Tlaxiaco
Oaxaca
Ixtepec
Nejapa
OAXACA
Acapulco
Salina Cruz
Puerto Angel
Tuxtla Gutiérrez
Tenosique
Tonalá
Comitán
CHIAPAS
Pijijapan
Tapachula
GUATEMALA
BELICE
102°
98°
94°
90°
86°
30°
26°
22°
18°
14°

CHAPTER II

MATERIAL AND METHODS.

Groundwater Model Development

The first phase of a groundwater model study consists of collecting all existing geological and hydrological data on the groundwater basin in question. This includes information on surface and subsurface geology, watertable, precipitation, evapotranspiration, pumped abstractions, stream flows, soils, land use, vegetation, irrigation, aquifer characteristics and boundaries, and groundwater quality (Boonstra and de Ridder, 1990).

Data Required To Develop The Groundwater Model

The table below shows the data required for developing and testing a numerical model.

Table 1 Data Required For Developing And Testing A Numerical Model. (Boonstra and de Ridder, 1990)

Physical Framework	Hydrological stress
1. Topography	1. Watertable elevation
2. Geology	2. Type and extent of recharge areas
3. Types of aquifers	3. Rate of recharge
4. Aquifer thickness and lateral extent.	4. Type and extent of discharge areas.
5. Aquifer boundaries	5. Rate of discharge
6. Lithological variations within the aquifer	
7. Aquifer characteristics	

Boonstra and de Ridder (1990) group these data into two categories:

1) data that define the physical framework of the basin, and
2) data that describe its hydrological stress.

The results of hydrogeological investigations are presented in the form of maps, geological sections and tables. As recommended by Boonstra and de Ridder (1990) the following set of maps were prepared :

1. Contour maps of the aquifer's upper and lower boundaries,
2. watertable-contour maps,
3. electronic topographical base map,
4. electronic geological base map,
5. electronic soil base map, and an
6. electronic land use and cropping pattern base map.

The various "paper" maps that have been assembled are shown in Table 2.

Table 2 Maps (paper maps) Now Available.

Type of Map	Scale	Number	AREA	Year	Prepared by
TOPOGRAPHIC	1:50 000	E14D58 E14D48 E14D67 E14D57	Tlacolula de Matamoros Villa Tlalixtac de Carrera Ejutla de Crespo Zaachila	1988 1988 1988 1988	Instituto Nacional de Estadistica Geografia Informatica (INEGI)
HYDROGEOLO-GICAL Permeability	1:100 000	7.6	Valley of Tlacolula	1984	S.A.R.H
SURVEY OF WATER USES	1:100 000	5.2.1	Valley of Tlacolula	1984	S.A.R.H
EVAPOTRANS-PIRATION.	1:100 000	4.1.4	Valley of Tlacolula	1984	S.A.R.H
SURFACE GEOLOGY	1:100 000	7.5.1	Valley of Tlacolula	1984	SARH
WATER TABLE ELEVATIONS	1:100 000	8.2.1	Valley of Tlacolula	1984	S.A.R.H
WATER TABLE ELEVATIONS	1:50 000 on MESH	CNA-04 1993	Aquifer of Tlacolula	1991 1994	C.N.A & Perraton
GROUND SURFACE and AQUIFER BASE	1:50 000 on MESH	CNA-04 1991	Aquifer of Tlacolula 1991	1991 1994	C.N.A & Perraton

C.N.A : Comisión Nacional del Agua.

S.A.R.H : Secretaria de Agricultura y Recursos Hidráulicos.

INEGI : Instituto Nacional de Estadística, Geografía e Informática.

Examination Of The Well-Driller's Logs And Bore Samples

Characteristics that shed light on the environment in which the sediments accumulated are the texture, size and shape of the mineral particles, their degree of sorting, color, organic-matter content, lime content, clay and gravel content, microfossils, and mineral compositions.

Driller's logs were examined to reveal the presence of key beds and to recognize lithology or fossil content that differs from the bed above and below them. Typical key beds can be a thin limestone bed, a coal or lignite bed, a pebble zone, an insoluble zone, and a horizon with a typical faunal assemblage.

To establish the vertical and horizontal relationship between the various sediment bodies as well as the stratigraphic boundaries that prevent or allow groundwater flow, a number of cross-sections were drawn in different directions at strategic locations over the basin.

This field work and analysis of stratigraphic correlation was carried out under the supervision of an experienced geologist who has over fifteen years experience in water exploration for the C.N.A..

In the valley of Tlacolula, twenty-five documented sites have been explored for water. Locations where these exploration wells were drilled are shown on Figure 1 of Chapter VII. In most cases, bore samples were collected and well-driller's examination of drilling cuttings and results of pumping tests are available.

Aquifer Type

According to Freeze (1975) the classification of aquifers requires schematization of the subsurface geology. Consecutive geological formations, different in age or origin but similar in water-transmitting properties are grouped into a single aquifer system. This work has been initiated by S.A.R.H in 1984 who prepared a qualitative map of permeabilities based on the preliminary Hydrogeologic Study in the Valley of Oaxaca conducted by TACSA (1983). Qualitative, because the area is identified according to zones of high, low and very low permeability without quantification.

Aquifer Thickness And Lateral Extent

The lateral extent of the aquifer, as found from wells, bore logs and geophysical

data was indicated on a map to derive an isopach (thickness) map of the aquifer. An isopach map requires two horizons, one at the top of the aquifer and one at the bottom.

When the aquifer is unconfined (TACSA, 1983), the two horizons are the impermeable base and the land surface. The net thickness can be calculated from the elevations of the two horizons. Local clay lenses within the aquifer, if any, are subtracted from the total thickness. The results at each control point are plotted on a map and lines of equal thickness are drawn. (Boonstra and de Ridder, 1990). This was done by the C.N.A (in 1992) and the aquifer base elevation at each node was computed.

Aquifer Parameters

The hydrologic properties of the aquifer were determined from existing pumping test data. Only the drawdown at the pumping well was recorded and therefore Dupuit's solution could not be applied.

When Dupuit's solution is applied, the curve obtained (say the Dupuit's curve) intersects the surface of the well below the true free surface. The elevation of the free surface was found using Boulton's method (1954, as reported by Bouwer, 1978).

Basic aquifer parameters (coefficient of transmissibility, coefficient of storage) were substantiated with additional pumping tests.

Watertable Elevation

The development of a groundwater basin model requires that sufficient and reliable data on the watertable be available because the model is calibrated by "history matching" that is by comparing computed watertable elevations with measured ones. A network of observation wells was therefore established throughout the basin..

In selecting proper sites for observation wells, one must consider variations in aquifer thickness, lateral and vertical variations in the aquifer's lithology and structural deformation of the aquifer if any.

More observation wells than elsewhere are needed in the recharge areas (e.g. irrigated areas), in local discharge areas (e.g. areas where groundwater is abstracted), and in areas where abrupt changes in hydraulic gradient occur.

Considerations For The Selection Of Observation Wells

The following criteria were used in selection of Indian wells to be investigated

as potential observation wells.

1. The quality of the ring and the seal around the well at the surface,
2. the quality of the casing and stability of the borehole,
3. the convenience with regards to accessibility to the owner by paved road and accessibility to the well within a reasonable walking distance from the paved road, and no less important
4. the cooperative participation of the owner.

Frequency Of Watertable Measurements

Boonstra and de Ridder (1990) recommend that the water levels in all the wells be measured at least once a month and for at least one year. Water level measurements were taken in 1983 and 1984 by TACSA. Measurements were taken by C.N.A twice in 1991. In this research, water table measurements were taken during the rainy seasons of 1994 and 1995 while establishing the network of observation wells.

Groundwater density being a function of salinity of the groundwater, water samples were taken in a number of representative observation wells. The electrical conductivity of these samples was determined in laboratory using a Wheastone bridge with a 60-cycle alternating current galvanometer. The total dissolved solids content of these samples was then estimated from the very highly correlated linear relationship found between the electrical conductivty and the total concentration of the 53 water samples collected in the research area by GEOCA in 1979. This is discussed in details in Chapter VIII.

Monitoring observation wells

The stadia method was adopted to establish horizontal and vertical coordinates of the monitored wells. The elevation of the highest point of the innermost casing of monitoring wells were surveyed to the nearest **5mm** above mean sea level, by reference to National Geodetic Vertical Bench Marks. In Chapter III the vertical and horizontal controls achieved in this research are discussed in more details.

Wilson's (1995) position on the use of domestic wells as monitoring observation wells is clear.

> " To provide meaningful information on ground water levels the screen must be hydraulically sealed off from the rest of the formation, the well should have been adequately developed. Water levels in uncased boreholes provide only a rough estimate of static water levels, and estimates are even more inaccurate in fine-grained material. Prior to measuring water levels any nearby wells should be turned off to reduce the potential drawdown in the monitoring well." Wilson's (1995)

Domestic wells in the research area are generally well developed. Their measurements may be inaccurate not because of inadequate hydraulic response but rather due to common errors such as not using the same referencing points, neglecting to calibrate the length of the probe tip and negligence in lowering the probe and taking reading. A domestic well tightly cased with good maintenance can give accuracy of 5 mm if a proper referencing system is established and if great care is taken in sighting/or sensing the water level.

Measuring Well Water Levels

In this research, an electric water level indicator which activates a current meter was used. The probe was made of lead, a soft metal that wears quickly and since the water level indicator has a tip which protrudes beyond the actual sensor, this length needed constant calibration with a measuring tape.

To get an accurate reading, raising and lowering the probe a few centimeters a couple of times was necessary after the probe entered the water. Two measurements of the static water level were taken from each well and measurements agreed within plus or minus 5mm when care was taken.

In water table measurements, the following routine was followed. First, precaution was taken to lower the probe to the meter stop mark above the anticipated water level. This round meter number was recorded and the probe was then lowered very slowly until full response of the current meter. A millimetric scale was then used to measure the length of the meter portion from this stop mark to the next predermined meter mark. The probe was then pulled up until the meter mark above the stop mark could be accessed to for a double check measurement.

Trying to lower the probe around a well pump is difficult. Knowing from

previous experience the anticipated water level in the well reduced the time and effort required to obtain a static water level when using the probe. After measuring the static water level, sounding the depth to the bottom of the well was then attempted but not always successfully as the tape may get hung up.

Nonaqueous phase liquid such as gasoline was not encountered.

Kolomogorov-Smirnov Test on the rainfall data

The following computer statistical package was used to carry out Kolomogorov-Smirnov Test on the rainfall data :

GEOPACK Geostatistics for Waste Management
Version 1.0e. IGWMC.-FOS 54 PC
by S.R. Yates and M.V. Yates. (1992).

Gauging Stations

In 1994, to complement the network of observation wells for monitoring the groundwater, six gauging stations were recommended to be set up on the river Salado for allowing a better quantification of the flow regime. Raghunath's (1985) recommendations for selecting the sites for stream gauging were considered. The cross-sectional areas were surveyed with a 50m tape and an engineering transit. As a preliminary reconnaissance work, the discharge was estimated with surface floats. The locations are shown in Appendix AB.

Determination of the mean velocity in each vertical section, computation of total discharge and plotting of the stage-discharge data were done as per the method given by Lynsley et al. (1958, Hydrology for Engineers).

Ground Water Sampling

Low flow-rate purging and sampling is preferable to high-rate purging and sampling and for this reason bailers are discouraged for sampling constituents. But as pointed out by Wilson (1995) if used very carefully by skilled operators, bailers may be able to produce volatile organic compounds samples comparable with other types of sampling equipment. In any case in this research only inorganic tests were conducted on the water samples.

The principle that was set for sampling was to minimize disturbance of the

stagnant water column, minimize the potential for increasing turbidity, and minimize the volume of potential contaminated purge water.

For wells developed in low-permeability material, some purging was done prior to sampling but at no time was a well purged to dryness or to a level such that the recharge rate could cause the formation water to vigorously cascade down the sides of the screen.

Concentrations of the following components represent our standard water - analysis; Na^{+}, K^{+}, Mg^{++}, Cl^{-}, $SO_4^{=}$, $CO_3^{=}$, HCO_3^{-}, NO_3^{-}. Total dissolved solids and hardness were also be determined.

Table 3 from Wilson (1995) shows that the polyethylene containers used were adequate for the nature of the chemical analysis made in this research. The samples were maintained between 20 °C and 30°C and taken to the laboratory within four hours. The samples were then transfered to a refrigerator and maintained at 4°C until their analysis which took place within 24 hours from the time of sampling.

TABLE 3 Containers, Preservation Techniques and Holding Times for Aqueous Matrices

Name	Container	Preservation	Maximum Holding time
Inorganic Tests			
Chloride	P,G	None Required	28 days
Hydrogen (pH)	P,G	None Required	24 hours
Nitrate	P,G	Cool, 4°C	48 hours
Sulfate	P,G	Cool, 4°C	28 days
Sulfide	P,G	Cool, 4°C add zinc acetate	7 days.

(After Wilson , 1995) NOTE : P :Polyethylene. G: Glass

Wells that were sampled are generally used for drinking purposes (domestic and municipal) and constructed in an aquifer with no apparent suspended solids, so samples did not usually require filtering except when foreign material such as straw or grass was bailed out with the water.

Control samples were used to correct possible systematic errors introduced through collection, handling, storage , transport, and laboratory procedures.

The Topographic base map

The procedure to make use of the Universal Transverse Mercator referencing system of Oaxaca state in our surveys; to accomplish geometric transformation and assign a common ground coordinate system to all electronic base layers within the GIS, is the main subject of Chapter III.

Compatibility and reproducibility of the method used for establishing the Geographic Information System

The procedure as well as the methodology for the preparation of basemaps are reproducible and compatible with functions and responsibilities of the Comisión Nacional del Agua (C.N.A). Maps and documents used were obtained from and/or with the assistance of the Manager. The sources of information used (INEGI, S.A.R.H, FIRCO, ADOSAPACO, COPLADE) are part of the Manager's immediate network of governmental agencies in Oaxaca with whom the Manager interacts on a routine basis.

The conversion of paper basemaps to raster files is achieved by simple scanning operation. This can be done by a micro reproduction store on a piece basis (as this was the case in this research). After registration of the basemaps and their attachment to a common geographic system, accurate digitizing can be accomplished directly on the screen with a micro-computer system that shares the same geographic information environment. The Geographic Information Software used in this research, is the same as the software used by the Manager.

The Hydrogeology map

Sources of information

Information on the hydrogeology of the research area is based on two sources, namely : the study of the hydrogeologic conditions of the Valley of Tlacolula conducted by the Geology Consulting firm (GEOCA) in June 1980 and the geology map of the State of Oaxaca prepared in 1974 by the groundwater department of S.A.R.H. To prepare the geology map, 31 geologic surveys were mapped at a scale of 1:500 000. The construction and calibration of the electronic hydrogeology map are discussed in Chapter III.

Thematic Elements and symbology

Among the five essential thematic elements of a general-purpose geologic map identified by Ulrich et al (1992), two elements are missing on the electronic hydrogeologic map prepared in this research study. The first missing element is the index map of sources and dates of geologic mapping of these sources. This information is however available on the geology map of the State of Oaxaca prepared in 1974. The second element refers to the hydrogeologic cross-sections. These cross-sections are needed to show both the vertical and horizontal relationships between the various sediment bodies as well as the stratigraphic boundaries that either prevent or allow groundwater flow. This work will require further research.

The density of symbols on the electronic hydrogeologic map is appropriate to the complexity of the hydrogeology, the map scale and the purposes of the map. Some geologic features were found to be inaccurately located with respect to local geographic features. These features are now shown on the electronic hydrogeologic map at their corrected position.

Positional Accuracy

Ulrich et al (1992) are of the opinion that standards for accuracy of point and line placement on topographic maps cannot be applied in the same way to geologic maps. For example, the contact bounding adjacent strata having a low inclination to the surface is depicted most accurately by reference to contours, whereas a fault is located most accurately by reference to physiographic features.

Ulrich et al (1992) report that the standard proposed by the U.S. Geological Survey states that an accurately located contact or point position should be located within (0.5mm) at a map scale of 1:24 000. This standard follows the "United States National Map Accuracy Standard" for topographic maps.

Ulrich et al (1992) recommend to show contacts and faults that are less well located by long-dash, short-dash, and dotted line types which designate approximate, inferred or indefinite, and concealed boundaries, respectively. Since all lines of our map have the same level of uncertainty they are shown as solid lines and the character of their uncertainty is described in note form directly on the map.

Colors and Patterns

Ulrich et al (1992) distinguish four main factors to be considered in color design for a geologic map:

1. the main theme presented by the map,
2. the use of previously adopted color schemes,
3. the matching of colors and patterns published on maps of adjacent or nearby areas, and
4. the need for clarity and contrast.

The above recommendations by Ulrich et al (1992) were considered in preparing the hydrogeology electronic base map.

Map of Natural Drainage Basins

The geology map was used for preparing the base map for drainage sub-basins . The geology map was traced onto Mylar sheet which was scanned at a resolution of 16 dots per mm in a Monochrome Bitmap format. The calibration of the drainage basin basemap was done on the basis of the overall watershed boundaries. The procedure is discussed in detail in Chapter V.

1994 Agricultural Production Map

A preliminary base map showing the agricultural production (dry farming) in the research area for each township was prepared using the following manner.

1) The crop production crop wise for the period of 1990-1995 was obtained from the field office of S.A.R.H/CADER[1] II.
2) The 1994 crop production specifically for the research area was extracted from the data collected in 1).
3) the area for each of the five main crops harvested in each township was reproduced on millimetric transparent graph paper at a scale 1:50 000 so that the area of agricultural production by crop could be super-imposed on the 1:50 000 topographic map. The area covered by each crop reproduced on transparent graph paper at a scale 1:50 000 was then located on the topographic map by the agricultural technician responsible for the reported production in the townships [2]

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[1] C.A.D.E.R; Centros de Apoyo al Desarrollo Rural.

[2] Enedina Montesnos Miguel , Francisco Velasco Betansos, Eladio Miguel Gonzales

under his/her responsibility. The agricultural technician was asked to locate from memory the actual distribution of the same crops. Township boundaries were traced according to the approximate location of their boundary monuments.

4) This author assisted this operation by keeping a continuous inventory of the area under each crop that had not yet been located. The map thus obtained shows, to a certain extent, approximate locations of the cropped areas, because they are derived from the technicians' perceptions of reality. They are bound however to reality through the total area for each crop in each township.

5) The same technicians recommended some field checks whenever the memorized location was uncertain.

6) The paper base map was then traced on Mylar sheets and scanned in a black and white bitmap mode . After conversion of the scanned image file to a format compatible with the image file editing software, a gray scale image format was generated from which an indexed color mode image format was generated using an arbitrarily five green color tones palette to represent the five major crops cultivated in the Research Area.

7) Polygons were painted in the green tone corresponding to their crops.

8) Political Township boundary lines were colored in red.

The map obtained is shown in Figure 1. This map is now ready for calibration. It is recommended to proceed for its calibration the same way as the calibration of the drainage basin. For this however, the legend describing the five green shades used for the five main crops produced in the research area must first be erased so as not to be accounted for by IDRISI when the AREA function is called. The five crops shown on this map are : 1) maguey, 2) corn and beans as inter-crop, 3) beans , 4) corn and 5) alfalfa. This map shows the dry-farming production. The base map for irrigated land has not been prepared yet but given the small area this may be incorporated as an addendum to the dry farming base map.

The irrigation infrastructure is listed in Table 4(A and B) whereas Table 5 (A,B,C,D) shows the agricultural production of 1994. Table 4B shows that a total area of 1143 hectares were irrigated by the infrastructure still operational in the

research area. By adding the totals of Table 5B with totals of Table 5C, an area of 484 hectares is obtained for the total irrigated area in the fall-winter cycle. It appears therefore that a significant part of the irrigation water is used to support spring-summer crops. The major winter crops are peas (253ha or 52%) and winter corn (142ha or 29%). By adding areas under cultivation for the three major spring-summer crops given in Table 5A one can see that dry farming in the research area accounts for approximately 14 350 hectares or 87% of the total farmed area. Out of these 14 350 hectares 88% of the area (12 665ha) is used for growing corn[3]. Perennials cover a total area of 1 619ha or 10% of the total farmed area, out of which maguey[4] represents about 69% and alfalfa 26%. Scientific names of the principal agricultural products of the Central Valleys are given at the end of the glossary. It is interesting to note that Cruz (1938) estimated that 3 390 hectares out of the 13 646 hectares covered by his soil survey in the valley of Tlacolula, were inadequate for irrigation because of salinity, topography or insufficient soil thickness. A total irrigated area of 1 650 hectares was estimated by Cruz (1938).

The Soil Map

The Soil Map is a map layer that is subect to a large positioning error because it was generated from many pieces. Indeed a 1: 50 000 soil paper mosaic map was created with reduced (1st reduction 50%, 2nd reduction 80%) xeroxed copy of a 1:20 000 soil map photocopied in pieces of 215mm x 280mm. The original survey was conducted with care in 1938 by Candido Cruz , an agricultural engineer working for the S.A.R.H.

Despite some positioning difficulties in the process of assembling the mosaic. The soil map obtained is of great value because the river and geologic features allow one to make valuable positioning corrections. Twenty one soil samples were collected from the first horizon within the area delineated by Tlacochahuaya - Santa Cruz - San Francisco Lachigolo and Rojas de Cuauhtemoc. The grain size analysis of these samples confirmed the textural classification of the soil series defined by

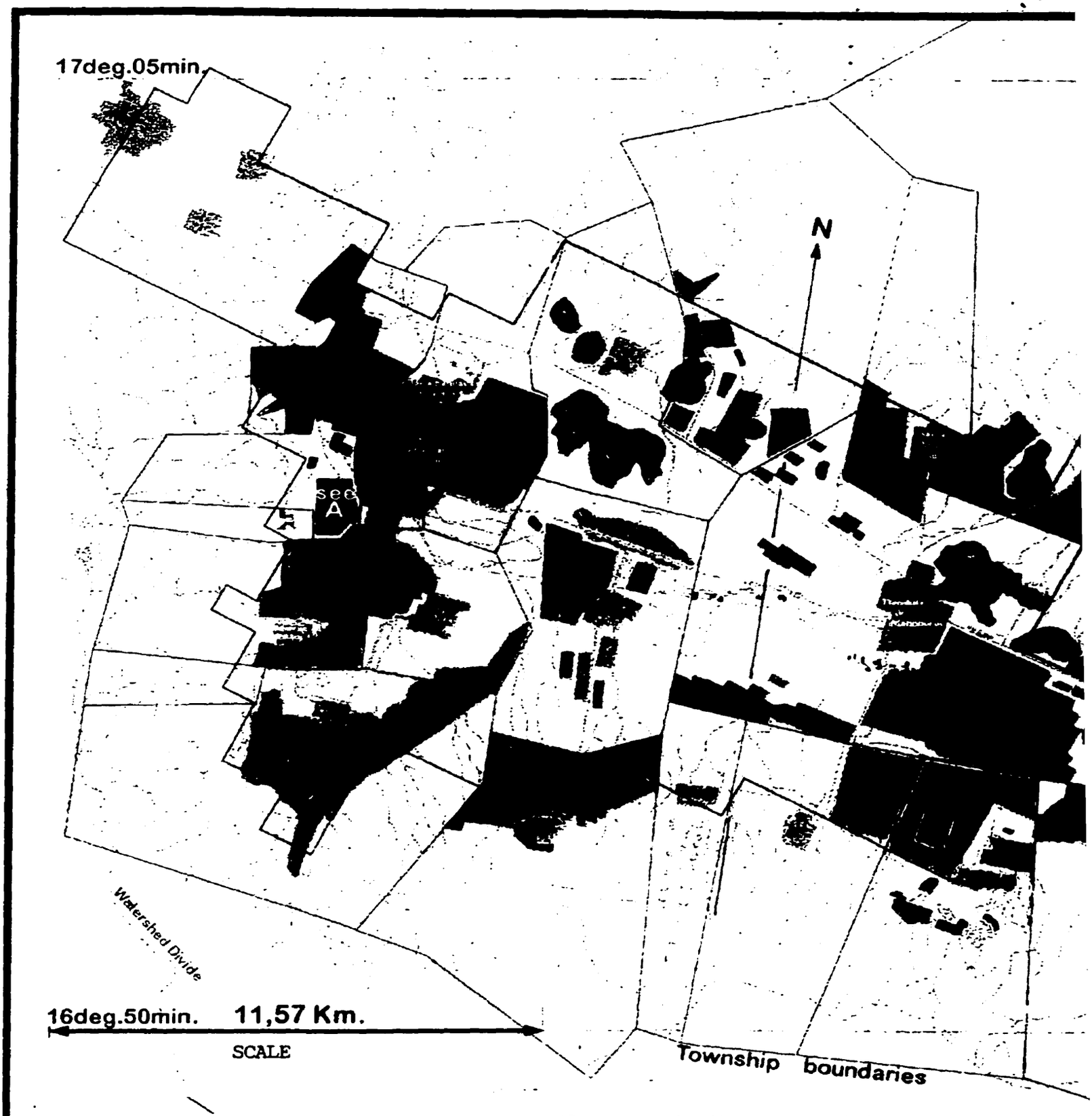
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[3] Corn is used here to designate corn varieties grown in the research area and for which a detailed description is given in the Glossary page .

[4] Maguey is a plant (genus Furcraea) related to the agaves from which a liquor called mezcal is produced.

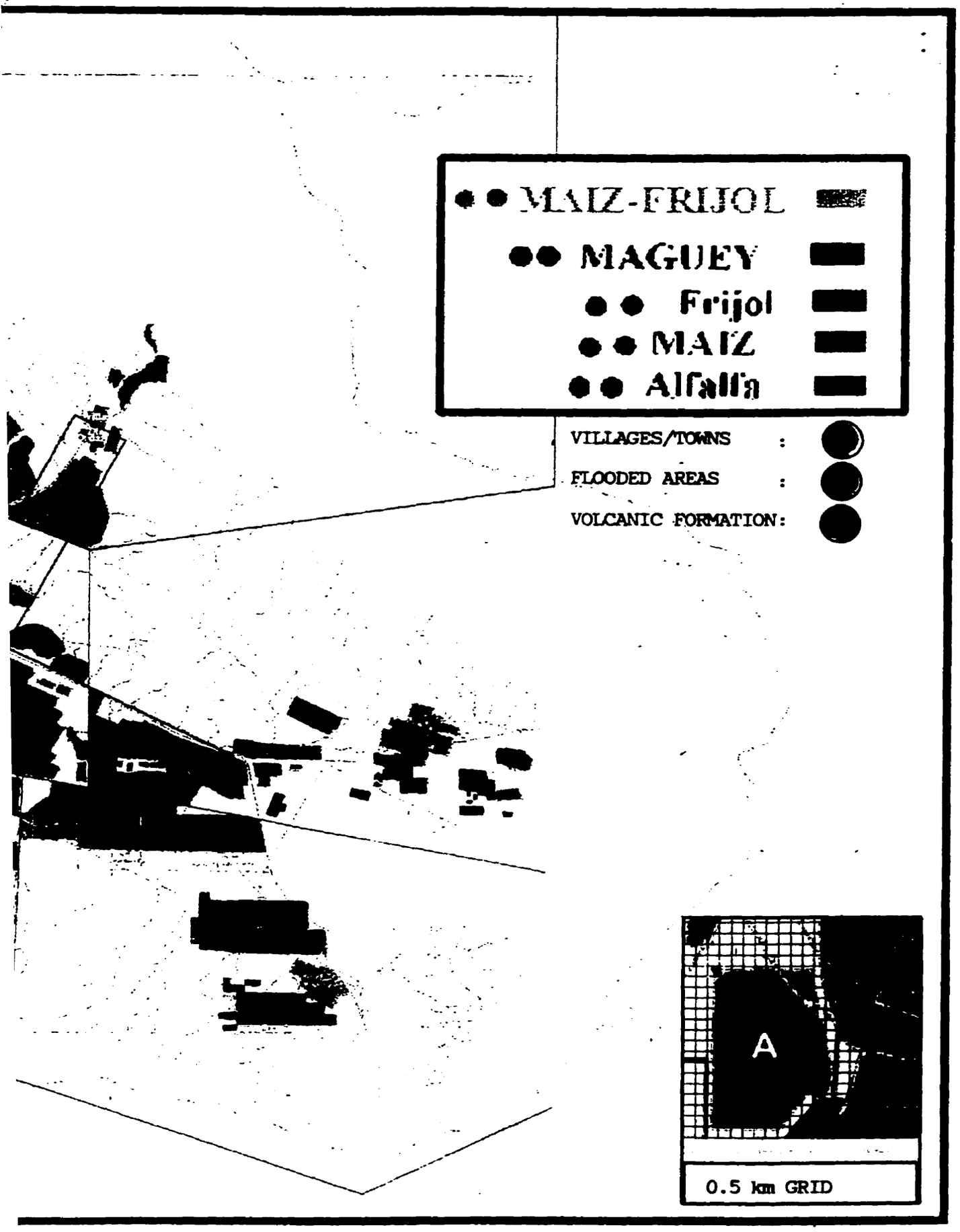
Cruz(1938) for the area of sampling. Seventeen of these samples are of clay texture, one is a loam and two are a fine sandy loam. This is consistant with Kirkby (1973) who reported the predominance of clay soils in this area (Figure K4 in Appendix K).

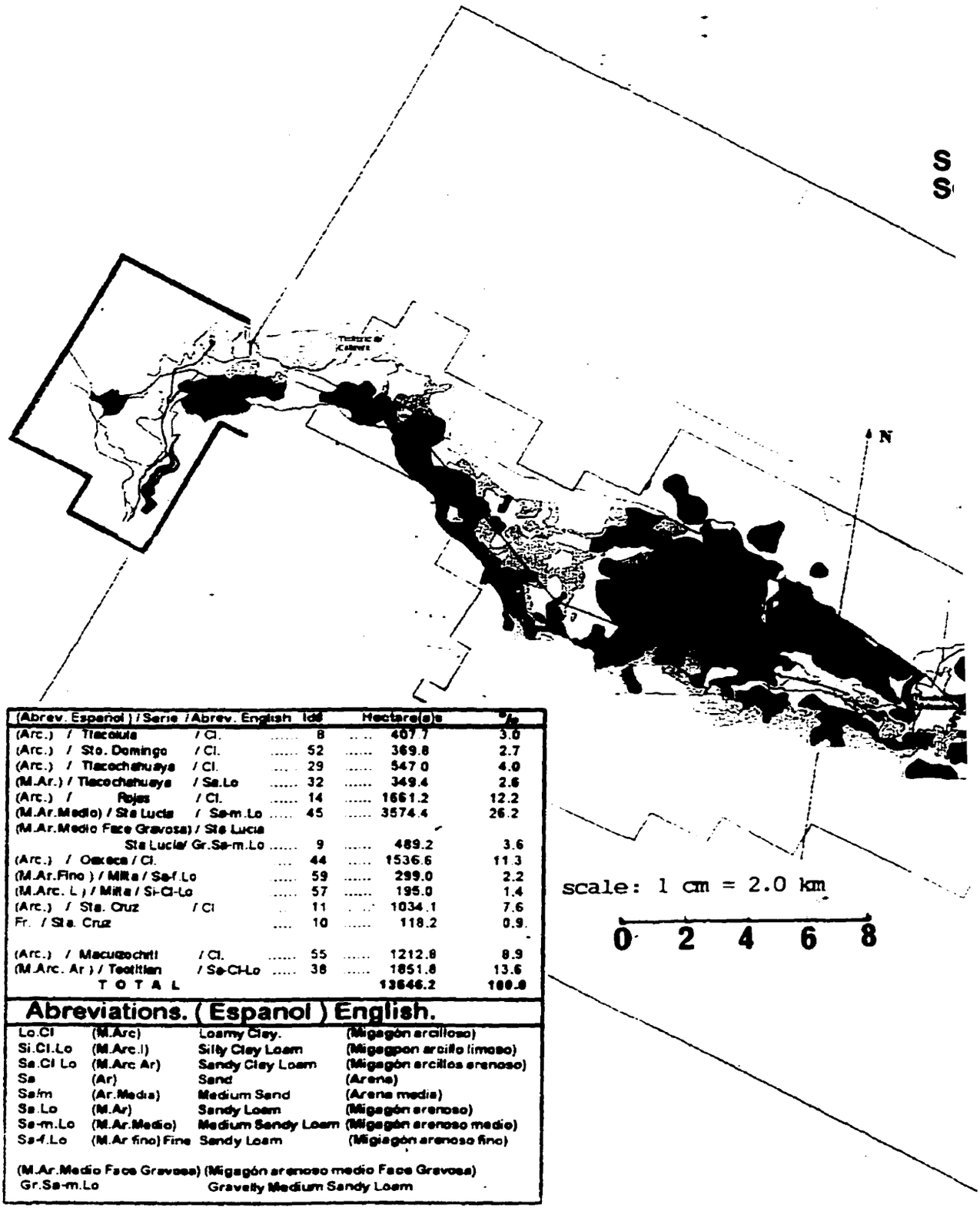
In a report available at the Biblioteca Dirección de Agrología at S.A.R.H's head office in Oaxaca, Cruz (1938) defines the fourteen soil series he identified in the Tlacolula basin. Cruz (1938) also estimated the water holding capacity of the major soil series from which irrigation water requirements can be established for the major crops under cultivation in this valley. The proposed soil map is printed out as Figure 2 and the legend is shown in Figure 3 The soil map is now ready for fine tuning of the boundaries of its soil series. It is recommended to proceed with the Rojas Soil Series first for its large coverage, for its strategic location on the map and above all for the monitoring of salt movements to obtain an early warning of groundwater salinization or pollution.



Prepared with the assistance of S.A.R.H. Tlacolula. 1996.

Figure 1. .Preliminary Agricultural Production Map


MAIZ-FRIJOL
MAGUEY
Frijol
MAIZ
Alfalfa
VILLAGES/TOWNS :
FLOODED AREAS :
VOLCANIC FORMATION:
A
0.5 km GRID



(Abrev. Español) / Serie	/ Abrev. English	Id#	Hectare(s)e	%
(Arc.) / Tlacolula	/ Cl.	8	407.7	3.0
(Arc.) / Sto. Domingo	/ Cl.	52	369.8	2.7
(Arc.) / Tlacochahuaya	/ Cl.	29	547.0	4.0
(M.Ar.) / Tlacochahuaya	/ Sa.Lo	32	349.4	2.6
(Arc.) / Rojas	/ Cl.	14	1661.2	12.2
(M.Ar.Medio) / Sta Lucia	/ Sa-m.Lo	45	3574.4	26.2
(M.Ar.Medio Face Gravosa) / Sta Lucia Sta Lucia	/ Gr.Sa-m.Lo	9	489.2	3.6
(Arc.) / Oaxaca / Cl.		44	1536.6	11.3
(M.Ar.Fino) / Milla / Sa-f.Lo		59	299.0	2.2
(M.Arc. L) / Milla / Si-Cl-Lo		57	195.0	1.4
(Arc.) / Sta. Cruz	/ Cl	11	1034.1	7.6
Fr. / Sta. Cruz		10	118.2	0.9
(Arc.) / Macuiltechil	/ Cl.	55	1212.8	8.9
(M.Arc. Ar) / Teotitlan	/ Sa-Cl-Lo	38	1851.8	13.6
T O T A L			13646.2	100.0

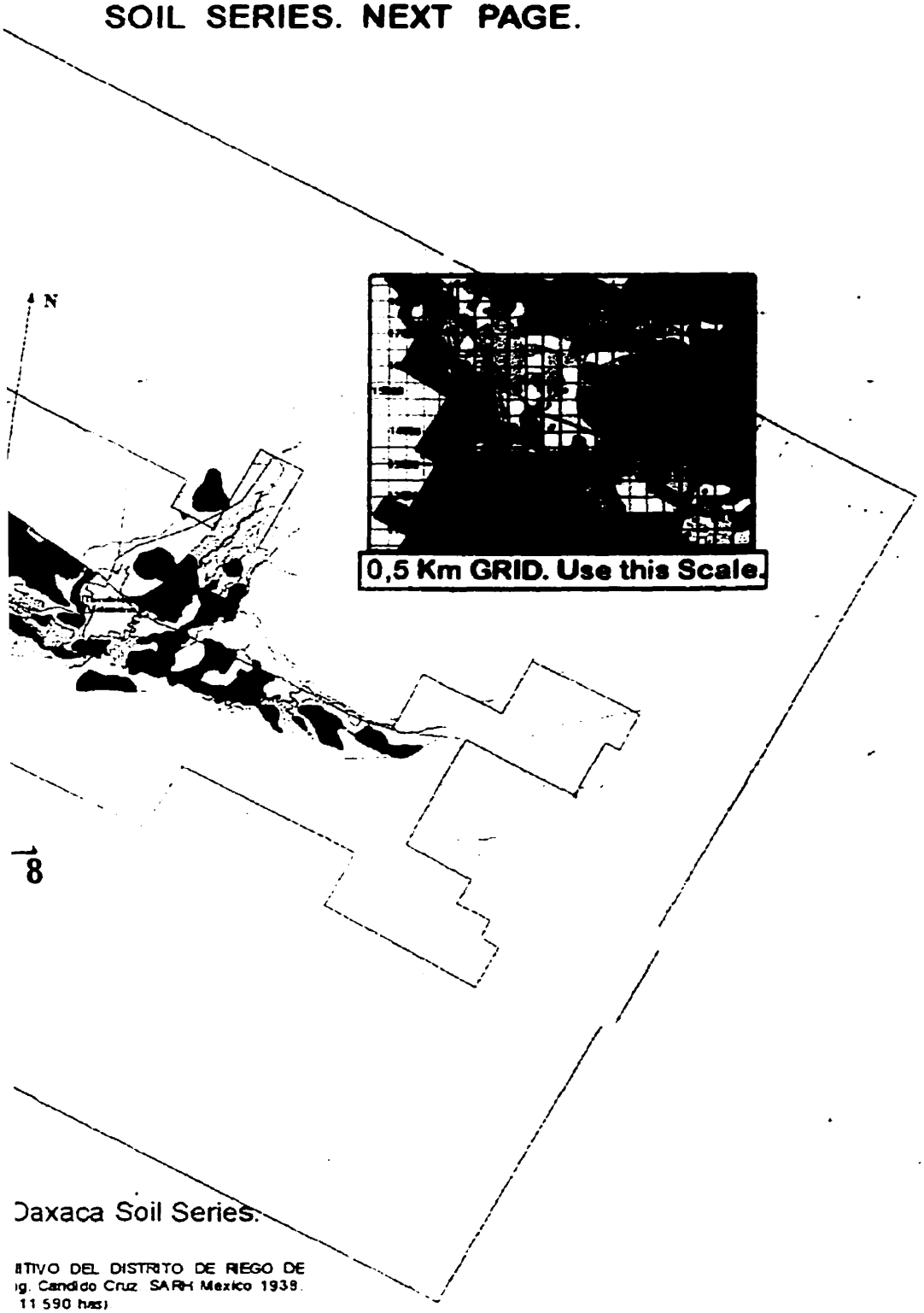
Abreviations. (Espanol) English.

Lo.Cl	(M.Arc)	Loamy Clay.	(Migagón arcilloso)
Si.Cl.Lo	(M.Arc.I)	Silty Clay Loam	(Migagpon arcillo limoso)
Sa.Cl Lo	(M.Arc Ar)	Sandy Clay Loam	(Migagón arcillos arenoso)
Sa	(Ar)	Sand	(Arena)
Sa/m	(Ar.Media)	Medium Sand	(Arena media)
Sa.Lo	(M.Ar)	Sandy Loam	(Migagón arenoso)
Sa-m.Lo	(M.Ar.Medio)	Medium Sandy Loam	(Migagón arenoso medio)
Sa-f.Lo	(M.Ar fino) Fine	Sandy Loam	(Migiagón arenoso fino)
(M.Ar.Medio Face Gravosa) Gr.Sa-m.Lo		(Migagón arenoso medio Face Gravosa) Gravelly Medium Sandy Loam	

Figure **2.** . Soil Map based on Oaxaca Soil
Adapted from :.

INFORME AGROECONOMICO DEFINITIVO DEL DISTRI
OAXACA. UNIDAD TLACOLOULA. Ing. Candido Cruz. SA
Study on 13,646.2 hectares (shown 11,590 has).

SEE LEGEND and DESCRIPTION of SOIL SERIES. NEXT PAGE.



Oaxaca Soil Series.

ITIVO DEL DISTRITO DE RIEGO DE
ig. Candido Cruz SARH Mexico 1939.
11 590 has)

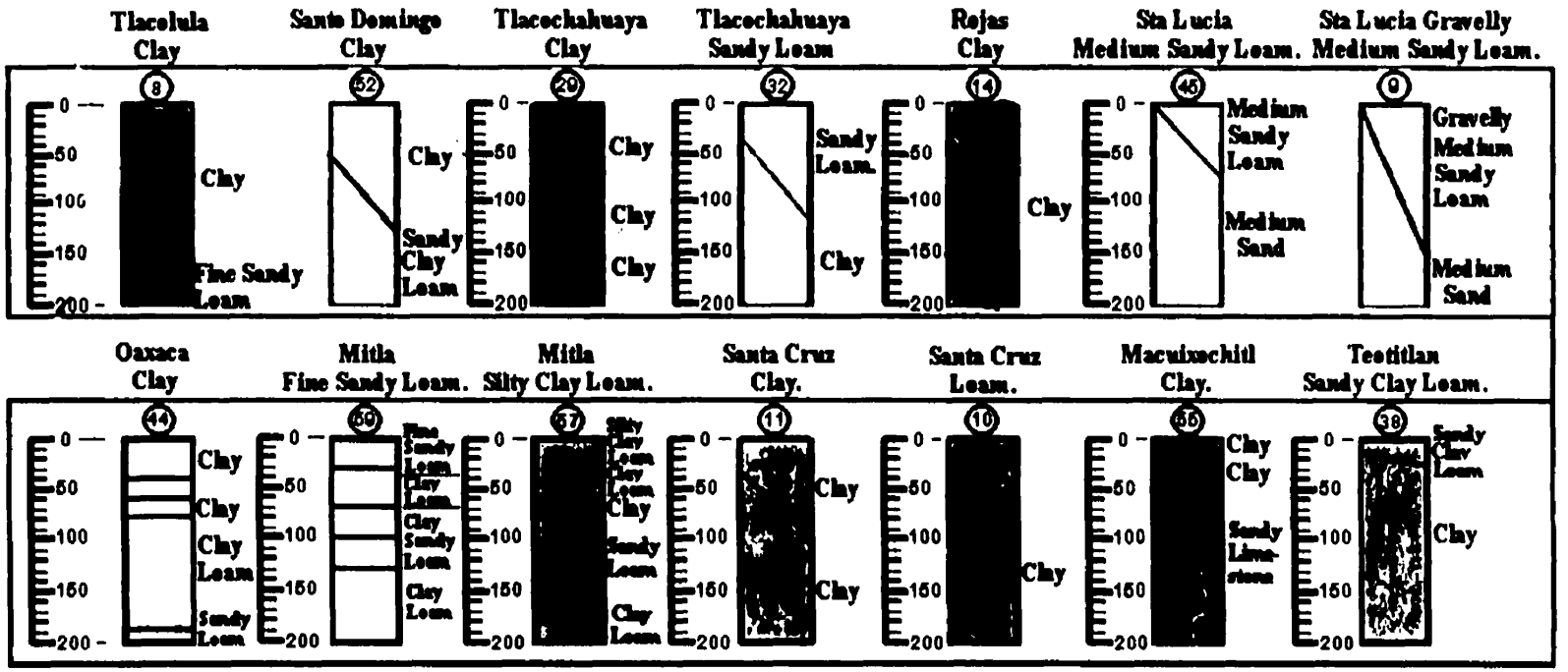


Figure 3. LEGEND FOR THE SOIL MAP. After Candido Cruz (1938) All scales in centimeters

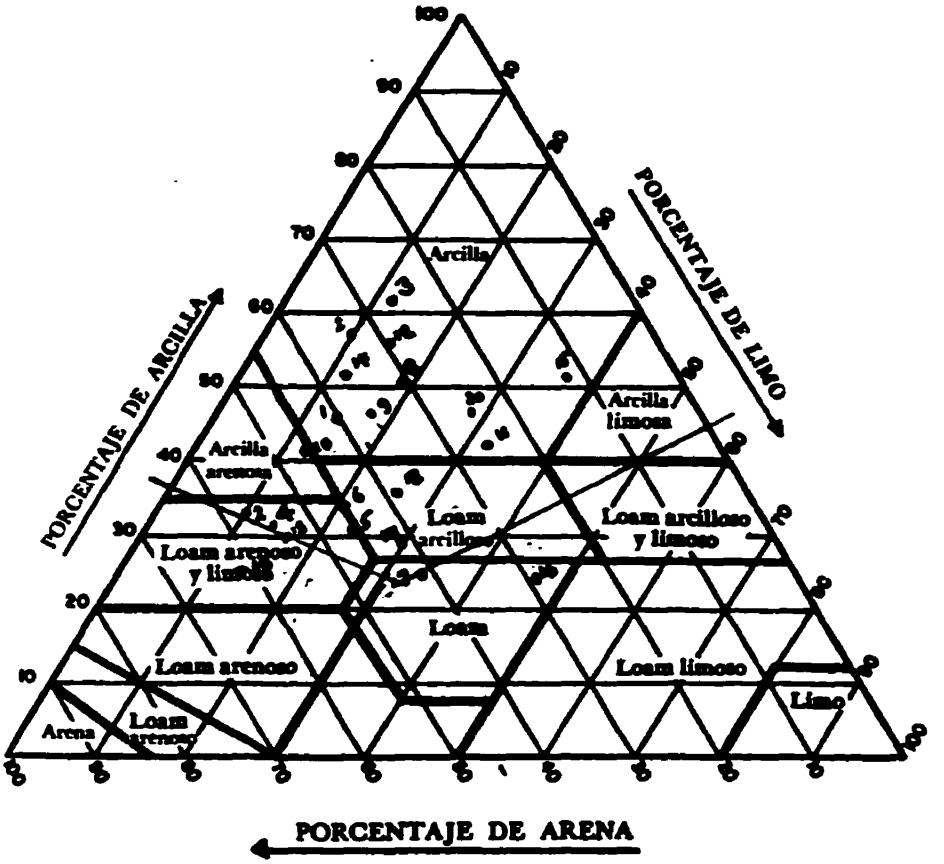


Figura 1-1. Proporciones de arena, limo y arcilla en diferentes clases básicas de textura de suelos. *(Tomadas del Manual Núm. 18 del Departamento de Agricultura de los Estados Unidos, 503 páginas ilustradas, 1951)*

Figure 4. Texture for the 21 soil samples collected.

ENGLISH	SPANISH
Clay	Arcilla
Silty clay	Arcilla limosa
Sandy clay	Arcilla arenosa
Loam arcilloso	Clay loam
Loam arcilloso y limoso	Silty and clay loam
Loam	Loam
Sandy and silty loam	Loam arenoso y limoso
Silty loam	Loam limoso
Silt	Limo
Sandy Loam	Loam arenoso
Sand	Arena
Percentage of %	Porcentaje de %

INFRASTRUCTURE.xls

TABLE 4A. IRRIGATION INFRASTRUCTURE IN THE RESEARCH AREA 1994. STATUS

NAME of the Infrastructue	Infrastructure TYPE	Irrigated Area	Irrigable AREA	System Efficiency	CROPS	CROP Area
		ha	ha	%		ha
ABASOLO I	**DEEP WELLS**	7.50	7.50	60%	Alfalfa	4.00
(EL TANQUE)					Corn	1.50
					Beans	2.00
TLACOCHA. II	DEEP WELL				Corn	10.00
El Camino Real		24.00	21.00	60%	Beans	5.00
					Chile	1.00
					Alfalfa	8.00
	DEEP WELL				Alfalfa	10.00
TLACOCHA. IV		28.00	25.00	60%	Corn	12.00
					Beans	5.00
					Chile	1.00
	DEEP WELL				Alfalfa	8.00
TLACOCHA. V		37.00	30.00	60%	Corn	20.00
					Beans	8.00
					Chile	1.00
EL CASAHUATE	DEEP WELL	11.24	9.00	60%	Alfalfa	9.00
					Corn	2.00
ROJAS I	DEEP WELL	20.00	20.00	60%	Alfalfa	20.00
ROJAS II	DEEP WELL	59.34	56.00	60%	Alfalfa	56.00
					Corn	3.00
ROJAS III	DEEP WELL	43.00	18.00	60%	Alfalfa	18.00
					Corn	25.00
					Alfalfa	**133.00**
T O T A L	**DEEP WELLS**	**230.08**	**186.50**	60%	**Corn**	**73.50**
					Beans	**20.00**
					Chile	**3.00**
Tanivet	Manantial	24.00	12.00	50%	Corn	24
Galeria Filtrante	Filtering Galery	52.00	temporal	not given	Alfalfa	1
					Corn	51
Piedra Azul	Storage Reservoir	145.00	10.00	not given	Alfalfa	10
			temporal		Corn	135
			temporal	not given	**Alfalfa**	**11**
T O T A L		**221.00**	**22.00**		**Corn**	**210**

Data from S.A.R.H/ C.A.D.E.R. 2. Tlacolula de Matamoros

Notes 1) temporal refers to dry farming where irrigation water is used to support spring/summer crops. In that case the irrigated area is not given but may be derived from the crop water deficit in summer.

Irrigable Area = Potential area that could be irrigated *Irrigated Area* = Actual Area under irrigation.

INFRASTRUCTURE.xls

TABLE 4B. IRRIGATION INFRASTRUCTURE IN THE RESEARCH AREA 1994. STATUS

NAME of the Infrastructue	Infrastructure TYPE	Irrigated Area	Irrigable AREA	System Efficiency	CROPS	CROP Area
		ha	ha	%		ha
LA CAIDA	**DERIVADORA**	22.00	1.00	60%	Alfalfa	1.00
Out of Salado Basin					Corn	21.00
XIRULFE	DERIVADORA	38.00	4.00	60%	Corn	4.00
Out of Salado Basin			temporal		Beans	34.00
XAASA	DERIVADORA	47.00	temporal	60%	Corn	47.00
Out of Salado Basin						
Benito Juarez	DERIVADORA	327.00	145.00	50%	Alfalfa	22.00
D-1					Corn	305.00
El Potrero	DERIVADORA	87.00	69.00	60%	Alfalfa	6.00
D-2			temporal		Corn	81.00
Sta Paula	DERIVADORA	52.00	29.00	50%	Alfalfa	4.00
Similar to D-1			temporal		Corn	48.00
Rhu-Gueubeh	DERIVADORA	100.00	temporal	50%	Corn	100.00
Abandoned	Vivero Forestal					
Leniche-Lachigolo	DERIVADORA	84.00	4.00	50%	Alfalfa	4.00
Not operational	Diaz Ordaz		temporal		Corn	80.00
Toma Nueva	DERIVADORA	19.00	12.00	60%	Alfalfa	7.00
TN	Magdalena Teitipac		temporal		Corn	12.00
EL MURO	DERIVADORA	24.00	11.00	60%	Alfalfa	11.00
	San Sebastian Teitipac		temporal		Corn	13.00

				Irrigation Command Area		
				Within->	Research	Cader 2
	DERIVADORAS				**ha**	**ha**
T O T A L	Within Cader 2 but	107.00	5.00	Alfalfa		5
	Out of Salado Basin			Corn		102
T O T A L	Within Cader 2 and	693.00	270.00	Alfalfa	54.00	
	within Salado Basin			Corn	639.00	
GRAND TOTAL	**ALL IRRIGATION INFRASTRUCTURE**			Alfalfa	198.00	203
Within Research Area		1144.08	478.50	Corn	922.00	1024
Within Cader 2.		1251.08	483.50	Beans	20.00	20
				Chile	3.00	3

Data from S.A.R.H/ C.A.D.E.R. 2. Tlacolula de Matamoros

Notes 1) temporal refers to dry farming where irrigation water is used to support spring/summer crops, In that case the irrigated area is not given but may be derived from the crop water deficit in summer.

Irrigable Area = Potential area that could be irrigated *Irrigated Area* = Actual Area under irrigation.

TABLE 5A. 1994 Agricultural Production

	Township	SPRING - SUMMER CYCLE Corn area Mech. ha	Not Mech ha	Yield tons/ha	SPRING - SUMMER CYCLE Corn-Beans Mech. ha	Not Mech ha	Yield tons/ha	SPRING - SUMMER CYCLE Beans Mech. ha	Beans Not Mech ha	Beans Yield tons/ha	PERENNIALS TO ESTABLISH Maguey Mech. ha	Maguey Not Mech ha	Alfalfa Mech. ha	Alfalfa Not Mech ha
*	Talcolula de Matamoro	1740	1160	0.9	50	75	0.7	15	15	0.6	2	6	0	10
*	Diaz Ordaz	180	490	1.2	50	200	0.8	0	60	0.6	0	0	0	0
*	Santa Ana del Valle	180	242	0.8	0	0	0	5	13	0.5	0	0	0	0
*	Magdalena Teitipac	250	300	0.9	65	185	0.7	5	10	0.7	0	0	0	0
*	San Juan Guelavia	150	170	0.9	30	30	0.7	10	10	0.7	0	0	0	0
*	San Bartolome Quialan	100	455	0.8	5	35	0.7	0	20	0.4	0	0	0	0
*	San Lucas Quiavini	500	180	0.8	80	55	0.6	20	0	0.6	0	0	0	0
	*** Tlacolula Promo II**	**3100**	**2997**		**280**	**580**		**55**	**128**		**2**	**6**	**0**	**10**
+	Villa de Mitla	600	600	1	15	0	0.6	20	20	0.6	0	0	0	0
+	Santiago Matatlan	400	1000	1	30	50	0.8	10	20	0.5	15	20	0	0
	+ MITLA-MATATL	**1000**	**1600**		**45**	**50**		**30**	**40**		**15**	**20**	**0**	**0**
o	San Sebastian Abasolo	210	50	1.2	30	0	0.7	5	0	0.7	0	0	0	0
o	Santa Cruz Paplutla	300	350	0.8	25	25	0.6	0	0	0	0	0	0	0
o	San Juan Teitipac	160	240	0.9	30	130	0.7	4	14	0.7	0	0	0	0
o	San Sebastian Teitipac	160	300	0.9	25	125	0.7	4	10	0.7	0	0	0	0
o	Rojas de Cuauhtemo	90	6	1	0	0	0	0	0	0	0	0	0	0
o	Santa Maria Guelace	150	50	0.8	0	3	0.6	2	3	0.6	0	0	0	0
o	San Francisco Lachigol	200	100	0.8	3	2	0.6	7	3	0.5	0	0	0	0
o	Tlacochahuaya	600	200	1	5	0	0.7	10	0	0.8	0	0	0	0
o	Teotilan del Valle	200	600	0.8	0	0	0	0	12	0.7	0	0	0	0
	o T O T A L	**2070**	**1896**		**118**	**285**		**32**	**42**		**0**	**0**	**0**	**0**
	GRAND TOTAL	**6170**	**6493**		**443**	**915**		**117**	**210**		**17**	**26**	**0**	**10**

data from S.A.R.H 94. **Mech:** Tillage operations are mechanized. **Not Mech:** Tillage is NOT mechanized.

TABLE 5B. 1994 Agricultural Production

	Township		ESTABLISHED PERENNIALS					ESTABLISHED PERENNIALS					ESTABLISHED PERENNIALS				
			Maguey	Alfalfa	Avocado	Apples		Peaches		Guayaba	Granada	Lemon	Lime	Orange	Papaya		
			Maguey	Alfalfa	Aguacate	Manzana	Ciruela	Durazno	Tejocote	Guayaba	Granada	Limón	Lima	Naranja	Papaya	Nispero	Anona
			ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
*	Talcolula de Matamoro		140	35	1.50	0	0	1.5	0	0	0	0	0	0	0	0	0
*	Diaz Ordaz		3	0	10	3	2	2	1	1	2	0	0	0	0	0	0
*	Santa Ana del Valle		0	0.75	0.5	0	0	0	0	0	0	0.25	0	0	0	0	0
*	Magdalena Teitipac		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*	San Juan Guelavia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*	San Bartolome Quialan		24	0	4	0	0	0	0	0	0	0	0	0	0	0	0
*	San Lucas Quiavini		110	0	2	0	0	0	0	0	0	1	0	0	0	0	0
	*** Tlacolula Promo II**		**277**	**35.75**	**16.5**	**3**	**2**	**3.5**	**1**	**1**	**2**	**1.25**	**0**	**0**	**0**	**0**	**0**
+	Villa de Mitla		190	0	20	0	0	2.5	0	0	1.5	2.25	0.75	1.25	0.75	0.5	0.75
+	Santiago Matatlan		637	0	4.75	0	0	0.5	0	0	0	6	5.5	2.25	0	1	0
	+ MITLA-MATATL		**827**	**0**	**24.75**	**0**	**0**	**3**	**0**	**0**	**1.5**	**8.25**	**6.25**	**3.5**	**0.75**	**1.5**	**0.75**
o	San Sebastian Abasolo		0	44	0	0	0	0	0	0	0	0	0	0	0	0	0
o	Santa Cruz Paplutla		5	10	0	0	0	0	0	0	0	0	0	0	0	0	0
o	San Juan Teitipac		0	**40**	0	0	0	0	0	0	0	0	0	0	0	0	0
o	San Sebastian Teitipac		0	21	0	0	0	0	0	0	0	0	0	0	0	0	0
o	Rojas de Cuauhtemo		0	170	0	0	0	0	0	0	0	0	0	0	0	0	0
o	Santa Maria Guelace		0	25	0	0	0	0	0	0	0	0	0	0	0	0	0
o	San Francisco Lachigol		0	10	1	0	0	0	0	0	0	0	0	0	0	0	0
o	Tlacochahuaya		0	52	0	0	0	0	0	0	0	0	0	0	0	0	0
o	Teotilan del Valle		6	20	0	0	0	0	0	0	0	0	0	0	0	0	0
	o T O T A L		**11**	**392**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	GRAND TOTAL	**0**	**1115**	**427.75**	**42.25**	**3**	**2**	**6.5**	**1**	**1**	**3.5**	**9.5**	**6.25**	**3.5**	**0.75**	**1.5**	**0.75**

data from S.A.R.H **Mech:** Tillage is mechanized. **Not Mech:** Tillage operations are NOT mechanized.

TABLE 5C. 1994 Agricultural Production

	Township	FALL - WINTER CYCLE PEAS Mech. ha	PEAS Not Mech ha	PEAS Yield tons/ha	FALL - WINTER CYCLE Small peas Mech. ha	Small peas Not Mech. ha	Small peas Yield tons/ha	FALL - WINTER CYCLE JITOMATE Mech. ha	JITOMATE Not Mech ha	JITOMATE Yield tons/ha
*	Talcolula de Matamoro	10	10	0.3	0	0	0	4	4	9
*	Diaz Ordaz	20	10	0.5	0	20	1.5	0	0	0
*	Santa Ana del Valle	0	10	0.3	0	0	0	0	0	0
*	Magdalena Teitipac	0	15	0.35	0	0	0	0	0	0
*	San Juan Guelavia	5	10	0.35	0	0	0	0	0	0
*	San Bartolome Quialan	2	18	0.3	0	0	0	0	0	0
*	San Lucas Quiavini	0	60	0.4	0	0	0	0	0	0
	*** Tlacolula Promo II**	**37**	**133**		**0**	**20**		**4**	**4**	
+	Villa de Mitla	20	20	0.6	0	0	0	0	0	0
+	Santiago Matatlan	7	10	0.4	0	0	0	0	0	0
	+ MITLA-MATATL	**27**	**30**		**0**	**0**		**0**	**0**	
o	San Sebastian Abasolo	0	2	0.5	0	0	0	0	0	0
o	Santa Cruz Paplutla	2	3	0.4	0	0	0	0	0	0
o	San Juan Teitipac	0	4	0.4	0	0	0	0	0	0
o	San Sebastian Teitipac	0	2	0.4	0	0	0	0	0	0
o	Rojas de Cuauhtemo	0	0	0	0	0	0	0	0	0
o	Santa Maria Guelace	0	2	0.5	0	0	0	0	0	0
o	San Francisco Lachigol	1	2	0.5	0	0	0	0	0	0
o	Tlacochahuaya	5	0	0.5	0	0	0	0	0	0
o	Teotilan del Valle	0	3	0.4	0	0	0	0	0	0
	o T O T A L	**8**	**18**		**0**	**0**	**0**	**0**	**0**	**0**
	GRAND TOTAL	**72**	**181**		**0**	**20**		**4**	**4**	

data from S.A.R.H **Mech:** Tillage is mechanized. **Not Mech:** Tillage is NOT mechanized.

		TABLE 5D. 994 Agricultural Production								
		FALL - WINTER CYCLE			FALL - WINTER CYCLE			FALL - WINTER CYCLE		
		Winter CORN			Beans	Beans		Wheat	Wheat	
	Township	Mech. ha	Not Mech ha	Yield tons/ha	Mech. ha	Not Mech ha	Yield tons/ha	Mech. ha	Not Mech ha	Yield tons/ha
*	Talcolula de Matamoro	30	21	1	0	1	0.6	0	0	0
*	Diaz Ordaz	5	8	1	0	0	0	0	20	0.8
*	Santa Ana del Valle	0	0	0	0	0	0	0	0	0
*	Magdalena Teitipac	1	2	1	0	0	0	0	0	0
*	San Juan Guelavia	0	0	0	0	0	0	0	0	0
*	San Bartolome Quialan	0	0	0	0	0	0	0	0	0
*	San Lucas Quiavini	0	0	0	0	0	0	0	0	0
	*** Tlacolula Promo II**	**36**	**31**		**0**	**1**		**0**	**20**	
+	Villa de Mitla	5	3	1.2	0	0	0	0	0	0
+	Santiago Matatlan	0	13	1.2	0	0	0	0	0	0
	+ MITLA-MATATL	**5**	**16**		**0**	**0**		**0**	**0**	
o	San Sebastian Abasolo	15	0	1.5	15	0	0.8	0	0	0
o	Santa Cruz Paplutla	0	0	0	0	0	0	0	0	0
o	San Juan Teitipac	0	0	0	0	0	0	0	0	0
o	San Sebastian Teitipac	5	0	1.2	5	0	0.7	0	0	0
o	Rojas de Cuauhtemo	5	0	1.2	3	0	0.8	0	0	0
o	Santa Maria Guelace	2	5	1.2	5	0	0.7	0	0	0
o	San Francisco Lachigol	2	0	1.2	2	0	0.7	0	0	0
o	Tlacochahuaya	15	0	1.5	10	0	0.8	0	0	0
o	Teotilan del Valle	0	5	1	0	0	0	0	0	0
	o T O T A L	**44**	**10**	**8.8**	**40**	**0**	**4.5**	**0**	**0**	**0**
	GRAND TOTAL	**85**	**57**		**40**	**1**		**0**	**20**	

data from S.A.R.H **Mech:** Tillage is mechanized. **Not Mech:**Tillage is NOT mechaniz

CHAPTER III.

MAP TRANSFORMATION

Introduction

The process of data acquisition, processing, interpretation and application consists of different phases. The applications of the obtained data and images strongly depend on the skill and the possibilities of the specialist to link data with other data sources like field studies, external reports, etc. Geographic Information Systems (GIS) are designed to accept large volumes of spatial data that are derived from different sources. Geometric transformations are then used to assign ground coordinates to a map or data layer within the GIS or to adjust one data layer so that layers can be correctly laid one over another. The procedure to accomplish this correction is termed registration. This is the main object of this chapter.

Review Of Basic Concepts

The Earth a Spheroid

The earth is an oblate spheroid of revolution, the length of its polar axis being somewhat less than that of its equatorial axis. Davis et al (1966) report that the values adopted (1924) by the International Geodetic and Geophysical Union are 12 713 799 meters for the Polar axis and 12 756 752 meters for the Equatorial axis. The polar axis is only 0.34% shorter than the Equatorial axis. Surveying which takes into account the shape of the earth is defined as *geodetic surveying*. Davis et al (1966) consider that when the area is not great, as for a state (understood a state of U.S.A) , the required precision may be obtained by assuming that the earth is a perfect sphere.

Irregularities (hills and valleys) along the measuring surface can cause ambiguities in distance (and thereby, location) . To alleviate this situation, it has long been common practice to reduce all measurements to a regular measuring surface - *a reference surface.*

Geoid

The geoid is the oldest reference surface. It is an equipotential surface of gravity defining all points in which the force of gravity is equivalent to that experienced at the ocean's surface. Since the earth spins on its axis and causes gravity to be counteracted

by centrifugal force progressively towards the equator, the geoid has the nature of an ellipse of revolution – an ellipsoid.

Reference Ellipsoids

Because of broad differences in earth materials, the geoid contains undulations that also introduce ambiguities of distance and location. It has become common practice to use and abstract reference surfaces that are close approximations to the shape of the geoid, but which provide perfectly smooth reference ellipsoids. By reducing all measurements to this idealized shape, ambiguities of distance and position are removed (IDRISI, 1995).

There are many different ellipsoids in geodetic use. When the center of the ellipsoid coincides with the center mass of the earth, the datum is known as a geocentric datum. The Clarke Spheroid (ellipsoid) of 1866, is used as the basis for geodetic coordinate systems of the continent of North America. It is the ellipsoid used by INEGI in Mexico and latitude and longitude with respect to this ellipsoid define positions on what is referred to as the North American Datum 1927.

Plane coordinates are a more workable medium than ellipsoidal (spherical) coordinates for digital application. As a result, surveyed locations are generally transformed to a plane grid referencing system before use. This is done through projection.

Projection

Projection of spherical positions to a flat plane cannot be achieved without distortion. The stretching and warping required to make the transformation work leads to continuous differences in scale over the face of the map, which in turn leads to errors in distance, area and angular relationships. It is however possible to minimize these errors so that certain geometrical qualities are maintained.

Of particular importance to Geographic Information Systems are the projections known as conformal or orthomorphic projections. These are projections in which the distortion is managed in such a manner that angular relationships are correctly preserved in the near vicinity of any location.

Mercator Projection

This cylindrical projection is formed by means of a cylinder touching the earth along the equator, all meridians appear as straight parallel lines. But on the sphere any

two such meridians are at a maximum distance apart at the equator and converge towards the poles. Showing the meridians parallel, therefore, results in a systematically increasing scale along the parallels of latitude as we pass from the equator toward the poles, with resulting distortion of all areas shown on the map. The change of scale along the parallel, varying with the latitude, is readily computed [1] by means of the formula:

$$S_c' = S_c \cos\phi \qquad (1)$$

in which S_c is the scale at the equator and S_c' is the scale at any latitude ϕ.

The particular feature of the Mercator projection is that the scale along the meridian is varied to agree with the scale along the parallel, so that although the scale varies from point to point on the map at any given point the scale is the same in all directions. The map is therefore conformal. It has also the important property that a line of constant true bearing or rhumb line , appears straight.

Transverse Mercator Projection

A transverse Mercator projection is the ordinary Mercator projection turned through an angle of 90° so that it is related to a central meridian in the same way that the ordinary Mercator projection is related to the equator. This projection is commonly used for the state plane coordinate systems of zones of greater north-south than east-west extent. The Mercator projection cylinder is made to cut the surface of the sphere along two standard lines parallel to the central meridian instead of being tangent to the sphere as in the ordinary Mercator projection.

Universal Transverse Mercator (UTM)

The UTM system uses the equator and the central meridian of a 6-degree wide zone as the true origin for the hemisphere. The point is then given arbitrary coordinates of 500 000 meters East and 0 (Zero) meter North. This system is widely used in North America and it is the same reference system used on the topographic maps (scale of 1:50000) prepared by ***the Instituto Nacional de Estadistica, Geografía***

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[1] Assuming the earth to be spherical. The polar diameter being only 0.34% shorter than the equatorial diameter , the variation from the truly spherical shape does not change the nature of the various map projections although it does make necessary certain corrections (Davis et al, 1966). A discussion of these refinements is beyond the scope of this research.

e Informática **(INEGI)** for each state of Mexico. The basic grid is 1000 meters and in the case of the research area, elevations are given by means of twenty meters contour lines. This system of plane coordinates has the advantage that all points in the state can be referred to without significant error in distance or direction arising from the difference between the reference surface and the actual mean surface of the earth. Moreover, the UTM grid system being linearly derived from the spherical coordinates, it follows that UTM coordinates can be transformed to Latitudes and Longitudes by simple arithmetics.

Differential Leveling

Throughout the Republic of Mexico are permanent "bancos de nivel" (bench marks) that are now under the responsibility of the *Dirección General de Geografía. Recuperación de Bancos de Nivel Departamento de Geodesia.* The Bench Mark BN-170 consists of a bronze plate set in concrete and was established by the Universidad Nacional Autónoma de México in 1969. It is strategically located at the cross roads of Tlacolula - Mitla - Matalan. It is the cross link between field survey work and the electronic base map which will be established in the course of this research. Data layers are registered to this common coordinate system.

Latitude and Longitude versus (Xmap; Ymap).

The UTM grid system on the topographic maps (scale of 1:50000) prepared by **INEGI** is denoted here as Xmap; Ymap. -

Method

To make use of the UTM Oaxaca state system in our surveys, the surveyor sets up the transit at the Geodetic Bench station BN-170, he then orients it on the line of known Azimuth, and runs surveys by traversing to the area under study. The coordinates of any point in the local survey can then be conveniently computed in terms of the state grid system by ordinary methods of plane surveying. The survey was checked by traversing back to the original station or to another triangulation station. Elevations were referred to the established system of bench marks.

A. Map Transformation

We shall now examine the final transformation and define the file of correspondence that will be used for the resampling function. We seek to transform the (x , y) coordinates into (x_M , y_M). X_M and Y_M are the reference axes that define

respectively the average orientation of the groundwater flow and the average orientation of the head gradient of the groundwater. The X_M - Y_M reference system lies at 28° [2] clockwise with respect to the X-Y local grid system of the topographical map. **Referring to Figure 1 .**

We first find (h , k) to define the position of the origin of the X_M - Y_M reference system

$$\mathbf{h = y_{MR} \cdot \sin(28°)} \qquad \mathbf{(2)}$$

$k = AC - CE$ and $CE / y_{MR} = \cos(28°)$

so $k = AC - y_{MR} \cdot \cos(28°)$ but y_{MR} is also $= CB \cdot \cos(28°)$

Therefore $k = AC - CB \cdot \cos(28°) \cdot \cos(28°) = AC - CB \cdot \cos^2(28°)$

$$\mathbf{k = AC - CB \cdot \cos^2(28°)} \qquad \mathbf{(3)}$$

$tg(28°) = x_{MR} / AR \Rightarrow AR = x_{MR} / tg(28°)$

$\sin(28°) = AS / AD \Rightarrow AS = AD \cdot \sin(28°)$

$y_{MR} = AR - AS = x_{MR} / tg(28°) - AD \cdot \sin(28°)$

$$\mathbf{y_{MR} = (x_{MR} / tg(28°)) - (AD \cdot \sin(28°))} \qquad \mathbf{(4)}$$

$$\mathbf{y_{MR} \text{ is also } = CB \cdot \cos(28°)} \qquad \mathbf{(5)}$$

As a first approximation we measure AD on the topographic papermap and we find AD = 205,5 mm that is 10 275 meters at a scale of 1:50 000. By measuring CB and x_{MR} we then calculate y_{MR} and verify our AD measurement by applying Equation 4. We find AD = 209,3 mm or 10467 meters at a scale of 1:50 000. This leads to a difference of 3,8 mm at a scale of 1:50 000 or 192 meters as a field distance.

This procedure is unacceptable and clearly shows the difficulty in setting perpendicular axes on a paper map and the relative positioning error obtained when using pencil marks. This error may be of no great significance for the groundwater model but is nevertheless useless since with the procedure below this positioning error can be avoided.

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[2] Actual angle is 27°56 ' but 28° will be used for easier reading. This corresponds to the general orientation of the ground water with respect to the main axis of the Valley as found from the static ground water levels of 1984.

Using our electronic base map [3] and working in a G.I.S. environment we proceed as follows.

To find (h , k).

I) **Find the ground water flow direction that is X_M orientation.** The orientation of the ground water flow principal axis is obtained from the groundwater equipotential map. In this research the boundaries of the Valley floor were drafted parallel to the orientation of the ground water flow and the line intersection of this frame with the reference local grid system were digitized as line segments (see Table 2). Angles were computed from the XY coordinates. A weighted orientation angle on a basis of the product of the length of the line segment and its orientation with respect to the XY coordinate system was calculated. This orientation was found to be 27°56 '. The Y_M axis is then set up perpendicular to X_M axis with a set square. The topographic map is scanned as shown in Figure 2.

II) **Find Y_M axis 1st approximation** : We digitize first the axis Y_M with six control points on the scanned copy of the topographic base map. These points are located on the Y_M axis at an enlargement 2X. These points are of course not all on the same straight line but rather subject to a visual positioning error.

III) **Find the best line that fits these six control points.** We then find by a linear regression the best line that fits these six control points. We get the lower and upper 95% Confidence interval of this regression line.

IV) **Calculate Y_M axis that is orthogonal to X_M** orientation while lying within the interval boundaries found in the linear regression of the six control points digitized in II).

V) Once the Y_M axis is set we then **fix the position of its origin.**
This origin is here arbitrarily set at 17 900 meters from the point "a"[4] . The position of the origin (h ; k) is then found as :

---

[3] saved under the image file name of XYMAP1.img in IDRISI environment.

[4] This corresponds to a 19 km distance from the point "b" which was initially selected to define the position of origin. Since the points "a" and "b" were both digitized and part of the six control points for setting our first approximate orientation of the Y_M axis, the distance |ab| was then calculated analytically and found to be 1 100 meters. It follows that the origin can then be set at 19.0 km from "b" or at 17.9 km from "a". The latter is preferred for convenience.

$(h : k) \in Y_M$

$|(h : k) \cdot (x_a ; y_a)| = 17\,900$

We find that $(h : k) = (-6321.2 : 8810.4)$

The procedure above meets our two requirements namely: X_M is parallel to the general groundwater flow and Y_M is perpendicular to X_M.

The linear regression that best fits the line defined by the six control points that were digitized in IDRISI environment is illustrated on Figure 3. The procedure and required computations to define the position of the origin (h;k) and the final orientation of the axes X_M and Y_M is summarized in Table 2.

Let us consider a point "p" of coordinates $(x_p : y_p)$ in the X:Y coordinates system. This point has respectively the coordinates $(x_{Mp} ; y_{Mp})$ and $(x_{mp} . y_{mp})$ in the $X_M : Y_M$ and $X_m . Y_m$ coordinates system. as shown on Figure 1. From simple trigonometry we can write:

$\cos\alpha = x_p / OP$ and $\cos\beta = y_{mp} / OP$ and $\sin\alpha = y_p / OP$

FROM WHICH

$$y_{mp} = x_p \cdot (\cos\beta / \cos\alpha) \quad \text{or} \quad y_{mp} = y_p \cdot (\cos\beta / \sin\alpha) \qquad (6)$$

$\sin\alpha = y_p / OP$ and $\sin\beta = x_{mp} / OP$ and $\cos\alpha = x_p / OP$

$$x_{mp} = y_p \cdot (\sin\beta / \sin\alpha) \quad \text{or} \quad x_{mp} = x_p \cdot (\sin\beta / \cos a) \qquad (7)$$

and from Figure 1.

$$y_{Mp} = y_{mp} + k_M \qquad (8)$$

$$x_{Mp} = x_{mp} + h_M \qquad (9)$$

where $k_M < 0$. and $h_m > 0$.

We then obtain From Eq(6) and Eq(8)

$$y_{Mp} = x_p \cdot (\cos\beta / \cos\alpha) + k_M \qquad (10)$$

We then obtain From Eq(7) and Eq(9)

$$x_{Mp} = y_p \cdot (\sin\beta / \sin\alpha) + h_M \qquad (11)$$

Expression of $(h_M ; k_M)$.

Let us call ω the angle that makes the arctangent of the ratio k to h that is: $\omega = tg^{-1}(h / k)$. The angle ω is expected to be negative that is counterclockwise.

The distance between the origin of the X:Y system (called O) and the origin of the X_M:Y_M system (called O_M) is given by

$$|O : O_M| = (h^2 + k^2)^{1/2} \quad (12)$$

Let us call ω_M the angle that makes the arctangent of the ratio k_M to h_M. Figure 1 shows that;

$$k_M = |O : O_M| \cdot \sin \omega_M = (h^2 + k^2)^{1/2} \cdot \sin \omega_M \quad (13)$$

$$h_M = |O : O_M| \cdot \cos \omega_M = (h^2 + k^2)^{1/2} \cdot \cos \omega_M \quad (14)$$

$$\omega_M = 90° + \omega - \sigma \quad (15)$$

where σ is the angle that makes the axis X_M with respect to the X axis.

This angle σ is the orientation of the principal axis of the ground water flow direction with respect to our XY coordinate system that was set parallel to the Latitude and Longitude system. This best fit of this variable orientation is 27°56' when estimated from ground water equipotential lines based on 1984 monitoring. We can therefore write: $\omega_M = 90° + \omega - 27.9406° = 62.0594° + \omega$

In summary **the transformation procedure** is as follows:

1. Calculate $\alpha = tg^{-1} (y_p / x_p)$. [$\alpha$ is to be expressed in decimal fraction].
2. Calculate $\beta = 62.06417° - \alpha$.
3. Calculate $\omega = tg^{-1} (h / k)$.

   Note that (h:k) was found previously to be (-6321.21; + 8810.37) meters.
4. Calculate $\omega_M = 90° + \omega - \sigma = 62.0594° + \omega$.
5. Calculate $k_M = |O : O_M| \cdot \sin \omega_M = (h^2 + k^2)^{1/2} \cdot \sin \omega_M$.
6. Calculate $h_M = |O : O_M| \cdot \cos \omega_M = (h^2 + k^2)^{1/2} \cdot \cos \omega_M$.
7. Calculate $y_{Mp} = x_p \cdot (\cos \beta / \cos \alpha) + k_M$
8. Calculate $x_{Mp} = y_p \cdot (\sin \beta / \sin \alpha) + h_M$

Calculations of (h_M, k_M)

- Found previously (h : k) = (-6321 ; +8 810) meters.
- we get $\omega = tg^{-1} (h / k) = tg^{-1} (-6321 / +8\,810) = -35.66°$.

  The minus sign indicates that the angle ω is counterclokwise to the Y axis.
- $\omega_M = 90° + \omega - \sigma = 90° - 35.66° - 27.94° = 26.40°$. and

- $|O : O_M| = (h^2 + k^2)^{1/2} = ((-6321)^2 + (8810)^2)^{1/2} = 10\,843$ m.
- $k_M = |O : O_M| \cdot \sin \omega_M = (h^2 + k^2)^{1/2} \cdot \sin \omega_M$.
  $= 10\,843 \cdot \sin(26.40°) = 4\,822$ m.
- $h_M = |O : O_M| \cdot \cos \omega_M = (h^2 + k^2)^{1/2} \cdot \cos \omega_M$.
  $= 10843{,}4 \cdot \cos(26.40°) = 9\,712$ m.

We verify $\omega_M = tg^{-1}(4\,822/9\,712) = 26.40°$.

Therefore $(k_M ; h_M) = (4822 ; 9712)$ m.

Modules of IDRISI for Windows that calculate quantities based on distance (such as AREA, PERIM, SURFACE and SPDIST) automatically accommodate a latitude/longitude reference system by making adjustments for the changing ground length of a degree of longitude as the latitude changes. These adjustments are based on a spherical assumption and do not require the presence of a reference file.

Survey of observation wells

Considering a groundwater gradient in the range of $3x10^{-3}$ to $15x10^{-3}$ (TACSA, 1983), the precision required in locating a certain observation well in the xy plane is not as demanding as the precision required on its elevation. To carry out the transit survey of low precision where only horizontal angles and distances are required, it was decided to adopt the stadia method. Traverses were closed and as a check after the traverse were brought to a closure, the initial station was occupied by the transit and the angle between the first and last lines of the traverse was measured. In this way the angular error of closure was determined.

Stadia intervals and horizontal angles (or directions) were observed as each point was sighted. Vertical angles were then observed only if greater than three degrees, that is large enough to make the horizontal distance appreciably different from the stadia distance. The transit used had a vertical circle reading to single minutes but vertical angles when needed, were read to the nearest 10(ten) minutes. Stadia intervals were observed both forward and backward from each set-up of the transit. In this way two independent stadia observations were made for each line or distance in the traverse. The closeness of agreement between the two values for each line is then a check against mistakes, and the mean is taken as the most probable value.

The directions of lines were determined by azimuths and were checked by magnetic bearings. According to Davis et al (1966), a maximum error of thirty (30)

seconds to one (1) minute is likely to occur in measuring horizontal angles under conditions where sights are unobscured, not steeply inclined, on well-defined points, with vernier reading to minutes and single observation of angle.

Davis et al (1966) are of the opinion that the precision of stadia surveying is such that ordinarily horizontal distances are determined to the three hundred millimeters and vertical distances to the nearest fifty millimeters.

The elevation of observation wells was determined in closed circuits through differential leveling. This task was done by a second crew and using a dumpy level. A list of National geodesic points available in the research area was obtained from the "Instituto Nacional de Estadística, Geografía e Informática" of Oaxaca. Numerous temporary bench marks were established for maintenance of the final network of observation wells.

Compiling Coordinates And Plotting The Polygons.

The angle of Magnetic North with respect to the local grid system on the 1:50000 topographic map (our basemap) was estimated using the grid-based geographic information and image processing system IDRISI [5] and digitizing the Magnetic Meridian Line on the scanned topographic map. Simple plane trigonometry as shown in Figure 5 is then applied on these coordinates and an angle of 7°27' clock wise with respect to the True North is obtained. This is done in Table 3.

This compares reasonably well with the magnetic declination given in the legend of the topographic map. Its orientation is 7°45' clock wise with respect to the True North with an annual variation of four (4) minutes. The convergence of the local grid with respect to the True North is 0°44' counter clockwise. The Magnetic North is therefore oriented at (7°45' - 0°44' = 7°01') clockwise with respect to the orientation of the UTM grid system. This rotational angle adjustment was applied on the starting Azimuth angle of the Mitla polygon.

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[5] Developed by the Graduate School of Geography at Clark University and introduced on the market in 1987. IDRISI is a popular raster-based microcomputer Geographic Information System (GIS) and image processing on the market. It is for its popularity and the fact that it is used by C.N.A in Mexico that this GIS software was used in this research. **It is not by any means suggested here that IDRISI is superior to its competitors on the market. Use of brand names in this thesis is for identification purposes only and does not constitute endorsement by the author.**

One unique magnetic declination was expected to apply for calculating the starting Azimuth angle of the thirteen other polygons which would allow compiling coordinates all under the common True North reference system.

However. when the coordinates of the Mitla traverse were calculated with a magnetic declination of 7°01' and displayed in the XYMAP1 reference system. the resulting polygon orientation was found to be off by approximately 2 degrees. When the same magnetic declination was applied to the surveyed polygon in Matatlan area. the plotted polygon was also found to be off but this time by slightly more than three degrees. In either case from the incorrect value of the starting Azimuth angle follows a polar increasing offset of the polygon stations with respect to their true position on the base map.

Investigating the possible sources of errors.

The possible sources of error identified by Davis et al (1966) in such a case of adjustment of Compass are: a needle bent. a pivot bent, a plane of sight not vertical. a sluggish needle. an error in reading the needle and possible magnetic variations. Davis et al (1966) consider that undetected deviations of the magnetic needle from whatever cause are generally the sources of the largest and most important systematic errors in compass work. Largely because of such variations. Davis et al (1966) conclude that no matter how finely constructed. the compass is not a suitable instrument except for rough survey.

Correcting The Gross Error.

If an angular error of three degrees is introduced at the starting point in a seventeen kilometers long closed traverse. such as in the case of the Mitla polygon. an offset exceeding four hundred meters would occur at the furthest point of the polygon from its start ! This is of course unacceptable. Since the error is introduced on the very first angle. a very good fit and correct re-orientation of the polygon could be obtained by means of the following simple trial and adjustment method.

Procedure Used In Fitting The Polygons On The Electronic Base map.

1. The polygon survey is first compiled with no magnetic declination.
2. The angle that induces a best fit for this polygon compiled with a zero magnetic declination is derived from simple trigonometry on the coordinates of three strategic points digitized under close zooming in IDRISI environment. Most of polygon stations coincide with physical features some of which are shown on the topographic map. Stations and points aimed at some physical features such as bridges. road intersections, established geodesic points, canal structures etc. are digitized directly on the map as well as their corresponding points on the polygon of zero magnetic declination. These strategic points are digitized under close zooming. The angle to guarantee a good fit is then calculated as shown on Table 4 and Figure 6 for the case of the Mitla polygon. This angular adjustment has the same effect as the local magnetic declination and is applied as such on the first Azimuth angle.
3. The coordinates are then compiled once more but with this new starting angle. A program was written in Qbasic [6] to perform these compilations in a quick and systematic manner. EXCEL[7] macros were then developed to arrange the compiled coordinates in an orderly vectorial format that can be displayed in IDRISI environment. It took some time to develop this computer program and trial and adjustment procedure but it turned out to be a powerful tool. Once the survey data input is complete. a new set of polygon coordinates can be derived and displayed within a few minutes.
4. The procedure is repeated if a better fit is visually apparent. This was generally not required.

Using this simple procedure a very good fit could be obtained on twelve out of the thirteen surveyed polygons. Fitting the survey polygon "Guelavia" was difficult. Due to its remote location, this polygon was not tied to another survey and the starting point could not be identified on the map. To fit this polygon one has to rely on two stations far from the starting point. This complicates the process because the

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[6] Registered trademark of MS-DOS QBasic Version 1.1 Copyright © Microsoft Corporation. 1987-1993.

[7] Registered trademark of Microsoft Excel for Windows 95. Version 7.0. Copyright © 1985-1995 Microsoft Corporation. 1987-1993.

coordinates of the starting point as well as the magnetic declination are then floating. Although the final fit looks good. it is recommended to proceed with two field checks to either confirm or if need arises to improve the final position of this polygon.
The error of closure of each traverse is shown in Table 5.

Target Precision set for Differential Leveling.

Davis et al (1966) identifies twelve causes of errors in levelling. Under normal conditions the important errors are accidental. provided the proper leveling procedure is observed. The resulting error may be expected to vary as the square root of the number of set-ups of the instrument or as the square root of the distance. Davis et al (1966) mention however that the demonstration has been made. that on very long lines of precise levels. the errors are proportional to some power of the distance between one half and one. indicating that in spite of every precaution there are certain small systematic errors which cannot be eliminated by any known method of procedure.

It was decided that ordinary leveling would be sufficient for determining with reasonable precision the relative elevations of the observation wells. In ordinary leveling Davis et al (1966) recommends sights up to 150 meters in length. Rod readings must then be taken to five millimeters [8] and backsights and foresights distances must then be balanced only when running for long distances uphill or downhill and turning points must be taken on solid objects. The maximum allowable error in meters is then set to $\pm 0.024 \sqrt{(\text{distance}).in..km}$.

Throughout the survey a well known fact became more and more apparent that is. although the precision of differential leveling is influenced by the instrument employed. it depends chiefly upon the care and skill of the leveler and upon the degree of refinement with which the work is executed .

The proposed Network

A preliminary network of 142 observation wells was proposed to the CNA. A network of 80 best of the 142 documented observation wells is recommended. Tables 1 to 7B in Appendix S show the polygon survey data that were compiled to obtain x, y coordinates. The elevations or Z ordinates were compiled separately. Tables 8A and 8B give the historical water table measurements taken by S.A.R.H in 1971-1972. The

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[8] Davis et al (1966) 's recommendations are expressed in British units. These values were converted and adapted to a metric survey system.

locations of the twenty nine wells that were monitored were located on the topographic base map and digitized within IDRISI environment. Tables 9a to 9f give the x.y coordinates of the 142 domestic that were documented in this research and proposed as a preliminary network. The dates when water table measurements were taken from these wells are also given in Tables 9A to 9F. Table 11 shows that some of the observation wells could not be surveyed. These wells were visually positioned on the topographic base map and then digitized within IDRISI environment. A possible positioning error of a radius of 50m is estimated. The Z error estimate is the mean error of closure of the profile surveys.

It should be noted that there is no guarantee that the wells selected in previous monitoring work (prior to 1994-1995) have similar hydraulic response as the wells selected in this research. This consisderation was made clear to the Manager and must be taken into account when deciding whether on not these data may be used for model calibration. It must be noted however that given the relatively slow response of this unconfined aquifer, reliability of the static levels monitored in these wells may be achieved by ensuring that sufficient time at rest is allowed for the water in the well to reach its true phreatic level. This was made clear to the well users who revealed their habits of water usage. By grouping observation wells, a check against local perturbations of the water table can be detected. The stable trend in the watertable response indicated by measurements shown in Appendix S . Tables 9A to 9F and 10A to 10F suggest that the hydraulic response of the observation wells was adequate .

The Transformation Routines to navigate between Grid systems.

Latitude and Longitude versus (Xmap; Ymap).

The UTM grid system on the topographic maps (scale of 1:50000). here denoted as (Xmap. Ymap) is related linearly to the Latitude and Longitude. This transformation routine is best programmed in a spreadsheet form. This is done by the template file called LATLONGtoXmapYmap.xls from which the cell formulas are extracted and shown in Table 6. Table 7 shows this transformation routine when used to transform the Latitude and Longitude values corresponding to the well locations surveyed by the Manager[9] in 1972 and 1973. These Latitude and Longitude values were

[9] Today the Manager is **C.N.A**- Oaxaca Organisation but in the 1970s the Manager was S.A.R.H-Oaxaca Organisation

read directly from the map provided in GEOCA (1980) report. Table 8 In Appendix S gives the water table elevation calculated from the water table depths recorded by S.A.R.H/C.N.A in this survey of 1972-1973.

Xmap, Ymap Converted to Xp, Yp and to X Flow, Yflow.

The X,Y coordinate system is a convenient system used in this research. It is a simple translation of (Xmap:Ymap) axes so that the origin of X , Y axes denoted as (x = 0, y = 0) coincides with the coordinates (x_{map}= 48.38 : y_{map}= 65.00).

The procedure, explained at the beginning of this chapter, is applied to transform the (x , y) coordinates to (x_{Mp} , y_{Mp}) in the (X_M , Y_M) ground water flow system where X_M axis is set parallel to the general orientation of the ground water flow. A spreadsheet form is appropriate to systematize the routine compilations required to transform the (x_{map} , y_{map}) coordinates to (x , y) and then to (x_{Mp} , y_{Mp}). Table 8 shows a typical output of the spreadsheet file created to that effect. This spreadsheet may be used with the spreadsheet LATLONGtoXmapYmap.xls to convert point coordinates from one system to another.

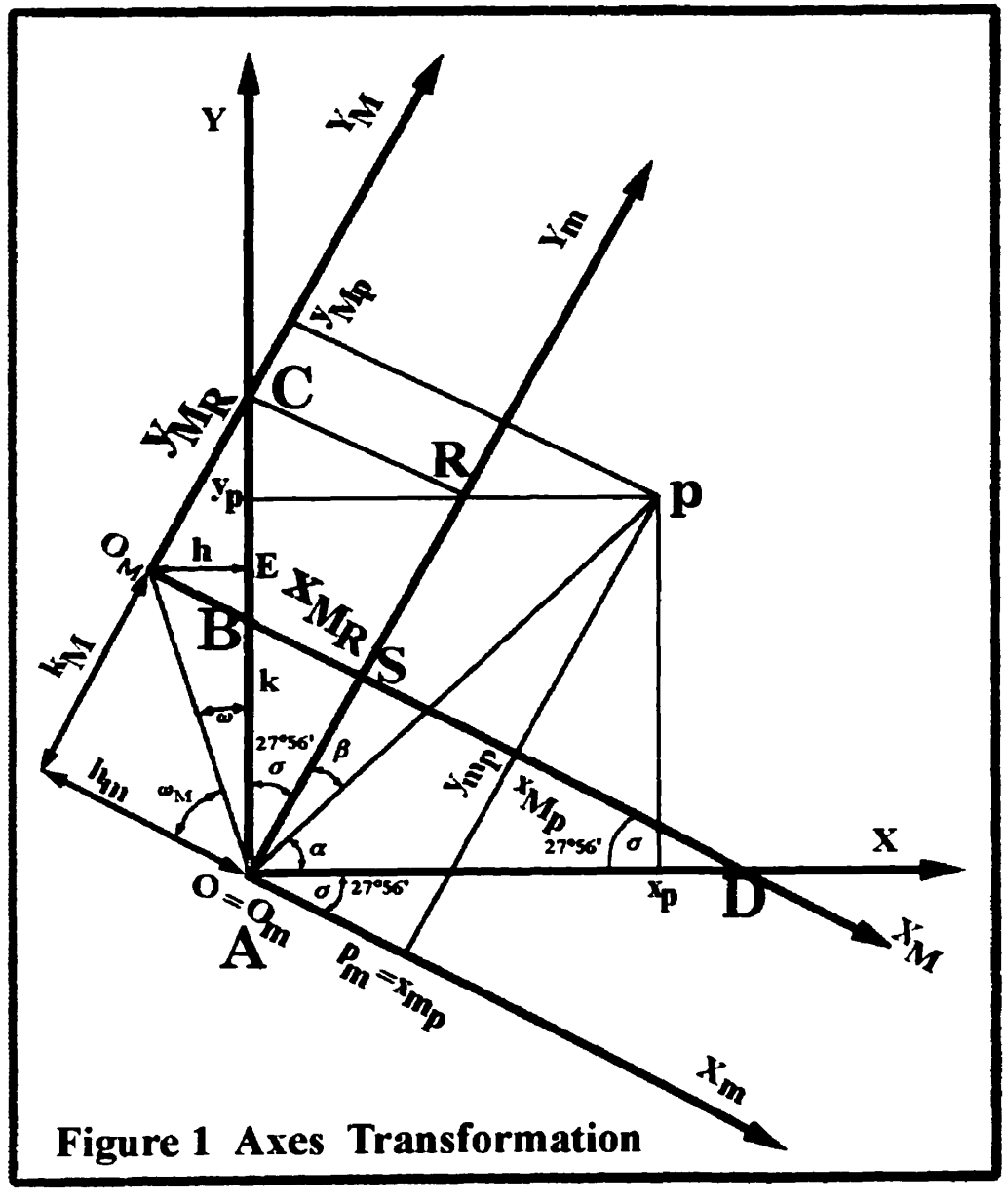


Figure 1 Axes Transformation

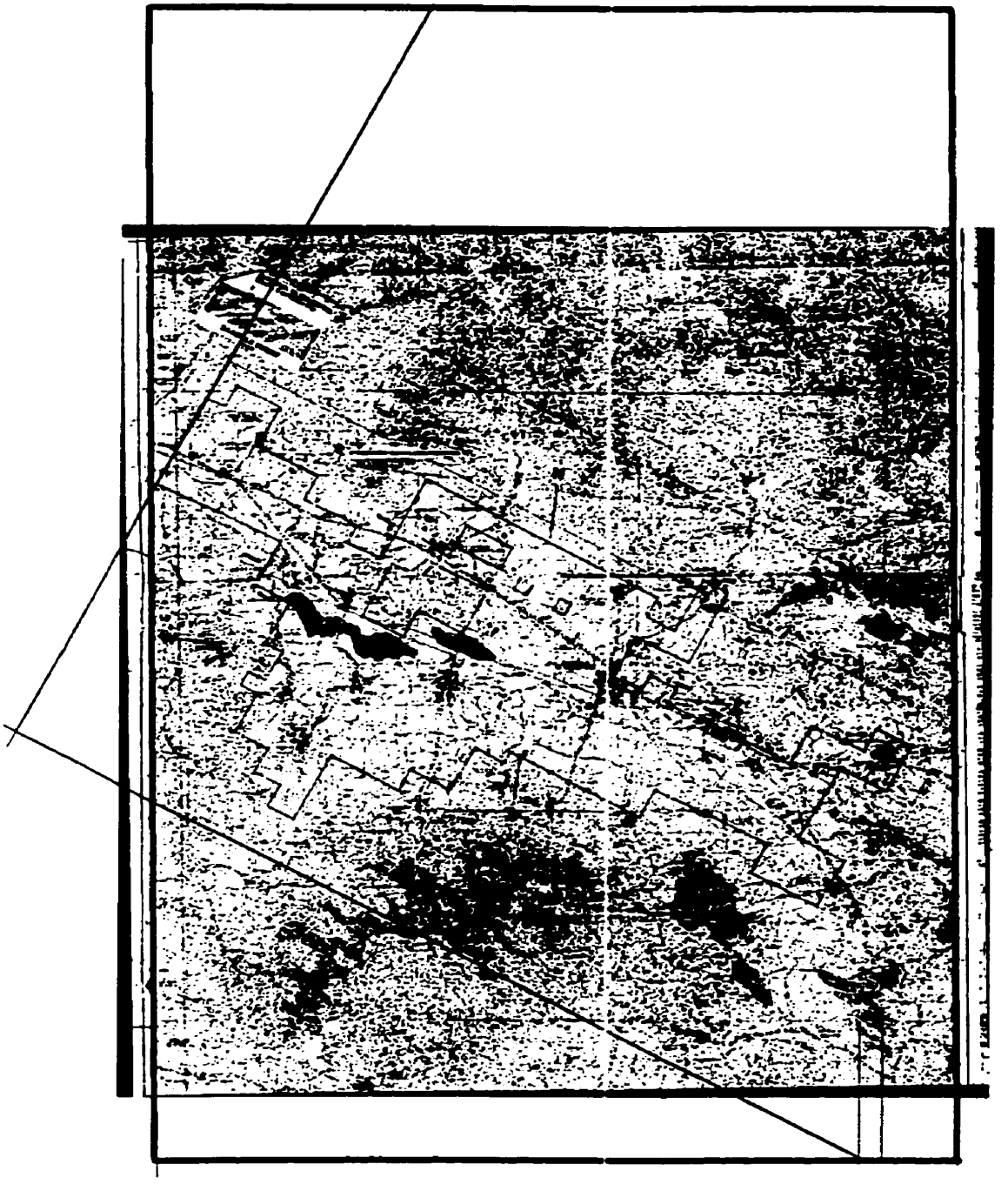


Figure 2 . The boundaries of the Valley floor are drafted with line segments parallel to the ground water flow .

intersection

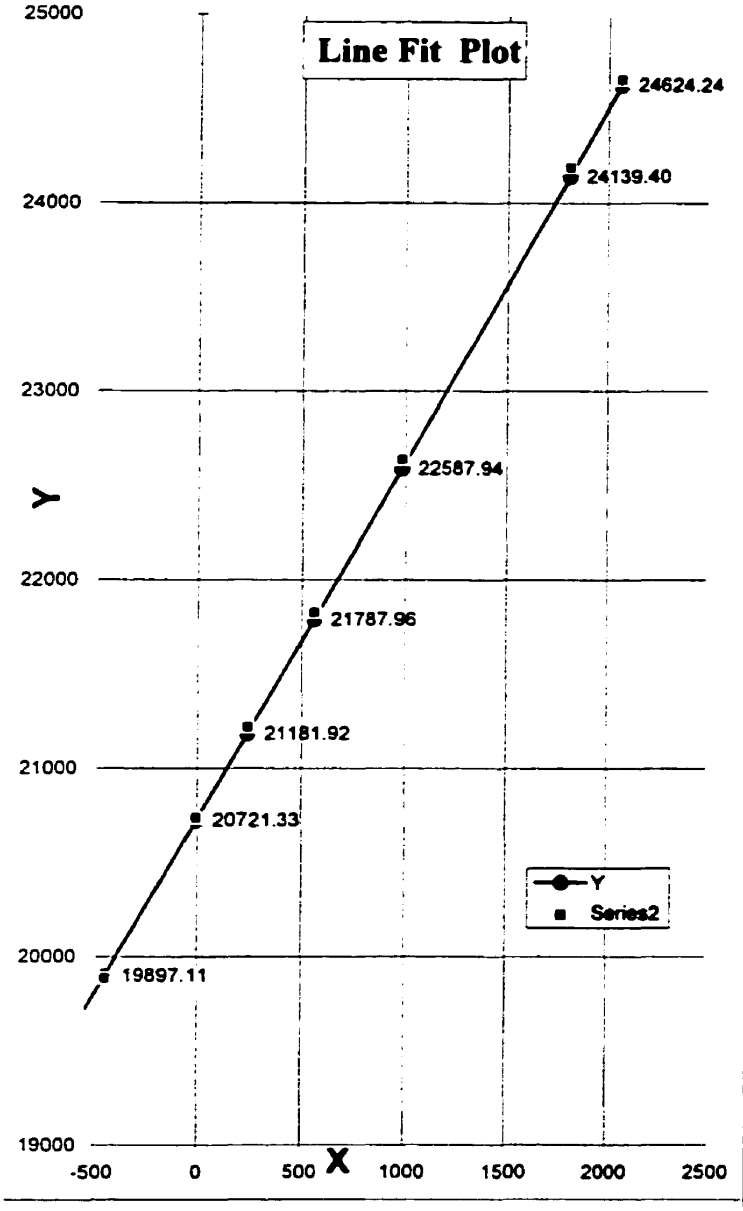


TABLE 1. Linear Regression Y_M axis

	Coefficients
Intercept ->	20730.0
X Variable 1->	1.9
X	**Predicted Y Preferred**
2065.2	24624.2
1808.1	24139.4
985.3	22587.9
561.1	21788.0
239.7	21181.9
-4.6	20721.3
-441.7	19897.1
-6321.2	8810.4
0.0	20730.0

X	**Y digitized**
2065.2	24652.2
1808.1	24188.6
985.3	22635.4
561.1	21826.7
239.7	21217.1
-4.6	20734.6
-441.7	19886.0

Predicted Y	**Residuals**
24673.0	-20.8
24184.3	4.4
22620.3	15.1
21813.8	12.8
21202.9	14.2
20738.6	-4.0
19907.7	-21.7

FIGURE 3. LINEAR REGRESSION LINE BEST FIT OF THE 6 DIGITIZED POINTS.

TABLE 2 SUMMARY SPREADSHEET SHOWING THE PROCEDURE USED IN DETERMINING X_M and Y_M axes, and the point of origin.

Weighed average of digitized line segments.			Linear Regression Coefficients of			Final Y_M orientation.		
Length*Angle	Length	Angle	Digitized control points of 1st Approx of Y_M axis.				Predicted Y	Distance
337388	11,840.56	28.4943	*Coefficients*	Intercept	X Variable 1	**X**	**preferred**	from
526642	18,604.94	28.3066				2065.19	24624.24	0.00
155871	5,606.24	27.8031	*Lower 95%*	20546.3529	1.8531	1808.07	24139.40	548.79
658405	23,629.19	27.8641				985.30	22587.94	2304.93
689984	24,855.17	27.7602	Average	20747.3320	1.9009	561.06	21787.96	3210.43
596259	21,439.05	27.8118				239.66	21181.92	3896.42
658405	23,629.19	27.8641	*Upper 95%*	20626.7208	1.9171	-4.60	20721.33	4417.77
599576	21,428.74	27.9800				-441.70	19897.11	5350.72
165609	6,001.44	27.5948	Preferred	20730	1.885657906	**-6321.21**	**8810.37**	**17900.00**
181462	6,540.39	27.7449				8386.39	15813.87	
4569602	163575	27.93583575				27.93778655	56.2671928	16.03156808
						Degrees	Minutes	Seconds
27.93583575	56.15014528	9.00871689				27	56	16
Degrees	Minutes	Seconds	**Note: x = -6321.21 is calculated by setting the distance**					
27	56	9	**from (2065,24624) equal to 17 900. This defines our origin.**					

INTERVAL BOUNDARIES of Y_M	Predicted Y			Predicted Y			Predicted Y	
X	**Lower 95%**	Residuals	X	**Avg**	Residuals	X	**Upper 95%**	Resduals
2065.19	24609.68	-42.52	2065.19	**24673.01**	20.81	2065.19	24736.34	84.14
1808.07	24126.01	-62.62	1808.07	24184.26	-4.36	1808.07	24242.51	53.89
985.30	22578.28	-57.07	985.30	22620.27	-15.08	985.30	22662.25	26.90
561.06	21780.24	-46.44	561.06	21813.84	-12.84	561.06	21847.43	20.76
239.66	21175.66	-41.48	239.66	21202.90	-14.24	239.66	21230.14	13.00
-4.60	20716.17	830.17	-4.60			-4.60		
-441.70	19893.94	7.94	-441.70	19907.72	21.72	-441.70	19921.49	35.49
-6240.04	8986.60		-6171.68	9015.69		-6104.27	9045.67	
8305.23	15623.07		8236.87	15657.32		8169.45	15690.67	
27.99505681	59.70340836	42.20450165	27.74751446	44.85086754	51.05205259	27.50397234	30.23834028	14.30041706
Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds
27	59	42	27	44	51	27	30	14

AXISANGL.xls

TABLE 3 The angle of Magnetic North with respect to the local grid system

diff. x (m)	diff. y (m)	distance (m)	Angle degrees	Angle degrees	Angle minutes
1738	0	1737.8			
0	13286	13286.3	7.4417	7	27

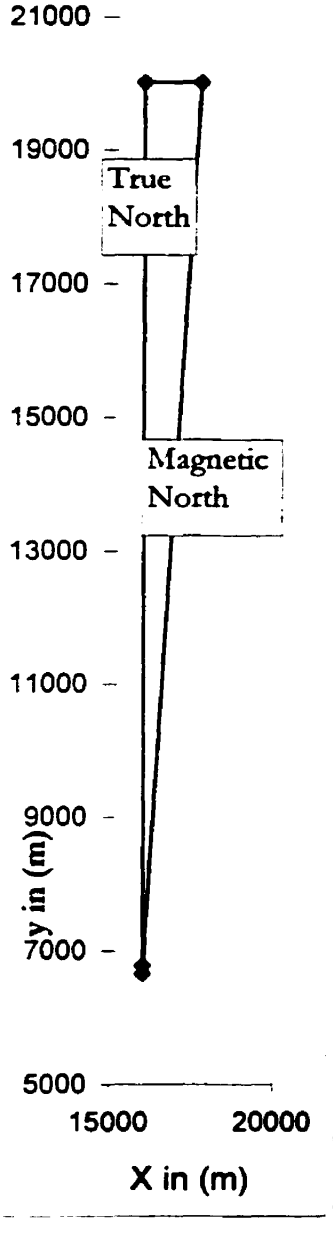


FIGURE 4 . Magnetic North versus True North.

TABLE 4 Calculating the "local magnetic declination" from digitized offset (see Figure below)

	X in (m)	Y in (m)	
point A	28456	7202	
point B	33702	8027	
point C	33843	7595	
point A	28456	7202	
diff. x	**diff. y**	**distance**	**Angle**
(m)	(m)	(m)	degrees
-141	432	454.323	
5387	394	5400.95	4.81
Angle (clockwise)			4 degr 48 min.

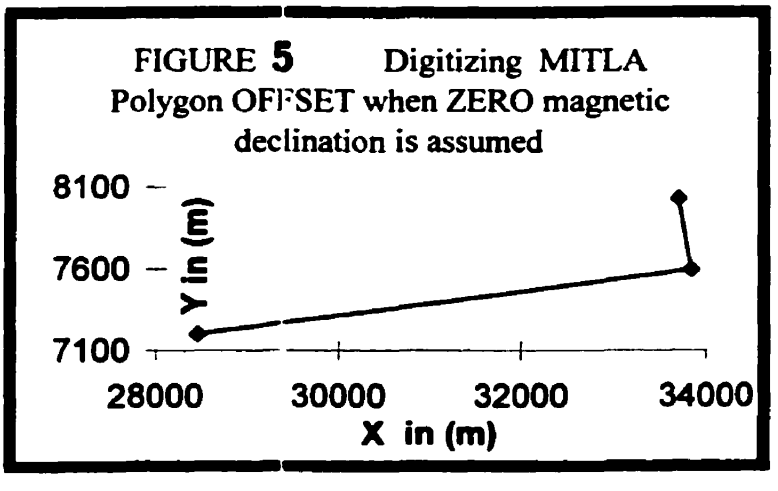


TABLE 5 Closure Errors and Relative Errors of Polygon Surveys,

	POLYGON file names (.DAT)	Number of sides	Polygon Length (m)	Closure Error X (m)	Y (m)	Relative Error %	Angle Error degrees	Allowable Angl. Error degrees	Calc. Magn.Decl. degrees
1	**ALFERE2**	27	5143	0.37	-57.05	1.11%	0.000	0.130	7.37
2	ZAPAT2	22	5920	5.63	6.31	0.14%	0.000	0.117	4.81
3	ANADIA2	21	6753	-29.5	-3	0.44%	0.011	0.115	5.91
4	DIAZORD2	17	2663	-0.13	12.08	0.45%	-0.467	0.103	4.84
5	SANSEBA2	47	8777	-15.62	-28.3	0.37%	0.021	0.171	5.85
6	SANJUA2	23	4048	7.58	9.37	0.30%	0.050	0.120	7.98
7	**SANTACR2**	58	13533	107.04	-15.18	0.80%	0.100	0.190	4.25
8	ROJA2	27	3636	3.35	6.31	0.20%	0.032	0.130	7.28
9	MITL2	94	17051	46.21	33.94	0.34%	0.336	0.242	4.81
10	MATATLA2	63	13537	1.6	3.72	0.03%	0.167	0.198	3.44
11	MAGUE2	20	3879	-1.73	0.84	0.05%	-0.032	0.112	3.44
11	GUELAVI2	55	9816	-4.02	22.27	0.23%	-0.183	0.185	15.50
12	**LACHIGO2**	39	9323	-28.39	76.13	0.87%	0.083	0.156	4.25
13	GUENDUL2	34	5993	0.57	2.12	0.04%	-0.011	0.146	5.75
				Absolute	Absolute	Relative			
	TOTAL	547	110070	251.74	276.62	0.34%	1.494	2.116	

	A	B	F	J	K	L	M	N
2		Table 6	LONGITUDE	LATITUDE	CONVERTED TO	Xmap Ymap.	USING FOUR POINTS	TO SHOW THE ROUTINE
3								
4		**MAP**	96.3833	17.1				
5		**Control**	96.5333	16.8833	**Xmap**	**Xmap**	**Ymap**	**Ymap**
6					w/r with respect to		w/r with respect to	
7		IDPOINTS	Longitude	Latitude	Calculated w/r to	Calculated w/r to	Calculated w/r to	Calculated w/r to
8		to Convert	in Fraction	In Fraction	Control at Xmap=79	Control at Xmap=63	Control at Ymap=92	Control at Ymap=68
9		**Y**	96.66	17.08	=79-((F9-F4)*(16*60)/9)	=63-((F9-F5)*(16*60)/9)	=+((J9-J$4)*(24*60)/13)+92	=+((J9-J$5)*(24*60)/13)+68
10		**AA**	96.7	17.07	=79-((F10-F4)*(16*60)/9)	=63-((F10-F5)*(16*60)/9)	=+((J10-J$4)*(24*60)/13)+92	=+((J10-J$5)*(24*60)/13)+68
11		**Z**	96.68	17.07	=79-((F11-F4)*(16*60)/9)	=63-((F11-F5)*(16*60)/9)	=+((J11-J$4)*(24*60)/13)+92	=+((J11-J$5)*(24*60)/13)+68
12		**X**	96.64	17.05	=79-((F12-F4)*(16*60)/9)	=63-((F12-F5)*(16*60)/9)	=+((J12-J$4)*(24*60)/13)+92	=+((J12-J$5)*(24*60)/13)+68
14		**Read**	**Longitude**	**Longitude**	**Xmap**	**Latitude**	**Latitude**	**Ymap**
15		**from**	**In Degr- Min.**	**in Fraction**	**Control Points**	**In Degr- Min.**	**in Fraction**	**Control points**
16		**the**	96° 23'	96.383	79	17° 06'	17.1	92
17		**MAP**	96° 32'	96.533	63	16° 53'	16.8833	68
19					Two control points are	used as Double Check.	Two control points are	used as Double Check.
20					**Xmap**	**Xmap**	**Ymap**	**Ymap**
21		IDPOINTS	Longitude	Latitude	Calculated w/r to	Calculated w/r to	Calculated w/r to	Calculated w/r to
22		to Convert	in Fraction	In Fraction	Control at Xmap=79	Control at Xmap=63	Control at Ymap=92	Control at Ymap=68
23		**Y**	96.66	17.08	50.41	50.41	89.24	89.24
24		**AA**	96.7	17.07	45.82	45.82	88	88.01
25		**Z**	96.68	17.07	47.54	47.54	87.7	87.7
26		**X**	96.64	17.05	52.34	52.34	86.31	86.31

LATLONGtoXmapYmap.xls

TABLE 7. WELLS LOCATIONS MONITORED by CNA In 1972-73. Xmap Ymap .

LATITUDE AND LONGITUDE CONVERTED TO Xmap Ymap.

	Longitude				Latitude				
	Degr	Min	Sec		Degr	Min	Sec	Xmap.	Ymap.
Y	96	39	5	96.65139	17	4	30	50.41	89.23
AA	96	41	40	96.69444	17	3	50	45.81	88.00
Z	96	40	42	96.67833	17	3	40	47.53	87.69
X	96	38	0	96.63333	17	2	55	52.33	86.31
S	96	37	25	96.62361	17	0	45	53.37	82.31
W	96	37	36	96.62667	17	3	38	53.04	87.63
V	96	36	45	96.6125	17	1	30	54.56	83.69
T	96	36	22	96.60611	17	0	25	55.24	81.69
U	96	36	0	96.6	17	1	0	55.89	82.77
N	96	35	0	96.58333	17	0	35	57.67	82.00
R	96	36	45	96.6125	16	57	15	54.56	75.85
Q	96	36	20	96.60556	16	55	40	55.30	72.92
P	96	35	15	96.5875	16	57	25	57.22	76.15
O	96	35	18	96.58833	16	59	50	57.13	80.62
N	96	33	52	96.56444	17	1	45	59.68	84.15
K	96	33	20	96.55556	16	54	15	60.63	70.31
J	96	32	30	96.54167	16	57	28	62.11	76.25
LL	96	32	18	96.53833	17	0	50	62.47	82.46
M	96	31	15	96.52083	17	1	45	64.33	84.15
F	96	29	50	96.49722	16	52	15	66.85	66.62
L	96	29	55	96.49861	16	54	22	66.70	70.52
E	96	28	45	96.47917	16	57	30	68.78	76.31
I	96	28	15	96.47083	16	59	45	69.67	80.46
D	96	26	15	96.4375	16	55	25	73.22	72.46
H	96	25	42	96.42833	17	0	8	74.20	81.17
G	96	28	2	96.46722	16	53	45	70.05	69.38
A	96	22	48	96.38	16	51	30	79.36	65.23
C	96	21	26	96.35722	16	55	40	81.79	72.92
B	96	19	38	96.32722	16	54	15	84.99	70.31

TABLE **8** USING THE SPREADSHEET " FINALCOMPILECOORD.XLS" to CONVERT Xmap, Ymap TO Xp, Yp AND TO Xflow,Yflow.

Xmin	Xmax	Ymin	Ymax	Scale X	Scale Y	Pi()/180	180/Pi()	Complem
-1663	37213	-8612	32938	999.84569	999.87968	0.02	57.30	62.0622
46.922	85.804	56.388	97.943					

k_M	h_M
-4822	9712

$x_{OM} = h$	$y_{OM} = k$

XYMAP2 or XXYYMAP2													XFLOW--YFLOW	
Xmap	Ymap	x_p	y_p	y_p/x_p	α	cos α	sin α	β	cos β	sin β	x_p X (cos β / cos α) y_{mp}	y_p x (sin β / sin α) x_{mp}	$x_{Mp} = x_{mp} + h_M$ x_{Mp}	$y_{Mp} = y_{mp} + k_M$ y_{Mp}
					degrees			degrees						
50	58	1414.5	-7000.2	-4.9	-78.6	0.2	-1.0	140.6	-0.8	0.6	-5521.6	4529.4	14241.4	-10343.6
55.187	59.005702	6601.2	-5994.6	-0.9	-42.2	0.7	-0.7	104.3	-0.2	1.0	-2203.2	8640.4	18352.4	-7025.2
50	65	1414.5	-1.0	0.0	0.0	1.0	0.0	62.1	0.5	0.9	661.8	1250.2	10962.2	-4160.2
50	64	1414.5	-1000.9	-0.7	-35.3	0.8	-0.6	97.3	-0.1	1.0	-221.5	1718.6	11430.6	-5043.5
50	72	1414.5	6998.1	4.9	78.6	0.2	1.0	-16.5	1.0	-0.3	6845.3	-2029.0	7683.0	2023.3
52	71	3414.2	5998.2	1.8	60.4	0.5	0.9	1.7	1.0	0.0	6898.8	206.1	9918.1	2076.8
50	70	1414.5	4998.4	3.5	74.2	0.3	1.0	-12.1	1.0	-0.2	5078.6	-1092.1	8619.9	256.6
49	78	414.7	12997.4	31.3	88.2	0.0	1.0	-26.1	0.9	-0.4	11676.9	-5723.1	3988.9	6854.9
46.922	56.388053	-1662.8	-8611.9	5.2	79.1	0.2	1.0	-17.0	1.0	-0.3	-8387.3	2565.8	12277.8	-13209.3
46.922	97.943366	-1662.8	32938.4	-19.8	-87.1	0.1	-1.0	149.2	-0.9	0.5	28320.6	-16901.1	-7189.1	23498.6
85.804	56.388053	37212.9	-8611.9	-0.2	-13.0	1.0	-0.2	75.1	0.3	1.0	9826.4	36910.8	46622.8	5004.4
Xmap.	Ymap.													
46.922	56.388053	-1662.8	-8611.9	5.2	79.1	0.2	1.0	-17.0	1.0	-0.3	-8387.3	2565.8	12277.8	-13209.3
85.804	97.943366	37212.9	32938.4	0.9	41.5	0.7	0.7	20.5	0.9	0.4	46534.3	17443.9	27155.9	41712.3

CHAPTER IV

CLIMATIC CONDITIONS WITHIN THE RESEARCH AREA

Literature Review

Introduction

The need for irrigation in the Valley of Oaxaca is based on the rainfall moisture availability throughout the year and rainfall variability between years. Irrigation water is needed to make up an annual water deficit and to remove the risk of drought at the time of planting.

Oaxaca de Juarez meteorological station

The meteorological station at Oaxaca de Juarez has the longest period of observations and is representative of the valley floor climate. Kirkby (1973) has analyzed the basic climatic data of the central valleys of Oaxaca. Figures and Tables (K#i) in **Appendix K** are taken from Ann Kirkby's research work in 1973 on the use of land and water resources in the past and present in the valley of Oaxaca , Mexico. Kirkby's research was one component of the Oaxaca research project on the prehistory and human ecology of the Valleys of Oaxaca. Findings from that research project were published in a series of volumes over several years. Kirkby's research work was published as a *Memoir* in Volume 1. A summary of her observations and analysis on the climatic conditions findings is now presented.

Figure K1 gives the mean monthly temperature, evaporation and rainfall, and one standard deviation above and below each mean value for Oaxaca de Juarez. This figure shows that it is rainfall rather than temperature or evaporation which is most variable both within and between years.

Dry versus Rainy season

Kirkby(1973) observes the precipitation data during the summer rainy season, and concludes that this rainy period characteristically begins in late April to early May but does not become well established until June with its mean rainfall of 137 mm. The rainy season has generally two peaks, one in June and a second one in September (mean

rainfall = 144 mm). By October mean rainfall has fallen to 44 mm, and the rainy season usually ends as abruptly as it began.

In the central valleys of Oaxaca there is a rainy period that usually starts after the second week of May and generally ends at the beginning of October. The rainy season. precipitation averages 90.5% of the total annual. It is possible to count on the soil moisture to produce crops but it is frequent that drought periods will affect very severely that crop. It can be said that water availability is what makes a good year.

The dry season is well defined and includes the end of October, the months of November, December, January ,February, March and part of April. This is usually followed by a month of transition (May most of the time) during which time the rainy season pattern slowly gets established. The average total rainfall observed at Oaxaca station in the dry season is only 62.6 mm. This is less than 10% of the total annual rainfall.

Water Deficit

From the records of rainfall and potential evapotranspiration the mean water deficit throughout the year is constructed (Fig K2). There is a deficit in every month ranging from about 100 mm in the growing season to almost 2000 mm at the end of the dry season in May.

The curve for 0.5 (ET-R)

Since crops are sown so that they do not cover more than half the surface area. Kirkby (1973) considers the curve for 0.5 (ET-R), as more relevant to the farming situations (Fig K2). The curve for 0.5 (ET-R), shows that between June and October there is, on average, just enough water to support agriculture.

Rainfall and the corresponding water deficit vary over the Valley chiefly with altitude but also with respect to topography and storm direction which produce characteristic rain shadow areas. Figure (K3) shows a rainfall map for the Valley based on available records, and Tables (K1a) and (K1b) give additional climatic data for selected stations to show variability with altitude and location on the valley floor.

Precipitation and Water Deficit versus Altitude

Mean annual precipitation rises with increasing altitude from 630 mm on the valley floor (Oaxaca de Juárez) to 1000mm+ on the divide. The decrease of potential evapotranspiration with increasing elevation (from 1890 mm at 1540 meters to 340 mm at 3100 meters) produces a large altitudinal variation in annual water deficit.

In Table K1, available moisture is indicated by the ratio of rainfall to potential evapotranspiration ($R:ET_0$ ratio) for the whole year and by the $R:ET_0$ ratio for the three critical summer months, June, July and August. The $R:ET_0$ ratio for the whole year varies from 0.34 on the valley floor to 2.9 at 3100 meters (Table K1). The $R:ET_0$ ratio for the three summer months, which is the time most important to cereal production, ranges from 0.81 at 1540 meters to 6.9 at 3100 meters; above the elevation of the valley floor and low piedmont there is not a significant water deficit for summer crops.

$R:ET_0$ ratios vs Valley's agriculture

On the valley floor, where almost all the Valley's agriculture is concentrated, the $R:ET_0$ ratios are much more critical. The eastern Tlacolula Valley suffers from the most severe rain shadow effect. The station at Tlacolula has the lowest recorded mean rainfalls and the highest potential evapotranspiration rate (2020 mm per annum).

Annual $R:ET_0$ ratios are therefore lowest in the eastern Tlacolula Valley (less than or equal to 0.26), but they are below 0.40 everywhere on the valley floor.

Evapotranspiration

A $R:ET_0$ ratio of 1.0 would mean that rainfall was sufficient to compensate for all potential evapotranspiration. Kirkby (1973) reviews the mechanisms proposed by Thornthwaite (1948, 1954) , Mather (1954), Vihemeyer and Hendrickson (1931) Chang (1965) and Holmes (1961) by which actual evapotranspiration declines as soil moisture become less than field capacity. Kirkby (1973) concludes that whichever view is adopted for the rate and mechanism of decline of the actual evapotranspiration as soil moisture conditions become less than field capacity, an average $R:ET_0$ ratio of 0.40 or less for the year is not sufficient to support cereal production in the winter. Some perennial crops can survive a winter without irrigation, but no harvest will be produced.

For the three summer months of June, July and August many parts of the valley floor have mean R:ET_0 ratios of 0.80 or more (Table K1b).

This average ratio, combined with cultivation techniques which conserve moisture and the less than 100 percent ground cover by crops, leads to reasonable expectation of one successful unirrigated crop during the rainy season. Kirkby (1973) points out one exception to this: the eastern Tlacolula Valley which has a lower R:ET_0 ratio in summer months. The greater frequency of low R:ET_0 ratios for this area compared with Oaxaca de Juárez increases the risk of harvest failure and makes it the most marginal agricultural area in the Valley.

Rainfall variability

The problem of getting enough water for crops is aggravated by the variability of rainfall from year to year, both in the amount of total rainfall and in the timing of the first major rains which, ideally, should coincide with planting. Variations in total rainfall for different years can be seen first in Figure K1c where the standard deviation for each month is superimposed on the mean value.

The distribution of rain within a particular growing season is also critical to the success of crops, and in the Valley of Oaxaca it can vary considerably from the almost symmetrical double-peaked mean pattern illustrated in Figure K1c.

In the important planting months of May and June only 57 mm (7percent of total) fell in 1933 compared to 302 mm (48 percent of total) in 1948. It is this variability, particularly during the planting period from April to June, that affects the time of planting, the location of crops and the ultimate success of the harvest.

Relative Humidity

The mid day relative humidity has less variation. In the dry months the relative humidity varies from 50% to 60%, whereas in the rainy season it is generally between 70% to 80%. If we make exception of the stormy days of September, the air is generally calm from September to the end of December with average monthly velocities generally inferior to 1.4 m/s. From January to April the wind average velocity is generally between 2.0 and 2.5 m/s. In May the air moves less with an average velocity

around 1.9 m/s. June is generally very calm less than 1.2 m/s . In July and August the average velocity is around 1.8 m/s.

Temperature

The temperature is not a limiting factor in the plain area. In Oaxaca an overall average annual temperature of 20.6°C with a variation of about 5°C has been observed for the last 40 years. The lowest monthly average temperature of 18.1° C occurs in December and January whereas the highest average monthly temperature is 23°C and usually takes place in May. The maximum annual temperature is on average 39 °C whereas the average minimum annual temperature is 1°C.

Two agriculturally distinct valley floor areas may be defined in the Central valleys of Oaxaca. Tlacolula Valley belongs to the higher cooler zone which includes all of Etla Valley. In this zone an absolute minimum temperature of -8 °C has been reported. The probability of air frost was estimated to be once every 3 years by Kirkby (1973). Frost in the mountains and in the exceptional cold may take place from November to February and rarely does early frost occur in October. A late frost can take place in March but in any case frost is never severe. It can be said that frost causes no significant damage to crops in this area.

Evaporation

Mean monthly pan evaporation follows the temperature curve with highest values in March, April and May; several months before maximum rainfall.

CLIMATIC DATA ANALYSIS

Introduction

In the following, Kirkby's (1973) analysis of climatic conditions is pursued. For this, historical climatic data were first collected and validated and then hydrologic sequences are prepared.

The rainfall and temperature data observed at the stations of Tlacolula and Cuajimoloyas are then tested for changes in time. Cyclic trends are also examined.

Findings of this analysis combined with Kirkby's conclusions allow us to quantify the dependable rainfall for the research area.

Preparing one Common Hydrologic Sequence.

The period of observation is 1960-1988. Tables (1 to 12) in Appendix AA show the monthly total precipitation[1] observed at the weather stations of Cuajimoloyas, Oaxaca de Juarez and Ayutla during the period 1961 - 1988. Tables (13-16) show the same for the station of Mitla for the period of 1981-1988.

In Table 17. of Appendix AA, are given notes pertinent toTables (1-16).

The Missing Data

Period of 1968-1980 : The station of Ayutla has missing data for the months of July 1975 and January 1976. Since Mitla station was inaugurated in 1980 . No climatic data was recorded at Mitla station made prior to 1980.

Period of 1981 -1988:

Cuajimoloyas:	Missing data in Sept, Oct, Nov and Dec 1985.
	Missing data in June, July, and December of 1988
Ayutla :	Missing data in July, august, Sept., October and November 1986.
Mitla:	Missing data in January, Feb, March, April, May, June, July 1981.
	Missing data in August, September, October., November and December 1988

To deduce the missing monthly precipitation data, the method recommended by Campos Aranda[2] (1984) was applied. This method is called the *método racional*

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[1] Total of Daily observations for each month..

[2] Collado (1990). has reported the work by Campos Aranda (1987) on the Construction of Hypothetical storms that reflect the effects of cyclones and Campos

deductivo by the author and may be translated as the rational deductive method (RDM), not to be confused with the rational method used to estimate watershed runoff. This method uses historical data available from a given station to interpolate missing data for the same station. It is different than the historical data interpolation method tested by Shih and Cheng (1987) where a missing monthly value is set equal to the average of all known monthly percentage values (%s of annual totals) for the same month.

Campos Aranda's method (1984) is detailed below and then compared with the correlation technique in which a stepwise regression is used to find the best correlation between the station with missing data and the stations with data. Linear correlation techniques and the spectral analysis method are preferred by Shih and Cheng (1987) rather than the historical interpolation method. In a spectral analysis, it is assumed that the data variation with time has a base period of 12 months. In this research the simple and multiple linear regression techniques are compared with the rational deductive method RDM by Campos Aranda (1984).

The Rational Deductive Method. Campos Aranda (1984)

$$Pr_i = (\sum Pr_k / (1200 - \sum S_i)) * S_i \qquad (1)$$

Pr_i : Unknown monthly rainfall in each incomplete year. In [mm].
i : each of the unknown months, (maximum of 11)

$\sum S_i$: Sum of the average rainfall percentages over the historical period for the months for which data are to be generated, in [%]

$\sum Pr_k$: Sum of monthly rainfall for the months with known precipitation in the incomplete years. In [mm].

S_i :Average monthly Rainfall % calculated as the average of monthly rainfall percentages for historical years with complete data. The S_i **% values are then** assumed for the months with unknown or missing data.

Aranda's work (1989) on the design of Reservoirs with techniques of optimization. The method presented here is reported by ie/isa.1993

The precipitation data are reported by the Ingeniería de evaluación y prospección, s.a de c.v. (ie/isa.**1993**) in an hydrologic study on the feasibility of the project "Diaz Ordaz" .This project consists of a storage dam proposed in the basin of the Arroyo seco one of the major subasins of the river Salado.

Generating the missing data of Ayutla data set

Table 1. shows the missing data generated by the Rational Deductive Method **(RDM)** , the Simple Linear Regression **(SLR)** and the Multiple Linear Regression **(MLR)** methods. When compared with a simple linear regression AYUTLA-OAXACA data the correlation coefficient only improves slightly after including the effect of Cuajimoloyas rainfall via a Multiple Linear Regression (R^2 = 0.69 compared to R^2 = 0.61). However, when sorting the data for a common set, six degrees of freedom are lost due to breaks in the records of either ones of the base stations. One more degree of freedom is lost in the cross sums of squares compilations .

The prediction obtained with the MLR offers no advantage over the SLR. The resulting predictor is indeed more evasive (wider 95% confidence Interval) and all five monthly rainfalls generated by the Rational Deductive Method fall within the Confidence limits set by the MLR. This is not the case when the same RDM generated rainfall data are plotted with the 95% Confidence Interval obtained for the Simple Linear Regression coefficients.

Applicability of Normal Distribution

The normal mean precipitation at Ayutla station for the 21 years period 1968-1988 is 1400 mm with a STD of 289 mm. The month of January receives on average 15.5mm of rain with a standard deviation of 12.6mm. The probability of having no rainfall was 2/19 or 10.5% in the nineteen years period with records of January rainfall, the probability for a negative rainfall being zero.

It appears therefore that the assumption for a precipitation that is normally distributed is of doubtful value in the month of January. The calculated confidence intervals for January 1976 and January 1986 are therefore questionable and the

January rainfall of 13.8mm as generated by RDM and qualified as too low when considering the lower 95% Confidence Limit of 19.3mm may be quite acceptable.

In Table 2 the same analysis is carried out on the seven rainfall monthly precipitation data points generated for the station of Cuajimoloyas. Again with the exception for the month of November, the Multiple Linear Regression technique offers no advantage over the Simple Linear Regression technique for the same reasons : R^2 is only slightly increased (from 0.76 to 0.80) but eight degrees of freedom are lost due to breaks in data recording .

The data generated by the Rational Deductive Method are clearly beyond the 95% Confidence Interval (CI) in two cases those are, the rainfall data generated for December and June 1988. The same careful attitude prevails therefore regarding the 95%CI obtained for December. The two other monthly average rainfall values generated for the months of September 1985 and July 1988 are labeled as TOO HIGH. These values are right on the upper boundary of the 95% confidence interval.

Generation Of Mitla Missing Data

In order to generate the rainfall data missing at MITLA station, ie/isa.(**1993**)[3] uses the inverse distance method better known as the U.S. National Weather Service method for river forecasting (refer to Paulhus and Kohler, 1952 as reported by Linsley et al, 1975) may be used. This method estimates precipitation at a point as the weighted average of that at four stations, one in each quadrants delineated by north-south and east-west lines through the point. In the case of Mitla station, three neighbour stations are available. The distance between these stations and Mitla are given below Figure 1 and the weight applicable to each station which is equal to the reciprocal of the square of the distance between the point (here Mitla) and the station .

As pointed by Linsley et al (1975) a shortcoming of this method is that it can never yield a point estimate greater than the largest amount observed or less than the smallest.

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[3] ie/isa.(**1993**) stands for "Ingeniería de evaluación y prospección, s.a de c.v., 1993"

Double Mass Analysis of Mitla record

To test the consistency of the record of Mitla station, its cumulative annual rainfall is then compared with the concurrent accumulated values of mean precipitation for the group of the three surrounding stations (Oaxaca, Cuajimoloyas and Ayutla). Figure 1 shows the double mass curve of Mitla Station.

A change of slope about 1981 indicates a change in the precipitation regime at Milta . To make the record prior to 1981 comparable with that of period 1981-1988, it should be adjusted by the ratio of slopes of the two segments of the double mass curve. Calculations of the correction factors are shown in Table 3 . Precipitation data before and after correction are shown in Table 4. The consistency of each of the three base stations were tested with the same method. Figures 3, 4 and 5 show the resulting double mass curves obtained for these stations. These records are consistent.

Milta Data are not retained for Analysis

Tables (1-16) of Appendix AA gives the resulting complete 21 years precipitation record. The percentage of missing data that was generated for obtaining this complete record is now discussed. Oaxaca had a complete set with no missing data whereas Ayutla had 5 (five) missing data out of the 252 (21x12) records i.e. 98% complete. For the Cuajimoloyas station, 7 (seven) data were missing for a completion of 97.2%. These data sets did not require any adjustment as they were found to be consistent with each other. Mitla generated data have doubtful value at the moment since only 84 out of the 252 months were actually observed. The Mitla data set will therefore not be used in this research.

The precipitation data of Oaxaca and Cuajimoloyas directly apply to the research area. Ayutla data will be used to assist us in deriving the isohyetes. Oaxaca station at an elevation 1515[4] meters above mean sea level reflects the precipitation recorded at the centroid of the three central valleys. Oaxaca Station is the closest weather station to the hydrometric station established at the junction of Salado and

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[4] Reported as 1550m by S.A.R.H Subdirección de Hidrología and 1540m by Kirkby (1973). In CLICOM archived data, the Station Geography shows an elevation of 1515m.

Atoyac River. Cuajimiloyas Station, at an elevation of 3110 meters[5], reflects the climatic conditions prevailing in the mountains on the northern side of the research area. The station located in Mitla reflects the Eastern conditions. Unfortunately its observation history is short with only eight continuous years of recording. The station of Tlacolula de Matamoros is strategically located at approximately the centroid point of the valley of Tlacolula which defines with Mitla the climatic conditions prevailing in the valley floor of our research area. Let us now examine these climatic conditions.

Precipitation observed at Tlacolula de Matamoros.

Tables (5A - 5 B) show the precipitation data recorded during the period of 1950 - 1987 at the station of Tlacolula de Matamoros. There is a continuous break in the records for the period of 1979-1983 inclusively. This break came as a result of the budget cut that took place at the national level following the crisis of early 1980s and is reported by Godinez (1990). Tables 6A, 6B ,6C and 6D give descriptive statistics of the monthly rainfall for Tlacolula Station. It can be seen that out of the thirty eight years within the period of 1950-1987, the number of monthly precipitation records varies from 26 to 32.

Two seasons appear clearly , a dry season from November to March followed by the transition month of April. The rainy season that usually lasts from May until the end of September. The wet season is followed by the transition month of October and then the dry season again.

It is interesting to note that this break down of the precipitation in two seasons is approached differently by Cruz (1938) who by concern for agricultural production divides the annual precipitation into four seasons. **The percentage of annual precipitation for each season is given for Oaxaca Station and in parentheses for Tlacolua:**

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[5] Reported as 3150m by S.A.R.H Subdirección de Hidrología and 3100m by Kirkby (1973). In CLICOM archived data, the Station Geography shows an elevation of 3110m.

1. Winter months: December, January and February with less than 1.3% (1,2%) precipitation of the annual rainfall.
2. Spring months: March, April and May with slightly less than 22.6% (19.3%) of the annual precipitation.
3. Summer months: June, July and August with slightly less than 49,9% (43.%) of the annual precipitation.
4. Autumn months: September, October and November with slightly less than 26.% (35.7%) of the annual precipitation.

When the rainfall data of the dry months are tested for normality with the Kolomogorov-Smirnov (KS) test, they all fail the test as shown in Table 8. This is not surprising since the precipitation distributions of the dry period deviate from a normal distribution being limited on the left by a minimum of zero or no rainfall.

The monthly total precipitation for the months of the wet season approach a normal distribution and pass the KS test for normality. The precipitation during the month of October, the month of transition from the rainy season to the dry season, barely passes the test. The hypothesis that the observed rainfall in May is normally distributed is rejected at a 0.10 level but fails to be rejected at a higher level of confidence.

Table 7 shows a detailed example of computation of deviations from the theoretical normal distribution . In this example the maximum deviation from a normal distribution is 0.146. The Kolomogorov-Smirnov critical test value at 0.10 level is 0.145. The null hypothesis H_0 is: **the observed sample distribution is taken from a normally distributed population with a mean m equal to the sample mean and a variance equal to the square of the standard deviation.**

The null hypothesis is rejected at 0.10 level since the maximum allowable deviation at that level is exceeded. However it is not exceeded at a higher level of confidence. At 5% probability the critical KS value is 0.159, the observed maximum deviation from normality although relatively high (0.146) is within the allowable limit of 0.159. This points out the weakness of the KS test as noted by Haan (1977). Neither

of the Chi-square nor the K-S are very powerful tests in the sense that the probability of accepting the null hypothesis when in fact it is false is relatively high. This according to Haan (1977) is especially true for small samples.

Testing for a time trend

During reconnoiteing of the wells in the research area, users remarked that there was less and less rainfall in recent years. This left the author with concern. By observing the rainfall data in the dry months, two characterisitics are noted. The great number of no rain or zero rainfall and the apparent periodicity and decrease in magnitude of the rare non zero rainfall events of the month of January. The question whether there is a time trend effect needs to be answered.

Time trend

The precipitation data set is divided into three periods: 1950-1958 / 1960-1968 / 1969-1977. There was no record in the year 1959. Table 9 shows the probability from a T-Test that these precipitation data belong to the same normal distribution. The precipitation data of 1950-1958 were tested with the precipitation data of the period 1960-1968. The precipitation data of 1960-1968 were tested with the precipitation data of 1969-1977 and finally the data of 1950-1958 were tested with the data of 1969-1977.

The null hypothesis H_0 of the t-test is: **the sample distributions observed in Period A and Period B are taken from normal populations for which the means $\mu_A = \mu_B$ against the alternative that the population means are different. It is assumed that the distributions are normal, with the same (unknown) variance and that samples are independent.** We shall see that this assumption for independence is justified since no clear periodicity and significant auto correlation could be demonstrated.

Gross Errors

In this research with the exception for the observations of Cuajimoloyas in the period 1988-1991 no precipitation outlier had to be discarded. Two values were found highly suspect on first scrutiny. Those values are the precipitation recorded in August

1969 (312.5mm) and the precipitation observed in May 1974 (212.5mm). Both of these values were found to be correct.

The null hypothesis $\mu_A = \mu_B$ **fails to be rejected.**

Table 9 shows the results of the t-test and the probabilities associated with a t-distribution. It can be seen that no significant difference was found in the avergage monthly precipitation between the periods 1950-1958, 1960-1968 and 1969-1977. However, since the distributions of the precipitation data in the dry months failed the Kolomogorov - Smirnov Test, the error introduced by non-normality needs to be assessed before drawing any conclusions.

Error Introduced By Non-Normality

Cochran (1947) summarizes results of the investigations conducted by Bartlett (1935) and by Pearson (1931) as reported by Cochran (1947) . Cochran's statement is quoted :

> " The consensus from these investigations is that no serious error is introduced by non-normality in the significance levels of the F-Test or the two-tailed t-test. While it is difficult to generalize about the range of populations that were investigated, this appears to cover most cases encountered in practice. If a guess may be made about the limits of error, the true probability corresponding to the tabular 5 percent significance level may lie between 4 and 7 percent. For the 1 percent level, the limits may be taken as ½ percent and 2 percent. As a rule, the tabular probability is an underestimate: that is, by using the ordinary F and t tables we tend to err in the direction of announcing too many significant results.

The one-tailed t-test is more vulnerable. With a markedly skew distribution of errors, where one tail is much longer than the other, the usual practice of calculating the significance probability as one-half value read from the tables may give quite a serious over or under-estimate", Cochran (1947).

The power of student's t-test may be improved by using Owen's (1965) tables where non-centrality of parameters are given to 5 decimal places for various levels of Type I and Type II errors.

In addition to its effects on the validity of tests of significance, non normality is likely to be accompanied by a loss of efficiency in the estimation of treatment effects and a corresponding loss of power in the F- and t-test.

In this research the standard error is used to indicate the measure of the amount of error in the prediction of y for an individual x so it is essential to check on non-normality related effects on the estimated standard error .

Cochran (1947) is of opinion that the effect of non-normality on estimated standard errors is analogous to the effect of the t-test. If a standard error is calculated specifically for each pair of treatments whose means are to be compared, the error variance is unbiased. Bias may arise, however, by the application of a pooled error to a particular pair of treatments. Pooling of errors was not required in this statistical analysis of monthly precipitation and temperature data.

The Nonparametric Wald And Wolfowitz's (1940) Method

A non parametric method was used to complement student t-test results for the monthly precipitation data that failed to pass the K-S test. The method that was used is explained by Kreyszig (1970). The test procedure is as follows. In the first step of the test, the two samples are combined into one pooled sample, values are identified so that their sampling origin can be found at anytime. This was done by underscoring all values of sample1. The pooled (and identified) values are then sorted in an increasing order of magnitude. This was achieved through a sorting operation in EXCEL environment.

Then the total number of runs in the resulting sorted pooled sample is counted. A " run " is a cluster of one or more values from the same sample. The number of runs obtained are then compared with the critical lower and higher number of runs required for rejecting the null hypothesis at the selected level of significance. These critical values are obtained from Kreyszig(1970) [6].

The **null hypothesis is that the distribution functions of the two continuous sample distributions are identical against the alternative that they are different.**

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[6] see Kreyszig (1970) , Table 10c in Appendix 4.

This non parametric method recommended by Kreyszig (1970) is based on the reasoning that if the hypothesis is true, we may expect that in the pooled and ordered sample, the values from either sample appear randomly mixed so that the number of runs is neither very small nor very large. If a tie x, y values from the two original sample occurs, Kreyszig(1970) recommends to break the tie by tossing a coin. This procedure was adopted. The probability function of the random variable {U = number of runs} is given in Kreyszig (1970)[7] .

No climatic measurement was taken in the period 1979-1983 at the Tlacolula station and due to many breaks in data for the short period 1984-1987, the analysis was therefore limited to the period 1950-1978.

Table 10 shows the results of the non parametric test of Equality of Distribution Functions for the periods 1950-1958 and 1969-1977. It can be seen that none of the tests leads to rejection of the hypothesis of equality of Distribution Functions. However, in the case of February the number of runs that are counted in the pooled sample is only four which gives a probability of 0.067 for the two samples to belong to a same normal population. This approaches the 5% significance level .

In December the test is meaningless because out of the 27 monthly total rainfall three only are non zeros. With 24 zero values, the test becomes a simple toss of a fair coin. In all other cases the probability associated with the number of runs is higher than 0.12.

As pointed out by Kreyszig(1970) we cannot expect that in the case of certain distribution the amount of information given by a nonparametric method is the same as that given by a method which is applicable to that particular distribution only. However the loss of information caused by the use of a nonparametric method is not very large and decreases as the sample size increases. The probability calculated with the nonparametric method can not be compared with the probability obtained with the two sided Student t-distribution because the decision making process for rejecting H_0 is different.

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[7] see Kreyszig (1970) p349.

In the nonparametric Wald and Wolfowitz's (1940) method the probability function is the probability of the random variable {U = number of runs}. On the right edge of Table 10B, is shown as an illustrative example, the probability of occurrence for each number of runs when the size of the two samples are equal to nine. This is the case when there is no break in the monthly precipitation data. The minimum number of runs is always two and the maximum number of runs is $n_1+n_2-1 = 9+9-1 = 17$. We can see that the probabilities of occurrence are equal on either side of the mode and the sum of all probabilities is equal to one.

The mode in this example is 10 runs and has the highest probability of occurrence that is 0.202. The total probability associated with the acceptance region at 5% significance level is 0,202 + 2(0.065+0.129+0.161)+0.032= 0.944 and the probability associated with the rejection region is 1 - 0.944 that is 0.056. The only assumption made when using the Nonparametric test is that the distribution of the population (here the precipitation distribution) is continuous.

For being non restrictive , the non parametric method designed by Wald and Wolfowitz (1940) is preferred to the student test for testing the monthly precipitation data where lack of fit with the normal distribution is found via the Kolomogorov-Smirnov Test.

Although the precipitation data show no significant difference in time (from one period to another) there is still concern because of the relatively low probabilities of equal mean obtained for the precipitation in the months of May, July, August, September and October. This concern is justified because as pointed out by Haan (1977) when we "accept" H_o , we have not proven H_o, only found evidence to support it. In that sense it is more appropriate to say that this analysis fails to reject H_o.

The following analysis on the temperature data was carried out with the objective to clarify our understanding of the prevailing climatic conditions in the flood plain.

Analysis of Temperature observed at Tlacolula station

Table 11 shows that a very good correlation exists between the average monthly minimum temperature and the average monthly rainfall data for the months of

September, October, November, January and April. The average annual rainfall is also highly correlated with the annual average minimum temperature. As expected in all cases the correlation is negative meaning the higher the minimum temperature may be the less rainfall there is. Statistics for the average monthly minimum temperature for the three periods (1950 - 1958, 1960 - 1969 and 1970 - 1978) are given in Tables (12 , 13 and 14).

Table 15 shows the results of a t-test of the hypothesis that the Average Monthly Minimum Temperature independently of the period of observation belongs to a same population. The procedure of analysis used for the Monthly Total precipitation data is repeated here with the Average Monthly Minimum Temperature. The data of the period 1950-1958 is compared with the data of the period 1960-1968 and then with the period of 1969-1977. The null hypothesis is $\mu_A = \mu_B$ **against the alternative that** $\mu_A \neq \mu_B$. **It is assumed that the distributions are normal, with the same (unknown) variance and that samples are independent.**

As we move in time from the period 1950 -1958 to more recent periods, the t-test leads to rejection of the null hypothesis with an increase of level of significance. The end result is that the average monthly minimum temperatures in the period 1970-1978 for nine out of the twelve months are now significantly different at 0.01 level than their corresponding average minimum temperatures for the same months measured in the period 1950-1958. The problem of non normality associated with a minimum zero value in the case of rainfall. has now become irrelevant in the case of temperature data. The Monthly Average Minimum Temperature observed in the other three months namely April, February and November shows a significant difference in time at a level of 0.030, 0.019 and 0.011 respectively.

In all cases the significant difference is the result of an increase of the Monthly Average Minimum Temperature which suggests that a one sided test would have been more appropriate. In a one sided t-test the probability values would have been twice smaller and the level of significance would be doubled. In all cases it can be said therefore that the monthly Average Minimum Temperature has significantly increased (at 0.01 level) from 1950 to 1978. It is interesting to note that this increase in

temperature has not been uniform in time. The increase was more pronounced from 1950 to 1968 that it was from 1960 to 1978.

The student test was performed assuming a normal distribution and equal variance. The normality was not checked as the temperature is not limited on either side of the distribution. Equal variance was also assumed. When assuming unequal variance (heteroscedatic) very little difference in the probability values was obtained. It must be mentioned that no minimum temperature and pecipitation data was measured in 1959 at the Tlacolula Station but the maximum temperature for some unknown reason was recorded. The average of totals of monthly average minimum temperature for the period 1959-1968 as measured at the station of Oaxaca is 151.89°C with a standard deviation of 2.91°C whereas for the period 1960-1968 it is 151.69°C with a standard deviation of 3.01°C. It follows therefore that generation of the Tlacolula missing observations of 1959 from Oaxaca temperature data would have made no difference in the outcome of this analysis.

Analysis of the Monthly Average Maximum Temperature

The same analysis was carried out on the Monthly Average Maximum Temperature and results are shown in Table 16. Data of 1959 are now included. Due to data unavailability for the year 1979, three periods are now considered those are: 1950-1959, 1960-1969 and 1970-1978. The year 1978 is incomplete. A two sided t-test was used and equal variance was assumed. The trend is definitely less obvious than in the case for the Average Minimum Temperature.

Analysis Of The Monthly Average Minimum Temperature Observed At Cuajimoloyas Station

In Table 17 a similar analysis is conducted on the Monthly Average Minimum Temperature recorded at Cuajimoloyas station located on the divide of the watershed at an elevation of 3110 meters above mean sea level. The data is split in two equal periods of thirteen years, those are 1956-1968 and 1970-1982. Note that no temperature measurement was taken in 1969. The increase in the Monthly Average Minimum Temperature is highly significant for the eight months from March to October inclusive,

whereas no significant difference in the Monthly Average Minimum Temperature could be detected for the rest of the year.

The Treatment Of Zeros In Precipitation Data Analysis

The treatment of zeros was also investigated. To conclude that no rainfall can be accounted for in the dry months is a reasonable assumption for estimating irrigation requirements for the crops of Tlacochahuaya, San Sebastian Abasolo and San Francisco Lachigolo. Nevertheless, the importance of understanding the dry season will remain crucial until proof is made that no climatic change is taking place that may have an impact on the water resources of the valley. In order to understand the precipitation pattern in the dry season one has to be able to handle the zero values. For irrigation water management, the need for a rigorous method to handle zero values is particularly unavoidable for estimating water availability in the transition months of April and October .

Moreover in the case of Cuajimoloyas the "dry months" are not as dry and zero values take a different meaning. This is clear when considering the precipitation observed at Cuajimoloyas in the month of December over the years as shown on Figure 5. By combining the C.N.A archived climatic data with the Common Hydrologic Sequence prepared for the period of 1961-1988, we have now extended the period of continuous precipitation data [8] to 1988. In the case of Cuajimoloyas station the period of observation is now from 1950 to 1988 [9]. Figure 5 shows that there were six years

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[8] The Temperature data is however not available for the period 1984-1988..

[9] Two monthly precipitation values for December are uncertain: the value of 15.7mm for the precipitation of Dec 1985 that was generated from the three base stations of Oaxaca, Mitla and Ayutla and the value of 44.5 mm for the precipitation of December 1983 . This value (44.5mm) was obtained from ie/isa. **(1993)** and could not be validated with the C.N.A archived (1955-1984) data for the station Cuajimoloyas in which case the precipitation data for December 1983 is missing. A rainfall of 55.0 mm was observed in December 1983 and a 24hours maximum rain of 33.0 mm was reported for the same month at the station of El Estudiante (elev. 1550m) located at 22 km from Cuajimoloyas station (elev. 3110m). The reported precipitation of 44.5 mm at Cuajimoloyas station is therefore possible. However since it could not be cross confirmed with another source, a note was added to the spreadsheet cell to that effect.

with no rainfall in December in the period 1956-1988. Three out of these six times when no rainfall took place, a peak rainfall was recorded the following year. The precipitation observed in December at Cuajimoloyas station suggests also the possibility of a periodic six-seven years cycle that may be attributed to a regional system [10].

We shall now examine the question of cyclic periodicity.

Periodicity

December peak rainfalls at Cuajimoloyas may be following a cyclic pattern but this periodicity can not be spotted on the correlogram of December rainfall. Similarly correlograms of February, March, April, June and July rainfalls as shown on Figures (7 to 17) do not show clear cycles either.

Testing periodicity

If periodicity exists then the auto correlation coefficient is significantly different than zero for a certain auto correlation lag. This is now tested using Haan's (1977) recommended test procedure on the auto correlation coefficients.

The 95% **confidence limit for the correlation coefficient** may be calculated as follows (Haan , 1977).

Upper Limit

$$= [-1 \pm (Z_{1-\alpha/2} \sqrt{(n-2)})] / (n-1)$$

Lower Limt

$$\text{Upper Limit} = [-1 + Z_{1-\alpha/2} \sqrt{(30-2)}]/(30-1) = [-1 \pm (1.96 \times \sqrt{28})]/29$$

Upper Limit = 0. 323

$$\text{Lower Limit} = -1 - Z_{1-\alpha/2} \sqrt{(30-2)}/(30-1) = [-1 - (1.96 \times \sqrt{28})] / 29$$

Lower Limit = -0.392

The values for the coefficient of autocorrelation for lags near the sample size are not reliable and the confidence intervals calculated above are not valid in that region. Haan(1977) reports that some authors recommend the maximum of correlation

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[10] This regional system is not identified here. The cyclic peaks in December rainfall (1958, 1964, 1971, 1977 and 1983) are self indicative.

lags not to exceed 10 to 25 percent of n ! Here, correlation lags for more than half the sample size were not plotted in Figures (7 to 17) so that a minimum number of fifteen monthly precipitation data were used in calculating the last serial correlation coefficient. This sample size is relatively small for testing periodicity. This emphasizes the importance of considering climatic observations as a practice that must never be discontinued. It is the total period of observation that defines our sample size and ultimately our number of degrees of freedom. Haan (1977) concludes that for small samples the width of the confidence interval on the serial correlation coefficients makes the above test not very powerful.

Considering the 95% confidence limits for the correlation coefficients, the correlograms indicate that on the basis of the precipitation data presently available, the monthly average precipitation for the months of December, February, March , April, June and July may be considered as being independent of each other.

Given the limited data, the possible periodicity shown on the correlograms for the monthly precipitation of January, May, August, September and October could not be confirmed at subsequent cycles (20, 30 etc..) and a spectral analysis at this point is bound to be fruitless.

Proposed format for summarizing the precipitation data

Tables (18A, 18B, 18C) show for each month the correlation coefficients between the annual precipitation recorded at the three base stations of the research area, those are: Oaxaca de Juarez, Tlacolula de Matamoros and Cuajimoloyas.

The percentage of assiduity given in the table is the total number of daily measurements divided by the total number of days in the period under consideration.

The percentage of continuity is also given in these tables and represents the percentage of continuous records with no break with respect to the total period under consideration. The continuous period is given at the bottom of each Month whereas the year beginning and the year ending the total period are shown at the top. The number of months in the total period is given right below the year ending the period whereas the number of total monthly precipitation data in the period is given to the right of the year ending the period. When the number of monthly records "n" is not the same for the

three stations, for example the month of June , the difference is then pointed out on top of the month label.

These Tables (18A, 18B, and 18C) are to be examined with the information appearing in Tables 19A , 19B and 19C. Table (19A, B or C) shows for each month the basic statistics corresponding to the precipitation observed daily in the month in question. Those statistics are: the Average, the Standard Deviation, the Coefficient of Variation, the 95% Confidence Interval and the 80% Confidence Interval. The statistics shown on the left half of the table are those obtained for the common period 1956-1987 whereas on the right half the same descriptive statistics are given but this time for the total period of recording available for the three stations.

Tables 18 and 19 summarize all precipitation data available at these three stations. The linear correlation coefficients indicate the potential use of a linear regression for generating missing data if any and indicate whether the precipitation for a given month may be attributed to a common meteorological system or not.

It can be seen in Tables (18A, B or C) that a common system is most likely responsible for the precipitation observed in January at the three stations. However, it appears that the rainfall in June, November, and December follows quite a different pattern at the three stations. Generation of missing data by linear regression would be inadequate in these months.

The importance of the meteorological station located in Tlacolula de Matamoros is also clearly demonstrated by Tables (18A, B or C) where on a year basis as well as for the specific month of June that is so critical for farming, no good correlation exits in the precipitation pattern with the other two stations. May and June are strategic months in farming operations in the valley.

The Months Of January, February, March, April and May

A frequency analysis of the rainfall for the months of January, February, March and April is given in Tables 20 -23 . In Tables 20 and 21 two methods of analysis are compared: the method based on the theorem of total probability and the method where a log normal distribution is assumed. For the months of March and April, the normal distribution is also examined in Tables 22 and 23.

For the months of January , february and March, independently of the method used, no rainfall with a probability of exceedance of 80% representing 1 in 5 dry years can be accounted for at any of the three base stations.

For the design rainfall with a probability of exceedance of 20% reresenting 1 in 5 wet years precipitation, the log normal distribution compares favourably with five out of the eight values obtained by the method based on the theorem of total probability for the stations of Oaxaca and Cuajimoloyas. In the case of Tlacolula de Matamoros, the 1:5 wet years design rainfall obtained by the two methods differs significantly for 3 out of the four dry months under consideration Considering that the total number of historical **non**-zero monthly rainfall values recorded during the four months of January, February March and April (period of 1956-1986, 6 years missing) are 38 , 57 and 61 respectively for the stations of Tlacolula, Oaxaca and Cuajimoloyas, it follows that zero rainfall values are what make the log normal distribution somehow an unreliable distribution for predicting the rainfall in the dry months.

This can be seen in Figures 18 and 19 which show the impact on the frequency analysis of logarithmically transformed rainfall data when choosing different values for the small constant to be added to the monthly rainfall zero values. The selection of this small constant to handle zero values in a log normal distribution introduces bias in the data which is not the case when using the theorem of total probability as recommended by Haan (1977).

May rainfall data with no historical zero rainfall value should be easier to handle by the manager but another difficulty is noted.

Figure 20 shows two probability plots of May rainfall measured at the station of Tlacolula. The curve between the 95% confidence limits corresponds to the probability plot for the May rainfall data measured during the period 1956- 1986. The series is incomplete. Six year data are missing. The second probability plot based on a continuous series for the period of 1960-1977 falls below the 95% lower limits on the probability plot as derived from the rainfall observed in 1956-1986. Figure 20 shows that the manager's selection of May design rainfall is approximate at best.

June rainfall

Kirkby (1973) claims that in cash-crop production, as well as subsistence corn production, peasant agriculturists of Oaxaca Central Valleys are aiming for satisfaction rather than for maximum profits. This mirrors the general pattern of land use in Mitla that is aimed at minimizing the worst possible outcome, but within that pattern, changes in corn distribution between zones in different years is according to Kirkby an event-matching procedure which tries to match land area to growing-season rainfall on the basis of June rainfall.

> "...if the rainfall in June (the main planting month) augurs good corn yields, fewer parcels of land are worked since the family can expect to get by with the produce of a smaller proportion of their total possible corn area" Kirkby (1973).

This consideration is important to the manager. It sets a basic difference between the design of an irrigation reservoir that must provide water to support dry-farming crops and the design of an irrigation used strictly for supporting cash crops in the dry months .

In the first case. Kirkby's (1973) claim that dry farming follows an event-matching procedure where dry farmed land area is reduced when June rainfall augurs good implies a water demand relatively stable whereas the demand from an irrigation reservoir that must provide water to winter crops only is the greatest at the same time that flows into the reservoir is the lowest.

But to the manager what may be more important than these technical considerations is the possible social implication in promoting irrigation in winter months which comes in contradiction with well established farming methods and in that sense may be a threat to sustainability.

The annual rainfall

Figure 21 shows that the annual rainfall recorded at Tlacolula de Matamoros is log normally distributed. Log $_{10}$ (rainfall values) do not statistically deviate from normality beyond 95% confidence intervals. In Table 24 can be found the regression statistics pertinent to Figure 21.

Figure 22 and Table 25 show that the cubic polynomial regression compares favourably with Log-Pearson III model for the probability plot of the annual rainfall measured at Tlacolula de Matamoros. Regression polynomial equations are easily obtained by first adding a trendline to the data series, then specifying the type of regression trendline as polynomial and finally entering in the order box the highest power for the independent variable. The cubic polynomial regression fits the data nicely as demonstrated by Figure 23. Regression polynomial equations are powerful tools accessible to managers.

Estimate Of Potential Additional Irrigable Land

1. Assuming that 75% of the runoff from the sub-basins east of Tlacolula de Matamoros could be stored in a reservoir. It is estimated that the runoff from these sub-basins amounts to approximately 33% (see Table 26) of the runoff measured at the outfall of the Salado river. It follows that approximately (75% x 33%) which equals to 25% of the annual Salado river runoff is a reasonable assumption for the volume of runoff that could be stored for irrigation purposes.

2. Assuming that the Reservoir Evaporation = Pan Evaporation

H_{net} = ((Runoff x 0.25)/Reservoir Area) - Reservoir Evaporation Depth + rainfall depth over the reservoir (2)

where

H_{net} = Net average height of water storage in [mm].

Reservoir Evaporation = Pan Evaporation = 1962 mm (see Table 28)

Based on 19 years reccords, Pan Evaporation averages 1962mm per year with a coefficient of variation less than 6%. For the same period the rainfall at Oaxaca station averaged 726mm with a coefficient of variation of 23 %.

Rainfall over the reservoir = Tlacolula Rainfall in [mm]

3. **Annual Runoff in cubic meters = (258.94 x P_{OAX}) - 152595 (3)**

(R^2=0.85, for n =11 years, see Figure 24)

where

P_{OAX} = Annual Precipitation at Oaxaca station in [mm].

The annual runoff measured at the outfall of the Salado River was found to be linearly correlated with Oaxaca rainfall. (see Figure 24)

The Annual Rainfall recorded at Oaxaca and Tlacolula Stations is then described in probabilistic terms.

4. **P_{OAX} = -496.4 x (Prob of Exceedance) +964.56** **(4)**

(R^2 = 0.94, n = 39 years, see Figure 25)

where

Prob of Exceedance =Probability of exceeding an annual rainfall value.

5. **P_{TLA} = -409.9 x (Prob of Exceedance) +716.18** **(5)**

(R^2 = 0.85, n = 24years, see Figure 23)

where P_{TLA} = Annual Precipitation at Tlacolula station in [mm].

Prob of Exceedance =Probability of exceeding an annual rainfall value.

6. Assuming a net storage of 75% . This means that the net losses (evaporation - rainfall) shall equal to a quarter of the depth of water in the reservoir had there been no water losses.
7. Assuming an overall irrigation efficiency of 70%.
8. Assuming the crop water demand and crop distribution shown in Table 29.

The potential additional irrigable land for summer/spring and winter crops are calculated in Table 30. The table below summarizes the results.

TABLE 31 ESTIMATE OF POTENTIAL ADDITIONAL IRRIGABLE LAND.

	SUMMER and SPRING CROPS					WINTER CROPS		
Prob of Exceed	CORN [ha]	BEANS [ha]	SORGHO [ha]	ALFALFA [ha]	**TOTAL [ha]**	CORN [ha]	PEAS [ha]	**TOTAL [ha]**
0.8	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
0.7	25	11	7	6	49	19	18	37
0.6	71	32	18	16	137	53	50	103
0.5	**117**	**52**	**30**	**26**	**225**	**86**	**82**	**168**
0.4	162	72	42	36	312	120	114	234
0.2	253	113	66	56	488	188	178	366

NOTE : Table 31 is a summary of Table 30 located at the end of this chapter.

It can be seen that the additional area that can be irrigated is relatively small. For average conditions, only 225 hectares of additional land cultivated in summer and spring could be irrigated and approximately 168 hectares of additional land could be irrigated in winter.

The actual potential for additional irrigable area is slightly higher than this considering that most of the irrigation water would be used prior to the dry season when the evaporation reaches its peak value. It follows that the total evaporation from the reservoir will be less than the annual estimate.

The possiblity for groundwater recharge which would bring a significant reduction of evaporation losses should be also examined. If a surface reservoir, or reservoirs can be used in combination with groundwater recharge there can be carry-over storage from wet years to dry years to stabilize the water supply and allow more irrigation in the dry years when it is needed the most.

The above analysis is preliminary. A detailed operation study of the reservoir is possible only after the reservoir site has been established . A cost-capacity curve based on the reservoir and dam costs for various elevations of the reservoir, combined with the storage-demand curve, would then yield a cost-demand curve showing the costs of providing rates of regulated flows.

This of course is beyond the scope of this research.

TABLE 1. GENERATION OF MISSING MONTHLY PRECIPITATION DATA FOR AYUTLA STATION

Simple Linear Regression

Regression Statistics

Multiple R	0.78
R Square	0.61
Adjusted R Squar	0.61
Standard Error	82.27
Observations	243

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regressior	1	2599505.3	2599505.3	384.1	8.63248E-52
Residual	241	1631029.4	6767.8		
Total	242	4230534.7			

AYUTLA Simple Regression

RDM	Predicted	95%lower	95%Upper	Status	
234.9	294.9	255.2	334.6	TOO LOW	1975
13.8	32.6	19.3	46.0	TOO LOW	1976
11.5	37.4	23.6	51.2	TOO LOW	1986
180.8	280.6	242.3	318.9	TOO LOW	1986
202.2	194.6	164.9	224.2	OK	1986
218.4	181.2	152.9	209.5	TOO HIGH	1986
214.1	216.2	184.4	248.0	OK	1986
68.2	101.2	80.9	121.4	TOO LOW	1986
33.0	40.0	25.9	54.1	OK	1986

Multiple Linear Regression

Regression Statistics

Multiple R	0.83
R Square	0.69
Adjusted R Square	0.69
Standard Error	74.31
Observations	236

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regressior	2	2876341.619	1438170.81	260.4	3.89E-60
Residual	233	1286596.953	5521.87534		
Total	235	4162938.572			

Multiple Regression

	Predicted	95%lower	95%Upper	Status
July	239.5	143.4	335.5	OK
January	20.6	5.6	35.5	OK
January	15.0	1.0	29.0	OK
June	254.1	155.7	352.6	OK
July	225.1	142.4	307.8	OK
August	174.6	106.0	243.1	OK
Septembe	215.1	132.8	297.4	OK
October	89.4	50.3	128.5	OK
Novembe	43.8	22.2	65.5	OK

TABLE **2**. GENERATION OF MISSING MONTHLY PRECIPITATION DATA FOR CUAJIMOLOYAS STATION

Simple Linear Regression

Regression Statistics

Multiple R	0.87
R Square	0.76
Adjusted R Squai	0.76
Standard Error	45.91
Observations	245

ANOVA

	df	SS	MS	F	Significance F
Regressior	1	1640533.3	1640533.3	778.510358	9.8922E-78
Residual	243	512067.2	2107.3		
Total	244	2152600.457			

Cuajimolo Simple Regression

RDM	Predicted	95%lower	95%Upper	Status	
166.1	146.0	162.2	129.9	TOO HIGI	1985
61.5	56.8	66.6	46.9	OK	1985
26.7	23.3	30.8	15.8	OK	1985
15.7	29.0	36.9	21.1	TOO LOW	1985
216.5	268.2	293.0	243.4	TOO LOW	1988
169.1	152.1	168.7	135.5	TOO HIGI	1988
20.4	22.7	30.2	15.3	OK	1988

Multiple Linear Regression

Regression Statistics

Multiple R	0.90
R Square	0.81
Adjusted R Square	0.81
Standard Error	41.48
Observations	236

ANOVA

	df	SS	MS	F	Significance F
Regressior	2	1700728.74	850364.37	494.3	1.479E-84
Residual	233	400841.7089	1720.35068		
Total	235	2101570.449			

Multiple Regression

	Predicted	95%lower	95%Upper	Status
SEPT	145.3	113.6	177.0	OK
OCT	76.5	56.1	97.0	OK
NOV	18.5	10.4	26.5	TOO HIGH
DEC	34.4	22.7	46.0	TOO LOW
JUNE	254.0	203.2	304.7	OK
JULY	166.6	129.9	203.4	OK
DEC	30.4	19.3	41.5	OK

DOUBLEMASSCURVE.xls

Figure 1 Double Mass Curve of MITLA Station Precipitation Data.

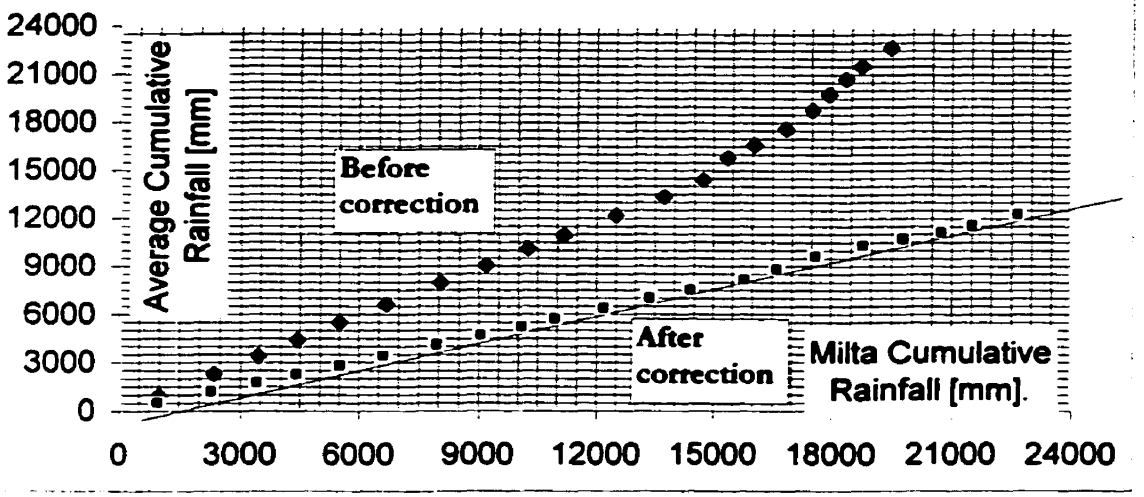


Table 3 Calculations of the Correction Factor

20733.2		**Correction**
17500	3233.2	**Factor**
14402.4	6330.8	0.511

The US. National Weather Service Method

Px = { Summation of (Pi x Wi) } / {Summation of (Wi)}

Px = Monthly Rainfall, [mm] for : the station (MITLA) with incomplete data . [km]

Pi = Precip. observed for the missing month at the closest stations (OAX,CUA,AYU).

$W_i = 1 / (D_i)^2$

D_i =Distance between each station and (MITLA) , [km]

Distance between closest stations and MITLA

D_i = [km]	OAXACA	CUAjimoloyas	AYUTLA	
MITLA	37.3	22.5	34	Sum
$W_i = 1 / (D_i)^2$ =	0.00072	0.00198	0.00087	0.00356

Figure 2. Double Mass Curve of OAXACA Station Precipitation Data.

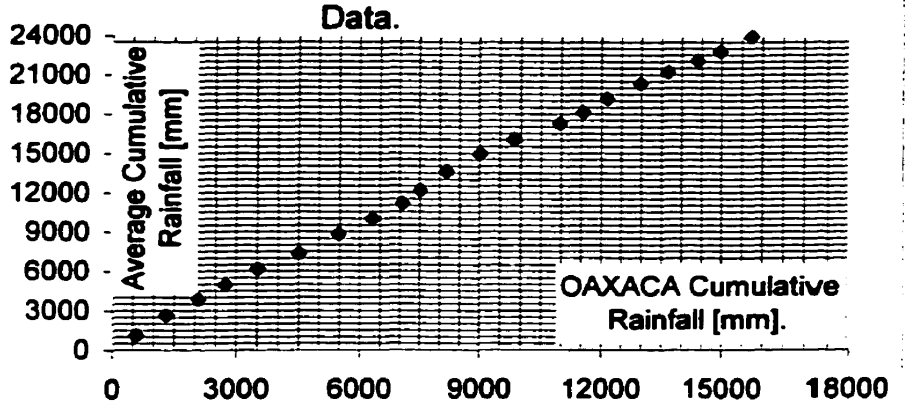


Figure 3. Double Mass Curve of CUAJIMOLOYAS Station Precipitation Data.

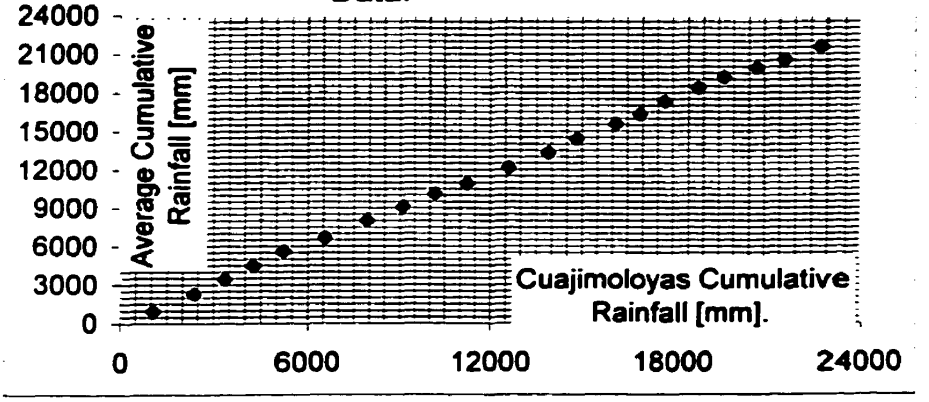
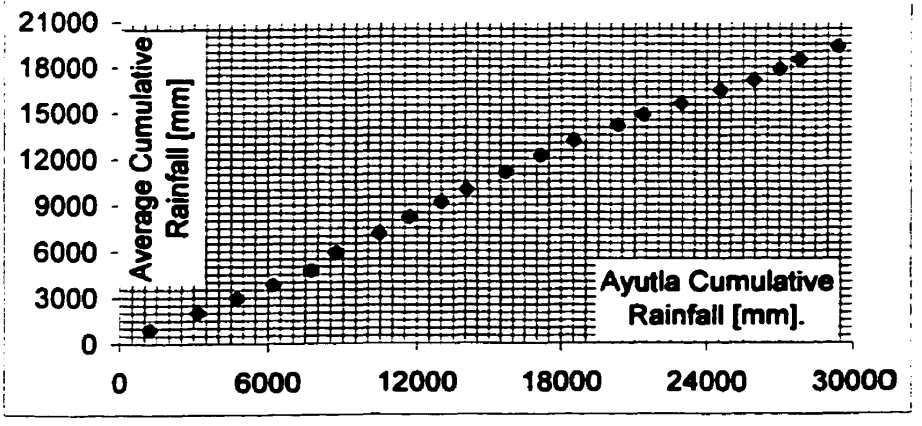


Figure 4. Double Mass Curve of AYUTLA Station Precipitation Data.



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TABLE 4 MITLA RAINFALL DATA CORRECTION FOR THE PERIOD (1968-1980) AS PER THE DOUBLE MASS METHOD

NON CORRECTED MITLA AVERAGE MONTHLY RAINFALL DATA . all in [mm]

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	ANNUAL
1968	45.9	12.6	3.6	41.3	154.0	264.5	105.7	106.4	127.5	53.8	26.2	71.4	1012.9
1969	13.7	14.1	27.2	52.7	54.7	129.4	226.6	499.4	215.9	81.1	25.6	6.0	1346.4
1970	4.1	9.4	0.4	22.5	57.7	201.6	179.6	293.0	237.7	56.4	20.4	3.4	1086.2
1971	1.1	0.9	27.8	12.7	56.1	128.1	136.8	225.6	214.2	103.9	47.9	36.4	991.5
1972	23.4	2.3	43.6	63.4	55.1	326.1	144.7	108.5	136.4	71.2	82.1	10.2	1067.0
1973	3.7	5.2	4.2	52.1	82.8	244.7	209.5	221.6	247.3	91.2	12.4	4.9	1179.6
1974	15.2	1.1	57.8	77.3	161.2	259.7	181.0	85.3	446.3	62.5	20.3	2.7	1370.4
1975	14.8	11.2	5.0	24.6	158.6	142.5	186.3	181.1	228.3	133.1	21.1	23.7	1130.3
1976	8.3	8.7	2.4	81.8	128.8	246.2	193.4	88.7	146.7	74.3	74.2	8.6	1062.1
1977	1.5	17.9	0.0	52.8	57.7	190.5	118.3	176.3	133.5	80.5	57.9	52.7	939.6
1978	0.9	13.5	45.6	38.8	97.8	332.9	220.9	129.6	281.1	113.4	18.0	20.4	1312.9
1979	7.2	19.0	18.0	96.5	82.4	103.0	189.7	235.9	369.2	68.2	21.8	17.6	1228.5
1980	11.4	2.1	5.0	46.6	98.5	151.9	134.8	236.4	255.6	50.8	14.2	8.3	1015.6

CORRECTED MITLA AVERAGE MONTHLY RAINFALL DATA as per Double Mass Curve Method..

** CORRECTION FACTOR 0.511 CORRECTED MITLA MISSING RAINFALL DATA *GENERATED FOR THE PERIOD (1

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	ANNUAL
1968	23.5	6.4	1.8	21.1	78.7	135.2	54.0	54.4	65.2	27.5	13.4	36.5	517.6
1969	7.0	7.2	13.9	26.9	28.0	66.1	115.8	255.2	110.3	41.4	13.1	3.1	688.0
1970	2.1	4.8	0.2	11.5	29.5	103.0	91.8	149.7	121.5	28.8	10.4	1.7	555.0
1971	0.6	0.5	14.2	6.5	28.7	65.5	69.9	115.3	109.5	53.1	24.5	18.6	506.7
1972	12.0	1.2	22.3	32.4	28.2	166.6	73.9	55.4	69.7	36.4	42.0	5.2	545.2
1973	1.9	2.7	2.1	26.6	42.3	125.0	107.1	113.2	126.4	46.6	6.3	2.5	602.8
1974	7.8	0.6	29.5	39.5	82.4	132.7	92.5	43.6	228.1	31.9	10.4	1.4	700.3
1975	7.6	5.7	2.6	12.6	81.0	72.8	95.2	92.5	116.7	68.0	10.8	12.1	577.6
1976	4.2	4.4	1.2	41.8	65.8	125.8	98.8	45.3	75.0	38.0	37.9	4.4	542.7
1977	0.8	9.1	0.0	27.0	29.5	97.3	60.5	90.1	68.2	41.1	29.6	26.9	480.1
1978	0.5	6.9	23.3	19.8	50.0	170.1	112.9	66.2	143.6	57.9	9.2	10.4	670.9
1979	3.7	9.7	9.2	49.3	42.1	52.6	96.9	120.5	188.7	34.9	11.1	9.0	627.8
1980	5.8	1.1	2.6	23.8	50.3	77.6	68.9	120.8	130.6	26.0	7.3	4.2	519.0

*the US. National Weather Service Method

** Derived from the DOUBLE MASS CURVE. Correction Factor = 0.511

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TABLE MONTHLY PRECIPITATION

5A TLACOLULA DE MATAMOROS

Data from: SECRETARIA DE RECURSOS HIDRAULICOS (S.A.R.H)

SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS

Years	Jan.	Feb.	Mar.	Apr.	May	June	July
	mm	mm	mm	mm	mm	mm	mm
1950				43.0	131.5	36.5	82.5
1951			0.0	10.0	79.0	193.0	60.5
1952	0.0	0.0	10.0	19.0	161.0	190.5	113.5
1953	0.0			10.0	7.0	104.5	46.0
1954				90.5	118.5	101.0	81.5
1955						68.0	208.0
1956	0.0	0.0	0.0	13.0	126.5	160.5	50.0
1957	0.0	12.0	9.0	19.5	76.5	191.5	64.5
1958	71.5	58.0	0.0	31.0	29.0	210.0	99.5
1959							
1960	0.0	0.0	0.0	49.0	24.0	162.5	82.0
1961	0.0	0.0	13.5	0.0	40.0	150.0	116.0
1962	0.0	0.0	0.0	44.0	12.0	134.5	23.0
1963	0.0	0.0	9.0	10.5	57.5	132.5	114.0
1964		0.0	0.0	30.5	85.0	103.5	64.0
1965	0.0	0.0	0.0	17.0	27.5	120.0	50.0
1966	0.0	0.0	23.0	62.5	73.0	123.0	55.5
1967	0.0	0.0	18.0	72.5	36.0	134.0	15.5
1968	20.0	2.5	0.0	11.0	75.0	207.0	89.0
1969	0.0	5.0	14.0	22.0	25.0	108.5	74.5
1970	0.0	4.0	0.0	0.0	42.5	167.0	33.0
1971	0.0	0.0	0.0	18.0	37.0	103.0	31.0
1972	0.0	0.0	9.0	90.0	17.5	271.5	37.5
1973	0.0	0.0	0.0	17.0	55.0	65.5	79.4
1974	0.0	0.0	29.5	27.5	212.5	152.5	101.5
1975	7.0	11.0	0.0	17.0	40.0	67.0	118.5
1976	0.0	0.0	0.0	23.0	88.0	90.5	95.0
1977	0.0	0.0	0.0	50.0	20.0	52.5	0.0
1978	0.0	0.0	21.0	24.0			47.0
1984	0.0	0.0	0.0	0.0	66.0	134.0	51.0
1985	0.0	0.0	9.0	34.0	43.0	52.0	76.0
1986	0.0	0.0	0.0	23.0	94.0	121.0	108.0
1987	0.0			0.0		222.0	38.0

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TABLE 5B	TABLE MONTHLY PRECIPITATION					
	TLACOLULA DE MATAMOROS					
Data from:	S. A. R. H					
	compiled by : E. Perraton 1996.					
Years	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL
	mm	mm	mm	mm	mm	mm
1950	58.0	55.5	125.5			532.5
1951	108.0	81.0	44.0			575.5
1952	56.5	165.5	13.0	10.0	0.0	739.0
1953	8.0	36.0	40.0		6.0	257.5
1954	20.5	214.0	82.5			708.5
1955		216.0	14.5			506.5
1956	43.5	99.0	0.0	0.0	0.0	492.5
1957	27.5	113.5	5.5	0.0	0.0	519.5
1958	128.5	161.5	24.5	42.0	13.0	868.5
1959					0.0	
1960	159.5	59.0	51.5	2.0	0.0	589.5
1961	6.0	51.0	0.0	34.5	0.0	411.0
1962	137.0	82.0	42.0	0.0	0.0	474.5
1963	92.5	160.5	0.0	0.0	0.0	576.5
1964	40.5	93.4	1.0	0.0	0.0	417.9
1965	30.0	45.5	64.0	0.0	0.0	354.0
1966	124.0	100.0	88.0	0.0	0.0	649.0
1967	28.0	61.5	30.5	35.5	0.0	431.5
1968	67.5	46.5	3.0	6.0	0.0	527.5
1969	302.5	97.5	12.5	2.0	0.0	663.5
1970	159.5	83.0	18.0	0.0	0.0	507.0
1971	145.0	115.0	40.0	0.0	0.0	489.0
1972	63.0	28.0	0.0	16.5	0.0	533.0
1973	131.0	89.0	25.0	4.5	0.0	466.4
1974	32.5	186.0	5.0	0.0	0.0	747.0
1975	53.5	147.0	25.0	0.0	0.0	486.0
1976	48.5	37.0	36.0	21.0	0.0	439.0
1977	84.5	48.5	23.2	13.0	13.0	304.7
1978						
1984	86.0	166.0	0.0	0.0	0.0	503.0
1985	86.0	33.0	29.0	0.0	0.0	362.0
1986	31.0	48.0	32.0	0.0	0.0	457.0
1987	0.0	34.0		0.0		

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TABLE 6A . MONTLHY RAINFALL DESCRIPTIVE STATISTICS . TLACOLULA			
NOVEMBER		**DECEMBER**	
	mm		mm
Mean	7.2	Mean	1.2
Standard Error	2.5	Standard Error	0.7
Median	0	Median	0
Mode	0	Mode	0
Standard Deviation	12.5	Standard Deviation	3.6
Sample Variance	156.6	Sample Variance	12.9
Kurtosis	2.3	Kurtosis	8.1
Skewness	1.8	Skewness	3.0
Range	42	Range	13
Minimum	0	Minimum	0
Maximum	42	Maximum	13
Sum	187	Sum	32
Count	26	Count	27
Conf. Level (95%)	5.1	Conf. Level (95%)	1.4
Conf. Level (80%)	3.3	Conf. Level (80%)	0.9
JANUARY		**FEBRUARY**	
	mm		mm
Mean	3.6	Mean	3.6
Standard Error	2.7	Standard Error	2.3
Median	0	Median	0
Mode	0	Mode	0
Standard Deviation	14.1	Standard Deviation	11.6
Sample Variance	200.1	Sample Variance	133.9
Kurtosis	22.4	Kurtosis	21.6
Skewness	4.6	Skewness	4.5
Range	71.5	Range	58
Maximum	71.5	Maximum	58
Sum	98.5	Sum	92.5
Count	27	Count	26
Conf. Level (95%)	5.6	Conf. Level (95%)	4.7
Conf. Level (80%)	3.6	Conf. Level (80%)	3.0
Note: Skewness and Kurtosis are questionable values when estimated from less than 50 sample data points.			

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TABLE 6B . MONTLHY RAINFALL DESCRIPTIVE STATISTICS . TLACOLULA			
March		April	
	mm		mm
Mean	6.1	Mean	28.3
Standard Error	1.7	Standard Error	4.4
Median	0	Median	22
Mode	0	Mode	0
Standard Deviation	8.7	Standard Deviation	24.3
Sample Variance	75.3	Sample Variance	589.9
Kurtosis	0.7	Kurtosis	1.1
Skewness	**1.3**	**Skewness**	**1.2**
Range	29.5	Range	90.5
Minimum	0	Minimum	0
Maximum	29.5	Maximum	90.5
Sum	165	Sum	878.5
Count	27	Count	31
Conf. Level (95%)	3.4	Conf. Level (95%)	8.9
Conf. Level (80%)	2.2	Conf. Level (80%)	5.8
May		June	
	mm		mm
Mean	65.5	Mean	133.2
Standard Error	8.9	Standard Error	10.1
Median	55	Median	132.5
Mode	40	Mode	134
Standard Deviation	48.1	Standard Deviation	56.0
Sample Variance	2312.6	Sample Variance	3140.3
Kurtosis	1.9	Kurtosis	-0.1
Skewness	1.3	Skewness	0.4
Range	205.5	Range	235
Maximum	212.5	Maximum	271.5
Sum	1899.5	Sum	4129.5
Count	29	Count	31
Conf. Level (95%)	18.3	Conf. Level (95%)	20.6
Conf. Level (80%)	11.9	Conf. Level (80%)	13.3
Note: Skewness and Kurtosis are questionable values when estimated from less than 50 sample data points.			

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TABLE 6C . MONTLHY RAINFALL			
DESCRIPTIVE STATISTICS . TLACOLULA			
July		August	
	mm		mm
Mean	72.0	Mean	78.6
Standard Error	7.1	Standard Error	11.6
Median	69.5	Median	60.5
Mode	50	Mode	159.5
Standard Deviation	40.1	Standard Deviation	63.5
Sample Variance	1605.1	Sample Variance	4026.6
Kurtosis	2.9	Kurtosis	3.9
Skewness	1.1	**Skewness**	**1.6**
Range	208	Range	302.5
Minimum	0	Minimum	0
Maximum	208	Maximum	302.5
Sum	2305.4	Sum	2358.5
Count	32	Count	30
Conf. Level (95%)	14.4	Conf. Level (95%)	23.7
Conf. Level (80%)	9.4	Conf. Level (80%)	15.4
September.		October	
	mm		mm
Mean	95.3	Mean	29.2
Standard Error	10.0	Standard Error	5.4
Median	83	Median	24.75
Mode	#N/A	Mode	0
Standard Deviation	55.9	Standard Deviation	29.8
Sample Variance	3127.8	Sample Variance	890.4
Kurtosis	-0.5	Kurtosis	2.7
Skewness	0.8	Skewness	1.5
Range	188	Range	125.5
Maximum	216	Maximum	125.5
Sum	2953.4	Sum	875.2
Count	31	Count	30
Conf. Level (95%)	20.5	Conf. Level (95%)	11.1
Conf. Level (80%)	13.3	Conf. Level (80%)	7.2
Note: Skewness and Kurtosis are questionable values when estimated from less than 50 sample data points.			

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TABLE 6D . MONTLHY RAINFALL DESCRIPTIVE STATISTICS . TLACOLULA	
	TOTAL
	mm
Mean	519.6
Standard Error	24.5
Median	504.75
Mode	
Standard Deviation	134.2
Sample Variance	18003.2
Kurtosis	0.6
Skewness	0.6
Range	611
Minimum	257.5
Maximum	868.5
Sum	15589
Count	30
Confidence Level (95%)	50.1
Conf. Level (80%)	32.5

Note: Skewness and Kurtosis are questionable values when estimated from less than 50 sample data points.

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Table 7 TLACOLULA Station. SEPTEMBER Rainfall 31 years.
KOLOMOGOROV-SMIRNOV TEST FOR DISTRIBUTION

X (mm)	NORM X	OBS. FREQ.	EXP. FREQ.	POS. DIFF	NEG. DIFF
28.0	-1.203	0.032	0.115	0.082	0.000
33.0	-1.113	0.065	0.133	0.068	0.101
34.0	-1.096	0.097	0.137	0.040	0.072
36.0	-1.060	0.129	0.145	0.016	0.048
37.0	-1.042	0.161	0.149	0.013	0.020
45.5	-0.890	0.194	0.187	0.007	0.026
46.5	-0.872	0.226	0.192	0.034	0.002
48.0	-0.845	0.258	0.199	0.059	0.027
48.5	-0.836	0.290	0.202	0.089	0.057
51.0	-0.792	0.323	0.214	0.108	0.076
55.5	-0.711	0.355	0.239	0.116	0.084
59.0	-0.649	0.387	0.258	0.129	0.097
61.5	-0.604	0.419	0.273	0.146	0.114
81.0	-0.255	0.452	0.399	0.052	0.020
82.0	-0.237	0.484	0.406	0.078	0.045
83.0	-0.219	0.516	0.413	0.103	0.071
89.0	-0.112	0.548	0.455	0.093	0.061
93.4	-0.034	0.581	0.487	0.094	0.062
97.5	0.040	0.613	0.516	0.097	0.065
99.0	0.067	0.645	0.527	0.119	0.086
0.0	0.085	0.677	0.534	0.144	0.112
113.5	0.326	0.710	0.628	0.082	0.050
115.0	0.353	0.742	0.638	0.104	0.072
147.0	0.925	0.774	0.823	0.048	0.081
160.5	1.166	0.807	0.878	0.072	0.104
161.5	1.184	0.839	0.882	0.043	0.075
165.5	1.256	0.871	0.895	0.024	0.057
166.0	1.265	0.903	0.897	0.006	0.026
186.0	1.622	0.936	0.948	0.012	0.044
214.0	2.123	0.968	0.983	0.015	0.048
216.0	2.159	1.000	0.985	0.000	0.017

Statisitical Test compiled with GEOPACK (version 1)./ S.A.R.H data.

Kolomogorov-Smirnov Test Statistic (β)	=	0.146
REJECT The Null Hypothesis At The (.10) Level Kolomogorov-Smirnov Critical (Test) Value	=	0.145
ACCEPT The Null Hypothesis At The (.05) Level Kolomogorov-Smirnov Critical (Test) Value	=	0.159
ACCEPT The Null Hypothesis At The (.01) Level Kolomogorov-Smirnov Critical (Test) Value	=	0.185

Null Hypothesis: Observed Distribution Same As A Normal Distribution

NOTE: results use the intrinsic hypothesis - i.e. the theoretical distribution uses the mean and std from the sample population

Table 8 TLACOLULA Station. MONTHLY RAINFAL Nov/Dec Jan/Feb
KOLOMOGOROV-SMIRNOV TEST FOR DISTRIBUTIC n=26/27 n=27/26

Kolomogorov-Smirnov Test Statistic (β) =	0.32/0.52		0.49/0.39
At The (.10) Level Kolomogorov-Smirnov Crit. (Test) Value	0.145	R	0.147
At The (.05) Level Kolomogorov-Smirnov Crit. (Test) Value	0.159	R	0.161
At The (.01) Level Kolomogorov-Smirnov Crit. (Test) Value	0.185	R	0.187

Table TLACOLULA Station. MONTHLY RAINFAL March April
KOLOMOGOROV-SMIRNOV TEST FOR DISTRIBUTIC n = 27 n = 31

Kolomogorov-Smirnov Test Statistic (β) =	0.352		0.184
At The (.10) Level Kolomogorov-Smirnov Crit. (Test) Value	0.145	R	0.145
At The (.05) Level Kolomogorov-Smirnov Crit. (Test) Value	0.159	R	0.159
At The (.01) Level Kolomogorov-Smirnov Crit. (Test) Value	0.188	R	0.185

Table TLACOLULA Station. MONTHLY RAINFAL May June
KOLOMOGOROV-SMIRNOV TEST FOR DISTRIBUTIC n = 29 n = 29

Kolomogorov-Smirnov Test Statistic (β) =	0.146		0.104
At The (.10) Level Kolomogorov-Smirnov Crit. (Test) Value	0.145	R	0.145
At The (.05) Level Kolomogorov-Smirnov Crit. (Test) Value	0.159	A	0.159
At The (.01) Level Kolomogorov-Smirnov Crit. (Test) Value	0.185	A	0.185

Table TLACOLULA Station. MONTHLY RAINFAL July August
KOLOMOGOROV-SMIRNOV TEST FOR DISTRIBUTIC n = 30 n = 30

Kolomogorov-Smirnov Test Statistic (β) =	0.092		0.136
At The (.10) Level Kolomogorov-Smirnov Crit. (Test) Value	0.142	A	0.147
At The (.05) Level Kolomogorov-Smirnov Crit. (Test) Value	0.157	A	0.162
At The (.01) Level Kolomogorov-Smirnov Crit. (Test) Value	0.182	A	0.1885

Table TLACOLULA Station. MONTHLY RAINFAL October ANNUAL
KOLOMOGOROV-SMIRNOV TEST FOR DISTRIBUTIC n = 30 n = 30

Kolomogorov-Smirnov Test Statistic (β) =	0.143		0.16
At The (.10) Level Kolomogorov-Smirnov Crit. (Test) Value	0.147	A	0.147
At The (.05) Level Kolomogorov-Smirnov Crit. (Test) Value	0.162	A	0.162
At The (.01) Level Kolomogorov-Smirnov Crit. (Test) Value	0.188	A	0.188

Null Hypothesis: Observed Distribution Same As A Normal Distribution

NOTE: results use the intrinsic hypothesis - i.e. the theoretical distribution uses the mean and std from the sample population (This is the usual case)

A : ACCEPT at the specified level

R : REJECT at the specified level

TABLE	9A	T TEST Results and Rainfall Statistics							
H_o: $\upsilon_1 = \upsilon_2$ and there is essentially no difference in precipitation between the two periods.									
H_1: $\upsilon_1 \neq \upsilon_2$ and there is a significant difference in precipitation between the two periods.									
Uneq variance.EXCEL Vers 7.0.									
		TLACOLULA De MATAMOROS .						TLACOLULA De MATAM	
Period A	Period B		TLACOLULA De MATAMOROS .						
T TEST Prob that	A Rains con	JANUARY	FEBRUAR	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
1950-1958	1960-1968	0.459	0.300	0.413	0.788	0.063	0.957	0.302	0.414
1960-1968	1969-1977	0.528	0.172	0.793	0.770	0.600	0.419	0.813	0.286
1950-1958	1969-1977	0.398	0.349	0.632	0.993	0.275	0.536	0.235	0.098
Period	Statistics	JANUARY	FEBRUAR	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
1950-1958	n	5	4	5	8	8	9	9	8
	Avg Rain	**14.3**	**17.5**	**3.8**	**29.5**	**91.1**	**139.5**	**89.6**	**56.3**
	STD	32.0	27.6	5.2	27.1	53.2	63.3	49.7	42.3
	cv	223.6%	157.6%	137.2%	91.9%	58.4%	45.3%	55.5%	75.0%
1960-1968	N	8	9	9	9	9	9	9	9
	Avg Rain	**2.5**	**0.3**	**7.1**	**33.0**	**47.8**	**140.8**	**67.7**	**76.1**
	std	7.1	0.8	9.1	25.4	25.8	30.1	35.9	54.7
	cv	282.8%	300.0%	129.5%	76.9%	53.9%	21.4%	53.1%	71.8%
1969-1977	N	9	9	9	9	9	9	9	9
	Avg Rain	**0.8**	**2.2**	**5.8**	**29.4**	**59.7**	**119.8**	**63.4**	**113.3**
	std	2.3	3.8	10.3	26.2	61.2	68.8	39.6	84.3
	cv	300.0%	172.5%	175.8%	89.2%	102.4%	57.4%	62.4%	74.4%

TABLE		TABLE	9B	T TEST Results and Statistics		
H_o: $\upsilon_1 = \upsilon_2$ and there is es		H_o: $\upsilon_1 = \upsilon_2$ and no difference in precipitation				
H_1: $\upsilon_1 \neq \upsilon_2$ and there is a		H_1: $\upsilon_1 \neq \upsilon_2$ and a significant difference in precip.				
Uneq variance.EXCEL Vers 7.0		Uneq variance.EXCEL Vers 7.0.				
		IOROS .		TLACOLULA De MATAMOROS .		
Period A	Period B					
T TEST Prob that	A Rains con	SEPT	OCT.	NOV	DEC	ANNUAL
1950-1958	1960-1968	0.073	0.665	0.715	0.214	0.227
1960-1968	1969-1977	0.502	0.386	0.691	0.347	0.679
1950-1958	1969-1977	0.235	0.233	0.559	0.453	0.401
Period	Statistics	SEPT	OCT.	NOV	DEC	ANNUAL
1950-1958	n	9	9	4	5	9
	Avg Rain	**126.9**	**38.8**	**13.0**	**3.8**	**577.8**
	STD	65.8	41.1	19.9	5.8	176.1
	cv	51.9%	105.9%	153.1%	151.6%	30.5%
1960-1968	N	9	9	9	9	9
	Avg Rain	**77.7**	**31.1**	**8.7**	**0.0**	**492.4**
	std	37.0	32.6	15.1	0.0	98.5
	cv	47.6%	104.7%	173.8%		20.0%
1969-1977	N	9	9	9	9	9
	Avg Rain	**92.3**	**20.5**	**6.3**	**1.4**	**515.1**
	std	51.9	13.2	8.3	4.3	127.5
	cv	56.2%	64.4%	130.4%	300.0%	24.8%

TABLE **10A**	Non Parametric test of Equality of Distribution Functions.							
1950-58	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**
1969-77	mm	mm	mm	mm	mm	mm	mm	mm
N1	5	4	5	9	9	9	9	8
N2	9	9	9	9	9	9	9	9
U= NRUNS	**6**	**4**	**6**	**8**	**8**	12	10	**8**
Probability [1]	0.168	0.067	0.168	0.129	0.129	0.129	0.202	0.161
t-prob TABLE	0.398	0.349	0.632	0.993	0.275	0.536	0.235	0.098
Lower 5%	4	3	4	**6**	6	**6**	**6**	5
Upper 5%	10	9	10	**13**	13	**13**	**13**	13
	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Lower2.5%	3	3	3	5	5	5	5	5
Upper 2.5%	11	9	11	14	14	14	14	13
	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Lower 1%	3	2	3	4	4	4	4	4
Upper 1%	11	9	11	15	15	15	15	14
	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE

TRUE : THE HYPOTHESIS H_0: IS ACCEPTED

TRUE : THE HYPOTHESIS H_0: IS REJECTED

Test designed by Wald and Wolfowitz (1940, as reported by Kreyszig, 1970)

1) The probability was calculated as per the Probability function P(U=u) for this test given in Kreyszig (1970p369).

TABLE **10B**	Non Parametric test of Equality of Distribution Functions.					
Sep.	**Oct.**	**Nov.**	**Dec.**	**TOTAL**	Example $n_1 = n_2 = 9$	
mm	mm	mm	mm	mm	U	P(U=u)
9	9	4	5	9	2	4.1135E-05
9	9	9	9	9	3	0.00032908
10	11	8	5	11	4	0.003
0.202	0.161	0.157	0.080	0.161	5	0.009
0.235	0.233	0.559	0.453	0.401	**6**	**0.032**
6	**6**	3	4	**6**	7	0.065
13	**13**	9	10	**13**	8	0.129
TRUE	TRUE	TRUE	TRUE	TRUE	9	0.161
5	5	3	3	5	10	0.202
14	14	9	11	14	11	0.161
TRUE	TRUE	TRUE	TRUE	TRUE	12	0.129
4	4	2	3	4	**13**	**0.065**
15	15	9	11	15	14	0.032
TRUE	TRUE	TRUE	TRUE	TRUE	15	0.009
					16	0.003
					17	0.00032908
					Total	1.00

TRUE : THE HYPOTHESIS H_0: IS ACCEPTED

TRUE : THE HYPOTHESIS H_0: IS REJECTED

Test designed by Wald and Wolfowitz (1940)

1) The probability was calculated as per the Probability function P(U=u) for this test given in Kreyszig (1970p369).

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TABLE 11 MONTLHY CORRELATIONS BETWEEN MIN TEMP AND AVERAGE MONTHLY RAINFALL. Periods (1950-1987)

AVG MAX TEMP °C		AVG MIN TEMP °C	AVG RAIN (mm)	MONTHLY CORRELATIONS		
Column 3.	Periods	Column1	Column 2			
23.70	1950-1958	1.14	14.3	**January**	Min Temp	Avg Rain
25.60	1960-1968	3.12	2.5	Min Temp	1	
25.79	1969-1977	4.59	0.8	Avg Rain	-0.92	1
	1984-1987	5.73	0.0			
25.78	1950-1958	2.64	17.5	**February**	Min Temp	Avg Rain
26.74	1960-1968	4.21	0.3	Column 1	1	
26.99	1969-1977	5.48	2.2	Column 2	-0.74	1
	1984-1987	7.90	0.0			
28.02	1950-1958	5.88	3.8	**March**	Min Temp	Avg Rain
28.83	1960-1968	7.18	7.1	Min Temp	1	
30.03	1969-1977	8.38	5.8	Avg Rain	-0.19	1
	1984-1987	9.33	3.0			
28.57	1950-1958	8.58	29.5	**April**	Min Temp	Avg Rain
29.57	1960-1968	9.60	33.0	Min Temp	1	
30.14	1969-1977	10.41	29.4	Avg Rain	-0.86	1
	1984-1987	12.35	14.3			
27.17	1950-1958	9.76	91.1	**May**	Min Temp	Avg Rain
28.62	1960-1968	11.02	47.8	Min Temp	1	
29.27	1969-1977	12.00	59.7	Avg Rain	-0.36	1
	1984-1987	13.90	67.7			
24.46	1950-1958	10.92	139.5	**June**	Min Temp	Avg Rain
25.96	1960-1968	12.40	140.8	Min Temp	1	
25.80	1969-1977	12.79	119.8	Avg Rain	-0.36	1
	1984-1987	14.80	132.3			
23.07	1950-1958	9.76	89.6	**July**	Min Temp	Avg Rain
25.04	1960-1968	11.30	67.7	Min Temp	1	
25.32	1969-1977	11.99	63.4	Avg Rain	-0.70	1
	1984-1987	14.00	68.3			
24.67	1950-1958	9.16	56.3	August	Min Temp	Avg Rain
25.70	1960-1968	10.90	76.1	Min Temp	1	
25.00	1969-1977	11.70	113.3	Avg Rain	-0.04	1
	1984-1987	13.88	50.8			

CORREL of RAINTLAC.xls

TABLE **11** MONTLHY CORRELATIONS BETWEEN MIN TEMP AND AVERAGE MONTHLY RAINFALL. Periods (1950-1987)

AVG MAX TEMP °C		AVG MIN TEMP °C	AVG RAIN (mm)	MONTHLY CORRELATIONS		
Column 3.	Periods	Column1	Column 2			
23.59	1950-1958	9.96	126.9	**Sept.**	Min Temp	Avg Rain
24.99	1960-1968	11.43	77.7	Min Temp	1	
24.90	1969-1977	11.81	92.3	Avg Rain	-0.87	1
	1984-1987	13.60	70.3			
23.72	1950-1958	6.74	38.8	**Oct.**	Min Temp	Avg Rain
24.88	1960-1968	8.98	31.1	Min Temp	1	
25.92	1969-1977	10.08	20.5	Avg Rain	-0.92	1
	1984-1987	12.37	20.3			
24.36	1950-1958	3.88	13.0	**Nov.**	Min Temp	Avg Rain
25.14	1960-1968	5.27	8.7	Min Temp	1	
25.86	1969-1977	7.29	6.3	Avg Rain	-0.97	1
	1984-1987	8.60	0.0			
23.68	1950-1958	1.60	3.8	**Dec.**	Min Temp	Avg Rain
25.36	1960-1968	3.70	0.0	Min Temp	1	
25.29	1969-1977	5.07	1.4	Avg Rain	-0.75	1
	1984-1987	7.57	0.0			
300.77	1950-1958	79.83	577.8	**ANNUAL**	Min Temp	Avg Rain
316.43	1960-1968	99.11	492.4	Min Temp	1	
317.44	1969-1977	112.21	515.1	Avg Rain	-0.92	1
	1984-1987	133.47	440.7			

TABLE 12.	Mean Monthly MINIMUM Temperature				TABLE 13.	Mean Monthly MINIMUM Temperature		
	period of :	1950 -1958			period of :	1960-1968		
1950 -1958		**Mean Monthly Max Temp**			**1960-1968**			
	n	AVG	STD	CV	n	AVG	STD	CV
		°C	°C	%		°C	°C	%
JAN/ENE	9	1.14	2.40	210%	10	3.24	0.85	26%
FEB/FEB	9	2.64	2.25	85%	10	4.5	1.60	36%
MAR/MAR	9	5.88	1.89	32%	10	7.47	1.48	20%
APR/ABR	8	8.58	1.59	18%	10	9.73	1.09	11%
MAY/MAYO	9	9.76	1.49	15%	10	11.07	1.01	9%
JUNE/JUNIO	9	10.92	1.16	11%	10	12.51	0.57	5%
JULY/JULIO	9	9.76	0.94	10%	10	11.41	0.75	7%
AUG/AGO	9	9.16	1.07	12%	10	11.12	0.98	9%
SEPT/SEPT	9	9.96	0.94	9%	10	11.43	0.33	3%
OCT/OCT	9	6.74	1.50	22%	10	8.99	0.98	11%
NOV/NOV	9	3.88	2.36	61%	10	5.27	1.29	24%
DEC/DIC	9	1.60	2.33	146%	10	3.71	1.02	28%
ANUAL	9	79.83	11.18	14%	10	100.45	6.61	7%

TABLE 14	Mean Monthly MINIMUM Temperature period of :				TABLE 15	Probability associated with a t-Test. Hypothesis : $\mu_A = \mu_B$ alternative is $\mu_A \neq \mu_B$		
1969-1977						A = 1950-1958	A= 1960-1968	A= 1950-1958
n	AVG	STD	CV			B = 1960-1968	B= 1969-1977	B =1969-1977
	°C	°C	%			$H_0 : T_A = T_B$	$H_0 : T_A = T_B$	$H_0 : T_A = T_B$
9	4.59	1.21	26%	JAN/ENE		0.033	0.012	0.001
9	5.48	1.87	34%	FEB/FEB		0.095	0.237	0.010
9	8.38	1.05	13%	MAR/MAR		0.104	0.146	0.003
9	10.41	1.26	12%	APR/ABR		0.135	0.224	0.018
9	12.00	1.10	9%	MAY/MAYO		0.054	0.071	0.002
9	12.79	0.72	6%	JUNE/JUNIO		0.003	0.360	0.001
9	11.99	0.69	6%	JULY/JULIO		0.001	0.100	0.000
9	11.70	1.21	10%	AUG/AGO		0.001	0.263	0.000
9	11.81	0.92	8%	SEPT/SEPT		0.000	0.237	0.001
9	10.08	1.35	13%	OCT/OCT		0.002	0.058	0.000
8	7.29	2.45	34%	NOV/NOV		0.146	0.039	0.011
9	5.07	1.75	35%	DEC/DIC		0.026	0.052	0.003
8	112.21	9.60	9%	ANUAL		0.000	0.007	0.000
				It is Assumed : The two populations are normally distributed and have equal variance.				

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TABLE **16a** Mean Monthly MAXIMUM Temperature
period of : 1950 -1959

Mean Monthly MAXIMUM Temperature
period of : 1960-1969 **16b**

1950 -1959	Mean Monthly Max Temp				1960-1969			
	n	AVG	STD	CV	n	AVG	STD	CV
		°C	°C	%		°C	°C	%
JAN/ENE	10	23.91	1.12	5%	10	25.64	0.41	2%
FEB/FEB	10	25.98	2.06	8%	10	26.96	1.64	6%
MAR/MAR	10	28.07	1.54	6%	10	28.84	1.08	4%
APR/ABR	10	28.53	1.61	6%	10	29.67	1.38	5%
MAY/MAYO	10	27.29	1.51	6%	10	28.79	1.03	4%
JUNE/JUNIO	10	24.64	1.49	6%	10	26.11	0.92	4%
JULY/JULIO	10	23.21	1.12	5%	10	25.07	0.62	2%
AUG/AGO	10	24.60	0.90	4%	10	25.47	1.01	4%
SEPT/SEPT	10	23.65	0.84	4%	10	24.84	1.32	5%
OCT/OCT	10	23.79	1.80	8%	10	25.01	1.62	6%
NOV/NOV	10	24.43	1.83	8%	10	25.22	1.74	7%
DEC/DIC	10	23.89	1.10	5%	10	25.35	0.70	3%
ANUAL	10	301.99	11.04	4%	10	316.97	6.42	2%

TABLE **16c** Mean Monthly MAXIMUM Temperature period of : **1970-1978**

n	AVG °C	STD °C	CV %		
9	25.96	1.32	5%	JAN/ENE	
9	26.97	1.13	4%	FEB/FEB	
9	30.21	1.06	4%	MAR/MAR	
9	30.54	1.64	5%	APR/ABR	
8	29.14	0.87	3%	MAY/MAYO	
8	25.59	1.23	5%	JUNE/JUNIO	
9	25.49	1.41	6%	JULY/JULIO	
8	25.20	1.70	7%	AUG/AGO	
8	25.08	1.57	6%	SEPT/SEPT	
8	25.89	1.63	6%	OCT/OCT	
7	25.86	1.17	5%	NOV/NOV	
8	25.29	1.25	5%	DEC/DIC	
9	298.10	58.45	20%	ANUAL	

TABLE **16d** Testing

Hypothesis : $\mu_A = \mu_B$ alternative is $\mu_A \neq \mu_B$

	A = 1950-1959 B = 1960-1969 $H_0 : T_A = T_B$	A = 1960-1969 B = 1970-1978 $H_0 : T_A = T_B$	A = 1950-1959 B = 1970-1978 $H_0 : T_A = T_B$
JAN/ENE	0.001	0.509	0.002
FEB/FEB	0.255	0.992	0.211
MAR/MAR	0.214	0.013	0.003
APR/ABR	0.107	0.229	0.015
MAY/MAYO	0.019	0.450	0.005
JUNE/JUNIO	0.018	0.335	0.159
JULY/JULIO	0.000	0.429	0.001
AUG/AGO	0.057	0.699	0.387
SEPT/SEPT	0.029	0.740	0.043
OCT/OCT	0.129	0.273	0.020
NOV/NOV	0.336	0.380	0.069
DEC/DIC	0.003	0.902	0.026
ANUAL	0.002	0.363	0.849

It is Assumed : The two populations are normally distributed and have equal variance.

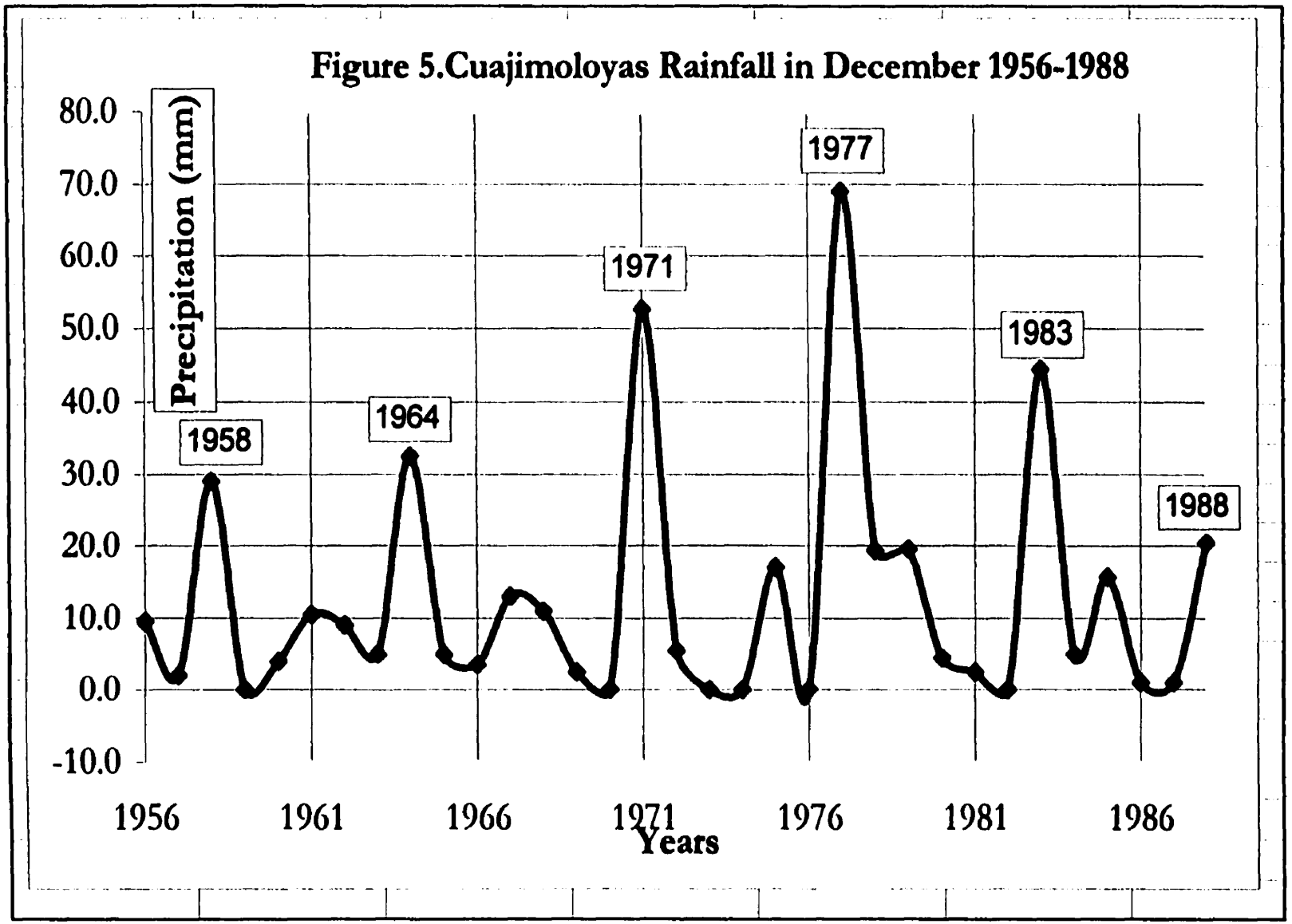
TABLE 17 Ttest CUAJIMOLOYAS MONTHLY AVG MIN TEMP 1956-968 vs 1970-1982.

Hypothesis : $\mu_A = \mu_B$ and the alternative is $\mu_A \neq \mu_B$ 2 Tails Normal.

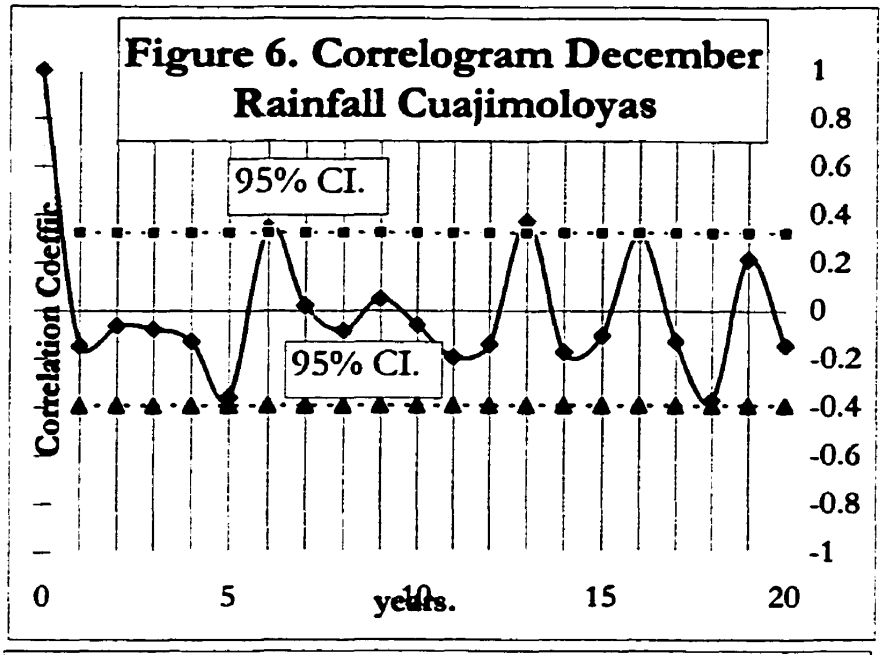
	1956-1968				1970-1982				1956-1968
	n	AVG	STD	CV	n	AVG	STD	CV	1970-1982
JAN/ENE	13	3.61	1.10	31%	13	3.66	1.08	29%	0.901
FEB/FEB	13	4.32	0.84	20%	13	4.19	1.00	24%	0.722
MAR/MAR	13	5.08	0.77	15%	13	6.02	1.08	18%	0.017
APR/ABR	13	5.71	0.78	14%	13	6.52	1.39	21%	0.083
MAY/MAYO	13	5.72	0.80	14%	13	7.36	0.88	12%	0.000
JUNE/JUNIO	13	5.16	1.30	25%	13	6.33	0.56	9%	0.009
JULY/JULIO	13	4.55	1.32	29%	13	6.02	0.54	9%	0.002
AUG/AGO	13	4.83	1.05	22%	13	6.03	0.56	9%	0.002
SEPT/SEPT	13	4.94	1.46	30%	13	6.08	0.35	6%	0.017
OCT/OCT	13	4.54	0.86	19%	13	5.79	0.57	10%	0.000
NOV/NOV	13	4.51	0.76	17%	13	4.70	0.81	17%	0.540
DEC/DIC	13	4.23	0.76	18%	13	4.27	0.65	15%	0.891
ANUAL AVG	13	4.77	0.41	9%	13	5.58	0.40	7%	0.000

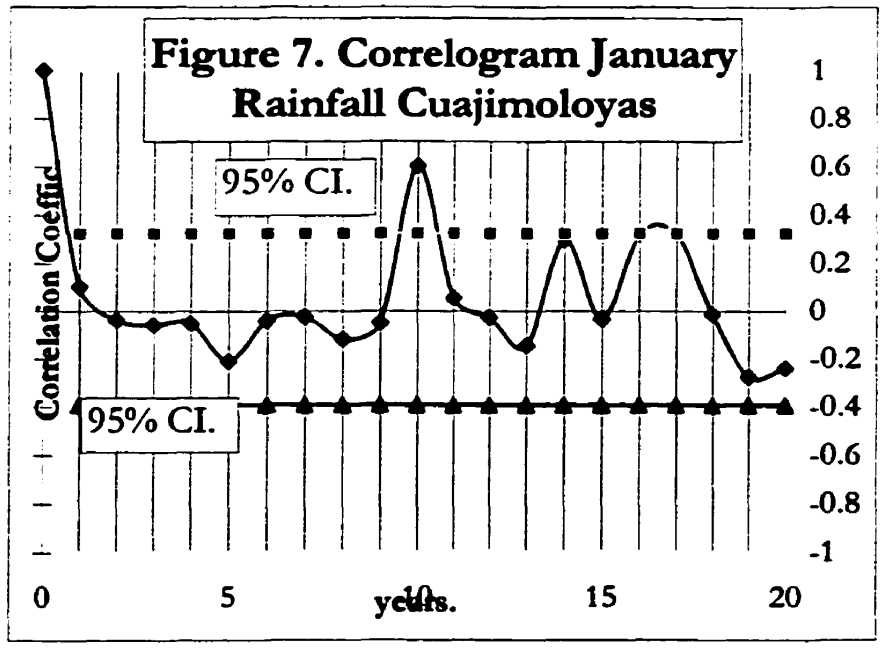
It is Assumed : The two populations are normally distributed and have equal variance

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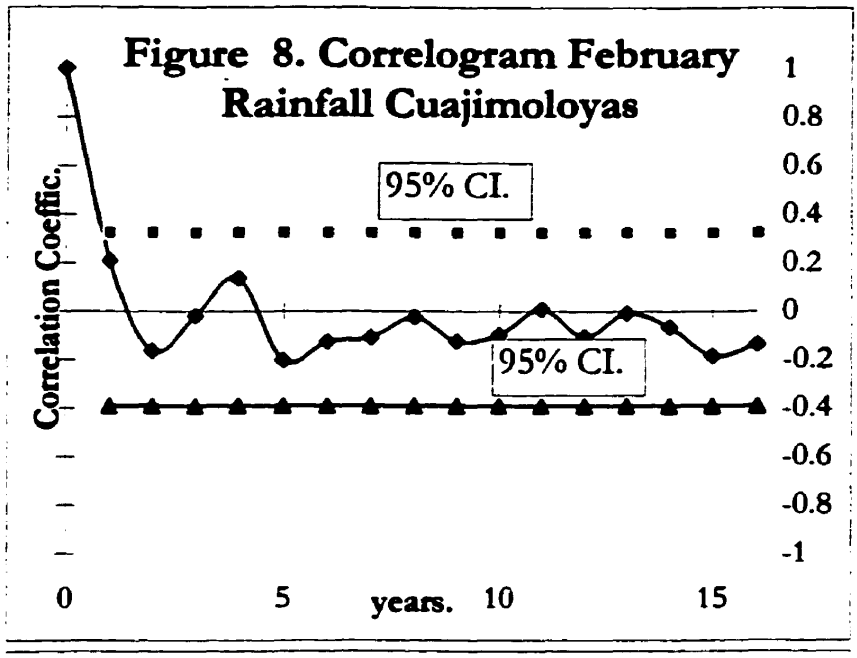


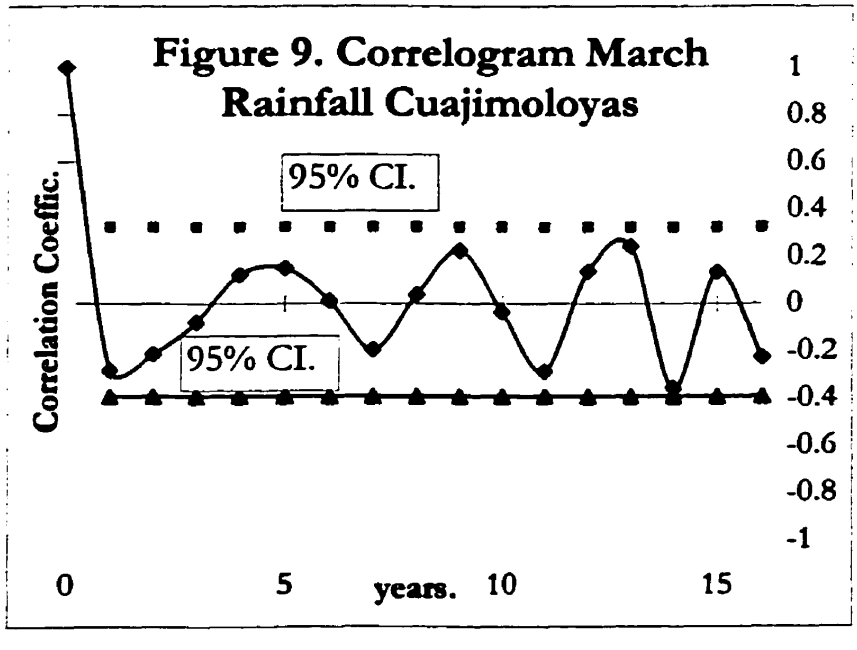
CUAJIRAINTEST.xls



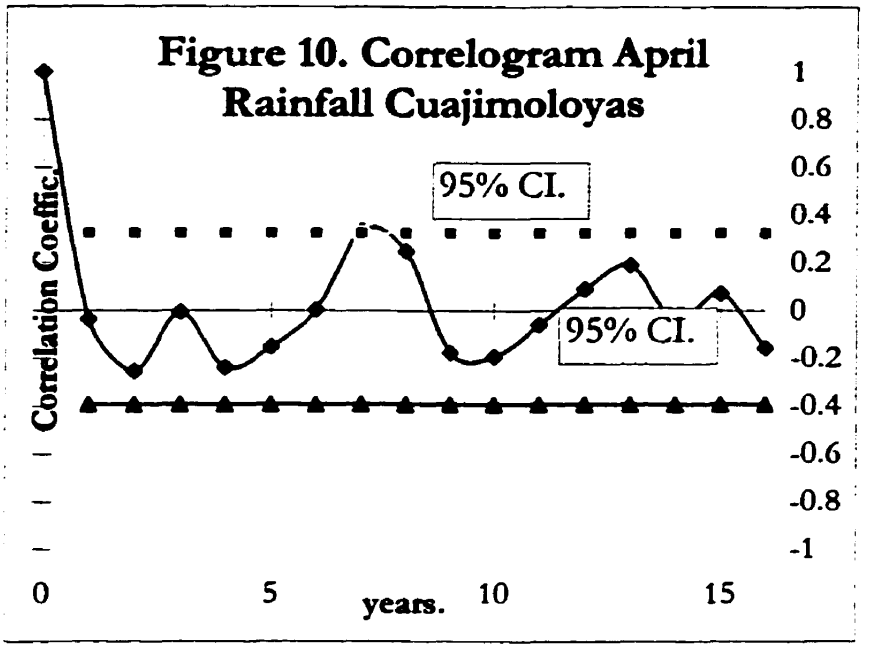


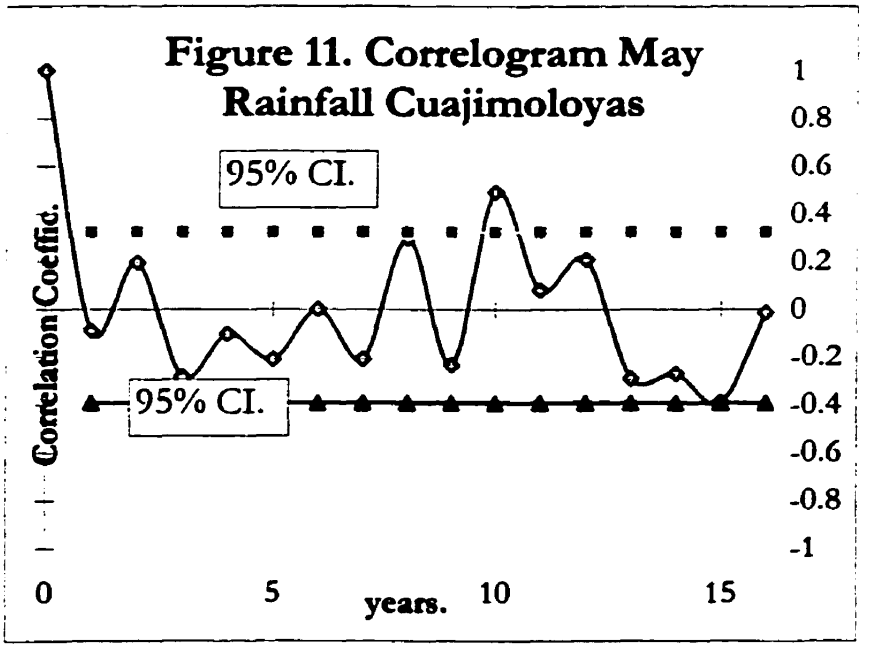
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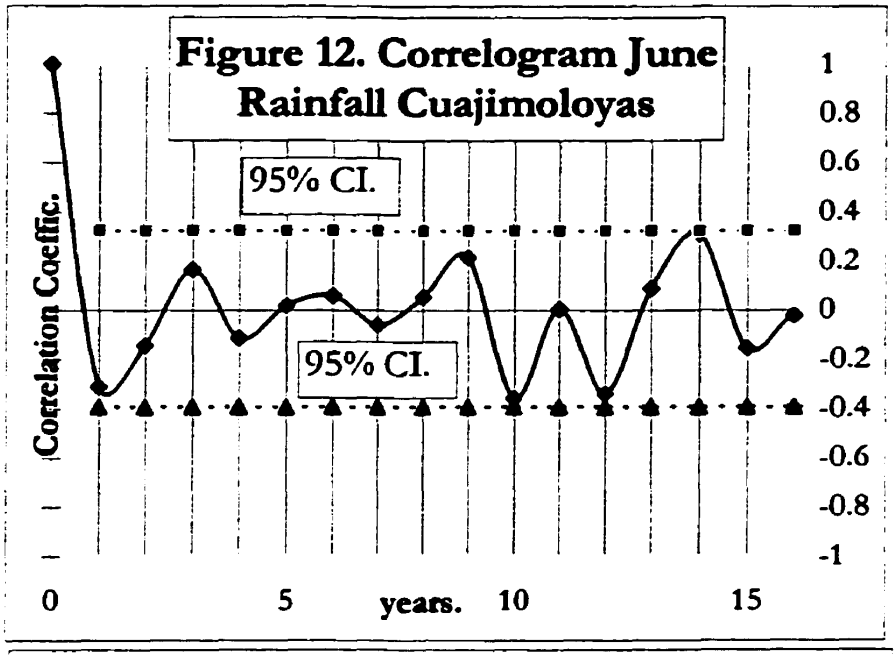


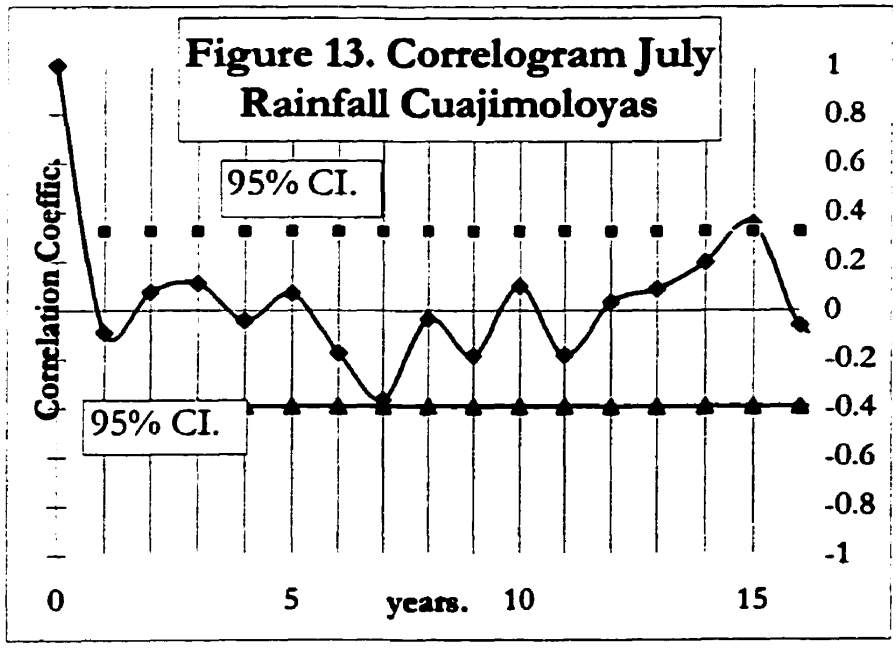
CUAJIRAINTEST.xls



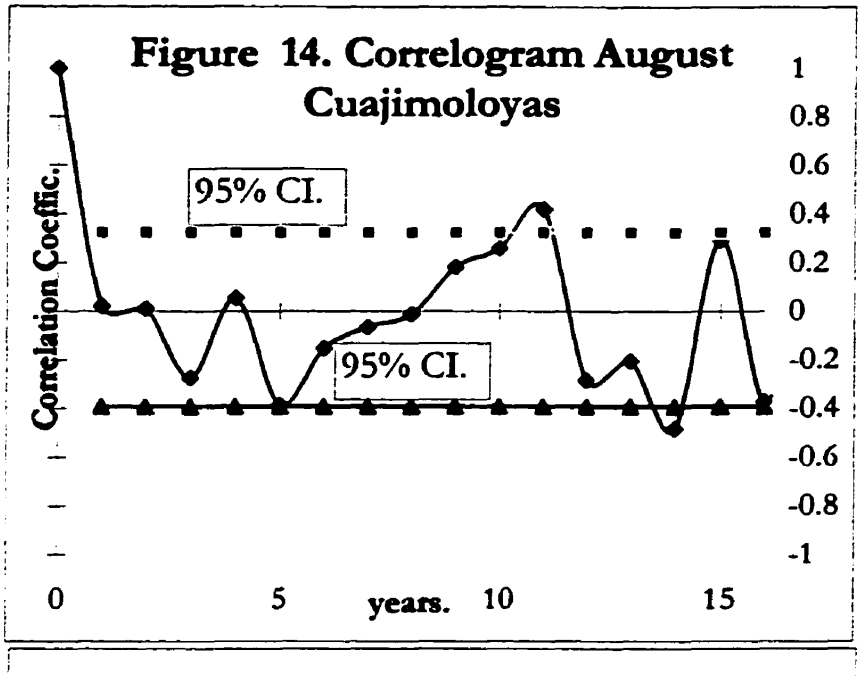


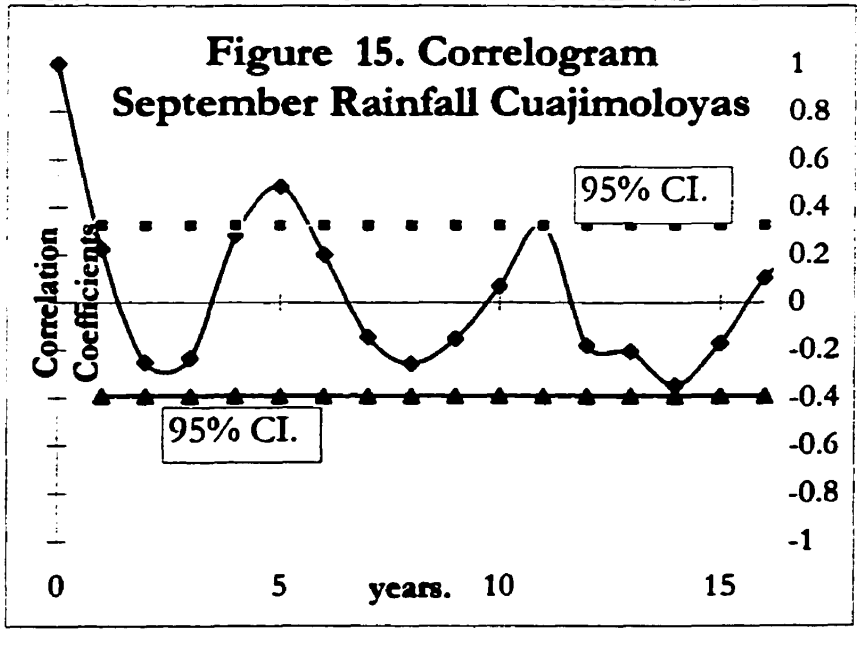
CORRELO of CUAJIRAINTEST.xls



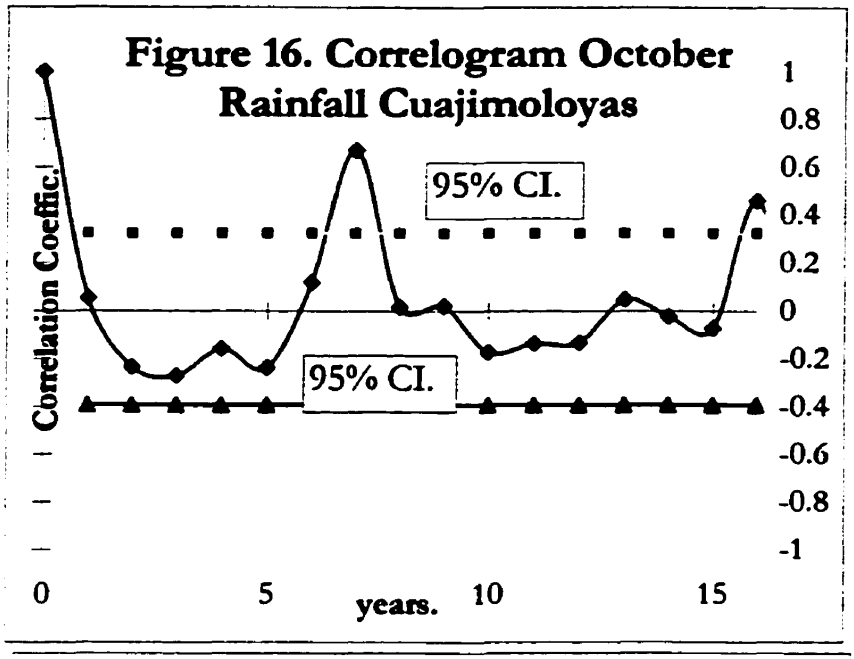


CORRELO of CUAJIRAINTEST.xls





CORRELO of CUAJIRAINTEST.xls



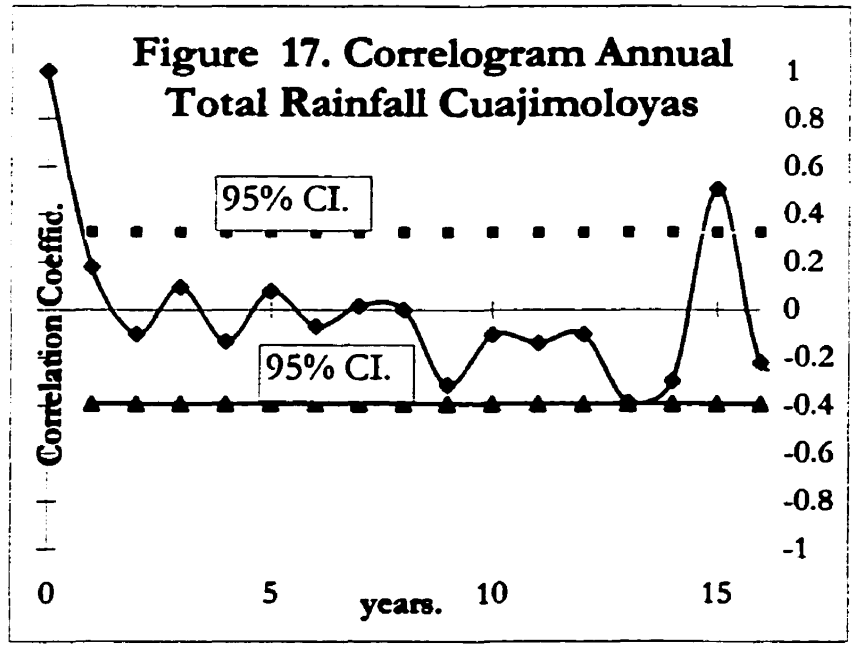


TABLE 18A Monthly Precipitation Data.
Correlation Coefficients. Assiduity and Continuity.
Tlacolula - Oaxaca - Cuajimoloyas.

Period	1956	1987	25	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	31	80.6%	<- % of assiduity
Tlacolula	1	**Oaxa.**	58.1%	<- %of Continuity
Oaxaca	0.97	1	**Cuaji.**	
Cuajimoloyas	0.92	0.94	1	**JANUARY**
Continuous.	1960	1978	18	Cont. Period
Period	1956	1986	22	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	73.3%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	0.32	1	**Cuaji.**	
Cuajimoloyas	0.78	0.59	1	**FEBRUARY**
Continuous.	1960	1978	18	Cont. Period
Period	1956	1986	25	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	83.3%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	0.54	1	**Cuaji.**	
Cuajimoloyas	0.84	0.47	1	**MARCH**
Continuous.	1960	1978	18	Cont. Period
Period	1956	1986	26	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	86.7%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	0.31	1	**Cuaji.**	
Cuajimoloyas	0.57	0.55	1	**APRIL**
Continuous.	1960	1978	18	Cont. Period
Period	1956	1986	24	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	80.0%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	0.67	1	**Cuaji.**	
Cuajimoloyas	0.66	0.72	1	**MAY**
Continuous.	1960	1978	18	Cont. Period

TABLE **18B** Monthly Precipitation Data.
Correlation Coefficients. Assiduity and Continuity.
Tlacolula - Oaxaca - Cuajimoloyas.

Period	1956	1986	30	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	100.0%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	0.22	1	**Cuaji.**	n Tlaco =26.
Cuajimoloyas	-0.01	0.59	1	**JUNE**
Continuous.	1960	1978	18	Cont. Period
Period	1956	1986	27	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	90.0%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	0.583175	1	**Cuaji.**	
Cuajimoloyas	0.715748	0.636114	1	**JULY**
Continuous.	1960	1978	18	Cont. Period
Period	1956	1986	28	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	93.3%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	0.75	1	**Cuaji.**	n of TLACO =25
Cuajimoloyas	0.88	0.84	1	**AUGUST**
Continuous.	1960	1978	18	Cont. Period
Period	1956	1986	26	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	86.7%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	0.64	1	**Cuaji.**	
Cuajimoloyas	0.81	0.66	1	**September**
Continuous.	1960	1978	18	Cont. Period

SUMMARIES OF RAINOAXACUAJITLACO.xls

TABLE **18C** Monthly Precipitation Data.
Correlation Coefficients. Assiduity and Continuity.
Tlacolula - Oaxaca - Cuajimoloyas.

Period	1956	1986	26	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	86.7%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	0.68	1	**Cuaji.**	n of TLACO =25
Cuajimoloyas	0.68	0.60	1	**October**
Continuous.	1960	1978	18	Cont. Period
Period	1956	1986	25	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	83.3%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	-0.16	1	**Cuaji.**	
Cuajimoloyas	0.64	-0.26	1	**November**
Continuous.	1960	1978	18	Cont. Period
Period	1956	1986	25	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	83.3%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	-0.13	1	**Cuaji.**	
Cuajimoloyas	0.66	-0.09	1	**December**
Continuous.	1960	1978	18	Cont. Period
Period	1956	1986	24	<- Tot Obsv.
Corr. Coef.	**Tlaco.**	30	80.0%	<- % of assiduity
Tlacolula	1	**Oaxa.**	60.0%	<- %of Continuity
Oaxaca	-0.06	1	**Cuaji.**	
Cuajimoloyas	0.54	0.16	1	**ANNUAL**
Continuous.	1960	1978	18	Cont. Period

Table 19A Monthly Precipitation Data. Tlaco.-Oaxa.Cuaji.

Descr. Stat of Monthly Rainfall Period	1956 - 1987			Descr. Stat of Monthly Rainfall 1950-87	1951-95	1955-88
n =>	25	25	25	27	44	33
JANUARY	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	3.9	4.8	12.6	3.6	3.6	10.5
STD (mm)	14.7	14.6	21.8	14.1	11.5	19.6
CV (%)	373%	303%	172%	388%	319%	186%
Conf.Intv 95%	6.0	6.0	8.9	5.5	3.5	6.9
Conf. Intv 80%.	3.9	3.9	5.8	3.6	2.3	4.5
n =>	22	22	22	26	44	33
FEBRUARY	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	3.7	5.4	10.3	3.6	5.7	14.3
STD (mm)	11.8	9.1	14.0	11.6	8.8	20.0
CV (%)	319%	168%	136%	325%	153%	139%
Conf.Intv 95%	5.2	4.0	6.1	4.6	2.7	7.0
Conf. Intv 80%.	3.4	2.6	4.0	3.0	1.7	4.6
n =>	25	25	25	33	43	26
MARCH	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	6.2	11.7	23.3	6.1	11.2	24.5
STD (mm)	8.9	12.7	27.5	8.7	12.7	27.1
CV (%)	144%	108%	118%	142%	113%	111%
Conf.Intv 95%	3.6	5.2	11.2	3.1	3.9	10.8
Conf. Intv 80%.	2.4	3.4	7.4	2.0	2.6	7.1
n =>	26	26	26	34	44	31
APRIL	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	27.2	35.2	50.3	28.3	40.6	54.0
STD (mm)	22.6	37.3	31.3	24.3	36.9	35.7
CV (%)	83%	106%	62%	86%	91%	66%
Conf.Intv 95%	9.1	14.9	12.5	8.4	11.2	13.0
Conf. Intv 80%.	5.9	9.8	8.2	5.5	7.3	8.5
n =>	24	24	24	34	44	29
MAY	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	58.4	85.5	104.9	65.5	87.3	100.4
STD (mm)	43.6	42.0	54.2	48.1	49.8	58.7
CV (%)	75%	49%	52%	73%	57%	58%
Conf.Intv 95%	18.2	17.5	22.6	16.7	15.1	22.1
Conf. Intv 80%.	11.9	11.5	14.8	10.9	9.9	14.5

Table 19B Monthly Precipitation Data. Tlaco.-Oaxa.Cuaji.

Descr. Stat of Monthly Rainfall Period	1956 - 1987			Descr. Stat of Monthly Rainfall 1950-87	1951-95	1955-88
n =>	30	30	30	33	44	32
JUNE	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	134.8	165.2	198.7	133.2	171.2	201.5
STD (mm)	55.2	69.3	85.7	56.0	73.0	83.3
CV (%)	41%	42%	43%	42%	43%	41%
Conf.Intv 95%	22.1	25.7	31.7	19.7	22.1	29.8
Conf. Intv 80%.	14.4	16.8	20.7	12.9	14.4	19.5
n =>	27	27	27	33	44	32
JULY	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	71.2	127.2	155.6	72.0	117.0	165.8
STD (mm)	42.5	76.0	75.9	40.1	65.2	68.2
CV (%)	60%	60%	49%	56%	56%	41%
Conf.Intv 95%	16.7	29.8	29.7	14.1	19.7	24.4
Conf. Intv 80%.	10.9	19.5	19.5	9.2	12.9	15.9
n =>	25	28	28	33	43	30
AUGUST	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	84.3	111.8	151.5	78.6	112.6	152.0
STD (mm)	66.4	66.9	96.8	63.5	67.0	93.9
CV (%)	79%	60%	64%	81%	60%	62%
Conf.Intv 95%	27.1	25.7	37.2	22.3	20.5	34.8
Conf. Intv 80%.	17.7	16.8	24.3	14.6	13.4	22.7
n =>	26	26	26	33	42	31
September	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	92.4	132.7	191.6	95.3	125.3	199.0
STD (mm)	52.6	67.3	74.7	55.9	71.0	85.8
CV (%)	57%	51%	39%	59%	57%	43%
Conf.Intv 95%	21.1	26.9	29.9	19.7	22.0	31.2
Conf. Intv 80%.	13.8	17.6	19.5	12.9	14.4	20.4

Table 19C Monthly Precipitation Data. Tlaco.-Oaxa.Cuaji.

Descr. Stat of Monthly Rainfall Period	1956 - 1987			Descr. Stat of Monthly Rainfall 1950-87	1951-95	1955-88
n =>	25	26	26	32	42	30
October	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	22.8	41.8	95.6	29.2	39.8	88.3
STD (mm)	22.4	34.8	65.5	29.8	39.5	63.0
CV (%)	98%	83%	69%	102%	99%	71%
Conf.Intv 95%	9.2	13.9	26.2	10.7	12.2	23.3
Conf. Intv 80%.	6.0	9.1	17.1	7.0	8.0	15.3
n =>	25	25	25	33	42	26
November	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	7.1	7.2	36.6	7.2	7.4	32.0
STD (mm)	12.8	13.3	36.7	12.5	13.0	33.3
CV (%)	180%	184%	100%	174%	175%	104%
Conf.Intv 95%	5.2	5.4	15.0	4.4	4.0	13.3
Conf. Intv 80%.	3.4	3.5	9.8	2.9	2.6	8.7
n =>	25	25	25	32	42	27
December	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	1.0	2.0	11.5	1.2	2.1	12.2
STD (mm)	3.6	4.8	17.2	3.6	4.7	16.7
CV (%)	346%	237%	150%	303%	225%	137%
Conf.Intv 95%	1.5	2.0	7.0	1.3	1.5	6.6
Conf. Intv 80%.	1.0	1.3	4.6	0.8	1.0	4.3
n =>	24	24	24	30	40	28
ANNUAL	**Tlaco.**	**Oaxa.**	**Cuaji.**	**Tlaco.**	**Oaxa.**	**Cuaji.**
AVG (mm)	511.2	751.0	1021.5	519.6	720.3	1049.1
STD (mm)	125.9	144.0	202.2	134.2	145.9	214.2
CV (%)	25%	19%	20%	26%	20%	20%
Conf.Intv 95%	52.6	60.2	84.5	56.1	61.0	89.5
Conf. Intv 80%.	34.4	39.3	55.3	36.7	39.9	58.5

January of RAINOAXACUAJITLACO.xls

TABLE 20	FREQUENCY ANALYSIS OF JANUARY RAINFALL.							
USING the Theorem of TOTAL PROBABILITY				USING LOG NORMAL DISTRIBUTION			
	TLACO	OAXA	CUAJI		TLACO	OAXA	CUAJI
# of Non zeros	3	8	16	Y = Ln (x)			
AVG of Non Zeros	32.8	14.8	17.6	Avg Y	0.4	0.7	1.8
STD of Non Zeros	34.1	23.7	25.8	STD Y	1.2	1.2	1.4
CV of Non Zeros	104%	161%	146%				
k = P(x>0)	0.14	0.38	0.76				
Return Period	5.00	5.00	5.00	RTN	5.00	5.00	5.00
1/RTN	0.20	0.20	0.20	1/RTN	0.20	0.20	0.20
P*(x)	-0.40	0.48	0.74		Standard Normal Inverse		
K_y	NA	-0.06	0.64		0.84	0.84	0.84
ybar	3.13	2.05	2.30		$y = s_y z + y_{avg}$		
S_y	0.73	1.28	1.14		1.44	1.74	2.92
Y_t	NA	1.98	2.98		x = EXP (y)		
X_t for 1 in 5 wet	**0.0**	**7.2**	**19.6**		**4.2**	**5.7**	**18.5**
Return Period (RTN)	1.25	1.25	1.25	RTN	1.25	1.25	1.25
1/RTN	0.80	0.80	0.80	1/RTN	0.8	0.8	0.8
P*(x)	-4.60	-1.10	-0.05		Standard Normal Inverse		
K_y	NA	NA	NA		-0.84	-0.84	-0.84
ybar	3.13	2.05	2.30		$y = s_y z + y_{avg}$		
S_y	0.73	1.28	1.14		-0.54	-0.35	0.60
Y_t	NA	NA	NA		x = EXP (y)		
X_t for 1 in 5 dry	**0.0**	**0.0**	**0.0**		**0.6**	**0.7**	**1.8**
Data from C.N.A / S.A.R.H. Oaxaca. Mexico. compiled by E. Perraton 1997. No data for 1959.							

February of RAINOAXACUAJITLACO.xls

TABLE 21 FREQUENCY ANALYSIS OF **February** RAINFALL.

as per the Theorem of TOTAL PROBABILITY				IF LOG NORMAL DISTRIBUTION			
	TLACO	**OAXA**	**CUAJI**		**TLACO**	**OAXA**	**CUAJI**
# of Non zeros	6	12	16	Y = Ln (x)			
AVG of Non Zeros	15.4	6.2	12.6	Avg Y	0.6	0.9	1.7
STD of Non Zeros	21.2	6.2	14.4	STD Y	1.2	1.0	1.3
CV of Non Zeros	138%	101%	114%				
k = P(x>0)	0.29	0.57	0.76				
wet 1:5	5.00	5.00	5.00	RTN	5.00	5.00	5.00
1/RTN	0.20	0.20	0.20	1/RTN	0.20	0.20	0.20
P*(x)	0.85	0.80	0.82		Standard Normal Inverse		
K_y	1.06	0.85	0.93		0.84	0.84	0.84
ybar	-1.26	0.64	0.11		$y = s_y z + y_{avg}$		
S_y	6.11	3.68	5.33		1.60	1.76	2.75
Y_t	1.35	2.27	2.26		x = EXP (y)		
Rain in (mm)1:5 wet	**3.9**	**9.7**	**9.6**		**5.0**	**5.8**	**15.6**
dry 1:5							
Return Period (RTN)	1.25	1.25	1.25	RTN	1.25	1.25	1.25
1/RTN	0.80	0.80	0.80	1/RTN	0.80	0.80	0.80
P*(x)	0.42	0.21	0.30		Standard Normal Inverse		
K_y	-0.21	-0.81	-0.53		-0.84	-0.84	-0.84
ybar	-1.26	0.64	0.11		$y = s_y z + y_{avg}$		
S_y	6.11	3.68	5.33		-0.35	0.01	0.59
Y_t	-1.77	-0.91	-1.12		x = EXP (y)		
Rain in (mm)1:5 dry	**0.2**	**0.4**	**0.3**		**0.7**	**1.0**	**1.8**

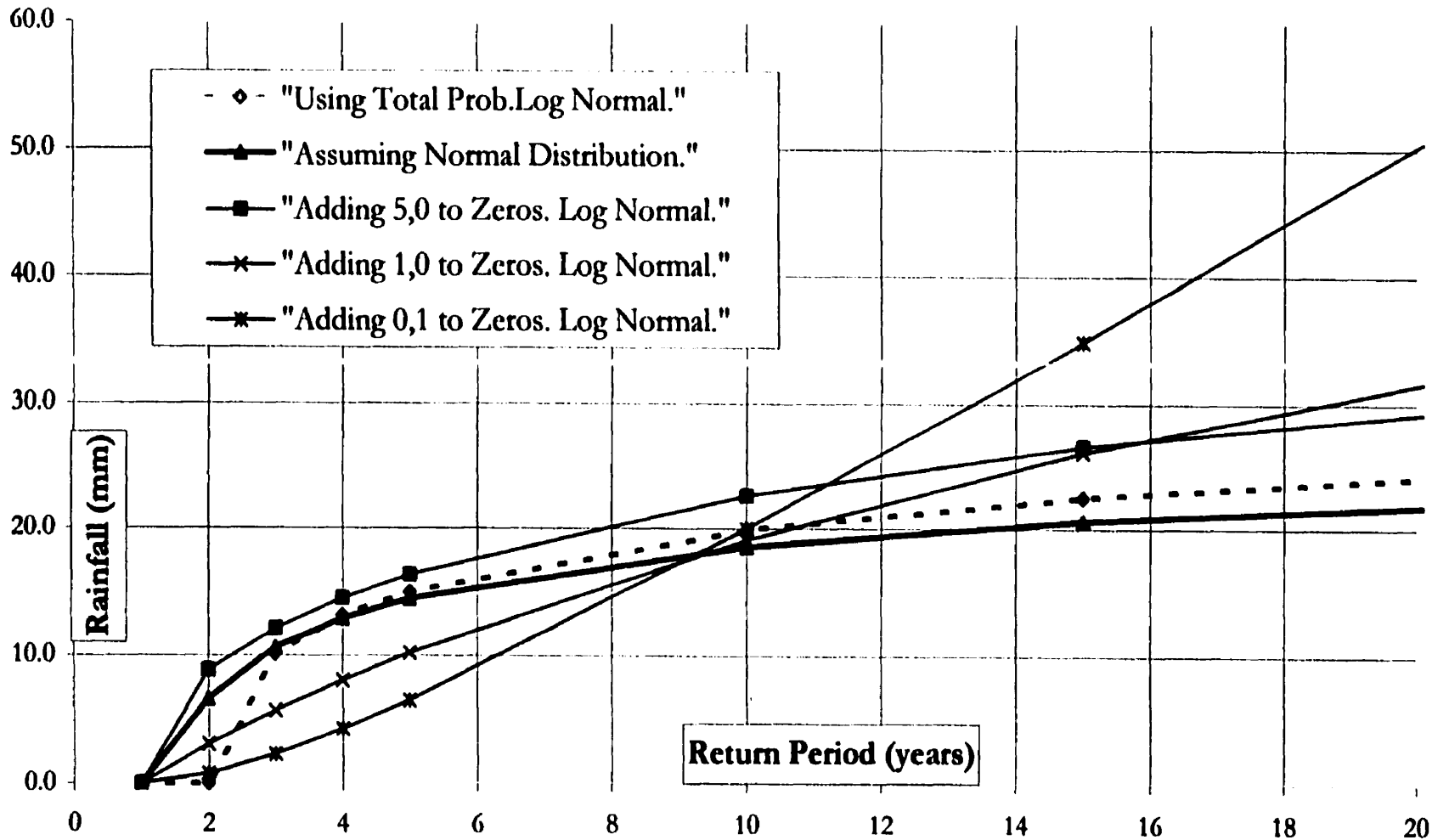
Data in hand with C.N.A / recorded by S.A.R.H. Oaxaca. Mexico.
Compiled by E. Perraton 1997. No data for 1959.

TABLE 22 FREQUENCY ANALYSIS OF MARCH RAINFALL.										
USING Theorem of TOTAL PROBABILITY								**Assuming NORMAL Distribution.**		
Assumin LOG NORMAL				**Assuming LOG NORMAL Distribu.**						
	TLACO	OAXA	CUAJI		TLACO	OAXA	CUAJI		TLACO	OAXA	CUAJI
# of Non zeros	9	16	17	Y = Ln (x)							
AVG of Non Z	16.2	15.1	29.7	Avg Y	1.1	1.7	2.2	Avg Y	6.6	11.0	23.0
STD of Non Ze	7.2	12.8	29.8	STD Y	1.4	1.4	1.6	STD Y	9.3	12.8	28.9
CV of Non Zer	45%	84%	100%								
k = P(x>0)	0.41	0.73	0.77								
1 in 5 WET	5.00	5.00	5.00	RTN	5.00	5.00	5.00	RTN	5.00	5.00	5.00
1/RTN	0.20	0.20	0.20	1/RTN	0.20	0.20	0.20	1/RTN	0.20	0.20	0.20
P*(x)	0.51	0.73	0.74		Standard Normal Inverse				Standard Normal Inverse		
K_y	0.03	0.60	0.65		0.84	0.84	0.84		0.84	0.84	0.84
ybar	2.70	2.45	3.04		$y = s_y z + y_{avg}$				$y = s_y z + y_{avg}$		
S_y	0.18	0.54	0.70		2.33	2.92	3.54		14.46	21.78	47.32
Y_t	2.71	2.89	3.56		x = EXP (y)						
1: 5 wet (mm	15.0	17.9	36.0	(mm)	10.2	18.5	34.5	(mm)	14.5	21.8	47.3
USING Theorem of TOTAL PROBABILITY				**USING LOG NORMAL DISTRIBUTION**				**USING NORMAL DISTRIBUTION**			
1 in 5 DRY	1.25	1.25	1.25	RTN	1.25	1.25	1.25	RTN	1.25	1.25	1.25
1/RTN	0.80	0.80	0.80	1/RTN	0.80	0.80	0.80	1/RTN	0.80	0.80	0.80
P*(x)	-0.96	-0.10	-0.04		Standard Normal Inverse				Standard Normal Inverse		
K_y	NA	NA	NA		-0.84	-0.84	-0.84		-0.84	-0.84	-0.84
ybar	2.70	2.45	3.04		$y = s_y z + y_{avg}$				$y = s_y z + y_{avg}$		
S_y	0.18	0.54	0.70		-0.06	0.55	0.77		-1.19	0.23	-1.41
Y_t	NA	NA	NA		x = EXP (y)				x = EXP (y)		
1: 5 dry (mm	0.0	0.0	0.0	(mm)	0.9	1.7	2.2	(mm)	MIN=0.0	0.2	MIN=0.0
Data from C.N.A / S.A.R.H. Oaxaca. Mexico. compiled by E. Perraton 1997. No data for 1959.											

TABLE 23		FREQUENCY ANALYSIS OF	APRIL		RAINFALL.					
USING Theorem of TOTAL PROBABILITY				**USING LOG NORMAL DISTRIBUTION**				**USING NORMAL DISTRIBUTION**			
	TLACO	**OAXA**	**CUAJI**		**TLACO**	**OAXA**	**CUAJI**		**TLACO**	**OAXA**	**CUAJI**
# of Non Zeros	20	21	22	Y = Ln (x)							
AvgNon Zeros	32.5	37.9	51.7	Avg Y	3.0	3.1	3.8	Avg Y	29.5	36.2	51.7
STDNon Zeros	22.1	38.7	32.0	STD Y	1.1	1.2	0.7	STD Y	23.1	38.6	32.0
CVNon Zeros	68%	102%	62%								
k = P(x>0)	0.91	0.95	1.00								
Return Period	5.00	5.00	5.00	RTN	5.00	5.00	5.00	RTN	5.00	5.00	5.00
1/RTN	0.20	0.20	0.20	1/RTN	0.20	0.20	0.20	1/RTN	0.20	0.20	0.20
P*(x)	0.78	0.79	0.80		Standard Normal Inverse				Standard Normal Inverse		
K_y	0.77	0.81	0.84		0.84	0.84	0.84		0.84	0.84	0.84
ybar	3.29	3.28	3.78		$y = s_y z + y_{avg}$				$y = s_y z + y_{avg}$		
S_y	0.38	0.71	0.32		3.98	4.09	4.35		48.90	68.68	78.63
Y_t	3.77	3.96	4.26		x = EXP (y)						
X_t for 1 in 5 wet	**43.2**	**52.5**	**71.0**		**53.6**	**59.5**	**77.5**		**48.9**	**68.7**	**78.6**
USING Theorem of TOTAL PROBABILITY				**USING LOG NORMAL DISTRIBUTION**				**USING NORMAL DISTRIBUTION**			
Return Period (RT	1.25	1.25	1.25	RTN	1.25	1.25	1.25	RTN	1.25	1.25	1.25
1/RTN	0.80	0.80	0.80	1/RTN	0.80	0.80	0.80	1/RTN	0.80	0.80	0.80
P*(x)	0.12	0.16	0.20		Standard Normal Inverse				Standard Normal Inverse		
K_y	-1.17	-0.99	-0.84		-0.84	-0.84	-0.84		-0.84	-0.84	-0.84
ybar	3.29	3.28	3.78		$y = s_y z + y_{avg}$				$y = s_y z + y_{avg}$		
S_y	0.38	0.71	0.32		2.07	2.03	3.18		10.10	3.68	24.77
Y_t	2.57	2.44	3.30		x = EXP (y)				x = EXP (y)		
X_t for 1 in 5 dry	**13.0**	**11.5**	**27.2**		**8.0**	**7.6**	**24.1**		**10.1**	**3.7**	**24.8**
Data from C.N.A / S.A.R.H. Oaxaca. Mexico. compiled by E. Perraton 1997. No data for 1959.											

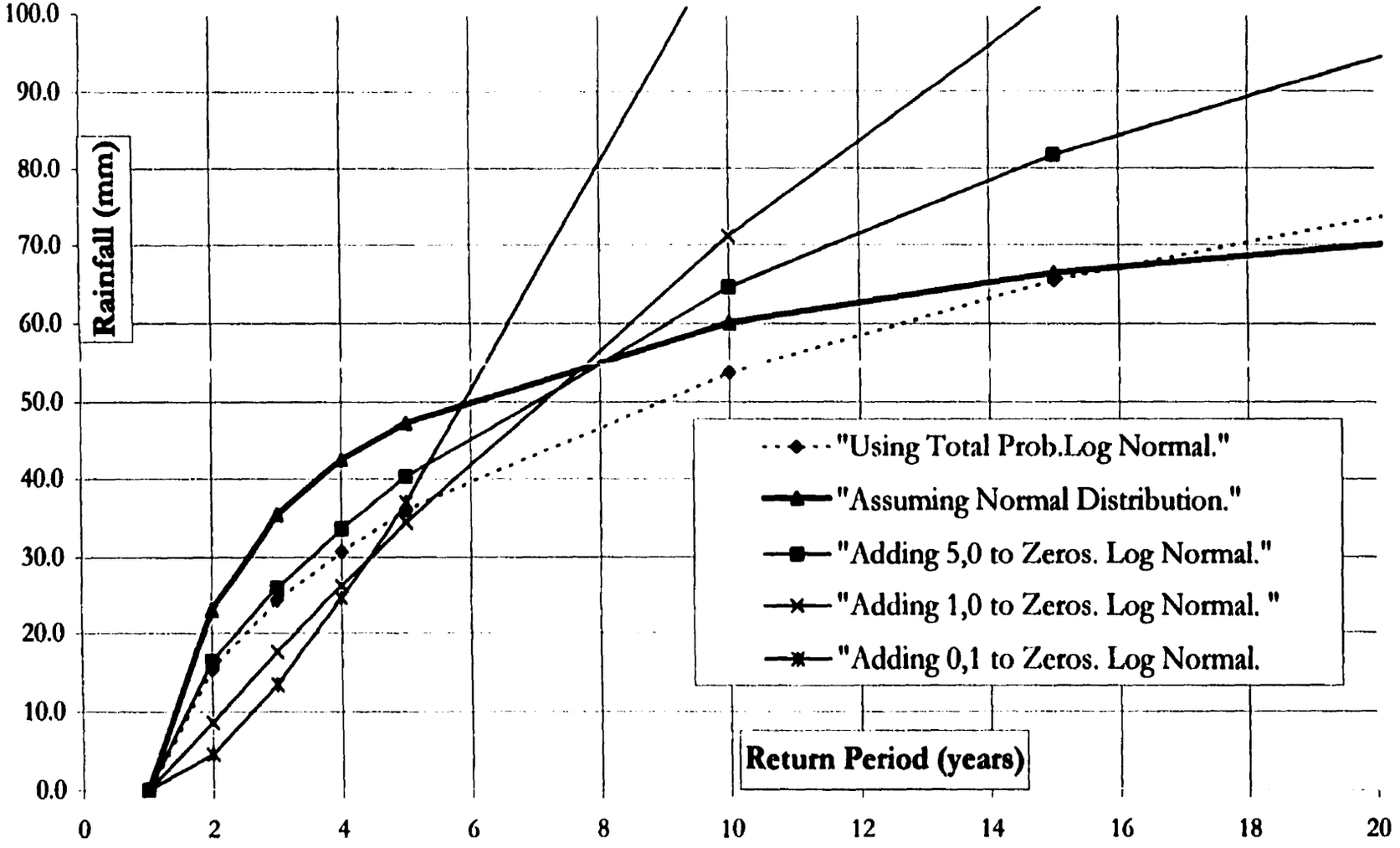
MARCHFIG Chart 1 of RainOaxaCuajiTlaco.xls

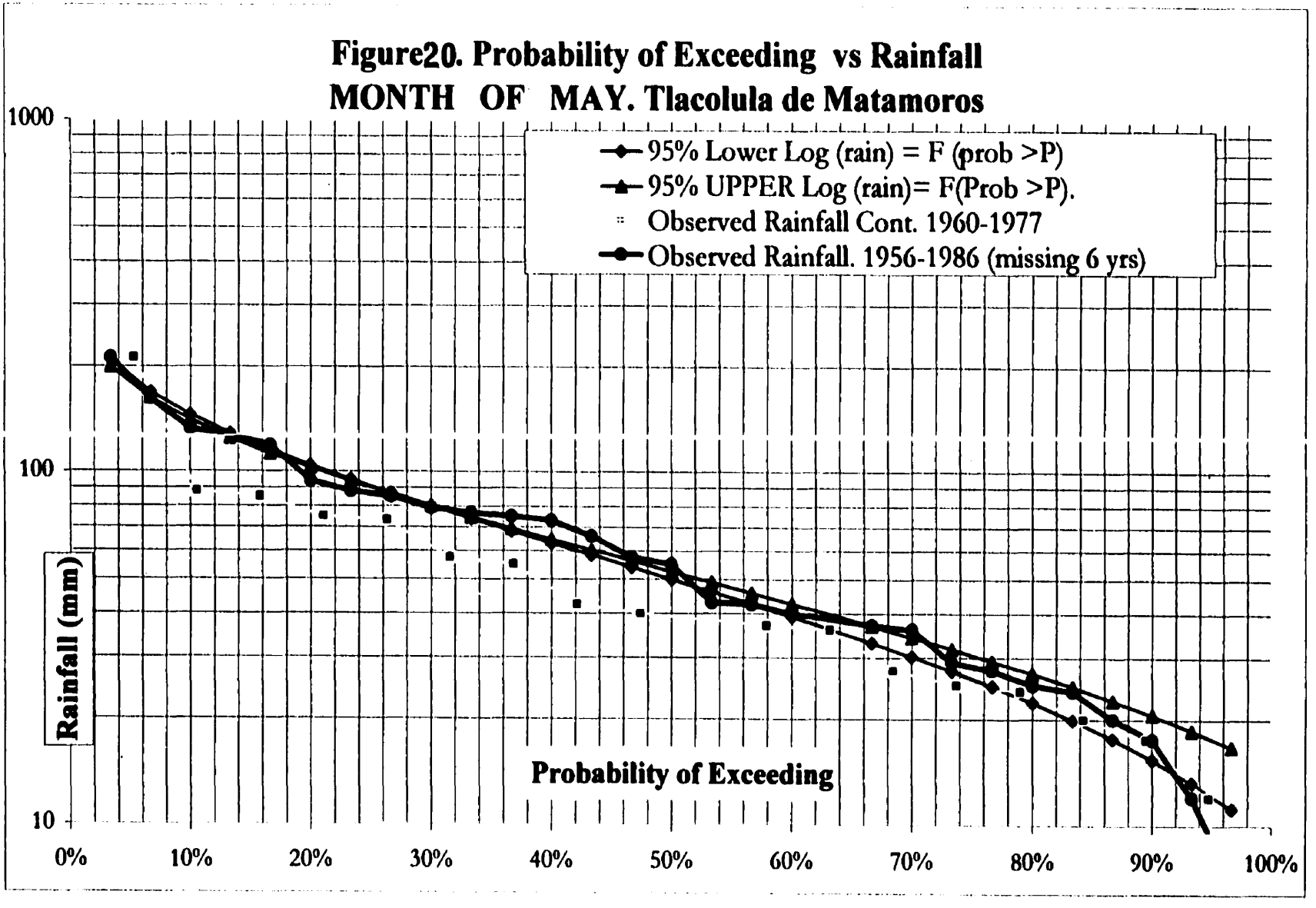
Figure 18 . Rainfall Depth in March vs Return Period Tlacolula de Matamoros.



MARCHFIG Chart 2 of RainOaxaCuajiTlaco.xls

Figure 19 . Rainfall Depth in March versus Return Period Cuajimiloyas.




Figure20. Probability of Exceeding vs Rainfall
MONTH OF MAY. Tlacolula de Matamoros
95% Lower Log (rain) = F (prob >P)
95% UPPER Log (rain)= F(Prob >P).
Observed Rainfall Cont. 1960-1977
Observed Rainfall. 1956-1986 (missing 6 yrs)
1000
100
10
Rainfall (mm)
Probability of Exceeding
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

RAINYEARTLACO.xls

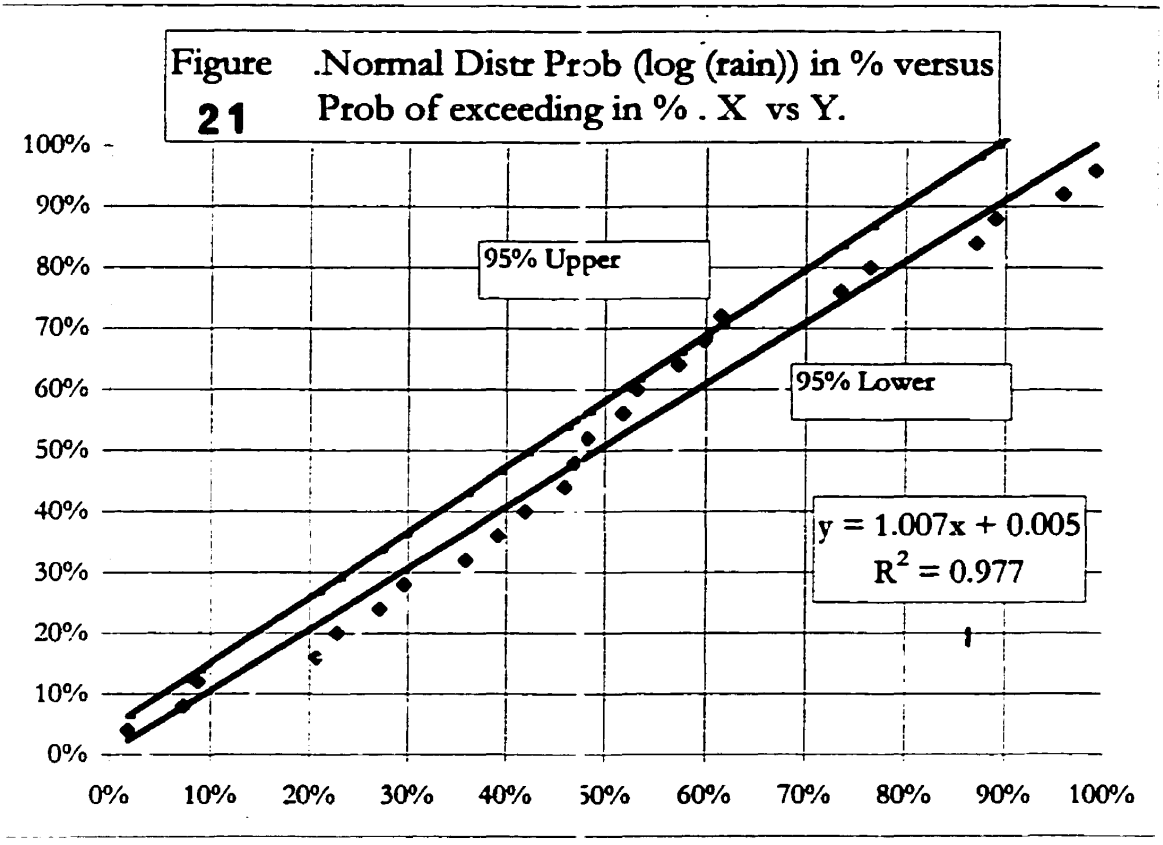


TABLE Regression Statistics . Prob of Occurrence Linearly Correlated with Normal Distr.

SUMMARY OUTPUT

24

Regression Statistics			df	SS	MS	F	Significance F
Multiple R	0.99	Regression	1	1.796951	1.7969508	918.3184	1.95492E-19
R Square	0.98	Residual	22	0.043049	0.0019568		
Adjusted R Squar	0.98	Total	23	1.84			
Standard Error	0.04	To test the hypothesis that means from observed probability and from					
Observations	24	a normal distr. are drawn from populations with the same mean .					

	Coeffic.	Stand Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.005	0.019	0.25	0.81	-0.034	0.043
X Variable 1	1.0066	0.033	30.3	1.95E-19	0.938	1.075

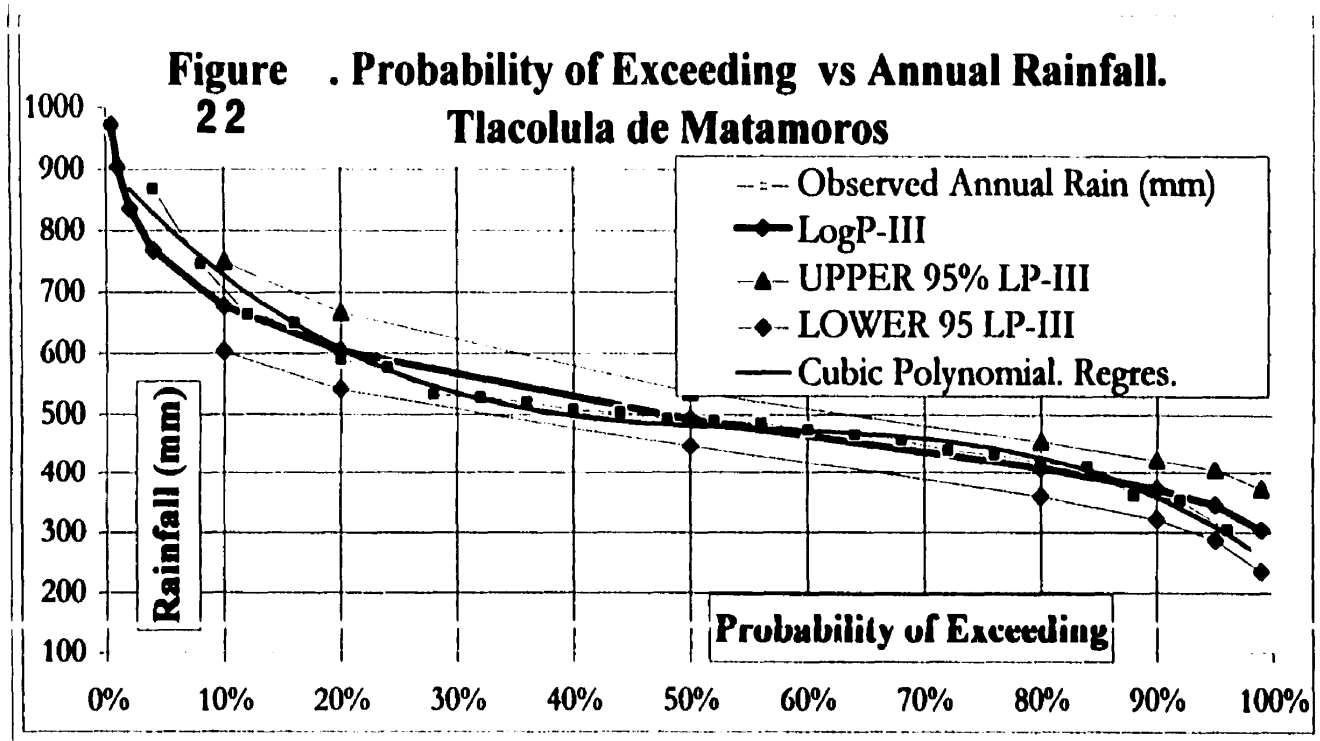


TABLE 25	Comparing Log Pearson III Distribution and Regression Polynomial Equations.							
Prob of Exc. ->	0.99	0.95	0.90	0.80	0.50	0.20	0.10	
Log Pearson	304	346	372	407	492	604	676	all in (mm)
UPPER 95	372	404	421	455	537	666	750	STD
LOWER 95	235	287	322	360	447	541	603	125.9
Poly 6	**277**	318	360	419	491	590	715	n = 24
Poly 3	260	309	359	426	482	607	728	Mean
Linear	310	327	347	388	511	634	675	511

Notes : Observed values are pratically equal to Poly 6 for which a R2 = 0.996 was obtained.
The value in bold is beyond sample range. Obtained by extrapolation.
Historical Rainfall Data 1956-1986 from S.A.R.H. Compilation by E. Perraton

normdistrplot Chart 1

Figure 23. Probability of Exceeding vs Rainfall ANNUAL. Tlacolula de Matamoros

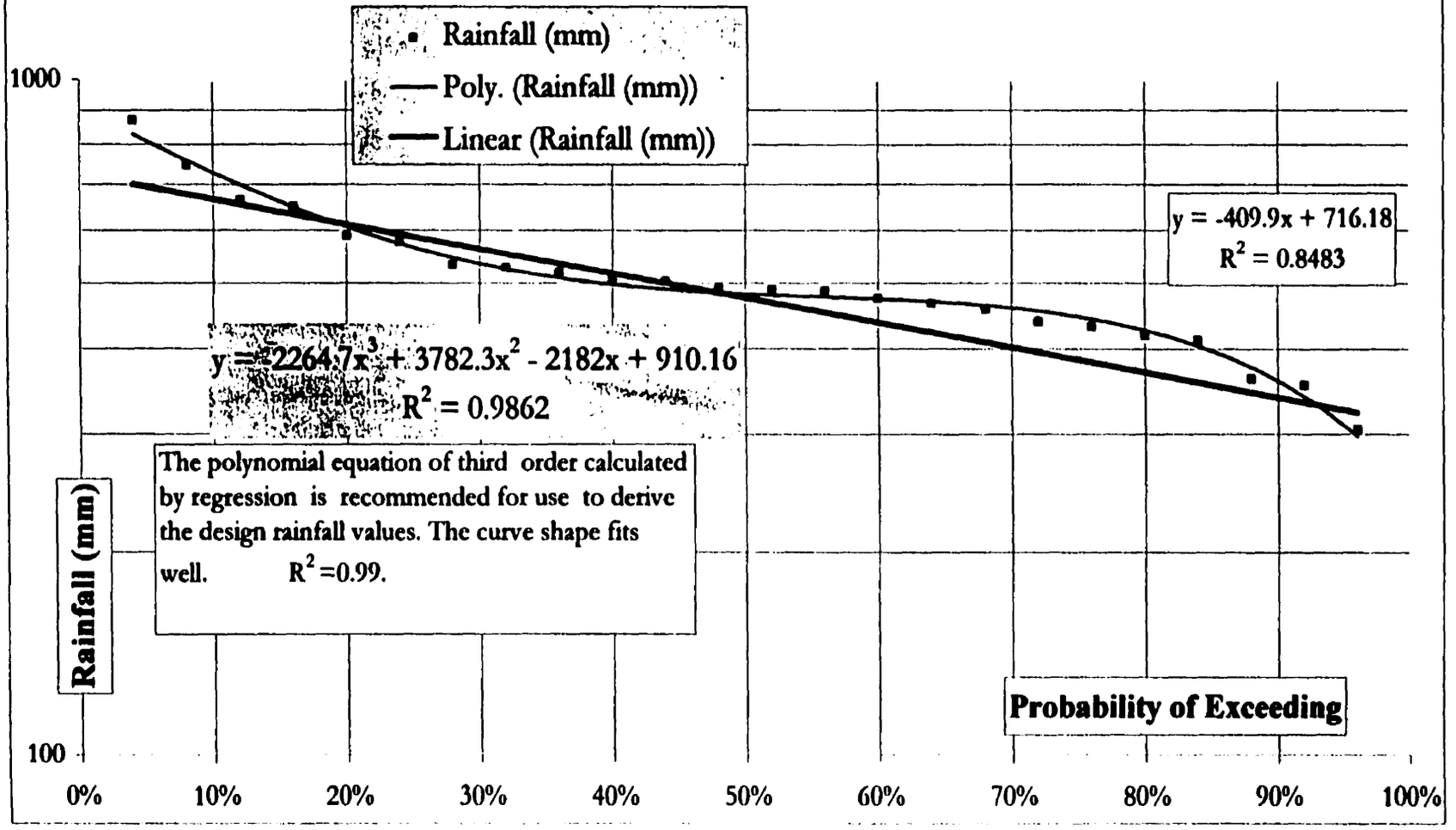


Table 26 RUNOFF FRACTION FROM BASINS UPSTREAM OF TLACOLULA

Sub-basin ID Fig p	Area [m^2]	Area Ratio	Rain Station	Average Rain [mm]	Rain Ratio	Combined ratio
37	488.6	0.004	TLACO	511	0.680	0.003
73	13,019.1	0.108	CUAJI	1022	1.361	0.147
80	310.2	0.003	TLACO	511	0.680	0.002
81	1,367.3	0.011	TLACO	511	0.680	0.008
82	1,647.0	0.014	TLACO	511	0.680	0.009
83	12,526.5	0.104	MITLA	604	0.804	0.083
84	4,400.5	0.036	MITLA	604	0.804	0.029
85	4,536.4	0.038	MITLA	604	0.804	0.030
86	1,965.1	0.016	TLACO	511	0.680	0.011
87	1,700.8	0.014	TLACO	511	0.680	0.010
Total Area ->	120,747.7			**OVERALL RATIO**		**0.332**

SEE Table 27 for Average Annual Rainfall data.

Table 27 **AVERAGE ANNUAL RAINFALL in [mm]**

Station ->	Tlacolula	MITLA	Oaxaca	Cuajimoloyas
n	24	Derived 24	24	24
AVG [mm]	511	604	751	1022
STD [mm]	126	148	144	202
CV	24.6%	24.5%	19.2%	19.8%
1981-1988		MITLA	Oaxaca	Cuajimoloyas
n		8	8	8
AVG [mm]		591	736	997
STD [mm]		153	180	179
CV		26.0%	24.5%	17.9%

Table 28 **Pan Evaporation and Rainfall data.**

OAXACA Station		Pan Evapo	Rainfall
n	------	19	19
Avg	[mm]	1962	726
STD	[mm]	115	165
CV	%	5.9%	22.7%
19 years data in period: 1954-1978 incl			

TABLE 29	IRRIGATION WATER DEMAND FOR A TYPICAL CROP SCHEME IN TLACOCHAHUAYA AREA													
			Water Demand in cm.									Water Demand		In cms.
CROP	CYCLE	AREA (ha)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL
			Water Demand in centimeter.									Water Demand		In cm.	
CORN / MAIZ	SUMMER	27.0						4.44	9.85	9.70	9.08				33.07
BEAN / FRIJOL	SUMMER	12.0						4.29	7.75	4.76					16.80
SORGHO / SORGO	SUMMER	7.0					4.13	7.64	9.93	4.63					26.33
ALFALFA / ALFALFA	SPRING	6.0	7.05	8.10	11.56	12.05	12.86	10.78	12.35	9.57	9.40	8.76	9.14	7.40	119.02
CORN / MAIZ	WINTER	20.0	10.48	12.90	14.07									6.50	43.95
PEAS / GARBANZO	WINTER	19.0	7.04	10.03	10.11										27.18
MONTHLY DEMAND		cm	24.57	31.03	35.74	12.05	16.99	27.15	39.88	28.66	18.48	8.76	9.14	13.90	266.35
MONTHLY DEMAND in % of ANNUAL			9.2%	11.7%	13.4%	4.5%	6.4%	10.2%	15.0%	10.8%	6.9%	3.3%	3.4%	5.2%	100.0%
CROP	CYCLE	AREA (ha)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL
			Water Demand in 1000 m^3 for irrigating this crop scheme											In 1000 m^3	
CORN / MAIZ	SUMMER	27.0						11.99	26.60	26.19	24.52				89.29
BEAN / FRIJOL	SUMMER	12.0						5.15	9.30	5.71					20.16
SORGHO / SORGO	SUMMER	7.0					2.89	5.35	6.95	3.24					18.43
ALFALFA / ALFALFA	SPRING	6.0	4.23	4.86	6.94	7.23	7.72	6.47	7.41	5.74	5.64	5.26	5.48	4.44	71.41
CORN / MAIZ	WINTER	20.0	20.96	25.80	28.14								0.00	13.00	87.90
PEAS / GARBANZO	WINTER	19.0	13.38	19.06	19.21								0.00	0.00	51.64
MONTHLY DEMAND x 1000		m^3	38.57	49.72	54.29	7.23	10.61	28.95	50.26	40.89	30.16	5.26	5.48	17.44	338.83
MONTHLY DEMAND in % of ANNUAL			11.4%	14.7%	16.0%	2.1%	3.1%	8.5%	14.8%	12.1%	8.9%	1.6%	1.6%	5.1%	100.0%

Source : S.A.R.H/ CADER II DIAGNOSTICO AGROLOGICO DE PROYECTOS DE OBRAS HIDRAULICAS PARA EL DESARROLLO RURAL.
Planeación General del Proyecto de Riego por Bombeo de Tlacochahuaya . September 1977.

TABLE 30 Calculations of Potential Irrigable Land.

Prob of Exceed.	Oaxaca Annual Rainfall	Annual Runoff x 1000	25% of Annual Runoff x 1000	Annual Pan Evap.	Tlacolula Annual Rainfall	NET WATER LOSSES	For 75% Net Storage STORAGE Reservoir AREA x 1000	NET Storage x 1000	Potential Additional Irrigable Area Assuming 70% Efficiency — Summer and Spring Crops CORN	BEANS	SORGHO	ALFALFA	TOTAL	WINTER Crops CORN	PEAS	TOTAL
									893	202	184	714		879	516	3388
									27	12	7	6		20	19	52
	mm	m^3	m^3	mm	mm	mm	m^2	m^3	ha	ha	ha	ha	ha	ha	ha	ha
0.8	567.4	0.0	0.0	1962	388.3	1573.7	0	0	0	0	0	0	0	0	0	0
0.7	617.1	7186.3	1796.6	1962	429.3	1532.8	293.0	1347.4	25	11	7	6	49	19	18	37
0.6	666.7	20040.8	5010.2	1962	470.2	1491.8	839.6	3757.7	71	32	18	16	137	53	50	103
0.5	716.3	32895.4	8223.8	1962	511.2	1450.8	1417.2	6167.9	117	52	30	26	225	86	82	168
0.4	766.0	45749.9	11437.5	1962	552.2	1409.8	2028.2	8578.1	162	72	42	36	312	120	114	234
0.2	865.3	71459.0	17864.8	1962	634.2	1327.8	3363.6	13398.6	253	113	66	56	488	188	178	366

Figure 24 Oaxaca Annual Rainfall versus Salado River Runoff

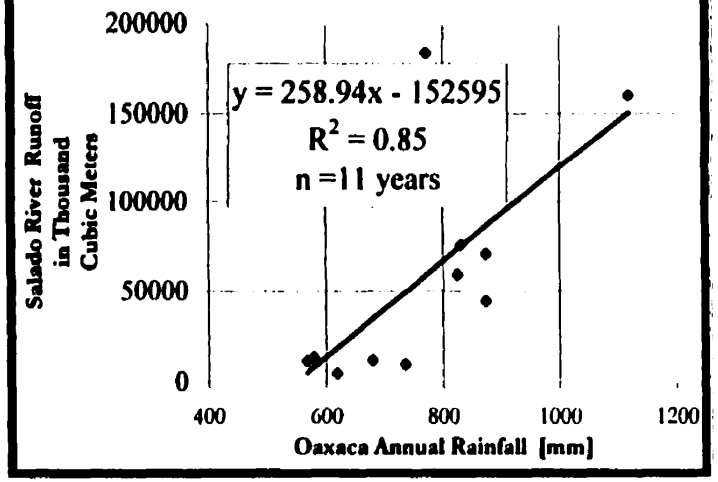
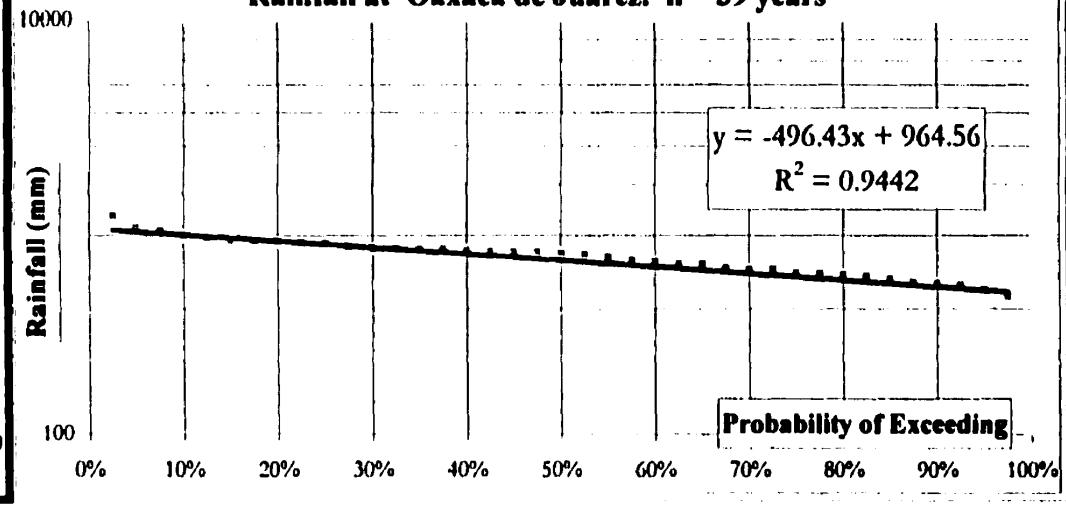


Figure 25 Probability of Exceeding vs Annual Rainfall at Oaxaca de Juarez. n = 39 years



CHAPTER V
THE SURFACE WATER REGIME

Introduction

The preparation of an aquifer flow model demands the quantification of water passing through each phase of the hydrologic cycle (precipitation, infiltration, runoff, evapotranspiration, groundwater recharge and abstraction), and a periodic accounting of the water storage in the soil, in surface reservoirs, and in groundwater reservoirs. To C.N.A what is more required today than the information derived from technical engineering studies is a scientifically rigorous investigation of the data available. First a review of the main characteristics of the Tlacolula sub-basin is presented.

The Rio Verde Watershed

Table 1 shows the main characteristics of the watersheds of the state of Oaxaca. The research area defined by the Tlacolula sub-basin is part of the Rio Verde watershed, the largest of the watersheds of the Oaxaca State. The Tlacolula sub-basin with an area of 1200 km^2 represents slightly more than 9% of the watershed.

The Tlacolula River

The central valleys of Oaxaca are drained by two rivers: the major river Atoyac, which flows north-south and its effluent: the river Salado[1] also called the Tlacolula River. The aquifer is composed of lightly consolidated clastical sediments which also form the deposits in the rivers Atoyac and the river Salado with its respective effluents.

Teitipac Area

This area is the western bulkhead of the Tlacolula Valley, the opposite side of the mountains from the eastern Valle Grande. This area is characterized by rugged limestone and volcanic mountains, dry piedmont with no large streams. In the north, the low piedmont grades into the alluvium of the smaller Rio Salado. In the south, next to San Juan and San Sebastián Teitipac, are two important basins with high water tables which according to Kirkby (1973) have existed throughout the prehispanic era. The low piedmont next to this alluvium, or the *bajíos (*bottomlands*)* at the Teitipacs, have

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[1] The Rio Salado given in Table 1 is NOT the Rio Salado located in the research area.

been at all times the preferred locations for agricultural or cropping activities. The Teitipac and eastern Valle Grande mountains have remained an important source for building stone and lime.

Northern Tlacolula

On the northern side of Tlacolula, the piedmont rocks are volcanic, with some older metamorphic still visible in the west. Kirkby (1973) identifies the limestone peninsula above Santiago Ixtaltepec, as the home of masonry and the rocky hills, at Tlacochahuaya, Macuixochitl, and east of Abasolo as composed of intrusive volcanics. These geological features were quickly located in the research area. Three of the four permanent, at times torrential-streams, fed by the Sierra Cuajimoloyas watershed reported by Kirkby (1973) flow within this research area. One flows through Tlalixtac de Cabrera, one through Teotilán del Valle , and one through Diaz Ordaz. The well-watered area north of Caballito Blanco is one of intensive agriculture with greater potential than its present level of exploitation.

Southern Tlacolula

On the opposide side of Tlacolula, the smaller Sierra Magdalena offers less runoff, and rainfall is less than on the northern side of the Valley. Almost all the land consists of residual soils that are dry, with a stony surface that slopes for four to five kilometers from the base of the mountains to the floodplain of the Salado. Only dry farming is possible here, and many farmers opt for raising maguey instead of corn. Kirkby (1973) reports several good spring-fed arroyos allowing irrigation farming on limited areas of the middle and high piedmont, at surprisingly high elevations but the agricultural technicians of Tlacolula District are unanimous, these streams are now most of the time dry and of no irrigation use anymore. San Bartolome Quialana has till today irrigation possibilities but on a small scale.

Tlacolula Alluvium

The main feature is the Río Salado's disappearance as a channelized river. The Salado begins with the waters from Río Grande de Mitla and the Díaz Ordaz tributary. But just east of San Juan Guelavía the channel is lost, and actually the stretch from

Lambityeco westward becomes more and more a seasonal marsh. Kirkby (1973) reports that salt deposits along this part of the river have been exploited recently and in the archaeological past.

Between San Juan Guelavía and San Sebastián Abasolo, a distance of six kilometers, water floods a broad area. It stands for months at a time after the beginning of the rainy season. Because of the hard-to-work clay soils, salt accumulation, and excessive water, much of the land has remained abandoned for agriculture since Kirkby (1973). Smith (1978, as reported by Kowalewski et al, 1989) gives evidence that in ancient times, there were fully developed groves of thick-trunked, tall mesquites that probably covered the valley floor. Kirkby (1973) describes the same area as nasty, brutish, short, dense, claustrophobia-inducing tangles of *huisache* and other low, spiny trees. The problem of soil and ground water salinity in this area is discussed in Chapter VIII.

Below Abasolo there is a channel once again, today regularized by a Recursos Hidráulicos project. The bottom lands from this point to the junction with the Atoyac are fairly fertile. With the high water that comes during rainy seasons, field and road drainage systems in this area can not prevent destructive flooding every year or so.

Mitla

The drainage of the Río Grande de Mitla is a pocket surrounded on three sides by mountains. For a tributary it has a broad piedmont, and the stream is fairly reliable. The surrounding volcanic tuff mesas are pocked with caves (archaeological survey by Kowalewski et al, 1989) and provide excellent building stone. Floodwater farming along the Río Grande is practised in the piedmont. The storage dam constructed east of Mitla near Guadalupe Victoria has not resisted the peak flood. Kirkby (1973) relates the highly reflective, whitish surface without much vegetation of the floor of the Mitla valley to the undurated sand described by Flannery (ed. 1970) as less heavily eroded since the Pleistocene than the piedmont elsewhere in the Valley and covered with less alluvium. The archaeological implication according to Kowalewski et al (1989) is that Mitla piedmont is the only place in the Valley with preceramic sites visible on the surface. The agriculture is however limited to restricted spots. The

vegetation is xerophytic , including among the predominant species *maguey, órgano, Jatropha, and huisache.*

Matatlán

The dry southeastern corner of the Tlacolula , extending from east of San Lucas Quiavini to Matatlán, receives according to Kirkby (1973) less rainfall than any other part of the Valley. This however could not be substantiated with meteorological data. Its arroyos, having little catchment, are almost always dry, except for the Río Matatlan which usually seeps under loads of maguey waste from the town's mescal distilleries. Maguey fields far outnumber milpas, and uncultivated lands are even more common. Erosion is severe, especially on the San Lucas Quiavini's slopes.

Historical flow measurements of the *Rio* Salado

The period with flow measurements was from 1978 to the first three months of 1992. Due to financial constraints these measurements were stopped in April 1992 and discontinued since then. Most of historical flow data were measured daily except for a few storms where two measurements on the same day were taken

These flow measurements were taken with a calibrated molinet. Once a year however for about a month the molinet was sent to Mexico D.F. for calibration and maintenance. This was done during the period of lowest runoff usually in February. There was an exception in 1986 where the molinete was returned after ten weeks which resulted in February and march missing data in 1986. During the annual maintenance period, flow measurements were usually stopped. This explains the cyclic break in the data set.

The person in charge of flow measurements usually goes on rest every seven days. This implies some interpolation is required for compiling monthly totals. In cases when a storm was taking place, the interpolation for generating missing data was not done linearly but rather by rational deduction from historical runoff measured at the same station in a sequence of similar rainfall events. In these cases the level of uncertainty was assessed and a note was added to the cell. Compiled statistics of Salado River Flow measurements are given in Table 2. The number of measurements

and number of interpolated values to compile the monthly total are also given in the Table 2. All notes added to the cells for cases where an assessment of minimum and maximum generated missing values was deemed to be required, are also printed out at the end of the Table.

Investigating the effects of interpolation on Flow measurement Statistics

The need for generating missing data for the days with no flow measurements was investigated. Table 3 shows the impact of missing data generation on total monthly runoff . The year 1978 is examined as a typical year. It is not representative however of the months with highest difference on runoff when comparing monthly total runoff with and without the generated missing data values. For this, we shall examine the months of May 1984, July 1985, July 1987, June and September 1988.

The number of days with missing data is certainly significant but not the major factor. In March 1978 there were 19 days when no flow was measured but this took place in the dry season. In March 1978 the average of the twelve days with flow measurements is 0.033 m^3/s . After interpolation of missing data , the average river flow of the 31 days becomes 0.035 m^3/s. The overall impact (| with - without generated data for missing days |) in March 1978 is therefore 0.5% only.

The impact of generating four missing data in July 1985 on the monthly total runoff is estimated to be around 11%! In May 1984 eight data are missing . The impact of generating the missing hydrometric data of May 1984 is around 30% of the most probable monthly runoff.

Rain is the obvious major factor that will dictate how important a missing day may be. This is why, the missing data has a minor impact in the dry months (less than 1.5%) whereas for the wet season this impact is generally in the range of 8% to 11% but may be as high as 30%.

The question of how reliable are the eight data generated in May 1984 demands an answer. In Table 4 the probable error magnitude on each of these eight data points is shown. This assessment of the error associated without the generation of the missing data is arbitrary. In the case of linear interpolation it is function of the boundary values that define the interpolation. A one day interpolation is not a guarantee

for accuracy. On the twelfth of May the flow that was measured was at a minimum, that is 0.049 m^3 /s. On the fourteenth it was 0.726 m^3 / s and on the following day it peaked at 19.023 m^3/s for a few hours.

Table 3 shows that ignoring the missing data results in a 30% over-estimation of the total runoff for the month of may 1984, whereas generation of missing data can limit this error to about 1.5%. The error estimate on the total runoff for the month of May 1984 when adding possible measurement errors to the uncertainty in generated data is most likely around 4% of the total runoff. Table 5 shows how the error estimate on monthly runoff that can be normally attributed to a measurement error, was estimated.

Two main sources of measurement error are examined those are: a possible error of scale reading and a possible error on the water average velocity due to a measurement error with the calibrated molinet.

A reading error in the order of 15 mm on the scale is a reasonable possibility. The scale was read with an accuracy of 0,01m, but reading could not be done at level and the water was not still. The molinet that was used for more than 12 years could not be tested since it had been replaced by a new one since then. According to the operator the accuracy of the new molinet is about the same as the old molinet. The new molinet (Price type) has been calibrated to translate the number of revolutions per minute to a linear average water velocity in m/s. A regression analysis was carried out on the calibration data and the results are shown in Table 6 .

The molinet was tested on the Arroyo Seco at locations 7 and 8 shown on Figure 9 and it was found that when combined to a light/or a sound beeper, counting the number of revolutions up to 30 rpm was relatively easy. For faster rpm however an error in calculating was often made. A solution to this problem was to take the average of at least three readings but as this was confirmed by the operator, in normal routine two readings are taken.

To be on the safe side it was therefore assumed that a reading error of 3% could be easily made on the calculated number of revolutions per minute (1 rpm per 30 rpm) . This error on the rotation was converted to a linear velocity using the 95%

confidence interval obtained on the regression coefficients as given in Table 6. The result in Table 7 is a 95% Confidence interval on the linear velocity when a reading error of 3% is added to the error estimate on the regression coefficients obtained from the calibration of the molinet

The error estimate on the linear velocity as obtained in Table 7 was used in Table 5. By converting the error estimate on the scale reading into an error on the cross-sectional area, the product of the error estimate on the linear velocity and the error estimate on the cross-sectional area gives the corresponding error estimate on the discharge. For this the river stage area rating curve was plotted from the cross-sectional survey data and expressed as Area = f (scale reading). Figure 1 shows the river stage area rating curve that was obtained.

By plotting the hydrometric data obtained in calibrating the stream gauge as shown in Figure 2, the river stage discharge rating curve is then expressed as Q = f(scale reading). The scale reading error can then be converted directly to an error on the discharge. The latter method compares favorably with the error on the discharge estimated as the product of the error estimate on the linear velocity and the error estimate on the cross-sectional area.

In either approach the error estimate on the accuracy of the discharge rating curve is not accounted for. This is no probably the greatest error of all..

Correlating Rainfall And Runoff

Table 8 shows the monthly rainfall observed at the stations of Cuajimoloyas and Mitla for the year 1978 and the period 1980-1988 and for the year 1978 and the period of 1980-1989 at the station of Oaxaca. The monthly runoff for the same period is shown in Table 8. The same data but this time on a yearly basis is shown in Table 9.

Weights of rainfall station and antecedent precipitation indexes for best correlation of rainfall versus runoff were found by trial and adjustment after multiple linear regression analysis on the weighted monthly rainfall versus the monthly runoff measured at the junction Atoyac-Rio Salado. Results are shown in Table 10 and in Figures 1 and 2.

Figure 5 shows the cumulative weighted rainfall versus the Cumulative Log_{10} Flow. The value of the coefficient of determination , R^2 is equal to 0.85. This implies that only 15% of the total sum of squares corrected for the mean is not explained by the regression equation shown on Figure 5. This indicates a close linear relation between the Log (cumulative Flow) and the weighted rainfall. When the cumulative rainfall recorded at Oaxaca is considered instead of the weighted rainfall, the coefficient of determination is lower; R^2 is then equal to 0.78. This is shown on Figure 6. The regression equation is slightly improved when Cuajimoloyas cumulative rainfall is linearly related to the Cumulative Log_{10} Flow. The coefficient of determination R^2 is then equal to 0.81. This is shown on Figure 7.

Morphology of the Tlacolula River basin.

The entire area of the basin whose surface runoff (due to a storm) drains into the river of the basin is considered as a hydrologic unit and is called drainage basin. Some useful relations based on the inter-relationship between the hydrologic character of a watershed and its physical character have evolved, but Linsley et al (1975) conclude in a relative inability so far to relate closely the physical and hydrologic features of watersheds. Linsley et al (1975) identified two basic reasons why tools for predicting hydrologic response from measurable physical features are more qualitative than quantitative;

1. the limitation by available maps which are compiled at different scales and to differing cartographic standards so that some physical descriptors may not be equivalent and
2. the complexity of the relationship between the essentially static physical features of a basin and the highly stochastic hydrologic characteristics.

This cartographic limitation has been reducing with the establishment of geographic information systems (GIS). A spatial map layer defining sub-basin boundaries and drainage network can be constructed from digital elevation data derived from a topographic map. This method based on waterflow paths over a land surface has the advantage that the flow-time from each point on the watershed can be calculated. A

time-area layer is then obtained in the GIS from which can be derived isochrones for any selected time intervals. This approach was taken by Chieng and Luo (1993).

The drainage sub-basins and main drainage networks are shown on the hydrogeology map prepared by S.A.R.H in 1979. It was used for preparing a base map layer for drainage sub-basins.

Justification for doing so does not rest on anticipated advantages over the method using digital elevation data but rather on the need for a verification of the correctness of the information given on the morphology of the Tlacolula River basin in the hydrogeology map.

Given the high cost of reproduction for scanning large size color maps and the relative simplicity of the information given on the hydeogeology map, it was decided to trace the map on Mylar sheet and to scan the traced base map copy at a resolution of 16 dots per mm. A Monochrome Bitmap image file was obtained. This brought the cost down considerably without loss of the information.

The image file was saved in a Tagged-Image File Format (TIFF) that is used to exchange documents between applications and computer platforms. The image file was then imported into Adobe-Photoshop environment.

Two maps were then prepared from the scanned geology map. A base map of drainage basins and a geology base map. After adding colors to the geology scanned Black and white map[2] as per the original color codes of the geology papermap. The resulting image map file was then saved in a TIFF format that can be read by Windows systems. The map with the drainage basin and the geology map were then calibrated to the scale of the 1:50 000 topographic base map. The calibration of the drainage basin base map was done on the basis of the overall watershed boundaries .

Table 11 shows the detailed calculations for calibrating the Salado Drainage Basin Map. The drainage sub-basins were delineated on the basis of the river network .

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[2] Only the main steps of the procedure are given here. Steps such as converting the Monochrome bitmap to a gray tone map and then to an indexed color map and creation of the palettes are not discussed since these are inherent to image file editing process.

A map with the river network was then archived for later use. Figure 8B identifies all sub-basins of Salado River. Table 12 gives the area of each sub-basin as calculated by IDRISI on the basis of our color code. Table 12 combined with Figure 8 allows the manager to visualize quickly the size and corresponding aspect of the drainage network of each sub-basin.

This drainage basin map layer is incomplete in terms of both the information content and registration of the sub-basins. This is unavoidable since the impact on water resources is not the same for all sub-basins. The second largest sub-basin identified as number 73 in Figure 8b drains a basin of approximately 13 000 hectares. Because of its impact on the quality of the groundwater this sub-basin will call the manager's attention more than all other sub-basins.

Freeze and Zapf-Gilje (1988) recognize this reality for the manager where data worth must be calculated in the context of how it will impact the manager's decisions between alternative designs.

Two topographic maps of standard 610 x 914mm at the scale of 1:50 000 were required to cover the research area . These two topographic maps identified as (E14D58) and (E14Dd48) were glued together and scanned at a resolution of 16 dots per mm. Later, a third topographic map identified as E14D59 was added to form a mosaic of three topographic maps to cover the eastern boundaries of the watershed. The watershed divides were then drawn in pencil directly on the topographic paper maps. The area of the watershed of the Rio Salado was planimetered. This area was going to be the quality control of the scale of the drainage basin base map.

Calibration of the topographic "raster" map is crucial since the calibrated topographic map of the research area serves as the base map for scale control , proper orientation, and proper setting of a common grid system. The procedure used for scale control and delicate setting of the grid system on the raster topo map that was to become our computerized base map is discussed in Chapter III. The calibration procedure for the geology map, the soil map, the agricultural production map and the map with drainage basins was done differently than for the topographic raster map. This procedure is now discussed.

In order to have a common scale and unlimited overlaying possible, the basic image boundaries of all maps need to be the same. Table 13 shows the calculations that are required to derive these common image boundaries. Logic demands that once the image size has been set for each raster map to be displayed at a same common scale (say 1:50 000) then in order to cover all paper maps, the greatest of the lowest boundaries of these maps are to be set as the new boundaries for each raster map.

This of course gives a canvas size that may look exaggerated for the raster map that covers the smallest area but this is needed for unrestricted image overlaying capabilities. Now to ensure a perfect fit and a single common XY grid system, two multi-channel image files were created within Adobe Photoshop software[3] environment. Those files and their channel layering system is defined in Table 14.

CALIBRATION was done using the top layer (the topo map) as the reference. A few words about layers and channels may help to visualize the process.

In a new Adobe Photoshop document, the image consists of only a background. The background can be thought of as the canvas under a painting. One or more layers can be added to the document.

Layers can be visualized as transparent sheets of acetate that are stacked on top of the background. All layers in a document share the same number of pixels, the same number of channels, and the same image model -- for example, the Red Green Blue model which depends on a light source to create color or the CMYK model which is based on the absorbing quality of four inks: cyan (C), magenta (M), yellow (Y), and black (K), CMYK, or the Grayscale model which uses up to 256 shades of gray to represent the image. In Adobe Photoshop, every pixel of a grayscale image has a

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[3] The software Adobe Photoshop. ©1989-1995., Adobe Systems, Incorporated. was used here because of its flexibility in working with large files and with a large variety of Image Formats. Corel Draw © 1988-1993 Corel Corporation offers the same advantages and was used successfully but had the inconvenience of more frequent file swapping slowing down editing operations. This problem however is likely corrected through a simple adjustment of the Windows variables of environment. Use of brand names in this thesis is for identification purposes only and does not constitute endorsement by the author.

brightness value ranging from 0 (black) to 255 (white). The values between 0 and 255 correspond to points on the grayscale spectrum.

A **channel** is the foundation of an image and is analogous to a plate in the printing process. Channels are basically used for creating masks that isolate part of an image. Some image types have only one channel; while other types have several channels. An image can have up to 16 channels.

A channel can be copied to another Adobe Photoshop document. Channels can be combined to form a single image. A number of operations on the channels can be performed on the corresponding pixels of two channels; that is, the pixels that correspond to the same location on the image.

In this research registration [4] of map layers was done within the Adobe Photoshop environment by means of trial and adjustment operation on map raster copies saved as 8-bit alpha channels. In Adobe Photoshop , the created channels are 8-bit grayscale representation of an image and are called alpha channels .

The registration rests on one common base map that is here the topographic raster scanned from the Topographic 1:50000 INEGI maps E14D48 - E14D58 - E14D59.

The calibration[5] consists in back and forth visual fits of the layer channel under calibration with the common topographic base map. This control topographic map appears as Channel 3 in Table 14.

The order of the channels can be changed anytime to view the channels more easily but its name and characteristics can not be modified.

A color for the mask of each alpha channel must be selected. A red mask works generally fine. However, the setting on the opacity of the mask itself to change

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[4] Registration is the procedure used to accomplish this adjustment of one data layer so it can be correctly overlaid on another of the same area.

[5] Here calibration is understood as the calibration of the maps to a common scale and grid system. This is not to be confused with the Adobe Photoshop calibration that is the process of adjusting the monitor and the Adobe Photoshop color conversion parameters to compensate for various factors that affect both the on screen image and

the appearance of the mask by revealing more or less of the underlying image is the most important feature of alpha channels. .

The top layer is here understood as the top channel listed by Adobe Photoshop which offers Red Green Blue (RGB) format capabilities whereas the alpha channels offers a starting platform set as grayscale [6] images. To accommodate these requirements a grayscale image of the topographic base map was created and maps were calibrated one at a time reserving the top layer for the final calibrated map in its indexed color format. The grayscale image control (our raster topo map) was saved in an alpha channel. A grayscale copy of the map to be calibrated was saved in an additional alpha channel.

When Adobe Photoshop converts a color image to grayscale, it discards all color information in the original image. When converting from a RGB mode, a Cyan - Magenta.- Yellow - Black (CMYK) [7] mode , or a Multi channel image, the gray levels of the converted pixels represent the luminosity of the pixels.

The calibration process at any stage of scale setting, rotation and translation of the map to fit the common base map and final tuning is all achieved visually the same way. The scale is the first step. Rotation of the map should not affect its scale and therefore control points that can be zoomed at in both layers, are selected from the map to be calibrated and from the control topo map. Let us call the map to be calibrated (GEOMAP) and the control map (TOPOBASE). A channel is created for the intermediate calibration steps. That channel is discarded at the end. It consists for the moment in a simple black canvas of same size as the control map. A line is drawn between the selected control points. The railway track served as convenient control points in this research.

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its conversion to printed output. The monitor was calibrated as per Adobe Photoshop calibration procedure.

[6] A grayscale image consists of various levels of gray. Depending on the number of bits of information saved when the image was scanned, a grayscale image can contain up to 256 levels of gray. Gray levels can range from 0 (black) to 255 (white).

[7] The CMYK mode is used when preparing an image to be printed using the process colors Cyan, Magenta, Yellow, and Black

The line control segment is compared and a length ratio measured in pixels defined our first guess of image size contraction or enlargement required for setting the control scale onto the map to be calibrated. The image size of GEOMAP is changed accordingly and saved under a new name say GEOMAP1. The new image file GEOMAP1 has all the same attributes as GEOMAP but a different size. The top layer GEOMAP is replaced by GEOMAP1. A slightly larger area than the image size on top layer is then selected and translated until one control point coincides with the corresponding control point on TOPOBASE.

Advantage is then taken of the fact that the area selected on the top layer with the marquee remains selected until it has been un-selected. The selected area is therefore rotated in a trial and adjustment process by varying the angle until the best fit is obtained. This is possible by undoing each angle rotation until the angle given the best fit is obtained. This way the exact rotation angle and scale ratio that needs to be applied to GEOMAP to visually best fit the reference base map TOPOBASE were quickly found.

These operations must be conducted and documented in such a way as to be repeated if desired. Proceeding with free hand angle rotation is not recommended because it can not be documented since the angle of rotation is not displayed. However, if the intermediate steps of scale control, translation and rotation do not need to be documented because the final calibrated map can be validated, these steps can then be performed by taking advantage of the free hand angle rotation and the related features.

In any case, one step will not be documented unless use of the rulers is made or a trial and adjustment process is used as in the case of the rotation. That is the final translation. This is not necessary if a copy of the original non calibrated file is archived as well as a copy of the calibrated file map. A third copy will be required that is the edited version of the calibrated map.

TIFIDRIS module of IDRISI for Windows was used to convert from TIFF to IDRISI for Windows or vice versa. TIFIDRIS will present a summary of the file characteristics as it completes the conversion. Any included palettes are converted.

In converting from IDRISI for Windows to TIFF, the name of the IDRISI file and of the palette to be exported are specified. The page resolution was usually set to 8 dots/ mm (200 dots per inch).

After calibration, conversion from TIFF to IDRISI for Windows is carried out with TIFIDRIS module followed by the documentation of the base map image files which is easily accomplished since every base map image is now assigned the same minimum and maximum X, Y as those set for the topographic base map.

Need for hydrometric stations

Based on the hydrologic analysis, five additional hydrometric stations strategically located within the research area, were proposed to the C.N.A. A visual survey of proposed stations was carried out with a technician assigned to hydrometric measurements and five locations for stream gauging were retained . The survey of the cross-sections was carried out by the same crews who conducted the surveys for positioning the 142 wells for observing groundwater fluctuations. The surface float method was used for this first reconnaissance work

Parker (1940) regards the surface float technique as a valuable tool in reconnaissance work, when time, material and labor for the more accurate systems are not available. To obtain any real degree of accuracy the method of surface floats requires that the ratio between surface and mean velocities be determined by more accurate methods such as systematic sounding with current meters.

If the cross section is uniform and the stream bed relatively constant, these measurements may be taken at the manager's convenience . Until then the selection of a multiplier in order to reduce the observed velocity to the mean velocity is necessary.

No constant ratio exists between the mean velocity over the whole cross-section and the maximum surface velocity or the mean of the surface velocities. Grunsky (as reported by Parker, 1949) finds that in sandy bottoms this ratio depends only upon the ratio between the width of the stream and the mean depth of the stream. Grunsky's ratios (as reported by Parker, 1949) were used in converting surface velocities to mean channel velocity. Parker(1949) 's refinement of these ratios to take into account the additional roughness of gravelly beds was also taken into consideration.

Effects of Gross Errors

Where no explanation can be found for an anomalous observation, the case for rejection is doubtful. Cochran (1947) shows some concern about discarding outliers. In his opinion, habitual rejection of outlying values leads to a marked underestimation of errors.

What is wanted is a test appropriate to the largest contribution of any observation (discarded outliers). Cochran recommends the following procedure. Calculate the significance probability, *p*, by the ordinary Student "t" table. Then use as the correct significance " *np* ", where *n* is the number of degrees of freedom in the actual error. This method was used.

Figures 10, 11, 12, 13 and 14 show the stream discharge rating curves obtained by the surface floating method at four out of the five stations proposed for hydrometric measurements and identified as No. 1, 2, 3 and 4 on Figure 9. At the bottom of Figures 10 and 11 are given in a tabular form the statistics that lead to the discarding of two outlier values after applying Cochran 's (1947) method.

Figure 12 shows the upper and lower limits of the stage discharge rating curve based on hydrometric measurements taken at station 2. When two measurements taken at Station 4 are discarded as outliers, a good linear fit is obtained for the discharge rating curve shown on Figure 14A.

Figure 13 shows however that no simple linear model could fit the measurements taken at Station 3. The cross section was found to be variable in time as a result of obstruction created by some garbage material thrown away on the left bank of the river by people who may have been given no other choice. The local contamination of the groundwater needs to be investigated and the hydrometric station must be shifhted further upstream. Stations 7 and 8 where the current meter was tested are recommended to replace Station 3.

The simple plot of stage versus discharge leads to a curve that is approximately parabolic but may show some irregularities (Linsley et al., 1975). The fact that a linear fit was found to be a good predicting model for three out of the four stream discharge rating curves is not in contradiction with the usual parabolic shape of the plot of stage

versus discharge. It is a direct consequence of the limitations of the surface float technique .

For the same reason, the surface float technique does not offer sufficient accuracy to justify additional hydrometric measurements form an auxiliary gage to account for the variations in discharge caused by rising and falling stages. Parker (1949) estimates that the difference in discharge caused by rising and falling stages does not generally exceed 5 or 7 percent.

The surface float technique is only approximate but has proved to be a valuable tool for making a selection of reliable hydrometric stations for better quantification of the surface water regime.

Parker's (1949) conclusion that the surface float technique is very useful when it is occasionally and systematically checked by more accurate methods, has found support in this research.

CUENCAS.xls

TABLE 1. Characteristics of the watersheds in the state of Oaxaca

Watershed	Area	Average Rainfall	Avg. Annual Runoff	% of Area in the state.	Runoff Coeff.
	(km^2)	(mm)	($x10^6 m^3$)	%	
Alto Balsas	8998	800	1079.76	21.9	0.15
Alto Coatzalcoalcos	8254	2036	11595.54	98.8	0.69
Bajo Coatzalcoalcos	1573	2510	2147.1	9.1	0.54
Rio Verde	18464	1366	7112.55	100	0.28
Costa de Oaxaca	8594	1710	3673.93	100	0.25
Rio Tehuanteoec	13186	800	1582.32	100	0.15
Istmo de Tehauntepec	6970	1090	1519.47	100	0.20
Rio Salado	3122	493	230.87	89.6	0.15
Rio Grande	4830	708	1309.72	100	0.38
Rio Santo Domingo	3516	3884	6828.07	100	0.50
Rio Tonto	3291	3639	4586.79	61.4	0.38
Rio Obisbo	560	1908	409.22	31.7	0.38
Rio Tesechuacan	3713	2038	2898.19	58.4	0.38
Rio San Juan	3690	1841	2717.32	39	0.40
Mal Paso	1744	1351	706.84	16	0.30
Costa Chica deGuerrero	4859	1650	1667.61	23.9	0.21
T O T A L	95364	1739	50065.3		0.30

Source: Comision Nacional del Agua. Gerencia Estatal en Oaxaca.
Programa Estatal De Aprovechamiento del Agua. Dic. 1992.

IMPORTANT NOTE: Rio Salado here given IS NOT the Rio Salado in the Research Area. The Tlacolula Sub-basin defines the basin considered in this Research . The Tlacolula Sub-basin is at the upstream east boundaries of the largest watershed of the Oaxaca State, the Rio Verde.

The Tlacolula Sub-basin is 1097 km^2 , its watershed Rio Verde 18 464 km^2

runoff1.xls

	B	C	D	E	F	H	I	J	K
1	TABLE 2A STATISTICS of SALADO RIVER FLOW at ATOYAC JUNCTION.								
2	MONTH	# aforo	# aforo	No. of	No. of	Average	STD	CV	TOTAL
3	-Year	Start	End	measur.	interpol.	m^3/s	m^3/s	%	X 1000 m^3
4	Jan-78	1	27	26	5	0.07	0.04	50%	170.8
5	Feb-78	27	51	24	4	0.07	0.04	51%	169.9
6	Mar-78	51	63	12	19	0.04	0.03	75%	96.0
7	Apr-78	63	88	25	5	0.03	0.02	61%	89.2
8	May-78	88	115	27	4	0.07	0.07	103%	188.8
9	Jun-78	115	143	28	2	3.36	5.52	164%	8698.9
10	Jul-78	143	170	27	4	0.65	1.12	173%	1733.0
11	Aug-78	170	197	27	4	0.24	0.21	86%	653.7
12	Sep-78	197	225	28	2	4.33	8.19	189%	11215.2
13	Oct-78	225	253	28	3	1.23	1.55	126%	3299.3
14	Nov-78	253	279	26	4	0.12	0.05	40%	306.6
15	Dec-78	279	306	27	4	0.10	0.07	70%	270.2
16	Mar-79	52	60	9	0	0.04	0.00	5%	incomplete
17	Apr-79	60	84	25	5	0.19	0.25	134%	489.9
18	Jan-80	1	28	27	4	0.14	0.03	22%	386.3
19	Feb-80	28	51	23	5	0.11	0.04	31%	275.0
20	Mar-80	52	53	1	30	0.07 Avg. is an Estimate			190.2
21	Apr-80	53	79	26	4	0.11	0.04	38%	275.0
22	May-80	79	106	27	4	0.18	0.17	95%	485.2
23	Jun-80	106	132	26	4	0.38	0.73	193%	978.0
24	Jul-80	132	161	29	2	1.31	5.71	435%	3517.4
25	Aug-80	161	190	29	2	11.65	20.71	178%	31206.7
26	Sep-80	190	217	27	3	10.69	21.33	199%	27717.8
27	Oct-80	217	244	27	4	3.29	5.50	167%	8817.3
28	Nov-80	244	269	25	5	0.33	0.07	21%	845.8
29	Dec-80	269	296	27	4	0.20	0.04	19%	523.8
30	Jan-81	1	28	27	4	0.10	0.08	76%	265.4
31	Feb-81	28	38	10	0	0.15	0.02	16%	incomplete
32	Mar-81			0	0				no data
33	Apr-81	39	65	26	4	0.06	0.04	58%	167.6
34	May-81	65	91	26	5	0.22	0.33	147%	598.0
35	Jun-81	91	121	30	0	23.91	27.76	116%	61964.7
36	Jul-81	121	148	27	4	11.10	6.65	60%	29732.6
37	Aug-81	148	175	27	4	12.13	15.10	124%	32496.7
38	Sep-81	175	201	26	4	9.42	7.87	84%	24419.4
39	Oct-81	201	228	27	4	2.59	1.81	70%	6937.0
40	Nov-81	228	253	25	5	0.81	0.25	30%	2101.9
41	Dec-81	253	280	27	4	0.40	0.09	22%	1067.6

runoff1.xls

2B

	B	C	D	E	F	H	I	J	K
1	TABLE STATISTICS of SALADO RIVER FLOW at ATOYAC JUNCTION.								
2	MONTH	# aforo	# aforo	No. of	No. of	Average	STD	CV	TOTAL
3	-Year	Start	End	measur.	interpol.	m^3/s	m^3/s	%	X 1000 m3
42	Jan-82	1	24	23	8	0.27	0.03	12%	723.5
43	Feb-82			0	0				no data
44	Mar-82			0	0				no data
45	Apr-82	25	50	25	5	0.25	0.18	74%	646.8
46	May-82	50	75	25	6	1.74	5.16	296%	4665.7
47	Jun-82	76	102	26	4	0.47	0.17	36%	1215.5
48	Jul-82	102	129	27	4	0.33	0.05	16%	889.2
49	Aug-82	129	155	26	5	0.21	0.06	31%	555.0
50	Sep-82			0	30				no data
51	Oct-82	181	207	26	5	0.24	0.09	40%	636.8
52	Nov-82	207	233	26	4	0.10	0.05	50%	253.2
53	Dec-82	233	260	27	4	0.03	0.01	42%	88.5
54	Jan-83	1	27	26	5	0.04	0.02	34%	117.1
55	Feb-83	27	38	11	0	0.07	0.01	9%	incomplete
56	Mar-83			0	0				no data
57	Apr-83			0	0				no data
58	May-83	39	45	6	0	0.06	0.03	49%	incomplete
59	Jun-83	45	71	26	4	0.20	0.26	126%	527.9
60	Jul-83	71	97	26	5	0.57	0.64	113%	1524.7
61	Aug-83	97	124	27	4	0.21	0.24	114%	572.3
62	Sep-83	124	150	26	4	0.28	0.17	61%	733.2
63	Oct-83	150	176	26	5	0.06	0.02	39%	157.1
64	Nov-83	176	202	26	4	0.04	0.02	41%	101.4
65	Dec-83	202	229	27	4	0.06	0.04	72%	166.6
66	Jan-84	1	23	22	9	0.04	0.00	7%	107.0
67	Feb-84			0	0				no data
68	Mar-84	24	41	17	0	0.12	0.26		incomplete
69	Apr-84	41	52	11	0	0.08	NOT RELIABLE		80.0
70	May-84	53	76	23	8	0.98	3.42	347%	2636.1
71	Jun-84	76	102	26	4	1.49	1.67	112%	3872.2
72	Jul-84	102	128	26	5	1.93	5.20	269%	5169.3
73	Aug-84	128	155	27	4	0.84	0.71	85%	2237.0
74	Sep-84	155	181	26	4	15.34	16.76	109%	39766.5
75	Oct-84	181	208	27	4	1.32	0.85	64%	3528.7
76	Nov-84	208	234	26	4	0.23	0.08	36%	597.5
77	Dec-84	234	260	26	5	0.14	0.02	12%	364.6

runoff1.xls

2C

	B	C	D	E	F	H	I	J	K
1	TABLE STATISTICS of SALADO RIVER FLOW at ATOYAC JUNCTION.								
2	MONTH	# aforo	# aforo	No. of	No. of	Average	STD	CV	TOTAL
3	-Year	Start	End	measur.	interpol.	m^3/s	m^3/s	%	X 1000 m^3
78	Jan-85	1	18	17	14	0.11	0.03	26%	299.0
79	Feb-85	28	39	11	17	0.06			145.2
80	Mar-85	40	50	10	21	0.03			92.7
81	Apr-85	50	76	26	4	0.16	0.13	79%	418.7
82	May-85	76	103	27	4	0.18	0.14	77%	477.8
83	Jun-85	29	55	26	4	0.53			
84	Jul-85	128	155	27	4	0.50	0.71	141%	1350.0
85	Aug-85			0	31	0.75			2013.9
86	Sep-85	182	207	25	5	0.56	0.52	93%	1440.6
87	Oct-85	207	234	27	4	0.52	0.97	188%	1384.7
88	Nov-85	234	260	26	4	0.17	0.04	22%	437.4
89	Dec-85	260	286	26	5	0.14	0.01	6%	385.4
90	Jan-86	1	28	27	4	0.13	0.01	12%	341.2
91	Feb-86	28	38	10	18				incomplete
92	Mar-86			0	31				no data
93	Apr-86	39	46	7	23				incomplete
94	May-86	46	73	27	4	0.19	0.11	55%	513.0
95	Jun-86	73	98	25	5	1.48	4.09	276%	3833.2
96	Jul-86	98	125	27	4	0.62	0.69	111%	1663.1
97	Aug-86	125	151	26	0	0.18	0.07	48%	399.9
98	Sep-86	151	177	26	4	0.13	0.08	60%	347.6
99	Oct-86	177	205	28	3	0.47	0.44	94%	1261.9
100	Nov-86	205	230	25	5	0.19	0.22	117%	492.9
101	Dec-86	230	257	27	4	0.03	0.00	7%	92.3
102	Jan-87	Feb-87	Mar-87	Apr-87					no data
103	May-87			0	31				incomplete
104	Jun-87			0	30				no data
105	Jul-87	59	86	27	4	0.62	0.52	84%	1657.5
106	Aug-87	86	112	26	5	0.93	0.75	81%	2490.3
107	Sep-87	112	138	26	4	0.34	0.08	23%	870.1
108	Oct-87	138	165	27	4	0.24	0.02	9%	653.6
109	Nov-87	165	190	25	5	0.24	0.00	2%	622.0
110	Dec-87	190	217	27	4	0.25	0.04	14%	676.7
111	Jan-88	1	19	18	13	0.26	0.07	28%	700.0
112	Feb-88	Mar-88	Apr-88						no data
113	May-88	20	29	9	22	0.32	1.19	375%	846.4
114	Jun-88	29	54	25	5	3.81	9.32	245%	9873.0
115	Jul-88	55	81	26	5	4.88	18.59	381%	13068.0
116	Aug-88	81	108	27	4	16.09	27.80	173%	43105.0
117	Sep-88	108	135	27	3	41.9	57.2	137%	108539.0
118	Sep-88	ESTIMATE	OF SEPT	MINIMUM		40	57	143%	103923.0
119	Sep-88	ESTIMATE	OF SEPT	MAXIMUM		44	59	134%	115155.0
120	Oct-88	135	159	24	7	1.70	0.91	54%	4552.0
121	Nov-88	159	185	26	4	0.56	0.09	16%	1464.1
122	Dec-88	185	212	27	4	0.27	0.03	10%	712.2

runoff1.xls

2D

	B	C	D	E	F	H	I	J	K
1	TABLE STATISTICS of SALADO RIVER FLOW at ATOYAC JUNCTION.								
2	MONTH	# aforo	# aforo	No. of	No. of	Average	STD	CV	TOTAL
3	-Year	Start	End	measur.	interpol.	m^3/s	m^3/s	%	X 1000 m^3
123	Jan-89	1	14	13	0	0.25	0.00	2%	incomplete
124	Feb-89			0	0				no data
125	Mar-89			0	0				no data
126	Apr-89	15	32	17	0	0.09	0.10	109%	incomplete
127	May-89	32	41	9	22	0.05	0.09	165%	145.3
128	Jun-89	42	68	26	4	3.71	6.25	169%	9606.0
129	Jul-89	68	94	26	5	1.39	1.12	80%	3732.0
130	Aug-89	94	122	28	3	2.14	4.21	197%	5729.0
131	Sep-89	122	147	25	5	7.62	12.82	168%	19747.0
132	Oct-89	148	174	26	5	0.93	0.32	34%	2479.5
133	Nov-89	174	200	26	4	0.36	0.13	35%	929.5
134	Dec-89	200	225	25	6	0.22	0.08	38%	586.6
135	Jan-90	1	27	26	5	0.12	0.04	34%	323.7
136	Feb-90	27	37	11	0	0.08	0.01	13%	incomplete
137	Mar-90			0	0				no data
138	Apr-90								no data
139	May-90								no data
140	Jun-90	38	59	21	9	0.36	0.08	21%	9606.0
141	Jul-90	59	85	26	5	0.59	0.66	113%	1568.5
142	Aug-90	85	112	27	4	0.30	0.06	21%	810.4
143	Sep-90	112	137	25	5	0.30	0.03	8%	782.4
144	Oct-90	137	164	27	4	0.20	0.02	8%	528.3
145	Nov-90	164	190	26	4	0.17	0.01	7%	452.9
146	Dec-90	190	1	13	18	0.12	0.03	28%	323.0
147	Jan-91	1	27	26	5	0.12	0.03	23%	320.3
148	Feb-91	27	50	23	5	0.07	0.01	12%	158.5
149	Mar-91	51	60	9	22	0.02	0.02	149%	43.0
150	Apr-91	61	72	11	19	0.02	0.02	141%	39.1
151	May-91	72	92	20	11	0.15	0.16	108%	399.8
152	Jun-91	92	117	25	5	5.61	16.99	303%	14544.4
153	Jul-91	117	144	27	4	12.33	22.68	184%	33021.7
154	Aug-91	144	171	27	4	0.62	0.27	43%	1652.1
155	Sep-91	171	196	25	5	2.67	5.93	222%	6933.0
156	Oct-91	196	223	27	4	2.49	3.39	136%	6667.8
157	Nov-91	223	249	26	4	1.18	0.28	24%	3069.3
158	Dec-91	249	273	24	7	1.18	0.28	24%	3171.6
159	Jan-92	1	27	26	5	0.22	0.02	7%	597.3
160	Feb-92	27	52	25	3	0.22	0.01	4%	546.2
161	Mar-92	52	69	17	0	0.22	0.01	2%	575.9
162	Stream Gauge data taken by S.A.R.H.1978 -1992. Measurements discontinued								
163	Servicio Hidrometrico Div. Rio Tehuantepec. Oaxaca. Oaxaca. Mexico								
164	Compilation by E. Perraton. 1997.								

runoff1.xls

2E

Cell: K20
Note: River flow ended February with 0.069m3/s. On the 31st of March the river flow was 0.066 m3/s. It is assumed that the flow decreased from 0.069 to 0.066 m3/s. No rain was recorded in February

Cell: K79
Note: Linear recession assumed from the 14th to the 28th.

Cell: K80
Note: . Constant baseflow the first 19 days and = 0.034 m3/s was assumed.

Cell: K84
Note: Min: 1275x1000 and max:1426x1000 cubic meters.

Cell: K105
Note: Min: 1592x1000 and Max: 1722x1000 cubic meters.

Cell: K111
Note: Min: 600x1000 and Max: 800x1000 cubic meters.

Cell: F113
Note: On these 22 days, no runoff for measurement.

Cell: K114
Note: Min: 9501x1000 and Max: 10245x1000 cubic meters.

Cell: K117
Note: Min: 103923 x1000 and Max: 115155x1000
cubic meters

Cell: K120
Note: Min: 4289x1000 and Max: 4815x1000 cubic meters.

Cell: K131
Note: Min: 19593x1000 and Max: 19901x1000 cubic meters.

Cell: E136
Note: 11 measurements because ends on 13th of February and not on the first of following month.

Cell: I140
Note: The STD and CV are based on the measurements taken from the 7th to the 30 of June. IT DOES NOT INCLUDE THE MONTHLY AVERAGE VALUE ASSUMED FOR THE SIX MISSING MEASUREMENTS FROM THE 1 to 6 incl of June AND USED FOR ESTIMATING MONTHLY TOTAL RUNOFF.

Cell: J140
Note: The STD and CV are based on the measurements taken from the 7th to the 30 of June. IT DOES NOT INCLUDE THE MONTHLY AVERAGE VALUE ASSUMED FOR THE SIX MISSING MEASUREMENTS FROM THE 1 to 6 incl of June AND USED FOR ESTIMATING MONTHLY TOTAL RUNOFF.

Cell: K140
Note: THE MONTHLY AVERAGE VALUE WAS ASSUMED FOR THE SIX MISSING MEASUREMENTS FROM THE 1 to 6 incl of June AND USED FOR ESTIMATING MONTHLY TOTAL RUNOFF.

Cell: K141
Note: Out of the five interpolations, one is uncertain, that is July 1st. On June 30 the flow is 0.276 and on July 2nd the flow is 1.010 . Linear interpolation (0.643) is here assumed as some rain occured on July 1st.

Cell: F146
Note: Here the interpolation for the days the technican went on vacation (16th-31st dec) is reasonable. On Dec 14 the Flow is

0.127 and on Dec 15th the Flow is 0.129 . Given that from Jan 01 to Jan 10 Avg flow is 0.131 and STD is 0.005 only (CV of 3.6% only) and no rain occured in between, we may reasonably assume that from Dec 16th to 31st the flow was 0.130 m3/s.

Cell: J146
Note: This is taken into account the interpolation for the days the technican went on vacation (16th-31st dec). Recall that on Dec 14 the Flow is 0.127 and on Dec 15th the Flow is 0.129 . Given that from Jan 01 to Jan 10 Avg flow is 0.131 and STD is 0.005 only (CV of 3.6% only) and no rain occured in between, it was therefore assumed that from Dec 16th to 31st the flow was 0.130 m3/s.

Cell: F149
Note: All interpolated values were 0.0 because of no runoff on these interpolated days

Cell: H149
Note: From 17 to 25 of March included no runoff.

Cell: F150
Note: All interpolated values were 0.0 because of no runoff on these interpolated days

Cell: H150
Note: On 01, 02, from 04 to 08 and from 14 to 18 of April there was no runoff.

Cell: K161
Note: Monthly volume is calculated with the average itself based on 18 measurements. Strong indication of constant baseflow of approximately 0.218 m3/s

TABLE 3 INVESTIGATING THE EFFECTS OF INTERPOLATION ON STATISTICS of SALADO RIVER FLOW at ATOYAC JUNCTION.

			BEFORE INTERPOLATION				AFTER INTERPOLATION				
MONTH -Year	No. of measur.	No. of interpol.	Average m^3/s	STD m^3/s	CV %	TOTAL X 1000 m^3	Average m^3/s	STD m^3/s	CV %	TOTAL X 1000 m^3	Difference %
Jan-78	26	5	0.06	0.04	56%	171.4	0.07	0.04	50%	170.8	0.4%
Feb-78	24	4	0.07	0.04	53%	169.3	0.07	0.04	51%	169.9	0.3%
Mar-78	12	19	0.04	0.03	75%	96.4	0.04	0.03	75%	96.0	0.5%
Apr-78	25	5	0.03	0.02	65%	88.1	0.03	0.02	61%	89.2	1.2%
May-78	27	4	0.07	0.08	105%	195.5	0.07	0.07	103%	188.8	3.6%
Jun-78	28	2	3.57	5.52	154%	9261.2	3.36	5.52	164%	8698.9	6.5%
Jul-78	27	4	0.69	1.19	173%	1842.7	0.65	1.12	173%	1733.0	6.3%
Aug-78	27	4	0.26	0.22	87%	683.0	0.24	0.21	86%	653.7	4.5%
Sep-78	28	2	4.62	8.41	182%	11977.6	4.33	8.19	189%	11215.2	6.8%
Oct-78	28	3	1.32	1.61	122%	3530.1	1.23	1.55	126%	3299.3	7.0%
Nov-78	26	4	0.12	0.05	40%	308.4	0.12	0.05	40%	306.6	0.6%
Dec-78	27	4	0.10	0.07	69%	267.8	0.10	0.07	70%	270.2	0.9%
May-84	23	8	1.28	3.94	309%	3423.0	0.98	3.42	347%	2636.1	29.9%
Jun-88	25	5	3.95	9.34	236%	10245.6	3.67	9.32	254%	9502.3	7.8%
Sep-88	26	4	40.09	57.17	143%	103923.6	44.43	58.93	133%	115154.8	9.8%
Jul-87	27	4	0.59	0.50	85%	1592.7	0.64	0.52	80%	1722.3	7.5%
Jul-85	27	4	0.48	0.68	143%	1274.9	0.53	0.71	134%	1426.1	10.6%

Stream Gauge data taken by S.A.R.H.1978 -1992. Measurements discontinued
Servicio Hidrometrico Div. Rio Tehuantepec. Oaxaca. Oaxaca. Mexico
Compilation by E. Perraton. 1997.

MAY1984FIN.xls

Table 4 Estimated confidence Interval on generated data for the eight Missing data of May 1984..

	Estimated Potential Error	Generated Value	Avg of Measur Flow (n=23)	Estimated Minimum	Estimated Maximum
	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
1-May-84	0.03	0.08	1.28	0.05	0.11
2-May-84	0.03	0.08	1.28	0.05	0.11
3-May-84	0.03	0.08	1.28	0.05	0.11
4-May-84	0.03	0.08	1.28	0.05	0.11
6-May-84	0.03	0.08	1.28	0.05	0.11
13-May-84	0.20	0.39	1.28	0.19	0.59
20-May-84	0.05	0.21	1.28	0.16	0.26
27-May-84	0.05	0.11	1.28	0.06	0.16
TOTAL . Generated Data	0.45	1.10	10.22	0.65	1.55
TOTAL Measured.	0.73	29.39	29.39	29.39	29.39
	I	**II**	**III**	**IV**	**V**
Daily Average m3/s	0.04	0.98	1.28	0.97	1.00
Number of days		31	31	31	31
Monthly runoff ->		2634.9	3423.0	2596.1	2673.8
Total Error Estimate				-38.9	38.9
Reliability of Data Generation				**-1.5%**	**1.5%**
Overestimation when no Generation			**29.9%**		

DEFINITIONS OF I, II, III, IV and V.

I : Error Estimate on Data generation column.
II: Case where Missing Data are generated
III: Case where missing data are set equal to average of measured flow.
IV: Estimated Most probable Minimum Flow.
V: Estimated Most Probable Maximum Flow.

TABLE 5 ERROR ESTIMATE ON MONTHLY RUNOFF DUE TO ERROR IN SCALE READING AND IN VELOCITY MEASUREMENT WITH MOLINET.

Scale Reading (m)	Area (m^2)	Avg Veloc (m/s)	Q (m^3/s)	Diff Q (m^3/s)	Indiv. Relative Accuracy	Sqrt(n-1) days	Error Month $x10^3$ (m^3/s)	Relative Error	Runoff.
0.61	0.376206	0.156	0.058594	0.016854	22.3%	5.477226	7.975826457	3.9%	
0.64	0.486071	0.194	0.094419	0.018971	25.1%	5.477226	8.977738065	4.4%	
0.62	0.431132	0.175	0.075448		Monthly Volume x 10^3 m^3 - - - >				202.1
Scale Reading (m)	Area (m^2)	Avg Veloc (m/s)	Q (m^3/s)	Diff Q (m^3/s)	Indiv.	Sqrt(n-1) days	Error Month $x10^3$ (m^3/s)	% Err Month.	
1.10	3.048849	1.028	3.13379	0.406524	11.5%	5.477226	192.3801825	2.0%	
1.13	3.335493	1.192	3.976375	0.436061	12.3%	5.477226	206.3582301	2.2%	
1.11	3.189472	1.110	3.540314		Monthly Volume x 10^3 m^3 - - - >				9482.4
Scale Reading (m)	Area (m^2)	Avg Veloc (m/s)	Q (m^3/s)	Diff Q (m^3/s)	Indiv.	Sqrt(n-1) days	Error Month $x10^3$ (m^3/s)	% Err Month.	
0.89	1.554657	0.551	0.857238	0.124968	12.7%	5.477226	59.13903518	2.2%	
0.92	1.722454	0.649	1.117184	0.134978	13.7%	5.477226	63.87572862	2.4%	
0.90	1.637011	0.600	0.982206		Monthly Volume x 10^3 m^3 - - - >				2630.7
On high Flow assumed Mean Velocity accuracy of 0.05 m/s									
Scale Reading (m)	Q (m^3/s)	Diff Q (m^3/s)	Indiv.	Sqrt(n-1) days	Error Month $x10^3$ (m^3/s)	% Err Month.			
0.76	0.358366	0.06106351	14.6%	5.477226	28.8972252	2.6%			
0.79	0.486923	0.06749309	16.1%	5.477226	31.93990995	2.8%			
0.78	0.41943		Monthly Volume x 10^3 m^3 - - - >		1123.4				

These estimates do not take into account the reliability of the river stage rating curve and the deviations of the assumed water velocity profile from the actual velocity distribution .

CONFINTERV of MAY1984.xls

TABLE 6. Linear Regression to establish the linear relationship between the Number of Revolutions per second as measured with the Molinet of type Price and the corresponding Average fluid velocity (m/s).

SUMMARY OUTPUT		Coefficients			
Regression Statistics		Avg.			Standard Error
Multiple R	0.9999	Intercept	0.0160		0.0020
R Square	0.9999	X Variable	0.6785		0.0013
Adjusted R Squ	0.9999		Lower 95%	Upper 95%	t Stat
Standard Error	0.0064	Intercept	0.0119	0.0201	7.9
Observations	39	X Variable	0.6760	0.6811	536.6
			Lower 99.0%	Upper 99.0%	P-value
		Intercept	0.0105	0.0215	1.70E-09
ANOVA		X Variable	0.6751	0.6820	1.34E-73
	df	SS	MS	F	Significance F
Regression	1	11.66	11.66	287941	1.34E-73
Residual	37	0.00	4.05E-05		
Total	38	11.66			

Table 7. 95% CInterval on the Linear Average Fluid Velocity when a 3% RPM error reading is made.

R (rpm)	Min V (m/s)	Max V (m/s)	%
10	0.121	0.137	12.7%
15	**0.176**	0.196	10.9%
20	0.231	0.254	9.9%
25	0.285	0.312	9.3%
30	0.340	0.350	8.9%
35	0.394	0.429	8.6%
40	0.449	0.488	8.4%
45	0.504	0.546	8.2%
50	0.558	0.605	8.1%
80	0.886	0.956	7.6%
100	**1.105**	1.189	7.4%

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TABLE 8a Monthly Salado River Flow and Corresponding Monthly Rainfall Data

				OAXACA	Cuajimoloyas	Mitla
SOURCE B			SOURCE A	RAIN	RAIN	RAIN
FLOW			FLOW	0.5	0.3	0.2
x 10^{-3} m^3	Year	Months	x 10^{-3} m^3	mm	mm	mm
171		**Jan**	170.8	2.5	0.0	0.5
139		**Feb**	169.9	0.4	5.0	6.9
380		**March**	96.0	0.0	62.0	23.3
74		**April**	89.2	3.2	48.0	19.8
179	**1978**	**May**	188.8	14.0	122.0	50.0
8721		**June**	8698.9	18.6	303.6	170.1
1659		**July**	1733.0	43.3	228.0	112.9
608		**August**	653.7	231.2	117.3	66.2
11333		**Sept**	11215.2	105.0	343.0	143.6
3052	A/B	**Oct.**	3299.3	66.2	112.4	57.9
270	RATIO	**Nov**	306.6	130.7	24.6	9.2
218	1.00	**Dec.**	270.2	35.5	19.6	10.4
341		**Jan**	386.3	1.9	15.5	5.8
236		**Feb**	275.0	0.9	0.0	1.1
133		**March**	190.2	6	6.5	2.6
156	**1980**	**April**	174.5	27.2	48.0	23.8
437		**May**	485.2	111.3	89.0	50.3
940		**June**	978.0	139.8	125.0	77.6
3523		**July**	3517.4	165.8	71.5	68.9
37981		**August**	31206.7	219.6	252.0	120.8
29313		**Sept**	27717.8	134.9	270.5	130.6
5920	A/B	**Oct.**	8817.3	16.6	39.5	26.0
67	RATIO	**Nov**	845.8	6.7	7.0	7.3
453	0.94	**Dec.**	523.8	0	4.5	4.2
226		**Jan**	265.4	0.0	4.0	4.5
674		**Feb**	incomplete	26.8	7.0	9.2
0		**March**	no data	30.3	35.4	8.8
152	**1981**	**April**	167.6	16.2	53.4	4.2
624		**May**	598.0	87.4	146.6	60.9
75585		**June**	61964.7	330.9	454.1	70.5
26458		**July**	29732.6	283.7	175.7	67.7
33012		**August**	32496.7	181.1	203.4	55.2
19710		**Sept**	24419.4	126.3	152.8	22.3
5264	A/B	**Oct.**	6937.0	35.3	53.2	14.8
1700	RATIO	**Nov**	2101.9	0.2	10.0	3.6
985	0.98	**Dec.**	1067.6	0.0	2.5	0.0

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TABLE 8 b Monthly Salado River Flow and Corresponding Monthly Rainfall Data

				OAXACA	Cuajimoloyas	Mitla
SOURCE B			SOURCE A	RAIN	RAIN	RAIN
FLOW			FLOW	0.5	0.3	0.2
x 10^{-3} m^3	Year	Months	x 10^{-3} m^3	mm	mm	mm
549		**Jan**	723.5	0.0	2.0	0.5
150		**Feb**	no data	33.3	36.2	18.9
1093		**March**	no data	15.0	35.5	2.6
595	**1982**	**April**	646.8	76.8	68.8	10.2
4252		**May**	4665.7	89.6	95.2	117.5
1005		**June**	1215.5	106.3	76.8	32.7
763		**July**	889.2	93.5	96.8	65.4
443		**August**	555.0	47.4	16.5	3.6
Avg Sept		**Sept**	no data	91.0	155.6	38.3
550	A/B	**Oct.**	636.8	20.6	191.1	15.8
215	RATIO	**Nov**	253.2	5.4	15.9	33.2
80	1.14	**Dec.**	88.5	0.0	0.0	3.1
99		**Jan**	117.1	0.3	12.5	0.0
130		**Feb**	incomplete	32.2	88.3	35.8
173		**March**	no data	18.6	39.5	52.8
0	**1983**	**April**	no data	0.0	0.0	0.0
37		**May**	incomplete	24.4	7.8	0.5
467		**June**	527.9	87.6	116.1	111.4
1280		**July**	1524.7	145.2	220.8	102.7
461		**August**	572.3	101.7	64.5	2.0
613		**Sept**	733.2	123.9	139.4	74.1
124	A/B	**Oct.**	157.1	12.4	26.8	11.8
110	RATIO	**Nov**	101.4	48.5	53.0	8.2
126	1.19	**Dec.**	166.6	18.2	44.5	10.2
97		**Jan**	107.0	5.2	0.0	0.5
289		**Feb**	no data	3.2	0.0	9.8
248		**March**	incomplete	20.5	57.0	1.5
43	**1984**	**April**	80.0	0.0	3.3	0.0
2559		**May**	2636.1	133.2	179.8	30.0
3361		**June**	3872.2	214.6	208.4	91.2
4590		**July**	5169.3	63.7	161.0	41.4
2078		**August**	2237.0	109.9	148.4	15.8
40510		**Sept**	39766.5	265.0	325.4	153.3
2875	A/B	**Oct.**	3528.7	9.7	5.5	0.0
493	RATIO	**Nov**	597.5	0.0	6.0	0.0
301	1.03	**Dec.**	364.6	0.0	5.0	0.0

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TABLE 8c Monthly Salado River Flow and Corresponding Monthly Rainfall Data						
				OAXACA	Cuajimoloyas	Mitla
SOURCE B			SOURCE A	RAIN	RAIN	RAIN
FLOW			FLOW	0.5	0.3	0.2
x 10^{-3} m^3	Year	Months	x 10^{-3} m^3	mm	mm	mm
255		**Jan**	299.0	0	0.0	0.0
163		**Feb**	145.2	0.1	12.5	0.0
89		**March**	92.7	4.3	6.5	0.0
370	**1985**	**April**	418.7	69.5	127.6	7.7
429		**May**	477.8	46.9	77.4	51.1
Avg June		**June**	no data	173.6	122.9	57.2
1199		**July**	1350.0	113.3	139.5	23.0
1768		**August**	2013.9	119	108.2	34.2
1660		**Sept**	1440.6	114.5	166.1	20.4
846	A/B	**Oct.**	1384.7	31.6	61.5	17.4
363	RATIO	**Nov**	437.4	0.5	26.7	0.6
323	1.13	**Dec.**	385.4	5.8	15.7	0.5
294		**Jan**	341.2	3.5	0.0	0.0
248		**Feb**	incomplete	4.8	28.5	0.0
122		**March**	no data	0.0	3.5	0.0
110	**1986**	**April**	incomplete	34.0	46.5	0.0
527		**May**	513.0	88.1	224.0	64.4
3498		**June**	3833.2	182.4	187.0	7.7
1367		**July**	1663.1	119.1	189.5	69.0
322		**August**	399.9	109.3	133.0	7.2
349		**Sept**	347.6	135.0	167.5	63.9
1162	A/B	**Oct.**	1261.9	50.4	63.5	3.6
357	RATIO	**Nov**	492.9	5.4	34.5	1.0
82	1.12	**Dec.**	92.3	3.0	1.0	1.0
377		**Jan**	no data	0.0	0.0	14.3
107		**Feb**	no data	2.5	10.0	0.0
241		**March**	no data	10.7	77.0	0.0
286	**1987**	**April**	no data	25.8	62.0	0.0
518		**May**	incomplete	98.8	80.5	13.3
Avg June		**June**	no data	142.4	261.5	87.4
1669		**July**	1657.5	92.4	219.5	38.3
1791		**August**	2490.3	100.0	69.5	42.9
758		**Sept**	870.1	94.3	118.5	10.7
560	A/B	**Oct.**	653.6	0.6	5.5	0.0
519	RATIO	**Nov**	622.0	0.0	8.0	0.0
605	1.18	**Dec.**	676.7	0.0	1.0	0.0

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TABLE 8d Monthly Salado River Flow and Corresponding Monthly Rainfall Data						
				OAXACA	Cuajimoloyas	Mitla
SOURCE B			SOURCE A	RAIN	RAIN	RAIN
FLOW			FLOW	0.5	0.3	0.2
x 10^{-3} m^3	Year	Months	x 10^{-3} m^3	mm	mm	mm
708		**Jan**	700.0	0.0	1.0	25.0
52		**Feb**	no data	0.0	0.0	11.1
146		**March**	no data	0.0	25.5	9.7
298	**1988**	**April**	no data	11.7	73.0	3.3
863		**May**	incomplete	68.5	93.5	49.4
8667		**June**	9873.0	227.9	216.5	79.2
12333		**July**	13068.0	120.1	169.1	76.1
48490		**August**	43105.0	238.5	292.5	30.2
97231		**Sept**	108539.0	88.2	186.0	53.1
3163	A/B	**Oct.**	4552.0	16.8	38.5	12.5
1244	RATIO	**Nov**	1464.1	0.0	5.0	9.0
615	1.06	**Dec.**	712.2	0.0	20.4	3.0
		Jan	incomplete	4.5		
		Feb	no data	0.0		
		March	no data	0.0		
		April	incomplete	1.3		
	1989	**May**	145.3	5.2		
		June	9606.0	44.8		
		July	3732.0	60.9		
		August	5729.0	323.9		
		Sept	19747.0	96.9		
		Oct.	2479.5	166.0		
		Nov	929.5	153.1		
		Dec.	586.6	17.1		

SALADO2.xls-Sheet 2.-

TABLE 8e Monthly Salado River Flow and Corresponding Monthly Rainfall Data						
				OAXACA	Cuajimoloyas	Mitla
SOURCE B			SOURCE A	RAIN	RAIN	RAIN
FLOW			FLOW	0.5	0.3	0.2
x 10^{-3} m^3	Year	Months	x 10^{-3} m^3	mm	mm	mm
		Jan	320.3	15.8		
		Feb	158.5	0.0		
		March	43.0	2.90		
	1991	**April**	41.8	0.0		
		May	399.8	0.0		
		June	14544.4	0.2		
		July	33021.7	134.7		
		August	1652.1	250.0		
		Sept	6933.0	96.7		
		Oct.	6667.8	61.8		
		Nov	3069.3	125.8		
		Dec.	3171.6	186.3		
		Jan	323.7			
		Feb	incomplete			
		March	no data			
		April	no data			
		May	no data			
	1990	**June**	933.8			
		July	1568.5			
		August	810.4			
		Sept	782.4			
		Oct.	528.3			
		Nov	452.9			
		Dec.	323.0			

Notes: Ratio A/B is Ratio of Source A Annual Flow and Annual Source B Annual Flow
Underline values are values that will be borrowed from Source B to complete missing or misplaced S.A.R.H stream gauge readings.

Source A. Compiled by E. Perraton 1997 from DAILY STREAM GAUGE Readings taken by S.A.R.H Subdirección de Hidrología. Servicio Hidrométrico. 1978 -1992.

Source B. Resumen Ejecutivo del Estudio del Estudio Hidrologico del Proyecto "DIAZ ORDAZ", Municipio Villa Diaz Ordaz en el Estado de Oaxaca, Para una Presa de Almacenamiento y Zona de Riego.

FLOWRAIN of SALADO2.xls

TABLE 9 Rainfall / Runoff data. Salado Watershed Area=1197km^2

	RAINFALL			RUNOFF	
	Oaxaca	Cuajimoloyas	MITLA	Runoff	Runoff
Year	(mm)	(mm)	(mm)	(mm)	x10^{-3} m^3
1976	752.1	1071.5	542.7	No data.	No data
1977	459.5	1040.2	480.1	No data.	No data
1978	650.6	1385.5	670.9	22.5	26891.5
1979	836.4	1270.0	627.8	No data.	No data
1980	830.7	929.0	519.0	62.8	75121.8
1981	1118.2	1298.1	321.7	133.5	159751.9
1982	578.9	790.4	341.9	10.9	13096.9
1983	618.8	781.0	409.5	3.6	4304.5
1984	825.0	1099.8	343.6	49.2	58909.4
1985	679.1	864.6	212.1	9.6	11445.3
1986	735.0	1078.5	217.7	7.9	9484.6
1987	568.5	913.0	207.0	9.4	11275.9
1988	771.7	1121.0	361.6	0.0	183447.7
1989	873.7	--	--	36.8	44024.9
1991	874.2	--	--	58.5	70023.1

No flow data in 1990.

Compiled by E. Perraton from DAILY STREAM GAUGE Readings taken by S.A.R.H Subdirección de Hidrología . Servicio Hidrométrico. 1978 -1992.

TABLE Weights of Rainfall Stations and Antecedent Precipitation Indexes for Best Correlation rainfall versus Runoff.

10. Period 1978/1980-1991. Salado River flow measured daily at Atoyac River junction.

Rio Salado Watershed Area: 1197 km^2. Measurements taken by S.A.R.H . Compiled by E. Perraton.

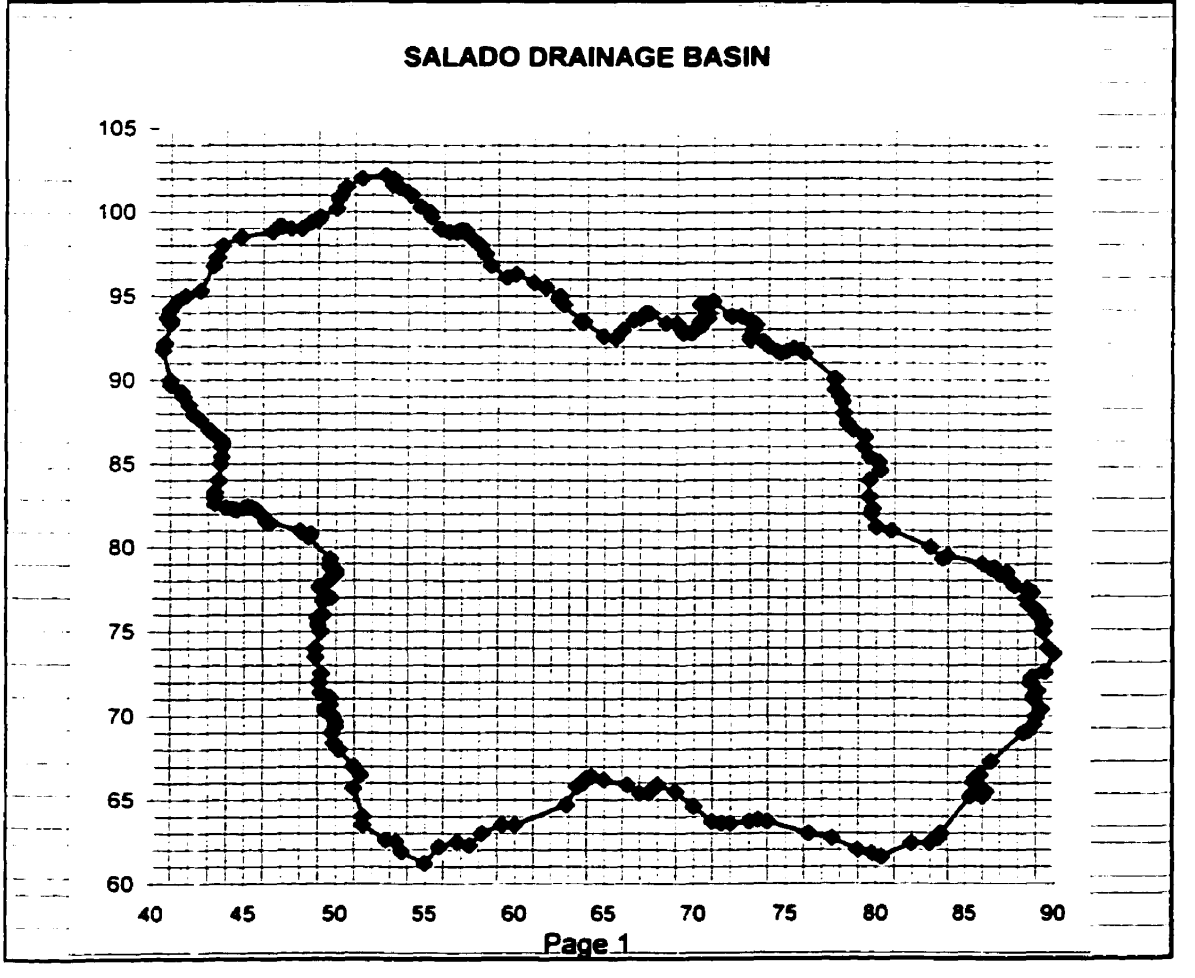
Weights of Rainfall Stations			Antecedent Precipitation Indexes.			EXPONENTIAL		Polynomial	Linear
	excluded 1990/91			excl 1990/91					
Oaxaca	Cuajimoloyas	Mitla	Po	P1	P2	R^2 with 1988[1].	R^2 without.	R^2 without.	R^2 without.
0.6	0.3	0.1	0.7	0.3	0	0.62	0.86	0.93	0.83
0.6	0.3	0.1	0.8	0.2	0	0.66	0.85	0.92	0.84
0.65	0.2	0.15	0.8	0.2	0	0.63	0.86	0.91	0.82
0.65	0.2	0.15	0.9	0.1	0	0.65	0.83	0.90	0.80
0.7	0.3	0	0.7	0.3	0	0.59	0.79	0.92	0.86
0.7	0.3	0	0.8	0.2	0	0.63	0.80	0.92	0.88
0.8	**0.2**	**0**	**0.8**	**0.2**	**0**	**0.61**	**0.80**	**0.93**	**0.90**
0.8	0.2	0	0.9	0.1	0	0.63	0.78	0.92	0.89
1	0	0	0.8	0.2	0	0.52	0.72	0.91	0.83
1	**0**	**0**	**0.9**	**0.1**	**0**	**0.57**	**0.74**	**0.92**	**0.86**
1	**0**	**0**	**1**	**0**	**0**	**0.59**	**0.74**	**0.92**	**0.85**

Notes: - The estimate of the 1988 annual rain of Cuajimoloyas is unreliable. See Cuairain.xls where 1121mm was obtained based on the rational deductive method Based on a regression analysis the high and low boundaries of the 95 % interval are 747mm and 1446 mm respectively.

- No flow data in 1979.
- P_0 is the the amount of rainfall during the present year.
- P_1 and P_2 are the amounts of rainfall for 2 years preceding the year in question.

RAINAREA

Table 11 Verification of the Salado Drainage Basin Map.			
1. Idrisi Calculation		hectares	km2
Area within basin = B		120,747.68	1207.48
Area outside = O		441,413.22	4414.13
Total Image Area = B + O		562160.9	5621.61
2. Image Area XY	meters		
X min (minimum X boundary)	-27565		
X max (maximum X boundary)	47056.9		
X max - X min = W	74622.2		
Y min (minimum Y boundary)	-29326		
Y max (maximum Y boundary)	46008		
Y max - Y min = H	75334.2		
TOTAL AREA = W x H		562160.89	5621.61
Difference in % between (B+O) and (WxH)			0.00%
3. Area planimetered			
Area within basin = P		120057	1200.57
Difference in % between B and P			-0.58%



Sheet1 of RAINAREA.xls

Table 12. Area of Salado polygonal sub-basins as calculated by Idrisi

Color Code	Area hectares	Color Code	Area hectares
0	0.67	63	115.17
1	441.48	64	1,372.86
2	160.24	65	418.04
3	0.87	67	1,453.15
4	164.53	72	9,013.65
5	0.33	73	13,019.12
6	4.42	74	3,994.23
7	79.95	77	790.22
9	883.50	80	310.24
12	1,011.93	81	1,367.30
14	178.12	82	1,647.00
16	0.27	83	12,526.48
19	986.15	84	4,400.49
20	541.32	85	4,536.35
21	489.76	86	1,965.14
23	5,344.59	87	1,700.84
31	1,104.21	88	1,874.87
32	438.40	90	3,239.76
37	488.56	91	537.51
39	0.40	123	8,041.02
42	13,269.49	166	0.27
43	2.68	171	0.60
44	0.20	173	218.90
47	2,655.65	176	0.80
49	1,531.96	181	0.54
50	586.25	186	0.07
52	6,513.28	191	0.40
55	4,855.76	193	671.97
58	2,064.65	214	397.42
59	330.19	243	0.07
61	145.71	252	0.07
62	2,857.61	**Canvas 255**	441,413.2

Refer to Figure 8. for Subwatershed Polygonal Areas Code Id.

saladob1.xls

TABLE 13 IMAGE BOUNDARY VALUES

SALADOB1.vec C;Etienne\Maps\Idrisi	x	y XYMAP sys.	xmap XXYYMAP2 system	ymap
Min	**-7960**	**-3796.6**	**40.6**	**61.2**
Max	**41432.4**	**37198.5**	**90**	**102.2**

XYMAP image C;Etienne\Maps\Idrisi	x	y	xmap XXYYMAP2 system	ymap
Min	**-1639**	**-8608**	**46.922**	**56.388**
Max	**37237**	**32942**	**85.804**	**97.943**

SALADOB1.vec **XYMAP image** C;Etienne\Maps\Idrisi		**XXYYMAP2 image**
Column	3025	3025
Rows	3273	3273

IMAGE REQUIREMENTS XXYYMAP and XXYYMAP2 TO BE ABLE TO DISPLAY THE ENTIRE DRAINAGE BASIN.

SALADOB1.vec C;Etienne\Maps\Idrisi	x	y XYMAP sys.	xmap XXYYMAP2 system	ymap
Min required	**-8566**	**-8608**	**All**	**All**
Max required	**41671**	**37576**	**All**	**All**

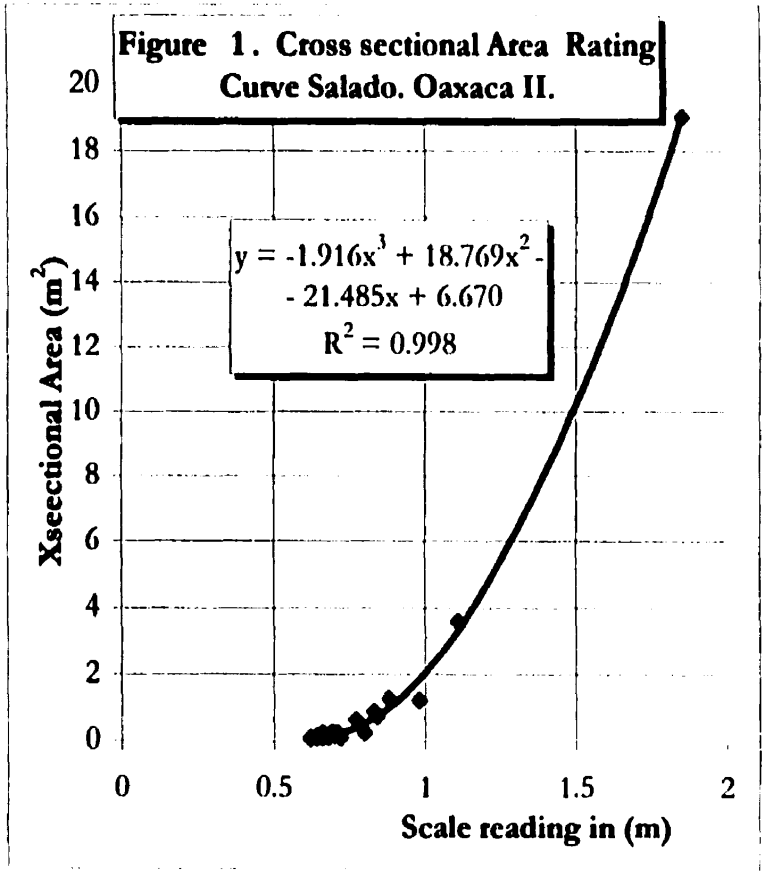
SALADOB1.vec **XYMAP image** C;Etienne\Maps\Idrisi		**XXYYMAP2 image**
Column required	3909	All
Rows required	3638	All

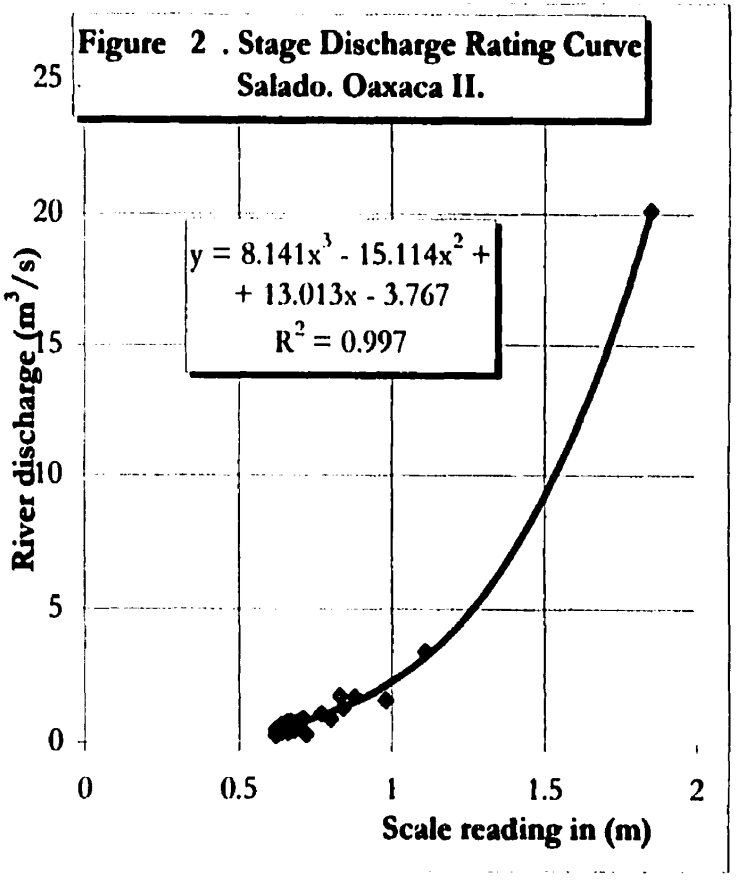
3025	38876		
3909.02	50237	49392.4	
4229.491	3273	41550	
	3638.03	46184	40995.1
		37576	
	set<min->	-8608	-3796
		37576	**37198.5**

Table 14. Multi-channel Image Files created for calibrating Maps

	Geologic.Tif	Salinelayers.psd
Channel #1.	Topographic Map.	Topographic Map
	15.1 Mega bytes	15,1Mega byte
	4238 x 3740 pixels.	4238 x 3740 pixels.
	* 8 dots / mm	* 8 dots /mm
Channel #2.	Original Geology Map	**Channel #4.**
	with River Network.	Water Salinity Graphs
	Gray Scale.	1994/1995.
Channel #3.	Water Salinity Graphs	
	1994/1995.	
Channel #4.	Water Salinity Graphs	Water Salinity Graphs
	1979	1979

*200 pixels/inch is the U.S.A software image resolution setting.


Figure 1. Cross sectional Area Rating Curve Salado. Oaxaca II.
y = -1.916x³ + 18.769x² -
- 21.485x + 6.670
R² = 0.998
Xseectional Area (m²)
Scale reading in (m)
0
2
4
6
8
10
12
14
16
18
20
0
0.5
1
1.5
2


Figure 2 . Stage Discharge Rating Curve Salado. Oaxaca II.
y = 8.141x³ - 15.114x² +
+ 13.013x - 3.767
R² = 0.997
River discharge (m³/s)
Scale reading in (m)
0
5
10
15
20
25
0
0.5
1
1.5
2

FLOWRAIN of SALADO2.xls

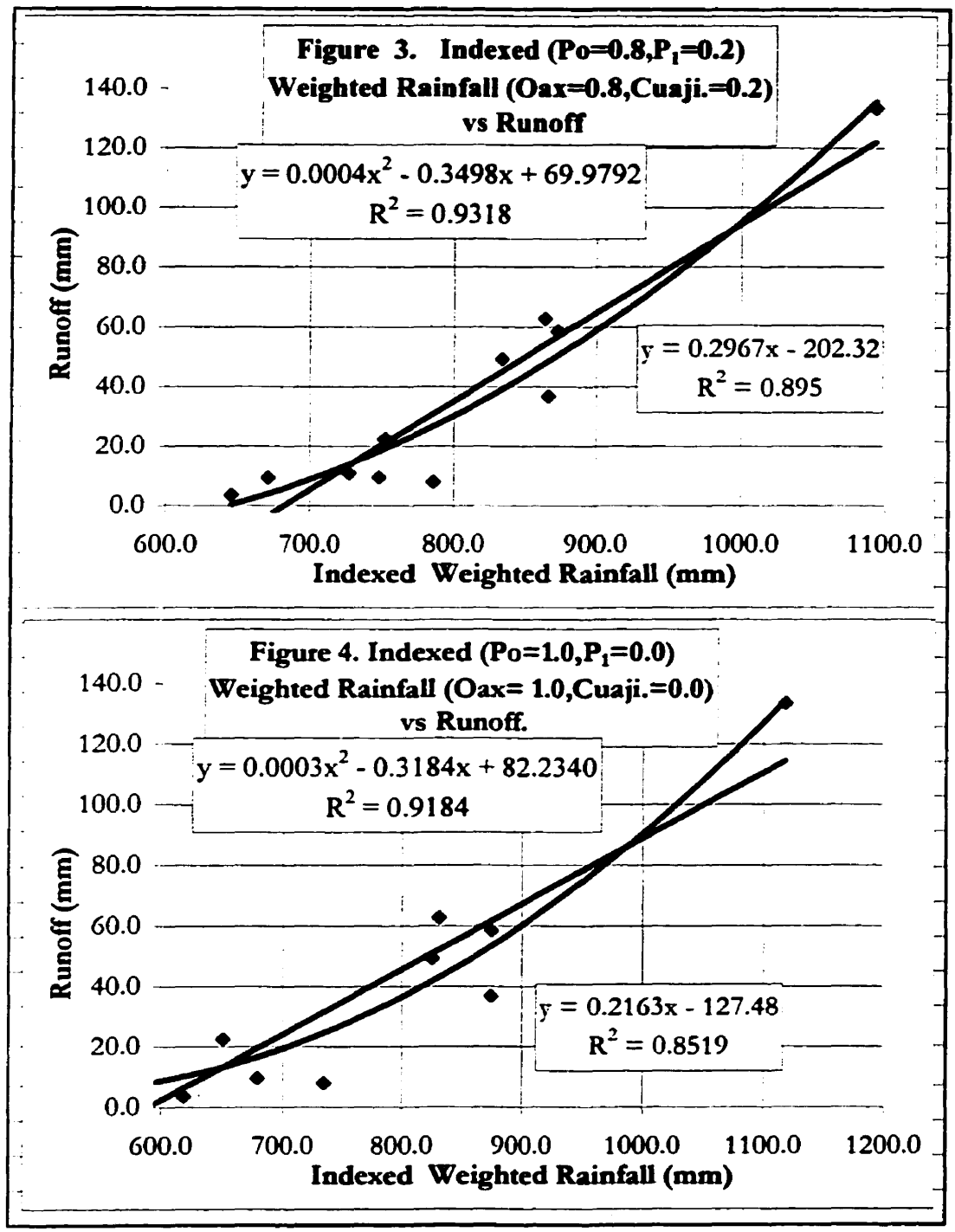
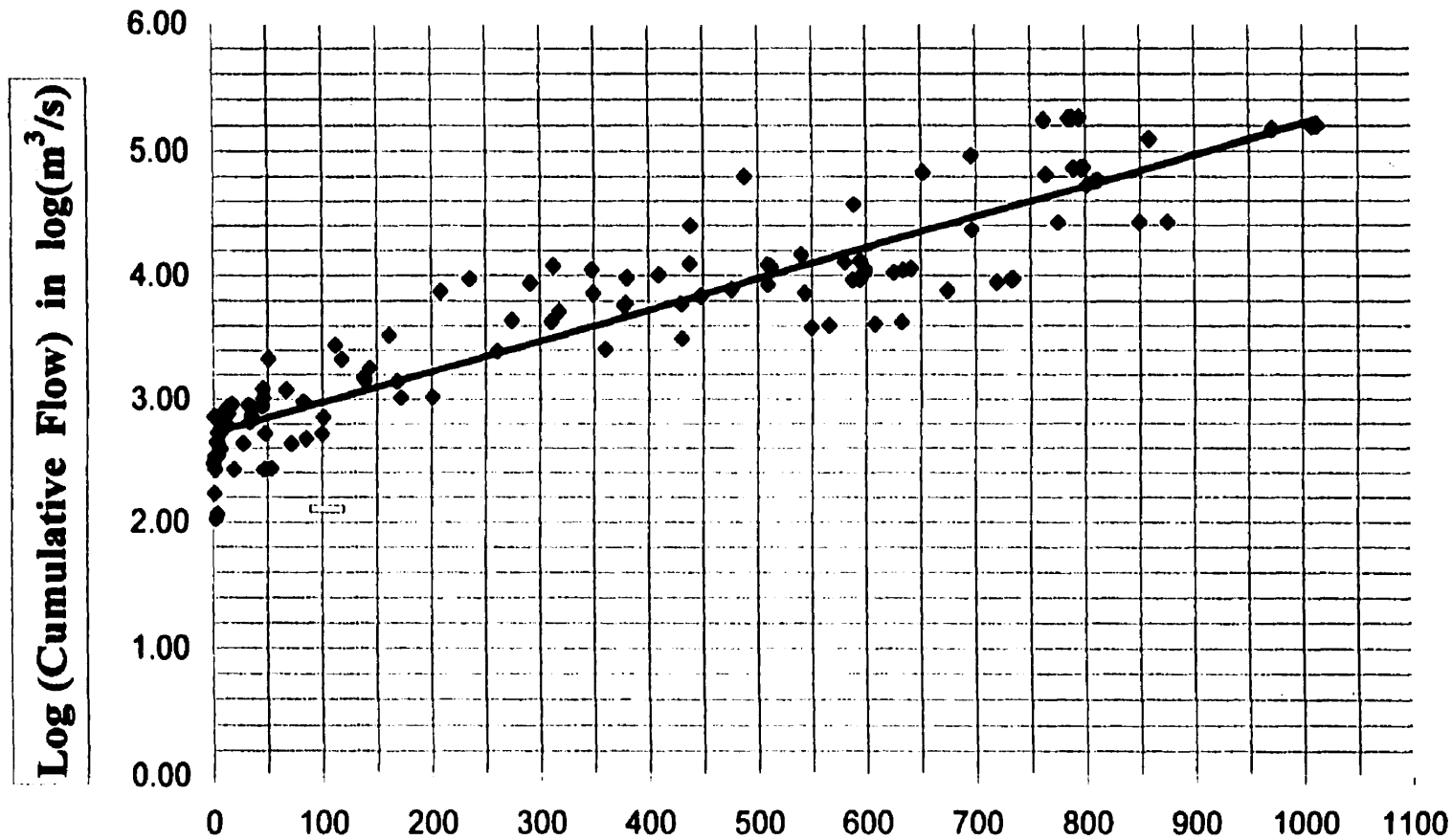
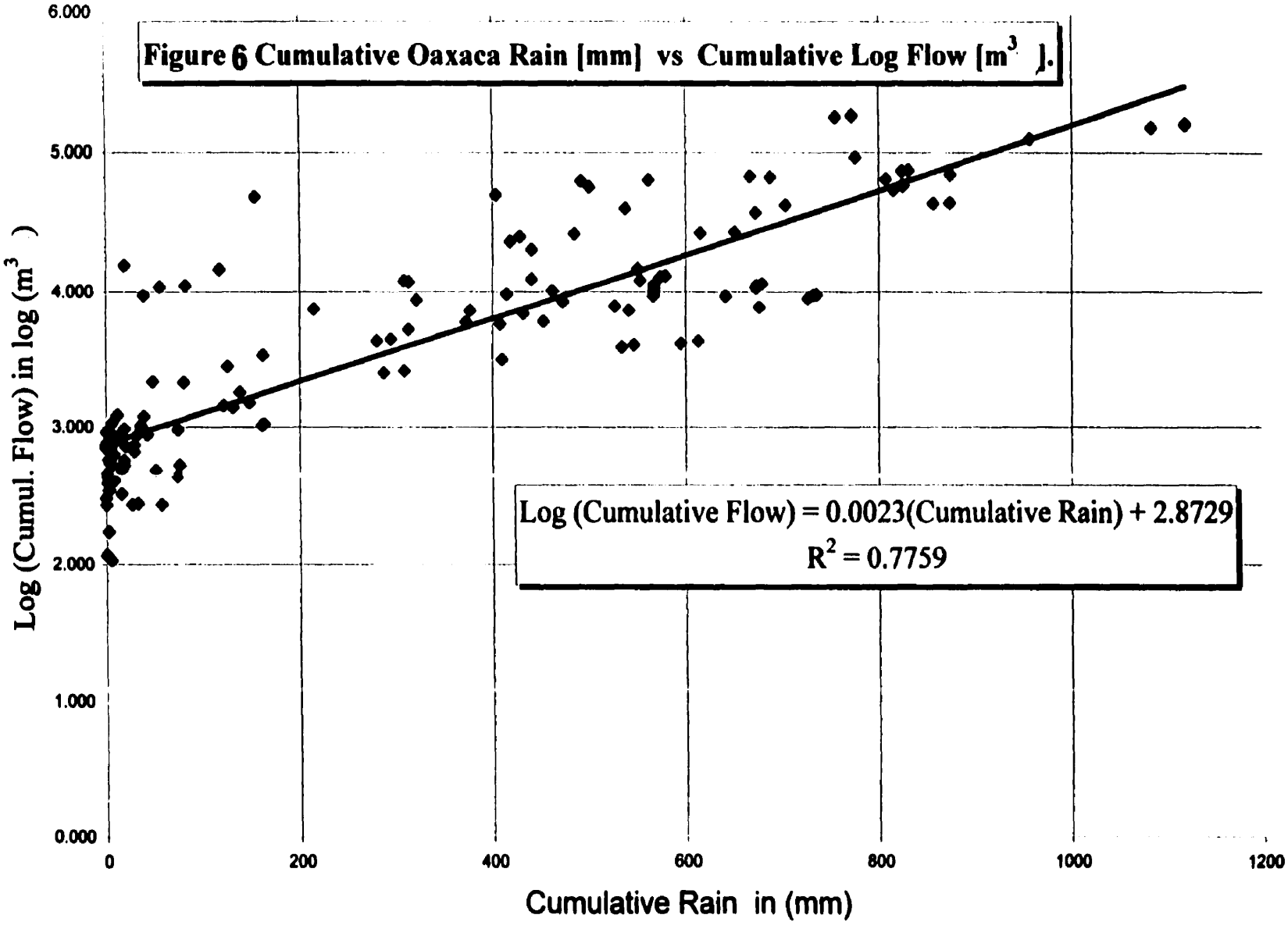


Figure 5. Cumulative Weighed Rainfall vs Cumulative Log Flow



Salado2.xls/Sheet 2/Chart 7



Salado2/Sheet2/Chart10

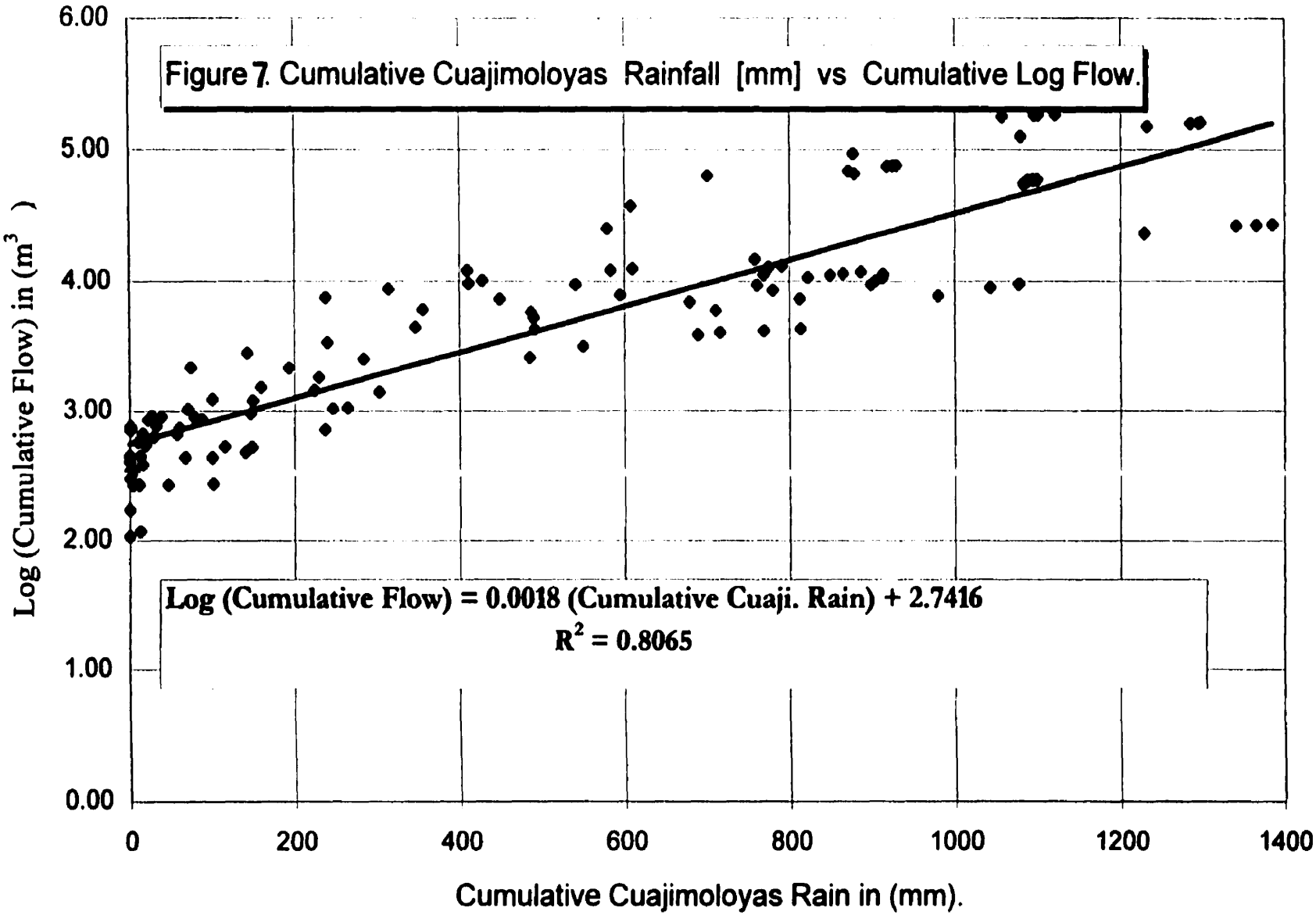




Figure 8. Drainage Sub-Basins of TLacolula Basin

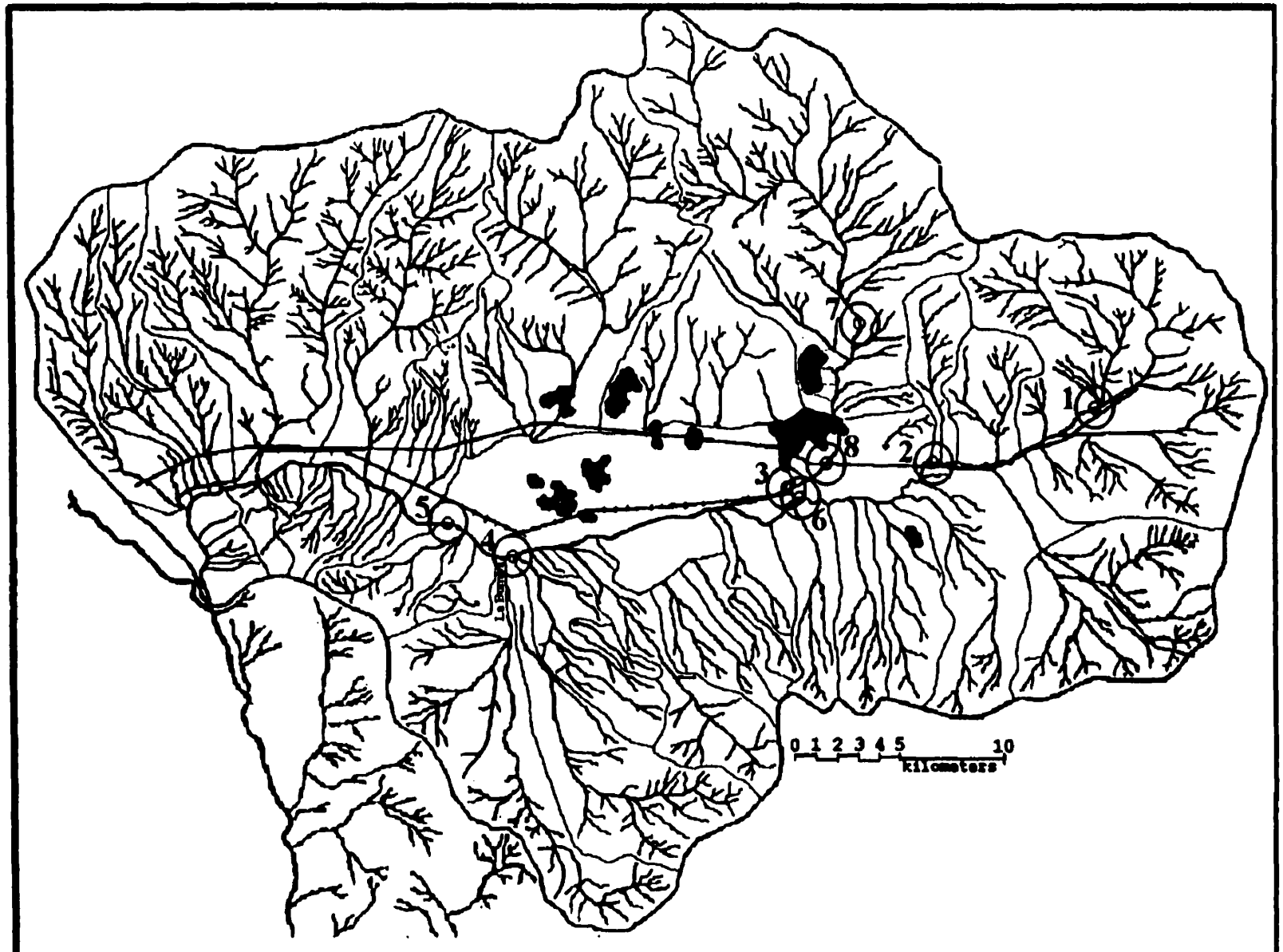
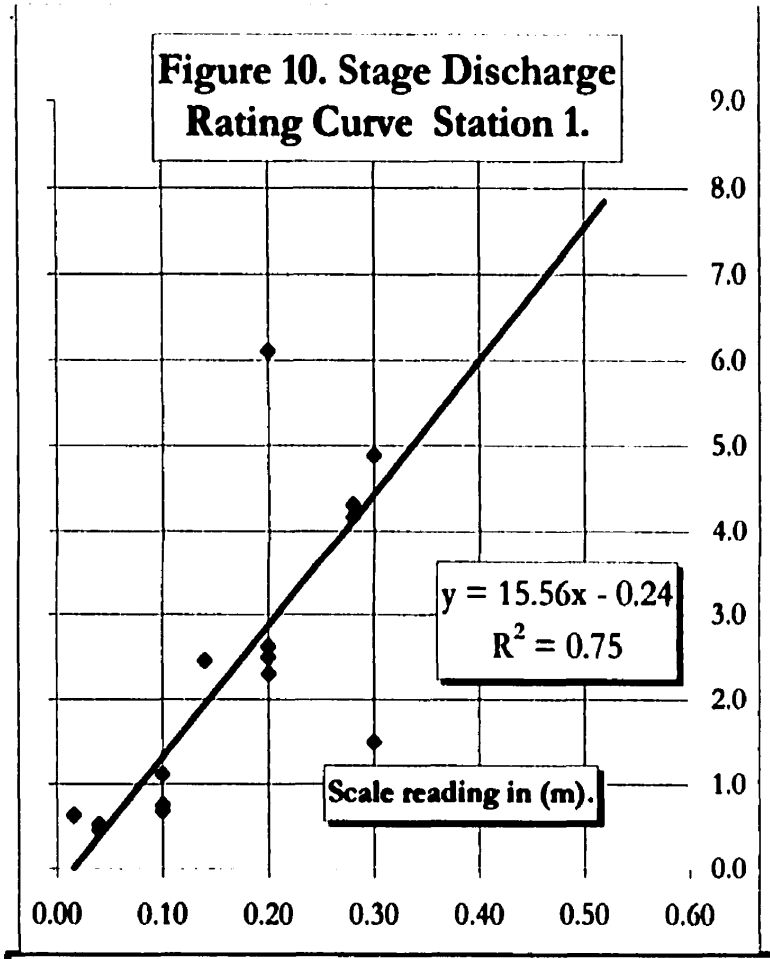
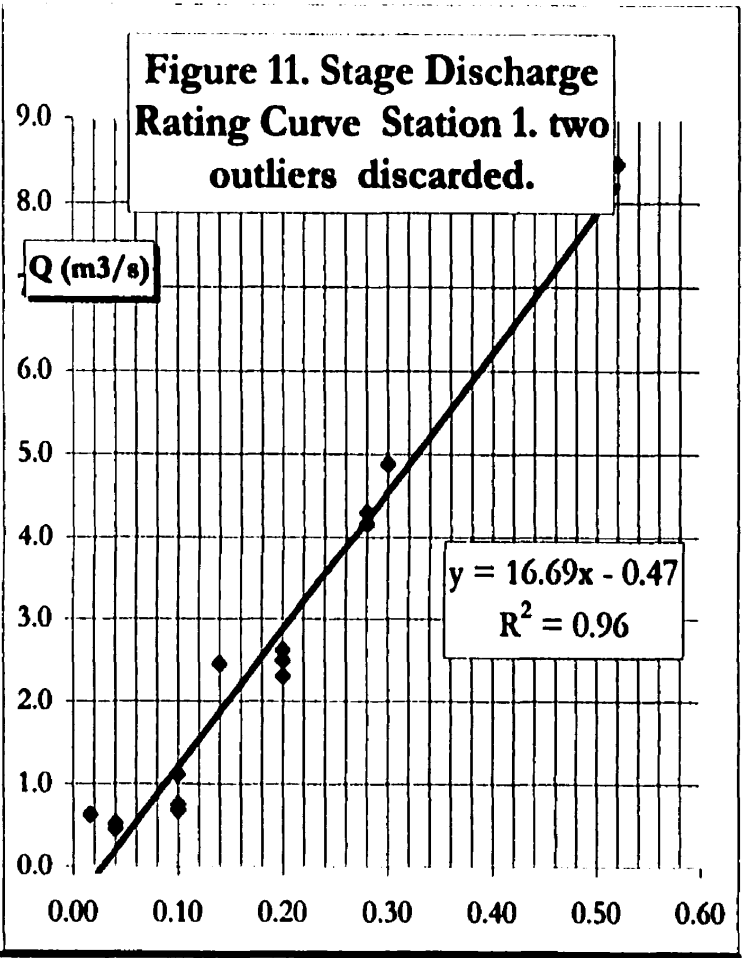


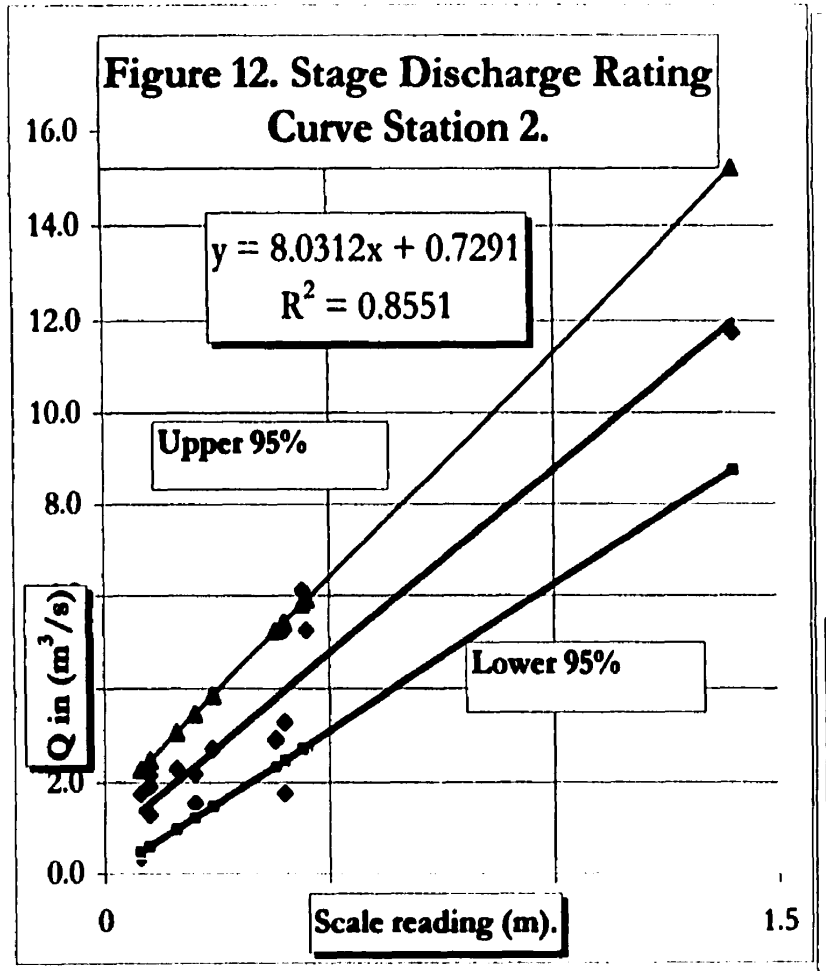
Figure 9 . Tested and Recommended Stream Gauge Locations.

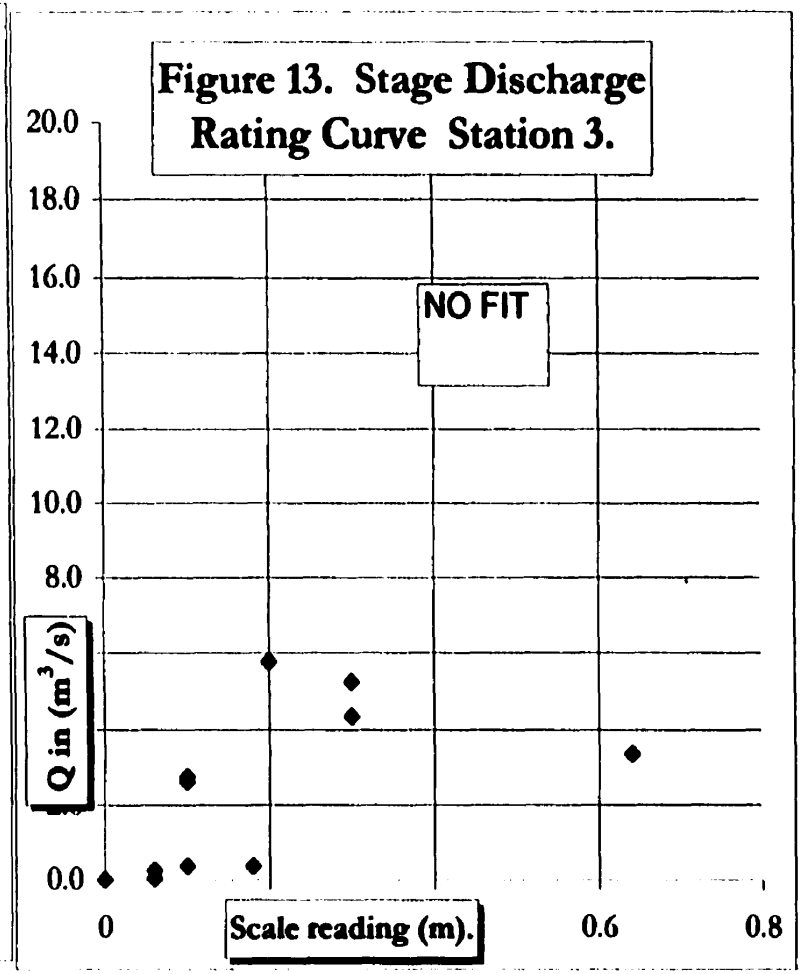


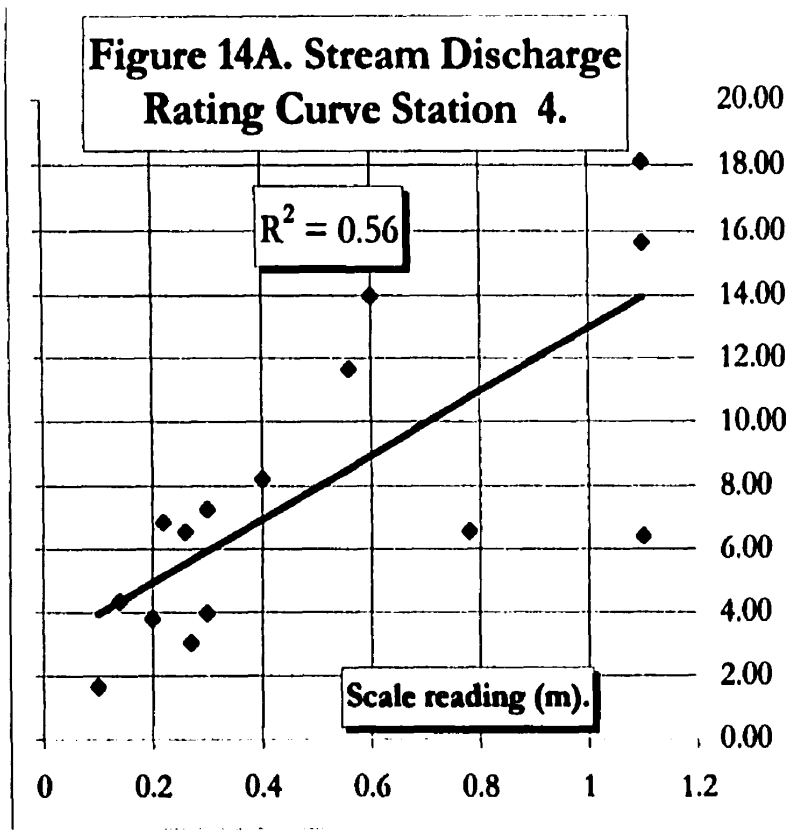


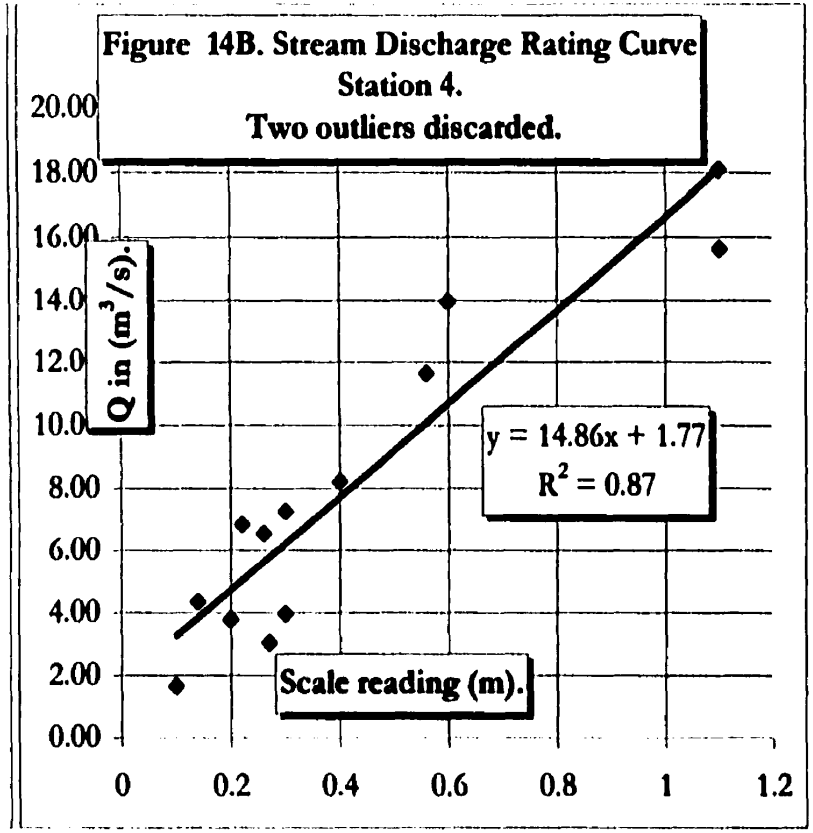
	df	SS	MS	F	p = Signific. F	np = #df X p	decision
Actual Error	16	22.00	1.38			n = 16 df	1) Discard
Suspected	2	19.38	9.69	51.779	3.73E-04	5.96E-03	2) Q by Molinet
Remainder	14	2.62	0.19			**0.60%**	3) More storms

In Cohran's example the suspect value is replaced by a missing plot value ,
Cohran (1947)uses the average between randomized blocks within the same treatment as missing value.
Here no replacement is made. Replacement with regression PREDICTED values leads also to 0,60%.


Figure 12. Stage Discharge Rating Curve Station 2.
y = 8.0312x + 0.7291
R2 = 0.8551
Upper 95%
Lower 95%
Q in (m3/s)
Scale reading (m).
16.0
14.0
12.0
10.0
8.0
2.0
0.0
0
1.5


Figure 13. Stage Discharge Rating Curve Station 3.
NO FIT
Q in (m3/s)
Scale reading (m).
20.0
18.0
16.0
14.0
12.0
10.0
8.0
0.0
0
0.6
0.8


Figure 14A. Stream Discharge Rating Curve Station 4.
$R^2 = 0.56$
Scale reading (m).
0
0.2
0.4
0.6
0.8
1
1.2
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00


Figure 14B. Stream Discharge Rating Curve Station 4.
Two outliers discarded.
Q in (m^3/s).
$y = 14.86x + 1.77$
$R^2 = 0.87$
Scale reading (m).
0
0.2
0.4
0.6
0.8
1
1.2
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

CHAPTER VI
GROUNDWATER FLOW MODELING
REVIEW OF LITERATURE

Introduction

Cunha et al. (1993) see two fundamental components to be accounted for in programming the optimal operation of an aquifer system hydraulically linked to a river with a set of predesigned hydraulic structures used to meet agricultural requirements. These two components are: the groundwater and the agricultural systems. This chapter deals with the first component.

The two most common groundwater flow modeling approaches that can be seen in the literature are the finite difference or finite element approach and the models based on the superposition principle. C.N.A. the manager of the aquifer, has expressed the desire to use a finite difference flow model. This focus will be kept in mind.

The problem of identifying the parameters of an aquifer model, known as the inverse problem, means the determination of the distributions of the storativity and of the transmissivity of the aquifer. The complete distributions are required if one wishes to forecast the future regime in the aquifer in response to various imposed activities of pumping and recharge.

There are four main steps in the identification procedure of aquifer parameters.

1. selection of a mathematical model to be used for forecasting water levels in the aquifer,
2. calculating the values of the parameters of the model using the data of the calibration period,
3. forecasting water levels of the aquifer for the calibration period, making use of the derived aquifer parameters and the information of operation during the calibration period, and
4. analysis of deviation between the response of the aquifer and that of the model.

These four steps in the identification procedure are detailed by Hefez (1975) in a flow chart where the operations are shown in chronological order. This flow chart is reproduced below in Appendix B.

This chapter deals with one operation that is the selection of the two key parameters: the transmissivity and the storativity. As a first glance, the literature review that follows may give the impression to extend beyond this task of aquifer parametrization. We shall see however, that this review is essential for guiding us in the analysis and interpretation of historical well test data keeping in view the formulation of the groundwater flow model.

The basic continuity equation for flow in a phreatic aquifer is usually analyzed based on Dupuit's assumption of horizontal flow with no internal sources and/or sinks; elastic storativity is also generally neglected. If the medium is assumed to be inhomogeneous and isotropic, the inhomogeneity that is generally considered is of Type 1 as per Bear's (1979) classification. In Appendix C the basic continuity equation that is obtained under these assumptions is discussed. Appendix C closes the discussion with a recall of the basis of the finite difference approach as a numerical solution to the basic continuity equation.

Transmissivity Definition

Sen (1995) summarizes various definitions of transmissivity found in the groundwater literature as follows:

- The rate of flow under unit hydraulic gradient through a cross section of unit width over the whole saturated thickness of the aquifer (Bear, 1979). By definition transmissivity is valid for Darcy (linear) flow only.
- The product of the thickness of the aquifer and the average value of the hydraulic conductivity (Hantush, 1964; Davis and De Wiest, 1966; Bouwer, 1978; Freeze and Cherry, 1979).
- The ratio at which water of prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of the properties of the liquid, the flow media, and the thickness of the media (Todd 1980 and Fetter 1980 as reported by Sen 1995).

Numerical Simulations To Account For The Variability

Until the end of the nineteen seventies, most attempts to account for the variability in flow properties of aquifer materials were based on the repeated numerical simulation of flow in systems consisting of deterministic arrays of elements (layers, rectangles, blocks, etc.). Within each of these elements the values of the flow property (e.g., hydraulic conductivity) are generated from specified probability distributions presuming statistical independence between elements.

Warren and Price (1961) performed a very extensive set of such Monte Carlo simulations investigating steady state and transient flow through heterogeneous porous media. They examined the influence of several probability distributions for hydraulic conductivity on the resulting solutions in one and three dimensions. Numerical simulations of groundwater flow were also carried out by McMillan (1966) to evaluate the relationship between hydraulic conductivity head for two-dimensional flows.

Lippmann (1973) used a finite element method to calculate the amount of fluid across two-dimensional heterogeneous geologic systems generated by a 'Poisson lines' model with Markovian properties. Lippmann found that meshes with elements of different size and shape describing the same model produced different results.

Wu et al. (1973) computed seepage across porous layers whose parameters are obtained from statistical distributions based on limited field data.

Concern About The Validity Of Deterministic Models

On the basis of the large head variance found from one-dimensional simulation, Freeze (1975) raises doubts about the accuracy of the deterministic models widely used in groundwater hydrology. These simulations by Freeze (1975) demonstrated that the standard deviation of hydraulic head decreased as the number of layers increased

Gelhar (1976) uses spectral theory to analyze the effects of one- and two-dimensional hydraulic conductivity perturbations on flow in a sloping phreatic aquifer. His results show that the head variance in the two-dimensional case is only a few percent of that for one-dimensional flow.

Bakr et al (1978) show an order of magnitude reduction in the variance of predicted hydraulic head relative to that of the one-dimensional case when the three-

dimensional nature of the flow system is considered. Those results (Bakr et al.,1978) together with those of Gelhar (1976) were good reasons for being more optimistic than Freeze (1975) concerning the validity and accuracy of deterministic groundwater flow models.

Weakness Of Most Simulation Studies Of The 70's

Bakr et al (1978) believed however, that a fundamental weakness of most of theses simulation studies is the way in which the discretized hydraulic conductivity field is generated for each realization. These generation methods simply do not relate to the basic probabilistic description of a continuum random field. The joint densities or covariances are not specified.

Bakr et al (1978) also recall the error resulting from the discretization of the flow equation that involves some approximation which may introduce some serious errors, especially when large discontinuities in conductivity occur between blocks.

Statistically Independence Neglects Spatial Structure

Bakr et al. (1978) comment that in the usual statistical approach to describing variability of flow properties, the observations are treated as being statistically independent regardless of their spatial location, and the data are used to estimate a probability density function for the property. This approach neglects the spatial structure inherent in the original data, because of the structured arrangement of different sediment types in the natural medium.

The approach taken by Bakr et al. (1978) involved a statistical description which incorporated the spatial structure of the property. They chose to represent the hydraulic conductivity continuum as a spatial stochastic process or a random field in three dimensions.

This concept of spatial structure of flow properties was already brought up by Greenkorn and Kessler (1969) who were also of the opinion that in general the probability density function (for hydraulic conductivity, for example) is a function of location and orientation.

Freeze (1975) had also expressed his view that the Probability Density Function should be described with five independent variables: three rectangular coordinates for location and two angular coordinates for orientation.

Stochastic Models To Represent Random Flow Variables

Stochastic modeling is not a new concept. Freeze (1975) is already of the opinion that the most realistic representation of a naturally occurring porous medium is a stochastic set of macroscopic elements in which the values of the three basic hydrologeologic parameters (hydraulic conductivity, compressibility and porosity n) are defined by frequency distributions.

In stochastic models the aquifer properties (hydraulic conductivity, transmissivity, storativity) are regarded as random spatial functions. As a result, flow variables like water head, specific discharge, velocity, etc. are also random functions.

Random Medium And Probability Distribution

A random medium may be thought of as one of a family of random media and formulation of flow problems in such random media results in field equations which are stochastic in place of a single equation of a whole family. Thus $K(X,\omega)$ either can be imagined as a family of sample functions $K(X)$, each having a certain probability of occurrence, or can be thought of as a series of random variables $k(X,\omega)$ at each location x_i. At each location, the random variable $K(X_i)$ can be presumed to have a probability distribution. This is the basis of the geostatistical description of a hydrogeological parameter.

Basis Of Geostatistical Description

Freeze and Zapf-Gilje (1988) represent the geostatistical description of a hydrogeological parameter in a discretized domain with blocks labeled i = 1,.., n by the specification of a vector of mean values, $[\mu_i]$ and an autocovariance matrix, $[\sigma_{ij}^2]$. They give as an example, the hydraulic conductivity being commonly found to be lognormally distributed, where it is usual to define the log hydraulic conductivity, Y_i, as

$$Y_i = \log K_i \qquad (1)$$

and to work with the parameter Y(x,y,z) rather than K(x,y,z). For the simple one-dimensional flow system we then have a sequence of Y values, $Y_i = Y(_{xi}) = \{Y_1, Y2, \ldots, Y_n\}$, each Y_i being defined for a small block of porous medium around $x = x_i$ (of as yet unspecified size).

The vector of means will be of length " ν " and the autocovariance matrix, ν by ν . At any unmeasured point, x_i , the value of Y_i is represented by a normal distribution with mean, μ_i, variance σ_{ii}^2 , and autocovariances, σ_{ij}^2

At any measured point, x_k, the value of μ_k in the vector of means becomes the measured value, Y_k, and in the absence of measurement error, $\sigma_{kk}^2 = 0$. Because of the influence of the autocovariances, a measurement at x_k influences the mean values and reduces the variances at neighboring points.

The distance over which such influences are felt is controlled by the autocorrelation length, l, (sometimes called the integral scale or fluctuation scale). The parameter, " l ", is a measure of the distance over which the autocovariances, σ_{ij}^2 , are non-zero. The autocovariance matrix can be converted into an autocorrelation matrix, [$\rho_{i,j}$], by dividing the autocovariances , σ_{ij}^2, by the variances, σ_{ii}^2 .

These geostatistical concepts , presented Freeze and Zapf-Gilje (1988) for Y in one dimension, apply equally well in two or three dimensions.

Stochastic Methods Applied to The Inverse Problem

In the last decade, stochastic methods have been introduced for solving the inverse problem in groundwater modeling. Newman and Yakowitz (1979) and Clifton and Newman (1982) proposed the use of krigging to generate the distributed prior estimation of log transmissivity and its covariance matrix estimation. Kitanidis and Vomvoris (1983) developed a geostatistical approach for solving the inverse problem in which the log transmissivity was considered to be a stochastic function random field. Dagan (1985) also considered the stochastic inverse solution of a two-dimensional steady flow problem. The stochastic approach has also been applied to some simplified field problems [Hoeksema and Kitanidis, 1985; Dagan and Rubin, 1988]. Sun and Yeh (1992)

Classification Of Media

Isotropy and Anisotropy

Greenkorn and Kessler (1969) classify media as follows: If the probability density function is independent of orientation, the medium is isotropic. If it is dependent on orientation, the medium is anisotropic . If the medium is expressible by a finite linear combination of delta functions, the medium is uniform; if it is not, it is nonuniform. If the distribution is monomodal, the medium is homogeneous; if it is multimodal, it is heterogeneous.

Homogeneity, Heterogeneity and Uniformity

The terms homogeneity, uniformity and heterogeneity are defined by Sagar (1978) in terms of joint probability distribution functions of the random variables defining K. The definitions are given in terms of the first two moments, i.e., the mean value function $\mu_K(X)$ and the covariance function $\omega_K(X_i,Xj)$ of a property $K(\mu,\omega)$

Homogeneity.

In a nonuniform and homogeneous medium the hydraulic conductivity has a constant mean but the covariance function is not a constant. A special case of a nonuniform, homogeneous medium in which the neighboring conductivity values are uncorrelated has been treated by Freeze (1975). As pointed out by Gelhar et al (1977), this is unrealistic, since some spatial correlation is expected between neighboring conductivities of a homogeneous medium.

Homogeneity And Uniformity

In a uniform, homogeneous medium the hydraulic conductivity has a constant mean, and the neighboring values are perfectly correlated. In such a case K can be assumed to be a simple random variable and sampling in space can be substituted for sampling over an ensemble.

Heterogeneity

If either of the conditions for homogeneity is violated then we have heterogeneity. Alpay (1972) proposes a threefold classification of heterogeneity. He defines microscopic heterogeneity as being pore to pore, macroscopic heterogeneity as being intraformational, and megascopic heterogeneity as being interformational or

regional. Under the macroscopic label he includes intraformational stratification contrasts and permeability trends.

Data Required To Estimate The Joint Probability Density Functions

In changing from the usual deterministic modeling of groundwater systems to stochastic modeling, the requirement of input data is considerably increased. Bakr et al. (1978) foresee the implication of this demanding data requirement and take a realistic stand by stating that data will practically never be available to estimate these joint probability density functions.

Sauty and Kinzelbach. (1988) show also their concern about the cost for collecting the data required by a stochastic approach of the heterogeneities of permeability and conclude that acquiring directly sufficient information on the permeability for a stochastic approach is generally not feasible in the frame of usual engineering contracts.

A more practical approach is usually taken. that is to consider only certain moments of the joint densities. In the absence of known statistical distributions for either $h(\Theta)$ or $K(\Theta)$ relationships, the method facilitates modeling by providing variability estimates that can be used to examine the uncertainty associated with water flow or solute transport in unsaturated media.

Carsel and Parrish (1988) present a method for developing probability density functions for parameters of soil moisture relationships of capillary head $h(\Theta)$ and hydraulic conductivity in unsaturated media $K(\Theta)$. The method employs a statistical multiple regression equation proposed in the literature for estimating [$h(\Theta)$ or $K(\Theta)$] relationships using the soil saturated water content and the percentages of sand and clay.

Although the soil database used by Carsel and Parrish (1988) is quite impressive (soil texture data obtained from measurements for all soils reported in SCS Soil Survey Information Reports, 42 books representing 42 states!), the soil-water properties were not measured but rather estimated.

To bear an attitude of precaution one recalls that Workman and Skaggs (1992) found that PREFLO and DRAINMOD models were quite sensitive to the error caused by using estimated rather than measured soil-water properties.

Approximate Answers For Statistical Averages of The Solution Variable

Early in the history of groundwater model development, it is acknowledged that the probability distribution will very rarely be known in detail and therefore a complete determination of the family of solutions and its associated probability distribution function is impossible. One is therefore led to look for approximate answers for statistical averages of the solution variable. A survey of some of the approaches followed in solving such a problem is given by Keller (1969). Two approaches are discussed by Sagar (1978).

One approach is to manipulate the field equations so as to obtain deterministic equations on the statistical averages of the solution variable . This involves some *a priori* assumptions regarding the stochastic dependence of parameters and the solution. Also, it produces an infinite set of deterministic equations which is usually truncated by invoking some physical argument before it can be solved.

A second approach is to attempt a general solution of the stochastic field equation in the sense that the solution to any member of the family of equations defined by the stochastic equation is a special case of the general solution. Sagar (1978a,b) has used this method when the stochasticity arrives via the forcing function and/or boundary conditions.

Robustness Of First-Order Approximations Of The Head Covariances

Dagan's analysis (1985) indicates that the first-order approximations of the head covariances, which have been employed extensively in previous studies because of their simplicity, are very robust. If the terms following the second-order ones are also decreasing, the first-order approximation can be employed with confidence for values of the log-conductivity variance approaching unity.

Sensitivity Analysis

In the case of a pumping well test , the influence function describes the strength of the influence of the flow properties at each location of the observed drawdown. Outside of the area of influence, the influence function vanishes uniformly, but inside the area of influence the influence function may vanish at isolated locations. Influence functions are closely related to sensitivity coefficients.

Sensitivity Coefficients

Sensitivity coefficients are simply first derivatives of the state-variables with respect to the input parameters. They indicate the rate and direction of change in the solution caused by a small perturbation of a parameter.

Methods for Computing Sensitivity Coefficients

There are three methods for computing sensitivity coefficients: the perturbation method, the direct method, and the adjoint method.

The Perturbation Method

The most common approach is the perturbation method wherein the basic equations that describe the phenomena under study are solved over and over as each parameter is perturbed by small amounts through its potential range of values. The method is simple but computationally inefficient.

Keller (1969) reviews the use of perturbation theory to treat certain problems involving a random medium which differs only slightly from a given deterministic homogeneous medium. Buyevich et al (1968) and Gelhar (1976) use this concept in their analysis. According to Sagar (1978), in most cases, however, it is difficult to ascertain the limits of validity of this theory.

Results of the perturbation approach such as employed by Bakr et al (1978) are valid for small fluctuations in the perturbed quantities. The results show that s_f must be small in comparison to 1 (one) for the perturbation approach to be valid. According to Bakr et al (1978) this limitation on s_f is quite restrictive with respect to the observed high variability of natural porous media. Typical values of s_f lie around 1, with some values as high as 3 (see for example, Freeze, 1975., and Bakr, 1976).

Oliver (1993) uses a perturbation approach to derive the Fréchet derivatives and kernels for the effect of two-dimensional areal variations in transmissivity and storativity on drawdown at an obervation well. His study shows that observation well drawdown is relatively sensitive to near well transmissivity variation, especially if the nonuniformity is not radially symmetric around the well.

The Direct Method

An equal computational effort is required by the direct method in which the primary equations are differentiated with respect to each parameter and the set of sensitivity equations is then solved by inversion to determine the sensitivity coefficients.

The Adjoint Method

The adjoint method requires only one 'adjoint' run in addition to the flow equations, regardless of the number of parameters involved. The adjoint method is computationally advantageous for problem where the number of performance measures is less than the number of parameters for which sensitivities are desired (Freeze and Zapf-Gilje, 1988).

Evidence For Lognormal Distribution of K

Freeze (1975) reports a large body of direct and indirect evidence to support the statement that the probability density function for hydraulic conductivity is log normal (direct evidence **as reported by Freeze, 1975**: Law , 1944; Bulnes, 1946: Warren et al., 1961; Willardson and Hurst, 1965; McMillan, 1966; Bennion and Griffiths , 1966; Burst et al., 1968 / indirect evidence as reported by Freeze, 1975: Atchison and Brown , 1957; Warren and Price, 1961; Bouwer, 1969; Davis, 1969).

If the hydraulic conductivity K is log normally distributed, we can define a new parameter Y = log K that is normally distributed, that is Y: $N[\mu_y, \sigma_y]$ where μ_y is the mean and σ_y the standard deviation.

Statistical Parameters For Log Normal Frequency Distribution Of Hydraulic Conductivity

Freeze (1975) summarized in Table 1. the σy estimates that could be gleaned from the various published log normal conductivity distributions for various rock and soil types. It appears that the range of s_y lies between 0,2 and 2,0. According to Freeze (1975) the statistical parameters he compiled from these sources did not support however the contentions that the variance in hydraulic conductivity distributions is dependent of the mean values.

TABLE 1. Statistical Parameters for Log Normal Frequency Distribution of Hydraulic Conductivity

(Y =log K , K is in Centimeters per Second). from Freeze (1975)

SOURCE	ROCK OR SOIL TYPE	n	μ_Y	σ_Y
Bennion and Griffiths (1966) as reported by Freeze (1975).	- Conglomerate	3 018	-4.59	0.94
	- Sandstone	56 991	-5.38	0.61
	- Marly limestone	7 060	-5.38	0.46
	- Muggy limestone	17 162	-5.60	0.53
Law (1944) as reported by Freeze (1975).	- Sandstone		-3.36	0.20
	- Sandstone		-3.82	0.40
	- Sandstone		-4.60	0.40
McMillan (1966) as reported by Freeze (1975).	- Sandstone		-5.46	1.00
	- Sandstone		-5.52	0.65
	- Sandstone		-4.60	0.32
	- Sand and Gravel			0.44
	- Sand and Gravel	42		0.72
	- Sand and Gravel	16		0.54
Willardson and Hurst (1965) as reported by Freeze (1975).	Clay Loam	33	-5.51	0.45
		330	-4.00	0.85
		287	-4.60	0.93
	Silty clay	339	-4.96	0.78
		36	-4.46	1.56
		352	-3.00	0.93
	Loamy sand	121	-3.68	0.86

n = number of samples μ_Y = Mean σ_Y = Variance of the function.

Probability Density Function For The Porosity

Most of the references listed in Table I also provide information on the probability density function for the porosity . It is invariably reported to be normally distributed. For values of m_n between 10 and 30%, s_n is reported to be in the range 3 -7 %.

Controversy About The Log-Normal Distribution As The Best Fit For Soil-Water Data

Cooke et al (1992) recognize that the probability density functions for hydraulic conductivity and related soil properties such as infiltrability and pore water velocity function have been assumed to conform to log-Gaussian (log normal) distributions.

Cooke et al (1992) report however, several examples to show that the log-normal assumption is not definitive.

As a first evidence, Cooke et al (1992) analyze the field hydraulic conductivity measurements taken by Nielsen et al (1973). These measurements were reported originally as log-normally distributed by Nielsen et al (1973). Cooke et al (1992) find however, that depending on the goodness-of-fit procedure used, there are at least eight other distribution functions that provide a better fit than the log-normal distribution.

Cooke et al (1992) analyze two more data sets, those are

1) The steady-state infiltrability measurements taken by Loague and Gander (1990) and

2) the pore-water velocity at 359 sites on a 150 ha field evaluated by Biggar and Nielsen (1976).

In both cases, the log-normal distribution was not the unique and best distribution for characterizing the spatial variability of these soil hydraulic properties. Cooke et al (1992) also refer to the study of the Borden aquifer in Canada where the largest sampling of hydraulic conductivity was taken. These data were analyzed by Stiducky (1986) who concluded that log-normal distribution fitted the data well. Cooke et al (1992) quote Woodbury and Stiducky (1991).

> "The inability to unambiguously distinguish between the various competing probability density functions to describe hydraulic conductivity is disturbing... It seems that the standard practice in groundwater hydrology of assuming that spatial variations in hydraulic conductivity follow a log normal distribution is subject to debate and that stochastic theories constrained by such an assumption may be restricted in their general applicability".

The Concept Of The Representative Elementary Volume (REV)

The geometry of the pores is, so complicated that it is generally simplified by abandoning the microscopic scale and analyzing it on the macroscopy level by introducing the concept of continuum.

Walton (1970) makes a clear distinction between the microscopic and macroscopic response of groundwater flow. On a microscopic scale the velocity of movement of a particle of water through the interstices of an aquifer is random. In stochastic modeling the aquifer properties (hydraulic conductivity, transmissivity, storativity) are regarded as random spatial functions. As a result, flow variables like water head, specific discharge, velocity, etc. are also random functions. The random medium is then viewed as a family of media. Each member is hydraulically characterized by its basic hydrologeologic parameters, each parameter having a certain probability of occurrence. So each basic parameter has its own probability distribution unknown to us.

Walton (1970) believes however, that on a macroscopic scale, the head and its gradient may be assumed uniform and equal to the average of the heads and gradients at many points over small volumes of the aquifer containing a great number of interstices. Consequently, the flow per unit area may there be assumed uniform and equal to the average of flows through many small elemental cross-sectional areas cutting a great number of these interstices.

These small representative volumes in Walton's mind are basically what Bear (1972) describes through his concept of representative elementary volume (REV) for defining macroscopic properties.

To Bear (1972), hydraulic conductivity, porosity, and storativity are all macroscopic properties. The REV (Representative Elementary Volume) is of course smaller than the total volume of the medium, yet it is much larger than the size of the individual pore.

Sagar (1978) notes that it is very difficult to decide on the size of the REV. For example, is it the usual size of the cored soil samples or is it the volume covered by a pumping test? Sagar (1978) concludes that the REV concept is therefore not precise and should be viewed only as a device for replacing the randomly varying macroscopic properties by single-valued quantities which then appear as coefficients in the deterministic hydrodynamic equations of flow.

The concept of REV could be more than just a mathematical concept and the fact that the size of REV remains to be defined does not invalidate its existence.. There is evidence in the field that supports this physical reality such as Dagan (1988) who concludes that the spread of solute is dominated by large-scale heterogeneity, rather than by pore-scale heterogeneity [1].

Statistical analyses have been carried out by Hoesksema and Kitainidis (1985) with data from 31 regional aquifers to quantify the "unstructured" and "structured" property variability as well as the distance over which two measurements of the quantity of interest tend to become uncorrelated (the integral scale).

Spatial Correlation Structure of T, K, and S

Data from 31 regional aquifers are analyzed by Hoesksema and Kitanidis (1985) to identify the horizontal spatial correlation structure of transmissivity (T), hydraulic conductivity (K), and storage coefficient (S). Results of their analysis indicate that the logarithms of these properties generally pass normality tests.

Table 2 below from Hoesksema and Kitanidis (1985) shows the minimum, median, average, and maximum values for each parameter of the log-transformed measurements from 31 regional aquifers.

The parameter "*f*" is the integral scale or range. We saw previously that its value represents the distance over which two measurements of the quantity of interest tend to become uncorrelated and therefore measures the extent of the spatial correlation. Variability which can not be attributed to significant spatial separation of measurement points is described by V_n (nugget). The variance of fluctuation attributable to spatial separation using the exponential form is V_s. The parameters V_n and V_s measure the "unstructured" and "structured" property variability.

To make useful conclusions from this table the numbers given in the "median value" columns are preferred. Hoesksema and Kitanidis (1985) explain that the reason for this is that the extreme cases tend to skew the mean value away from the typical

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[1] The amazing macroscopic level of "self-adjustment " of drainage systems and this ability to behave with continuity in its search for stability and uniformity suggests

value. Furthermore, the extreme results (in particular the maximum values) are probably affected by the problems with parameter identifiability . The mean values for integral scale are comparable to the results presented in the work by Delhomme (1979).

Variability Pattern versus Aquifer-Bearing Formation

Hoesksema and Kitanidis's analysis (1985) shows that bedrock aquifers typically display smaller structured transmissivity variability and larger unstructured transmissivity variability than aquifers composed of unconsolidated materials. The larger unstructured variability is possibly related to extreme transmissivity values associated with localized fractures. The smaller structured variability is due to the greater uniformity of the material structure over large distances.

Possibly due to the measurement error and scarcity, Hoesksema and Kitanidis (1985) report that **no** significant spatial correlation could be detected in a regional scale between measured values of storage coefficients.

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that total randomness in flow response is not a long term reality.

TABLE (2) Summary of Parameter Estimation (Log-Transformation Models Only).

from Hoeksema and Kitanidis (1985). One mile = 1,609 km.

Parameter	Minimum Value	Median Value	Mean Value	Maximum Value	No. of Runs	Aquifer Material State	Aquifer Property
Vn	0.00	0.88	2.65	16.3	10	Consolidated	Transmissivity
Vs	0.00	0.30	0.83	5.17	10	Consolidated	Transmissivity
l, miles	1.4	14.8	17.4	44.7	7	Consolidated	Transmissivity
Vn	0.00	0.43	1.14	7.10	19	Unconsolidated	Transmissivity
Vs	0.07	0.88	1.52	6.00	19	Unconsolidated	Transmissivity
l, miles	2.7	11.9	28.3	282.1	19	Unconsolidated	Transmissivity
Vn	0.00	0.39	0.74	3.24	14	Unconsolidated	Hydraulic Conductivity
Vs	0.00	0.56	0.96	3.77	14	Unconsolidated	Hydraulic Conductivity
l, miles	0.8	6.3	16.4	127.0	19	Unconsolidated	Hydraulic Conductivity
Vn	0.160	1.55	2.99	12.1	8	Unconsolidated	Storage Coefficient
Vs	0.00	0.00	0.22	1.56	8	Unconsolidated	Storage Coefficient
l,miles	24.1	no data	no data	99.0	2	Unconsolidated	Storage Coefficient

V_n = Variance not attributable to spatial separation; unstructured property variability

Vs = Variance of fluctuation attributable to spatial separation; structured property variability

l = Distance over which two measurements become uncorrelated. 1 mile = 1.1 km

Sensitivity of Models to Errors in Soil Hydraulic Properties

A sensitivity analysis of the PREFLO model (Workman and Skaggs, 1992) indicated that the model was most sensitive to errors in K(Θ) and h(Θ) data that were used as input. In both studies, the sensitivity to the K(Θ) relationship was investigated by varying the magnitude of the K(Θ) values while maintaining the original shape of the relationship. The sensitivity to the shape of the K(Θ) relationship was not studied.

Workman and Skaggs (1992) find that PREFLO and DRAINMOD were sensitive to the error caused by using estimated rather than measured soil-water properties. They evaluated the sensitivity of the model by computing the difference in yearly totals for simulated evapotranspiration , infiltration , runoff, and drainage for each of the three years between the totals obtained while using various levels of estimated data and the totals obtained while using the measured K(Θ) and h(Θ) data.

Workman and Skaggs (1992) find that the ability of the hydrological simulation models PREFLO and DRAINMOD to correctly simulate evapotranspiration, infiltration, runoff, and drainage was more a function of the accuracy of the soils input data than the type of model being used. Both models are found sensitive to the estimated K(Θ) data.

Darcy's law Limits of validity

Darcy's law is valid only when flow is laminar, and can not be applied to soils with large-size grains. The flow of groundwater is not laminar in soils with particle sizes greater than those of coarse sands.

According to Walton (1970), from both theory and experiment, almost all natural groundwater flow has Reynolds numbers less than unity, and Darcy's law is therefore generally applicable. In some rock aquifers, such as dolomite, containing cracks and crevices, the flow may deviate from Darcy's law. Flows in the immediate vicinity of a heavily pumped well with steep hydraulic gradients may violate Darcy's law. Kashef (1986) concludes that ordinarily it may be assumed that the flow is laminar, and the analyses may be based on Darcy's law with modifications to account for turbulence in the immediate vicinity of production wells.

The Specific Permeability, Intrinsic Permeability

The specific permeability, intrinsic permeability, physical permeability, or simply permeability (Taylor, 1948) is noted "K_p". **K_p** depends on the soil properties only and is related to K as follows:

$$K = K_p \frac{\gamma_w}{\mu} \qquad (2)$$

where μ = the absolute or dynamic viscosity, g×s /cm ^{2} .
γ_w = the unit weight of water, g/cm^3.

The Hydraulic Conductivity K And The Permeability K_p

The constant K of proportionality between the average macroscopic velocity **v** and the hydraulic gradient i_g in Darcy's Law is the hydraulic conductivity, coefficient of permeability, or transmission constant. Most groundwater hydrologists and agricultural engineers prefer the term hydraulic conductivity, whereas geotechnical engineers prefer the term coefficient of permeability.

To complete the discussion below on the fundamental characteristics of the specific yield and the storage coefficient, a memory refreshment on BASIC PRINCIPLES AND FUNDAMENTAL DEFINITIONS in soil mechanics is given in Appendix A.

The Coefficient Of Volume Compressibility

According to the consolidation theory, the hydraulic conductivity is given as:

$$K = c_v\, m_v\, \gamma_w \qquad (3)$$

where K = hydraulic conductivity, cm/s
c_v = coefficient of consolidation, cm^2/s
m_v = vertical compressibility of the soil, cm^2/g
γ_w = unit weight of the fluid, g/cm^3.

Once the coefficients c_v and m_v are determined from consolidation tests, K can be easily determined from the above equation. The coefficient m_v is also known as the coefficient of volume compressibility.

The coefficient of compressibility is defined as follows:

$$m_v = - dn/dP \qquad (4)$$

where P is the pressure applied to the sample in the consolidation test,

n is the total porosity.

So the coefficient of compressibility is defined as the change of porosity with the change of pressure applied [2]. The minus sign indicates that the porosity decreases when the pressure applied increases.

also from (2) we get:

$$c_v = K / (\gamma_w \times m_v) \qquad (5)$$

Storage Coefficient Of A Confined Aquifer

S the coefficient of storage is given analytically as follows (Jacob, 1950):

$$S = n \gamma_w (\beta_w + \frac{m_v}{n}) D_q \qquad (6)$$

From Eqs. (3, 4, 5) and (6) we get:

$$S = n \gamma_w \beta_w D_q + \gamma_w m_v D_q = d\frac{\gamma_w}{dp} n D_q - \gamma_w \frac{dn}{dp} D_q \qquad (7)$$

where β_w = the water compressibility or the reciprocal of its bulk modulus E_w.

D_q = the thickness of the confined aquifer.

γ_w, n were defined previously.

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[2] In the soil mechanics literature it is customary to treat -dn/ds'= m_v, as the coefficient of volume change. The coefficient of compressibility is noted as m_v by Narasimhan and Kanehiro (1980) and defined as = -de/ds', where n is the porosity, e is the void ratio and s' is the effective stress. The coefficient of compressibility is defined by Smith (1957) and Capper and Cassie (1976) as m_v and = - (1/(1+e))×de/dp where p is then understood as the effective pressure applied to the soil, the pressure which causes the soil particles to consolidate. In any case, the coefficient of compressibility is to be understood as the decrease in unit volume per unit increase of effective pressure.

m_v = may be determined experimentally from a consolidation test as discussed earlier.

Considering a vertical prism of height D_q (the thickness of the confined aquifer) and of a **unit cross section**, then $D_q = V$ numerically. If the medium is completely saturated, then we get :

$n = V_v / V = V_w / V$ and $dn = dV_w / V$. Since $dP = - dr'$.. With proper substitution (Kashef, 1986) we get:

$$S = dV_w / dh \qquad (8)$$

For a unit value of dh , $S = dV_w$, which is the change in the volume of water in the pores of the prism under consideration owing to a change of unit total head. **Thus S is defined as** " the volume of water released from storage, from a soil prism of a unit cross-sectional area and a depth equal to the entire thickness of the aquifer, due to a unit change in the hydraulic head ".

Compressibility And Elasticity Of Aquifers

The volume of water released from storage consists of two components: water expansion due to compressibility characteristics of water and water released due to a decrease in pore space resulting from compression of the soil skeleton.

The compressibility and elasticity of aquifers have long been recognized. **The volume elasticity of aquifers is relatively important in the storage of groundwater only under artesian conditions.** To illustrate this Walton (1970) reports the findings of Ferris et al (1962) who consider the forces acting on the aquifer-aquitard or aquifer-aquiclude interface.

If the aquifer is compressible and elastic and the total load on the interface remains constant, then a reduction of water pressure due to pumping from a well results in an increase in the load borne by the skeleton of the aquifer. The aquifer is compacted, reducing the interstitial space. At the same time, the water expands to the extent permitted by its elasticity.[3]

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[3]Water withdrawal from an artesian aquifer lowers the piezometric surface and increases the effective stress which represents the intergranular pressure (grain-to-

In response to the slight expansion of the water itself and a small decrease in porosity due to the slight compaction of the skeleton of the aquifer, a certain amount of water will be released from storage within the aquifer. In response to cessation of pumping, the water pressure gradually increases, resulting in compression of the water and expansion of the skeleton of the aquifer. This releases interstitial space for storing water moving into the part of the aquifer affected by the skeleton.

Kashef (1986) estimates the ratio of the volume of water released from storage due to water expansion to that released due to the soil compressibility to be in the range of 0.1% to 0.4% .

If the artesian aquifer is perfectly elastic and water levels in recharge and discharge areas do not change, the original artesian head will ultimately be restored. (Walton, 1970).

Jacob's (1940) original definition of the coefficient of storage was given in terms of aquifer thickness and change in aquifer thickness rather than volume. In doing so, he was primarily concerned with the one-dimensional problem of radial flow to a fully penetrating well.

The Coefficient Of Specific Storage S_s

The coefficient of specific storage S_s is defined as

$$S_s = \frac{S}{D_q} = \gamma_w (n \beta_w + m_v) \qquad (9)$$

where all terms are defined previously.

The S_s unit is cm^{-1}. Although the use of S_s as a parameter is uncommon, it is more logical to use than S, which depends on the depth of aquifer D_q. Kashef(1986) explains that in comparing two confined aquifer of the same soil characteristics but with different depths, S_s would then be constant, while S would vary.

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grain pressure). The effective stress (σ') therefore compresses the soil skeleton, reducing the volume of the pores. This is a direct result of Terzaghi's (1943) equation: $\sigma' = \sigma_t - u$ where s_t is the total stress equal to the weight of the material above the cross-sectional area, u is the upward water pressure or neutral stress.

The specific storage parameter is still used by many in the restricted sense of a coefficient occurring in the partial differential equation describing fully saturated flow. However, with the significant increase in our computational abilities using powerful numerical integration techniques, Narasimhan and Kanehiro (1980) believe there is a need to have a more fundamental appreciation of the storage parameter as it relates to transient fluid flow in porous media. Such a fundamental approach is taken by Narasimhan and Kanehiro (1980) who express the specific storage S_s in four different ways depending on the choice of volume-normalization form.

Specific Yield Or Storage Coefficient Of Unconfined Aquifers

In unconfined aquifers, a drawdown produces water drainage by gravity through the drawdown depth and water release from storage from theoretically the entire saturated thickness of the aquifer.. Water is partially retained around the particles by the forces of molecular attraction between the solid surfaces of these particles and the water molecules (adhesion) and between the water molecules close to these solid surfaces (cohesion) .

The ratio of the volume of water retained in a soil mass to the total volume of this mass is the *specific retention, field capacity or water-holding capacity*. The difference between the porosity "n" and the field capacity (or specific retention) after drainage by gravity is completed is the specific yield or drainable porosity S_y .

The drainable porosity was introduced originally by Boussinesq (1903, as reported by Broughton, 1972) who showed that the differential equation for steady state flow to parallel subdrains in a homogeneous soil obtained by the Dupuit-Forcheimer assumptions could be adjusted to the case of nonsteady flow by adding a rate of change of drainable soil water in storage term S_y dh/dt (noted as f dy/dt in Broughton, 1972) where S_y was then defined as the drainable porosity or specific yield.

The water yield by gravity produced by a certain drawdown is not instantaneous. The yield capacity increases gradually with time from zero to its maximum value S_y during the drainage process. The intermediate delayed yield S_{ya} is of magnitude less than S_y . The portion of the soil prism below the lowering water table after its drawdown

is also affected by the drop in head in the same manner as in confined aquifers. Therefore, the total amount of water released from storage in unconfined aquifers after a certain time corresponds to a storage coefficient $S_{t,y}$ in which:

$$S_{t,y} = S_{ya} + S \quad (10)$$

In water-table aquifers, the coefficient of storage is therefore given by:

$$S_{t,y} = S_y + \gamma_w n D (\beta_w + \frac{m_v}{n}) \approx S_y \quad (11)$$

where D is the saturated thickness of the aquifer and al other terms were defined previously.

The delayed yield can be visualized as a small portion of the storage coefficient S that is associated with compression of the aquifer similar to a confined aquifer and a large portion that is associated with dewatering of pore space due to a falling water table.

Walton (1970) explains that under water-table conditions, the compressibility of aquifers is negligible in comparison with S_y , the specific yield associated with the gravity drainage of interstices.

Thus the coefficient of storage of unconfined aquifers is basically equal to the specific yield or drainable porosity. This should be very good news since drainable porosity is simply expressed as a percentage of soil volume being filled with air as the soil is drained from saturation to field capacity. As noted by Broughton (1972), this concept may be appealing in simplicity but this simplicity is an illusion.

First, the soil moisture content does not change abruptly but rather gradually from saturation to field capacity as the pore water tension increases above the water table. The depth of this transition may also be different when the profile is draining than when it is recharging. The drainable porosity may also vary with depth.

Broughton (1972) tested four methods of determining drainable porosity and finds that the most suitable method is to take volumetric soil samples when the soil is at field capacity. The measured field capacity water content may then be subtracted from

the saturation water content to get a value for drainable porosity. It should be noted that Broughton's measurements relate to depths of up to three meters from the soil surface.

Boonstra and De Ridder (1990) is of the opinion that the collection of volumetric soil samples or in-situ measurement of the watertable drop and the amount of water drained are techniques that are time-consuming and therefore most probably be limited to just a few sites of the basin. This produces a far from reliable picture of the areal distribution of the specific yield.

Surprisingly, Boonstra and de Ridder (1990) prefer the grain-size method applied to well logs. Boonstra and De Ridder (1990) give a table with orders of magnitude and ranges of specific yield of different materials (after Morris and Johnson, 1967). Provided that driller's logs are available and the logs give sufficient details on the grain size distribution and on clay and gravel contents of the layers pierced, then a weighted mean specific yield is calculated for the zone in which the watertable fluctuates by applying the grain-size method based on the specific yield values found in the table for the materials matching those identified by the well driller.

Aquifer Pumping Test

Steady-State Flow Conditions

A constant rate of pumping Q does not mean that the flow is steady. In a steady-state flow system, the magnitude and direction of water velocity at any point in the medium remains constant at all times; otherwise the flow would be transient.

The circle of influence, is a groundwater divide, which is the boundary between the zones that are affected and unaffected by pumping. Through a period of pumping t, the water volume pumped from the well is derived entirely from the zone between the effective radius (r_w) of the well and the radius of influence (r_e) of the well. Luthin (1957, see 1983) emphasizes the importance of estimating the effective radius of the "as built" well system.

If there is no natural (or artificial) **recharge**, the pumped water is derived solely from storage. After a long period of time (theoretically $t = \infty$), the rate of compressibility of the soil material becomes negligible, leading to almost stationary

values of the radius of influence and the drawdown profile curve. In the case of an unconfined aquifer that is extensive and with no source of recharge or leakage, steady-state conditions can not be reached because the free surface continues to drop at a decreasing rate by continuous pumping, thus expanding the zone of influence over time.

Kashef (1986) notes that stationary values of $r_{e,t}$ and $h_{w,t}$ are produced mainly by the effect of natural recharge rather than by reaching 100 percent soil compressibility.

After a definite time however, the major portion of ultimate compressibility (for example 90 percent) is reached. Beyond this period, the change in drawdown is negligible. In conclusion, a steady-state condition may then be assumed to occur after a reasonably long time beyond which no appreciable changes in drawdowns are measured.

Precautions To Take In Drawdown Measurement

Walton (1970) insists on the fact that drawdown is not to be determined from the level that was measured just prior to the start of the aquifer test. **Ideally water levels should be measured for a period prior to pumping equal to the pumping period.** The water-level trend before pumping starts is then extrapolated through the pumping period, and differences between extrapolated stages of the water level that would have been observed if the well had not been pumped and water levels measured during the pumping period are then computed. Moreover, before water-level data are used, they must be adjusted for the following :

1) pumping rate changes in nearby production wells,
2) atmospheric-pressure fluctuations,
3) application or removal of heavy loads in the vicinity,
4) tidal or river efficiency, and for the
5) Formation losses.

Mathematical expressions of confined and unconfined flow in an aquifer test assume an ideal well without screen or casing. If the well is screened throughout the depth of the aquifer, screen losses are produced by friction during water entry to the well. When a gravel pack is needed, the piezometric surface near the well is subjected to

additional lowering due to the additional head losses resulting from turbulent flow within the gravel pack surrounding the well.

Delayed Yield In Pumping Cycle

The restricted air movement in the vadose zone due to layers of high water content produces below atmospheric pressures in the pore air above the water table, which cause the water table initially to drop faster than the dewatered zone. **The initial yield thus is less than the full specific yield, which develops after a certain water table drop.**

Flow to a pumped well in an unconfined aquifer commonly produces water level drawdowns in observation wells, that when they are plotted against time on logarithm paper do not conform to the Theis equation (Theis, 1935) but show an inflection in the resulting curve (Bouwer and Rice, 1978). The inflection can be produced by analytical solution of the flow system, if the initial yield S_{ini} is taken to be smaller than the final yield $S_{fin.}$ obtained after continued pumping. For this reason, the phenomenon has variously been called delayed yield, delayed drainage, delayed gravity response, or delayed water table response.

It is important to understand this phenomenon which illustrates the various stages in a pump cycle.

Boulton (1963) as reported by Krozynski and Dagan (1975) introduced the concept of delayed yield for unconfined formations, by assuming that the total storativity is the sum of an instantaneous storativity and a gravitational one (at the free surface), the latter one responding with an exponential time delay. In Boulton's solution the drawdown is governed by the instantaneous storativity at short times and by the effective porosity at long times.

Moench and Prickett (1972) consider the aquifer to be initially confined but changing to an unconfined aquifer as the piezometric surface dropped below the upper confining layer. This produces an abrupt increase in S after a certain drop in piezometric surface.

According to Krozinski and Dagan (1975), Moench and Prickett's (1972) approach of a confined aquifer situation changing to an unconfined condition is

physically sound but does not explain delayed yield in true, unconfined aquifers. Boulton's delay in the release of pore water from storage conflicts with the theory of vertical drainage of a uniform soil in response to a falling water table, which shows that the drainage rate is highest immediately after a drop in water table even if such a drop is instantaneous (Youngs, 1960).

Narasimhan and Zhu (1993) are of the opinion that although Boulton did not provide a rational physical explanation, his exponential assumption has some merit in that it implicitly provides for a time dependent drainage process which seems to occur in the unsaturated zone.

Cooley and Case (1973) have shown that Boulton's equation is an exact solution of flow in an nonhomogeneous system composed of a rigid phreatic aquitard on top of a main aquifer. Boulton's delay index is related to the thickness, hydraulic conductivity, and specific yield of the aquitard.

Neuman (1974) has generalized Dagan's (1967) solution by incorporating compressibility in the equation of flow. His results are similar to those of Boulton (1963), i.e., elastic response dominates drawdown at the beginning and free surface at large t'. Neuman (1974) does not introduce artificial coefficients however, and his solution depends solely on elastic storativity and drainable porosity. Neuman suggests that the compressibility of unconfined aquifers may be much larger than that of similar confined layers, and has therefore more important role than is generally assumed. This contention, however, was based mainly on the analysis of pumping tests by Prickett (1965) and would apply where drawdowns are large for long durations.(eg. Mexico City).

Effects Of The Unsaturated Zone

It has been found that flow in the unsaturated zone causes faster drawdowns at early times and slower ones at later times than those predicted by saturated flow theory.

Neuman (1972) concludes that unsaturated flow effects are insignificant and analyzes the system on the basis of two storage coefficients: a small S that is associated with compression of the aquifer similar to a confined aquifer and a large S that is associated with dewatering of pore space due to a falling water table. The transition

from the small storage coefficient to the large storage coefficient then followed from the analytical solution.

Krozinski and Dagan (1975) believe that the unsaturated zone may have some influence upon drawdowns only in the case of very shallow rigid aquifers and/or soils with an unsaturated zone of large effective vertical extent. Even in those marginal cases its influence could only be detected at the onset of pumping at very shallow observation wells close to the pumping well. Krozinski and Dagan (1975) are of the opinion that if the dimensionless product a'D is large then the unsaturated zone rapidly adjusts itself to the free surface drop, and its influence upon the flow in the unsaturated zone becomes negligible.

where **1/a'** may be regarded as the 'characteristic thickness of the unsaturated zone'.

D is the initial saturated thickness of the aquifer.

Typical values of **1/a'** for sand may range between 0.1 meter < 1/a' < 0. 05 meter.

Estimating Aquifer Parameters From A Pumping Test In An Unconfined Aquifer

Fully penetrating wells

The coefficient of transmissibility and storage of water-table aquifers with fully penetrating wells and constant-discharge conditions may be determined from aquifer test data by the type-curve graphical method devised by Boulton (1963) and described by Prickett (1965).

Edwards (1991) analyzed the data from a constant head pumping test from a horizontal well by use of four analytical methods (as reported by Edwards, 1991) :

- Two methods developed by the Bureau of Reclamation and presented by Dumm (1954).
- Kirkham and Gaskell's method (1950).
- Moody's method (1966)

Each of these methods is applied to find the specific yield. Hydraulic conductivity was determined by Darcy's Law. Edwards (1991) develops also his own method and compares with the results obtained from the four methods above.

The five methods are explained in detail and can be directly applied to any similar pumping test in an unconfined aquifer. A plot comparing the calculated heads to the recorded data indicates that the calculation underestimates the drawdown toward the beginning of the pumping test and overestimates the drawdown toward the end of the 30 hours test.

Partially Penetrating Wells in an unconfined aquifer

Partial penetration is not an exception but a common case according to Sen (1995) who says :

> " Most often in practical studies the wells are partially penetrating due to economic reasons or simply because of lack of knowledge about the true saturated thickness of aquifer".

In a case of partial penetration, Thiem's equation is not applicable because groundwater flow encountered in patially penetrating wells results in a complex flow net leading to three-dimensional flow. At the sharp corners escpecially, the groundwater velocity is comparatively higher than any other part of the entrance section. The velocity distribution is nonuniformm violating the validity of Dupuit-Forchheimer assumptions.

However if we assume that at large distances from the pumping well the velocity is again uniformly distributed and the streamlines are parallel to each other, one can conclude that Thiem's equation is applicable at large distances, but for small distances, a new formulation is necessary. Sen (1995) reports that practical experiences tend to indicate that beyond a radial distance equal to twice of the saturation thickness, the drawdown is approximately equal to that of the fully penetrating case.

Partial penetration and anisotropy, have been considered by Dagan (1967). Incorporation of partial penetration makes the solution valid much closer to the pumping well than the extension of the Theis formula to unconfined aquifers which is developed with the assumption of a constant horizontal velocity component along the vertical. Anisotropy as discussed previously is taken into account by a horizontal

coordinate stretching. Newman (1974) has generalized Dagan's (1967) solution by incorporating compressibility in the equations of flow. At sufficient time, Dagan and Newman's solutions approach each other, and both converge to the Theis solution for large horizontal radial coordinate and long pumping time.

For a confined aquifer in unsteady-flow, Hantush's modification of the Theis method or of the Jacob method, can be applied. Whereas in steady-state flow the method developed by Huisman (1964) can be used. For unconfined aquifers under unsteady-state conditions, the Streltsova curve fitting method or the Newman curve-fitting method can be used. All these methods are well explained by Kruseman and de Ridder (1990).

In general a penetration exceeding 85% can be considered as a full penetration.

Single Well Test

A single well test is a test where water table readings are taken only from the main well and from no observation well. Because of the man-made disturbances around the well that affect the groundwater movement especially in the viscinity of the well, single well tests are often not reliable. This is why it is said that a well test is conducted primarily to evaluate well characteristics and not the aquifer. In a single-well test, well-bore storage must be considered when analizing the drawdown data.

Papadopulos and Cooper (1967) observed that the influence of well-bore storage on the drawdown in a well decreases with time and becomes negligible at time

$t > 25\ r^2_c\ /\ KD$, where r_c is the radius of the unscreened part of the well, where the water level is changing.

In order to determine whether the early-time drawdown data are dominated by well-bore storage, Kruseman and de Ridder (1990) recommends to make a log-log plot of drawdown versus pumping time. If the early-time drawdowns plot as a unit-slope straight line, we can conclude that well-bore storage effects exist.

In order to find out what the drawdown in a well would be if it were pumped at a rate that differs from the rate during the pumping test, Jacob (1947) introduced the step-drawdown test.

A step-drawdown test is a single-well test in which the well is pumped at a low constant discharge rate until the drawdown within the well stabilizes. The pumping rate is then increased to a higher constant-discharge rate and the well is pumped until the drawdown stabilizes again. This process is repeated at least three steps, which should all be of equal duration (Kruseman and de Ridder , 1990).

If the drawdown is recorded at the pumped well only then Dupuit's solution can be applied but the solution becomes approximate because the radius of influence is then calculated using an approximate solution and the effective radius of the well is also approximated.

By applying the principle of superposition to Jacob's equation, Hantush (1964) could express the drawdown in a well during the nth step of a step-drawdown test. The resulting procedure suggested by Hantush (1964) and Bierschenk (1963) is applicable if the following assumptions[4] are satisfied:

1. The aquifer is confined, leaky or unconfined;
2. The aquifer has a seemingly infinite areal extent;
3. The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by the test;
4. Prior to pumping, the piezometric surface is horizontal (or nearly so) over the area influenced by the test;
5. The well penetrates the entire thickness of the aquifer and thus receives water by horizontal flow;
6. the aquifer is pumped step-wise at increased discharge rates;the flow to the well is an unsteady state;
7. the non-linear well losses are appreciable and vary according to the expression CQ^2.

[4] In Appendix D, are given the assumptions made by Hantush(1967) in his solution for continuous recharge from both circular and rectangular basins. We shall comment these in the analysis of our single well test data.

Rorabaugh (1953) is of the opinion that the non linear losses do not necessarily vary with the square of the flow rate as suggested by Jacob but rather with the flow rate the power P. In Roraboug's method the last assumption is replaced by : the non-linear well losses are appreciable and vary according to the expression CQ^P. Kruseman and de Ridder report that the value of $P = 2$ is still widely accepted.

When Dupuit's solution is applied, the curve obtained (say the Dupuit's curve) intersects the surface of the well below the true free surface. The elevation of the free surface can be found using a relationship derived by Rabbit and Caldwell (1948). This is explained by Kashef (1986) who also derives the total-head and the pressure-head diagrams.

In the case of water-table wells the distribution of the vertical velocity component at a vertical section is linear (Polubarinova-Kochina, 1962 as reported by Kashef , 1986). The vertical velocity decreases gradually from a maximum value at the free surface downward to zero at the impermeable stratum. This linear distribution of the vertical velocity component produces a parabolic distribution of the total-head diagram. Monitoring of observation wells during pumping tests, increases reliability and makes estimate of drawdown profiles possible.

Recovery Tests

The analysis of a recovery test is based on the principle of superposition that after the pump has been shut down, the well continues to be pumped at the same discharge as before and that an imaginary recharge, equal to the discharge, is injected into the well.

The Theis recovery method is widely used for the analysis of recovery tests. Newman (1975) showed that the Theis recovery method originally derived for confined aquifers can be applied to unconfined aquifers for late-time recovery that is when the effects of elastic storage, which set in after pumping stopped, have dissipated. The residual drawdowns (s') will then fall on a straight line in the semi-log s' versus t / t' plot used in the Theis recovery method.

Idealized Assumptions

Kashef (1986) believes that the accuracy of the aquifer test results are affected only slightly by the "idealized assumptions", such as uniform thickness of the aquifer, horizontal boundaries, and homogeneity of aquifer materials. Although most aquifers are anisotropic, the effect on drawdowns is minor (U.S Bureau of Reclamation, 1977 as reported by Kashef, 1986) when the test well and its observation wells are fully penetrating. If the aquifer is strongly anisotropic or the wells are partially penetrating, solutions such as cited in Walton (1970) can be used but often these solutions are only approximate.

The Assumption Of An Infinitely Extensive Aquifer

The assumption of an infinitely extensive aquifer is practically never realized because of the existence of boundaries such as recharge streams and vertical barrier boundaries. In these cases, the method of images can be used with certain restrictions:

1. the drawdown in the well should be no more than 50% of the original saturated thickness of the aquifer.
2. the recorded drawdown should be adjusted before use by:

$$s_{dj} = s_d - (s^2_d / 2 h_u) \qquad (12)$$

where s_{dj} = adjusted drawdown at radius r.

s_d = measured drawdown in an observation well at a well distance **r** from the pumped well.

h_u = undisturbed height of the water table above the impervious boundary.

It is important to identify the presence of these boundaries and to locate them accurately with respect to the pumped well.

The Assumption of No Recharge

A second important assumption in most analyses of gravity wells, is that all water pumped from a well comes from storage within the aquifer and/or water yield due to gravity drainage of the zones above the continuously lowering free surface. The effects of recharged bodies, such as precipitation, irrigation water, and leakage and

seepage from water bodies such as streams rivers and lakes must be estimated so that they can be added by superposition.

Other Methods Of Analysis Of Pumping Well Tests

There are text books that explain the mathematical interpretation of pumping test data. Walton (1970) gives excellent review of numerous case studies. Bear (1979) and Bouwer (1978) are also treasures. Kruseman and De Ridder (1979, 2nd edition 1990) cover most of classical methods of analyzing pumping tests, as well as the more modern method of analyzing pumping tests in unconfined aquifers with delayed yield. Their excellent book is often referred to in the analysis of well test data. Kashef (1986) is very refreshing with its concise and well illustrated approach. Among many other sections in his book, his chapter on water wells was greatly appreciated . In Luthin's book (1967) , the chapter on theory of land drainage with tube-wells written by Dean F. Peterson, Jr. is also very helpful for understanding the hydraulics of pumping. Appreciation must also be given to Sen (1995) for his book that will also be referred to in this analysis.

Slug Test

The slug test is one of the most commonly used techniques by hydrogeologists for estimating hydraulic conductivity in the field. This technique consists of measuring the recovery of head in a well after a near instantaneous change in water level at that well. It is basically the same as the auger hole method commonly used in subsurface-drainage.

In terms of slug tests in unconfined aquifer, solutions to the mathematical model describing flow in response to the induced disturbance are complex because of the nonlinear nature of the model in its most general form. The technique of Bouwer and Rice (1976) which employs empirical relationships developed from steady state simulations using an electrical analog model, is commonly used. Amoozegar and Warrick (1986, as reported by Hyder et al, 1994) summarize related methods employed by agricultural engineers.

Hyder et al (1994) present a semi-analytical solution to a mathematical model describing the flow of groundwater in response to a slug test in a confined or unconfined porous formation. Their model is used to investigate the error rhat is introduced into hydraulic conductivity estimates through use of accepted practices. Hyder et al (1994) give also a good review of most commonly used solutions for slug tests in confined and unconfined aquifers.

Estimating Transmissivity From The Specific Capacity Of A Well

It is necessary to estimate the transmissivity from the specific capacity (yield per unit drawdown) of wells, as the determination of T by use of the equations discussed previously is often not feasible. Lohman (1972) pointed out a problem qualified then as a very modern but that has become since a daily concern : data collection is on one hand relatively costly but on the other hand, mathematical models require a large number of values of T so that transmissivity-contour maps (T maps) may be constructed.

In unconfined aquifers, such T maps imply also the construction of water-level contour maps and bedrock contour maps, from which may be obtained maps showing lines of equal saturated thickness. Lohman (1972) reports that a quantitative investigation of a 150-mile (240 km) reach of the Arkansas River valley in eastern Colotado required a T map of about 750 values. About 200 values of T were estimated from the specific capacity of wells. About 525 values were estimated by geologists from studies of logs of wells and tests holes. The remaining 25 values, thus only about 3 percent of the values were actually determined from pumping tests.

Specific Capacity

If we solve the Cooper and Jacob's equation for confined aquifer for Q/s_w (specific capacity), using s_w as the drawdown in the discharging well, and r_w, as the radius of the well, and **assuming that the well is 100 percent efficient**, we obtain that the specific capacity of a well is nearly proportional to T at a given value of t but gradually diminishes as t increases by the amount of (1 / (log t)).

This simple relationship can be written as:

$$\frac{Q}{S_w} \approx \frac{B}{\log_{10} t} \qquad (13)$$

where **t** is the time elapsed since pumping started, [min]

B is an empirical constant for the well

s_w is the measured drawdown, [m] and

Q is the pumping rate, [m^3/min]

Several methods were developed for estimating transmissivity from specific capacity from the above relationship in which well losse are neglected. . Lohman (1972) reports the methods developed by Theis (1963a), Meyer (1963), Bedinger and Emmet (1963) and Hurr (1966) . Although the latter uses the Theis and Boulton (1954) equations to allow for delayed yield from storage in the more complicated case of an unconfined aquifer, Lohman (1972) observes that none of the above methods includes corrections for well efficiency.

In all above methods it is assumed that the well is a 100 percent efficient well. No wells are 100-percent efficient. The concern for well losses is not a new concept . Jacob (1947 as reported by Lohman ,1972) was the first to describe a method for determining the effective r_w and the well loss from a multiple-step drawdown test.

Jacob (1947) has approximated the head loss resulting from the relatively high velocity of water entering a well screen as being proportional to some power of the velocity approaching the square of the velocity which in turn is nearly proportional to Q^2: thus head loss is nearly equal to CQ^2, where C = a constant of proportionality. Adding this to our previous relationship leads to:

$$\frac{Q}{S_w} \approx \frac{B}{\log_{10} t} + CQ^2 \qquad (14)$$

where Q, s_w, t and B were defined previously.

C is the well loss coefficient so that

CQ^2 are well head losses due to entrance high velocity, [m]

In an uncased well in say sandstone, r_w may be assumed equal to the radius of the well, but Lohman (1972) notes that in screened wells in particular soils, in which the

finer particles have been removed near the screen by well development , or in gravel-packed wells, the effective r_w generally is larger than the screen diameter.

Rorabaugh (1953 as reported by Kruseman and de Ridder, 1990) derived a similar equation for determining well loss and presents a more exact method for evaluation of well loss **when a larger range of pumping rates is encountered.** Lohman (1972) proposes when the aquifer is fairly permeable and the production well can be pumped at rates exceeding 135 m^3/d (25 gpm) , to compute the value of C in the above equation from the data of the variable-rate well -production test, by using Jacob's (1946) equation

$$C = \frac{\left(\frac{\Delta s_i}{\Delta Q_i}\right) - \left(\frac{\Delta s_{i-1}}{\Delta Q_{i-1}}\right)}{\Delta Q_{i-1} + \Delta Q_i} \qquad \textbf{(15)}$$

where C is the well loss coefficient and

the Δ terms represent increments of drawdown produced by each increase ΔQ in the rate of pumping.

These increments are determined by taking in each case the difference between the observed water level and the extension of the preceding waterlevel curve. Steps of any length of time may be used provided the values chosen are for the same length of time in each step. Equation (15) assumes that the well is stable and that C does not change during the variable-rate well-production test.

Walton (1970) warns us that newly completed production wells and old wells are sometimes unstable and the value of C is affected by changes in pumping rates. The value of C computed for steps 1 and 2 may be greater or less than that computed for 2 and 3 if the production well is unstable.

Walton (1970) adds that sand and gravel often may shift outside a production well during step 3 under the influence of high rates of pumping, resulting in either the development or clogging of the pores of the aquifer immediately behind the production-well screen.

If the value of C for steps 2 and 3 is considerably less than that for steps 1 and 2, it is probable that development has occurred during the variable-rate well-production test. A large increase in C with higher pumping rates indicates clogging of the production-well screen or wall.

If development during the pumping period is large, $\Delta s_2/\Delta Q_2$, will be greater than $\Delta s_3/\Delta Q_3$ and solution of Jacob's Equation will be impossible.

Logs Of Wells And Tests Holes

Table 3 was adapted from Hurr's work in the Arkansas River valley in 1963 by Lohman (1972) who recommends its application when using the layer suerposition method. This according to Lohman (1972) has been successfully used by geologist in Arkansas and Oklahoma (Bedinger and Emmet, 1963), in Nebraska, and in Clalifornia.

Methods Of Estimating Storage Coefficient

One may multiply the thickness in meters times 10^{-6} m^{-1}. Values thus estimated are incorrect as no allowances are made for porosity or for compressibility of the aquifer, but according to Lohman (1972) they are fairly reliable. Such estimates may be improved upon by comparison with values obtained from reliable pumping or flow tests. Extrapolation to other parts of an aquifer may be made with adjustments for thickness as this rule-of-thumb relationship.

TABLE 3. Average values of hydraulic conductivity of alluvia materials in the Arkansas River valley, Colorado

MATERIAL	Saturated Hydraulic	Conductivity
1.0 m/d= 24.5 U.S gallons/square feet	**After Todd (1970) Range (m/d)**	**Hurr (1963)[1] Mean (m/d)**
Shale	0.04 - 4.0	
Limestone (excluding cavernous..)	0.04 - 4.0	
Sandstone	0.40 - 40.0	
BOULDERS		
Gravel		
Coarse	4.0 - 400.0	305
Medium		290
Fine		275
Sand		
Gravel to very coarse	4.0 - 400.0	240
Very coarse		210
Very coarse to coarse		150
Coarse	4.0 - 400.0	75
Coarse to medium		30
Medium	4.0 - 40.0	15
Medium to fine		9
Fine	0.40 - 40.0	5
Fine to very fine		1.5
Very fine	0.04 - 4.0	1
Sandy loam	4.0×10^{-3} - 4.0	
Loam	4.0×10^{-4} - 4.0×10^{-2}	
Silt loam	4.0×10^{-4} - 4.0×10^{-2}	
Silt	4.0×10^{-4} - 4.0×10^{-2}	
Sandy Clay Loam	4.0×10^{-4} - 4.0×10^{-2}	
Silty Clay Loam	4.0×10^{-5} - 4.0×10^{-3}	
Sandy Clay	4.0×10^{-6} - 4.0×10^{-4}	
Silty Clay	4.0×10^{-7} - 4.0×10^{-5}	
Clay	4.0×10^{-7} - 4.0×10^{-5}	0.3

[1] **Hurr (1963 as repoted by Lohman, 1972).**

Methods Of Estimating Specific Yield

The specific yield generally ranges between 0.05 and 0.3 (5% - 30 %) and long periods of pumping are generally required to drain water-bearing material. In absence of any determination, Raghunath's (1985) recommended values for some common formation materials as shown on Table below. In this research, whenever a detailed description of the material was given by the driller then Todd (1970) recommended values for specific yield was used in estimating the specific yield. Table 4 shows typical values of porosity and specific Yield of some common formation materials.

Table 4. Porosity and Specific Yield of some common formation materials.

Formation material	Porosity (%)	Specific yield (%)
Clay	45 - 55	1 - 10
Sand	35 - 40	10 - 30
Gravel	30 - 40	15 - 30
Sand & Gravel	20 - 35	15 - 25
Sandstone	10 - 20	5 - 15
Shale	1 - 10	0.5 - 5
Limestone	1 - 10	0.5 - 5

*adapted from Raghunath (1985)

CHAPTER VII

ANALYSIS OF HISTORICAL WELL DATA

Introduction

Figure 1. shows the locations of exploration wells drilled by S.A.R.H (period 1970-1995) and their geologic environment. Figures (1a, 1b, and 1c) show the same wells but on topographic maps of different zoom display and according to different groupings that will be convenient for analysis. The coordinates of exploration wells are given in Table 1.

The groundwater in the area west of Tlacolula has been explored over a period of thirty years. Today. this aquifer is more highly more exploited than the rest of the Valley aquifers due to its greater potential. The exploration on the east side of Tlacolula no less intensive was however concentrated on the Tanivet area where it is reported that following the drilling of the exploration well POM1B-62, this artesian well ejected a 35 meter fountain yielding 200 lps of brine (in the range of 22000ppm). These two areas are treated separately although it will be seen that the geology of the Tanivet area throws additional light on the hydrogeological nature of the Tlacolula Valley.

Steady-state conditions

Steady-state conditions are rarely achieved. The municipal well of San Francisco Lachigolo is typical. it is operated less than four hours a day to fill up the municipal tank. The wells for irrigation are run more often for longer periods of time. Still. they are generally run for less than twelve hours. Productive wells are operated in batch conditions. Exploration wells conducted by the S.A.R.H during their exploration program in this research never reach steady-state conditions but they usually approached the pseudo-steady state by the end of the step-drawdown test. In many intermediate steps however the drawdown pumping was not maintained long enough to approach Jacob's straight lines conditions.

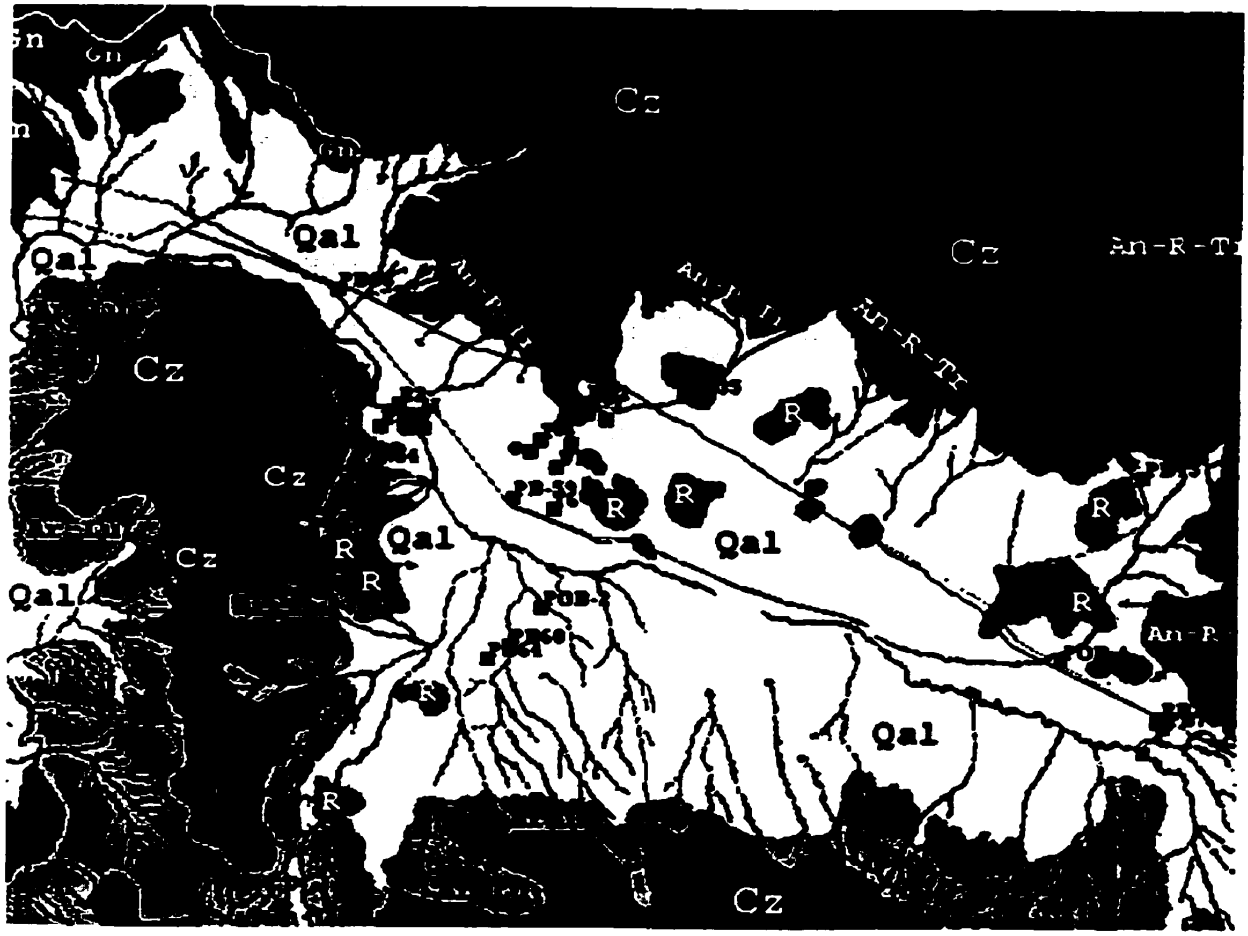


Figure (1)Map showing the groundwater exploration in the research area by S.A.R.H from 1973 - 1990.

HYDROGEOLOGY	KEY
ALLUVIUM. Given its lithological composition and its low compaction state the alluvium shows permeables characteristics with an hydrogeological potential in proportion to the thickness of the sediments and to the prevailing annual volume of recharge.	Qal
VOLCANIC. This formation form a compacted unit of microcrystallic texture with little development of interstices for storage of water and reduced permeability. This formation may have a good hydrogeological potential if fractured internally.	R Tr
LACUSTRINE DEPOSITS Materials deposited by lake waters. Given its lithology and low state of consolidation, these deposits present good storage potential but they are generally deposited with evaporites resulting in high salinity.	Ar Cg
Andesitic, Rhyolitic and Tuff Unit that has potential for water storage in very local areas of the subsoil containing in several zones some saline water due to contact with the overlaying formation .	An R Tr

HYDROGEOLOGY	KEY
Marine Rocks. Given its topographic position, stratigraphy and high clay content, this unit behaves as an impervious layer. **MARINE SEDIMENTS**	Cz Ar Lu
Impervious unit. Complete alteration of theses schists results in clay soils of poor hydrogeologic characteristics.	Eq Schists
Impervious material which at the surface has undergone a long process of weathering and granular disintegration to form a weathered product that is part of the alluvium . Granitic Gneiss	Gneiss Gn

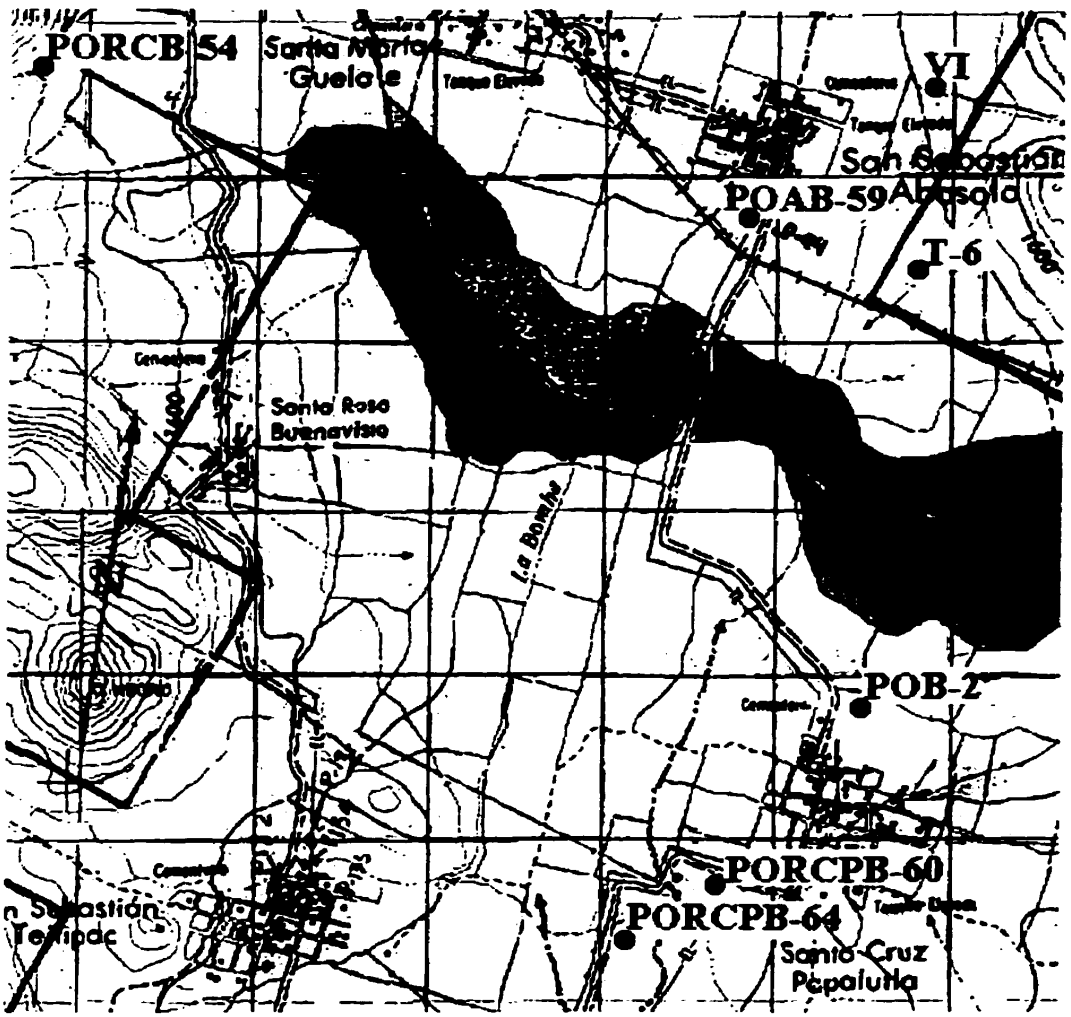


Figure 1a Map showing Exploration Well Locations PORCB-54, POAB-59, POB-2, T-6, VI, PORCPB-64 and - 60. 1 km grid.

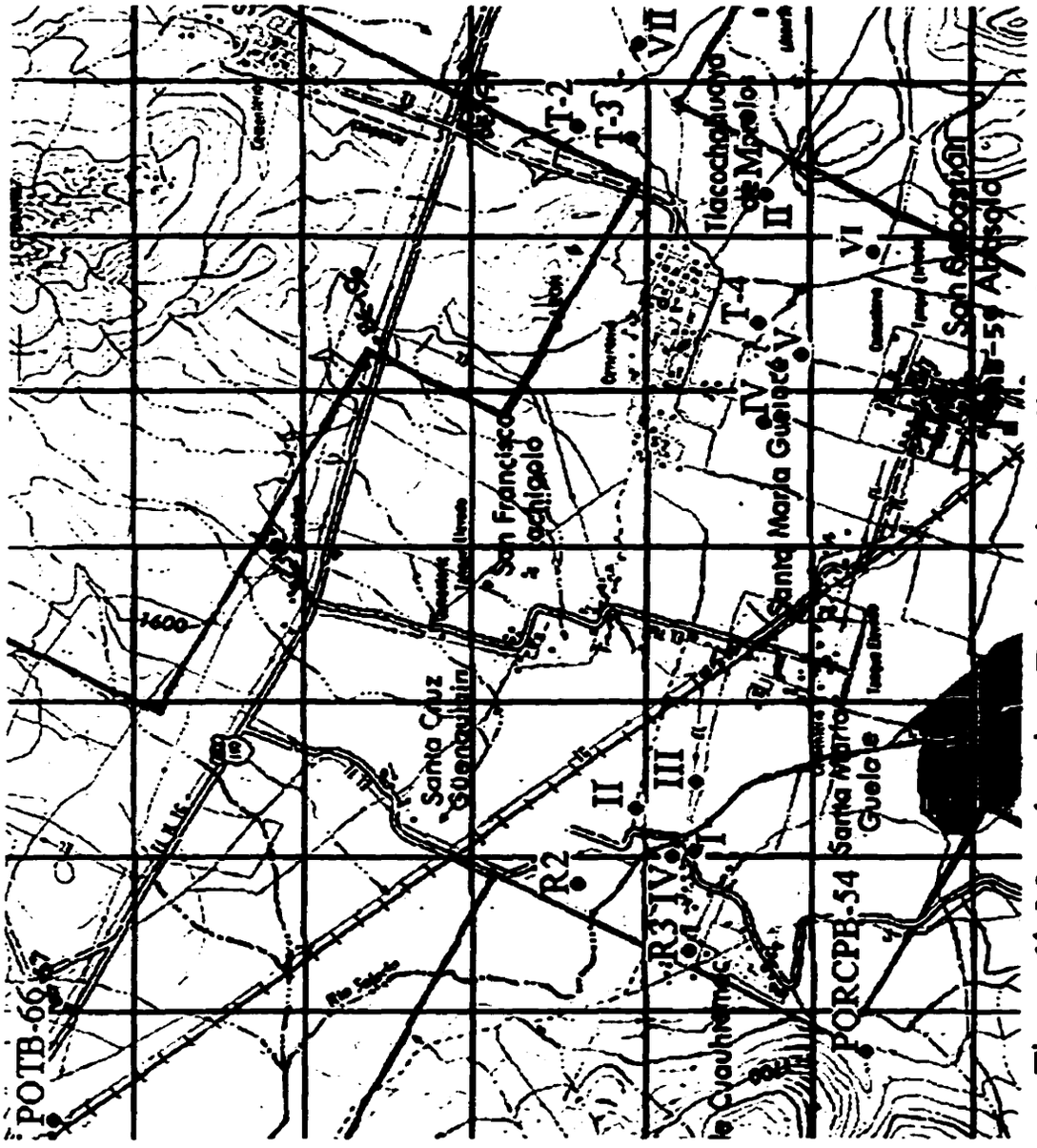


Figure 1b Map showing Exploration Well Locations. 1 km grid.

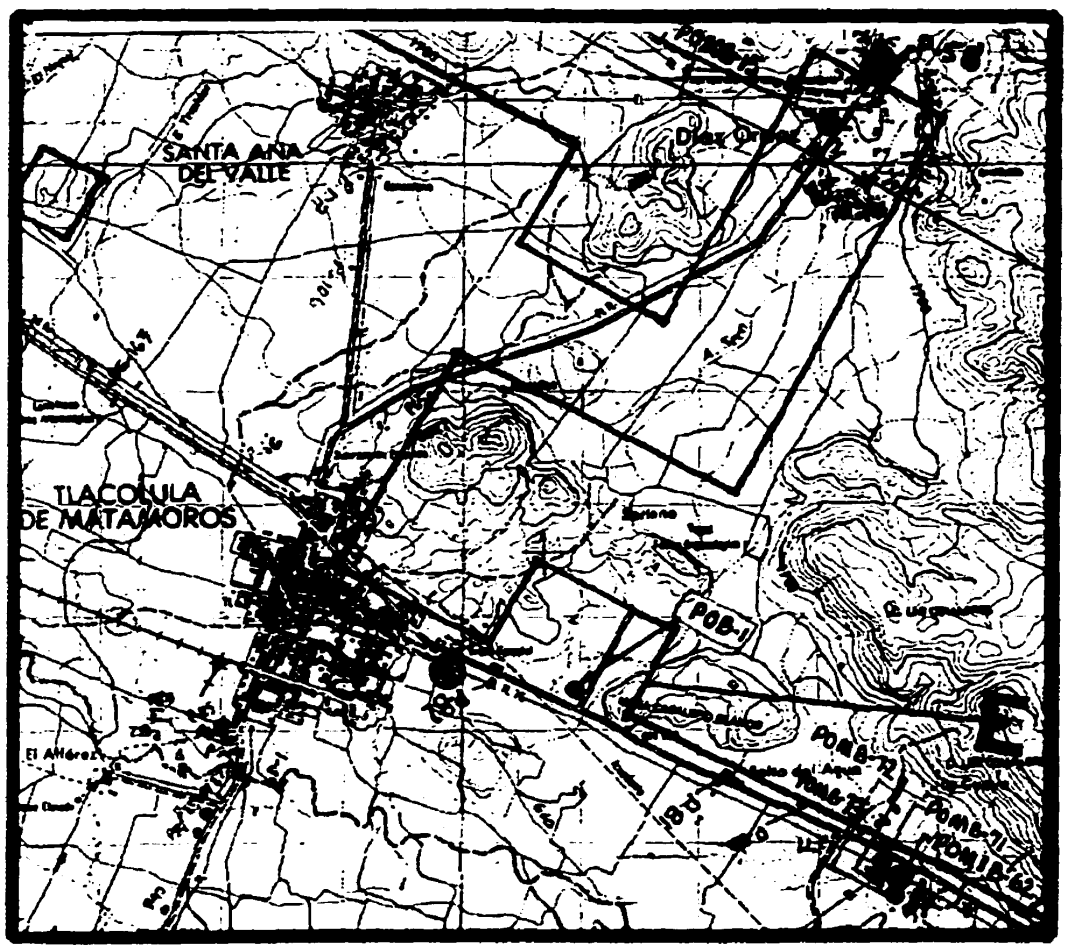


Figure 1c **Exploration well locations. PODOB-15,**
1 km grid **POMB-71,72 and 73. POB-1 and POM1B-62**

WELLSDP1

TABLE 1 X Y COORDINATES OF EXPLORATION WELLS

Serial #	X	Y	Deep Wells ID	Documented as
1	3696	20497	POTB-66	POTB66
2	5277	17399	R-2	ROJAS2
3	4802	16739	R-3	ROJAS3B
4	5483	16688	I	LACHIGOWELL
5	5766	17056	II	LACHIGO2
6	5946	16700	III	LACHIGO3
7	5445	16827	IV	
8	4172	15710	PORCB-54	ROJAS1
9	7591	10402	PORCB-64	POCPB 64
10	8157	10745	PORCB-60	POCPB 60
11	8980	11811	POB-2	POB-2
12	8221	14834	POAB-59	POAB_59
13	9263	14491	T-6	TLACOC6
14	9327	15634	VI	TLACOC6b
15	8671	16091	V	TLACOC1B
16	8259	16192	IV	TLACOC1BB
17	9700	16281	II	TLACOC2B
18	8916	16358	T-4	TLACOC4
19	10600	16954	VII	
20	10124	17119	T-3	TLACOC3
21	10188	17412	FIRCO-T2	
22	12682	17627	POMB-35	
23	24471	15418	PODOB-15	PODOB_15
24	22376	10364	POB-1	POB -1
25	24548	7875	POTO-61	
26	25127	8713	POM1B-62	
27	24960	8827	POMB-71	POMB-71
28	24921	8726	POMB-72	POMB 72
29	25050	8535	POMB-73	POMB_73

Cases of Partial penetration

A review of the well drilling history of the Tlacolula Valley indicates that drillers would generally reach the aquitard and drill through it for a few meters. Exceptions are the following wells.

1. The exploration wells POMB-71, POMB-72 and POMB-73 dug at Tanivet where exploration of the top unconfined aquifer was the main concern.
2. The well drilled near Tlacochahuaya and identified as Tlacochahuaya Well No. 4 is a possible case of partial penetration depending on the extent of fractures in the Rhyolite.
3. The well drilled at Diaz Ordaz PODOB-15 may also be of partial penetration since the aquitard was never reached. The extent of penetration and the saturated thickness is however difficult to estmate because no other well has been explored close by. The closest well that is POB-1 at 5.4 km from PODOB-15, shows however signs of similar formation and suggests that drilling of PODOB-15 was stopped only a few meters before reaching the volcanic formation.
4. In the case of the well POMB-35 by San Mateo Macuixochitl the low yield of 1.54 lps suggests that the limestone is not fractured and full penetration was therefore achieved.
5. The aquitard was definitely not reached in the 101 meters drilling of the well POCPB-60 . This will be discussed in detail in the analysis of the corresponding well test data.
6. Surprisingly, no well test was conducted for the well POCPB-64 also drilled in the volcanic formation even though the aquitard was not reached after 172 meter drilling. The relatively low yield of 3.99lps obtained in POCPB-60 of similar formation at less than 0.7km from POCPB-64 has probably lowered considerably the driller's expectation for POCPB-64.

ANALYSIS OF HISTORICAL WELL DATA

We shall now attempt to make scientific use of the historical pumping well test data. Only methods of analysis that have proven to be reliable are used.

Reliability of historical Well Test Data

The Manager C.N.A, has a valuable experience and a good understanding of well development. Only two records were entered with an obvious typing mistake and very few outlier measurements were encountered in the analysis. The well test data can be qualified as reliable.

A problem arises from the fact that all water table depth readings were only taken directly from the well being pumped. Difficulties reside therefore in the complexity of the flow in the vicinity of a well that is drilled in an unconfined aquifer. Todd (1980) recommends to take the following precautions when using the equilibrium equations:

- Not to use in calculations in a free aquifer drawdowns exceeding 10% of the aquifer thickness and
- Not to use measurements at points where the slope of the cone of depression exceeds 15% and .
- To locate the nearest observation well at least 1.5 times the aquifer thickness to minimize effects of convergent flow on test results.

The types of Well Tests and Details of Well Development

Tables (1A, 1B and 1C) summarize the types of well tests and details of well development that took place in the research area. The symbols used in this table are defined at the bottom of the table. All information pertaining to these well tests has been collected from the sources listed in Tables (2A and 2B).

This information which takes the form of individual reports for each well that was drilled and includes the driller's logs with construction details and the well test data, can be made available upon request. The history of the exploration of the aquifer of the Central Valleys of Oaxaca is analyzed in this chapter.

The following standard tests are noted : the regular drawdown test where the discharge is maintained constant; the variable discharge test; the step drawdown test and the full recovery test. There is also mention of a declining step drawdown test that is conducted after a period of development of the well.

This is a common practice since 1980 and it consists in bringing the well discharge down in steps after completion of its development. This corresponds to a partial or controlled recovery in opposition to a full recovery test in which case the pump is shut off. This "declining step procedure" creates additional difficulties in the analysis but Table 1A and Table 1B suggest that this practice after fifteen years of implementation is here to stay. It was therefore decided to investigate possible avenues of analysis for this problem. All of these tests were single well tests.

To substantiate the tests in the specific area of Lachigolo , two additional tests were performed in 1994 those were , a drawdown test and a slug test.

The development of the newly drilled wells since 1980

At the beginning of exploration, the era of 1970-1978, the well test reports are more documented. Drawdown measurements were taken with reliability and consistency throughout the history of groundwater exploration but the development process of new wells matured.

This change was not caused by the coming of new people since Table 2(A and B) tells us that the same key players were involved since the inception of the exploration of the aquifer in the research area. This fact explains why the active participation of these few engineers to this research study was so valuable.

POTB66

The driller's log profile of this well is shown on Figure 2 . We note the presence of a layer where some fine and medium size granular material of calcareous nature bound with 15% clay. was encountered. This material was found to be of no aquifer value and that section was left unscreened. It is assumed however that the packing of the granular material was not continuous and therefore not confining the

water underneath and seepage through it was not impeded. The aquifer is therefore assumed to be either unconfined or leaky.

The static water level of 4.17 m recorded on a first of February suggests that the water table may come within 1 m to the surface frequently since the rainy season peaks from June to September and February usually corresponds to the third quarter of the dry season.

The Well is developed in Steps

The first pumping period was carried out in step -drawdown fashion for 900 minutes. This was done as follows: first the well was pumped at a low constant-discharge rate of 5.16 lps until the drawdown reached 31.2 meters. Soil stabibility was not reached, the water was turbid . The pumping rate was then increased to 5.41 lps until the drawdown rate stabilized. The drawdown was then 42.6 meters This process was repeated a third time at a rate of 5.65 lps (RPM of 1150) and once more at a relatively constant discharge of 5.88 lps.

During these last two steps, the pumping time was insufficient for the drawdown to stabilize or even pseudo-stabilize. Then the discharge rate was reduced to 5.16 lps and a constant drawdown was reached at about 44.1 meters. Before shutting off the pump for recovery , the well discharge was brought down to 4.62 lps for two hours.

These two hours were again not sufficient for the drawdown to stabilize. At the beginning of the recovery the drawdown was 46.6 meters. Figure 3 below shows the drawdown vs time curve of this first pumping test.

Table 3 shows that this single well test can be hardly taken as as a step-drawdown test because the increase in pump discharge was not enough to allow a clear differentiation of each step on a log-log scale. It was therefore no surprise to get a solution using Rorabaugh's method that does not allow us to quantify the exact contribution of non-linear losses.

TABLE 1A WELL TESTS CONDITIONS., ANSWERS TO WHEN ? WHAT ? and HOW ?.

	Date	WELL ID	DESCRIPTION OF TESTS OPERATIONS
1	Feb-79	POTOB66	48h Development + 1h RECOVERY + (64-48)h Development + +1h RECOVERY + 9h STEP Drawdown in 3h steps. + +1h RECOVERY + 14h Constant RPM + 1h RECOVERY + +10h Qcst vs Drawdown +1h RECOVERY
2	Apr-83	TLACOC1_1	24h Step Drawdown Test 1 in 3h Steps.
3	Apr-83	TLACOC1_2	24h Step Drawdown Test 2 in 3h Steps.
4	Dec-88	TLACOC1B	48h Development + Declining 3h Steps Drawdown 24 h
5	Dec-88	TLACOC1BB	Unspecified Development + Declining 3 hSteps Drawdown 24 h
6	May-84	TLACOC2B	48 h Development + Declining 3hSteps Drawdown 24 h
7	Jun-83	TLACOC3	Unspecified Development + Declining 3 h Steps Drawdown 24 h
8	Sep-85	TLACOC4	No Well Test. Only a Driller's Log Profile.
9	Jul-88	TLACOC6	No Well Test. Only a Driller's Log Profile.
10	Aug-88	TLACOC6b	No Well Test. Only a Driller's Log Profile.
11	May-78	ROJAS1	60h Development + Declining 2h Steps Drawdown 10h
12	Oct-78	ROJAS2	52h Development + Declining 2h Steps Drawdown 24h
13	May-87	ROJAS3B	48h Development + Declining 5h Steps Drawdown 24h

TABLE 1.B WELL TESTS CONDITIONS., ANSWERS TO WHEN ? WHAT ? and HOW ?.

	Date	WELL ID	DESCRIPTION OF TESTS OPERATIONS
14	Nov-80	LACHIGOWELL	66h Development + Declining 2 h Steps Drawdown 6h
15	Feb-93	LACHIGO2	Unspecified Development + Declining 3 hSteps Drawdown 24h
16	Apr-95	LACHIGO3	36h Development Constant Q Drawdown Test
17	Feb-79	POCPB 60	6h Development + 1h Changing pump filter + + (47-6)h Declining Q (s/Q vs Log (t)) + 10h RECOVERY +(71-47 h Development + 10h RECOVERY
18	Jun-78	POCPB 64	No Well Test. Only a Driller's Log Profile.
19	Apr-78	POAB59	24h Development + 2h RECOVERY + 8h Q_{cst} vs Drawdown + 2h RECOVERY + 8h Q_{cst} vs Drawdown+ 2h RECOVERY
20	May-73	PODOB15	48h Development + 8h RECOVERY + 14h STEP Drawdown in 2h Steps + 10h Q_{cst} vs Drawdown +12h RECOVERY + + 400 Minutes Step Drawdown in 5x80 minutes steps
	Jul-70	POB -1	10h Development + 8h RECOVERY Drawdown curve BUT NO Records of DRAWDOWN TEST.

TABLE 1C WELL TESTS CONDITIONS., ANSWERS TO WHEN ? WHAT ? and HOW ?.

	Date	WELL ID	DESCRIPTION OF TESTS OPERATIONS	
22	Oct-70	POB-2	No Well Test.	Only a Driller's Log Profile.
23	Apr-79	POMB-71	No Well Test.	Only a Driller's Log Profile.
24	Aug-79	POMB-72	No Well Test.	Only a Driller's Log Profile.
25	Oct-79	POMB-73	No Well Test.	Only a Driller's Log Profile.

Symbols -> 2h = two Hours (47-6)h = 41 hours from hour 6 to hour 41.

Q_{cst} = Constant Discharge. s = Drawdown t = time Log (t) = Log_{10} (time)

Development =	The water is turbid, the well is in development and the soil - gravel matrix is in process of stabilization
RECOVERY =	FULL recovery, I.e the Pump is shut off. The well is recovering.
Declining 2h Steps=	Similar to a reverse step drawdown after development .The recovery is restrained by decreasing the well discharge in 2 hours steps.

AGENCIES.xls

TABLE 2A AGENCIES THAT PERFORMED THE WELL TESTS

YEAR	STATE AGENCY DESCRIPTION
1973-1978	S.A.R.H Dirección de Servicios de Apoyo a la producción Subprograma de Infraestructura Rural Residencia de Perforación de Pozos Registro de Desarrollo. S.A.R.H - S.A.P -P.I.R - P.P - R.D Ing. Jaime Robles Garcia Ing. Jose Olvera Flores.
1980	S.A.R.H Obras Hidraúlicas Para el Desarrollo Rural Departamento de Perforación de Pozos Ing. Jaime Robles Garcia Ing. Jose Olvera Flores.
1983	S.A.R.H Obras Hidraúlicas Para el Desarrollo Rural Departamento de Perforación de Pozos Ing. Jose. A. Chavez. Figueroa Ing. Jose Olvera Flores.
1987- 88, ...	S.A.R.H Jefatura del Programa de Desarrollo Rural Sub-programa de Infrestructura Rural Residencia General de Perforación de Pozos Registro de Aforo. Ing. Jose. A. Chavez. Figueroa Ing. Jose Olvera Flores.

AGENCIES.xls

TABLE 2B AGENCIES THAT PERFORMED THE WELL TESTS

YEAR	STATE AGENCY DESCRIPTION
1993	S.A.R.H Banco nacional de credito Rural. BANRURAL FIDEICOMISO DE RIEGO COMPARTIDO Gerencia Estatal de Oaxaca. Ing. Jose. A. Chavez. Figueroa Ing. Jose Olvera Flores.
1995	Instituto Estatal del Agua.
1993/97.	IN THIS RESEARCH PERIOD McGill Univ./Macdonald College in collaboration with C.N.A./Gerencia Estatal de Oaxaca Coordinator S.A.R.H /BANRURAL-Gerencia Estatal Oaxaca
C.N.A	Comisión Nacional del Agua
S.A.R.H	Secretaria de Agricultura y Recursos Hidraulicos
I.M.T.A	Intituto Mexicano de Technología del Agua

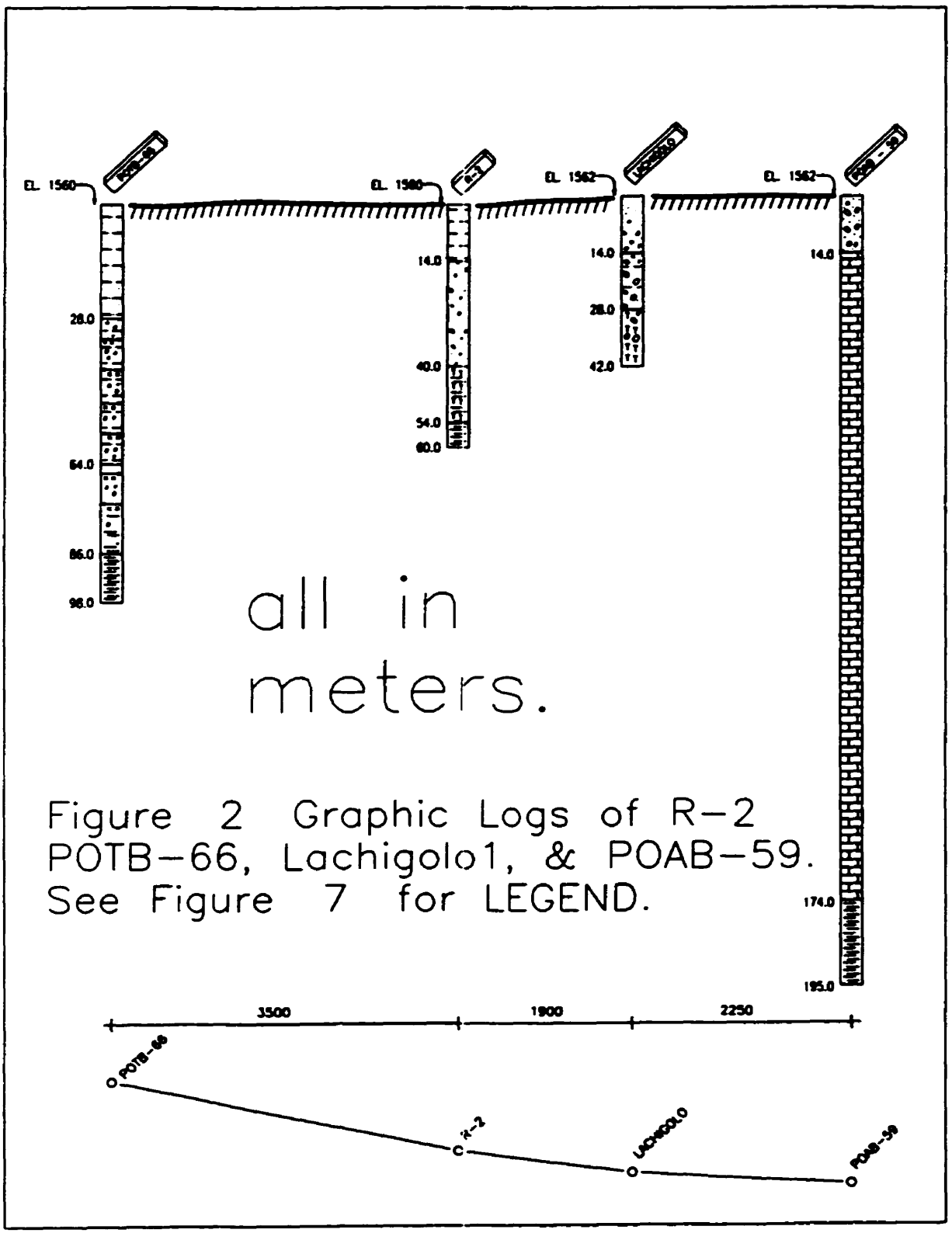


Figure 2 Graphic Logs of R-2 POTB-66, Lachigolo1, & POAB-59. See Figure 7 for LEGEND.

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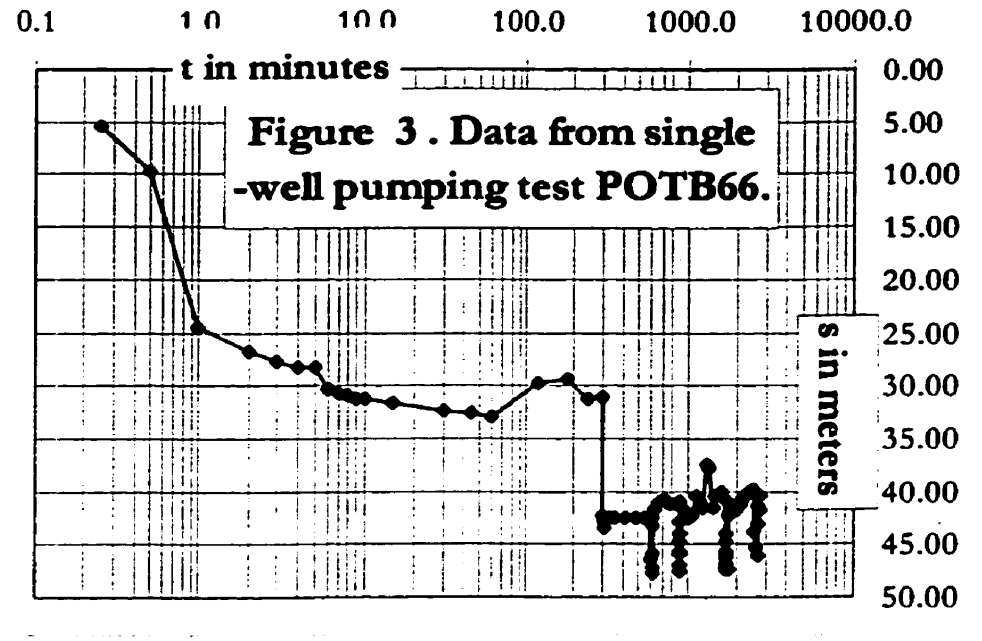


Figure 3 . Data from single -well pumping test POTB66.

This is illustrated on Figure 4. where the Aquifer loss coefficient (A) can not be derived from the best linear regression fits of Log (s/Q -A) versus Log (Q).

A fact remains. the non-linear losses associated with the well loss coefficient (C) appear in the highly correlated linear regression fits shown on Figure 4. to be related with the discharge Q raised by an exponent that may vary from 2.2 to 4.0. This is in agreement with previous findings reported by Kruseman and De Ridder (1990).

In the first pumping test. after thirty hours of pumping the water level reached 46.50 m. The discharge was then maintained constant at 5.16 LPS (445 m^3/d) for 13 hours In that time the water level went up 2.5 m to reach 44.5m. The specific capacity Q/s is then 445 m^3/d OVER 44m = 10.1 $m^3/d/m$ of drawdown. This well is classified as a low productive well by Sen (1995). When using Walton (1970 approximate method , as described in Appendix G., a transmissivity of 6.5 m^2/d is found for a 24 h pumping.

This Transmissivity value is based on a specific yield of 0.20. If adjustment were made as per Walton's method (described in Appendix G.) for a specific yield of 0.10 a transmissivity of 17.2 m^2/d would result.

Pocpb60.xls

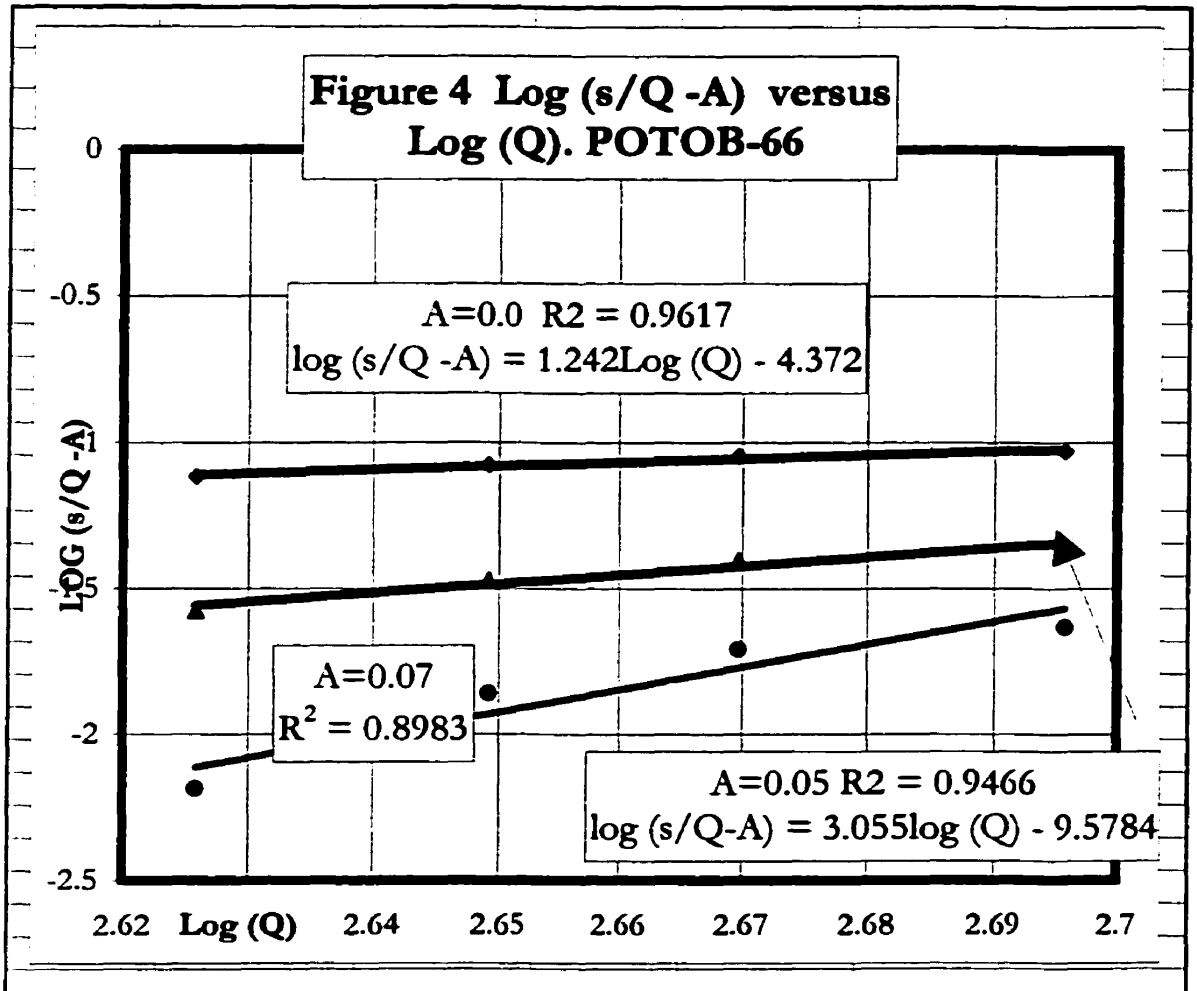
TABLE 3 STEP DRAWDOWN ANALYSIS. RORABOUGH's METHOD.
WELL POTB-66.

Step No.	time min	Sum of s/Q *t	Q lps	Avg s/Q	Q m^3/d	log (Q)	s/Q d/m^2
1	36.9991	244.65	4.89	6.6124	422.5	2.626	0.077
2	659.988	4778.7	5.16	7.2406	445.8	2.649	0.084
3	769.002	5954.6	5.41	7.7433	467.4	2.67	0.090
	13.0146	104.99	5.745	8.0674	496.4	2.696	0.093

Step	s/Q	LOG10(s/Q -A)					
No.	d/m^2	0.00	-0.50	-0.05	0.03	0.05	0.07
1	0.077	-1.12	-0.2	-0.9	-1.3	-1.576	-2.185
2	0.084	-1.08	-0.2	-0.87	-1.3	-1.471	-1.86
3	0.090	-1.05	-0.2	-0.86	-1.2	-1.402	-1.707
	0.093	-1.03	-0.2	-0.84	-1.2	-1.363	-1.631

Well Test performed in 1978. by SARH. Direccion de Geohidrologia y Zonas Arida.Oax, Oaxaca, Mexico. Analysis by E.Perraton 1997.

Pocpb60.xls



$$\Sigma\Delta s = s = AQ + CQ^n$$

$s = 0.00Q + (10)^{-4.372}Q^{2.2422}$	for A = 0.00	$R^2 = 0.9617$
$s = 0.05Q + (10)^{-9.5784}Q^{4.0545}$	for A =0.05	$R^2 = 0.9466$
$s = -250Q + 2.39697Q^{1.00042}$	for A =-250	$R^2 = 0.9707$

The recovery period was monitored and the residual drawdowns were investigated. The method of analysis is basically Theis's method the same as detailed in the analysis of the revovery tests of POCPB-60. Calculation are shown in Figure 6. Whereas Figure 5 shows the location of the well and confirms that no recharge boundary was present within the radius of influence. From the first recovery test a very low transmissivity of $2.9m^2/d$ is obtained. The second recovery test is consistant with the first test and the transmissivity is about the same ($2.7m^2/d$).

POB-1 Yagul Well Test

This well is located near the archaeological site of Yagul. The drilling exploration was conducted on a 402 meters profile by rotary drilling at an opening diameter of 30 cm . This hole was enlarged for the first 100 meters to a diameter of 55 cm (22"). No construction details regarding the installation of the well casing and gravel pack could be found.

The driller's log shows the following profile:

0-28	m	Small Gravels with clay and gravels
28-294	m	Volcanic Tuff
294-406	m	Small Gravels and Clay

The drawdown curve was plotted but the original data of this drawdown test could not be traced. Our analysis will be limited to the drawdown curve with the reservation that it can not be substantiated with actual data.

We note a first increase in the rate of drawdown when the water reaches a level of 18.85m that is 10 minutes after start. This may coincide with the end of the drainage of the gravity water stored above the cone of depression in the close vicinity of the well.

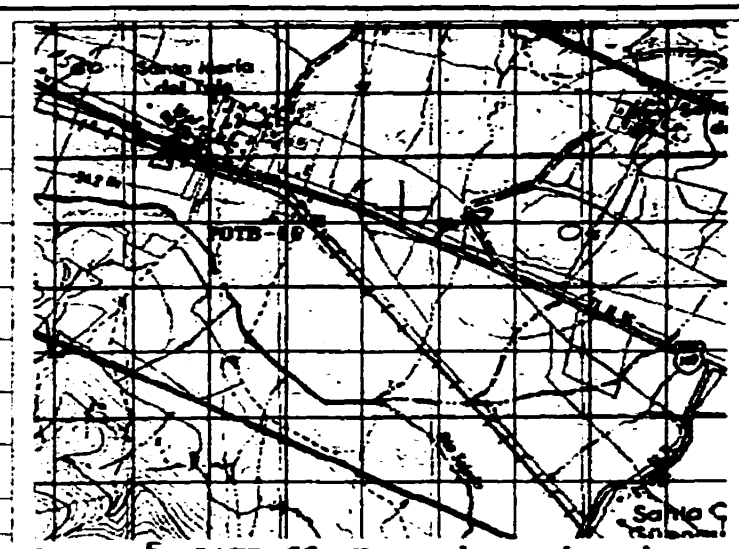
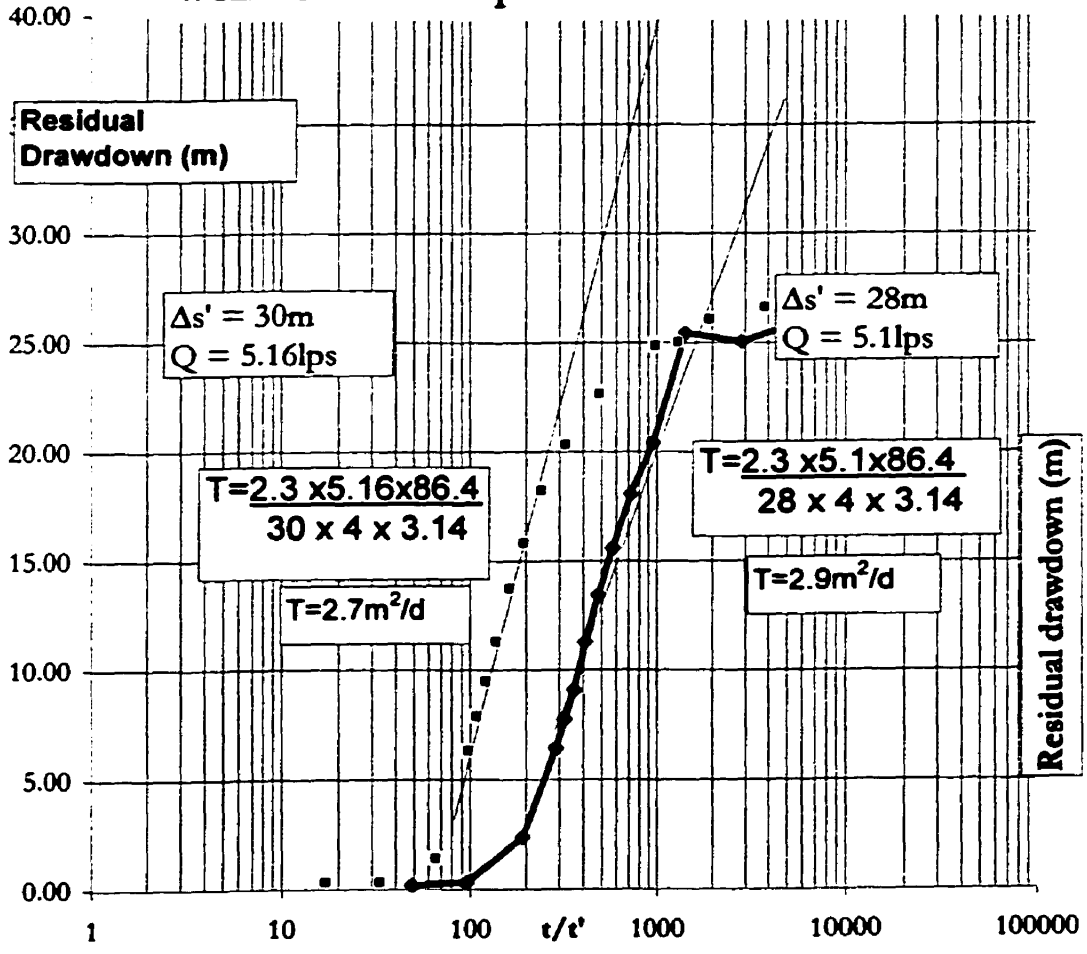


Figure 5 POTB-66. No recharge boundary can be seen within 500 meters. 500 m grid

Figure 6. Recovery Tests 1, and 2.
Well POTB-66. Exploration 1979. SARH.



Recovery Tests conducted by S.A.R.H 1979.
Compiled by E. Perraton

The drawdown curve increases abruptly after 240 minutes of pumping that is when the cone of depression has spread and the clay or dense volcanic tuff is reached. After 5 hours of pumping during which the drawdown keeps increasing, the well is shut off. Information on the summary sheet of the exploration report is consistent with the discharge of eleven (11) lps given at the top of the drawdown curve. The static level given on the summary sheet is 6.37m compared to 6.53 m on the drawdown curve. The difference may be an indication that at least two tests were conducted as this was found to be generally the case in S.A.R.H (C.N.A). reconnaissance studies.

No straight line method can be used. At best, we could read residual drawdown data from the plotted drawdown curve for the recovery period, but this information would be of uncertain value in light of the following.

The well profile shows there is no potential productive aquifer except within the upper 28 meters. The profile displays a layer 276 meters thick (28 to 294m) of volcanic Tuff of relatively low permeability as confirmed by the rapid drawdown that took place when the cone of depression approached this layer as described above.

Following the layer of volcanic formation, the driller's log indicates the presence of well cemented conglomerates from 294 meters to 406 m. These conglomerates are made of small gravels and gravels well cemented with a plastic clay and form a continuous impervious layer.

POCPB-64 and POCPB-60

Only the driller's logs showing the aquifer profile and the graph of perforation are available. The profiles of POCPB 64 and POCPB60 are shown together on Figure 7. Figure 8 shows that these wells are located close to Santa Cruz Papalutla. POCPB-64 profile is analyzed in conjunction with its twin profile. POCPB-60.

If we join the lines of equal material as done on Figure 7 we can picture two volcanic eruptions which resulted in a deposit of about 22m of volcanic ash from each eruption. We note a layer of andesitic tuff. The profile is as follows:

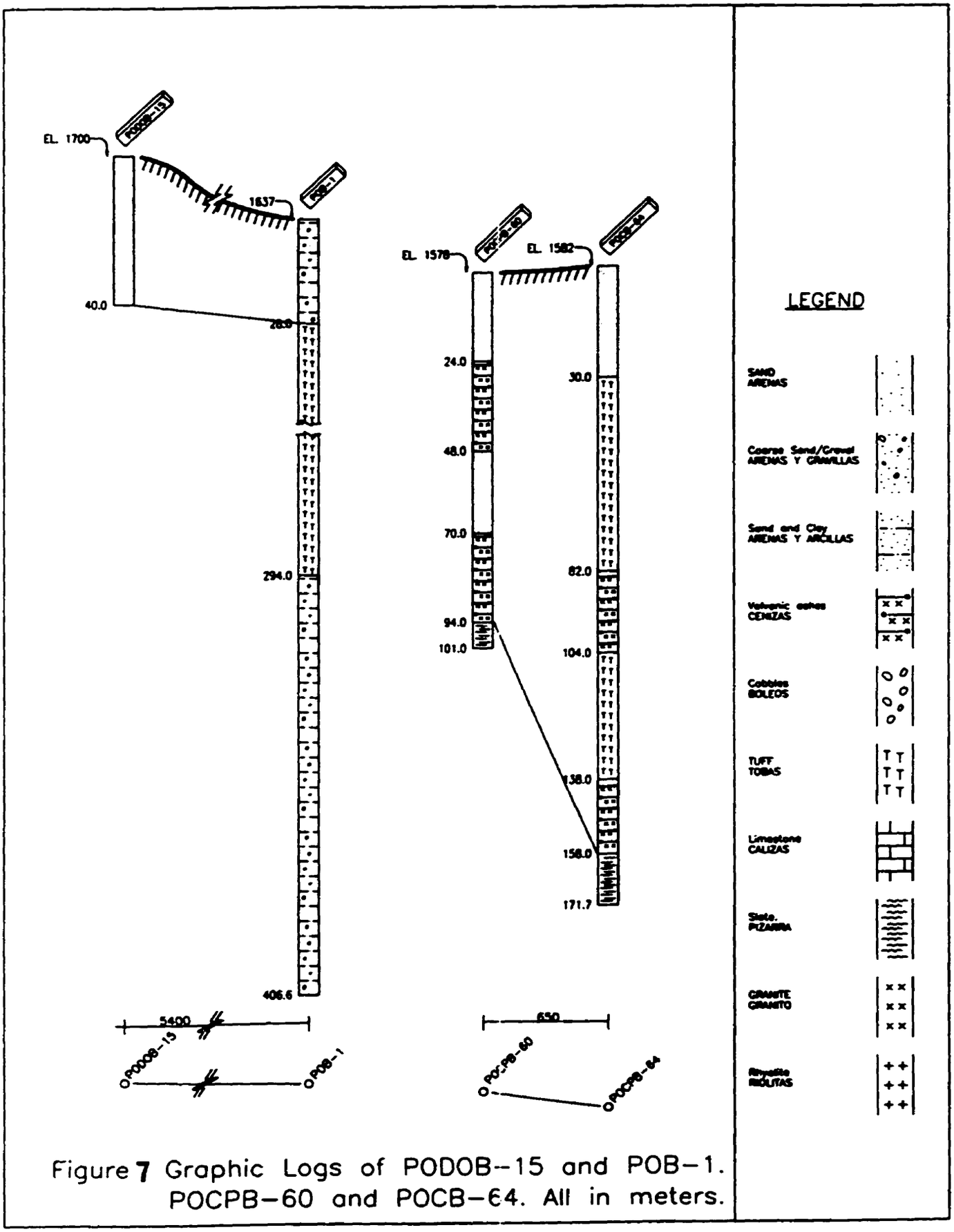


Figure 7 Graphic Logs of PODOB–15 and POB–1. POCPB–60 and POCB–64. All in meters.

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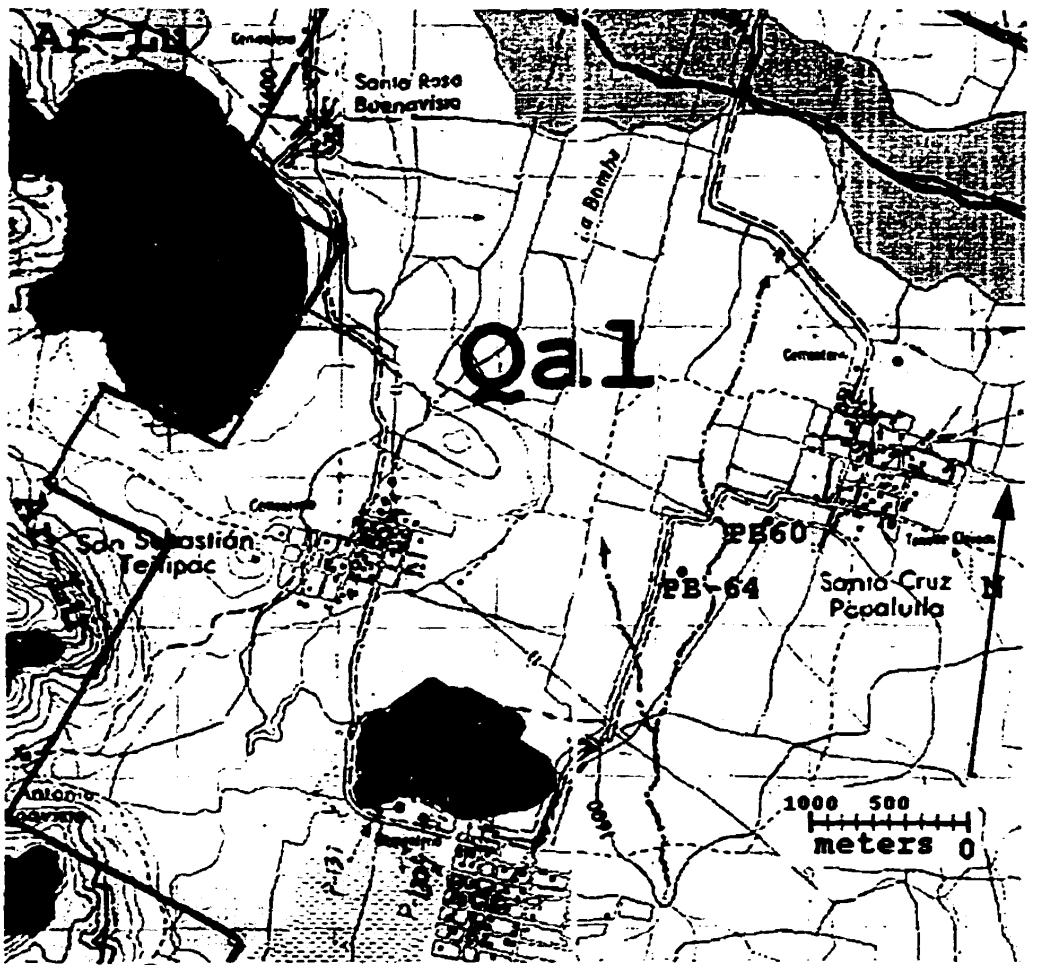


FIGURE 8 POCPB-64/POCPB-60. Andesitic Formation: R
Marine Sediments: Ar-Lu and Cz (limestone).
Qal: Alluvium One Km grid.

Layer		Material
0-8	m	Fine Sand
8-30	m	Volcanic ash1.
30-82	m	Andesitic Tuff.
82-104	m	Volcanic ash
104-138	m	Andesitic Tuff. (Tobas andesita)
138-158	m	Sand Very Fine 30 % and Fine size 70%
158-172	m	Claystone and fine sand.

POCPB-60

This well is located 650 meters north-east of POCPB-64 close to Santa Cruz Papalutla and is identified as PB-60 on Figure 8. The driller's log shows a relatively uniform granular material of volcanic origin. The driller recorded the presence of coarser material as drilling progressed. We note however a relative uniformity in the response of the aquifer during pumping and during recovery from which it appears that stratification does not play a significant role. This unconfined aquifer is therefore assumed to be relatively homogeneous and isotropic.

Although the driller reports the presence of a granular material for the last seven meters of drilling from which we should be inclined to conclude that full penetration was not achieved. we take note of the driller's contradictory expression "arenas de pizarra" which translates into "sands of slate ". In light of the geologic environment, this layer is interpreted as the transition zone between the granular volcanic formation and the sedimentary rocks of claystone texture that is the major geologic formation of the mountain unit right on the back of the volcano called El Negro and the one located at San Juan Teitipac. These volcanoes are most likely responsible for the volcanic profiles of both POCPB60 and POCB64 identified as PB-60 and PB-64 on Figure 8.

The well test with its low yield of four(4) lps and rapid drawdown suggests that the entire profile of granular texture must be relatively compact due to presence of some binding agent. It is reasonable to assume that the last layer, where some clay

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1 Volcanic ash was left on the site of digging an Indian well at location P-52. One can feel a clay texture once wet. Dry texture seems to mask the clay content.

was encountered, has a low permeability. The profile of POCPB-64 confirms the presence of claystone about thirty meters deeper suggesting that claystone was approached which explains why drilling was not continued. For these reasons the well was assumed to be fully penetrating, that is with at least 85% penetration.

Despite the fact that the drawdown curve (see Figure 9) looks typical of a step drawdown, this single-well test could not be successfully analyzed as a step drawdown test. Let us see why.

Limits of applicability of Rorabaugh's method

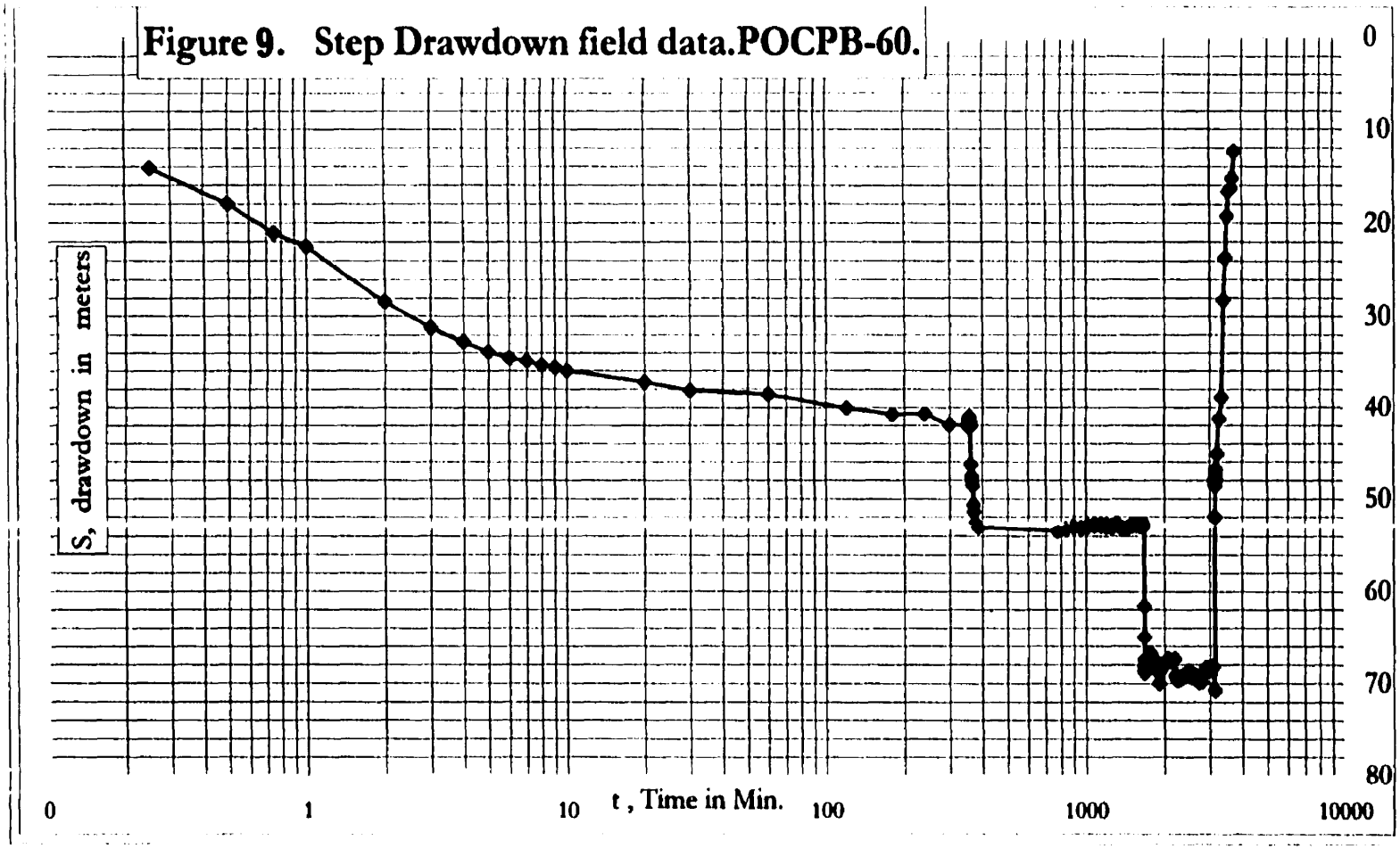
The drawdown steps may be clearly differentiated but because of the low increments of the flow rate from one step to another, application of Rorabaugh's method was not useful.

The reason for this can be visualized as follows: the plot of s/Q versus Q on log-log paper shows a very narrow spectrum with both the s/Q and Q values falling within a few divisions of one log cycle. This makes the determination of the corresponding straight line and the interception of the straight line with the Q_n=1 axis questionable. This avenue was not pursued any further. The well test **TLACOC2B** a four steps drawdown test where Q measured ranges from 1790 to 2531 m^3/d for a measured drawdown that ranges from 5.6 to 22 m, and the test **Tlacohahuaya 1bis**., a two steps drawdown, where Q ranged from 1194 to 2922 m^3/d for a drawdown that ranges from 2.7 to 14.6m are two additional well tests where well tests data fall off Rorabaugh's method limits of applicability.

Analysis of recovery test data

Because hysteresis effects do not play any part in Newman's theory of delayed watertable response, an unconfined aquifer's delayed watertable response to pumping is fully reversible according. We recall that Newman (1975) shows that the Theis's method is applicable for late-time recovery data of wells pumping an unconfined aquifer.

Since the transmissivity of the aquifer is calculated from the slope of the semi-log straight line, Kruseman and de Ridder (1990) concludes that those differences on



Well Test performed in 1978. by SARH. Direccion de Geohidrologia y Zonas Arida.Oax, Oaxaca, Mexico. Analysis by E.Perraton 1997.

the residual drawdown are, or become, constant with time, i.e. well losses, partial penetration, do not affect the calculation of the transmissivity. They remind us however to make allowance for those influences on the resisdual drawdown that do not become constant with time, e.g. well-bore storage .

Two out of the three recovery tests were analyzed. The third recovery test (#3) was rejected because the test was stopped prior to late time recovery.

As expected the residual drawdowns fall on a straight line in the semi-log of the residual drawdown versus t/t'. Calculations are shown on Figure 10. The fluctuations in the pump discharge were small and Q was relatively constant with the exception of the first 30 minutes of pumping. A summary of the calculations of the weighted average discharge (Q) prior to these recovery tests is shown in a tabular form at the bottom of the Figure 10.

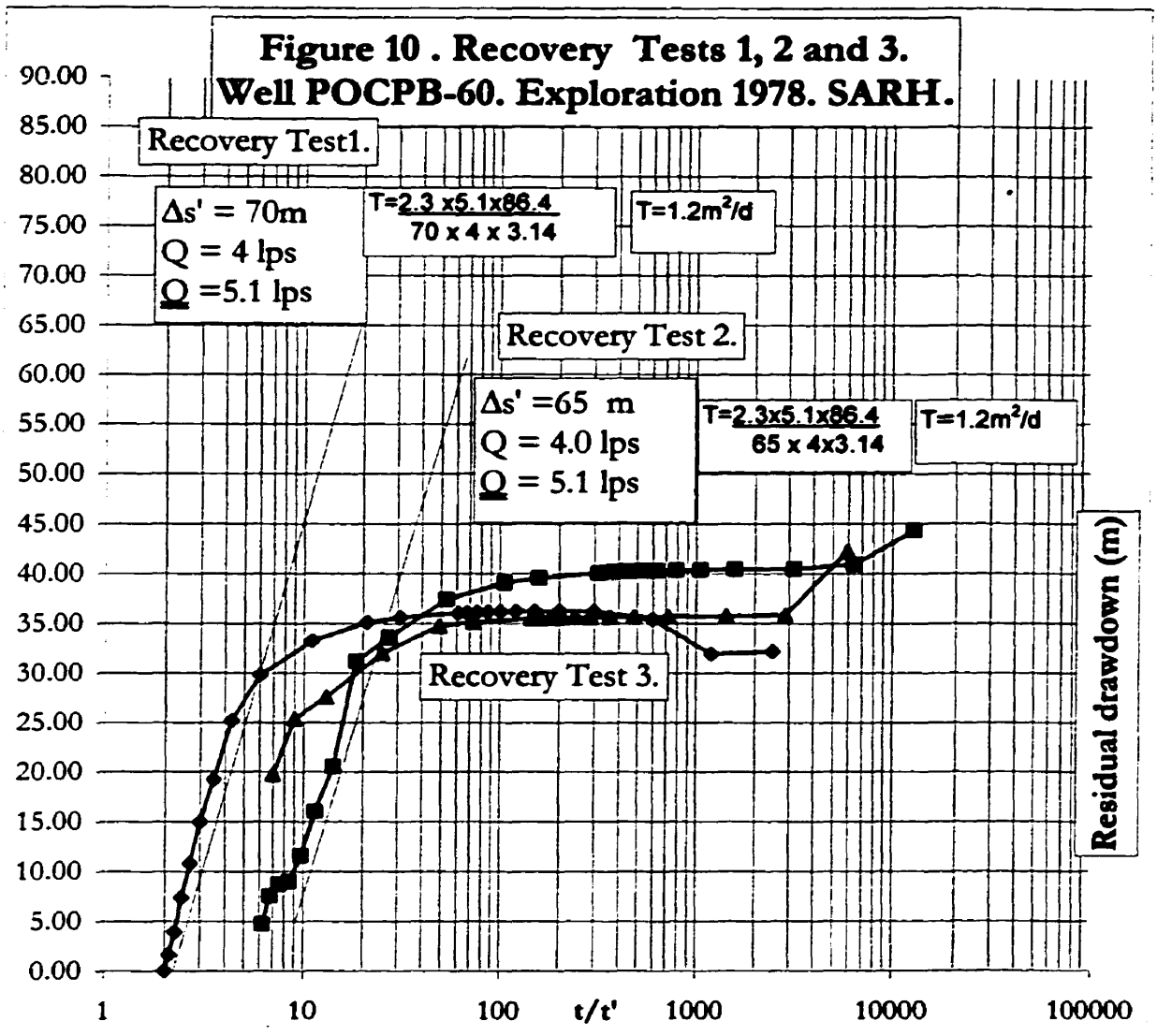
It is not possible to obtain an absolute value of the specific yield with the recovery test. An estimate of the specific yield was obtained in the following manner. In a single-well test, the drawdown is influenced by well losses and well-bore storage. Given the relatively low values of Q (< 5 lps) from early pumping onward, it may be reasonable to assume that the well losses are negligible compared to the large drawdown.

The influence of well-bore storage

Papadopulos and Cooper (1967) observed that the influence of well-bore storage on the drawdown in a well becomes negligible at time exceeding ($25\ r_c^2 / KD$) where r_c is the radius of the unscreened part of the well, where the water level is changing.

Kruseman and de Ridder (1990) applies this boundary equation to estimate when Jacob's straight line equation becomes applicable. Their example rests on a value of (KD) of 1800 m^2/d and $r_c = 0.185m$ in which case the well-borage effect becomes negligible after (25 x 0.1852 / 1800) that is 0.00048 day or 41 seconds.

If the transmissivity is low however, this boundary time for the well bore storage effect becomes very long. For instance if $T = 20\ m^2/d$ then the well-borage effect would become negligible only after one hour of pumping!



Theis For unconfined aquifers only late-time recovery data can be used.

$$\Delta s'_w = 2.30Q/(4\pi K D)$$

TABLE 4. Calculation of Weighted Q of Pumping Periods Prior to Shut OFF.

	Total Volume	Time period	Q weighted	Q weighted
	x 60 liters	min	lps	m^3/d
RECOVERY 1.	16181	3145	5.1	444.5
RECOVERY 2.	7053	1380	5.1	441.6

Well Test performed by S.A.R.H. Exploration 1978. Analysis by E. Perraton 1997.

It may be reasonable to argue that when an aquifer is made of material of low permeability then during the first instants of pumping the well may be taken as a closed underground tank from which water is to be lifted. The water in the well is then pumped out and the water level declines rapidly to the level where the outside system starts interacting.

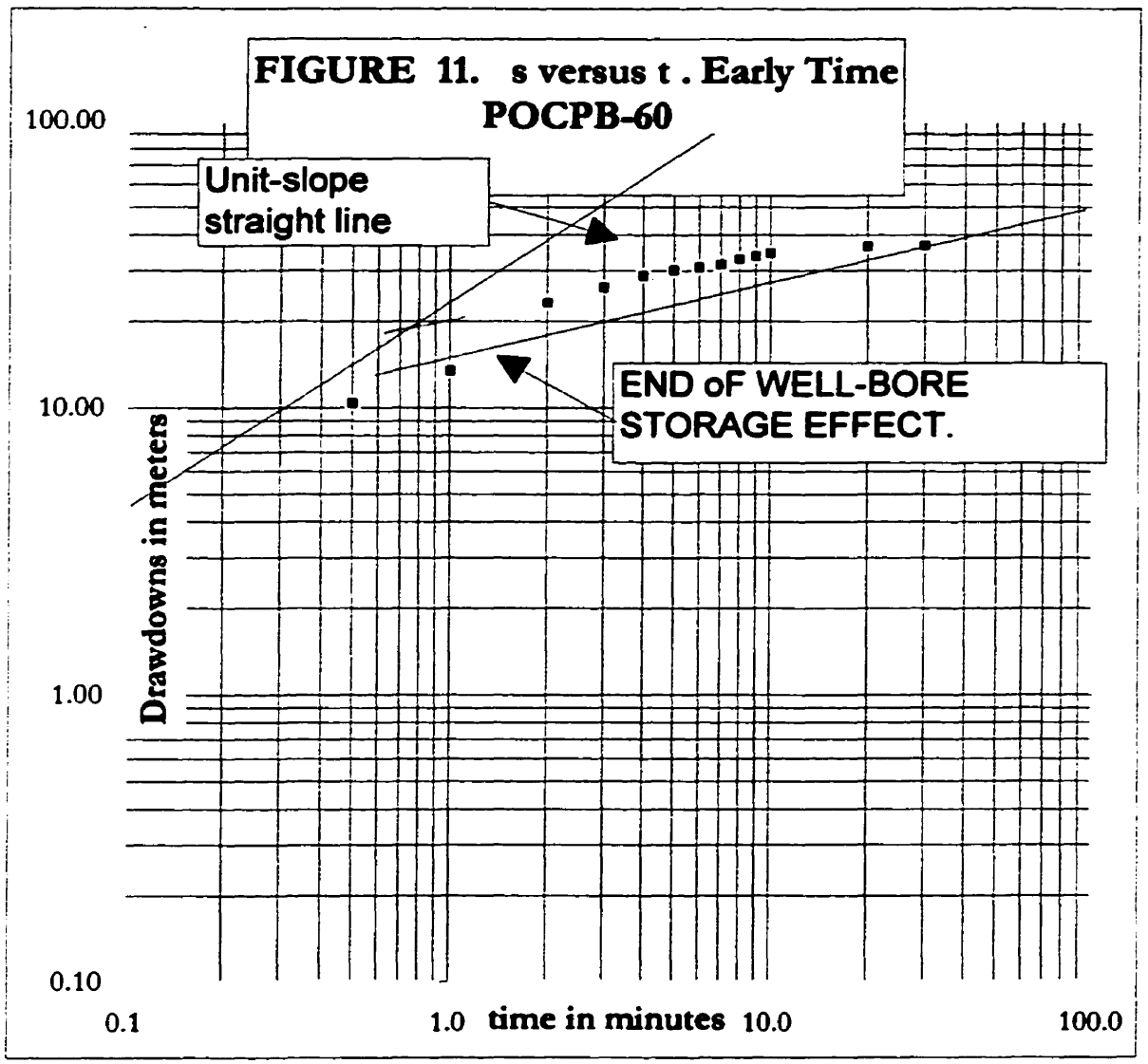
By plotting the drawdown versus time on log-log paper (Figure 11) as proposed by Kruseman and de Ridder (1990) we can see that the straight line of unit slope fits the test data for the first 2 minutes. This time period is taken as the period when the well bore storage effect is significant. After this two minutes period the drawdown response remains linear (on log-log paper) but the slope flattens down.

This corresponds to the response of the aquifer to early pumping which is modeled by Newman as the Theis-type straight line fit to the portion of the early drawdown data. Sen's (1995) reasoning that there is no significant delayed yield in this portion because the depression cone has not yet developed to the extent that gravity drainage can take place toward the water table, is also noted. After 30 minutes the drawdown response becomes relatively flat .

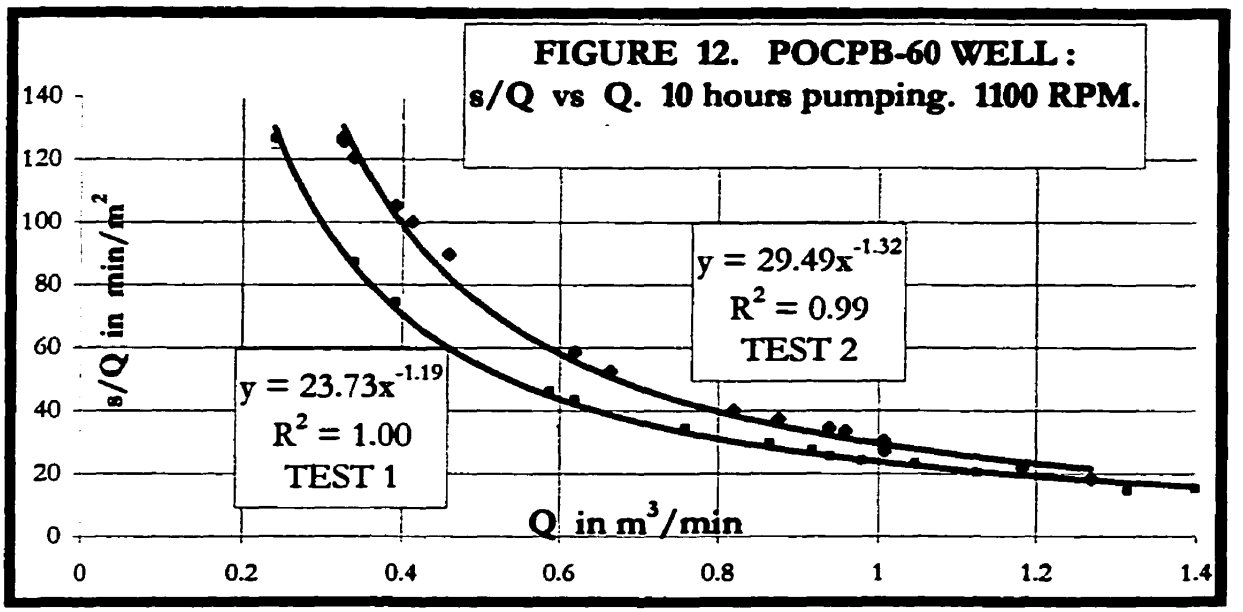
This corresponds to the intermediate zone between the two Theis typical curves of the early and late pumping time of an unconfined aquifer. Pumping was stopped after 10 hours, that is prior to reaching the late Theis-type drawdown response.

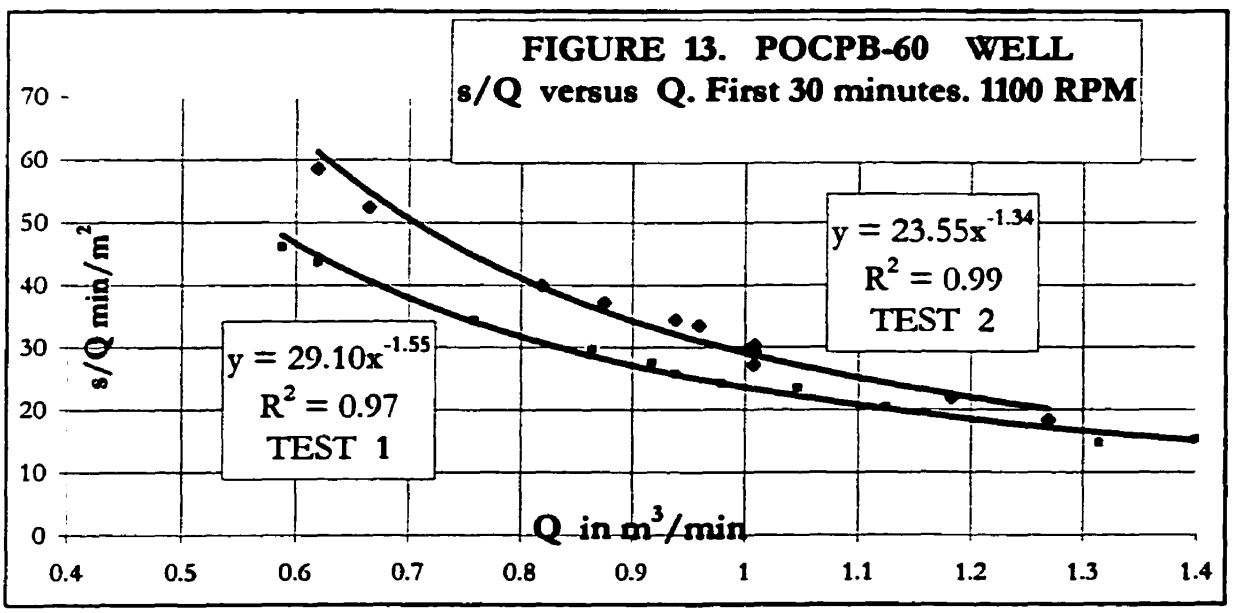
Need for further research on early time pumping

The reason for our interest in the early pumping time becomes clear with Figures (12 and 13) . This figure discloses two important facts. First that the discharges and the drawdowns in TESTS 1 and 2, were very highly linearly correlated ($R^2 > 0.97$). Secondly, the rapid decline in head in this early pumping time results in exponential decrease of the pump discharge with the sharpest decrease soon after the start of pumping. Aron and Scott (1965) derived a method for such phenomena in confined aquifers. No equivalent method for variable single-well tests in an unconfined aquifer was found in the literature.


FIGURE 11. s versus t . Early Time
POCPB-60
Unit-slope
straight line
END oF WELL-BORE
STORAGE EFFECT.
100.00
10.00
1.00
0.10
Drawdowns in meters
0.1
1.0
time in minutes
10.0
100.0

pocpb60.xls Abatimiento.





For the reasons given above it is not surprising that early pumping in confined aquifers shows a similar rapid decrease in discharge as do the present variable-discharge single-well tests in this unconfined aquifer. Such similarities are of course restricted to a very particular early time of pumping when well-borage effects are over and before the end of the early Theis-type response of unconfined aquifers. This period corresponds to t greater than two minutes and smaller than 30 minutes in this particular case of POCPB-60. This defines the time boundaries of the data that fall under the following analysis.

Application of Restrictive Models

For the application of restrictive models, and the use of models for confined aquifers to represent unconfined aquifers, Sen (1995) notes the following conditions:

In rather thick saturation thickness, D, the maximum drawdown, s_w, must be relatively small. $(s_w / D) \times 100 < 10$ is according to Sen (1995) a good criterion for the application of confined aquifer models to unconfined aquifers.

Based on the theoretical studies of Boulton (1963), the time-drawdown record must be taken at observation wells at distances of 0.2 to 0.6 times the saturation thickness. Boulton (1963) gave the minimum interval after the start of pumping for confined aquifer models to be applicable as $((5 S_y D) / K)$ in which S_y and K are the specific yield and hydraulic conductivity respectively.

With this condition, Jacob's straight line method becomes applicable for unconfined aquifers at large times. For thin saturation thickness aquifers, Jacob suggested correction of drawdown prior to applications of confined aquifers models. This is discussed in the literature review.

Sen (1995) concludes that none of the above-mentioned conditions guarantees the full applicability of confined aquifer models to unconfined aquifers.

TLACOCb2b and ROJAS1

Dupuit's assumptions are no more valid for these single well tests and the drawdown measured in the pumped well is expected to have a significant amount of vertical seepage inside the well.

To complicate the problem further, the discharge was measured only after well development. To our advantage however, measurements of the discharge during the declining steps drawdown period are very highly linearly ($R^2 > 0.98$, see Figue 17b) to the drawdowns measured from the pumped well.

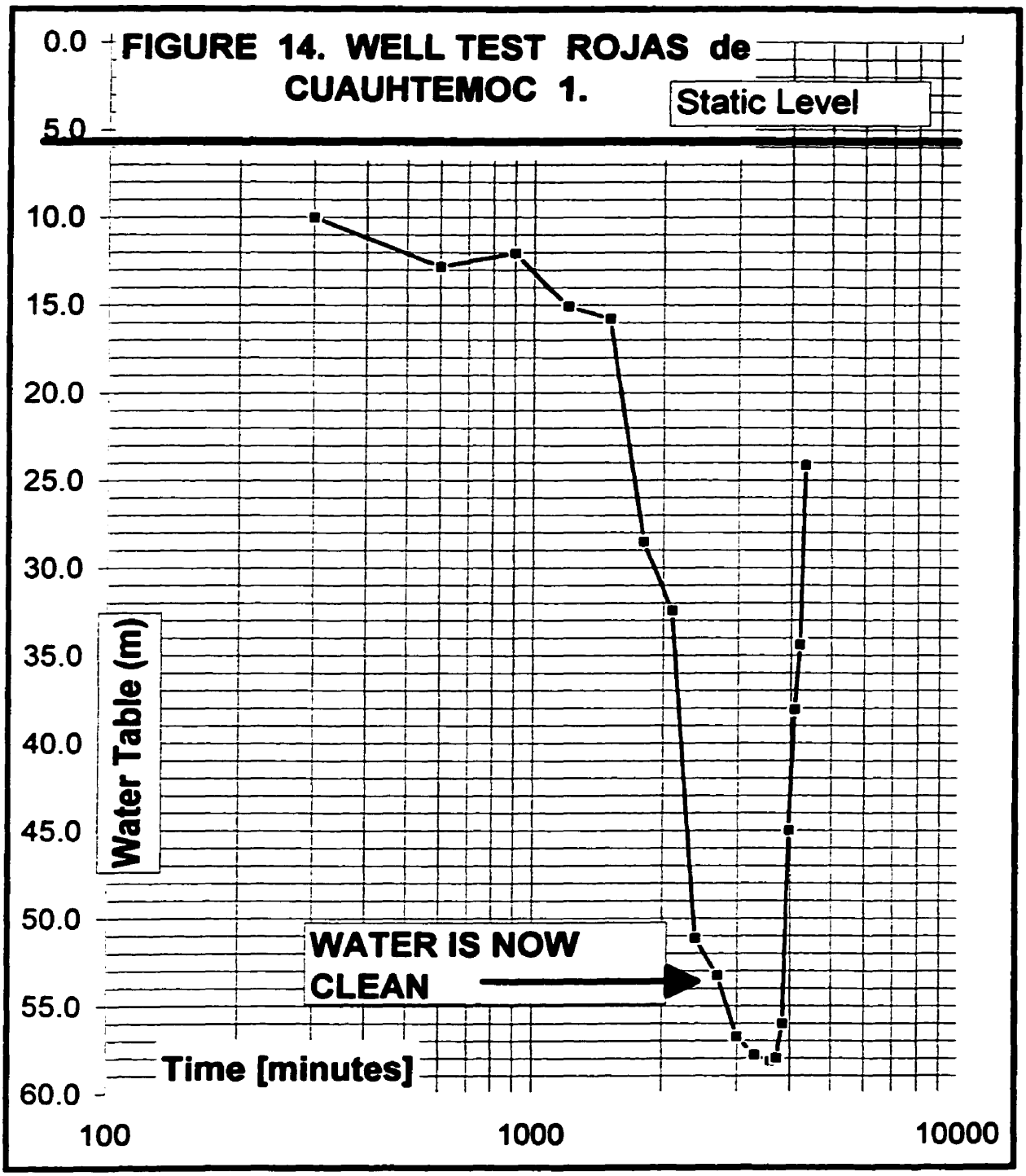
This linear relationship is therefore used to estimate the probable discharge that took place prior to completion of development. This is of course questionable, especially in light of the fact that during development the response of the system is very noisy due to the instability of the soil-gravel medium around the well. But it can be seen from the drawdown curve in Figure 14 that the aquifer response already shows some consistency hours prior to full stabilization of the gravel-soil matrix.

However, it is a fact that our knowledge of the variable Q is limited. Consistency of the discharge measurements indicates that the method for measuring Q was appropriate. This method consists in taking piezometric readings from a calibrated orifice of 152 mm diameter. The discharge is then calculated using a formula for this calibrated orifice.

It is important to note that in the last seven hours of the 62 hours period of pumping that preceded the controlled well recovery period, the drawdown was relatively constant. The highly correlated relationship between the corrected drawdown and the discharge measured in the last 10 hours of the well test as shown on Figures (15, 16, 17 and 18) suggests that the discharge must have been also relatively constant for these seven hours when the drawdown was constant.

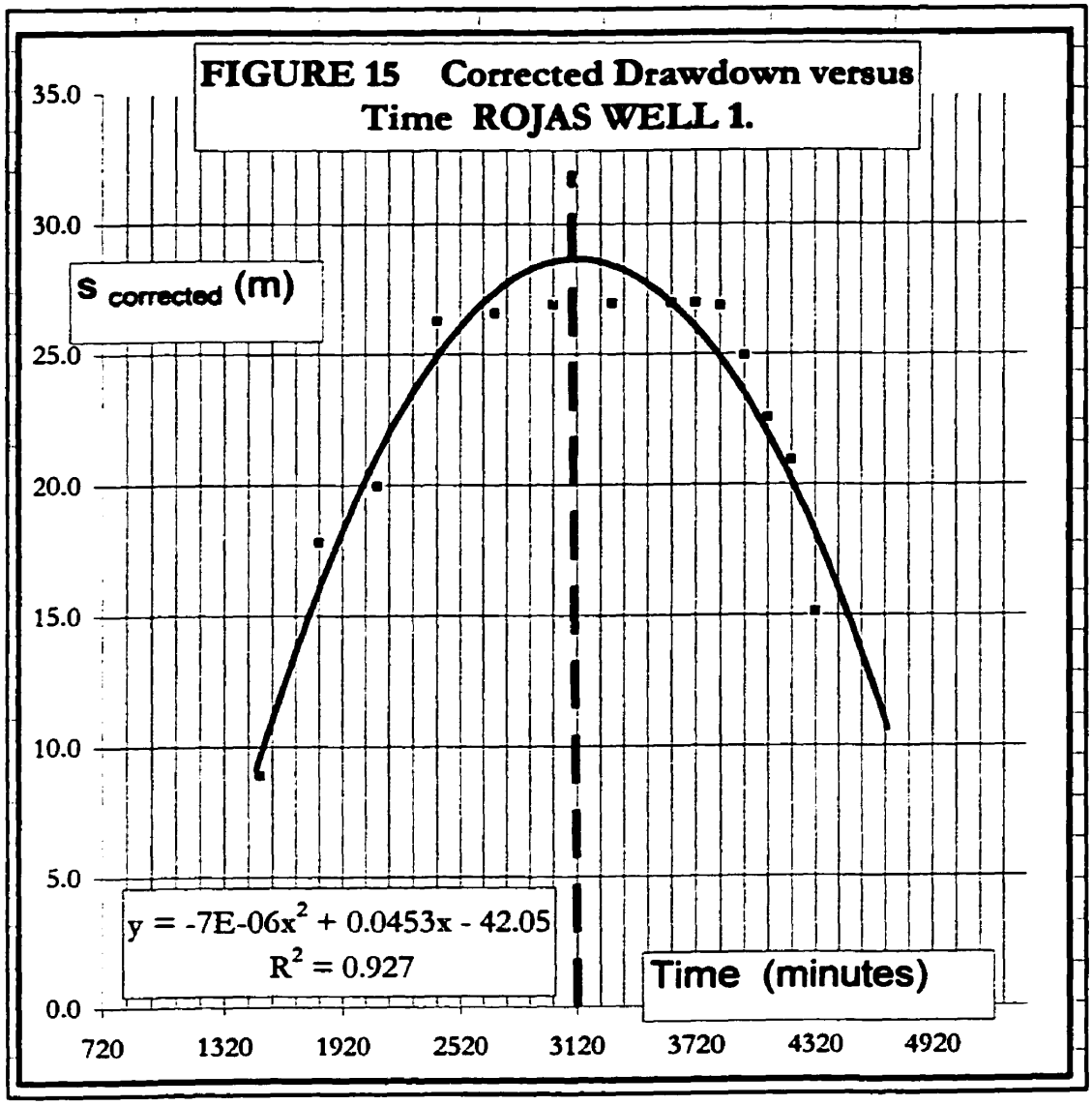
This with the fact that the water had already turned clear confirming therefore that the well development was over, make us conclude that the well had approached a quasi steady-state. On either side of this point of time, to a small variation in pump discharge (increase or decrease) the drawdown at the pumping well is expected to respond linearly. This is shown in Figure 15 and this is the basis for the following proposed method of analysis.

Sheet5 of Rojas1full.xls



The Well test was conducted by S.A.R.H May 1978.
The well test Data was compiled by E.Perraton.
THIS WELL TEST IS IDENTIFIED AS PORCB-54 by S.A.R.H .

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FIGURE 16. Q versus time. Estimated and measured. ROJAS 1.

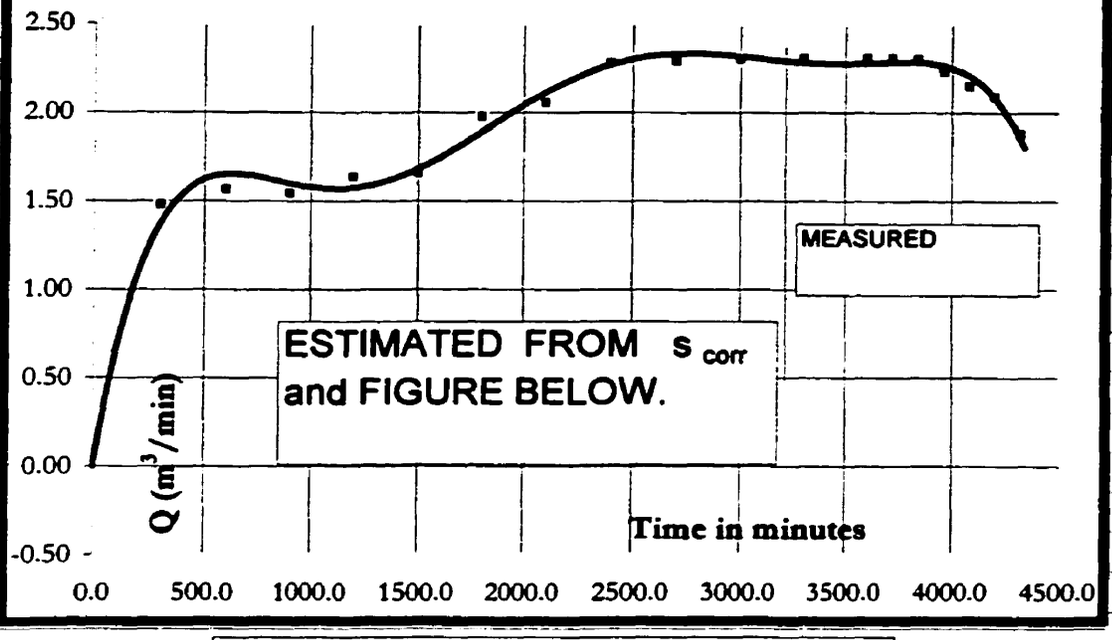
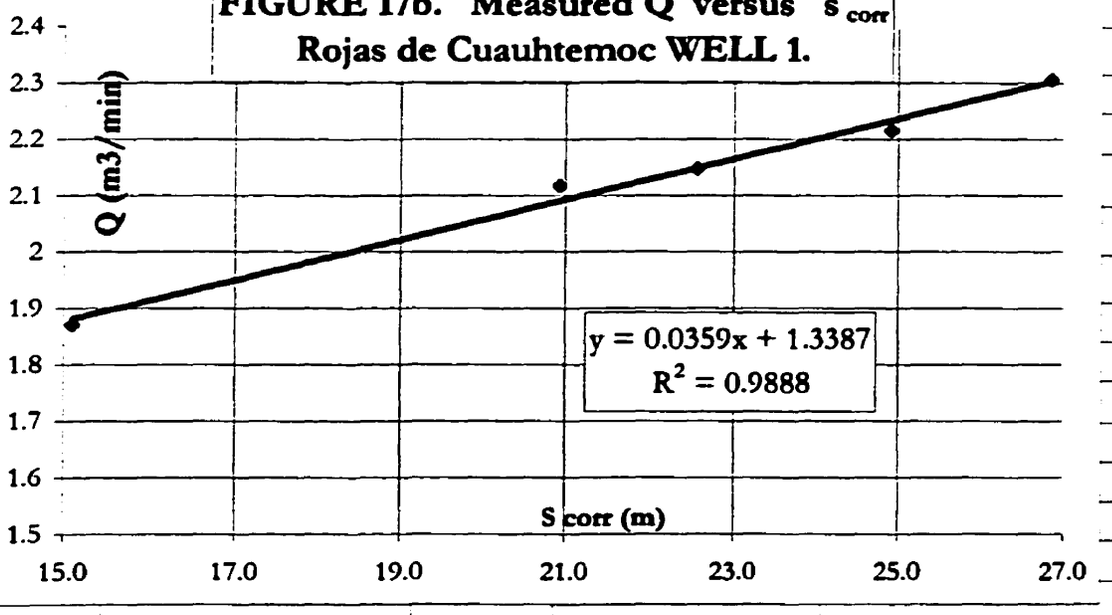
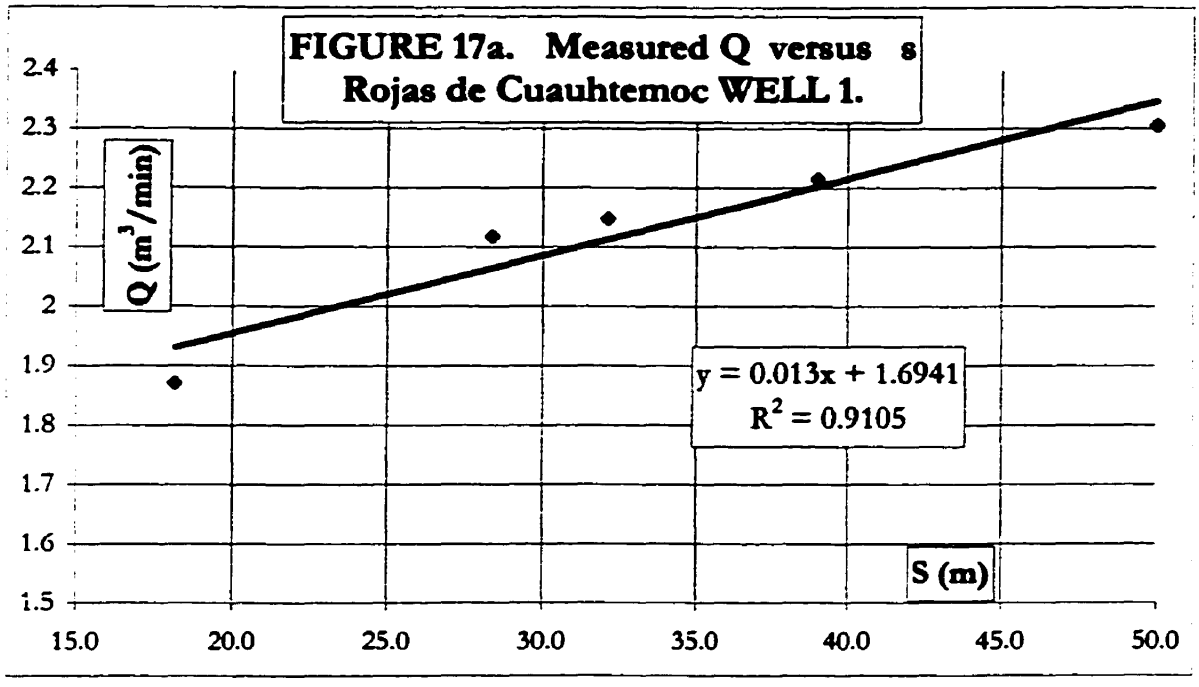


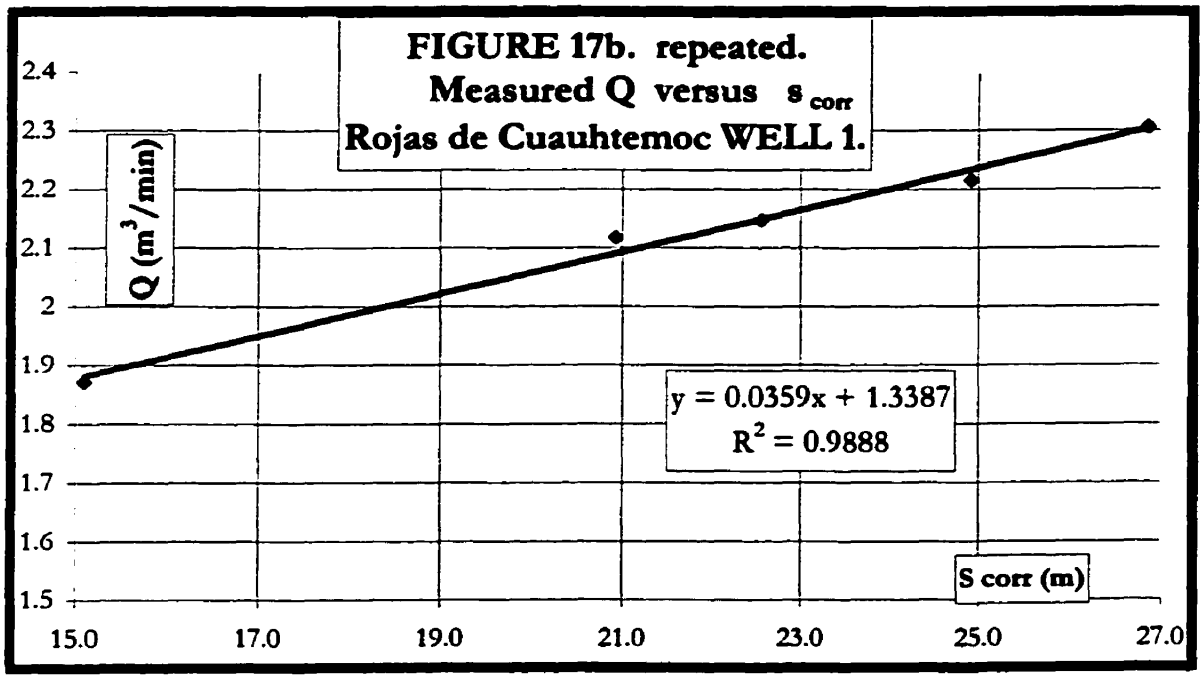
FIGURE 17b. Measured Q versus S corr Rojas de Cuauhtemoc WELL 1.



The Well test was conducted by S.A.R.H May 1978.
The well test Data was compiled by E.Perraton.
THIS WELL TEST IS IDENTIFIED AS PORCB-54 by S.A.R.H .

Sheet6 of Rojas1full.xls





The Well test was conducted by S.A.R.H May 1978.
The well test Data was compiled by E.Perraton.

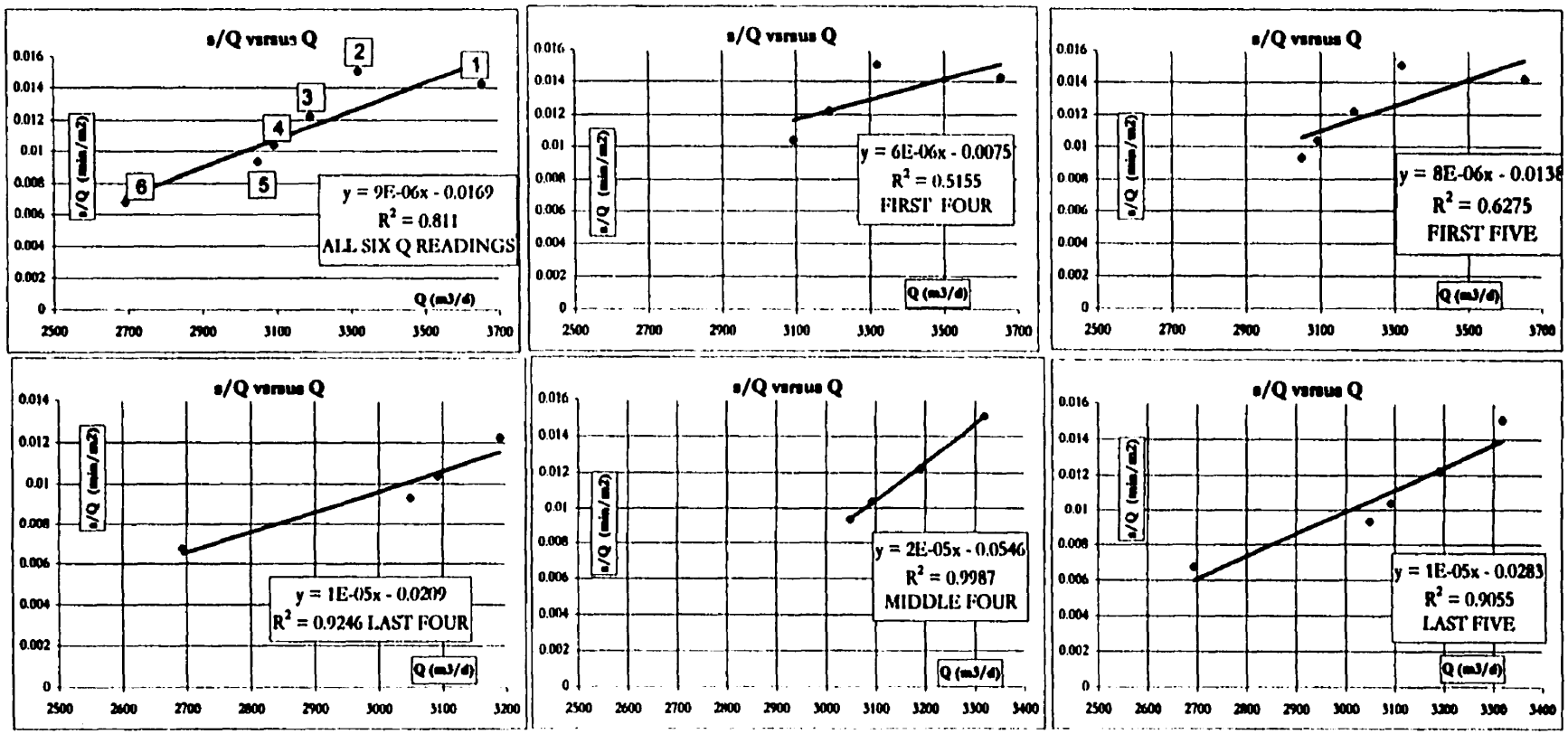


FIGURE 18 . THE LAST FIVE READINGS OF Q ARE RETAINED. .
At the highest discharge , the drawdown was probably not given enough time to stabilize.

Seepage

Figure 15 shows the corrected drawdown versus time from 22 hours of pumping onward. Figure 17b where Q versus s_{corr} is plotted shows a better linear fit than Q versus s. The application of Jacob's[2] correction on this single well test data is to compensate for the variation of the saturated thickness in this unconfined aquifer but it does not account for the correction on the drawdown measured in the well that is needed due to seepage along the inside wall of the well. Jacob's correction applied after correction for seepage as estimated by Boulton's (1954) method was examined as well as the case where the seepage is ignored.

In the case of the well ROJAS1 (PORCB-54) a seepage of approximately (0,12 x s_w) or (12%) was estimated using Boulton(1954) method for transient flow in unconfined aquifers. Boulton's method allows ones to estimate the head of water inside the well and therefore accounts for seepage. In the case of TLACOC2B this seepage is estimated to be 36%. Detailed calculations of the seepage in the case of TLACOC2B are given in Appendix G.

Simulation

A parabola symmetrical about t = 3120 minutes is a good fit of the well - aquifer response suggesting that the test was reversible in the late pumping period. We can take advantage of this situation by reversing the last 10 hours period that is when the partial well recovery was carried out through a series of two hours decreasing steps in which the pump speed discharge was reduced by 100 RPM every two hours for a total of ten hours. This is done in Figure 19 whereas Table 5 shows in a spreadsheet form how this simulation is set up.

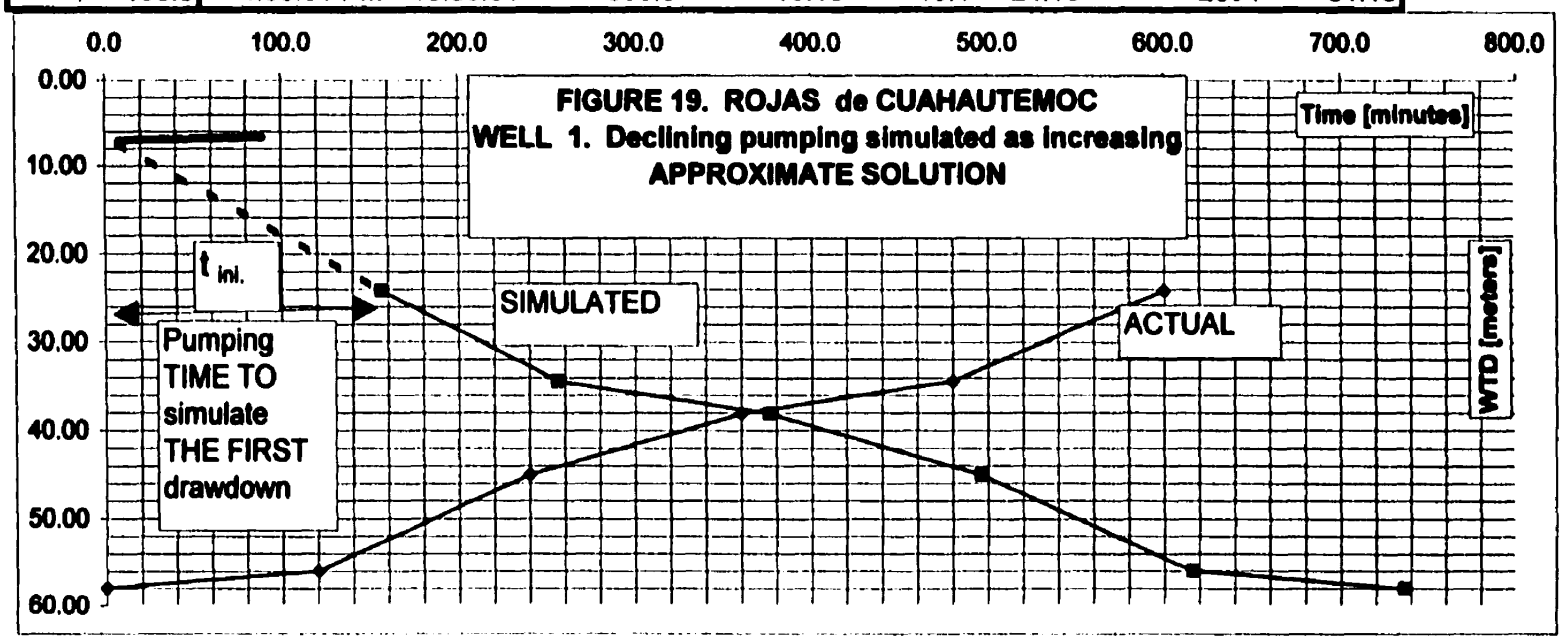
The starting time of this simulated pumping test, that is the time of pumping required for the water in the well to reach the desired drawdown, is not known. It is

---

[2] Jacob's correction that is $s_{corr} = s - (s^2/2D)$ where " s " is the measued drawdown and D is the saturated thickness of aquifer material.

TABLE 5. ROJAS WELL 1. Following 62 hours of pumping. Q is brought down in steps DATA ANALYSIS

	Total depth ->	60 meters	Sat. Depth	54 meters	r_w (m) ->	0.19			
	Static Level ->	6 meters	Gravel pack	12 mm	Well dia (mm)	356			
Time since	Data from S.A.R.H exploration. Analysis by E. Perraton.				$s_{corr} = s - (s^2 / (2 \times D))$				
Simulation	Time since peak drawdown.			s	s_{corr}	WTD	Q	Q	
minutes	(hour:min:sec)	hh:min:sec	(minutes)	(m)	(m)	(m)	(m^3/d)	(lps)	
	6:00:00			0.0		6.00			
736.0	6:00:00 AM	0:00:00		0.0	52.00	27.0	58.00	3653	42.28
616.0	8:00:00 AM	2:00:00		120.0	50.00	26.9	56.00	3319	38.42
496.0	10:00:00 AM	4:00:00		240.0	39.00	24.9	45.00	3190	36.92
376.0	12:00:01 PM	6:00:01		360.0	32.10	22.6	38.10	3092	35.79
256.0	2:00:01 PM	8:00:01		480.0	28.40	20.9	34.40	3049	35.29
156.0	4:00:01 PM	10:00:01		600.0	18.16	15.1	24.16	2694	31.18



reasonable to assume however, that this "starting time" is specific to the well-aquifer response. The solution is found by trial and error the following manner. To each starting time corresponds a specific linear regression fit between the log (s_{corr} / Q) and log (t / r^2) and therefore a pair of T and S values. A representative sample of this family of T ans S solutions is shown in Table 6.

The resulting family of possible T and S values takes the parabolic shape shown on Figure 21. The vertex of this parabola is the point of a unique solution that is where for a given specific yield [1] T the transmissivity has a unique value. This is the solution of our problem . This also corresponds to the maximum S value. Depending on how long the pumping period was and how close the steady state was approached, the corresponding S value will approach or not the delayed specific yield.

FIGURE (copy of 21)
Possible solutions of S and T

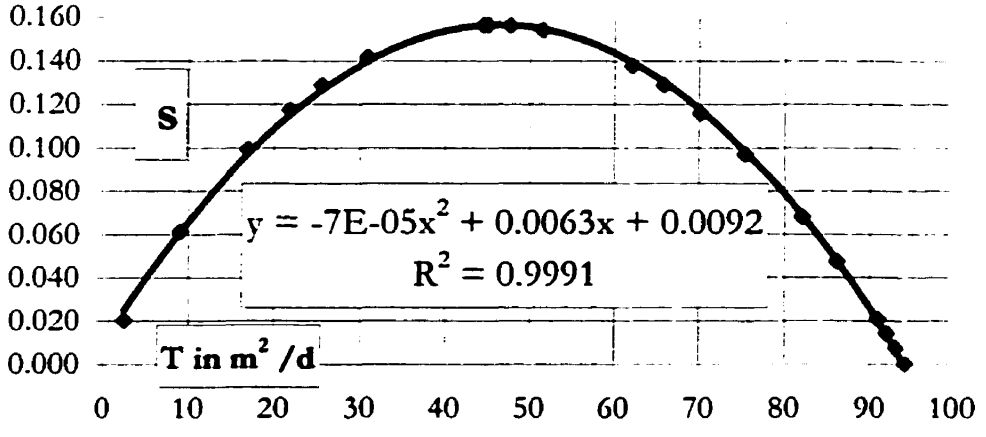


Figure 20 shows a typical example of these linear regression fits obtained. In the case of the well ROJAS1, a value of T = 45m^2/d and S = 0,16 was found when the drawdown measurements were corrected as per Jacob's correction without correction for seepage compared to a value of T = 52.5 m^2/d and S = 0.17 when the drawdown measurements taken from the pumping well are corrected for seepage first.

TABLE 6. CALCULATIONS OF T and S for various SIMULATED STARTING TIME

r_w = > 0.19		s_{corr} /Q versus log (t/r^2)		r_w = 0.20 m			min
t_{ini} (min)	R2	slope	intercept	T (m^2/min)	T (m^2/d)	S	time (min)
0.0	0.874	0.759	7.950	0.241	347	-5.6891	-21
10	0.975	2.063	2.914	0.089	128	-0.2819	-3
20	0.988	2.533	1.048	0.072	104	-0.0673	-1
26.9	0.992	2.791	0.009	0.066	94	-0.0005	0
27	0.992	2.794	-0.005	0.066	94	0.0003	0
28	0.993	2.829	-0.146	0.065	93	0.0075	0
29	0.993	2.863	-0.284	0.064	92	0.0143	0
30	0.993	2.896	-0.421	0.063	91	0.0207	0
35	0.994	3.058	-1.079	0.060	86	0.0475	1
40	0.995	3.210	-1.703	0.057	82	0.0681	1
50	0.995	3.493	-2.873	0.052	75	0.0970	2
60	0.994	3.756	-3.969	0.049	70	0.1159	2
70	0.993	4.004	-5.012	0.046	66	0.1288	3
80	0.991	4.241	-6.016	0.043	62	0.1377	3
120	0.984	5.118	-9.782	0.036	51	0.1538	4
140	0.980	5.529	-11.572	0.033	48	0.1559	4
156	0.977	5.849	-12.976	0.031	45	0.1562	5
160	0.977	5.928	-13.324	0.031	44	0.1561	5
300	0.959	8.545	-25.094	0.021	31	0.1415	6
400	0.950	10.324	-33.316	0.018	26	0.1287	7
500	0.944	12.070	-41.517	0.015	22	0.1174	7
700	0.935	15.509	-57.987	0.012	17	0.0993	8
1500	0.919	29.031	-125.510	0.006	9	0.0613	9
6000	0.9052	104.32	-535.98	0.002	3	0.0203	10

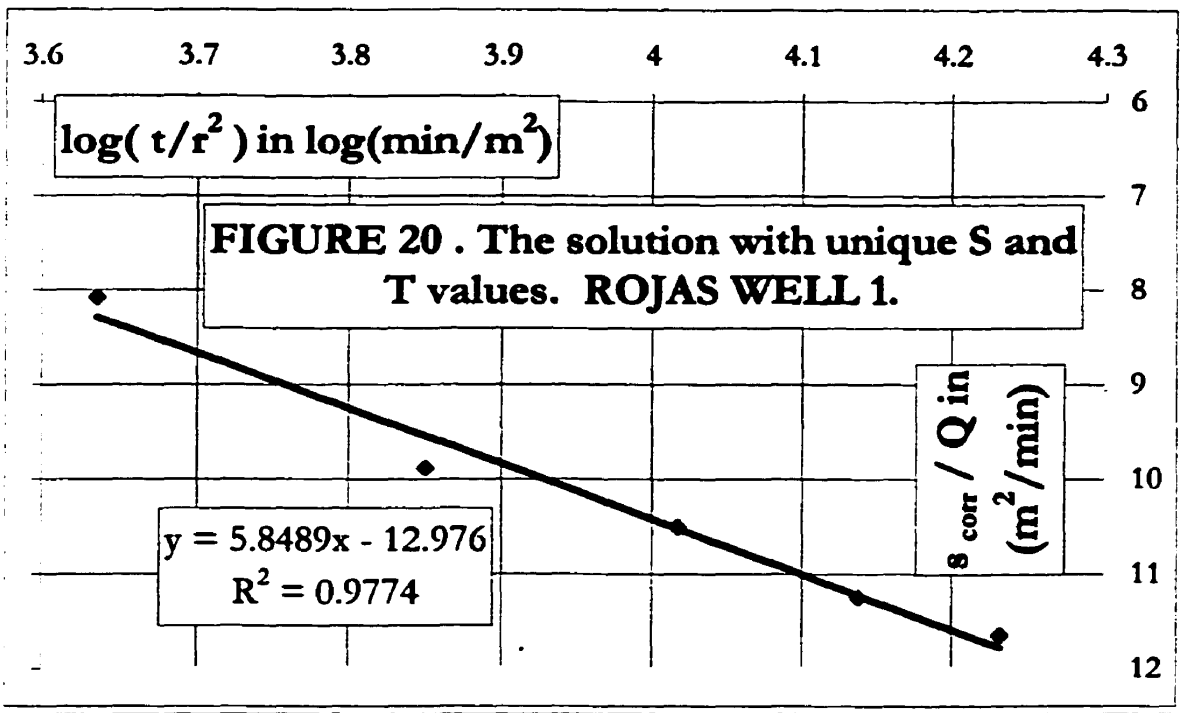
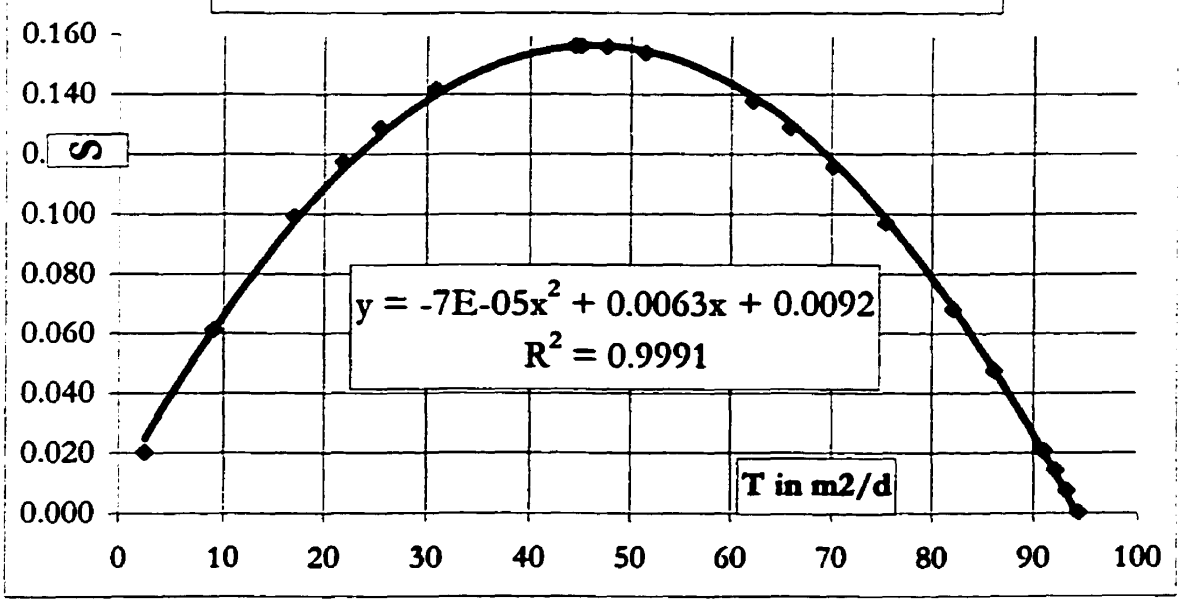


FIGURE 20 . The solution with unique S and T values. ROJAS WELL 1.

Figurre 21. Possible solutions of S and T



Partial Recovery Method

The same data were also analyzed as a partial recovery using the principle of superposition. In the case of full recovery the imaginary injection well is of the same magnitude as the pumping well so that the resulting measured discharge is zero. In the case of partial recovery, the discharge of the injection well is less than the discharge of the pumping well and the measured discharge is therefore greater than zero during recovery.

Appendix F shows the two solutions (an Approximate and a Better solution called IIA and IIB solutions) that were derived in such a case. There again, a family of possible T and S values are obtained. Table F.1 shows the calculations whereas Figure F.1 shows the results. A third curve is shown in Figure F.1 that is the residual drawdown curve that could be expected if full recovery had taken place. This is called CASE I.

The transmissivity being calculated from the slope of these lines. CASE I must have the same slope as CASE IIB. CASE IIA being approximate, the slope is somewhat different.

The ratio (s_I / s_{II}) is the ratio of the corrected drawdown (CASE I / CASE IIB) to be expected when comparing partial to full recovery for this test. This ratio plus the value of the specific yield that is expected to exceed 0.10 guide us in the selection of the S and T value. By this method T is estimated to be in the range of 35 to 40 m^2/d for a value of S between 0.10 and 0.20.

There is a minimum time interval after the start of pumping for Jacob's modification of Theis's method to be applicable. This corresponds to the pumping time that must be exceeded so that the straigh-line segment can be distinguished from a time-drawdwon plot on a semi-log paper. Boonstra (1989) procedure described in ILRI #48 is used for calculating this minimum time which appears under the column MINIMUM TIME.

TABLE (7) POSSIBLE T and S solutions.

Well ROJAS1 (PORCB-54)

corrected	r_w =>	0.2 m			
s_I / s_{II}	T	T	S	R^2	Minimum
ratio	m^2/min	m^2/d			time (min)
0.44	0.054	78.2	0.00001	0.9996	0
0.51	0.047	68.2	0.0001	0.9995	0
0.59	0.040	**58.1**	**0.001**	0.9993	0
0.71	0.033	47.9	0.01	0.9990	0
0.84	0.028	**40.6**	**0.05**	0.9986	2
0.88	0.027	38.7	0.075	0.9985	3
0.91	0.026	37.4	0.1	0.9984	4
0.91	0.024	34.2	0.2	0.9984	8

corrected drawdown as per Jacob (1954)

$s = s - [s^2/(2 \times \text{Sat. Thickness})]$

The proposed method can be best understood with Figures (22a and 22b) which describes in flow chart form the investigated procedure for solving the single well test when development is followed by declining Q. The well test TLACOC2B is also anlayzed with the proposed method. See Appendix F, Tables (F.5 , F.6) and Figures (F.3 , F.4) for detailed compilations.

POAB-59. WELL TEST.

The piezometer set on the calibrated orifice at the well outlet was not operational during the 24 hours drawdown test preceding the first recovery of the well. The piezometer worked for 8 minutes only in the second drawdown test after which time Q was down to 7.7 lps with a 2 cm piezometer reading. Considering the crew's experience and the fact that the drawdown had already started to stabilize after 6 minutes with still half of the initial saturated thickness while a constant RPM was maintained throughout the test, it is then reasonable to consider a 15-20% possible error on the Q estimate of 6.8 lps.

The recovery period is analyzed keeping in mind this level of confidence on the discharge Q during the pumping period preceding the recovery periods. Figure 23 shows the graphic logs for the well POAB-59. Figures (24, 25 and 26) show the three recovery tests that were conducted by S.A.R.H . Calculations of the transmissivity are also shown on Figures (24, 25 and 26). Unfortunately the specific

yield can not be obtained by this method but an estimate can be derived using the layers superposition method.

Each layer of different granulometry is assigned a specific yield that is typical for aquifer materials of the same granulmetry. The weighted mean average specific yield is calculated on the basis of relative thickness of each material. An estimate of the transmissivity can be obtained the same manner and this done for nineteen of the twenty five well tests that constitute the historical well tests conducted in the research area by S.A.R.H and C.N.A in the history of groundwater exploration in the groundwater basin of the Slado River.

Appendix **J** shows these weighted means calculated for the specific yield and the transmissivity. When compared with our results from well tests, the weighted mean values for the transmissivity is always larger. This was expected because the conductivity is function not only of the size of the pores but also of their disposition. This was demonstrated experimentally by Bouma et al (1978) who found that very small variation on the width of planar "necks" in the flow system of a clay soil had a strong effect on the saturated conductivity.This is indeed the basic difficulty in estimating K_{sat} in clay soils by methods which use realtive volume of voids. Clays soils represent 43% of the 13 646 hectares of soil surveyed by Cruz (1938) for the agroeconomic study of the irrigation district of **Tlacolula.**

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One driller's log is available for the single well test performed by S.A.R.H in May 1973. The well was rotary drilled with a bit 310 mm diameter to a depth of 40 meters using water as lubrification liquid in which cuttings were removed by a rotating suction pipe. The 310 mm diameter hole was then enlarged to 380 mm for a length of 39 meters deep leaving the last meter at 310 mm diameter.

A 250mm casing 40 meters long was introduced in the hole and a properly selected gravel-pack was fed into the annular space around the 250 mm casing.

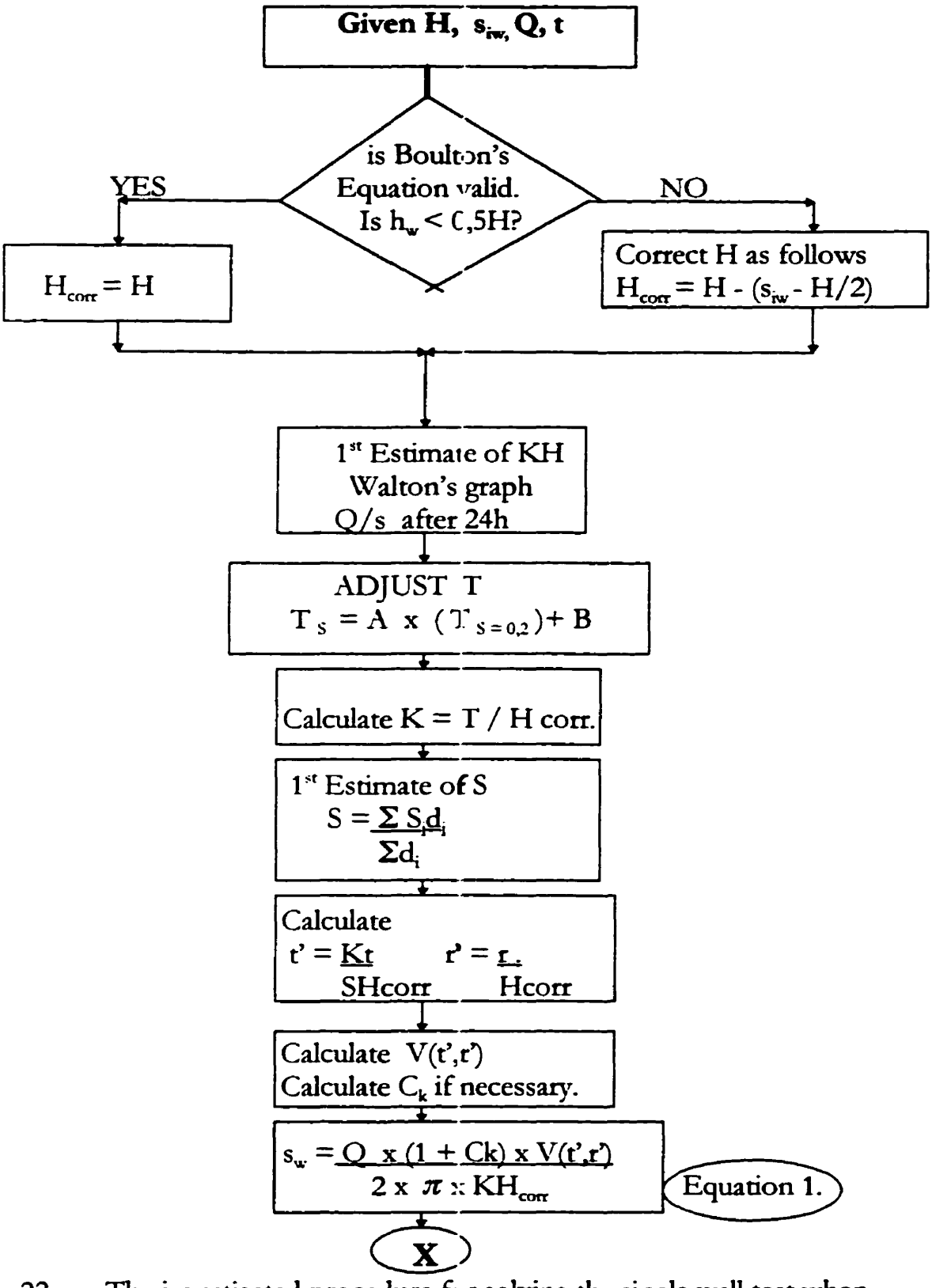
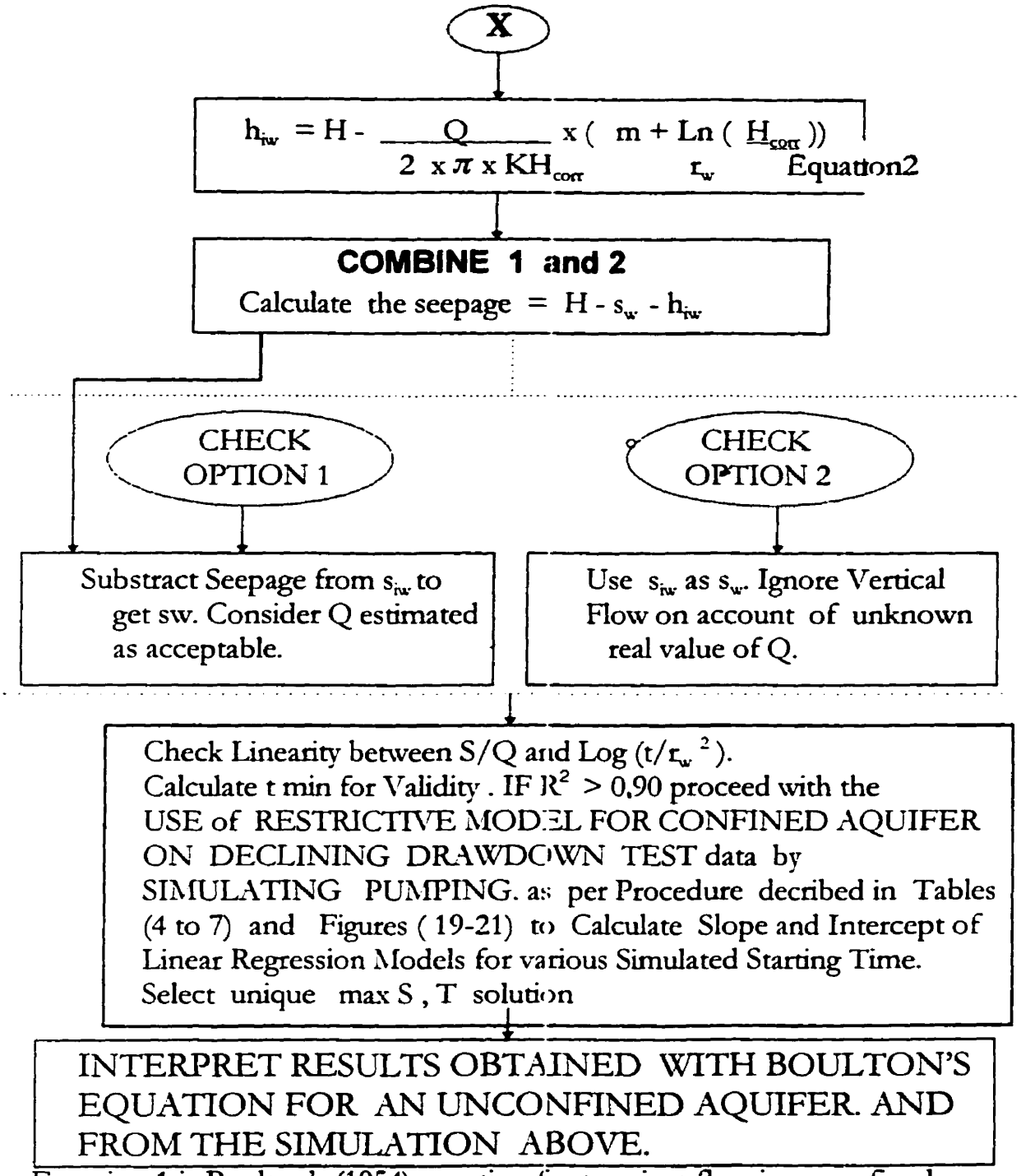


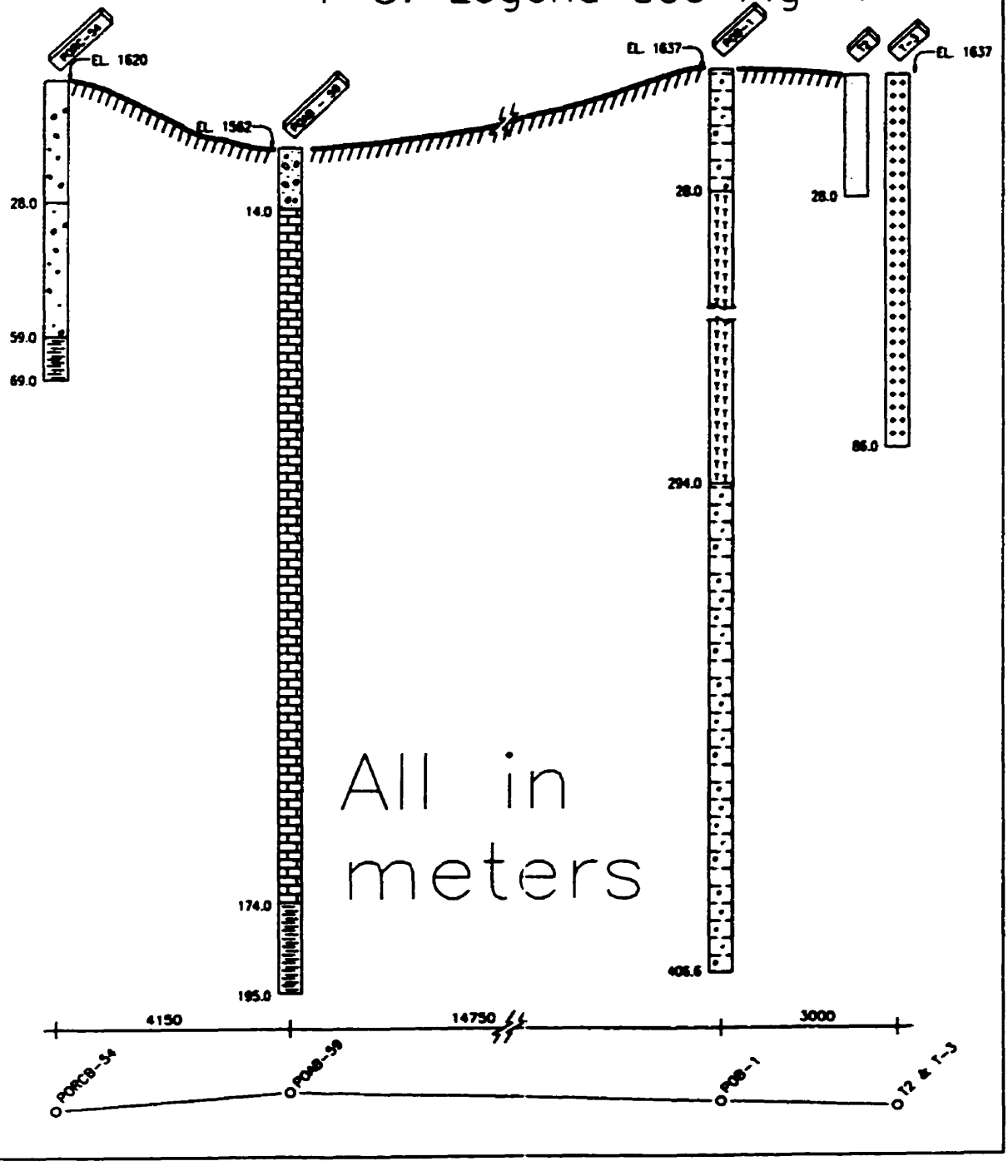
Figure 22a The investigated procedure for solving the single well test when development is followed by declining Q .



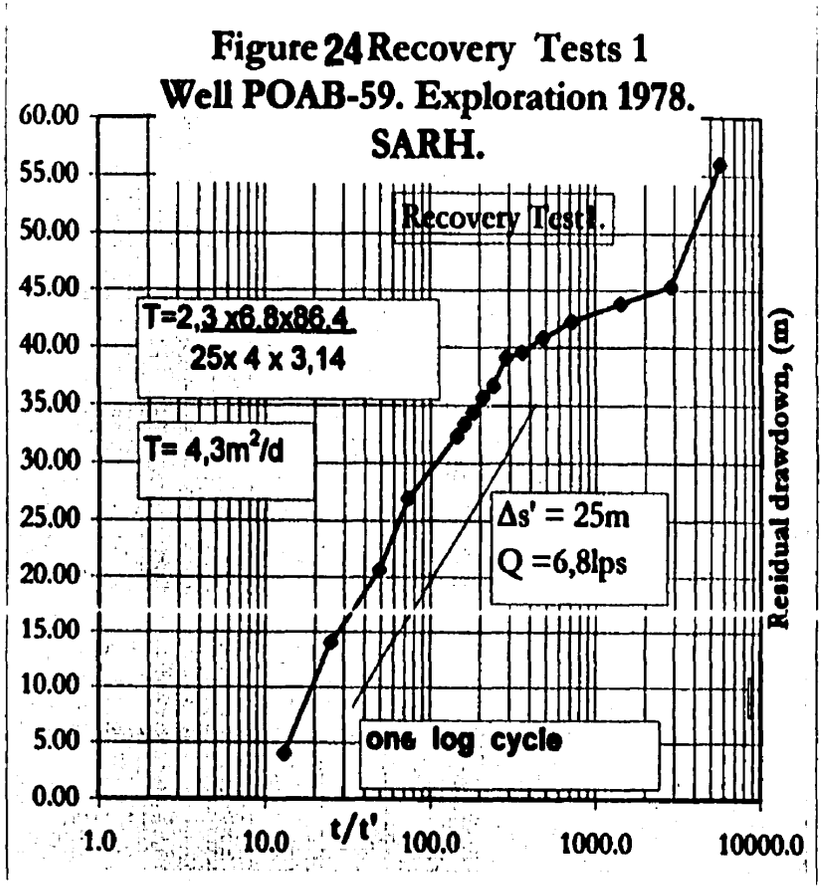
Note: Equation 1 is Boulton's (1954) equation for transient flow in unconfined aquifers; $h_{iw} < 0,5$ H. (s_{iw} max < 0.5 H). Equation 2 is Boulton's (1954) equation for calculating the water level in the well when taking the surface of seepage into account but neglecting well losses.

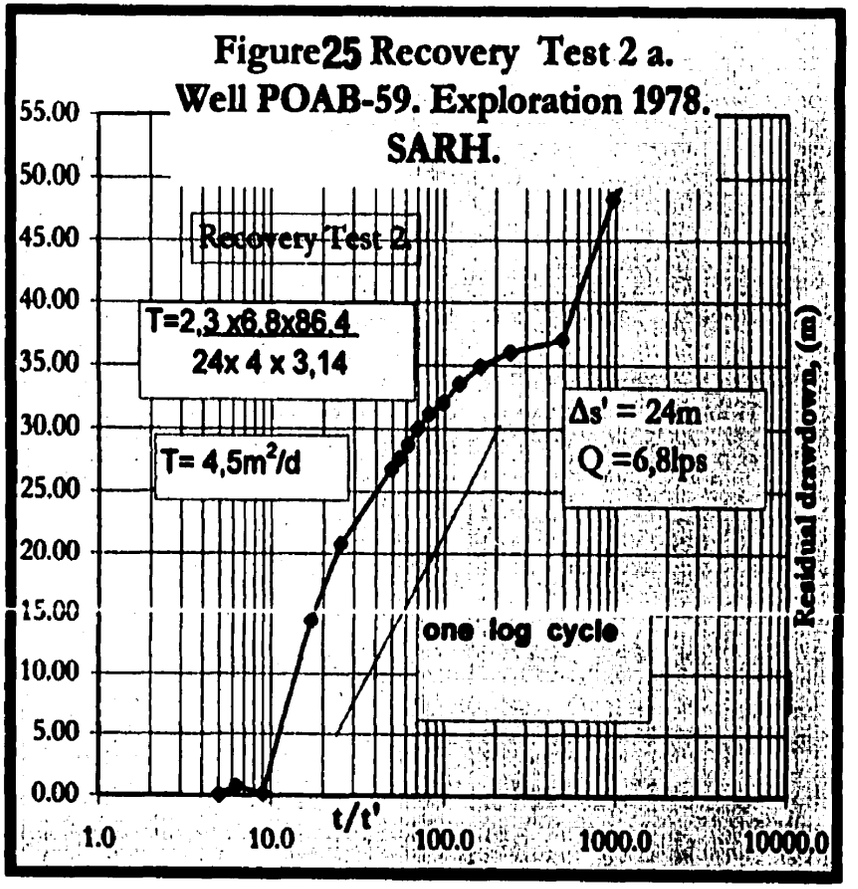
Figure 22b The investigated procedure for solving the single well test when development is followed by declining Q .

Figure **23** . Exploration Wells PORB−54 PoAB−59, POB−1, T−2 and T−3. Legend see Fig 7

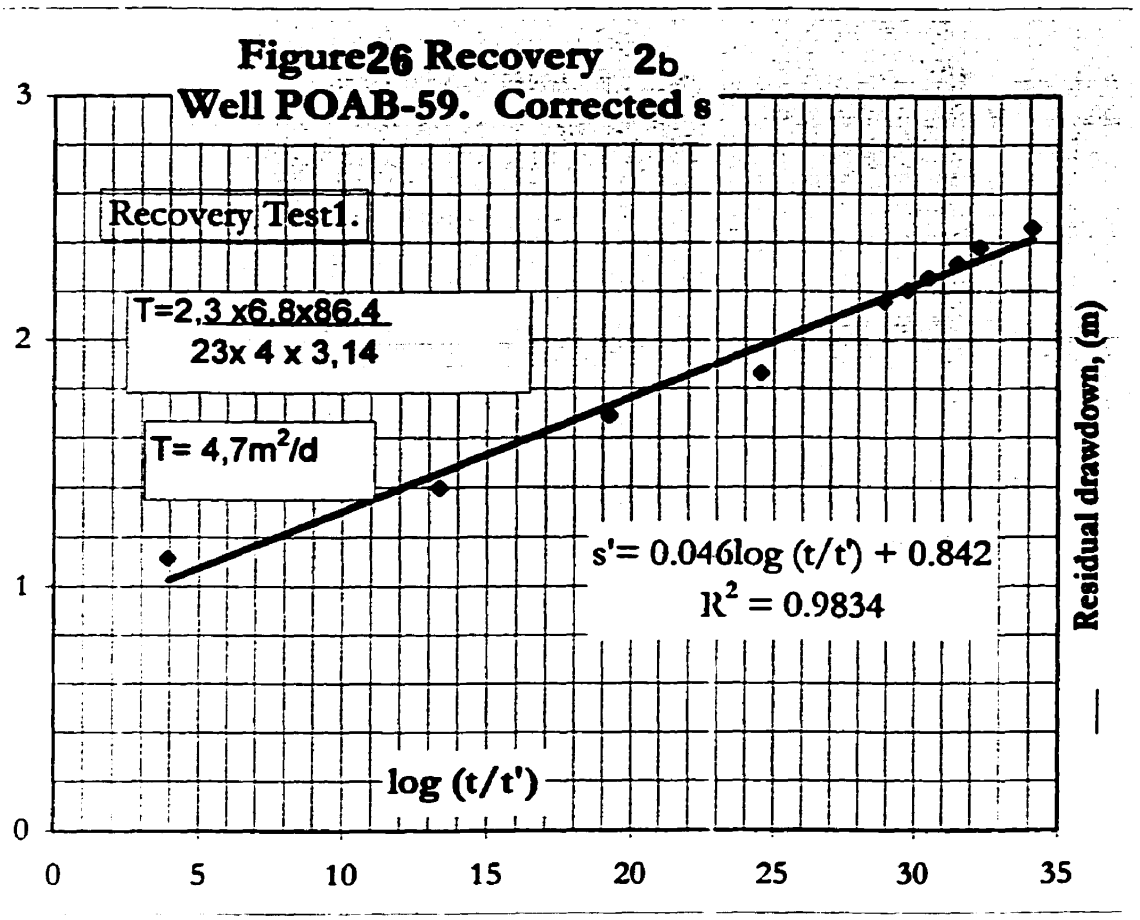


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Figure 24 Recovery Tests 1
Well POAB-59. Exploration 1978.
SARH.
Recovery Test 1.
T=2,3 x6,8x86,4
25x 4 x 3,14
T= 4,3m²/d
Δs' = 25m
Q =6,8lps
one log cycle
Residual drawdown, (m)
t/t'
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1.0
10.0
100.0
1000.0
10000.0


Figure 25 Recovery Test 2 a.
Well POAB-59. Exploration 1978.
SARH.
Recovery Test 2.
T=2,3 x6,8x86,4
24x 4 x 3,14
T= 4,5m²/d
Δs' = 24m
Q =6,8lps
one log cycle
Residual drawdown, (m)
t/t'
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1.0
10.0
100.0
1000.0
10000.0

POAB59.xls


Figure26 Recovery 2b
Well POAB-59. Corrected s
Recovery Test1.
T=2,3 x6,8x86,4
23x 4 x 3,14
T= 4,7m²/d
s'= 0.046log (t/t') + 0.842
R² = 0.9834
log (t/t')
Residual drawdown, (m)
0
1
2
3
0
5
10
15
20
25
30
35

To keep surface water from entering the well, the annular space outside of the casing was filled with cement grout and the top of the well was provided with a watertight seal.

The production well was then developed through a step drawdown until signs of clear water. The pumping rate was at that point decreased in steps where once more at each step pumping was maintained constant until soil stabilty was achieved. This first development took 48 hours after the aquifer was given time to recover.

After well development, a single well drawdown step test was conducted . This test consisted of four steps of two hours each in which the pumping rate was kept constant. These two hours were generally sufficient for the water to turn clear indicating that soil stability was achieved. The step drawdown procedure was then reversed through three decreasing steps of two hours to bring the pumping rate back to its first step value. After these 14 hours of pumping, the aquifer was given two hours to recover during which time residual drawdown measurements were taken.

Step Drawdown Analysis

The drawdown curve is shown on Figure 27. The step drawdown pumping procedure described above is clear on this figure. Table 8 shows the calculations for the discharge Q of each step. Table 11 shows the Step Drawdown Well Test Data whereas Figure 28 shows the application of Rorabaugh's Method and the linear best fit Log (s/Q -A) versus Log (Q) for A = 0.00 and for the solution A =1.85. Tables (9 and 10) show the R^2 values obtained for five values of A equal to 0.00 that is when no linear drawdown component is considered, A=1.83 and A =1.87 those are the A values on either side of the solution A=1.85. In Table 10 the linear and non linear head losses were calculated with the A=1.85 and the corresponding C and M values found by Rorabaugh Method.

In Figure 29. Rorabaugh's method is apllied on data after Sheahan (1971). Table 12 compares PODOB-15 and Sheahan's data in order to understand the limits of applicability of Rorabaugh's method. The difference between these two data sets is clear. Sheahan (1971)'s test was conducted for a much larger range of Q. Lohman

(1972) is of the opinion that Rorabaugh's method presents a more exact method for evaluation of well loss **when a large range of pumping rates is encountered.**

Residual drawdown data for the first recovery are given in Table 13. A transmissivity of 51.3 m^2/d was found. Figure 30 shows the detailed calculations.

Slug Test and Well Test at San Francisco Lachigolo.

The municipal Well of Lachigolo was pumped for 12 hours and the water table drawdown was observed from nearby observation wells identified as P54, P49, P52, P53, P146 (new observation well at the school), P51 and P50. The discharge of the well was measured from the municpal tank.

Table 14 shows the observations made from these observation wells. The radial distance (r_i) between the pumped Well and the observation wells is also given in Table 14. Boonstra 's (1989) computer program SATEM was used to analyze data. Figures (31, 32 and 33) show the matching curves obtained. Anisotropic transmissibility is prevailing around the municipal well.

A slug test, was conducted on the domestic well of Lachigolo primary school which is located 60 meters east of the deep well of the municipality.

Bouwer and Rice's (1976 as reported by Sen, 1995) method of analysis was used to analyze the data. Water Table Observations, data compilation and results are shown in tabular form in Tables 14, 15 and 16.

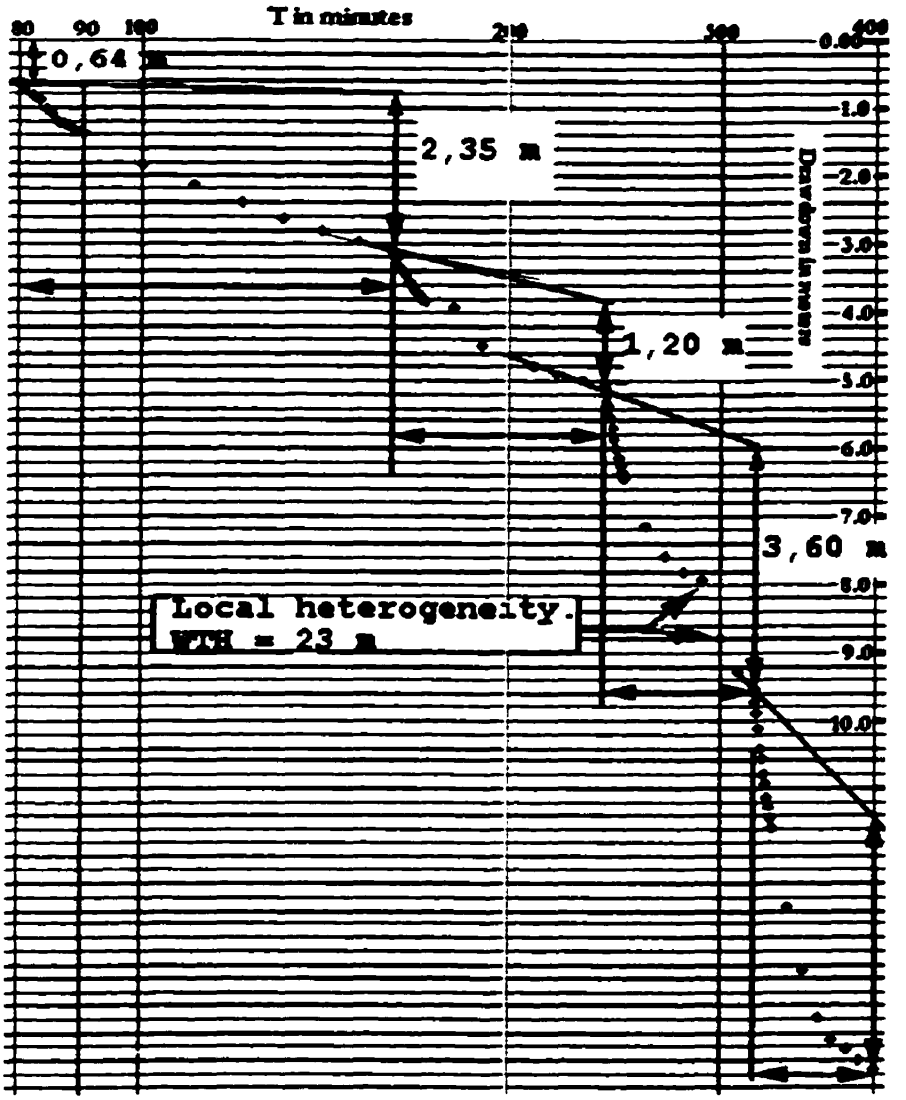
An hydraulic conductivity of 0.10 m/d was obtained by the slug test suggesting that the soil permeability from the village well is low in the direction toward the school. The axis WELL-P53 is the axis of greatest permeability. This axis WELL-P53 is in the direction of shortest distance to the river and is approximately perpendicular to well-school axis.

Table 18A, B, C and D gives a summary of data of well tests that were analyzed in this research.

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[1]Capital **S** is used for Specific yield , small **s** is used for drawdown..

Fig. 27. Step Drawdown Single Well Test PODOB-15.



File:PODOB15step2345.psd

(27)

PODOB15.xls.

TABLE 8 . Calculation of weighted Q for STEPS 1, 2, 3 and 4.

STEP	Q	time	volume	Q weighed	
	(lps)	(min)	(liters*60)	(lps)	(m3/min)
1	5.26	80	420.8	5.26	0.316
2	8.11	2	16.22		
	7.89	18	142.02		
	7.67	20	153.4		
	7.44	40	297.6	7.62	0.457
3	8.32	4	33.28		
	8.11	6	48.66		
	7.89	20	157.8		
	7.67	50	383.5	7.79	0.467
4	9.12	7	63.84		
	8.92	3	26.76		
	8.73	10	87.3		
	8.53	50	426.5		
	7.67	10	76.7	8.51	0.511

TABLE 9 Coefficients A, M and C versus R^2

A	R^2	M	C
(min/m^2)			(m)
0.00	0.9601	3.93	2.25
1.83	0.9977	8.82	3.71
1.85	**0.9978**	**9.05**	**3.79**
1.87	0.9977	9.32	3.87

$$\log (s/Q - A) = M \log (Q) + C$$

$$(s) = (10^{C} Q^{M+1}) + AQ$$

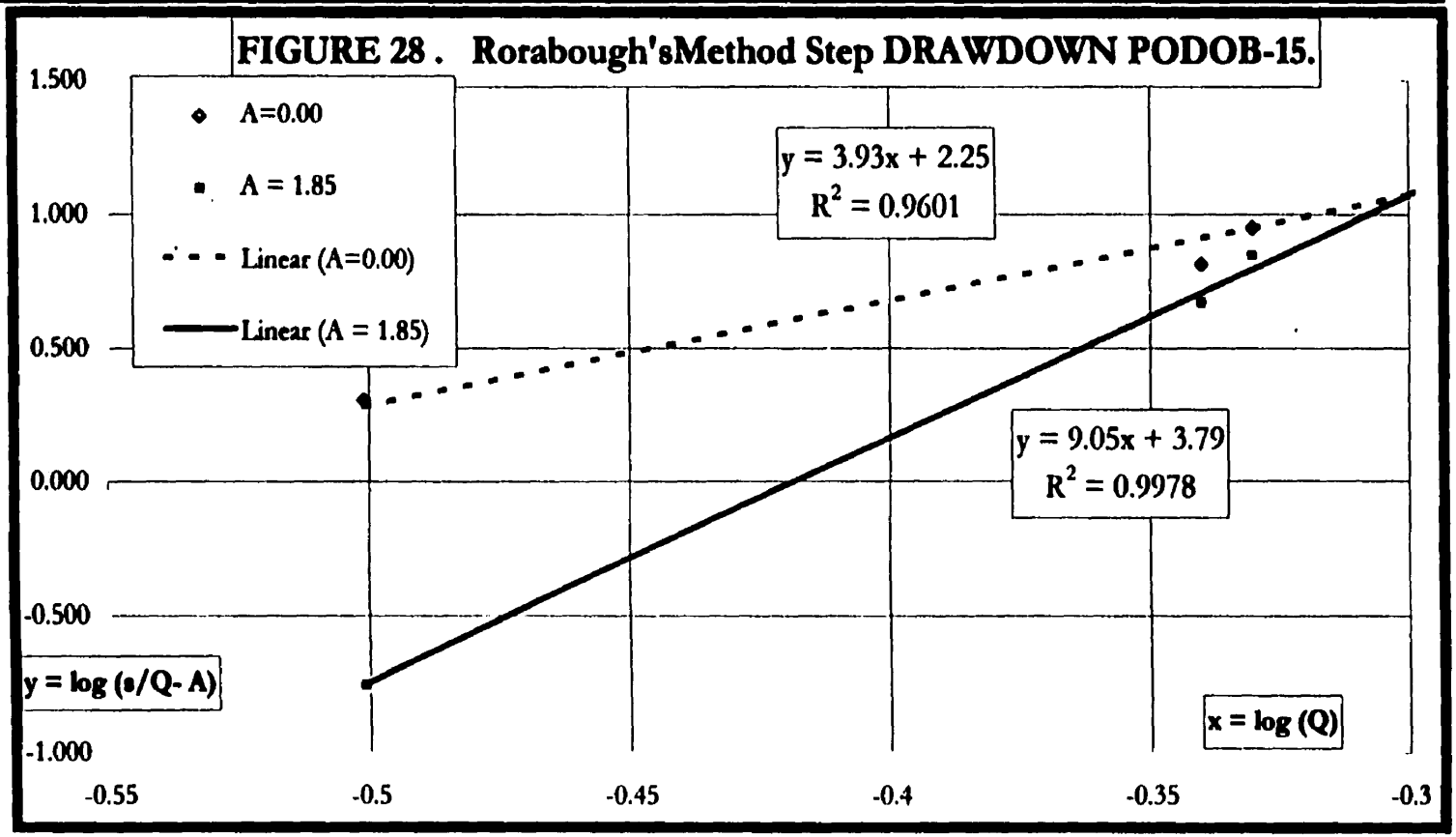
$$(s) = (10^{C} Q^{M+1}) + AQ$$

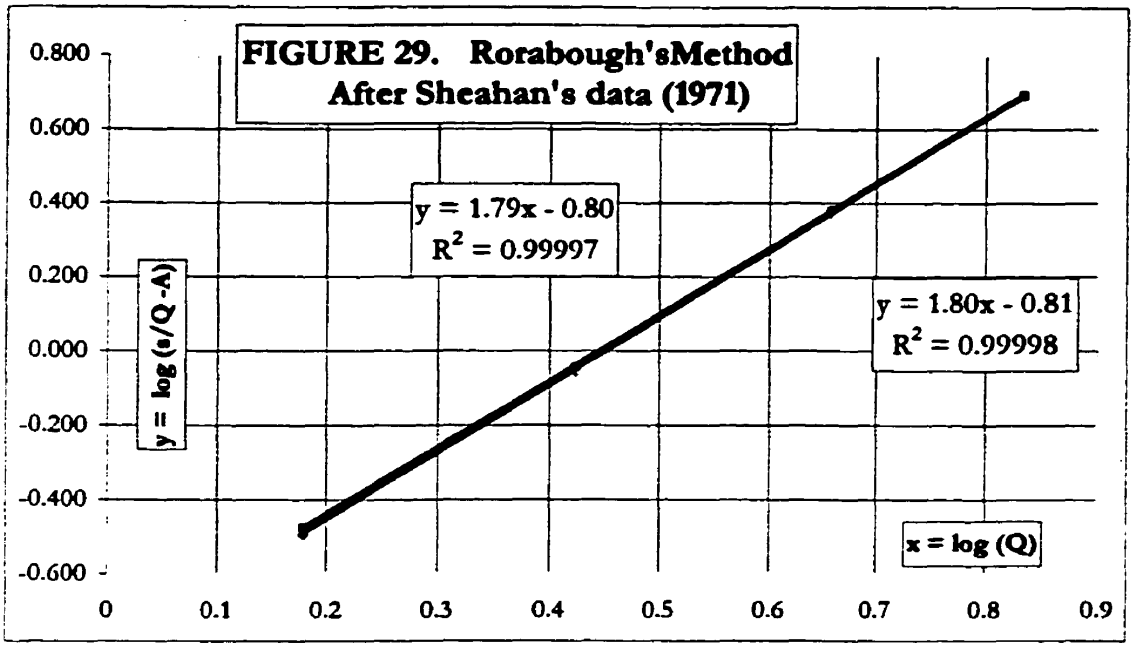
TABLE 10 Linear and non-linear Losses . s predicted vs s observed.

			$10^{C}Q^{M+1}$	AQ	s calc	$S_{obsv.}$	$S_{obsv.}$
	Q weighed.		non linear	linear	Total	non corr	corr.
Steps	(lps)	(m^3/min)	(m)	(m)	(m)	(m)	(m)
1	5.26	0.316	0.06	0.58	0.64	0.64	0.64
2	7.62	0.457	2.33	0.85	3.17	3.09	2.97
3	7.80	0.468	2.96	0.87	3.82	5.07	4.74
4	8.51	0.511	7.14	0.94	8.09	9.52	8.36

TABLE 11. STEP DRAWDOWN WELL TEST DATA. PODOB-15. Test by SARH. 1978. Analysis by E. Perraton

Step No.	Q m^3/min	log (Q)	Δs meters	s= ΣΔs meters	s/Q A=0.00 min/m^2	log (s/Q)	(s/Q)-A 1.85	Log (s/Q -A)	(s/Q)-A 1.830	Log (s/Q -A)
1	0.3156	-0.50086	0.64	0.64	2.028	0.307	0.178	-0.750	0.198	-0.704
2	0.4569	-0.34018	2.35	2.99	6.544	0.816	4.694	0.672	4.714	0.673
3	0.4674	-0.33031	1.20	4.19	8.964	0.953	7.114	0.852	7.134	0.853
4	0.5108	-0.29175	3.60	7.79	15.251	1.183	13.401	1.127	13.421	1.128





$y = M x + C$

$\log (s/Q-A) = M \log (Q) + C$

$(s) = (10^{C} Q^{M+1}) + AQ$

$(s) = (10^{C} Q^{M+1}) + AQ$

s is the drawdown in meters.

Q is the discharge in m3/min

M, C Constants found graohically.

A

TABLE 12. Rorabough's (1953) Method. Sheahan's (1971) dataversus PODOB-15.

Data After Sheahan, (1971 as reported by Kruseman and de Ridder (1990)							
Total				*** L og (s/Q -A) ***		Solution	L og (s/Q -A)
S_w	Q	log (Q)	s/Q	0.00	1.41	<- A ->	1.40
m	m^3/min		d/m2	*** L og (s/Q -A) ***		(s/Q -A)	L og (s/Q -A)
2.62	1.51	0.1789769	1.74E+00	0.239	-0.488	0.325	-0.475
6.1	2.65	0.4232459	2.30E+00	0.362	-0.050	0.892	-0.045
17.22	4.54	0.6570559	3.79E+00	0.579	0.377	2.383	0.379
42.98	6.81	0.8331471	6.31E+00	0.800	0.690	4.901	0.691

COMPARING Sheahan 1971 with PODOB15.					
Total			Total		
s	Q	s/Q	s	Q	s/Q
m	m^3/d	d/m^2	m	m^3/d	d/m^2
2.62	2180	1.20E-03	0.64	454.5	1.41E-03
6.1	3815	1.60E-03	2.99	657.9	4.54E-03
17.22	6540	2.60E-03	4.19	673.1	6.22E-03
42.98	9811	4.40E-03	7.79	735.5	1.06E-02

Rorabough (1953) and Sheahan (1971) as reported by Krusemand and de Ridder (1990)

RECOVERY

TABLE 13 . RECOVERY TEST 1. PODOB15.

t time since pump start minutes	t' time since pump stop minutes	t/t'	Water Tabl Height	Residual Drawdown
			13.55	
600.0	**0**		**24.14**	**10.59**
600.2	0.2	2452	23.62	**10.07**
600.5	0.5	1226	23.28	**9.73**
601.0	1.0	605	23.32	**9.77**
602.0	2.0	302	19.33	**5.78**
603.0	3.0	201	18.55	**5.00**
604.0	4.0	151	18.09	**4.54**
605.0	5.0	121	17.77	**4.22**
606.0	6.0	101	17.66	**4.11**
607.0	7.0	87	17.49	**3.94**
608.0	8.0	76	17.37	**3.82**
609.0	9.0	68	17.26	**3.71**
610.0	10.0	61	17.18	**3.63**
620.0	20.0	31	16.50	**2.95**
630.0	30.0	21	16.07	**2.52**
660.0	60.0	11	15.32	**1.77**
690.0	90.0	8	14.25	**0.70**
720.0	120.0	6	14.17	**0.62**
750.0	150.0	5	13.85	**0.30**
780.0	180.0	4	13.83	**0.28**
840.0	240.0	4	13.58	**0.03**
900.0	300.0	3	13.56	**0.01**
Original water table		13.55		

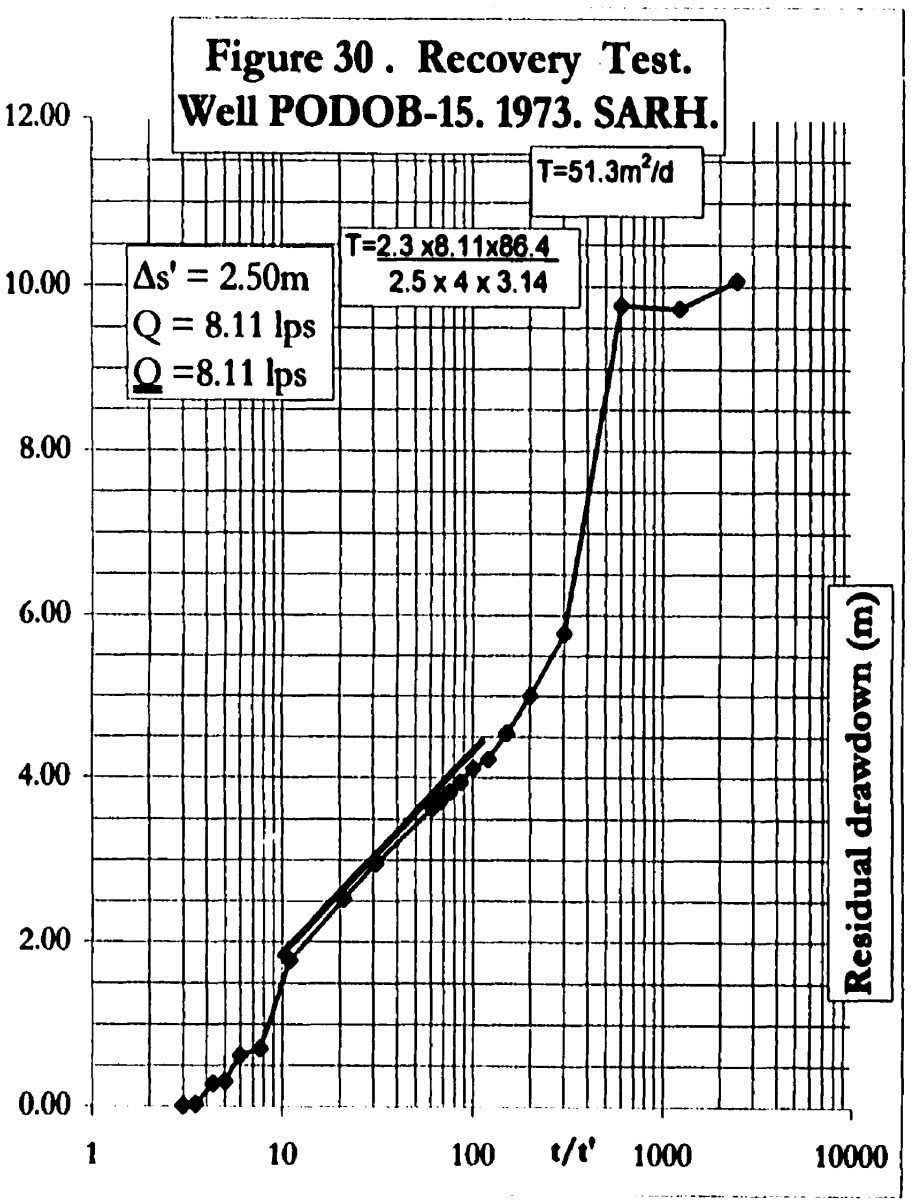
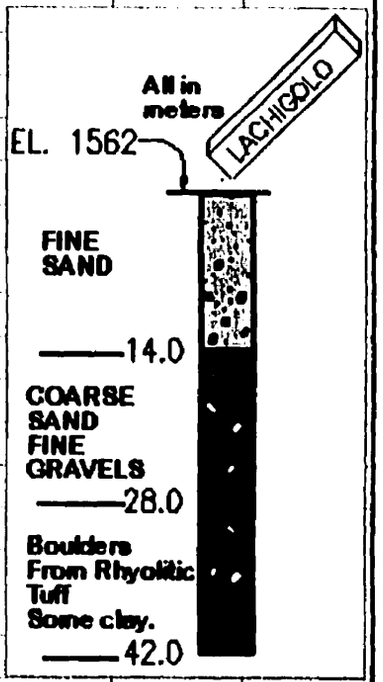


Table 14 LACHIGOLO WELL TEST. JULY 1995.

		Q =1.13 l/s	- - - - observations taken					- - - - -	- - - -
		WELL	P-54	P-49	P-52	P-53	P-146	P-51	P-50
r	(m)	0	1.6	520.1	163.5	85.0	60.0	333.9	307.4
X	(m)		7026	6833	6923	7064		7077	7064
Y	(m)		17170	17653	17297	17246		17500	17475
Z	(m)		1562.58	1563	1561.77	1562.13		1561.97	1561.64
TIME							School		
	min.								
9:00	0	7.045	6.850	5.068	6.900	5.765	5.065	5.340	5.425
9:05	0:00		22.245			5.770	5.065		
11:17	137			5.061	6.880				
11:30	150					5.860		5.270	5.440
11:50	170						5.910		
13:50	290					5.875	C		
14:00	300		26.240				A		
14:10	310				6.865		N		
14:20	320						C	5.385	5.443
14:30	330			5.035			E		
17:10	490						L	B . P	
17:25	505		27.960				E	O U	
17:30	535				6.940	5.865	D	M M	5.440
17:40	545			5.050				E P	
18:50	590					5.875		R D	
19:00	600		27.400		6.99			O	
19:20	620			5.02				N 80 liters	

Well Test conducted by E. Perraton July 1995.



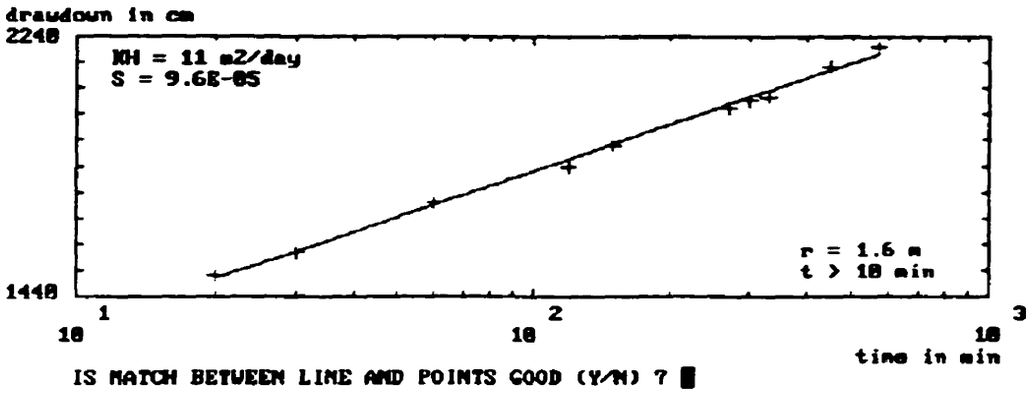


FIGURE 31. USING SATEM from Boonstra (1989). Drawdown curve at r =1,6 m. Lachigolo.

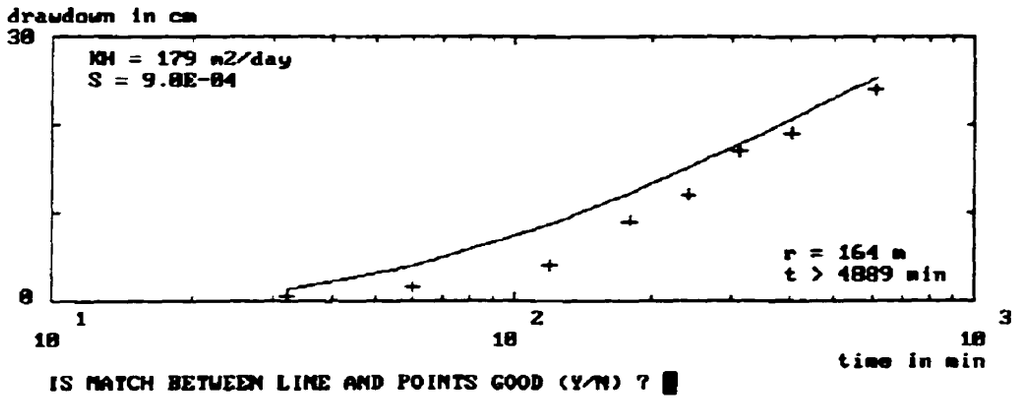


FIGURE 32 USING SATEM from Boonstra (1989). Drawdown curve at r = 164 m. Lachigolo.

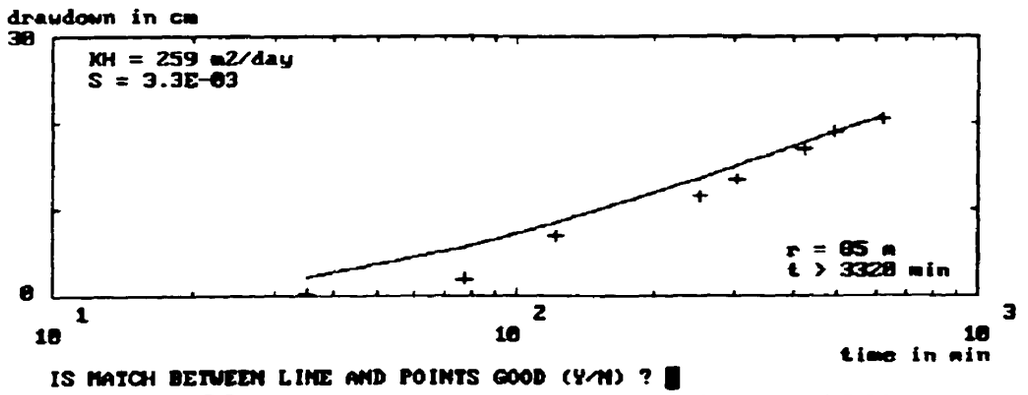


FIGURE 33. USING SATEM from Boonstra (1989). Drawdown curve at r = 85 m. Lachigolo.

Test conducted by E. Perraton 1995.

TABLE 15. Slug Test Data Lachigolo Well.

L	a	b	d	D
m	m	m	m	m
40.00	5.21	7.29	7.29	34.79
$2r_c$	$2r_w$	d/r_w	A	B
m	m	-	A & B from Graph	
1.05	1.05	13.89	1.90	0.30
t	$Ln(h)_{calc.}$	$h_{t\ calc.}$	$h_{0\ calc.}$	$[\ln (h_0/h_t)]/t$
min	Ln (cm)	cm	cm	1/min
100	4.5185	92	215	0.008500

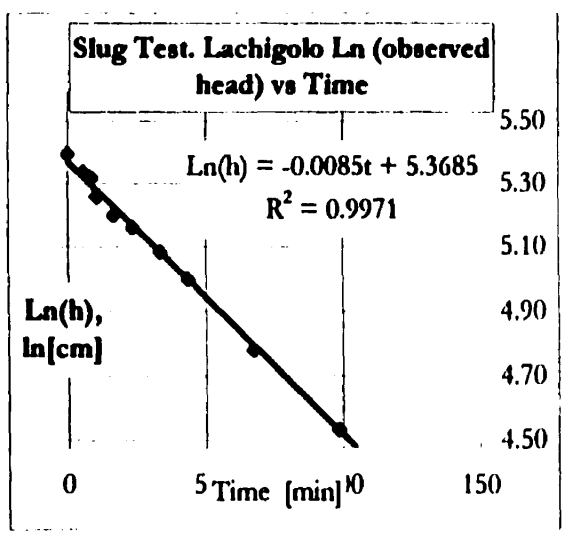
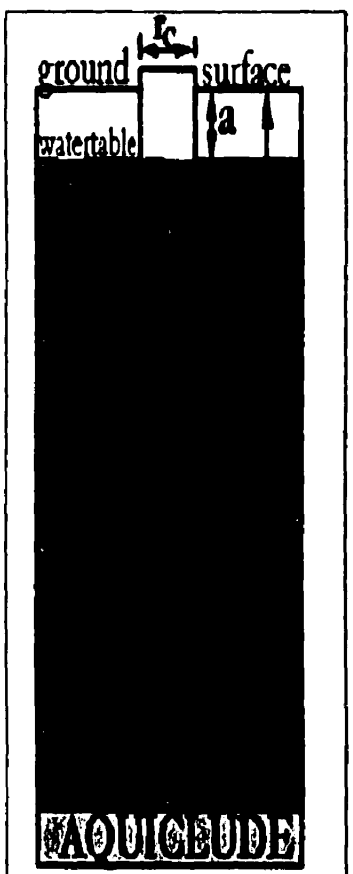


TABLE 16. Slug Test Data Lachigolo Well.

$WTD_{t=0}$ = 5.21 m

t	WTD_t	h	Ln (h)
min	m	cm	Ln (cm)
0	7.41	220	5.39
5.5	7.29	208	5.34
8.5	7.25	204	5.32
10.5	7.13	192	5.26
16.5	7.02	181	5.20
23.5	6.95	174	5.16
33.5	6.82	161	5.08
43.5	6.69	148	5.00
67.5	6.4	119	4.78
98.5	6.14	93	4.53
116	6.02	81	4.39



Slug Test

TABLE 17 Slug Test Data Analysis by Bouwer-Rice's method
Lachigolo Well.

$\ln(R/r_w) =$	$[1.1/(\ln(b/r_w)) + \{(A + B\ln[(D-b)/r_w])/(d/r_w)\}]^{-1}$		
$\ln(R/r_w) =$	[0.4181 + 0.2224] $^{-1}$		
$\ln(R/r_w) =$	**1.561**		
See TABLE . for the Slug Well Test Data .			
K =	$((r^2_c \ln(R/r_w)/2d)^* \ln(h_0/h_t))/(t)$		
K =	7.16E-05	m/min	
K =	**0.103**	**m/day**	

Test conducted by E. Perraton 1995.at San Francisco Lachigolo Mexico
Analysis by E. Perraton. 1997.

of ALL TESTS RESULTS

TABLE 18A WELL TESTS DEVELOPMENT AND EXPLORATION .							
			Aquifer	Well	Screen	Static	Saturated
No.	WELL ID.		thickness	depth	depth	Level	Thickness
		p	(m)	(m)	(m)	(m)	(m)
1	POTB 66	30	86	98	0-32/60-98	4.17	81.83
2	TLACOC1_1	4	40	40	33	8.9	31.1
3	TLACOC1_2		40	33	29.8	9.43	30.57
4	TLACOC1B	6	50	53.36	53.36	9	41
5	TLACOC1BB	6	50	53.36	53.36	8.5	41.5
6	TLACOC2B	5	58	82	41	9.5	48.5
6	TLACOC2B		58	82	41		
7	TLACOC3	3	46.7	46.7	46.7	9.1	37.6
8	TLACOC4	2	> 32 m ?	44	40		
9	TLACOC6	1	18	NO WELL TEST			
9	TLACOC6	1	57	NO WELL TEST			
10	TLACOC6b		36	NO WELL TEST			
11	ROJAS1	15	60	60	60	6	54
12	ROJAS2	5	60	60	50.9	1.9	58.1
13	ROJAS3B	7	60	60	58	4	56
14	LACHIGOWELI	8	50	50	42	1.84	48.16
15	LACHIGO2	1	50	50	50	4.5	45.5
16	LACHIGO3	2	53.5	43.5	43.5	6.7	46.8
17	POCPB 60	24	101	101	30 - 101	7.7	93.3
18	POCPB 64	12	171	171	70-82	NO WELL TEST	
19	POAB_59		174	195	20-195	20.0	154.0
19	POAB_59	24	174	195	20-195	24	150.0
20	PODOB_15	21	40	40	40	13.55	26.45
21	POB -1	9	406	406	398	6.53	399.47
22	POB-2	5	79.5	79.5	6-60	NO WELL TEST	
23	POMB-71	6	31	NO WELL TES		NO WELL TEST	
24	POMB 72	6	28.5	28.5	2-28.5	NO WELL TEST	
25	POMB_73	7	86	86	0.00	NO WELL TEST	
	SYMPBOL -->	p	=	# of pages of information collected .			

of ALL TESTS RESULTS

TABLE 18B WELL TESTS		Dynamic Levels			
		Dynamic Levels		Drawdowns 3h or End[1]	
No.	WELL ID.	3h	24h	s	s corr
		(m)		(m)	(m)
1	POTB 66	44.95	45.7	33.7	26.7
2	TLACOC1_1	27.5	14.4	18.6	13.0
3	TLACOC1_2	28.5	11.9	19.1	13.1
4	TLACOC1B	39.7	23	30.7	19.2
5	TLACOC1BB	33.83	11.58	25.3	17.6
6	TLACOC2B	31.5	15.1	22.0	17.0
6	TLACOC2B				
7	TLACOC3	45.52	16	36.4	18.8
8	TLACOC4	CONFINING ON TOP 10 m.			
9	TLACOC6	TOP PHREATIC LAYER 0- 20 m			
9	TLACOC6	57 m Confined Layer of Volcanic Formation			
10	TLACOC6b				
11	ROJAS1	58	24.16	52.0	27.0
12	ROJAS2	27.5	14.4	25.6	20.0
13	ROJAS3B	39.9	12.3	35.9	24.4
14	LACHIGOWELI	27.5	14.4	25.7	18.8
15	LACHIGO2	30.82	12.4	26.3	18.7
16	LACHIGO3	25.8	43.5	19.1	15.2
17	POCPB 60	40.81	68.13	33.1	27.2
18	POCPB 64	NO WELL TEST NO WELL TEST			
19	POAB_59	89.4	96.7	69.4	53.8
19	POAB_59	94.1		70.1	53.7
20	PODOB_15	21.93	24.14	8.4	7.1
21	POB -1	19.6	21.05	13.1	12.9
22	POB-2	NO WELL TEST NO WELL TEST			
23	POMB-71	NO WELL TEST NO WELL TEST			
24	POMB 72	NO WELL TEST			
25	POMB_73	NO WELL TEST			
SYMPBOL --> [1]Drawdown after 3 hours or at the end of develop.					

TABLE 18C WELL TESTS				Discharge measured	
		Drawdown 24h		Q	Q
No.	WELL ID.	s	s corr	3H	24 h
		(m)	(m)	(lps)	(lps)
1	POTB 66	41.53	31.0	5.16	3.99
2	TLACOC1_1	5.5	5.0	12.88	9.76
3	TLACOC1_2	2.47	2.4	14.64	10.74
4	TLACOC1B	14	11.6	39.41	29.23
5	TLACOC1BB	3.08	3.0	33.83	13.82
6	TLACOC2B	5.6	5.3	29.29	18.9
6	TLACOC2B				
7	TLACOC3	6.9	6.3	7.	
8	TLACOC4			NO WELL	TEST
9	TLACOC6			NO WELL	TEST
9	TLACOC6			NO WELL	TEST
10	TLACOC6b			NO WELL	TEST
11	ROJAS1	18.16	15.1	42.28	31.1
12	ROJAS2	12.5	11.2	82.25	25.69
13	ROJAS3B	8.3	7.7	25.39	20.7
14	LACHIGOWELI	12.56	10.9	16.52	13.96
15	LACHIGO2	7.9	7.2	15.44	10.91
16	LACHIGO3	36.8	22.3	2.17	2.17
17	POCPB 60	60.43	40.9	5.17	5.42
18	POCPB 64	NO WELL TEST		NO WELL TEST	
19	POAB_59	69.4	53.8	7.0	6.8
19	POAB_59	70.1	53.7	6.8	6.8
20	PODOB_15	10.59	8.5	8.11	8.11
21	POB -1	14.52	14.3		11.0
22	POB-2	NO WELL TEST		NO WELL TEST	
23	POMB-71	NO WELL TEST		NO WELL TEST	
24	POMB 72			NO WELL TEST	
25	POMB_73			NO WELL TEST	
	SYMPBOL -->				

of ALL TESTS RESULTS

TABLE 18D WELL TESTS			Specific Capacities		
		Q/s	Q/s	Q	Q
No.	WELL ID.	3h	24h	3h	24h
		(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)
1	POTB 66		8.3	446	345
2	TLACOC1_1	59.8	153.3	1113	843
3	TLACOC1_2	66.3	375.7	1265	928
4	TLACOC1B	110.9	180.4	3405	2525
5	TLACOC1BB	115.4	387.7	2923	1194
6	TLACOC2B	115.0	291.6	2531	1633
6	TLACOC2B				
7	TLACOC3			575	
8	TLACOC4		NO WELL TEST		
9	TLACOC6		NO WELL TEST		
9	TLACOC6		NO WELL TEST		
10	TLACOC6b		NO WELL TEST		
11	ROJAS1	70.2	148.0	3653	2687
12	ROJAS2	277.6	177.6	7106	2220
13	ROJAS3B	61.1	215.5	2194	1788
14	LACHIGOWELI	55.6	96.0	1427	1206
15	LACHIGO2	50.7	119.3	1334	943
16	LACHIGO3	9.8	5.1	187	187
17	POCPB 60	13.5	7.7	447	468
18	POCPB 64		NO WELL TEST		
19	POAB_59	8.7	8.5	605	588
19	POAB_59	8.4	8.4	588	588
20	PODOB_15	83.6	99.4	701	701
21	POB -1				
22	POB-2		NO WELL TEST		
23	POMB-71		NO WELL TEST		
24	POMB 72		NO WELL TEST		
25	POMB_73		NO WELL TEST		
	SYMPBOL -->				

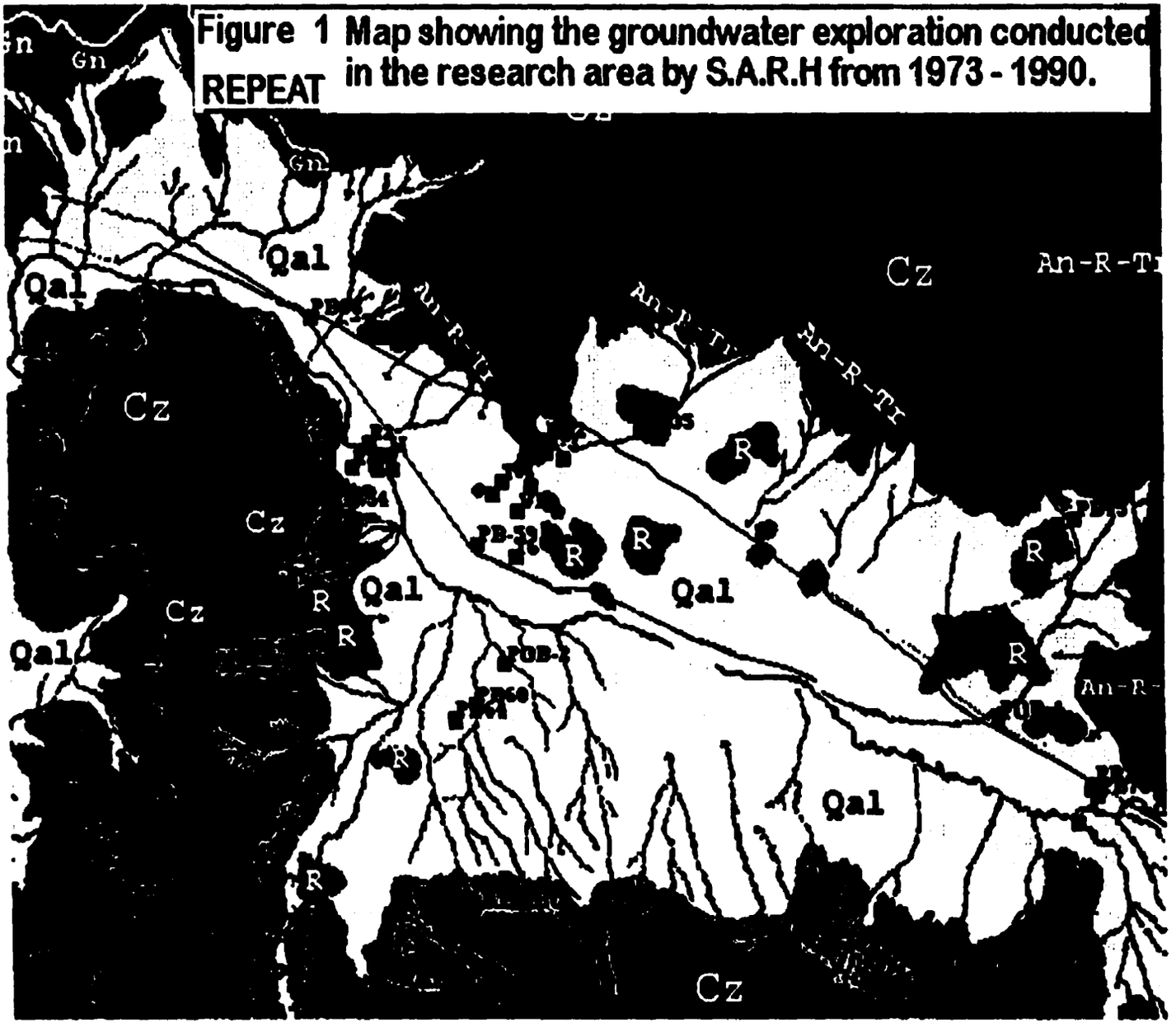


Figure 1 Map showing the groundwater exploration conducted in the research area by S.A.R.H from 1973 - 1990.

REPEAT

GENERAL DISCUSSION.

Safe Yield

> "The term *safe yield* has about as many definitions as the number of people who have defined it." Lohman (1972).

The term "safe yield" was first defined by Meinzer (1920, as reported by Lohman 1972) as :

> "The rate at which the ground water can be withdrawn year after year, for generations to come, without depleting the supply" .

Edelman (1983) proposes the superposition method for the analysis of the maximum rate at which groundwater can be withdrawn from an aquifer or a certain geographical area.

Long Term Management Of Water Resources.

Let us first **define the following terms**:

r[1]: Recharge of the aquifer from the upper, nonsaturated soil layers, as a volume of water per unit time and per unit area of the aquifer. [length · time^{-1}]

Q: Quantity of Flow through an arbitrary cross-section, e.g the flow towards a well. [length^3 · time^{-1}]

Φ : Potential, defined as pressure. [mass ·length^{-1} · time^{-2}]

If several wells are exploited in the same aquifer, they interact and their interaction is assumed to correspond mathematically to the superposition of these systems.

Edelman's Model [2] (1983) is the following:

System I

The natural state before water extraction is defined by :

- The true values of F in the rivers and the lake.
- The true **r** values

---

[1] Edelman (1972) uses the synbol n. To avoid confusion with porosity, the symbol **r** is preferred.

[2] Edelman (1972) uses the term Model to represent any material arrangement , either in nature or in a laboratory.

- The true supply along the rocky border.
- No extraction from the well.

System II

The change of state brought about by the extraction is defined by :

- $\Phi = 0$ in the rivers and the lake.
- $\mathbf{r} = 0$
- No supply along the rocky border.
- The true extraction Q_0 from the well.

System III

The final state of the aquifer under exploitation is defined by:

- The true values of Φ in the rivers and the lake.
- The true $\mathbf{r}$ values
- The true supply along the rocky border.
- The true extraction $\mathbf{Q_0}$ form the well.

Edelman (1983) concludes that in such a model **the specific capacity of a well** is determined by System II **and depends only on**:

- the form and the nature of the boundaries of the aquifer
- the position of the well
- the transmissivity KD (or KH) of the aquifer and
- the diameter of the well.

The specific capacity is then independent of the original flow pattern, as defined by System I and independent of :

- the levels of the lake and the rivers.
- the recharge $\mathbf{r}$ and
- the supply along the rocky border

If several wells are exploited in the same aquifer, they interact and their interaction corresponds mathematically to the superposition of these systems. System II shows that the quantity of water extracted from the wells is counterbalanced by a change of the flow passing through the boundaries with the lake and the rivers.

If the surrounding **water courses can supply unlimited quantities of water,** the maximum extraction from a given set of wells depends finally on the maximum drawdown in the wells to be allowed. Edelman (1983) brings three **considerations for**

the selection of the maximum drawdown admitted in the main pumping well. These considerations are discussed in the context of findings of this study.

Formal considerations for the selection of the maximum drawdown to be admitted in the main pumping well.

In the case of a phreatic aquifer the drawdown should be small compared with D (the saturated depth is here denoted as H for the saturated Height of water on the aquibase). This was often not the case in the well tests. The water level was often brought down to half of the saturated height or less.

Technical consideration:

The pump characteristics may limit the water lift. This has not been the case in the development of the deep wells that were drilled in the research area by S.A.R.H. In the case of the numerous shallow Indian wells, a pump is often used although this is the case for probably less than 10% of the number of indian wells in the area.

When this is the case the pump generally exceeds the capacity of the shallow well. It follows that the maximum admissible drawdown in indian wells is generally not limited by the pump water lift but by the depth of the well. This explains why the pumping period in indian wells rarely exceeds two hour continuous pumping. The well is then given time to recover and pumping takes place again. It is also common practice to operate these small pumps for less than a total of 6 hours within the same day.

Economic consideration:

The water lift may be restricted by a maximum allowable pumping cost per unit water volume. In addition to this economic constraint, concern for the stability of the soil in the vicinity of the well was also very important. This is a consideration that is not mentioned by Edelman (1972).

Irrigators do not share equally this concern for ensuring stability of the gravel pack. However, this concern was omnipresent during well development throughout groundwater exploration. Care was taken not to operate the well too aggressively so as to prevent excessive soil erosion and plugging of the gravel pack. The discharge was increased in small steps only after clear water had taken place for a certain duration.

This was achieved via a step drawdown test with steps of two to three hours. Another revealing common practice was to proceed with a 24 hours partial recovery in decreasing step drawdown.

This concern for proper operation of the well was also observed in the case of the operation of the municipal wells of the valley. Although this restrained pumping did not prevent the municipal well of Lachigolo from getting plugged. A new well was drilled less than 5 meters from the old one but neither the story from the local people nor the drilling report were clear on what actually happened with regard to the old well.

Hydrogeologic units.

Literature Review.

The information on the hydrogeology of the research area comes mainly from the report on the study of the hydrogeologic conditions of the Valley of Tlacolula conducted by the Geology Consulting firm (GEOCA) in June 1980. The same firm conducted similar studies on the Valley of Etla and the Valley of Zimatlan, the other two central valleys of the state of Oaxaca.. GEOCA's hydrogeologic studies were conducted with scientific rigor. Prior to these studies, a map of the geology of the State of Oaxaca was prepared in 1974 by the groundwater department of S.A.R.H. To prepare this map, 31 geology map pieces produced by as many different authors were assembled in a mosaic and reproduced ar a scale of 1:500 000.

The year preceding GEOCA (1980) study, the State of Oaxaca "Dirección General de Asentamientos Humanos y Obras Públicas del Estado de Oaxaca." implemented an exploration programme to locate sources of drinkable water for the city of Oaxaca de Juarez that may be worth the cost of their development. From this study emerged the "PLANO GEOHIDROLOGICO 1:150 000" , that is a color map of the Hydrogeology of the Central Valleys of Oaxaca.

The color code used in this map is a home made system but nevertheless the legend is clear and the information on the hydrogeology of the Central Valleys of Oaxaca is of great value. However, errors in the positional accuracy of the geology map were found and corrections that are porposed will need field checks. This registration procedure is examined in details in Chapter III.

The preliminary Hydrogeologic Study in the Valley of Oaxaca conducted by (TACSA) in 1983 is also referred to. The special efforts made by the C.N.A in exploring the Tanivet Area (1979) and the valuable studies that followed the drilling of the famous artesian well El Brotante are also brought to contribution in the section on groundwater quality. The expoloration wells in this area have revealed the position of lacustrine deposits and evaporites.

The hydrologic units identified below are pratically the same as those identified and described by the S.A.R.H Dirección de Geohidrología y Zonas Aridas in the special report on the drilling of the Artesian Well El Brotante. The fact the hydrogeological units were identified almost twenty years ago (in 1978) and that the actual extent of these units are still to be defined is a direct consequence of the cost of the field work required to position the boundaries of these units to the desirable level of accuracy defined below. Moreover since stratigraphy has not been established, these units are still to be seen as tentative units regardless of the fact that no reference could be found which may suggest revisions in the proposed hydrogeologic units.

The region that includes the research area is characterized by the presence of metamorphic, sedimentary and igneous rocks which are of geologic time from precambrian to recent (Holocene). The metamorphic rocks constitute what is called " EL COMPLEJO BASAL OAXAQUENO" The oaxaquenan complex basement. The eldest rocks that crop out in the research area consists of gneisses quartzite feldspartite and hornblende which constitute the Precambrian basement of the area. (TACSA, 1983)

The sedimentary rocks that comprise the limestone, sandstone, margas, claystone and alluvium are also distributed in the whole valley .

Igneous rocks are composed of Rhyolite, rhyolitic and andesitic tuff resting on sediments from the Mesozoic and Tertiary ages.

In the area of Acatlan the metamorphic rocks that are exposed have a different aspect than those of the Oaxaca region. This difference lies in the fact that the metamorphic rocks of Acatlan are mainly schists "esquitos" whereas those of the Oaxaca valley are mainly gneisses.

According to GEOCA (1980) the sedimentary Mesozoic marine column is incomplete and embraces a stratigraphic range from the Late Cretaceous (Inferior) to the Middle Cretaceous and maybe part of the Early (Upper (Superior)) Cretaceous.

The style of the deformation that can be observed in the Mesozoic rocks is in appearance harmonious of a unit with respect to each other, and these rocks do not show evidence that they had undergone any grade of metamorphism. The same rocks have been covered randomly by lavic flows (derrames) of intermediate composition with associated piroclastic and epiclastic material.

Figure 34 shows the hydrogeologic map layer that was registered to the topograhic base map. Figures (35 and 36) show the legend for the map of hydrogeoly of the research area as translated and adapted from:

PLANO GEOHIDROLOGICO GOBIERNO DEL ESTADO DE OAXACA. PLANO 3-1-B. Dirección general de Asentamientos humanos y Obras Públicas del Estado de Oaxaca. Estudio para determinar las fuentes recomendables para el abastecimiento de agua potable de la ciudad de Oaxaca. México. Abril 1979

The following hydrologic units could be reconciled from GEOCA(1980) and TACSA (1983) :

1. **Alluvium of the Cuarternary.** The alluvium of 30 to 40 meters thickness is composed of sand, gravels and silt of good relatively permeability and covers the low areas of the valley. Exploration Wells that were drilled gave yields of 9.8 to 31.1 lps for 24 hours pumping and 13.0 to 82.0 lps for 3 hours pumping.
2. **Extrusive Rocks of the Middle Tertiary age are** composed of volcanic rocks of rhyolitic, andesitic constitution . Also common are corresponding tuffs of either constitution and tuff-breccias where fragments of boulder to gravel size can be found. The area of San Juan Teitipac is typical of this volcanic profile with at least two pyroclastic eruptions. Each eruption gave off a deposit of approximately twenty meters of ash material with some 18m of coarser tuff of rhyolitic origin. In certain occasions the volcanic rocks may be fractured and form a local aquifer. Wells perforated give a yield 5.0 to 11.0 lps for 24 hours pumping..

3. **Salty Clays of the Early Tertiary age (Terciario Inferior).** These sediments do not crop out in the research area but were encountered during exploration of the well Yagul 1. They seem to have deposited in clay sequence of about 100 m thickness. Due to the uniformity in the grain size, with grains generally very fine, these clays show practically no permeability .

4. **Margas Tanivet.** Composed of sediments formed during the precipitation of the $CaCO_3$ deposited on the Clay (about 50% clay 50 % $CaCO_3$). Sometimes the sedimentation may result in very fine layers of various colors. The permeability is generally low. When these sediments are well cemented they are practically impermeable. On rare occasions fracturation and/or splitting of the clay may occur making these sediments moderately permeable. In the research area, this formation can be found in the area between the localities of Matatlan and Tanivet.

5. **Early Cretaceous age.** Composed of alternating layers of sandstone , shale and limestone. Sandstone layers are of fine texture and vary from 10 to 30 centimeters. The limestone is of light grey color with layers from 20 to 40 centimeters thick . The claystone is plastic of grey color. Due to the presence of shale they usually behave as impervious bodies or in some locations there may filter and slowly seep small quantities of water. Limestone is not cavernous. POTB66 Well yielded 4.0 lps and POAB-59 gave a yield of 6.8 lps.

6. **Precambrian Rock.** Formation of rocks that went under a high grade of metamorphism and composed mainly of gneisses of brown color. Due to their high density these rock behave as a highly compact material and therefore may be considered as impervious.

7. **Limestone from the Middle Cretaceous age.** Composed of limestone of beige color, and fine texture, may be well fractured with channels. They are distributed in the mountain range Juarez that embraces the valley of Tlacolula. May be seen as outcrops at the exit of the valley.

Stratigraphy

The stratigraphy has not been established because of no continuous stratigraphic sequence. It is not surprising that in their report GEOCA (1980) warns us that the units defined therein are to be viewed as lithological units that are basically descriptive. Ages that are assigned to these units are tentative. GEOCA adds to their warning the recommendation for additional scientific support to these age determinations in these translated terms " these age determinations based on the relationships observed in the field would benefit from a paleontologic (on Areniscas and lutitas) as well as a radiometric (on igneous and metamorphic rocks) support".

Below the extrusive rocks of the Tertiary, we find clay sediments which contain a large quantity of salt (the result of evaporites) . These sediments have a thickness exceeding 150 meters and reach a depth of 300 meters below surface as found in 1970 though the drilling of the exploration well POB-1 in Tlacolula. This was later confirmed during the exploration for potable water in the city quarter Infonavit in Oaxaca (some 30 kms east of Tlacolula) where the same clay sediments reach the depth of 320 meters for a thickness of 270 meters. The layer below these lacustrine sediments shows sedimentary rocks of the Cretaceous Superior (Margas Tanivet, soft calcareous rock sometimes siliceous, a mixture of clay and limestone) of the Cretaceous Middle (Mountain of San Antonio de la Cal) of the Cretaceous Inferior in Teitipac and rocks of the Jurassic in San Pablo Etla and Santa Lucia del Camino.

The sedimentary column in the valley is variable. Its thickness is approximately 1350 meters. In some location a volcanic formation about 200 meters thick of rhyolitic nature and the Cuaternary alluvium of approximately 40 meters thickness cover the sedimentary column and the resulting geologic section from Jurassic until today measures approximately (1350+250+40) 1640 meters. This interpretation is illustrated by the sketch profile on Figure 37A. Figure 37B shows the geologic interpreation of the profile shown in Figure 37A and the line of cut for the profile in question. The legend of the symbols and the color code used are the same as the symbols and color code used in the hydrogeology map and defined in Figures 35 and 36 .

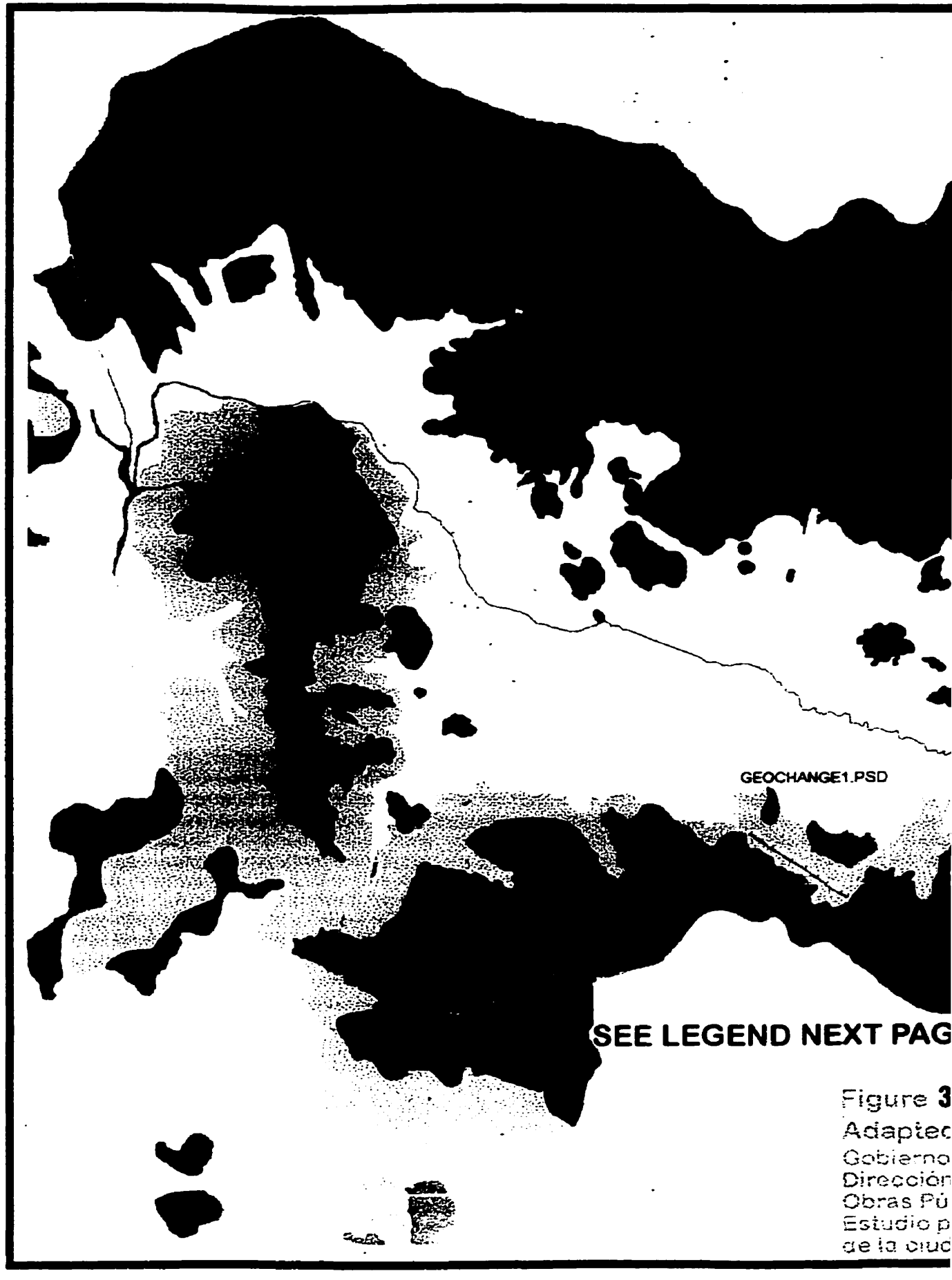


Figure 3
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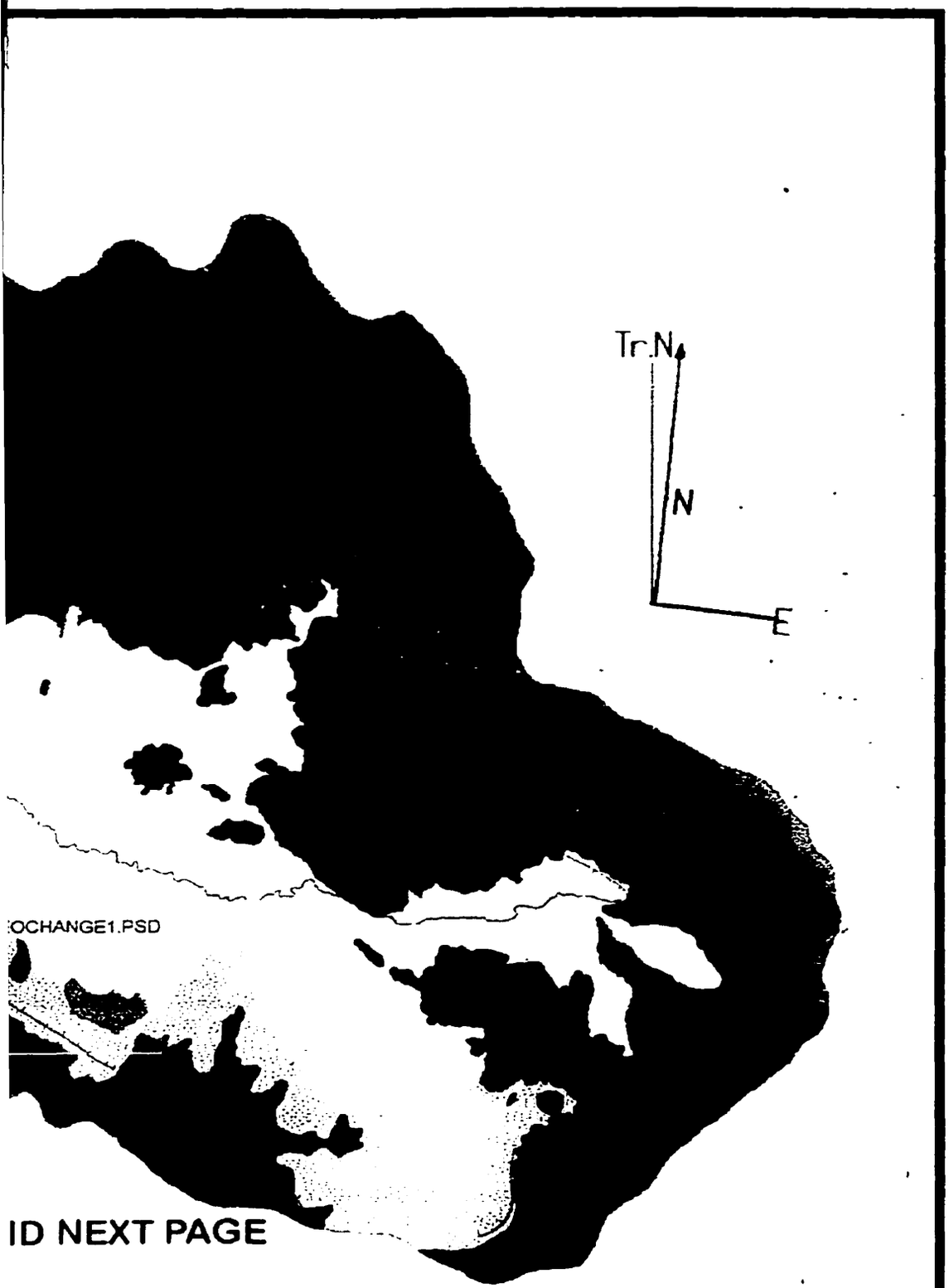


Figure **34** . Preliminary Hydro geology Map.
Adapted from
Gobierno del Estado de Oaxaca.
Dirección General de Asentamientos Humanos.
Obras Públicas del Estado de Oaxaca.
Estudio para determinar el abastecimiento de agua potable de la ciudad de Oaxaca. **Drawn from April 1979 Data.**

SYSTEM	FORMATION	GEOLOGIC NATURE	HYDROGEOLOGY	KEY
CUATER-NARY	ALLUVIUM	Unconsolidated sediments in a heterogeneous mix of gravels and sands forming deposits in variable vertical and lateral developments. Thicknesses of sediments range from 10 to 90 m depending on their location in the valley.	ALLUVIUM. Given its lithological composition and its low compaction state the alluvium shows permeables characteristics with an hydro-geological potential in proportion to the thickness of the sediments and to the prevailing annual volume of recharge.	Qal
TERTIARY	VOLCANIC SUPERIOR	Association of rocks consisting of rhyolites (R) and Tuff of the same composition (Tr) showing a domic structure with inclined fronts of outpouring towards the valleys. Known thickness of 250 m	VOLCANIC. This formation form a compacted unit of microcrystallic texture with little development of interstices for storage of water and reduced permeability. This formation may have a good hydrogeological potential if fractured internally.	
	LACUSTRE	Unit registered in the subsoil of the valleys making an heterogeneous alternating mixture composed of fine sand with prominance of clay. Thickness may reach 100 m.	LACUSTRINE DEPOSITS. Materials deposited by lake waters. Given its lithology and low state of consolidation, these deposits present good storage potential but they are generally deposited with evaporites resulting in high salinity.	Cg
	VOLCANIC INFERIOR	Dense volcanic rocks classified as Andesitic , Rhyolitic and Tuff of irregular extension in the subsoil, showing in surface a structure of the mantle in discording position with the rocks of the cretaceous system.	Unit that has potential for water storage in very local areas of the subsoil containing in several zones some saline water due to contact with the overlaying formation .	

Figure 35 HYDROGEOLOGY OF THE TLACOLULA AQUIFER. Adapted from : PLANO GEOHIDROLOGICO GOBIERNO DEL ESTADO DE OAXACA. PLANO 3-1-B. Direccion general de Asentamientos humanos y Obras Publicas del Estado de Oaxaca. Abril 1979.
Estudio para determinar las fuentes recomendables para el abastecimiento de agua potable de la ciudad de Oaxaca. Mexico. **Use this legend with the HYDROGEOLOGY MAP.**

SYSTEM	FORMATION	GEOLOGIC NATURE	HYDROGEOLOGY	KEY
CRETACIC	MARINE SEDIMENTS	Sedimentary rocks of marine origin basically integrated by limestones with massive structure of reduced thickness, alternating clay limestone, claystone and sandstone with stratification of 0,05 to 0,30 m. Can be identified by its montainous relief. In the subsoil can be found at variable depth with thicknesses exceeding 100 m.	Marine Rocks. Given its topographic position, stratigraphy and high clay content, this unit behaves as an impervious layer.	Cz / Ar - Lu
CAMBRIAN	COMPLEX METAMORPHIC	Shists micaceous with conspicuous foliation as a result of medium-grade metamorphism. They have a "fajeada" structure and a laminar texture. These rocks oppose little resistance to erosion, and crop out the flanks of the mountain unit.	Impervious unit. Complete alteration of theses schists results in clay soils of poor hydrogeologic characteristics.	Eq
PRE-CAMBRIAN	COMPLEX METAMORPHIC	This unit is the oldest of the region. Classified as granitic gneiss, these rocks have a domal relief and foliated structure. They are found at the foot of the mountains and they form the base of the alluvium.	Impervious material which at the surface has undergone a long process of weathering and granular disintegration to form a weathered product that is part of the alluvium .	Gn

Figure 36 HYDROGEOLOGY OF THE TLACOLULA AQUIFER. Adapted from : PLANO GEOHIDROLOGICO GOBIERNO DEL ESTADO DE OAXACA. PLANO 3-1-B. Direccion general de Asentamientos humanos y Obras Publicas del Estado de Oaxaca. Abril 1979.
Estudio para determinar las fuentes recomendables para el abastecimiento de agua potable de la ciudad de Oaxaca. Mexico. **Use this legend with the HYDROGEOLOGY MAP.**

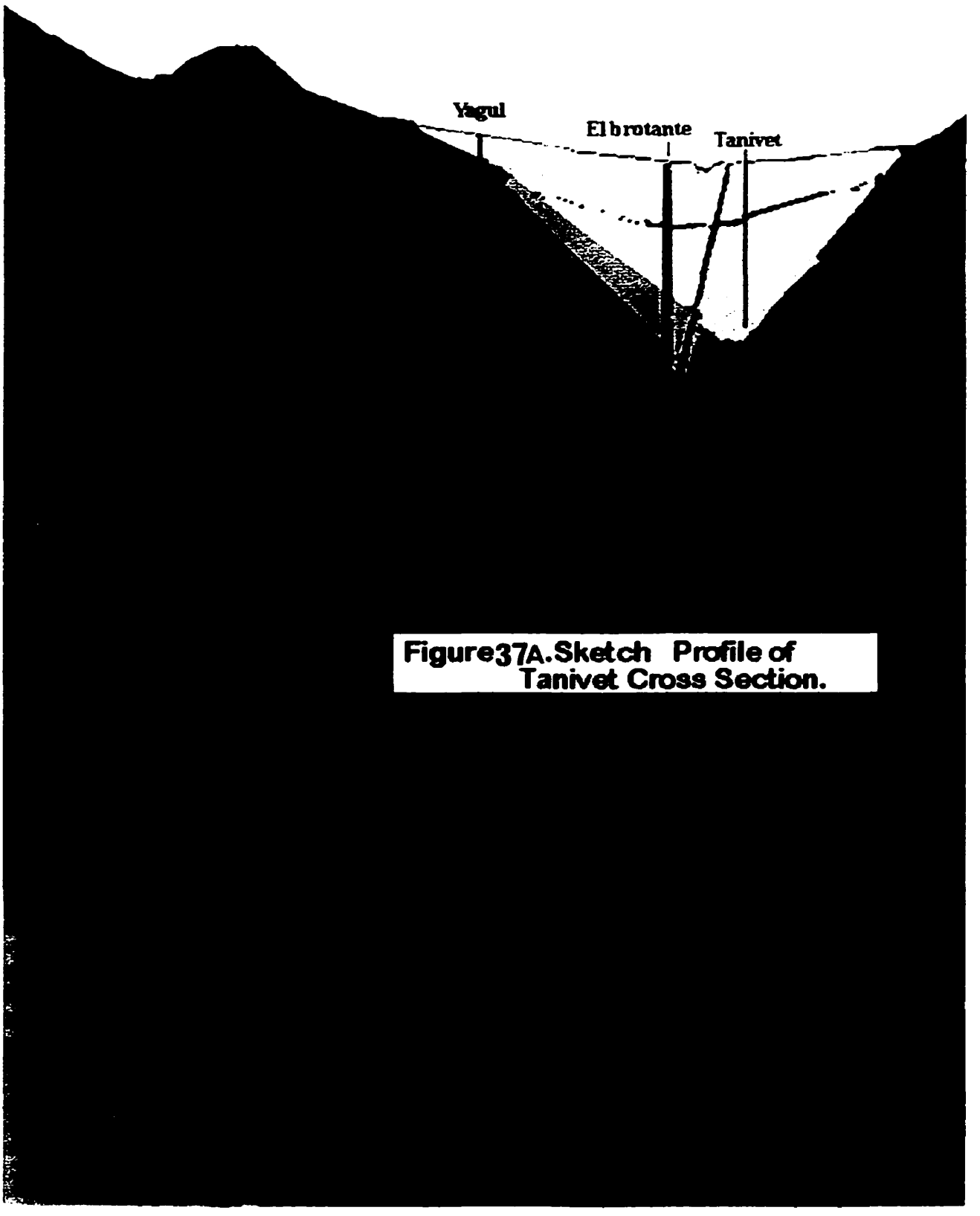


Figure37A.Sketch Profile of Tanivet Cross Section.

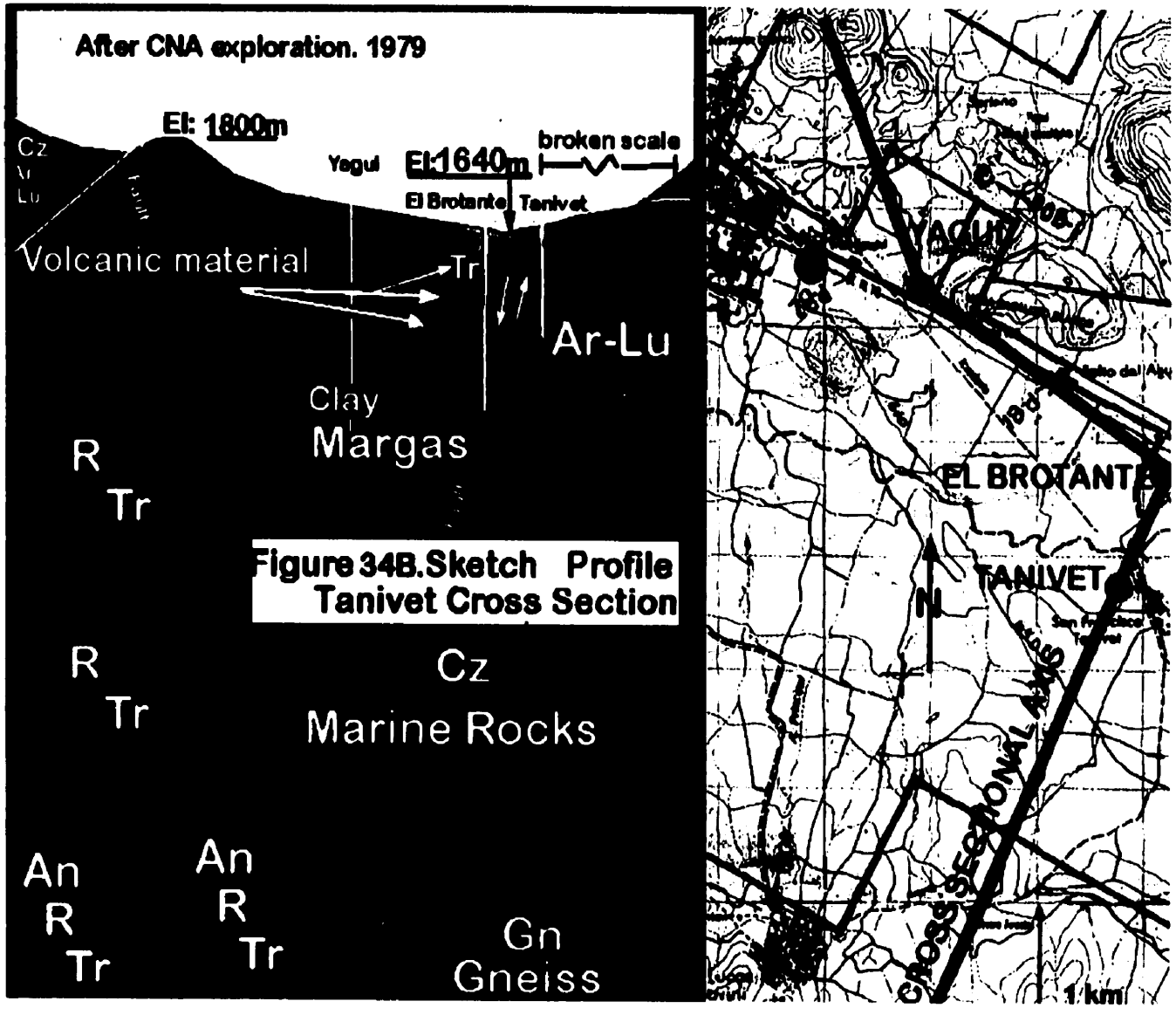


Figure 34B. Sketch Profile Tanivet Cross Section

CHAPTER VIII

GROUNDWATER QUALITY MONITORING

Introduction

Groundwater quality, as determined by its chemical and biological constituents, its sediment content, and its temperature, is of great importance in determining the suitability of a particular groundwater for a certain use. The chemical composition of a groundwater can be indicative of its origin and history.

In reviewing the information from previous studies, a clear concern for the long term intrusion of saline water from localized saline areas into adjoining sweet water zones was reported (TACSA, 1983., GEOCA, 1980).

It appears essential that in the planning of groundwater development in the research area, special care is needed to avoid such intrusion. This can be done by limiting pumping in areas close to saline water zones and by stabilizing groundwater tables at depths in fresh groundwater areas such that steep gradients from saline areas are not created. Hydrogeologic studies conducted in the Tanivet Area have confirmed the presence of lacustrine deposits and evaporites. This will be discussed in detail under the section : EL BROTANTE.

When setting objectives for this research study, it was decided to assess the quality of groundwater over the area in order to determine the suitability of water for irrigation and/or to obtain an early warning of groundwater salinization. In order to fix a proper reference base line of salinity level, the three-dimensional salts distribution in the soil combined with a detailed areal distribution of groundwater quality should be assessed. This of course is beyond the scope of this thesis research.

In order to set our target parameters, our objectives must be clear. The main objectives here are to determine the suitability of water for irrigation and to obtain an early warning of groundwater pollution.

Special attention will be paid to locations of potential saltwater intrusion and locations of induced recharge of "polluted" water from the rivers, streams or saline wetlands.

Target Parameters

In order to meet the objectives, target parameters must now be set. Quality standards for irrigation water are generally based on 1) the total salt concentration of the water as it effects crop yield through osmotic effects, 2) the concentration of specific

ions that may be toxic to plants or that have an unfavorable effect on crop quality, and 3) the concentration of cations that can cause defloculation of the clay in the soil and resulting damage to soil structure and declines in infiltration rates.

Quality criteria and classification schemes for irrigation water were developed by Doneed , Eaton and Wilcox (Wilcox and Durum , 1967 as reported by Bouwer, 1978. Based on these schemes Ayers (1975, as reported by Bouwer, 1978) developed the set of guidelines used for classification of samples (Table 1). Ayers (1975)'s guidelines are shown in Table 2.

Concentrations of the following components represent our standard water - analysis; Na^+, K^+, Mg^{++}, Cl^-, $SO_4^=$, $CO_3^=$, HCO_3^-, NO_3^-. Total dissolved solids and hardness were also determined.

Water Sampling

Samples of water were collected from Indian wells. A well was first emptied either by pumping (10 to 15 minutes) at a low abstraction rate or by use of a bucket.

Water samples were collected after natural recharge of the well. Care was taken to sample wells that had been under operation for at least two[1] years to ensure that soil stability in the infiltration area had been attained.

To ensure that the analysis of a sample taken would represent the average quality of water in the zone surrounding the well and which in depth corresponded to length and situation of the infiltration area. Careful attention was paid to the depth and location of infiltration area.

The depth to the aquifer was measured and the saturated thickness of the aquifer was derived from a linear interpolation of the bore logs of deep wells drilled in the vicinity . See Materials and Methods for more details on water sampling.

Salinity hazard

Three hazards associated with the use of irrigation water are distinguished by Smedema and Rycroft (1983): the salinity hazard, the sodicity hazard and the toxicity hazard. The salinization / sodification hazards can be estimated, on the basis of the amount and types of salts contained in the water. Irrigation development

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[1] Soil stability in the infiltration area is most likely achieved within one year. However, it was reported to be common practice to clean the well thoroughly (with scarification) at the end of the first dry period and in less frequent occasions deepening of the well is also practiced.

should not be undertaken without analysis and appraisal of the water to be used for irrigation.

The salinity hazard refers to the danger that the use of the irrigation water will lead to osmotic problems in the soil/plants. Few crops experience osmotic problems when the electrical conductivity of a saturated soil water extract (EC_e) in the root zone is less than 2 mmho.cm^{-1} . If assumption is made that leaching of the salt residues is achieved with a volume of water equal to 5 -10% of the actual irrigation water required by the crop, then a safe limit for the salinity of the irrigation water would be around 1 mmhos.cm $^{-1}$.

The U.S Salinity Laboratory system (U.S. Salinity Lab. Staff, 1954) divides waters into four classes with respect to conductivity, the dividing points between classes being at 250, 750 and 2.250 micromhos. cm^{-1} . These class limits were selected in accordance with the relationship between the electrical conductivity of irrigation waters and the electrical conductivity of saturation extracts of soil where generally a good correlation can be established.

The frequency distribution of the electrical conductivity of three groups of irrigation waters with respect to these four classes has been determined on the basis of a number of water sources and acreage irrigated in U.S. The interpretation of this broad classification is given by U.S. Salinity Lab. Staff, (1954) in the following terms:

- " In general, waters with conductivity values below 750 micromhos. cm^{-1} are satisfactory for irrigation insofar as salt content is concerned, although salt-sensitive crops may be adversely affected by the use in the range 250 to 750 micromhos.cm^{-1}.
- Waters in the range of 750 to 2 250 micromhos. cm^{-1} are widely used, and satisfactory crop growth is obtained under good management and favorable drainage conditions, but saline conditions will develop if leaching and drainage are inadequate.
- Use of waters with conductivity above 2 250 micromhos. cm^{-1}. is the exception, and very few instances can be cited where such waters have been used successfully. "

The FAO system is based upon an assumed irrigation regime with a leaching percentage of 15%. In the FAO system, somewhat higher limits apply than in the US system . Smedema and Rycroft (1983) comment that U.S Salinity Laboratory limits

appear to be conservative.

Sodium-Adsorption Ratio

The sodium-adsorption ratio is defined by the equation

$SAR = Na^{+} / ((Ca^{++} + Mg^{++})/2)^{1/2}$. ..... (1)

Where Na^{+}, Ca^{++} and Mg^{++} represent the concentrations in milli equivalents per liter of the respective cation.

Calcium and magnesium concentrations are found by titration with Ethylene-diamine-tetra-acetate.

Adjusted SAR

The SAR was adjusted to include the added effects of precipitation and dissolution of calcium in the soil as related to the concentration of CO_3^{2-} and HCO_3^{-}. The adjusted SAR value is calculated as per Bouwer's (1978).

Sodicity hazard

This hazard may be appraised on the basis of the two main diagnostic parameters; the EC_i used to appraise the possible harm likely to result from using the water, and the toxicity hazard.

In classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of the crop. The relationship to average conditions must be kept in mind in connection with the use of any general method for the classification of irrigation waters. U.S. Salinity Lab. Staff (1954).

A diagram for classifying irrigation waters was suggested by Wilcox (1948). and this was subsequently modified by Thorne and Thorne (1951, as reported by U.S. Salinity Lab. Staff, 1954) for the classification of waters of Utah state.

The diagram for the classification of irrigation waters is based on the electrical conductivity in micromhos.cm^{-1}. and the sodium adsorption ratio. The curves delimiting the several sodium classes can be constructed by the use of the following empirical equations:

Upper curve : SAR = 43.75 - 87.87 (log EC) ..... (2)

Middle curve : SAR = 31.31 -6.66 (log (EC) ..... (3)

Lower curve : S AR= 19.87 -4.44 (log EC)..... (4)

where SAR is the Sodium Adsorption ratio; EC= electrical conductivity in micromhos per centimeter; log = logarithm to base 10.

Surveys To Assess The Quality Of The Groundwater

GEOCA[2] (1980) conducted a survey to assess the quality of the water in the Valley of Tlacolula and its potential use for irrigation. This survey took place in February 1979 and the chemical analysis of the fifty three samples collected is shown in Figures 3 to 6.

In 1994, 31 samples were collected from observation wells that had been randomly chosen among the observation wells surveyed for the groundwater monitoring network. Thirteen samples (13) were collected in 1995 in the area immediately west of Tlacolula.

Calcium and Magnesium were determined by Titration with Ehtylene-diamine-tetra-acetate for samples collected in 1994 and 1995. The concentration of sodium was estimated from the linear relationship between the electrical conductivity and the total concentration of the 53 water samples collected in the research area by GEOCA in 1979 . This highly linear correlation shown in Figure 1 was used to deduce the concentration of sodium in the water samples collected in 1994-1995. It is assumed that the proportion of sulfate and bicarbonate waters in the research area has not changed so that the relationship between the electrical conductivity and the sum of cations (and anions) should still apply. The chemical analysis of the 31 samples collected in 1994 and the samples collected in 1995 is shown in Figures 7 to 10.

The area immediately west of Tlacolula area was sampled in 1995 because the water quality assessment based on 1994 samples suggested the presence of a localized saline water corridor crossing the 190 road at the west entrance of Tlacolula city. This saline water intrusion is well known by the brick maker at the entrance of Tlacolula.

Figure 10A compares the chemical analysis of the groundwater observed at these locations in October 1994 with September 1995. The chemical analysis of the samples collected from wells P66 and P83 is basically the same in 1995 as it was in 1994. In either year, the water was brackish whereas the ground water sampled from P64 in Diaz Ordaz remained fresh. The well P-108 located in San Juan Guelavia shows a significant increase in chloride ions from 1994 to 1995. Sodium decreases slightly but due to the different scale used for plotting the concentration the effect is exaggerated on Figure 10A.

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[2] GEOCA's survey was conducted in 1979 the year before publishing findings of

Figure 10B shows two rows of four graphs side by side representing on the first row the chemical analysis of four water samples collected around Tlacolula de Matamoros and on the second row three samples collected near San Juan Guelavia while one sample was collected from the domestic well P-106 located on the west side of the road at the entrance of Santa Ana del Valle.

The flat area of San Juan Guelavia is well known for its standing water which shed large amount of moisture during the rainy season so that the soil is often temporarily waterlogged. Waterlogging conditions can be also observed near Santa Cruz Papalutla. The soil map constructed from Cruz's survey (1938) shows that two soil Series are encountered at these locations: the Rojas and the Santa Cruz Papalutla Soil Series. The Rojas Soil Series, developed from recent alluvial deposits represents the soil conditions that are the most limiting for agricultural production in the research area. A typical profile is described by Cruz (1938) in the following terms.

Rojas Soil Series as described by Cruz (1938)

Horizon	0 - 2.00 m
Color when Wet	Dark brown
Color when Dry	Grey
Texture *USDA	Clay (clay: 78%, silt 11%)
Structure when Wet	"terronosa[3] " to large columnar
Structure when Dry	hard "terronosa"
Consistency when Wet	Hard
Consistency when Dry	Very compacted
Porosity	Dense
Natural Drainage	poor. Strongly anaerobic
pH	7.6
Water holding capacity	47.63%
Wet relative density	1.74

Cruz (1938) estimated that the water drained from Rojas Soil Series contained an average total dissolved alkaline salts of 1.04 kg/m^3.

Rojas soil series is inappropriate for agriculture. Out of the 13 646 hectares of

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their Geologic Study in June 1980.

[3] Translation of "terronosa" could not be found. From field observations, medium granular structure is tentatively suggested.

alluvium soils surveyed by Cruz's (1938) in the Tlacolula basin, approximately 1 660 hectares belong to Rojas Soil Series.

Mapping the results

The coordinates of the locations where water samples were collected in 1979 were determined in IDRISI environment by digitizing on the electronic topographic base map their best visual fitted location. The procedure to prepare the Water Quality base map was the following.

Procedure To Prepare The Ground Water Quality Base Map

1) Make spreadsheets to include the following:
   a). Ca^{++}, Mg^{++}, Na^{+}, HCO_4^{-}, Cl^{-}, SO_4^{-}
   b). K^{+}, CO_3^{-}, SO_4^{-}, NO_3, residual Na_2CO_3.
   c). Calculate SAR and adjusted SAR values,

2) Make Graphs of 1.**a)** versus X.Y Z.

3) Import graphs in Adobe and overlay on the topographic base map according to respective locations of collected samples Two layers are then created showing in graph form the Chemical Analysis of
   1979 Samples.
   1994 and 1995 Samples.

4) Edit these layers for best contrast display.

Figures 11, 11b, 13a and 13b show two of the three layers of the water quality base map that are presented here split in two areas. These figures illustrate the chemical analysis from each well sampled in either 1979 or 1994 survey. By keeping the surveys on different layers, each chemical survey can then be displayed separately on the topographic base map. New surveys are added as new layers. Surveys from 1979 and 1994 can be combined by overlaying their corresponding layers. The topographic base map serves then as a common registration point network.

When the water quality data file (Waterqual.xls) is retrieved in EXCEL environment all details relative to the chemical analysis data become directly accessible. In this way, graphical representation of the data is left to the software that is appropriate for this task whereas the calibration and registration are accomplished visually in an image software editor. All layers are registered to the

same common Topograhic base map. These layers saved are then saved as image files in a format convertible by the Geographic Information System. Documentation of the created GIS file after conversion of the image file can proceed with the same parameters as for the topographic base map.

To accommodate human eye in reading a printout of the ground water quality base map, the map will generally need to be split. In order to keep an appropriate area coverage, the graphs showing the chemical analysis will normally appear small on the print out. This problem is inexistent when working within the image software environment because zooming capability is restricted only by the size of the pixel. To compensate for these printing limitations, a copy of the graphs can be printed out separately at a convenient size. This is done in Figures 3 to 10.

Once the two layers have been registered to the common topographic base map. any other layer registered to the same base map may be brought in and combined with others. This is done in Figures 12 and 14.

Figure 12 shows the chemical analysis of the samples that were collected in 1994 in the vicinity of Tlacolula de Matamoros laid over the Geology/Topo base map. Local evaporites in the clay sediments around Tlacolula are likely responsible for the high concentration of sodium and chloride ions in water samples collected from the shallow wells no. P66 and P83. The reported salt deposits in Santa Ana del Valle bear this hypothesis but it is equally possible that the salts were detached from one or more of the three northwest-southeast trending Cretaceous sedimcntary belts. In either case the area that is affected defines the Rojas Soil Series the boundaries of which are shown on Figure 14.

Table 1 summarizes the suitability of water for irrigation based on the U.S salinity Lab Staff (1954) classification. for the water samples collected by GEOCA (1979) within the research area (30 out of the 53 samples meet this criterion) and those collected in 1994. Samples of 1995 are excluded because the sampling was not conducted randomly.

In 1979 survey , 64% of the samples were found to be of low or medium salinity level and 36% of the samples were found to be of high or very high salinity level. In 1979 survey, 9% of the samples were found having a high or very high sodium hazard. In 1994, 37% of the samples were of medium salinity level and 63% were of high or very high salinity level. In 1994, 12% of samples were found having a high or very high sodium hazard. Sample P66a of 1994 survey was excluded because

this sample was not taken randomly but rather selected for complementing P66.

Table 2 shows the implications of each level of salinity and sodium hazard on soil and crop management practices as specified by U.S salinity Lab. Staff (1954). Table 3 shows for each sample collected in 1994[4], its classification for irrigation as per U.S salinity Lab. Staff (1954) classification, its corresponding salinity and sodium hazard level and the expected effect of the residual sodium carbonate on the water quality. Table 2 may be used by the manager to facilitate his interpretation of Table 3.

DISCUSSION

In the Tlacolula Valley , the following locations experience problems of water salinity. Also, the source of salinity is briefly discussed.

San Juan Guelavia

Two locations were reported as having evaporite mounds from which the sodium chloride salt was extracted. The first mound must have been relatively important since it was reported to have been exploited for over a decade. The area of the second mound was located in the village itself (San Juan Guelavia). The evaporite was described as a mound of approximately 1.6m height x 3.0m base diameter from which material was removed and taken elsewhere in a two weeks operation. The evaporite was discovered when digging for housing construction.

Santa Ana del Valle

It is also known that near Santa Ana del Valle there used to be a salt deposit that was exploited for years. Samples collected at the west entrance of Tlacolula de Matamoros confirmed the presence of brackish water.

In order to understand the origin of the saline water that is present at some specific locations the case of the artesian well EL BROTANTE will now be given.

The well El Brotante

Tanivet Area

The well EL BROCANTE was drilled in the Tanivet area in May 1978. It was reported by the driller that following the drilling of an exploration well POMB-62., an artesian well ejected 200 lps of a brine water (in the range of 22 kg/m^3) in a 35 meter fountain.

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[4] Classification of other samples collected (GEOCA,1979., Perraton, 1995) is also available upon request.

The confined aquifer of artesian conditions was encountered at a depth of 300 meters. The exact extent of this confined aquifer is still unknown .

The discovery of this artesian aquifer has been the major event of groundwater exploration of the Central Valleys of Oaxaca. After almost 20 years most people still remember the famous well "EL BROTANTE" not so much because of its spectacular artesian conditions and its 35 m fountain jet but more because the saline water contaminated the area surrounding the well for a radius more than 100 m.

Until 1994, nobody had yet farmed the immediate 100 m contaminated zone . The government had to quickly mobilize resources for sealing the well after which an investigation was conducted. The investigation took place from June 1978 to May 1979 and helped C.N.A to recover their credibility on the local scene as a responsible manager of the water resources.

To what extent this investigation allowed C.N.A to recover their trustworthiness from the local population? If the answer to this question is beyond the scope of this research, that investigation however, allowed a much better understanding of the hydrogeology of the area. We shall now discuss the findings that are pertinent to our objective to characterize the parameters of the aquifer(s) in the research area.

The artesian well

The numbers given are from [5]Silva and Vasquez.

Location : Parallel 187 ° 56'
Meridian 94 ° 26'.

The well ejected in a thirty five [6] meter high fountain 200 lps (stabilized at 120 lps) of a saline solution and 200 000 lps of CO_2. The pressure of CO_2 was estimated to be 5 kg/cm^2. We take note that the same pressure was estimated to be 3.5 kg/cm^2 in 200 000 lps of CO_2 in another report.

Whatever the exact pressure must have been, that pressure created a vacuum of conic shape that caused the water to rise in nearby shallow domestic wells.

Table 4 shows the chemical analysis of two water samples collected from the

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[5] Technical Report of C.N.A.May 1079. El Pozo Brotante de Mitla by Eng. Marco A. Garcia Silva and Ing. César A. Lara Vasquez. Presented by Ing. S.de la Cruz Campa.

[6] The estimated height of water of 35m is questioned in light of the piezometric level of 12,35m measured for this artesian aquifer. This is discussed under the section "Three Aquifers were identified"..

artesian well and one sample from a stream nearby. Davis and De Wiest (1966 as reported by Bouwer ,1978) classified water with a TDS of 1 kg/m^3 to 10 kg/m^3 as brackish, of 10 kg/m^3 to 100 kg/m^3 as salty, and of more than 100 kg/m^3 as brine. The relation between conductance and TDS depends on the particular ions in solution. For irrigation water and most other natural waters, 1 micromho customarily is taken as equal to 6.4×10^{-4} (0.00064)kg/m^3 (Bouwer,1978). It follows that the water flowing from the artesian well aquifer with an electrical conductivity of 18 000uohmo/cm groundwater of the artesian aquifer has a TDS content of approximately 11.5 kg/m^3. This water is salty as per Davis and DeWiest's classification. By way of comparison, the TDS content of sea water is about 34 kg/m^3 and that of saturated NaCl solution more than 300 kg/m^3.

The interest was however not so much in assessing the potential use of this water primarily of sodium-carbonate nature which is of course unfit for either drinking or irrigation purposes but rather in the understanding of its origin and extent. No less fascinating was the presence of large volume of CO^2 under pressure which had not been discovered anywhere else in the state of Oaxaca [7].

Sealing the well

The phenomenon was spectacular and so was the engineering that was required to stabilize and seal the well. Only a summary of these operations is given here. First 60 truck loads of stones were dumped to prevent further cavitation and allow machinery to approach the well. A concrete torpedo (a cylinder 273mm x 12 m) was lowered in the well to hopefully reduce flow but the torpedo got stuck at a depth of 97m without significant impact on the flow rate and pressure. A "T" control valve was placed and secured on top of the well.

Then 55m^3 of heavy mud composed of Barite and Bentonite (density of 1850kg/m^3) were injected of at a pressure of 6,9 atmospheres (100 lb/in^2) to bring the flow down by 2/3, then 92 m^3 of a lighter mud mixture of density 1300 kg/m^3 were added. The flow was then stopped and the water leveled off at 12m in the well. An inner 210mm diameter pipe was inserted but got stuck at 96m,. Concrete was then injected to seal the well from the depth of 92m to the depth 196 m below ground

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[7] Presence of CO_2 was discovered within the watershed of Papaloapan where streams with "boiling water" were observed in San Lorenzo Albaradas. but this is not comparable to the artesian well in Tanivet area.

level. Once the concrete was set, the well was re-perforated down to 300m. The well was then in good operation and under control. Taking all precautions, two more wells were drilled nearby.

Three aquifers were identified

In order to assess the geologic profile , two more wells were drilled in the vicinity of the artesian well. This local exploration allows C.N.A geologists to identify the presence of three aquifers on top of each other.

The top aquifer is phreatic. At this location the water is fresh but with bacteriological contamination from domestic wastes and/or animals. The piezometric level is 9.03m.

The second aquifer has also fresh water but does not suffer bacteriological contamination . This intermediate aquifer is confined and has a piezometric level of 9.77m.

The deep aquifer is artesian and highly saline. This water is primarily of sodium-carbonate nature and corresponds to water that was trapped and remained in permanent contact with evaporitic sediments located under the volcanic cover.

The sodium chloride originates from the evaporites of the Tertiary formation. These clay marine sediments form a layer that ranges from 150m to 300m thick covered by the extrusive rocks of the Tertiary era. The well POB-1 shows that these marine sediments are encountered at about 300m below ground level in the Tanivet area. The CO_2 and calcium carbonates are the end products of the weathering of the limestone of the Middle Cretaceous sediments. TACSA (1983) is of the opinion that the large flow of the artesian well can probably be attributed to secondary solution openings.

This interpretation can be visualized as a network of fractures and interconnections in the limestone that somehow reach the geologic fault of Tanivet from where a lateral connection to the artesian well developed through the pseudo-stratification and fracturation of the volcanic formation of rhyolitic material. This interpretation is illustrated by the sketchy profile on Figures 34A and 34B of Chapter VII. The deep confined aquifer has a piezometric level of 12.35m.

This aquifer is also characterized by the presence of CO_2 which calcareous bodies may have produced by friction during the process of spreading or formation of the geologic faults induced by tectonic movements that are frequent in this area.

Calcium

Since the solubility of these minerals is low, water from igneous or metamorphic rocks tend to be low in calcium as well as in Total Dissolved Solids (TDS). In sedimentary rock, calcium occurs as carbonate (calcite and aragonite), calcium magnesium carbonate (dolomite), calcite (limestone), and calcium sulfate (gypsum and anhydrite). Calcium carbonate is one of the main cementing agents for sandstone and other detrital rock (Bouwer, 1978). Groundwater from limestone and other calcareous deposits is generally hard and can be expected to be a saturated solution of calcite.

In the research area calcium comes from the dissolution of calcareous rocks and from the calcitic feldspars that constitute an important part of the igneous rocks of the region (GEOCA, 1980). This element was found in groundwater samples collected in 1994 at concentration from 0.023 to 0.178 kg/m^3 with an average of 0.070 kg/m^3 and a coefficient of variation (CV) of 55%. GEOCA's (1979) survey found concentrations of Calcium within the research area in the same range that is an average of 0.092 kg/m^3 with a CV of 77%.

Sodium

Within the research area, igneous rocks are composed of sodic feldspars which once weathered by water may detach to join the sodium ion in solution. They are found also in evaporites sediments that can be easily dissolved. Sodium element was found in groundwater in 1994 from zero concentration to a maximum concentration of 1.488 kg/m^3 with an average of 0.255 kg/m^3 and a CV of 139%. GEOCA's (1979) survey shows an average concentration of Sodium of 0.123 kg/m^3 with a coefficient of variation CV of 246%.

Chemical Analysis Data Tables

Schemes have been developed to classify groundwater according to the concentrations of these ions using trilinear diagrams and categories like calcium-sodium and chloride water. However, Bouwer (1978) is of the opinion that while such classifications may be valuable in describing the general type and geochemical history of a given groundwater, a complete chemical analysis with the results in tabular form is more valuable in determining the suitability of a groundwater for a particular use. This is done Appendix AC .

Given the small sample size, these surveys are subject to an important error estimate and for this reason caution is recommended in their interpretation.

Sheet10 of Waterqua.xls

Figure 1 Concentration of Irrigation waters as related to conductivity.

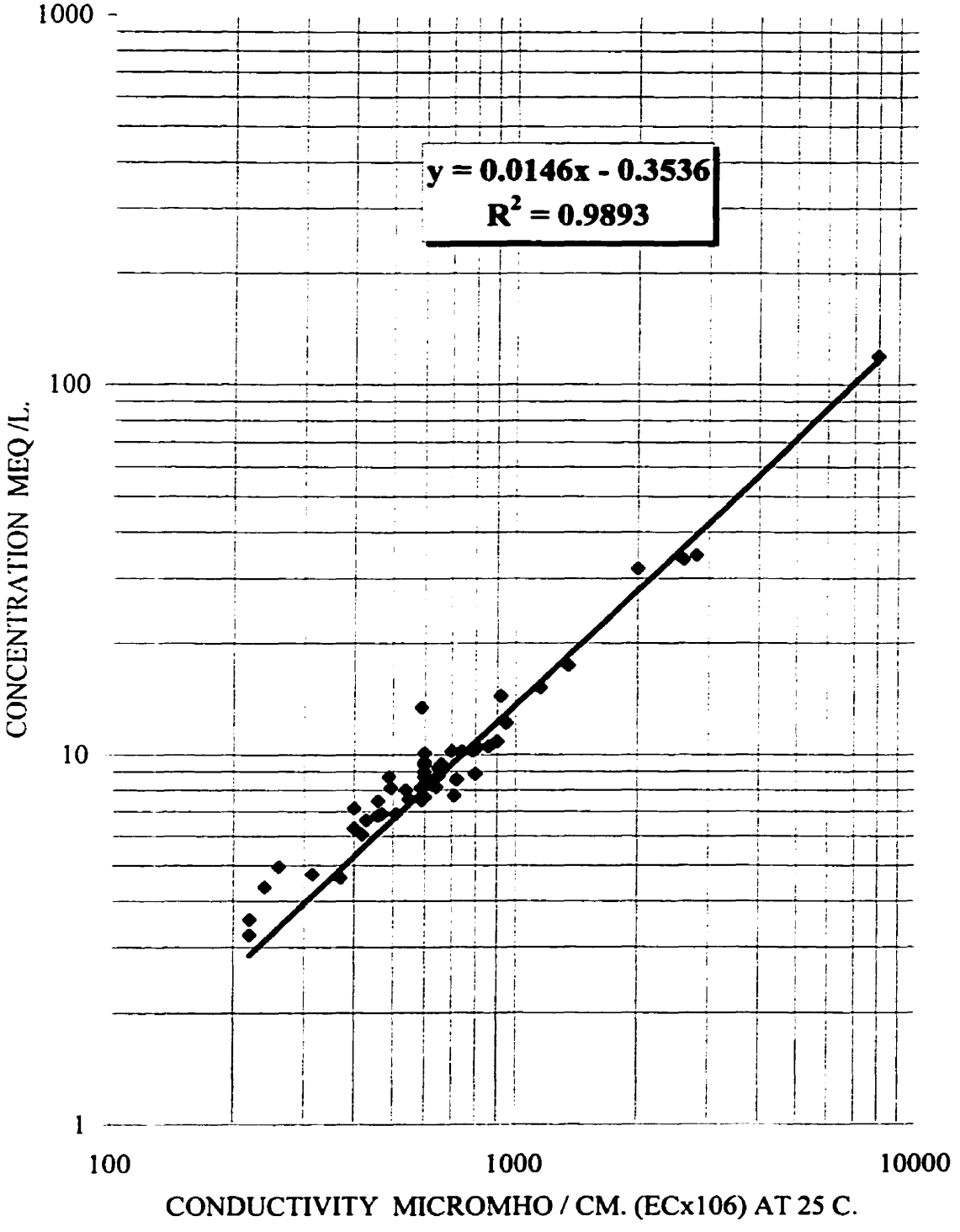
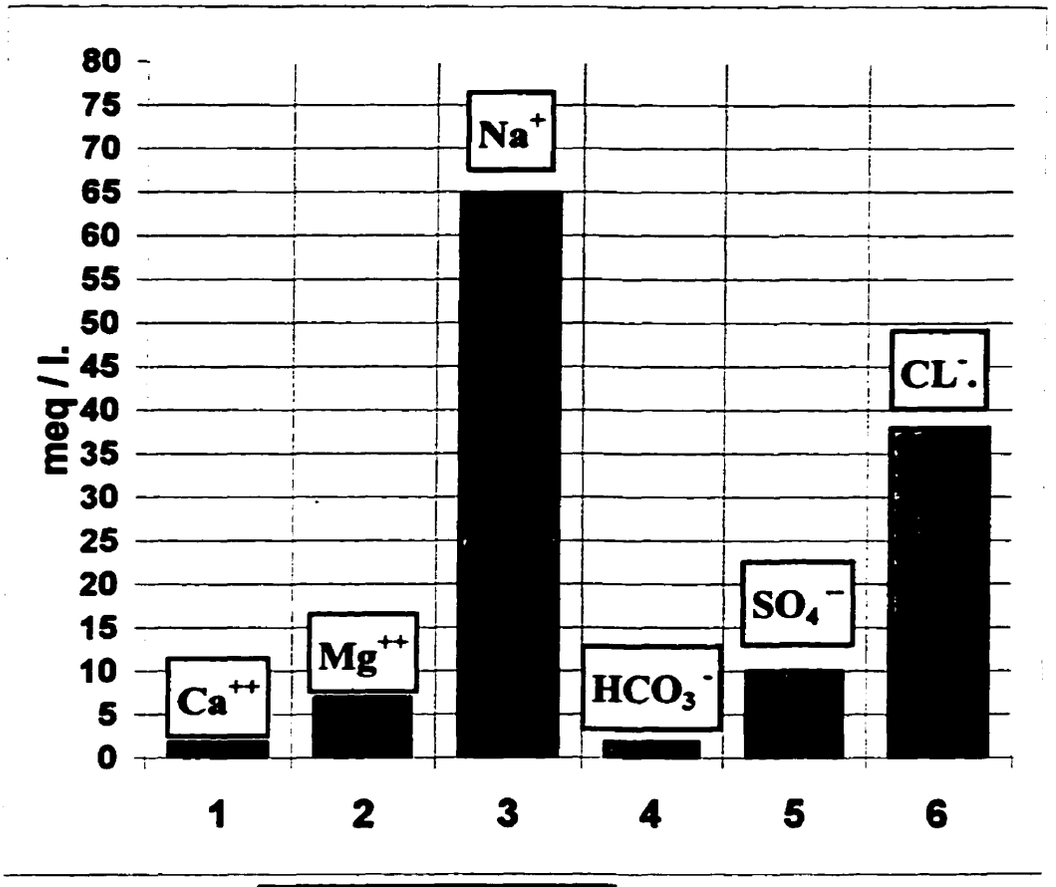


FIGURE 2. USE THIS KEY SYSTEM FOR GRAPH INTERPRETATION of FIGURES 3 to 13.



Pozo P-66

To illustrate the KEY system. P66 brackish water is used. This is representative of the local saline conditions only.

To convert to ppm Multiply graph values by equivalent weight below.

	Ca++ Calcium	Mg++ Magnesiun	Na+ Sodium	HCO3- Bicarbonat	SO4- Sulfate	Cl- Chloride
Equivalent Weight [g]	20.04	12.16	23.00	61.01	48.03	35.46

Prepared by Etienne 12/3/97

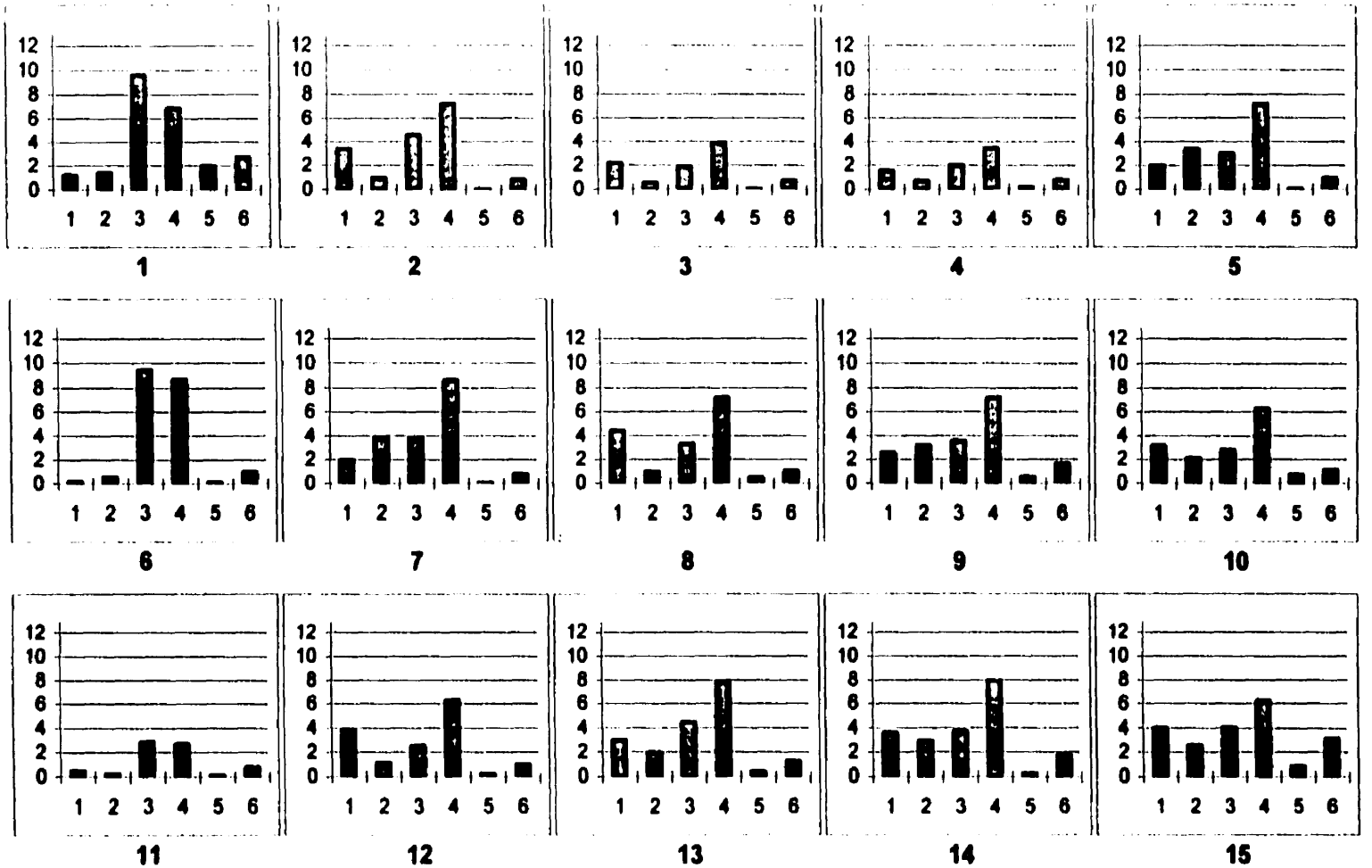


Figure 3 **Chemical Analyses Water Samples No. 1 to 15 inclusive.**
Water Samples collected in February 1979, GEOCA

Prepared by Etienne 12/3/97

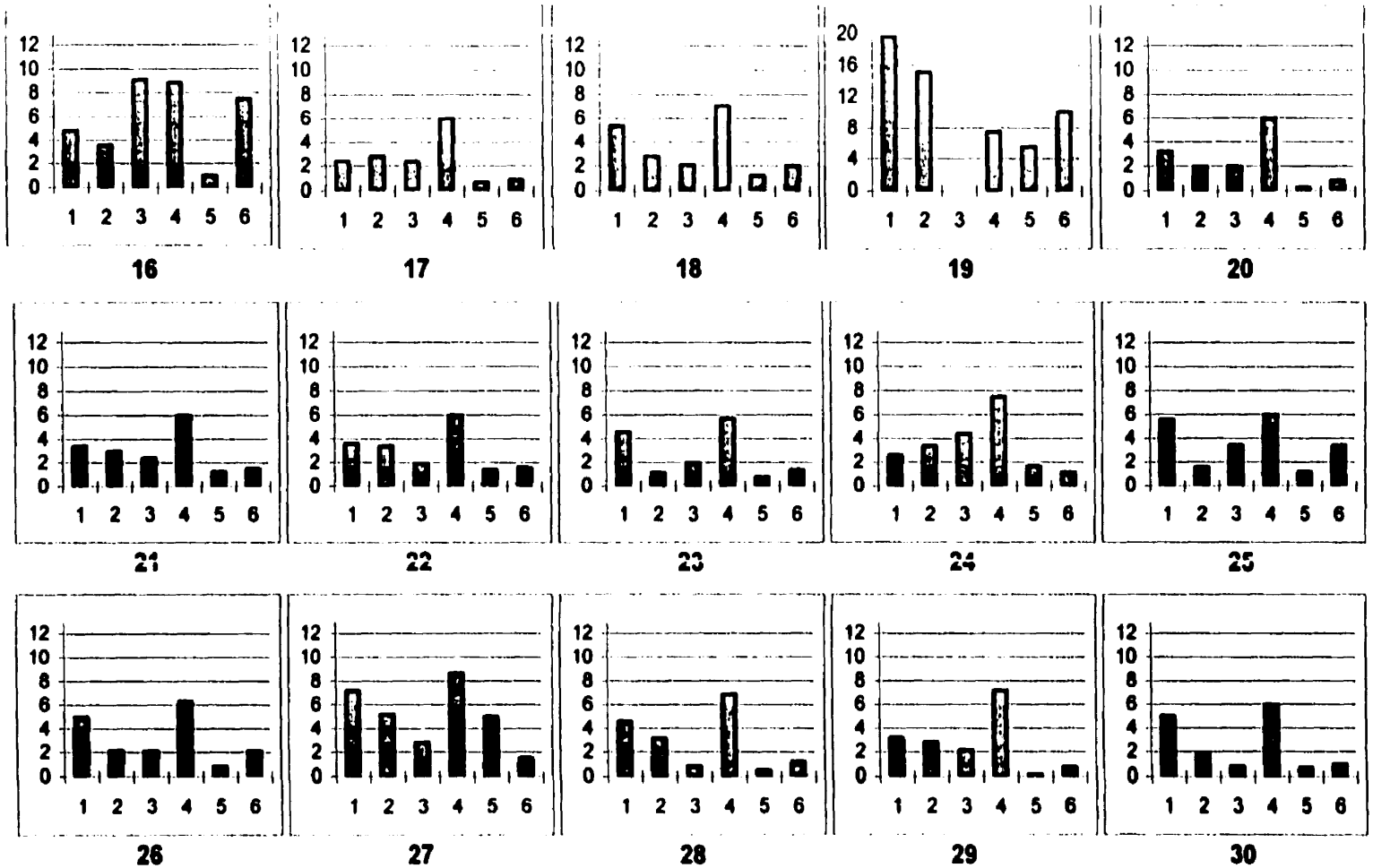


Figure 4 **Chemical Analyses Water Samples No. 16 to 30 inclusive.**
Water Samples collected in February 1979, GEOCA

Prepared by Etienne 12/3/97

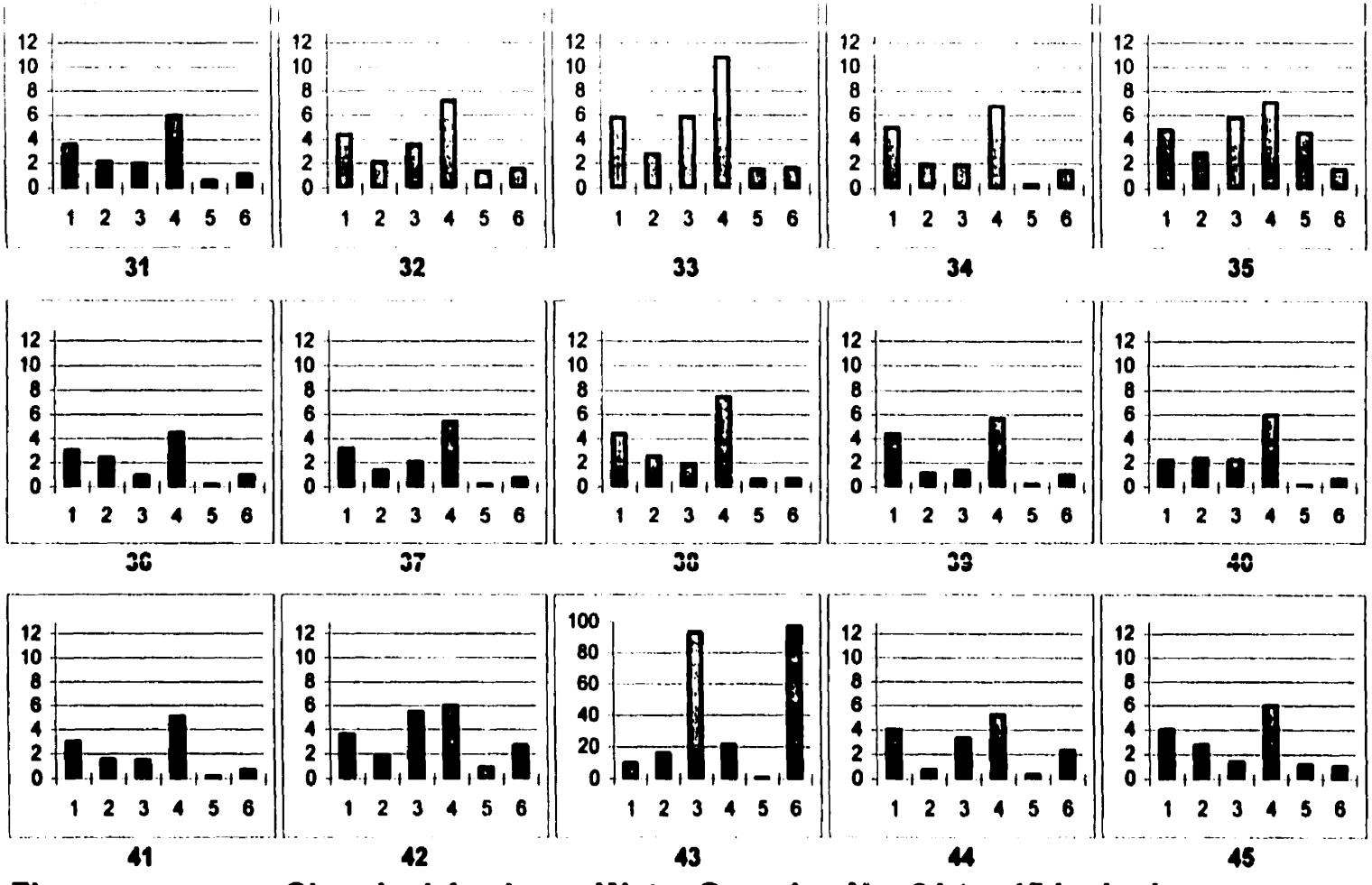


Figure 5 **Chemical Analyses Water Samples No. 31 to 45 inclusive.**
Water Samples collected in February 1979, GEOCA

Prepared by Etienne 12/3/97

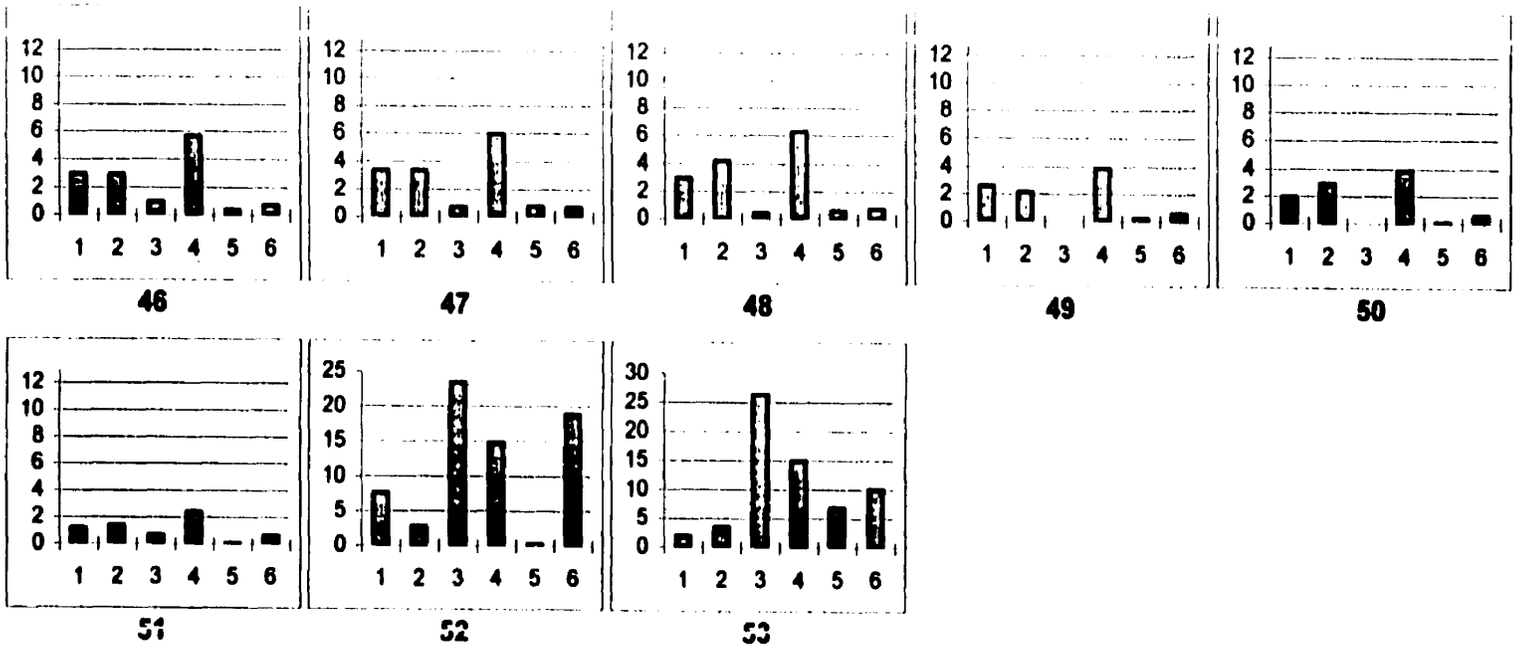


Figure 6 **Chemical Analyses Water Samples No.46 to 53 inclusive.**
Water Samples collected in February 1979, GEOCA

Prepared by Etienne 12/3/97

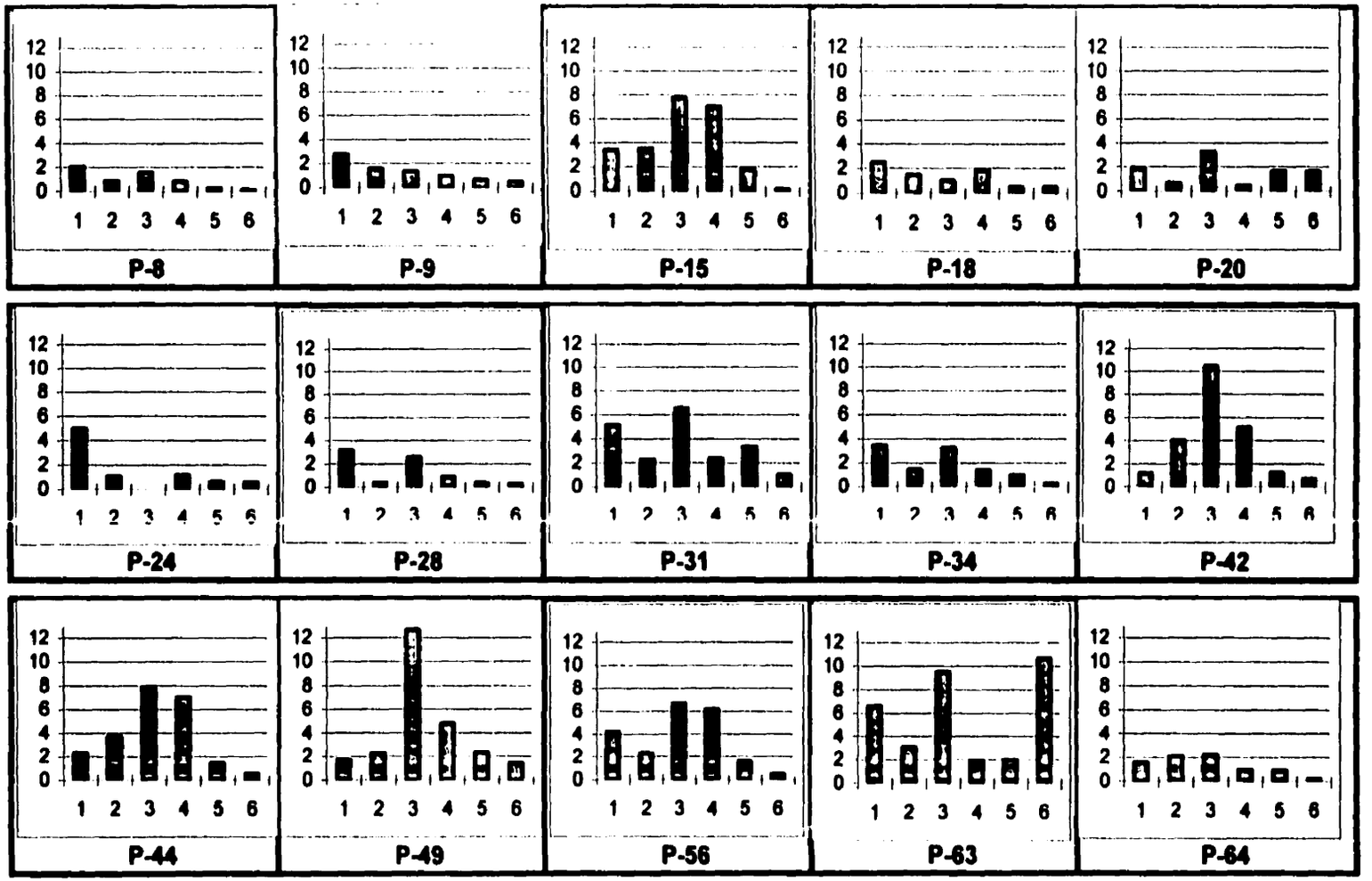


Figure 7 Chemical Analyses Water Samples from Observation Wells

P8 , P9, P-15, P18, P20, P24, P28, P31, P34, P42, P44, P49, P56, P-63 and P-64.
Samples Collected in Sept-Oct. 1994. E.Perraton

Prepared by Etienne 12/3/97

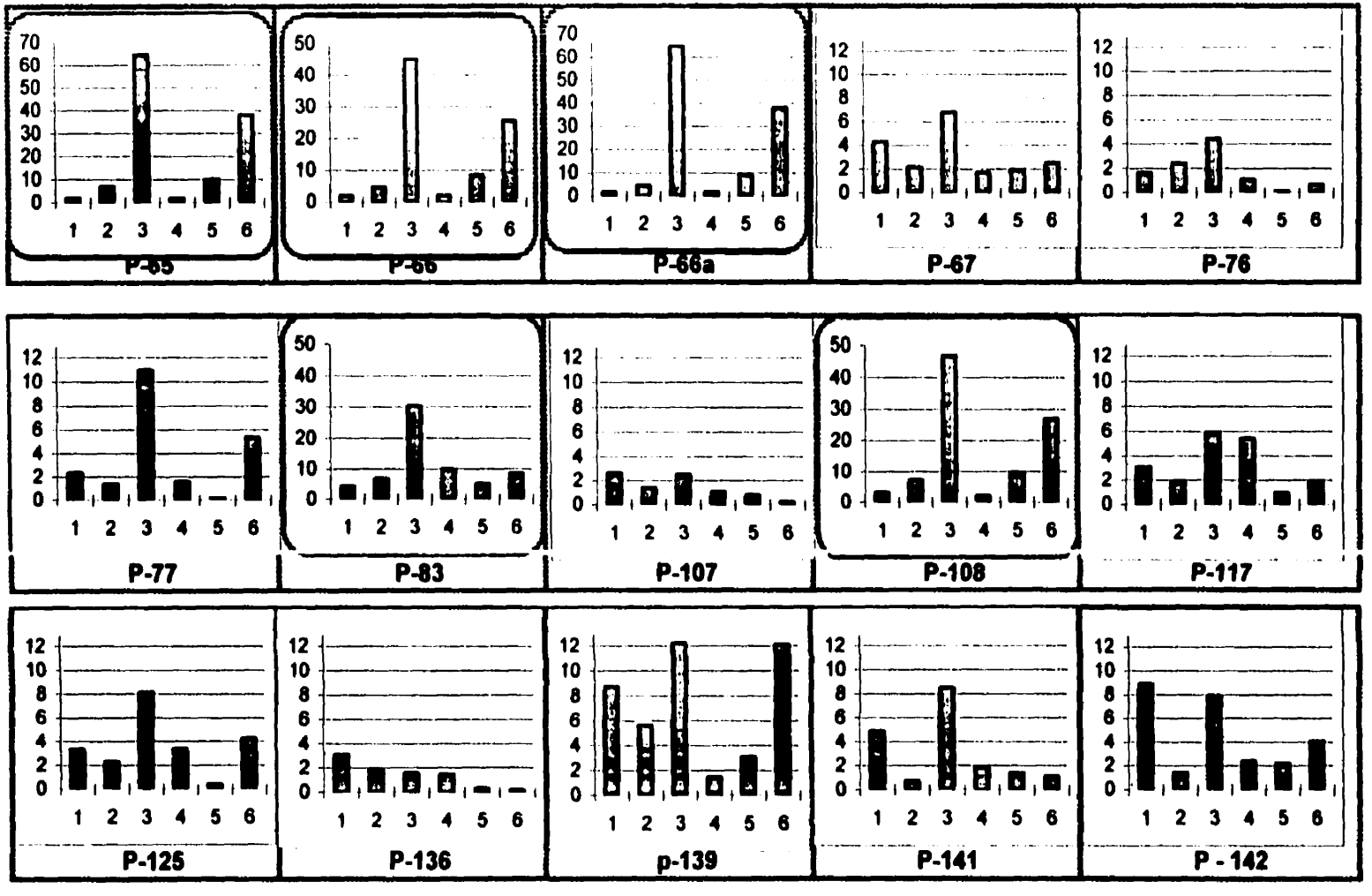


Figure 8 Chemical Analyses Water Samples from Observation Wells

P65, P66, P66a, P67, P76, P77, P83, P1-7, P108, P117, P125 , P136...

Samples Collected in Sept-Oct. 1994. E.Perraton

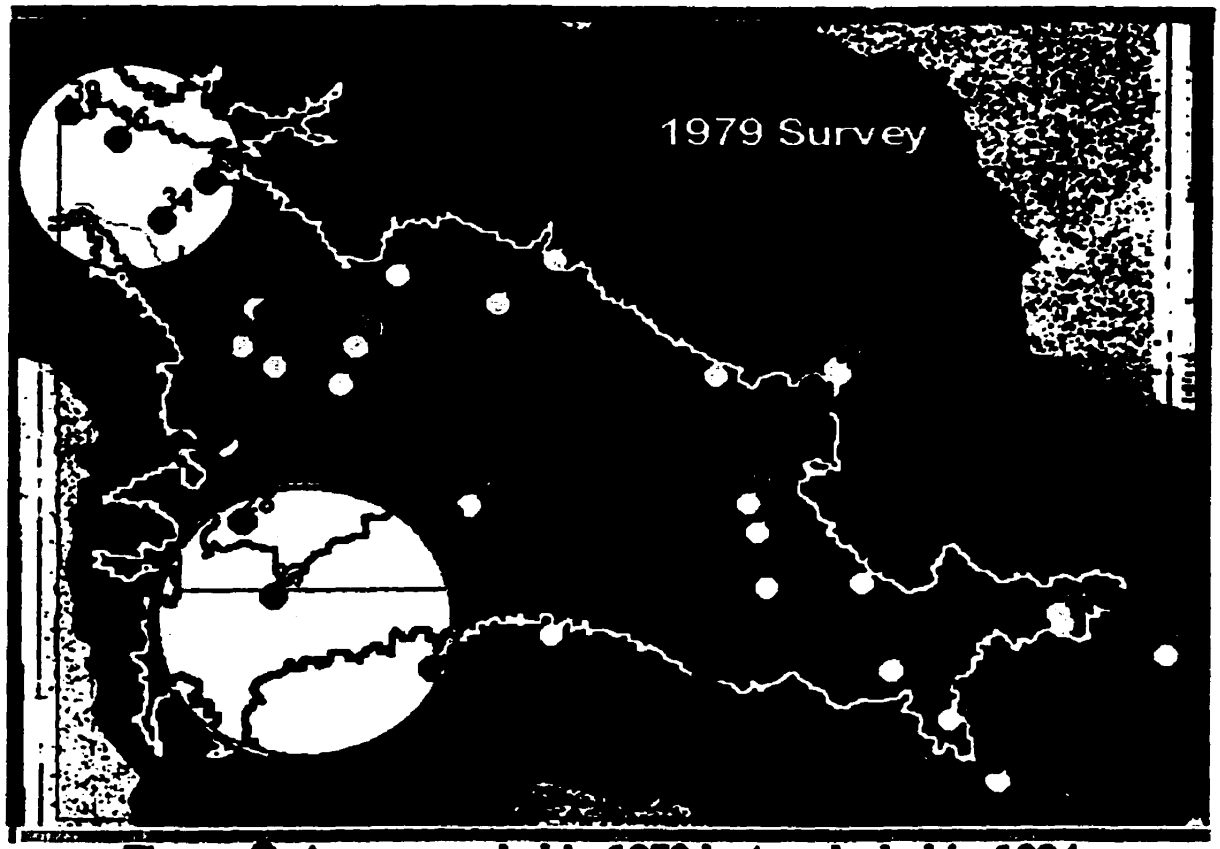
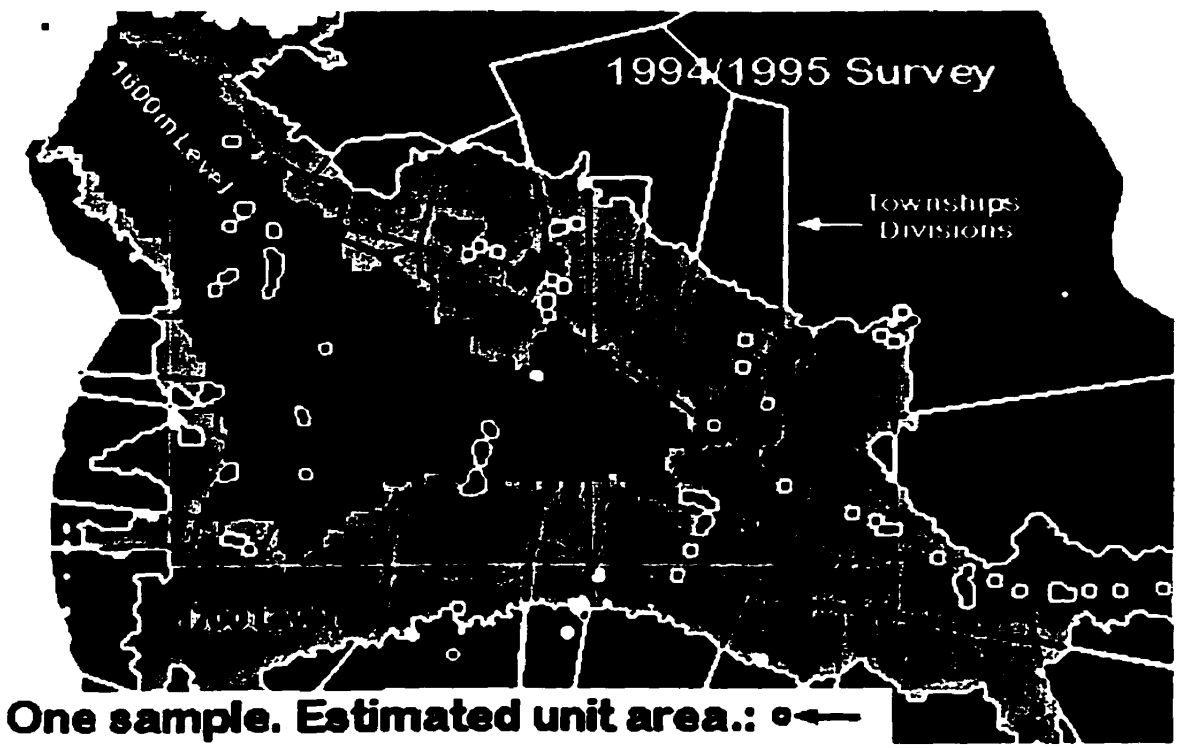


Figure 9. Area sampled in 1979 but excluded in 1994. Samples no. 25.27.28 and 34.35.36 39.



One sample. Estimated unit area.:

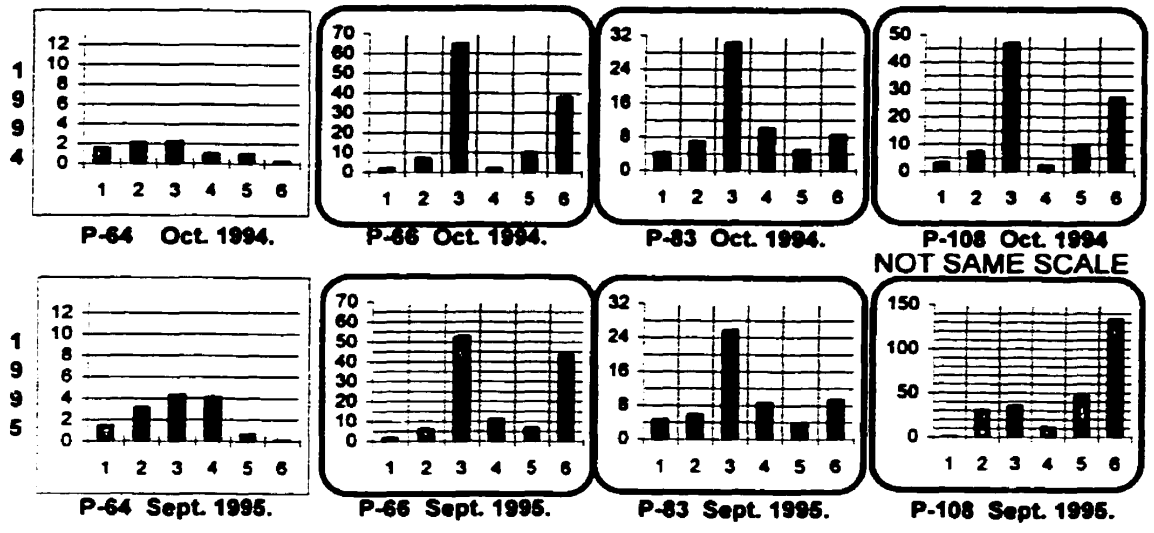


FIGURE 10A. Comparing the Groundwater sampled at P-64, P-66 , P-83, P108 1994 VERSUS 1995.

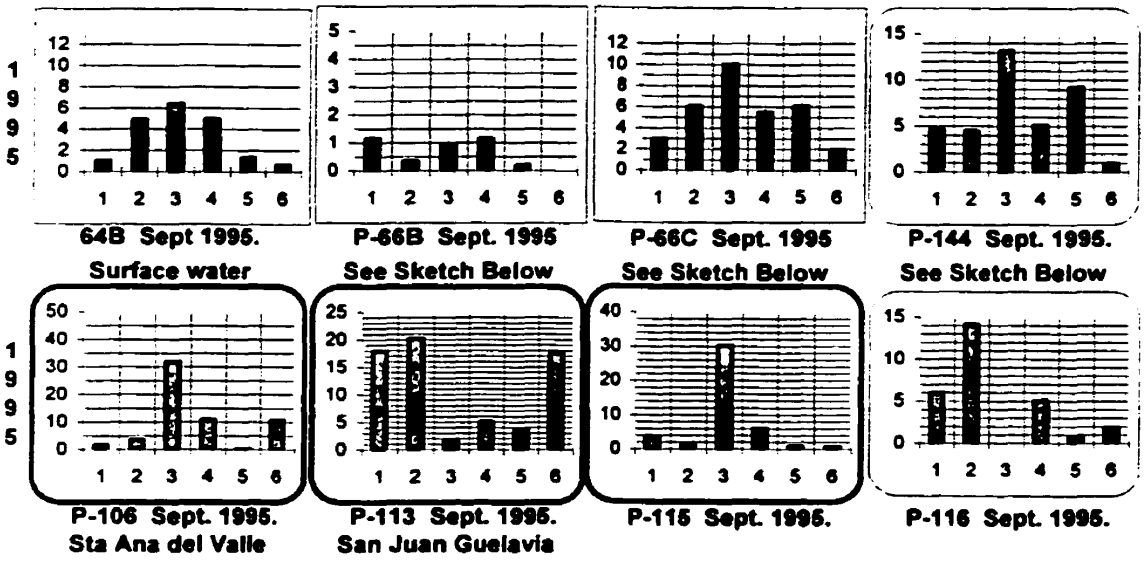
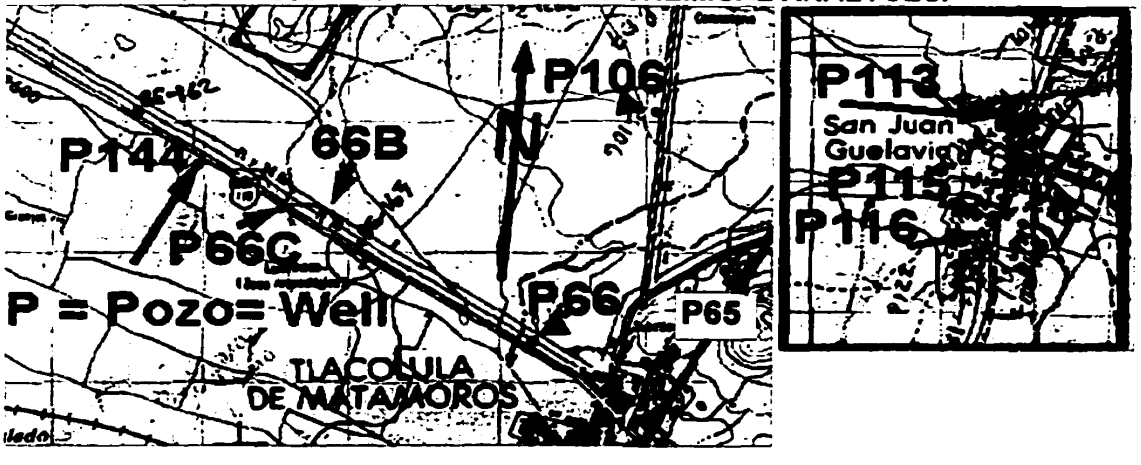


FIGURE 10B. 1995 WATER SAMPLES CHEMICAL ANALYSES.



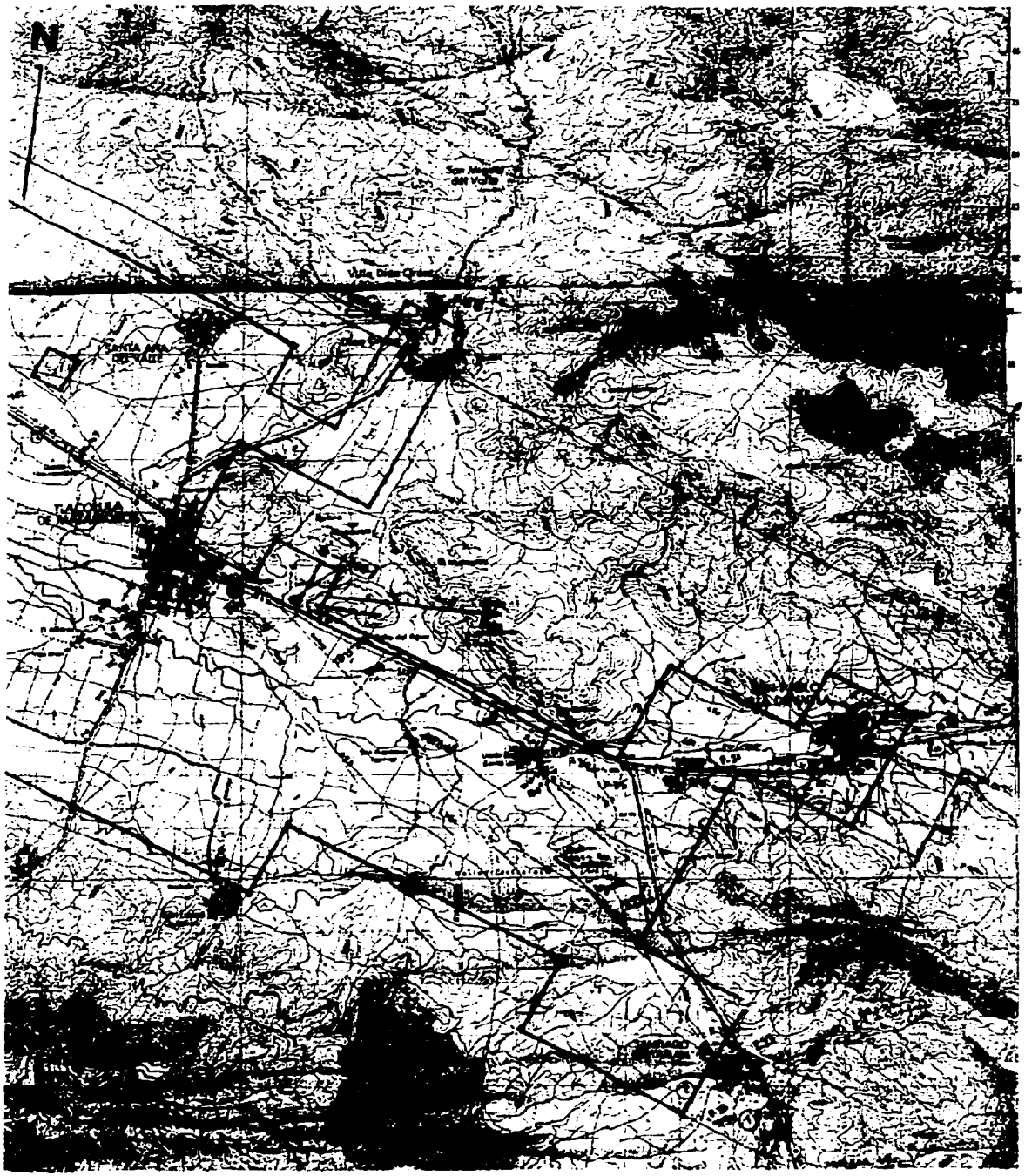


Figure 11a Chemical analysis of water sampled East of Tlacolula Lay over next page using Corner crop Marks.

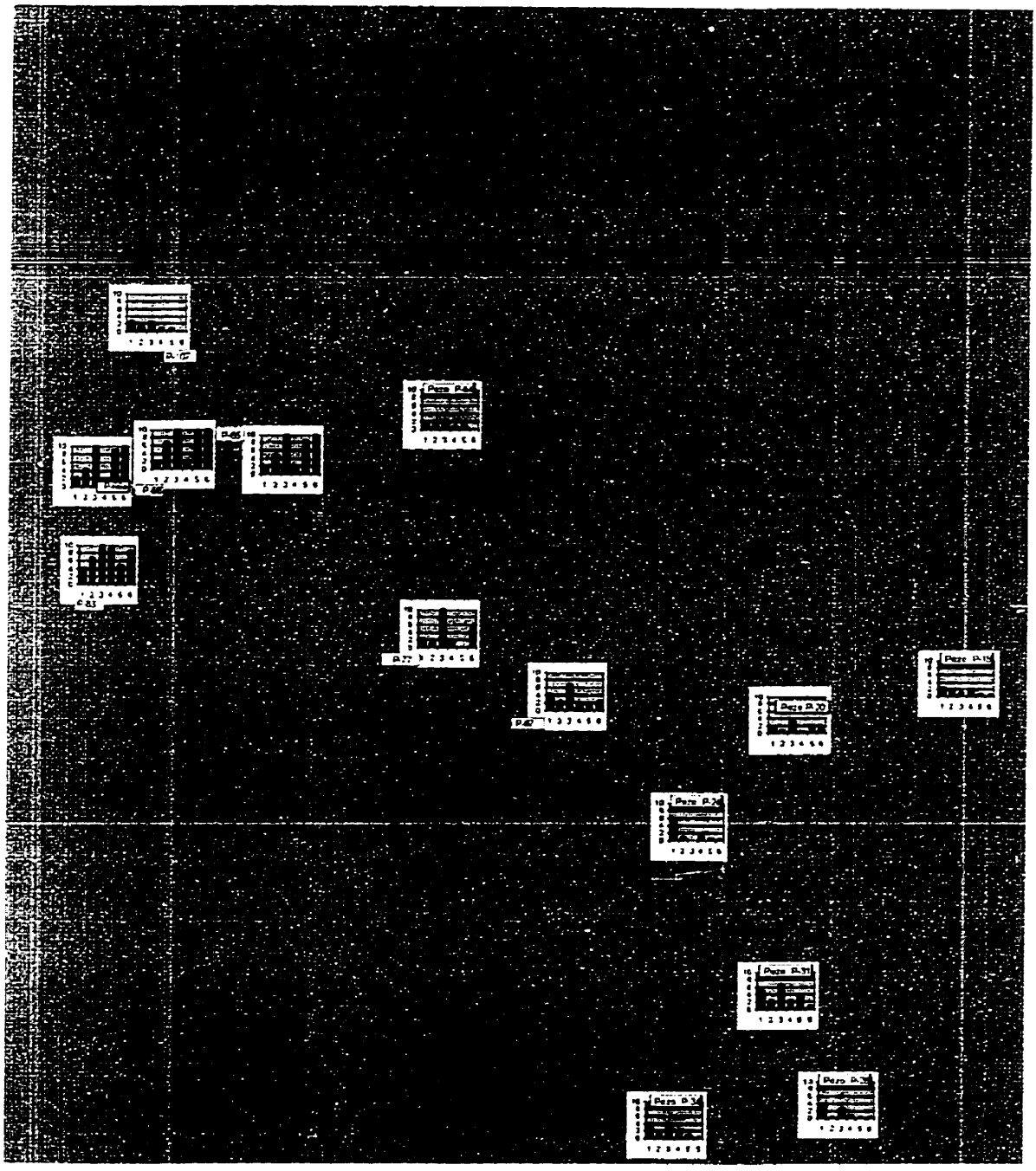


Figure 11b Chemical analysis of water sampled East of Tlacolula Lay over next page using Corner crop Marks.

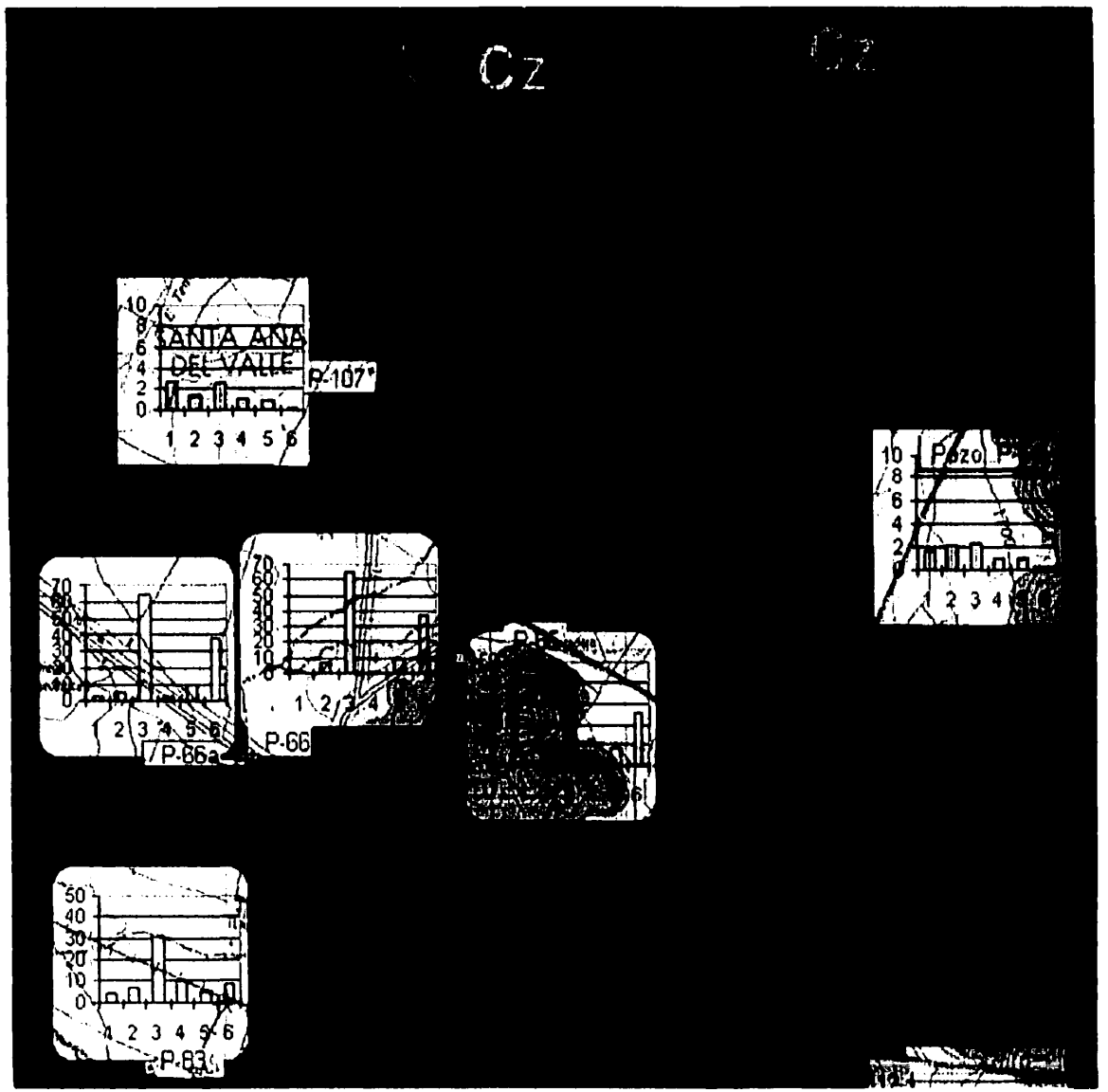


Figure 12. Salinity of Ground water Sampled nearby Talcolula.

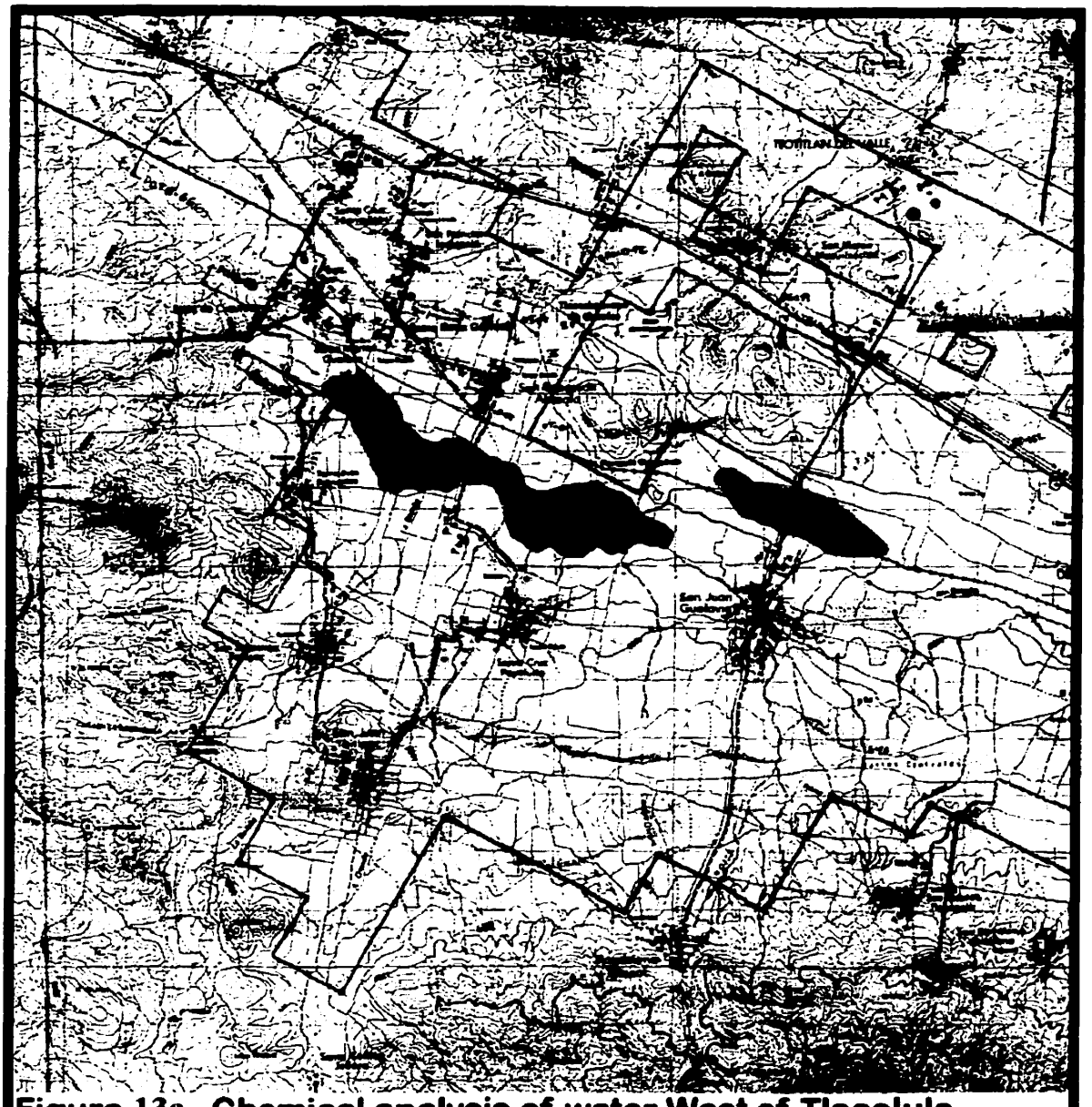


Figure 13a .Chemical analysis of water West of Tlacolula.
Lay over next page using Corner crop Marks.

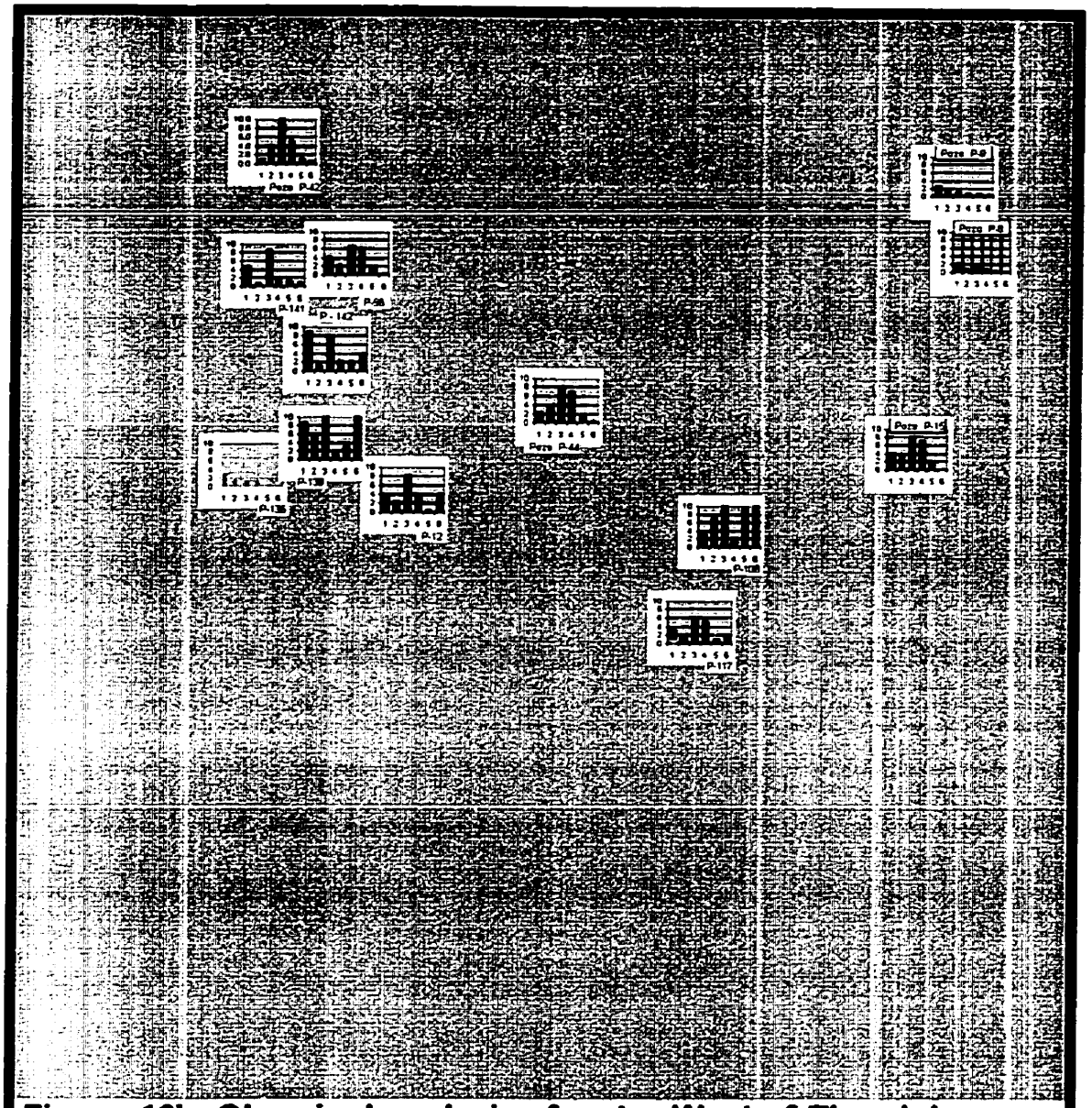


Figure 13b Chemical analysis of water West of Tlacolula. Lay over next page using Corner crop Marks.

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UMI

waterqua.xls

	A	B	AP	AS	AT	AU
2	Table 3.			Classification of Ground-Water samples.Use for irrigation as per USDA 1954.		
3		Pozos	C - S			Residual Sodium Carbonate.
4		Well	Class	Conductivity	Sodium Hazard	Effect of [ ] on quality.
5						
6	P	8	21	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
7	P	9	21	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
8	P	15	33	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
9	P	18	21	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
10	P	20	21	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
11	P	24	21	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
12	P	28	21	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
13	P	31	32	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
14	P	34	21	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
15	P	42	34	HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
16	P	44	33	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
17	P	49	34	HIGH CONDUCTIVITY	VERY HIGH Na	1.25<RSC<2.5. => Marginal Water
18	P	56	32	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
19	P	63	32	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
20	P	64	21	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
21	P	65	44	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
22	P	66	44	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
23	P	66a	44	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
24	P	67	32	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
25	P	76	21	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
26	P	77	33	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
27	P	83	44	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
28	P	107	21	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
29	P	108	44	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
30	P	117	32	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
31	P	125	33	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
32	P	136	21	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
33	P	139	33	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
34	P	141	33	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
35	P	142	32	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
36	P	143	21	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
37	Samples collected 1994. and data analysis by E. Perraton 1997.					
38	Chemical Analysis by C.N.A.					

TABLE 4 Chemical Analysis Of Two Water Samples Collected From The Artesian Well And One Sample From a Stream Nearby

	Sample 107. 12 March 1979	Sample 110 29 March 1979	Stream Guila.112 29 March 1979
Temperature:	28 °C	Not given.	28 °C
pH at 25.5 °C.	6.95	7.20	7.65
Elect.Condu.@23°C	18000uohmo/cm	18000uohmo/cm	1000uohmo/cm
Total Hardness:	1.995 kg/m^3	1.000 kg/m^3	0.820 kg/m^3.
Hardness Ca.$CaCO_3$	0.746 kg/m^3.	0.731 kg/m^3	0.692 kg/m^3.
Hardness Mg.	0.349 kg/m^3	0.269 kg/m^3.	0.128 kg/m^3
Bicarbonates.HCO_3^-	2.647 kg/m^3	5.429 kg/m^3	1.037 kg/m^3.
Chlorides Cl^- :	11.175 kg/m^3	11.676 kg/m^3	2.471 kg/m^3.
Sodium. Na^+	7.525 kg/m^3.	9.625 kg/m^3.	1.638 kg/m^3
Potassium. K^+	0.550 kg/m^3.	1.075 kg/m^3	0.113 kg/m^3
Density at 15%C	1 017.5 kg/m^3	1 017.0 kg/m^3	1 003.5 kg/m^3

Samples collected by S.A.R.H (1978-1979)

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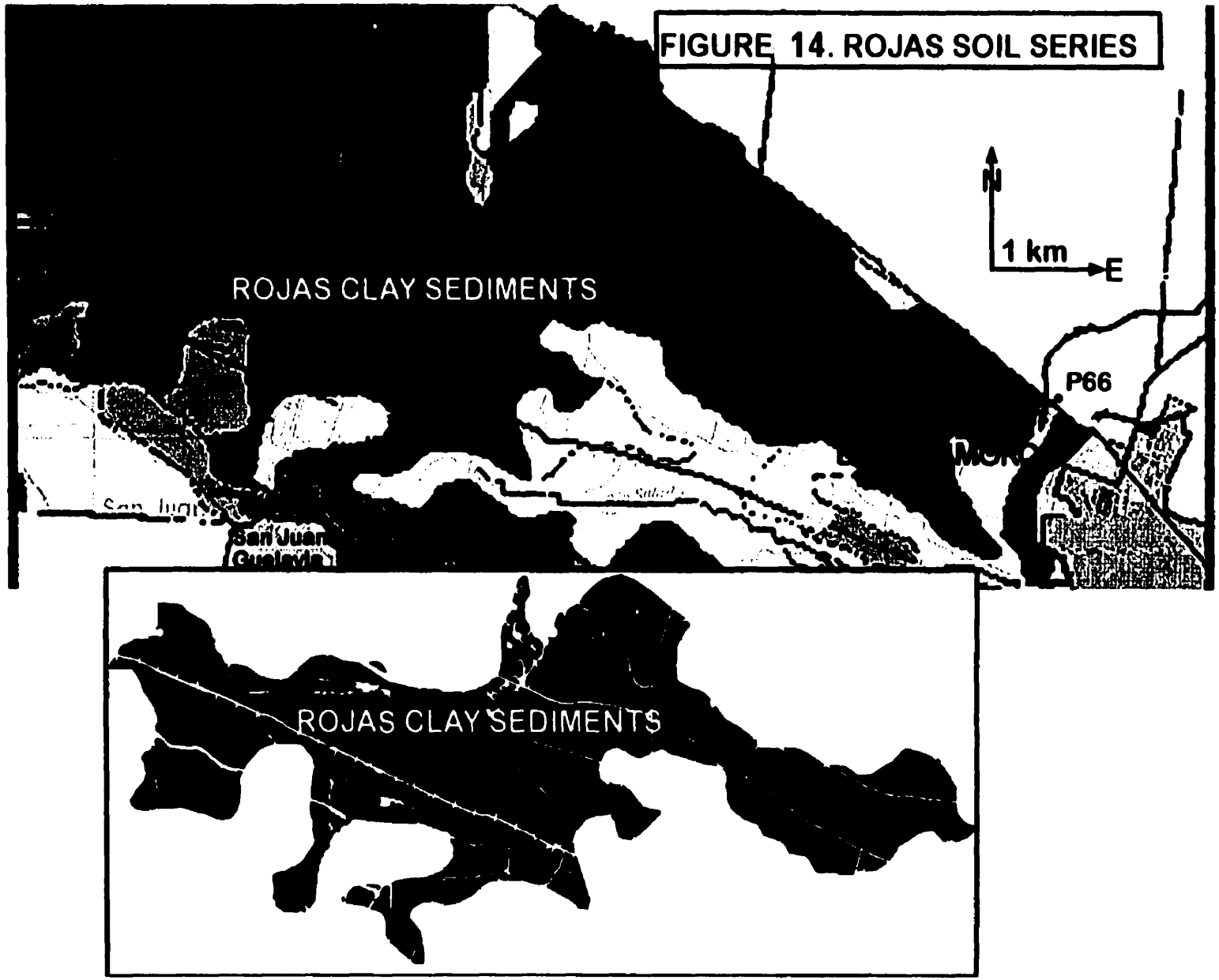


FIGURE 14. ROJAS SOIL SERIES

CHAPTER IX

SUMMARY OF CONCLUSIONS

From the observations and calculations during the course of the research described in this Thesis, the important findings and conclusions are summarized as follows:

Establishment of the Manager's Geographic Information System

The methodology for the preparation of basemaps developed in this research is reproducible and compatible with functions and responsibilities of the Comisión Nacional del Agua (C.N.A). Important aspects of the computerized mapping technique for the establishment of the Manager's Geographic Information System are given in Chapter III.

The distributions of monthly total precipitation data.

The monthly total precipitation for the months of the wet season was found to approach a normal distribution whereas the precipitation distributions of the dry period deviate from a normal distribution being limited on the left by a minimum of zero or no rainfall.

Testing for a time trend

The data of the period 1950-1958 is compared with the data of the period 1960-1968 and then with the period of 1969-1977. The precipitation data show no significant difference in time (from one period to another) but the relatively low probability of equal mean obtained for the precipitation in the months of May, July, August. September and October. is a source of concern . This research has demonstrated that the monthly Average Minimum Temperature recorded at Tlacolula Station had significantly increased (at 0.01 probability level) from 1950 to 1978. The increase was found to be more pronounced from 1950 to 1968 that it was from 1960 to 1978. The same analysis was carried out on the monthly Average Maximum Temperature but the increase in the monthly Average Maximum Temperature was found to be less pronounced.

June rainfall

Kirkby's (1973) important social consideration was reviewed in light of findings of this research. Kirkby (1973) claims that in cash-crop production, as well as subsistence corn production, peasant agriculturists of Oaxaca Central Valleys are aiming for satisfaction rather than for maximum profits and crop production therefore follows an event-matching procedure where dry farmed land area is reduced when June rainfall augurs good. This implies a water demand relatively stable since production is increased at the same time as water availability is increased. .

A threat to sustainability was found to be most probable when average rainfall conditions are prevailing while maintaining irrigation in winter months because of the contradiction with well established dry farming and because of competition between irrigation and community household water needs in the driest part of the year.

Regression polynomial equations are powerful tools accessible to managers

The cubic polynomial regression was found to compare favorably with Log-Pearson III model for the probability plot of the annual rainfall measured at Tlacolula de Matamoros.

The Treatment Of Zeros In Precipitation Data Analysis

The method based on the theorem of total probability as recommended by Haan (1977) was found to be a powerful tool in frequency analysis of monthly precipitation data with recurrence of no rainfall as this is the case in the winter months of January, February, March and April. The selection of a small constant to handle zero values in a log normal distribution was found to introduce significant bias in the data .

For the months of January . February and March, independently of the method used, no rainfall with a probability of exceedance of 80% representing 1 in 5 dry years can be accounted for at any of the three base stations.

For the design rainfall with a probability of exceedance of 20% representing 1 in 5 wet years precipitation, the log normal distribution compares favorably with five out of the eight values obtained by the method based on the theorem of total probability for the stations of Oaxaca and Cuajimoloyas. In the case of Tlacolula de Matamoros,

the 1:5 wet years design rainfall obtained by the two methods differs significantly for 3 out of the four dry months under consideration.

Periodicity

December peak rainfalls at Cuajimoloyas may be following a cyclic pattern but this periodicity was **not** found to be highly significant on the correlogram of December rainfall. Similarly, correlograms of February, March, April, June and July rainfalls did not show clear cycles.

The possible periodicity shown on the correlograms for the monthly precipitation of January, May, August, September and October could not be confirmed at subsequent cycles (20, 30 etc..) . Given the sample size (n=33 years), no spectral analysis was conducted at this point.

Proposed Table Formats

Two Table formats complementary of each other are proposed for summarizing the monthly precipitation data . The first Table shows for each month the percentage of assiduity, the percentage of continuity, the total period , and the linear correlation coefficients in the monthly precipitation pattern with two adjacent stations.

The second Table format shows for each month the basic statistics corresponding to the precipitation observed daily in the month in question. Those statistics are: the Average, the Standard Deviation, the Coefficient of Variation, the 95% Confidence Interval and the 80% Confidence Interval.

The proposed Table formats are used for analyzing the precipitation data sets recorded at the three base stations representative of the conditions prevailing in the Tlacolula basin. These Tables show that a common system is most likely responsible for the unusual precipitation observed in January at the three stations. However, it appears that the rainfall in June, November, and December follows quite a different pattern at the three stations. Generation of missing data by linear regression would be inadequate in these months.

The importance of the meteorological station located in Tlacolula de Matamoros was also clearly demonstrated by these Tables. On a year basis as well as for the specific month of June that is so critical for farming, no good correlation exists in the

precipitation pattern with the other two stations. It is recommended that priority be given to continuing the rainfall and temperature observations for the next century at least at the three base stations. Farmers who intend to do irrigation scheduling should have their own rain gauge.

Surface Water Regime

With regard to hydrometry, the Manager is faced with two basic problems: the discontinuity in the measurements and the uncertainty of the measurements. The discontinuity was found to be of four natures;

1) discontinuity in measurements due to financial constraints in which case measurements are stopped for an undefined period of time.
2) discontinuity in measurements in the dry season when the molinet was sent for calibration.
3) weekly discontinuity in measurements on the day of rest taken by the gauge person and.
4) discontinuity in measurements on days of molinet break downs.

This research shows that discontinuity due to financial constraints is a major problem. Flow measurements initiated in 1978 were stopped abruptly due to financial constraints in April 1992. No measurements have been taken at the outfall of the Salado river since then.

Investigating the effects of interpolation on Flow measurement Statistics

When the missing flow measurements for the period of hydrometric measurements of 1978 to the first three months of 1992 are generated by rational deduction from historical runoff measured at the same station in a sequence of similar rainfall events. the overall impact (| with - without generated data for missing days |) on the total monthly runoff was estimated to be 0.5% in March 1978. around 11% in July 1985 and around 30% in the worst case of May 1984.

The uncertainty in hydrometric measurements

Uncertainty results from all errors made and/or errors that may be attributed to hydrometric measurements. The reliability of the material (PRICE TYPE MOLINET) and method (Gauge Scale reading) used in hydrometric measurement was investigated.

The molinet was tested at two locations. The molinet was combined to a light source and a sound beeper for counting the number of revolutions. It was observed that an error of 1 RPM every 30 RPM was made occasionally by the operator. This error on the rotation was converted to a linear velocity using the 95% confidence interval obtained on the regression coefficients calculated by regression analysis on the molinet calibration data.

A reading error in the order of 15 mm on the Gauge Scale was considered to be a reasonable possibility. By converting the error estimate on the scale reading into an error on the cross-sectional area, the corresponding error estimate on the discharge was calculated as the product of the error estimate on the linear velocity and the error estimate on the cross-sectional area. Total monthly error estimates on discharge measurements were then estimated for flow conditions typical of the seasonal surface water regime. When consideration was given to compensating error effects, the most probable error associated with hydrometric measurements when expressed in terms relative to the total flow was around 2.0% in the wet season and about 4.0% in the dry season. It must be noted that the error estimate on the accuracy of the discharge rating curve was excluded from this analysis.

Reliability of Historical Well Test Data

The first conclusion that may be drawn after review of historical well test data is that the Manager (C.N.A-Oaxaca Head management office) has a good understanding of well development and takes great care in maintaining well test records. Only two records were entered with an obvious typing mistake and very few outlier measurements were encountered in the analysis. The well test data can be classified as reliable.

Equally apparent is the fact that all well tests are **Single Well Tests.** Numerous water table readings were taken during pumping and during recovery but all readings were taken from the well being pumped.

The cost for drilling an observation well and a shortage of equipment are probably the reasons for the Manager to take this decision path. If determination of the true nature of the aquifer seems to be secondary to the Manager, it is clear however that for him the evaluation of well characteristics is essential.

Steady-state conditions

From this research conclusion can also be made that exploration well tests conducted in the Tlacolula basin never reached steady-state conditions but they usually approached the pseudo-steady state by the end of the step-drawdown test. In many intermediate steps pumping was not maintained long enough to approach Jacob's straight line conditions.

Full penetration is usually achieved

The review of the 25 documented reports of exploration wells drilled in the research area shows a clear concern for the driller to reach the aquitard [1]. Exceptions were made for the following specific reasons:

1. The exploration wells POMB-71, POMB-72 and POMB-73 dug at Tanivet where exploration of the top unconfined aquifer was the main concern.
2. The well drilled near Tlacochahuaya may be a possible case of partial penetration depending on the extent of fractures in the Rhyolite. In San Mateo Macuixochitl the low yield suggests that the limestone was not fractured and full penetration was therefore achieved.
3. The well drilled at Diaz Ordaz may also be of partial penetration but the well profile of similar formation at 5.4 km south of this location indicates that drilling at Diaz Ordaz was stopped only a few meters before reaching the aquitard.
4. The aquitard was definitely not reached in the 101 meters drilling of the volcanic formation encountered in Santa Cruz Papalutla. The profile exposed in the 172metres drilling at 650 meters from there confirms the presence of claystone beginning thirty meters deeper than the bottom of the 101 meters deep drilling in

[1] A geologic formation of rather impervious nature which transmits water at a very slow rate compared to an aquifer is called an "aquitard".

Santa Cruz Papalutla. These wells were therefore assumed to be fully penetrating. that is with at least 85% penetration.

The types of Well Tests and Details of Well Development

The following standard tests were noted : the regular drawdown test where the discharge is maintained constant; the variable discharge test; the step drawdown test and the full recovery test. Since 1980 a common practice has taken place. the development of the well is followed by a controlled recovery period rather than by a total shut off of the pump.

Limits of application of Rorabaugh 's (1953) method

Rorabaugh's method could not be used to quantify the exact contribution of non-linear losses because of the low increments of the flow rate from one step to another which do not allow a clear differentiation of each step on a log-log scale of the discharge versus the drawdown.

Recovery tests

Recovery tests were analyzed using the Theis (1935)'s method applicable for late-time recovery data of wells pumping an unconfined aquifer. The residual drawdowns were found to fall on a straight line in the semi-log of the residual drawdown versus versus t/t'.

Typical Drawdown Curve observed

The early-time drawdowns plot as a unit-slope straight line was found to be a convenient tool for determining the time period of significant well bore storage effect. In the typical volcanic formation of Santa Cruz Papalutla, the well bore storage effect dissipates after two minutes.

At the end of the well bore storage effect. the Theis-type straight line was found to fit this early drawdown data for 30 minutes after which time the drawdown response became relatively flat. This period was identified as an intermediate zone between the two Theis typical curves of the early and late pumping time of an unconfined aquifer. Pumping was often stopped prior to reaching the late Theis-type drawdown response.

A common practice since 1980 consists in bringing the well discharge down in steps after completion of its development. This well development technique was investigated in this research

The practice of well development followed by a controlled recovery period

It may be concluded that this type of well development adds difficulties to analysis of the single well test data since the discharge is measured only after well development. Drawdown and discharge data show that this long (50 hours and more) and smooth development of the well followed by a period of partial recovery where the pump discharge is brought down in two hours steps, is an effective tool for building a stable and reliable aquifer-well system. A significant linear correlation (R^2>0.95) between the measurements of the discharge and the drawdowns from the pumped well during the controlled well recovery period was noted. The drawdown curve for the typical well in Tlacochahuaya shows consistency in the aquifer response even hours prior to full stabilization of the gravel-soil matrix. For the last seven hours of the 62 hours period of pumping that preceded the controlled recovery period, the water was clear and the discharge and the drawdown were relatively constant. Conclusion was made that the aquifer-well system had then approached a quasi steady-state.

The fact that no flow measurement was taken prior to well development adds a significant weight of uncertainty in either the application of Boulton's method or in the application of the principle of superposition for the controlled recovery period.

Description of the proposed method of analysis

The response of the controlled recovery of the unconfined aquifer system in quasi-steady state discharge and drawdown conditions is simulated as an equivalent confined aquifer-well response subject to a step pumping test. Recall is made that a step-drawdown test is a single-well test in which the well is pumped at a low constant discharge rate until the drawdown within the well stabilizes. The pumping rate is then increased to a higher constant-discharge rate and the well is pumped until the drawdown stabilizes again. This process is repeated at least three steps, which should all be of equal duration.

The time for the simulated pumping test to reach the quasi-steady state discharge and drawdown conditions prevailing at the end of the controlled recovery period, is unknown. It is reasonable to assume that the time-drawdown response reflects specifically the aquifer parameters. The pumping time for the drawdown to reach the first step in the image step drawdown test (or the last step of the partial recovery period) is found by trial and adjustment in the following manner.

To each starting time corresponds a specific linear regression fit between the log (s_{corr} / Q) and log (t / r^2) and therefore a pair of T and S [2] values. The resulting family of possible T (transmissivity) and S (specific yield) values takes a parabolic shape. The vertex of this parabola is the point of a unique solution that is where for a given specific yield, T the transmissivity has a unique value. This is the solution of our problem .

The vertex of this parabola also corresponds to the maximum S value. It is reasonable to hypothesize that depending on how long the pumping period was and how close the steady state was approached, the corresponding S value found by this method will approach or not the delayed specific yield. Application of the proposed method of analysis demands adjustments of the drawdown measurements for vertical seepage inside the well. Seepage was accounted for by using Boulton (1954) method of analysis for transient flow in unconfined aquifers and by using the linear correlation between the drawdowns and the discharge. A seepage of (12%) was found in the case of the well drilled in Rojas de Cuahautémoc and 36% in the case of the well drilled in Tlacochahuaya.

Jacob's [3] correction was also applied to compensate for the variation of the saturated thickness in this unconfined aquifer.

Using the proposed method for analyzing the single well test data, corresponding to the controlled recovery period, of the well developed at Rojas de Cuahautémoc, a transmissivity of 52.5 m^2/d and a specific yield of 0.17 were found.

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[2] Capital S is used for Specific yield , small s is used for drawdown.

The same single well test data of the controlled recovery period were also analyzed as a partial recovery test using the principle of superposition. By this method, the transmissivity was estimated to be in the range of 35 to 40 m^2/d for a value of specific yield most likely in the range of 0.10 to 0.20.

The hydrogeologic units

The following hydrogeologic units could be reconciled from GEOCA(1980) and TACSA (1983) :

1. **Alluvium of the Quaternary.** The alluvium of 30 to 40 meters thickness is composed of sand, gravels and silt of good relatively permeability and covers the low areas of the valley. Exploration Wells that were drilled gave yields of 9.8 to 31.1 lps for 24 hours pumping and 13.0 to 82.0 lps for 3 hours pumping.
2. **Extrusive Rocks of the Middle Tertiary age are** composed of volcanic rocks, of rhyolitic, andesitic constitution. Also common are corresponding tuffs of either constitution and tuff-breccias where fragments of boulder to gravel size can be found. Wells perforated give a yield 5.0 to 11.0 lps for 24 hours pumping..
3. **Salty Clays of the Early Tertiary age (Terciario Inferior)** . These sediments do not crop out in the research area but were encountered during exploration of the well Yagul 1. They seem to have deposited in clay sequence of about 100 m thickness. These clays show practically no permeability .
4. **Margas Tanivet.** Composed of sediments formed during the precipitation of the $CaCO_3$ deposited on the Clay (about 50% clay 50 % $CaCO_3$). The permeability is generally low. When these sediments are well cemented they are practically impermeable. This formation could be found in the research area between the localities of Matatlan and Tanivet.
5. **Early Cretaceous age.** Composed of alternating layers of sandstone , shale and limestone. Sandstone layers are of fine texture and vary from 10 to 30

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[3] Jacob (1944) proposed the following correction $s_{corr} = s - (s^2/2D)$ where " s " is the measured drawdown and D is the saturated thickness of aquifer material.

centimeters. The limestone of light grey color with layers from 20 to 40 centimeters thick is not cavernous. The claystone is plastic of grey color. Due to the presence of shale the claystone usually behaves as impervious bodies. POTB-66 Well yielded 4.0 lps and POAB-59 gave a yield of 6.8 lps.

6. **Precambrian Rock.** Formation of rocks that went under a high grade of metamorphism and composed mainly of gneisses of brown color. Due to their high density these rock behave as a highly compact material and therefore may be considered as impervious.
7. **Limestone from the Middle Cretaceous age**. Limestone of beige color, and fine texture that may be seen as outcrops at the exit of the valley.

The geologic profile of Tanivet

The stratigraphy has not been established because of no continuous stratigraphic sequence. Only one tentative profile was discussed from which was concluded the following.

The sedimentary column in the valley is variable. Its thickness is approximately 1350 meters. In some location a volcanic formation about 250 meters thick of rhyolitic nature and the Quaternary alluvium of approximately 40 meters thickness cover the sedimentary column and the resulting geologic section from Jurassic until today measures approximately (1350+250+40) 1640 meters. Below the extrusive rocks of the Tertiary, we find clay sediments which contain a large quantity of salt (the result of evaporites) . These sediments have a thickness exceeding 150 meters and reach a depth of 300 meters below surface. The layer below these lacustrine sediments shows sedimentary rocks of the Cretaceous Superior (Margas Tanivet, soft calcareous rock sometimes siliceous, a mixture of clay and limestone) of the Cretaceous Middle (Mountain of San Antonio de la Cal) of the Cretaceous Inferior in Teitipac and rocks of the Jurassic in San Pablo Etla and Santa Lucia del Camino.

Three aquifers were identified

The local exploration of 1979 by C.N.A geologists allows to identify the presence of three aquifers.

1. The top aquifer is phreatic. At this location the water is fresh but with bacteriological contamination from domestic wastes and/or animals. The piezometric level is 9.03m.
2. The second aquifer has also fresh water but does not suffer bacteriological contamination . This intermediate aquifer is confined and has a piezometric level of 9.77m.
3. The deep artesian aquifer has a piezometric level of 12.35m and is highly saline. This water is primarily of sodium-carbonate nature and corresponds to water that was trapped and remained in permanent contact with evaporitic sediments located under the volcanic cover.

The sodium chloride originates from the evaporites of the Tertiary formation. These clay marine sediments form a layer that ranges from 150m to 300m thick covered by the extrusive rocks of the Tertiary era. The well POB-1 shows that these marine sediments are encountered at about 300m below ground level in the Tanivet area. The CO_2 and calcium carbonates are the end products of the weathering of the limestone of the Middle Cretaceous sediments. TACSA (1983) is of the opinion that the large flow of the artesian well may be attributed to secondary solution openings in the limestone that somehow reach the geologic fault of Tanivet from where a lateral connection to the artesian well has probably developed through the pseudo-stratification and fracturation of the volcanic formation of rhyolitic material.

This aquifer is also characterized by the presence of CO_2 which may have been produced by friction of calcareous bodies during the process of spreading or formation of the geologic faults induced by tectonic movements that are frequent in this area.

Groundwater Quality Monitoring

The chemical analysis from the fifty three wells sampled in 1979 and from the thirty one wells sampled in 1994 was mapped on two different image layers. That way each chemical survey can be displayed separately on the topographic base map and can still be combined by overlaying their corresponding layers. New surveys will be added

as new layers and the topographic base map will remain the common registration point network.

In 1979 survey , 64% of the samples were found to be of low or medium salinity level and 36% of the samples were found to be of high or very high salinity level. In 1979 survey, 9% of the samples were found having a high or very high sodium hazard. In 1994, 37% of the samples were of medium salinity level and 63% were of high or very high salinity level. In 1994, 12% of samples were found having a high or very high sodium hazard.

Calcium

In the research area calcium comes from the dissolution of calcareous rocks and from the calcitic feldspars. This element was found in groundwater samples collected in 1994 at concentration from 0.023 to 0.178 kg/m^3 with an average of 0.070 kg/m^3 and a Coefficient of Variation (CV) of 55%. GEOCA's (1979) survey found concentrations of Calcium within the research area in the same range that is an average of 0.092 kg/m^3 with a CV of 77%.

Sodium

Within the research area, igneous rocks are composed of sodic feldspars which once weathered by water may detach to join the sodium ion in solution. They are found also in evaporites sediments that can be easily dissolved. Sodium element was found in groundwater in 1994 from zero concentration to a maximum concentration of 1.488kg/m^3 with an average of 0.255 kg/m^3 and a CV of 139%. GEOCA's (1979) survey shows an average concentration of Sodium of 0.123 kg/m^3 with a coefficient of variation CV of 246%.

Given the small sample size and the large coefficient of variation in the concentration of sodium, caution is recommended in their interpretation. The information gathered from these surveys indicates however the potential for an increase sodicity hazard in specific areas which emphasizes the importance in monitoring the quality of the groundwater (in particular the sodium content and total salinity) as the irrigation development is undertaken.

CHAPTER X
RECOMMENDATIONS FOR FURTHER RESEARCH.

Introduction

The optimal operation of an aquifer system linked to a river where agriculture sets the water demand, rests essentially on two systems: the ground water and the agricultural system. Two components will therefore dictate the mechanics of the model: a ground-water physical component and an Agricultural Function. This is the approach taken by Cunha et al (1993) and adopted in this research.

The focus of this research was to examine together the causes and symptoms of the technical problems concerned with the definition of the two model components. The next step is the elaboration and calibration of the model. However to make such models useful and effective, appropriate technology will need to be developed together with the identification of key parameters for evaluating the social and economic pertinence of the proposed alternatives offered to water users.

The following is a discussion on those elements of investigation where further research is highly recommended in light of the findings of this research work.

Research On Methods Of Financing Manager's Costs

The following levels of action have been recognized as necessary to allow a better recovering of CNA costs and to reverse the tendency for a greater participation of the tax resources to increase and improve services of irrigation, potable water and municipal water systems. Those are:

- The increase of the tributary base of the various users of water.
- The application of the new legislation (Ley de Aguas Nacionales),
- The realization and actualization of the contributing Water Users Associations,
- The implementation of a consumptive use permitting process and a water fee collection system based on actual costs incurred by the CNA in the management of the water resources.

Auto financing is seen by the Authorities as a matter of crucial importance because hydraulic works have been financed primarily by fiscal revenues (80% in the period 1980-1990)[1] making the hydraulic development of the state extremely vulnerable. The difficulties in the public finances in the last decade have transpired directly on the moneys allocated for the development of the hydraulic infrastructure of the state.

With largely insufficient money allocated on the maintenance of the existing water infrastructure and on the expansion of the infrastructure to allow an increase in the agricultural production, the present situation is now seen as critical.

Research work is required to examine various scenarios of financing the Manager's operations.

Research on Present changes in farming practices and their impact on Ground water depletion

Kirkby (1973) defines Oaxaca's agricultural potential, and measures the output of all known Valley Zapotec farming techniques. Kirkby (1973) has brought strong historical evidence that a maximization of the agro-production has never been until now an important goal for this farming community.

Rather than resorting to environmental imperatives, **Kirby (1973) concludes that Oaxacan villages has probably always been under-productive for reasons** which are directly **related to the "satisfying" world view of the Valley Zapotec.**

No scientific evidence is in hand that can prove that the present agricultural development is unstainable. There are clear signs however that the production in the area of San Sebastian Abasolo, Tlacochahuaya, and San Francisco Lachigolo is aimed at maximizing its returns.

In 1991, SARH estimated that 132 607 hectares were under cultivation in the central valleys of Oaxaca. The area under irrigation is then approximately 9000 hectares. **Corn**[2] and beans were cultivated in 90% of this area. The impact of irrigation

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[1] From C.N.A. 1992. Programa Estatal de Aprovechamiento del Agua. P71

[2] Corn is used to designate corn varietes grown in the research area and for which a detailed description is given in the Glossary.

is obvious when we consider that the average yields obtained in the central valleys are 800 kilograms/hectare for corn and 400 kilograms/hectare for beans when no irrigation water is applied. With irrigation, these yields are more than doubled; 2000 kg/ha for corn and 1000 kg/ha for beans. Alfalfa has also been found to be a very lucrative crop when irrigated.

Irrigation is very demanding. In Tlacochahuaya for instance, corn in the summer requires an average of 120 mm of irrigation depth to supplement rainfall. Whereas in winter irrigation requirements are doubled due to lack of rain. Producing alfalfa all year round requires over 1000 mm of water. Peas is probably the least demanding for water among winter crops with a need of about 140 mm of supplementary irrigation.

Ignoring the social development inputs required for the implementation of long term water management strategies is a guarantee for failure. Communally managed systems require a social contract based on mutually acceptable and reciprocal responsibilities between the water agency and the beneficiaries. Research is required to examine the present variability among farming practices and their relative impact on groundwater depletion. The basic question as what should be a fair water fee can be best answered in the context of a research project to prevent any bias in the process.

Continuous Monitoring to establish the Long Term relationship between minimum water levels

In this zone of deficient precipitation, ground water is discharged primarily by summer-autumn evaporation and run-off. Thus, the water table usually declines to a minimum level in spring and reaches a maximum at the end of the summer, (end of rainy season) .

The features of the ground-water régime that change over a long-term period are of scientific and practical interest. A direct relation can be drawn between the long-term maximum water levels in the spring and the long-term average annual water levels, i.e the greater the spring maximum the higher the average water level.

This relation according to Boonstra and de Ridder (1990) allows some judgement concerning the average annual water level if the value of the spring

maximum is known. For a number of regions a sufficiently accurate relationship between minimum water levels (spring and autumn-winter, respectively) can be established. This demands continuous monitoring of the water table.

Should there be seasonal pumping of ground water in a region, the foregoing relationship can be drawn only to the accuracy with which the potential withdrawals can be projected.

Seismic Surveys

Monitoring permeabilities directly on the entire flow domain is not feasible. Copty et al (1993) have proposed the use of seismic-data, the velocity-permeability pressure relationship to update through a Bayesian method, the image of the permeability field. The resolution and accuracy of seismic surveys are relatively high according to Zodhy et al (1974, as reported by Copty et al , 1993).

Research to establish correlation between seismic data and hydrological properties of the subsurface is recommended.

The use of seismic surveys was envisaged at the beginning of this research but due to financial constraints, this avenue was abandoned. A Canadian engineering firm with this expertise may be approached for mutual benefits.

Research on Furrow irrigation

No infiltration test has ever been conducted in the research area and this parameter is crucial for the surface irrigation practiced in the Central Valleys.

This irrigation practice is common for cash crops and farmers are particularly skillful in controlling the front advancing time with their planting pace. This is illustrated on Plate 1(p403) where two farmers from San Sebastian Abasolo are planting some garlic while controlling the first irrigation run. This type of irrigation is less efficient than pot irrigation but no field data specific to the soil conditions of the area could be found. Research on furrow irrigation is urgently needed. Merriam and Keller (1978 as reported by Walker, W.R. 1989, FAO-45) have established the procedure and tested the equipment and supplies required for Furrow Irrigation Evaluation procedure.

Research on Climatic trends versus Corn Production

Kirkby (1973) found a significant correlation between corn yield and water consumption. This confirmed Kikrby's analyses of variance in which of the many factors involved, the prime determinant for corn yield in the Central Valleys of Oaxaca, was the availability and hence consumption of water.

In the Tlacolula area, rainfall is so low that even some flood water-farmed land can produce corn with yield of only 0,2 - to 0,4 metric tons per hectare. Given the highly significant negative correlation between the minimum temperature and rainfall and given that a significant increase in the average monthly minimum temperature was observed from 1950-1980, it becomes important to assess whether this temperature trend is still prevailing, or not, and to examine its impact on agricultural production. Corn is the recommended crop to be investigated.

Need For Further Research In Liasoning With Users Of Groundwater Water For Irrigation.

The operation of the irrigation wells of the valley does not show the same transparency as does the operation of the municipal wells of San Sebastian Abasolo, Lachigolo or Tlalixtac de Cabrera.

Most of information on existing irrigation infrastructure in the valley is somehow difficult of access [3] but available. The annual report on the agricultural activities of irrigation units can be tracked down but the operation of the infrastructure itself is less documented.

In the case of operation of irrigation wells, this responsibility rests with Well Committees. These committees are democratic and generally run by farmers who are reluctant to paperwork. Expenditures for well maintenance and payment of electricity bills are normally documented. To know the total hours of pumping so as to estimate total abstraction, an estimate based on the consumption of energy would be more

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[3] Without the assistance of C.N.A, the access to this information would have been impossible. C.N.A. does not have yet a centralized bank of data and the information is kept by various agencies but C.N.A has legal authority and uses it effectively.

instructive at this moment than a survey conducted directly on the population or on the Well Committees.

By law everyone must give access to the C.N.A officers but given the general belief that all groundwater flow studies including the present one will necessarily result in an increase of water fees and a loss of control on the operations of the wells, no much contribution can be expected from the Well Committees. A climate of trust must be recovered between the users and the Water Authority or serious liaison difficulties are to be expected.

These difficulties were encountered in the frame of this research. In order to draw an inventory of all existing wells in the Central Valleys of Oaxaca, an interesting project was set up with the C.N.A at the inception of this research. The inventory was to be conducted by students of the secondary level who were going to be credited for their social service provided to the local community.

A very positive response was obtained from the school directors and the student committees. When the project was brought to the farming community for elaborating a strategy of implementation, a strong opposition came from farmers. No scientific survey was conducted to identify the opponents but the belief that water abusers and squatters are the key persons who are opposing implementation of a closer vigilance of the water resources of the Valley finds a popular support.

Research on the social impact of a closer vigilance of water resources

The media has far more than its due share of impact on the present management practices in Oaxaca. The media in Oaxaca set the agenda for the government action. Table 1 shows that pressure applied by the Media on C.N.A reached its peak in 1994 shortly after the first rains. The reason lies not only in the water infrastructure deficiencies but in the nature of the climate. Less than four weeks before the floods of June 8 1994, the Press was reporting severe water shortage for 47 500 residences.

Wolf (1966) has argued that it is not simply the existence of potential surpluses or shortages that stimulates development but also the presence of institutional means and imperatives within the organizational structure of society to mobilize them.

This according to Kirkby (1973) holds important implications as to how cultural development has proceeded in the past, how far resources are exploited today, and how far planned agricultural and economic development can succeed in the future if it is not accompanied or preceded by fundamental changes in society.

It is concluded that further research must be undertaken on the socio-anthropological impact of implementing a closer vigilance of the water resources. The work by Kowalewski et al (1989) on Prehispanic Settlement Patterns in Tlacolula, Etla, and Ocotlan and Lees' (1973) research on Socio-political aspects of Canal irrigation in the Valley of Oaxaca, Mexico will be the starting point for this research .

Research on manager - computer interaction in managing water resources for agricultural production .

In Appendix AD, software difficulties encountered in this research are presented under a classification based on the nature of their difficulties.

Even if these difficulties are not related to errors that are likely to occur in establishing a base mapping system and in that sense they do not affect the accuracy of the system, they do reflect however, computer problems that are bound to be faced in water management and which can not be neglected. These problems change continuously and solutions are found. It is probable however that new problems of the same nature will replace old ones.

Research is needed to investigate possible solution paths to handle these problems in a systematic manner so as to be able to account for them at all stages of a research project. Research on manager - computer interaction in managing water resources for agricultural production is needed.

Research on the proposed method of analysis for solving the single well test when development is followed by declining Q

Given the relatively high cost for drilling observation wells, it is recommended to investigate single well tests and well development procedures that are compatible with the range of pumping normally encountered in irrigation. This research should aim at some tangible recommendations for well development procedures that would ensure predictability in hydraulic flow conditions in the well and allow application of

single well test data obtained in constructed well-aquifer system. The method of analysis that is proposed in Figure 22 of Chapter V for analyzing **single well test data where development is followed by declining Q** is an interesting avenue since the well development procedure then assumed is a practice already implemented by the manager. Long time pumping tests shall also be part of the research porposal.

TABLE 1 The MEDIA SET UP MANAGGER's AGENDA.
Example. Rainy Season 1994.

Spanish Title	Newspaper	Date
Afecta estío 130 colonias. **Escasez de agua en las 47mil 500 tomas domiciliarias.** Cobros indebidos y mal servicio de Adosapaco: Profeco.. Los cortes, posible violación a derechos humanos: CEDH.. Detectan restos de heces fecales en agua purificada	NOTICIAS	May 9, 1994
El Atoyac, el río más contaminado del mundo.	EL EXTRA	June 8, 1994
Tratamos nuestras aguas residuales: IMSS. **Reconoce que es incongruente que sean las instituciones de salud las que también contaminen los arroyas y ríos de la ciudad de Oaxaca.**	EL EXTRA	June 8, 1994
Las alcantarillas de la ciudad resultaron insufficientes	Diario Noticias	June 8, 1994
Más agua para la ciudad. ADOSAPACO, el I.T.O , la C.N.A. y el Ayuntamiento citadino firman acuerdo de colaboración de pozos profundo para abastecer del vital líquido a la ciudad de Oaxaca. Ante la severa temporada de estiaje de 1994...	El Imparcial	June 10, 1994
12 casos de cólera en Oaxaca. Se pretende beneficiar a más de 14000 habitantes.	El Imparcial	June 10, 1994
Acciones inmediatas se implementaron en Matatlán. **El desbordamiento del río afectó a una decena de casas..** Se sará orientación sobre el funcionamiento de letrinas y la cloración de pozos como una medida para evitar el brote de enfermedades diarreicas.	EL EXTRA	June 15, 1994

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GLOSSARY

ACCURACY

Accuracy is measured indirectly by using reference materials. It is the degree of agreement between the measured value and the true value. Accuracy is an expression of the amount of bias in the data. Wilson (1995.)

AQUIFER, AQUITARD. AQUICLUDE.

An **aquifer** is a saturated bed, formation , or group of formations which yields water in sufficient quantity to be a source of supply. An aquifer serves as a transmission conduit and storage. Todd (1959) traces the term aquifer to its latin origin: aqui comes from aqua, meaning water, and -fer, from ferre, to bear.

An **aquitard** is a saturated bed, formation, or group of formations which yields an appreciable quantities of water to drains, well, springs, and seeps compared to an aquifer **but** through which **appreciable leakage** of water is possible.

An **aquiclude** is a saturated bed, formation, or group of formations which yields **inappreciable quantities** of water to drains, wells, springs, and seeps and through which there is an appreciable movement of water reservoir.

AQUIFER. ARTESIAN

An **artesian aquifer** is one in which groundwater is confined under pressure by overlying and underlying aquitards and water levels in wells rise above the top of the aquifer. Artesian aquifers are classified as leaky or nonleaky depending upon whether groundwater in the aquifer is confined by aquitards or aquicludes.

Piezometric surface.

The imaginary surface to which water rises in wells tapping artesian aquifers is called the piezometric surface. An artesian aquifer becomes an unconfined aquifer when the piezometric surface declines below the top of the aquifer.

AQUIFER. UNCONFINED

An **unconfined aquifer** is one in which groundwater possesses a free surface open to the atmosphere. The upper surface of the zone of saturation is called the watertable or the nappe.

COEFFICIENT OF STORAGE.

The **coefficient of storage** of an aquifer is the volume of water the aquifer releases from, or takes into, a storage per unit area of the aquifer per unit decline or rise of head. Under water-table conditions, the coefficient of storage is equal to the specific yield, provided gravity drainage is complete. The coefficient of storage of

water-table aquifers ranges from about 0.02 to 0.30. The storage of artesian aquifers may range from about 0.00001 to 0.001. (Walton, 1970)

COMPARABILITY

is the ability to compare one data set, measuring system or piece of equipment with another. Data should be comparable from site to site. Wilson (1995)

COMPLETENESS

is the amount of valid data obtained for a measurement, compared to the expected amount of data required for the measurement. Completeness expresses the fraction of measurements that area not identified as "outlyers"

$$\% \text{ Complete} = \frac{\text{Number of valid data points}}{\text{Total number of data points from collected samples.}} \times 100$$

CORN.

Corn is an important food and fodder crop in the study area. The common name, corn, is used in the thesis text rather than botanical names.

Kirby (1973) classifies corn grown in the Valley of Oaxaca[1] Oaxaca into four main groups: 3 month (violento) indian corn, 4 to 5 month (tardon) indian corn, 6-month cajeta Indian corn and 6-month hybrid varieties.

The short growing season of the 3 month corn is advantageous in dry conditions where the danger from drought is increased rather than decreased by a longer time in the ground and in areas where all-year-round cropping is possible. Its disadvantage is its low yield compared to tardon and hybrid varieties when moisture conditions are good. Conversely, **tardon corn's** higher yields under good connditions are offset by greater risk of failure when conditions are less favourable, and by the longer time it occupies the ground when the two or three crops per year are grown.

Cajeta corn has a longer growing season and is adapted to colder conditions so that in the Oaxaca Valley it is found only high up the mountains. Kirby (1973) adds that hybrid varities of corn have the advantage of much higher yields if moisture and mineral conditions are favourable, but they require more water and fertilizer than are generally available, and without these, yields may fall below those of the indian corns.

[1] Here the three valleys around Oaxaca de Juarez are seen as the one Valley of Oaxaca with three sub-basins, Etla Tlacolula and Zimatlan. To designate the same Valley , the name of Central Valleys of Oaxaca or " Valles Centrales " is used commonly by the manager. C.N.A.

Furthermore, hybrid corn is sterile and new seed must be brought each year, whereas the indian varieties can be sown from seeds from the previous year's harvest.

Within the alluvium and piedmont zones of the Valley, the choice of type for most farmers is between the violento and tardon varieties. In fields with similar moisture conditions and similar yields, density of maiz plants from 30,000 to 80,000 plants per hectare has been measured by Kirby (1973).

Cultivators see their alternative strategies in the following terms:
High plant densities are preferred in fields with optimum moisture conditions to get the maximum possible yield of cobs. As moisture becomes less favourable, optimum plant density decreases.

Kirby (1973) found that in the sample of 166 milpas there was slight, although not significant trend to increasing plant density with increasing yield which reflects better moisture conditions.

The data show that in a wet year little distinction is made in plant density between the milpas on the high alluvium and those with optimum average moisture conditions (high water table), but a relatively larger proportion of seed is expended in the piedmont.

DEPOSITS. UNCONSOLIDATED

Unconsolidated deposits of sand and gravel are the most important aquifers. The types of occurrence of these aquifers may be grouped as: watercourses. abandoned or buried valleys, plains and intermontane valleys.

Watercourses

Watercourses consist of a stream channel together with the groundwater in alluvium that underlies the channel and forms the bordering flood plains. Wells in watercourses are readily recharged by infiltration of water in the steam channel.

Plains

Stream-deposited sand and gravel occur beneath the plains in broad belts. Sand and gravel underlie parts of Coastal Plains where formation are partly marine and partly fluviate in origin. Aquifers of plains are recharged directly from precipitation and from streams. Many stratigraphic units along Coastal Plains grade oceanward from partly alluvial deposits into entirely marine units. This gradation is accompanied by a tendency for the sediments to become progressively finer grained. The bulk of the sediments are clays and silts. (Walton, 1970)

Intermontane Valleys.

In basins bordered by mountains ranges occur huge volumes of unconsolidated deposits including sand and gravel. There is some recharge directly from precipitation, but generally most recharge is by seepage from streams into the alluvial fans lying between the base of mountains and the basin floors)Walton, 1970). Subsurface flow through the walls of the mountains into intermontane valley deposits is also appreciable. The storage of these aquifers is very large in comparison to annual recharge in the arid regions.

DEPOSITS. EOLIAN

Eolian deposits (formed by the wind) are far less abundant than either stream or glacial deposits. Eolian deposits can be divided into two types, loess and dune sand. Loess is not commonly an aquifer because of its low permeability and because where its permeability is the highest it is usually in high topographic positions where subsurface drainage is efficient.

DUPLICATE SAMPLES:

Duplicate samples are samples taken from the same monitoring point, one immediately after the other, using the sample equipment. One duplicate sample per day should be considered the minimum. Wilson (1995)

ELECTRICAL CONDUCTIVITY:

The reciprocal of electrical resistivity. The resistivity is the resistance in ohms of a conductor, metallic or electronic, which is one centimeter long and has a cross-sectional area of 1 cm^2. Hence, eletrical connductivity is expressed in reciprocal ohms per centimeter, or mhos per centimeter. (U.S. Salinity Lab. Staff, 1954) .

EQUIVALENT; EQUIVALENT WEIGHT

The weight in grams of an ion or compound that combines with or replaces 1 gram of hydrogen. The atomic weight or formula weight divided by its valence. (U.S. Salinity Lab. Staff, 1954.)

FACIES

The change in the "look" or aspect of the sediments is called a change in sedimentary facies. Facies are identifiable parts of different nature belonging to any genetically related body or system. (Anderson and Woessner, 1992).

GRAVITY YIELD

Gravity yield is the percentage of the total volume of rock occupied by groundwater that will drain under the action of gravity during a given period of drainage.

GYPSUM

A mineral and a rock composed essentially of hydrous calcium sulfate, in the crystalline state $Ca\ SO_4 - 2\ H_2O$. Density 2.3. Soft , can be scratched with the finger-nail, water-soluble. (Plaisance, G. and A. Cailleux. 1981). Gypsum is sufficiently soluble to develop a high permeability. Water which is hard and high in sulphate is often pumped from gypsum..

IGNEOUS ROCKS

Beside the sedimentary and metamorphic rocks, a third great family of rocks usually contains visible grains, often larger than the grains in most sedimentary rocks. But the rocks of this third group occurred in unusual forms. These rocks have once been melted, and have then moved as molten liquids. After cooling and solidifying they form igneous rocks. These rocks are therefore solidified from a melt.

INTERSTICES, SUBSURFACE AND GROUNDWATER

Most rocks contain open space, called interstices, in which water may be stored and through which water can move. Water that exists in the interstices of rocks is called **subsurface water.** (Meinzer 1959); that part of subsurface water in interstices completely saturated with water is called **groundwater.** In drainage of agricultural lands the term groundwater is sometimes used to denote the water in the partially saturated layers above the water table.

Subsurface water in interstices above the zone of saturation in the zone of aeration where interstices are only partially saturated with water is called **vadose water.**

INTERSTICES. ORIGINAL

The interstices of rocks may be divided into two groups, original and secondary (Meinzer,1959). Original interstices came into existence when the rocks were formed and can be subdivided into those of sedimentary origin and those of igneous origin.

INTERSTICES. SECONDARY

Secondary interstices are the result of processes by which rocks were modified after coming into existence and largely comprise joints and other fracture and solution

openings. Secondary interstices are produced mainly by shrinkage , pressure, and deformation of rocks, commonly vary in number and size.

Secondary interstices are also produced by the chemical decomposition of rocks and the solution and subsequent removal of the soluble products, or by the solution and removal of soluble rocks. The removal of the calcareous cement from the original interstices of a sandstone or the removal of soluble material such as limestone results in abundant secondary opening in many areas.

LIMESTONES AND DOLOMITES

Limestones and dolomites, vary widely in permeability. The most important aquifers are those in which secondary solution opening occur. In regions where limestone forms the land surface and extends to considerable depth, groundwater dissolves the rock and waters are hard because of dissolved mineral matter.

METAMORPHIC ROCKS

Deeper burial would subject the rock to such high temperatures and pressures that the obvious marks of a sedimentary origin would be lost. These rocks that have changed their form in response to high pressure or high temperature are called metamorphic rocks.

MILLIEQUIVALENT

One thousandth of an equivalent.

MILLIEQUIVALENT PER LITER

A milliequivalent of an ion or a compound in 1 liter of solution.

PERMEABILITY.

Permeability is a measure of the ease of movement of groundwater through aquifers and aquitards. The field coefficient of permeability of an aquifer, P, is the rate of flow of water, in cubic meters per day, through a cross-sectional area of 1 square meter of the aquifer under a hydraulic gradient of 1 meter per meter at the prevailing temperature of the water.

POROSITY

The porosity of a rock is a measure of the interstitial space of the rock and is expressed quantitatively as the percentage of the total volume of rock occupied by interstices (Meinzer, 1959).

Table 1. Representative Porosity Ranges for selected rocks (Walton, 1970)

Rocks	Porosity %
Clay	45-55
Sand	35-40
Gravel	30-40
Sand and gravel	20-35
Sandstone	10-20
Shale	1-10
Limestone	1-10

In general, a porosity greater than 20 percent is considered large, a porosity between 5 and 20 percent is considered medium and a porosity of less than 5 percent is considered small.

PRECISION

is a measure of the probability that a measurement will fall within certain confidence limits. Precision is measured by repeated analysis of the same sample and may be expressed in terms of standard deviations. Wilson (1995.)

RECHARGE

The major sources of recharge are generally direct precipitation on intake areas and/or downward percolation of stream runoff. Recharge direct from precipitation and by infiltration of surface water involves the vertical downward movement of groundwater under the influence of vertical head differentials. Thus, recharge involves vertical leakage of water through deposits. The quantity of vertical leakage varies from place to place and is controlled by the permeability and thickness of the deposits through which leakage occurs, the head differential between sources of water and the aquifer, and the area through which leakage occurs.

REPRESENTATIVENESS

is the degree to which data accurately and precisely represent the ground water being sampled. Representative samples statistically are a subset consisting of the average characteristics of the set. Wilson (1995.)

SANDSTONE AND CONGLOMERATE.

The porosity of sandstone and conglomerate is generally much lower than that of their equivalents, sand and gravel, because of the presence of cementing materials between grains. The interstices of quartzite generally are almost completely closed by cementation, and the rock yields water from joints or other secondary openings.

Many sandstones are only partly cemented and yield most water from the original interstices between grains and from joints. Sandstone wells seldom have yields as high as the yields in unconsolidated sand and gravel.

SEDIMENTATION. CLASTIC AND CHEMICAL

Clastic sedimentation involves the mechanical deposition of individual grains, sometimes called clasts, from the Greek klastos, meaning "broken" from some preexisting rock or mineral. **Chemical sedimentation** involves the crystallization of mineral matter from solution, by either organic or inorganic means. The two processes intermingle in varying degrees and the resulting sedimentary accumulation will include varying amounts of clastic and sedimentary materials.

SEDIMENTATION . INORGANIC CHEMICAL

The result of evaporating seawater is as follows: First we find some calcium carbonate precipitates , followed by gypsum ($CaSO_4 \times 2H_2O$), followed by halite (table salt, NaCl), followed by a large number of magnesium and potassium compounds.

The volumetrically most important sedimentary rock-forming minerals are:

1. Quartz SiO_2
2. clay anhydrous aluminium silicate
3. calcite $CaCO_3$
4. dolomite $CaMg(CO_3)_2$
5. goethite $(FeO \times OH)$
6. hematite (Fe_2O_3)
7. halite (NaCl)
8. gypsum $(CaSO_4 \times 2H_2O)$

SEDIMENTARY ROCKS.

Sands becomes sandstone, muds become mudstone, silts become siltstones, and lime sediments (made of calcium carbonate) become limestones. Compacted muds are called shales. Some geologists prefer to use shale for a mud-derived rock that splits easily along the sedimentary layers and mudstone for a massive rock that does not split

along the layering. A sedimentary rock made up of pebble-size or larger sediment is known as conglomerate. Dolomite is made up of the mineral of the same name.

The evaporites include rock salt, made up of the mineral halite, and gypsum , after the dominant mineral of the same name.

SHALE, SILT, GLACIAL TILL

Shale, silt, glacial till, weathered residual rocks, and poorly sorted alluvium often have high porosities but retain much water by molecular attraction and have a low permeability.

SPECIFIC YIELD, ADHESION vs COHESION

The attraction between the walls of interstices and the adjacent molecules of water is called **adhesion**; the attraction between adjacent molecules of water is called **cohesion**. The walls of interstices retain a film of water by adhesion and some water is retained in detached interstices.

The **specific yield** of a rock is a measure if the water-yielding capacity of the rock and is expressed quantitatively as the percentage of the total volume of water released from or added to storage in a water-table aquifer per unit (horizontal) area of aquifer and per unit decline or rise of the water table..

SPECIFIC RETENTION

The specific retention of a rock is a measure of the water-retaining capacity of the rock and is expressed quantitatively as the percentage of the total volume of rock occupied by groundwater that will be retained in interstices against the force of gravity.

The porosity of a saturated rock is equal to the sum of specific yield and the specific retention. For most rocks, gravity drainage of interstices is not instantaneous and the water-yielding capacity increases at a diminishing rate as the time of drainage increases, gradually approaching the specific yield.

SPLIT (LABORATORY) SAMPLES.

A split sample is similar to a duplicate sample except that part of a sample is analyzed by one laboratory and the other part is analyzed by a separate laboratory.

SURFACE RUNOFF AND GROUNDWATER RUNOFF

Streamflow consists of surface runoff and groundwater runoff. **Surface runoff** is precipitation that find its way into the stream channel without infiltrating into the soil. **Groundwater runoff** is precipitation that infiltrates into the soil or to the water table

and then percolates into the stream channel. Groundwater runoff includes bank storage and interflow.

TRANSMISSIBILITY. (transmissivity)

The coefficient of transmissibility T, indicates the capacity of an aquifer to transmit water through its entire thickness and is equal to the coefficient of permeability multiplied by the saturated thickness of the aquifer, in meters.

TRIP BLANKS

A trip blank is a sample filled by the analytical laboratory with reagent grade deionized water. Wilson (1995)

ZONE OF AERATION, INTERMEDIATE ZONE, CAPILLARY ZONE.

The zone of aeration is subdivided into the soil water zone, the intermediate zone, and the capillary zone. The **soil water zone** consists of soil and other materials near the surface which discharge water into the atmosphere by evapotranspiration.

The **capillary zone** extends immediately above the zone of saturation to the limit of capillary rise of water. The **intermediate zone** lies between the soilwater and capillary zones (capillary fringe).

Principal Agricultural Products Produced In The Central Valleys Of Oaxaca and Sold On Local Market (excluding cereals)

Common spanish name	Common English name	Scientific name
Manzana	Apple	Pyrus melus L.
Albaricoque (Chabacano)	Prune	Prunus armeniaca.
Chile (five common varietes)	Chile	Capsicum annum L.
Chile de agua		
Chile poblano		
Chile Jalapeño		
Chile huajillo		
Chile ancho		
Chile de la Costa Chica		Capsicum
Frijol	Bean	Phaesolus vulgaris L.
Garbanzo	Pea	Pisum sativum L.
Lechuga	Lettuce	Lactuca sativa L.
Ajo	Garlic	Allium sativum L.
Cebolla	Oinion	Allium cepa L.
Durazno	Peaches	Prunus persica.
Papa	Potatoes	Solanum tuberosum L.
Rábano	Radish	Rasphanus sativus L.



Plate 1. Well in construction and furrow system
Mitla. x =31298 y = 7126 z rim= 1673.8 z ground =1673.3m.

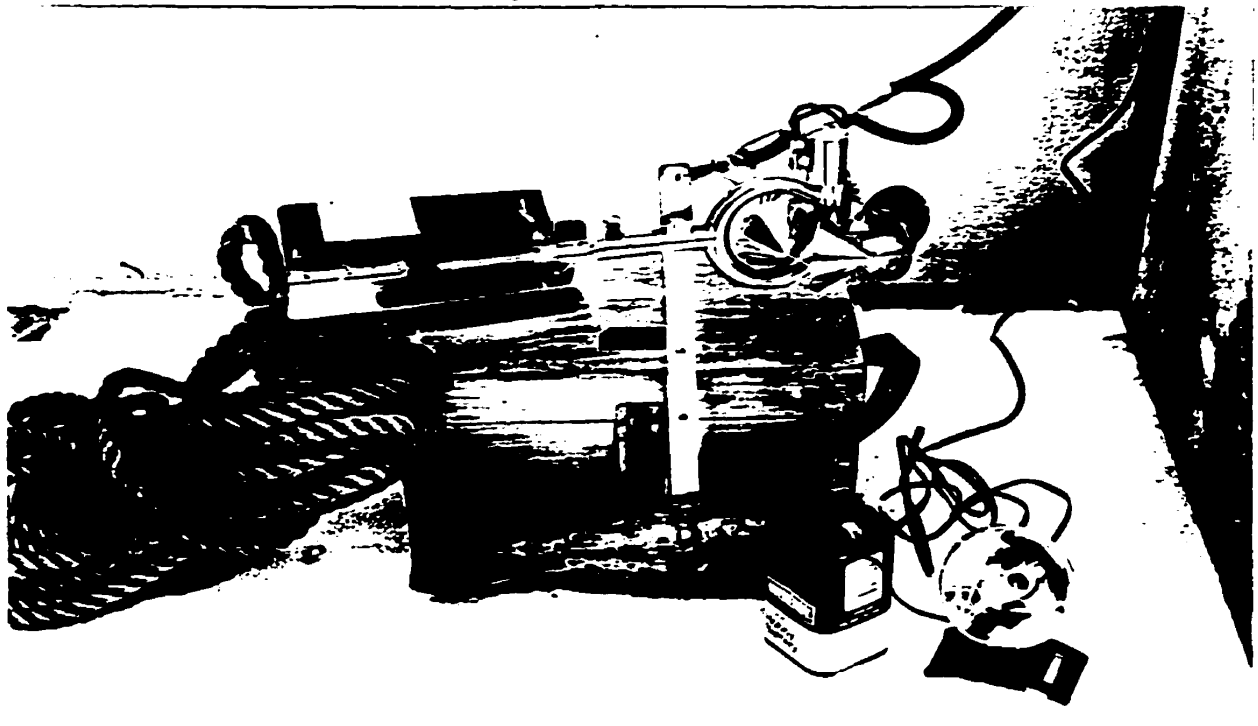


Plate 2. Molinet, type Price,. Weight for carrying the sounding-line to the bottom. Light Pulses. Nylon cable set not to get soaked.

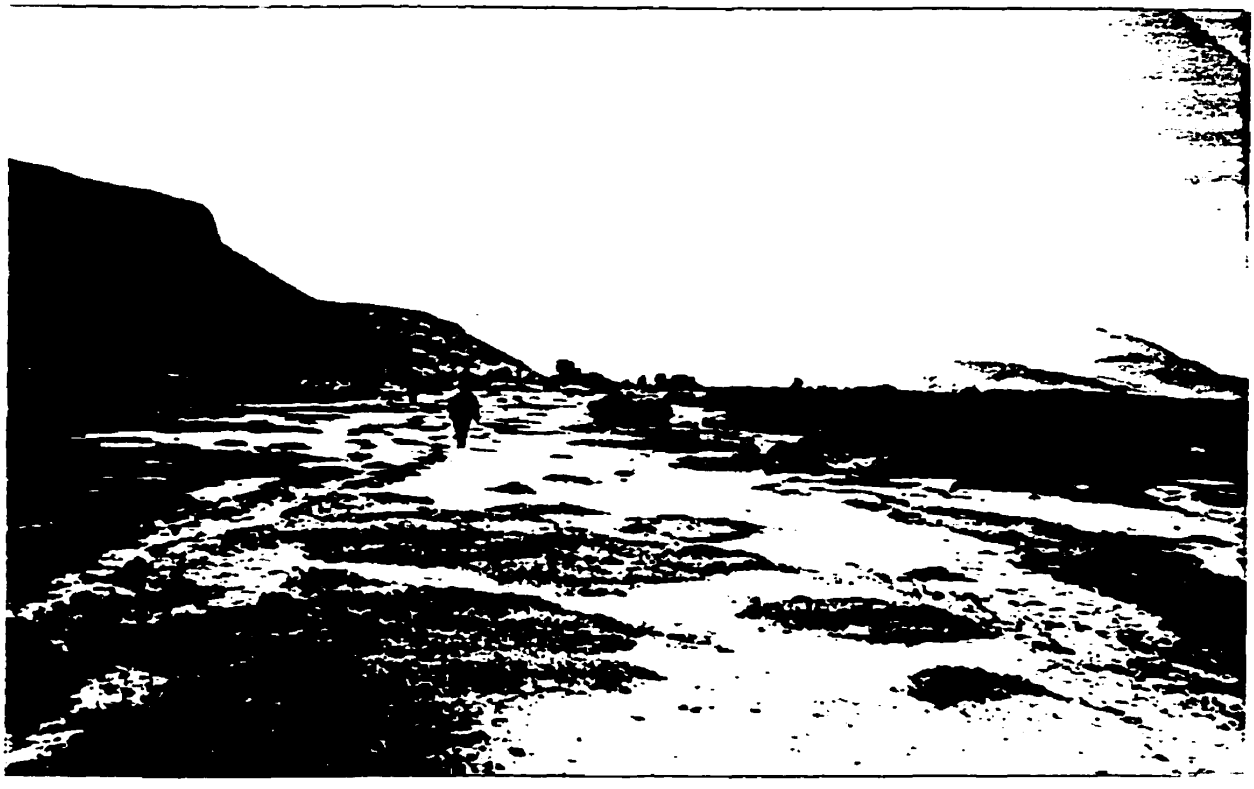


Plate 3. Salt deposit left by evaporation of the brackish water of the artesian well El Brotante in 1979. Picture taken in July 1994.



Plate 4. The planting pace is synchronized with the advance water front in the furrow. Garlic(Alium sativum L.). San Sebastian Abasolo1995

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APPENDIX A. FUNDAMENTAL DEFINITIONS

VOLUME-WEIGHT RELATIONSHIPS

If the specific gravity of the soil grains of a saturated soil specimen is assumed or determined and if the water content is known, the porosity and saturated unit weight of the soil can be calculated. This and other relationships can also be established by drawing what is called a phase diagram. See Fig A.1. In a phase diagram, each material (air, water, and solids) is completely segregated from the others. In practice this is of course impossible.

The weights are indicated on one side and the volumes on the other.The weight of air is considered zero as compared with the weights of the water and the solids. In order to determine the weight-volume relationships, the following ratios are defined:

Percent porosity; $n(\%) = (V_v/V)\times 100$ **(A.1)**

Void ratio

$$e = (V_v/V_s) \quad \textbf{(A.2)}$$

$$\textit{also} \quad n = \frac{e}{1+e} \quad \text{OR} \quad e = \frac{n}{1-n} \quad \textbf{(A.3a, A.b)}$$

where V_v = **the volume of voids (see Fig A.1)**
V_s = **the volume of solids (see Fig A.1)**
V = **the total volume (see Fig A.1)**

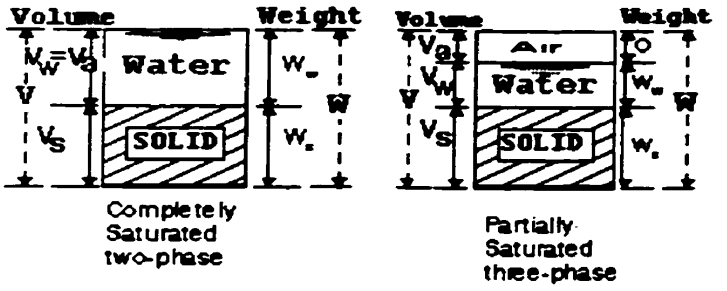


Figure A.1 Phase Diagrams for two cases of saturation

The porosity is always less than 1.0 (n (%) < 100) but the void ratio may be less, equal to, or greater than 1.0.

% water content: $w(\%) = 100 \times W_w / W_s$ **(A.4)**

% degree of saturation: $S_r(\%) = 100 \times V_w / V_v$ **(A.5)**

Bulk (mass) unit weight $\gamma_m = W/V$

When $S_r = 100\%$, the bulk unit weight is called the saturated unit weight g_{sat}. When $S_r = 0\%$, γ_m = dry weight = $W_s/V = \gamma_d$

Unit weight of the soil particles: $g_s = W_s/V_s$ **(A.7)**

Specific gravity of solid matters: $G = \gamma_s / \gamma_w = W_s/(V_s \gamma_w)$ **(A.8)**

where γ_w = the unit weight of water at 4°C.

Submerged unit weight: $g' = (\gamma_{sat} - \gamma_w) = (W - V \times \gamma_w) / V$ **(A.9)**

The Hydraulic Conductivity K And The Permeability K_p.

The constant K of proportionality between the average macroscopic velocity v and the hydraulic gradient i_g in Darcy's Law is the hydraulic conductivity, coefficient of permeability, or transmission constant. Most groundwater hydrologists and agricultural engineers prefer the term hydraulic conductivity, whereas geotechnical engineers prefer the term coefficient of permeability.

Poiseuille-Hagen's law and the factors affecting K.

K depends on properties of both the medium and the fluid. In most groundwater problems, the fluid is generally water (fresh, brackish, or salty) and the flow medium may be soil or rock or both. Poiseuille-Hagen's law for the flow of fluids through capillary tubes and the derived equation for calculating K can not be used as such because of the complexity involved in finding reasonable and acceptable values for the shape factor C_s and D_s. The equation illustrates however very clearly the factors affecting hydraulic conductivity. The derived equation is :

$$K(cm/s) = C_s \frac{\gamma_w}{\mu} \frac{e^3}{(1+e)} D_s^2 \qquad \textbf{(A.10)}$$

where
- μ = the absolute or dynamic viscosity, g×s/cm^2
- γ_w = the unit weight of water, g/cm^3
- e = the void ratio of the soil..
- n = the porosity of the soil = e / (1+e).
- C_s = a shape factor that depends on the pattern of the capillary tube system in the soil and on the tortuosity of the flow path.
- D_s = the diameter of an *ideal* flow medium which consists of spherical grains of equal size and which behaves collectively (with regard to such hydraulic characteristics as head loss) as actual soil under consideration.

It is clear from Poiseuille's equation (A.10) that K varies as the square of the average grain size. The effects of temperature and pressure changes can be also be estimated. For instance if the *soil structure of the soil medium remains unchanged,* then we get

$$K_2/K_1 = (\gamma_w/\mu)_2/(\gamma_w/\mu)_1 \qquad \textbf{(A.11)}$$

γ_w changes slightly with temperature whereas μ changes considerably. As pointed out by Kashef (1986), at 4°C, μ is about 5 times its value at 100°C, while γ_w changes only about 1.04 times. Therefore A.11 can be approximated by:

$$K_2/K_1 = \mu_1/\mu_2 \qquad \textbf{(A.12)}$$

APPENDIX B

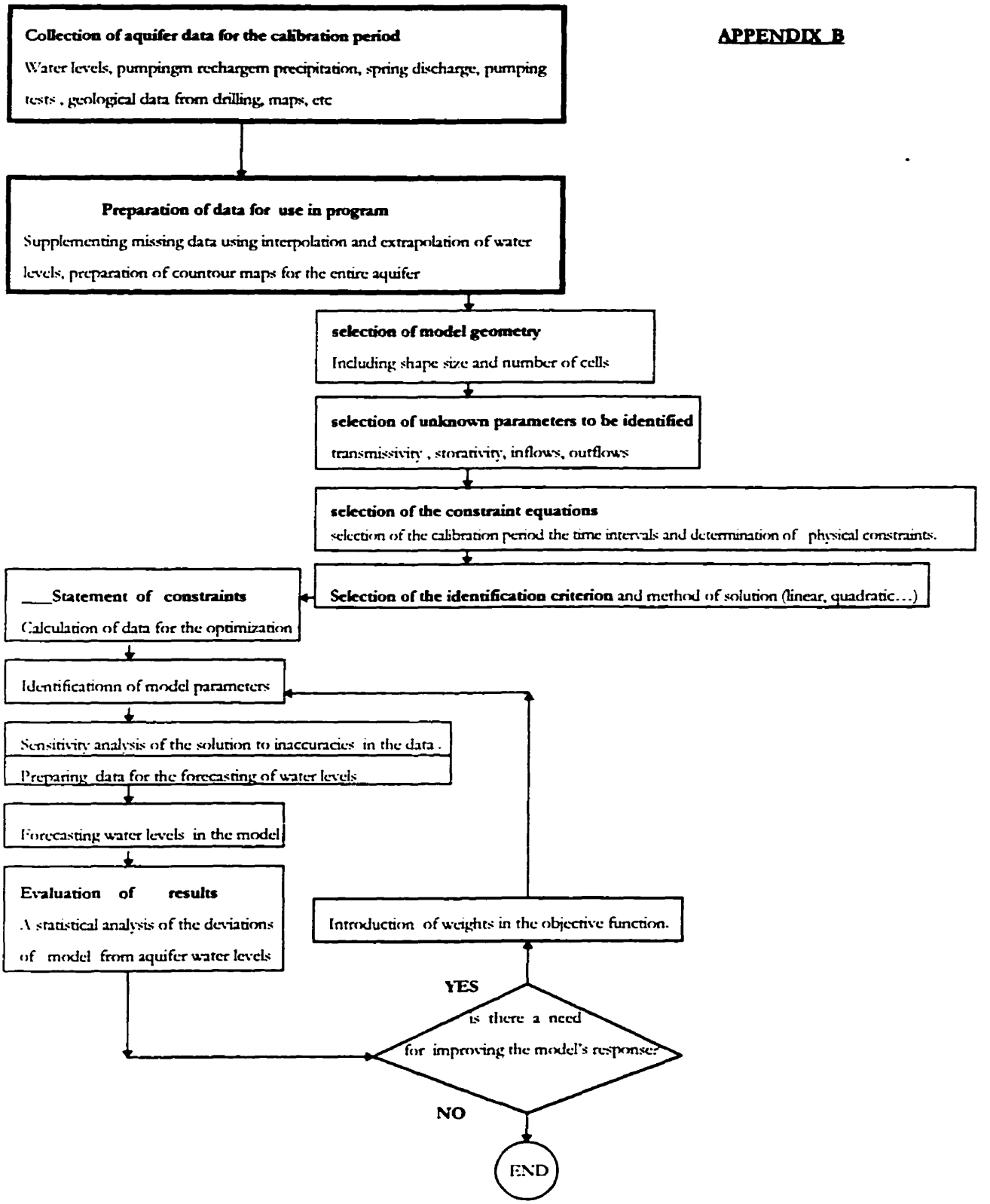


FIGURE B.1 Detailed flow chart for identification of model parameters. Hefez et al (1975).

APPENDIX C. BASIC CONTINUITY EQUATION

The flow in a phreatic aquifer is usually analyzed based on Dupuit's assumption of horizontal flow with no internal sources and/or sinks. Moreover, in the balance equation that is derived from an elementary volume , the elastic storativity is generally neglected.

Bear (1979) explained that this is a reasonable simplification as the storativity from the pore space is much larger than that resulting from the elasticity of the water and the solid matter. When the water table is lowered, the pressure drops throughout the aquifer below it. This pressure drop should (in principle) cause water to be released from storage in the aquifer, due to the elastic properties of the aquifer and the water.

However, this volume of water released due to elastic storage is small compared to the actual volume of water drained from the pore space. For this reason the elastic storativity is usually neglected.

When the medium is assumed to be inhomogeneous and isotropic, the inhomogeneity that is generally considered is of Type 1 as per Bear's classification. In Type 1 inhomogeneity, the variable transmissivity (and permeability of course) may be expressed as a function of the space coordinates in the form $T = T(x,y)$. We note however that with the limited data available for the permeability , the variability of the permeability is often reduced to the simple case where the project area is split in two homogeneous and isotropic media.

The basic continuity equation obtained is then:

$$\frac{\partial}{\partial x}\left(h\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(h\frac{\partial h}{\partial y}\right) + \frac{N}{K} = \frac{S_y}{K}\left(\frac{\partial h}{\partial t}\right) \qquad \textbf{(C.1)}$$

This equation is the Boussinesq equation. Here $N=N(x,y,t)$ is the rate of accretion which is positive when vertically downward. This accretion may be the net effect of natural replenishment, artificial recharge, pumping etc. In the case of evaporation or evapotranspiration N has a negative value. 9

Linearization Of The Transmissivity.

Unlike the transmissivity in a confined aquifer, the transmissivity of the phreatic aquifer may vary both in space and in time as h= h(x,y,t).

It is a common practice (Anderson and Woessner, 1992) to assume that:

$$T_x = K_x \cdot h \qquad \textbf{(C.2)}$$

$$T_y = K_y \cdot h \qquad \textbf{(C.3)}$$

where "h" is the saturated thickness. When K_x·h and K_y·h are used, the resulting equation is still the nonlinear Boussinesq equation:

$$\frac{\partial}{\partial x}(K_x\, h \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(K_y\, h \frac{\partial h}{\partial y}) = S_y\, (\frac{\partial h}{\partial t}) - N \qquad \textbf{(C.4)}$$

The above equation is said to be non-linear because of the product h·δh/δx. The non-linearity of the equation becomes clear by realizing that

$$\frac{\delta h^2}{\delta x} = 2h\,\frac{\delta h}{\delta x} \quad \text{and} \quad \frac{\delta h^2}{\delta y} = 2h\,\frac{\delta h}{\delta y} \qquad \textbf{(C.5a, b)}$$

and rewriting equation (1,4) after proper substitution of the above

$$\frac{\partial}{\partial x}(K_x \frac{\partial h^2}{\partial x}) + \frac{\partial}{\partial y}(K_y \frac{\partial h^2}{\partial y}) = 2\, S_y\, (\frac{\partial h}{\partial t}) - 2N \qquad \textbf{(C.6)}$$

In the above equation, the non-linearity results from "h" appearing to the second power on the left hand side of the equation and to the first power on the right hand side. The result is that two types of nonlinearities exist. The first linearity is on the diffusivity term and the second on the square term $(\delta h/\delta x)^2$. Each nonlinearity was treated separately by Leznicki and Korfiatis (1987) and the resulting equations are solved by implicit finite difference techniques. Several authors have presented various forms of linearizations, perturbation, and numerical techniques to obtain approximate solutions (Scott and Hanks,1962;Hornberger, et al., 1970; Babu, 1976; Gureghian, 1978; Daly and Morel-Seytoux, 1981).

Anderson and Woessner (1992) conclude that there is, however, a relatively easy way to deal with the non-linearity which does not involve specialized techniques. By using the current (known) value of the saturated thickness, the equation can be effectively linearized in a numerical model.

This simple "linearization" technique was originally proposed by Hantush in the calculation of the rise of the mound of groundwater at the centre of a recharge area. This technique implies however the use of the transmissivity calculated with the current head (say at m^{th} iteration) for the calculation of the new head (at the $(m+1)^{th}$ iteration). In theory, this transmissivity value should be adjusted with the new head value and then used to refine the estimated value of the head at the m+1 iteration. This results in an iterative process to find the transmissivity within an iterative process to calculate the head at a given node.

No less is important to use a proper internodal transmissivity value to get a correct description of the flow between nodes. To obtain the proper transmissivity between nodes, we must apply a mean internodal transmissivity value . Let us see this in more details.

Calculation Of Local And Internodal Transmissivities.

To estimate the internodal transmissivity, the harmonic mean is superior to the arithmetic mean as it reflects the fact that two transmissivities arranged in series are equivalent to two parallel resistances (W.Kinzelback "Groundwater modelling",1986) and therefore they add harmonically which leads to the following average:

$$\overline{T}_{(i,j)} = \frac{2 \, x \, T_{(i,j)} \, x \, T_{(i+1,j)}}{T_{(i,j)} + T_{(i+1,j)}} \qquad \text{(C.7)}$$

where T(i,j) and T(i+1,j) are the local transmissivities at the nodes (i,j) and (i+1,j) respectively.

These local transmissivities are calculated as mentioned before that is as the product of the permeability and the saturated thickness at each node. The saturated thickness is the depth of water which is the current head elevation minus the bottom elevation of the aquifer at the corresponding node. Since the hydraulic conductivity is assumed to be constant in time, it follows that the local transmissivity varies as the depth of water.

Numerical Solution

There is no analytical solution to the above equation (C.6.) The numerical solution can be obtained through a finite difference approach. The difference approach first involves replacing the continuous aquifer system parameters by an equivalent set of discrete elements.

Numerical methods require a discretization of in time and space. The difference method replaces the partial differential equation of flow by a set of difference equations in discretized space and time.

Space discretization

The aquifer is first divided up into a rectangular grid. The nodal distances in -x - and - y - direction are Δx and Δy.

Trescott et (1976 as reported by Bear., 1979) suggest in order to avoid large truncation errors and possible convergence problems to use $\Delta x_i / \Delta x_{i-1} \leq 1.5$.

whenever a variable grid is employed. They also recommend a grid orientation that minimizes the number of nodes outside of the considered aquifer domain. In an anisotropic aquifer the orientation of the grid is crucial and must be with its axes parallel to the principal directions.

Time discretization

Time is discretized into time level t_0, t_1, t_2 .... The implicit backward difference and Crank-Nicholson schemes are unconditionally stable. Bear (1979) adds that the later (Crank-Nicholson scheme) is preferred because of its increased accuracy.

It is a fact to remember that small time increments are needed for accuracy when water levels are fluctuating rapidly. So the desirable scheme becomes one that uses small time increments for greater accuracy during times of rapidly fluctuating water levels and progressively larger increments for efficiency when water levels move more slowly. This sophisticated management of the time increments has the undesirable feature that computed drawdowns or heads do not correspond to even days, but are printed at fraction of days.

For simplicity and easier data analysis, uniform time increments will be used in our model . We shall keep in mind however that accuracy demands smaller time steps.

Finite -difference formulation and the theory behind the numerical methods is given in many references (see for example Varga,1962; Pinder and Brefehoeft, 1968, Remson et al , 1971; Cooley, 1974; Pinder and Gray, 1977). Many methods are also available for the solution of the system of finite-difference equations. Remson et al (1971) and Pinder and Gray (1977) provide a systematic and detailed presentation of these various methods as they pertain to aquifer simulation.

APPENDIX D. HANTUSH's ASSUMPTIONS

Hantush(1967) presents solutions for continuous recharge from both circular and rectangular basins and his solutions serves as a reference bench mark for most of research papers on artificial recharge.

The assumptions made by Hantush are the following

- The aquifer is infinite in areal extend.
- the aquifer is homogeneous, isotropic
- the aquifer is resting on a horizontal impermeable base;
- the hydraulic properties of the aquifer remain constant in time and space;
- the rate of deep percolation is constant in time and space.
- the constant rate of deep percolation relative to the hydraulic conductivity is so small that the vertically downward percolation is almost completely refracted in the direction of the tilt of the water table. (this means the flow due to percolation is vertically downward until it reaches the water table).
- the water table is assumed to remain below the bottom of the spreading basin.
- the height of the water table above the base of the aquifer is approximately equal to the average head over the depth of saturation.
- the rise of the water table relative to the initial depth of saturation does not exceed 50%.

Because of the geometry of the flow, the main groundwater divides (boundaries across which no flow takes place) lie along the x and y axes.

APPENDIX E. SIMULATION OF PARTIAL RECOVERY.

Say Q_m = The measured PUMP Discharge .

Say Q_1 = A positive pumping well.

Say Q_2 = A negative pumping well that is an injection well.

We set both Q1 and $Q_2 > 0$ and we use a negative sign in the volume balance equation to express the counter effect of Q_2 on Q_1 . Any measured pump discharge can then be written as :

$$\mathbf{Q_m = Q_1 - Q_2} \qquad \textbf{(E.1)}$$

In a step drawdown test, as long as the pump discharge keeps increasing we can then express

$$\mathbf{Q_m = Q_1 - Q_2 = Q_1} \quad \textbf{that is} \quad \mathbf{Q_2 = 0}$$

If the pump is shut off then we can analyse the drawdown by simulating continuous pumping superimposed by continuous injection of the same magnitude.

So $Q_2 = Q_1$ **If the pump is shut off**

in which case we can write :

$Q_m = Q_1 - Q_2 = 0$ this is the standard recovery test.

If recovery is slowed down in such a way that the injection is less than the pumping we then get $Q_2 < Q_1$.

When the pump discharge is brought down in steps.

$Q_m = Q_1 - Q_2 > 0$ This is the case when the pump discharge is brought down in a decreasing step procedure.

Equation E.2

The Theis recovery method (Theis, 1935., as reported by by Kruseman and de Ridder, 1990) is strictly speaking only valid for confined aquifers which are fully penetrated by a well that is pumped at a constant rate. At late time, the effects of elastic storage, which set **in after pumping is stopped**, have dissipated. The residual drawdown will then fall on a straight line in the semi-log s' versus t/t'. In a partial recovery, the effects of elastic storage are less pronounced and will become negligible when

s' versus $\left(\left(Q_1 Log_{10}(t)\right)-\left(Q_2 Log_{10}(t')\right)\right)$ fall on a straight line. This condition is assumed here . It is also assumed that observations are made in the near vicinity of the well after a sufficiently long pumping time so that $(r^2 S) /(4 \pi T t) < 0{,}01$ in which case Jacob's method (Cooper and Jacob, 1946 as reported by Kruseman and de Ridder, 1990) may be applied.

Equation E.2

$$S'=\left(\frac{2{,}3}{4\pi.T}\right)\bullet\left(\left(Q_1 Log_{10}\frac{4T}{Sr^2}\right)-\left(Q_2 Log_{10}\frac{4T}{S'r^2}\right)+\left(Q_1 Log_{10}(t)\right)-\left(Q_2 Log_{10}(t')\right)\right)$$

s'= residual drawdown in (m).

r = distance from well to piezometer in (m).

T = KD = Transmissivity in (m^2 /min).

S'= Storativity during partial recovery.

S = Storativity during pumping.

t = Time since the start f pumping in (min).

t'= Time since the end of step drawdown, in (min).

Q_1, Q_2 = as defined above.

When **S** and **S'** are constant and equal and the transmissivity is constant. Equation E.2 can be written as

Equation E.3

$$S' = \left(\frac{2,3}{4\pi.T}\right) \bullet \left(\left(Log_{10}\frac{4T}{Sr^2}\left(Q_1 - Q_2\right)\right) + \left(Q_1 Log_{10}(t)\right) - \left(Q_2 Log_{10}(t')\right)\right)$$

so the residual drawdown s' = function (Q_1, t, Q_2, t')

since $Q_m = (Q_1 - Q_2)$ by definition we then have;

Equation E.4

$$S' = \left(\frac{2,3}{4\pi.T}\right) \bullet \left(\left(\left(Q_m\right)Log_{10}\frac{4T}{Sr^2}\right) + \left(Q_1 Log_{10}(t)\right) - \left(Q_2 Log_{10}(t')\right)\right)$$

When Q_1, Q_2 and therefore Q_m is function of time then the above equation becomes difficult to handle. Let us see the case of Rojas Well Test. 1.

ROJAS WELL 1.

Rojas well test No 1 is typical of the well development and declining step drawdown procedure established by the manager and for which data analysis was investigated in this research. We note that Q_1 was not measured during development but Q_m was measured from the beginning of the declining 2h steps drawdwon until the end. The partial recovery took 10 hours or 5 steps of 2h each. The development preceding the partial recovery took 60 hours. Development of the well was usually carried out in 48 hours or slighlty longer.

We can plot Q_m versus the corrected drawdown for the period when the pump discharge was measured during partial recovery that is for $4\,320 \text{ min} < t < 3\,600$ min.
From Figure 16 of Chapter VII we see that the measured discharge Q_m was almost constant during that time and equal to 2,10 m^3/min. Given the small value of r since residual drawdown were measured from the well and given the long pumping time, it follows that $u < 0{,}01$. Jacob's method may then be applied provided the effects of elastic storage have dissipated. This is assumed to be the case. From Equation E.2 we get:

$$S' = \left(\frac{2,3}{4\pi.T}\right) \bullet \left(\left(Log_{10}\frac{4T}{Sr^2} \bullet (2,10)\right) + \left(Q_1 Log_{10}(t)\right) - \left(Q_2 Log_{10}(t')\right)\right)$$

This the form semi-log :

s' = mx + b

where $m = \left(\frac{2,3}{4\pi.T}\right)$

$$x = \left(\left(Q_1 Log_{10}(t)\right) - \left(Q_2 Log_{10}(t')\right)\right)$$

b = intercept of the straight line of the semi-log plot of

s' versus $x = \left(\left(Q_1 Log_{10}(t)\right) - \left(Q_2 Log_{10}(t')\right)\right)$.

The intercept where s' = 0,0 is at a point x = -b/m. At this point, the equation E.2 can be written as :

$$\left(\left(Q_1 Log_{10}\frac{4T}{Sr^2}\right) - \left(Q_2 Log_{10}\frac{4T}{S'r^2}\right) = +\left(Q_1 Log_{10}(t)\right) - \left(Q_2 Log_{10}(t')\right) = -\left(\frac{-b}{m}\right)\right.$$

Knowing Q_1, Q_2, T and r we can then calculate S/S', that is the relative change of the storativity.

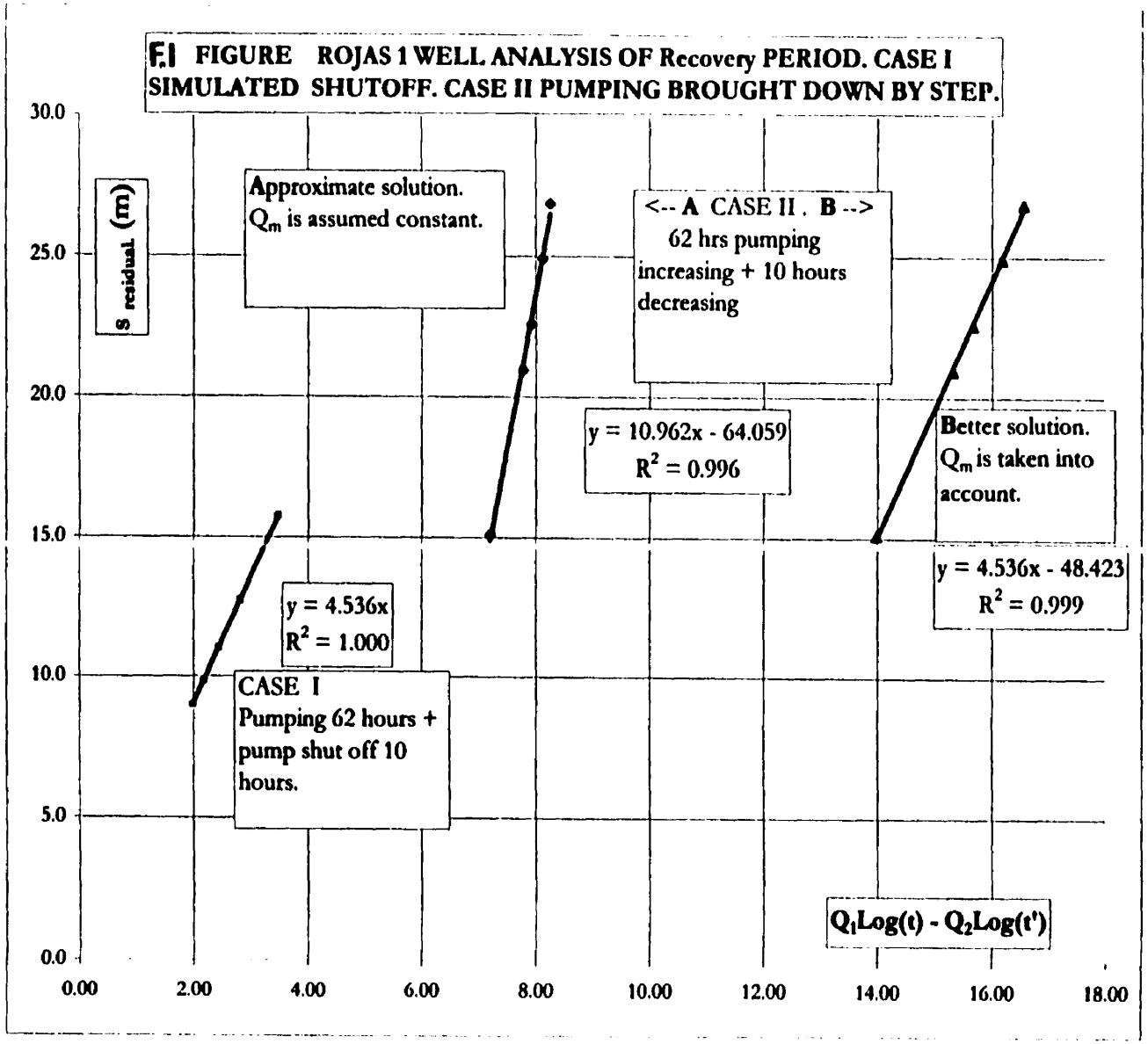


TABLE F. 1 T and S solutions			
corr. s_I/s_{II} ratio	T m^2/d	S	R^2
0.44	78.2	0.00001	0.9996
0.51	68.2	0.0001	0.9995
0.59	58.1	0.001	0.9993
0.71	47.9	0.01	0.999
0.84	40.6	0.05	0.9986
0.88	38.7	0.075	0.9985
0.91	37.4	0.1	0.9984
0.91	34.2	0.2	0.9984
Min time for restrictive model.			
T m^2/d	S	min time hours	
78.2	0.00001	0.00	
68.2	0.0001	0.05	
58.1	0.001	0.59	
47.9	0.01	7.22	
40.6	0.05	42.56	
38.7	0.075	66.98	
37.4	0.1	92.41	
34.2	0.2	202.11	

APPENDIX F

TABLE F2 ROJAS de CUAUHTEMOC WELL TEST 1. DATA .

Total depth ->	60	m	Sat Depth	54	m	r_w	0.19 ~~0.38~~	m	
Static Level ->	6	m	Gravel pack	12	mm	Assumed R_o	250	m	
Sreened depth ->	60	m	Well dia	356	mm				

Time (hour:min:sec)	Time since pump start (hh:min:sec)	t' Time since pump start (minutes)	s Drawdwon (m)	s_{corr} (m)	WTD (m)	Q (m^3/d)	Q (lps)	RPM	Q/s (m^2/d)
16:00:00					**6.0**				
9:00:00 PM	5:00:00	300	4.0	3.9	10.0				
2:00:00 AM	10:00:00	600	6.8	6.4	12.8				
7:00:00 AM	15:00:00	900	6.1	5.7	12.1				
12:00:00 PM	20:00:00	1200	9.1	8.3	15.1				
5:00:00 PM	25:00:00	1500	9.8	8.9	15.8				
10:00:00 PM	30:00:00	1800	22.5	17.8	28.5				
3:00:00 AM	35:00:00	2100	26.5	20.0	32.5				
8:00:00 AM	40:00:00	2400	45.2	26.3	51.2				
1:00:00 PM	45:00:00	2700	47.3	26.6	53.3				
6:00:00 PM	50:00:00	3000	50.7	26.9	56.7				
11:00:00 PM	55:00:00	3300	51.8	27.0	57.8				
4:00:00 AM	60:00:00	3600	52.2	27.0	58.2				
6:00:00 AM	62:00:00	3720	52.0	27.0	58.0	3653	42.3	1700	70.2
8:00:00 AM	64:00:00	3840	50.0	26.9	**56.0**	3319	38.4	1600	66.4
10:00:00 AM	66:00:01	3960	39.0	24.9	45.0	3190	36.9	1500	81.8
12:00:00 PM	68:00:00	4080	32.1	22.6	38.1	3092	35.8	1400	96.3
2:00:00 PM	70:00:00	4200	28.4	20.9	34.4	3049	35.3	1300	107.4
4:00:01 PM	72:00:00	4320	18.2	15.1	24.2	2694	31.2	1200	148.3
					20.5			1100	
Data from S.A.R.H exploration. Analysis by E. Perraton.						3166	36.6	1000	

NOT MEASURED UNTIL the WELL DEVELOPMENT WAS COMPLETE

TABLE F3 CALCULATIONS for WELL ROJAS 1. Recovery by decreasing Q in steps.

$Q_m = Q1 - Q2$. Q_1 = Pumping prior to recovery. Q_2 = Simulated injecting well Q_m = measured Q

S	r	T (m^3/min)	T (m^3/d)
0.001	0.2	0.040347	58.1

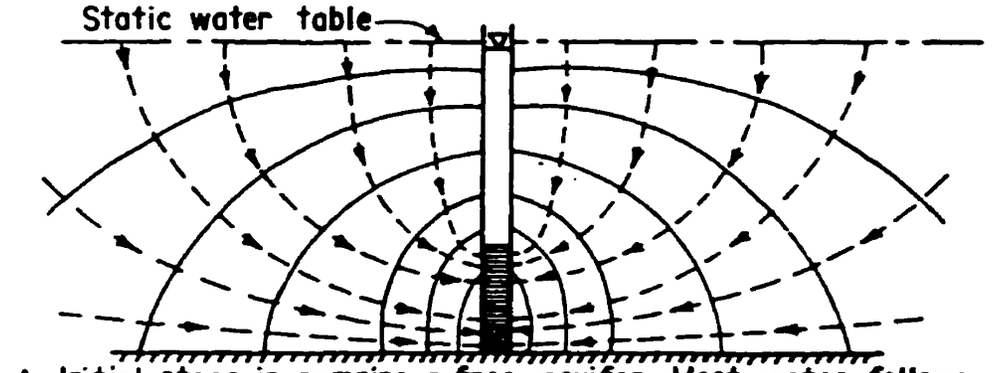
Q_m Esti.	t	t'	Q_1	Q_m	Q_2	COL A	COL B	COL C	Col (A+B-C)	Col D	Col (A-C)	Col (A-B)	s corr	$s_{res.}$ (corr)
m^3/min	min	min	m^3/min	m^3/min	m^3/min	Q_1Log(t)	Log $4T/r^2S)*Q_m$	Q_2Log(t')		Q_1Log(t')			(m)	(m)
1.48	300.0	1	1.48		0.00	3.66	5.33	0.00	8.99		3.66		3.9	
1.57	600.0	1	1.57		0.00	4.36	5.66	0.00	10.01		4.36		6.4	ESTIMA-
1.54	900.0	1	1.54		0.00	4.56	5.57	0.00	10.13		4.56		5.7	TED
1.64	1200.0	1	1.64		0.00	5.04	5.91	0.00	10.95		5.04		8.3	RESIDUAL
1.66	1500.0	1	1.66		0.00	5.27	5.98	0.00	11.25		5.27		8.9	DRAW-
1.98	1800.0	1	1.98		0.00	6.44	7.13	0.00	13.57		6.44		17.8	DOWN
2.06	2100.0	1	2.06		0.00	6.83	7.41	0.00	14.24		6.83		20.0	BY
2.28	2400.0	1	2.28		0.00	7.71	8.23	0.00	15.94		7.71		26.3	THEIS's
2.29	2700.0	1	2.29		0.00	7.87	8.27	0.00	16.14		7.87		26.6	METHOD
2.30	3000.0	1	2.30		0.00	8.01	8.31	0.00	16.32		8.01		26.9	
2.31	3300.0	1	2.31		0.00	8.12	8.32	0.00	16.43		8.12		27.0	
2.31	3600.0	1	2.31		0.00	8.20	8.32	0.00	16.52		8.20		27.0	
	3720.0	1.0	2.31	2.31	0.00	8.24	8.32	0.00	16.55		8.24		27.0	SHUTOFF
	3840.0	120.0	2.31	2.30	0.00	8.27	8.30	0.01	16.56	4.80	8.26	3.47	26.9	15.7
	3960.0	240.0	2.31	2.23	0.07	8.30	8.05	0.17	16.18	5.49	8.12	2.81	24.9	12.7
	4080.0	360.0	2.31	2.15	0.16	8.33	7.75	0.40	15.67	5.90	7.92	2.43	22.6	11.0
	4200.0	480.0	2.31	2.09	0.22	8.36	7.54	0.58	15.31	6.18	7.78	2.17	20.9	9.9
	4320.0	600.0	2.31	1.88	0.43	8.39	6.78	1.18	13.99	6.41	7.20	1.98	15.1	9.0

Rojas1full.xls

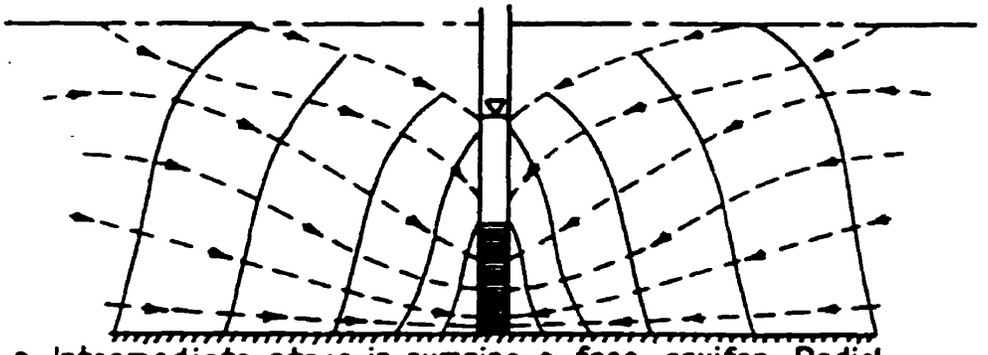
TABLE F4 DETAILS OF EACH T and S solution ROJAS WELL 1.

Case II s_{corr} (m)	Case II s_{corr} (m)		T. m2/d	S	Full I	Appr. IIa	Better II b
			78.25	C.00001			
26.9	11.7	slope			3.3682	10.962	3.3684
22.6	8.2	Intercept			0	-64.06	-45.57
15.1	6.7	R^2			1	0.9961	0.9996
			68.22	0.0001			
26.9	13.41	slope			3.8634	10.962	3.8632
22.6	9.4	Intercept			0	-64.06	-46.78
15.1	7.64	R^2			1	0.9961	0.9995
			58.1	0.001			
26.9	15.75	slope			4.5363	10.962	4.5358
22.6	11.03	Intercept			0	-64.06	-48.423
15.1	8.971	R^2			1	0.9961	0.9993
			47.86	0.01			
26.9	19.1	slope			5.5075	10.962	5.5073
22.6	13.4	Intercept			0	-64.06	-50.8
15.1	10.9	R^2			1	0.9961	0.999
			40.57	0.05			
26.9	22.55	slope			6.4964	10.962	6.4961
22.6	15.8	Intercept			0	-64.06	-53.21
15.1	12.9	R^2			1	0.9961	0.9986
			38.72	0.075			
26.9	23.6	slope			6.8068	10.962	6.8073
22.6	16.5	Intercept			0	-64.06	-53.97
15.1	13.5	R^2			1	0.9961	0.9985
			37.39	0.1			
26.9	24.5	slope			7.0489	10.962	7.0483
22.6	17.1	Intercept			0	-64.06	-54.56
15.1	13.9	R^2			0	0.9961	0.9984
			34.18	0.2			
26.9	24.5	slope			6.4964	10.962	6.4961
22.6	17.1	Intercept			0	-64.06	-53.21
15.1	13.9	R^2			1	0.9961	0.9986

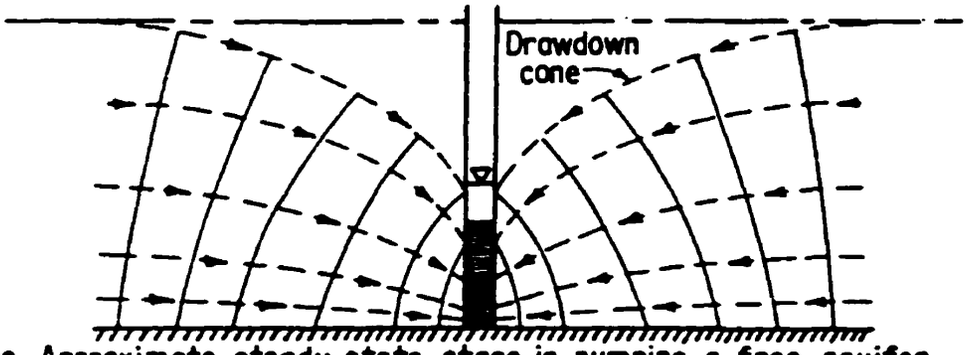
Sheet3



A. Initial stage in pumping a free aquifer. Most water follows a path with a high vertical component from the water table to the screen.



B. Intermediate stage in pumping a free aquifer. Radial component of flow becomes more pronounced but contribution from drawdown cone in immediate vicinity of well is still important.



C. Approximate steady state stage in pumping a free aquifer. Profile of cone of depression is established. Nearly all water originating near outer edge of area of influence and stable primarily radial flow pattern established.

— · — · — Flow lines

——— Equipotential lines

FIGURE F2 Development of flow distribution about a discharging well in a free aquifer—a fully penetrating and 33-percent open hole. 103-D-1410.USDI (1981)

TABLE F.5. TLACOC2B WELL TEST DATA ANALYSIS Data from S.A.R.H exploration. Analysis by E. Perraton.

Total depth	82 meters	Sat Thickness	72.5 meters	rw	0.19	
Static Level	9.5 meters	Gravel pack	12 mm	Assumed Ro	250	
Sreened depth	41 meters	Well dia	356 mm	c where T=(Q/scorr)*c		1.14

Time (min)	Time hour:min:sec	Time since pump start hh:min:sec	t' Time since pump start (min)	s Drawdwon s (m)	S corr	WTD WTD (m)	Q m^3/d	Q lps	Q/s m^2/d
	11:40:00		0.0			9.50	m3/d	lps	m2/d
2240.0	12:00:00 PM	0:20:00	20.0	31.50	24.7	31.50	2530.66	29.29	80.3
2060.0	3:00:00 PM	3:20:00	200.0	31.50	24.7	31.50	2530.66	29.29	80.3
1880.0	6:00:00 PM	6:20:00	380.0	28.20	22.7	28.20	2309.47	26.73	81.9
1700.0	9:00:01 PM	9:20:01	560.0	28.20	22.7	28.20	2309.47	26.73	81.9
1520.0	12:00:01 AM	12:20:01	740.0	24.25	20.2	24.25	2109.02	24.41	87.0
1340.0	3:00:01 AM	15:20:01	920.0	24.25	20.2	24.25	2109.02	24.41	87.0
1160.0	6:00:02 AM	18:20:02	1100.0	18.00	15.8	18.00	1789.34	20.71	99.4
980.0	9:00:02 AM	21:20:02	1280.0	18.00	15.8	18.00	1789.34	20.71	99.4
800.0	12:00:02 PM	24:20:02	1460.0	15.10	13.5	15.10	1632.98	18.9	108.1

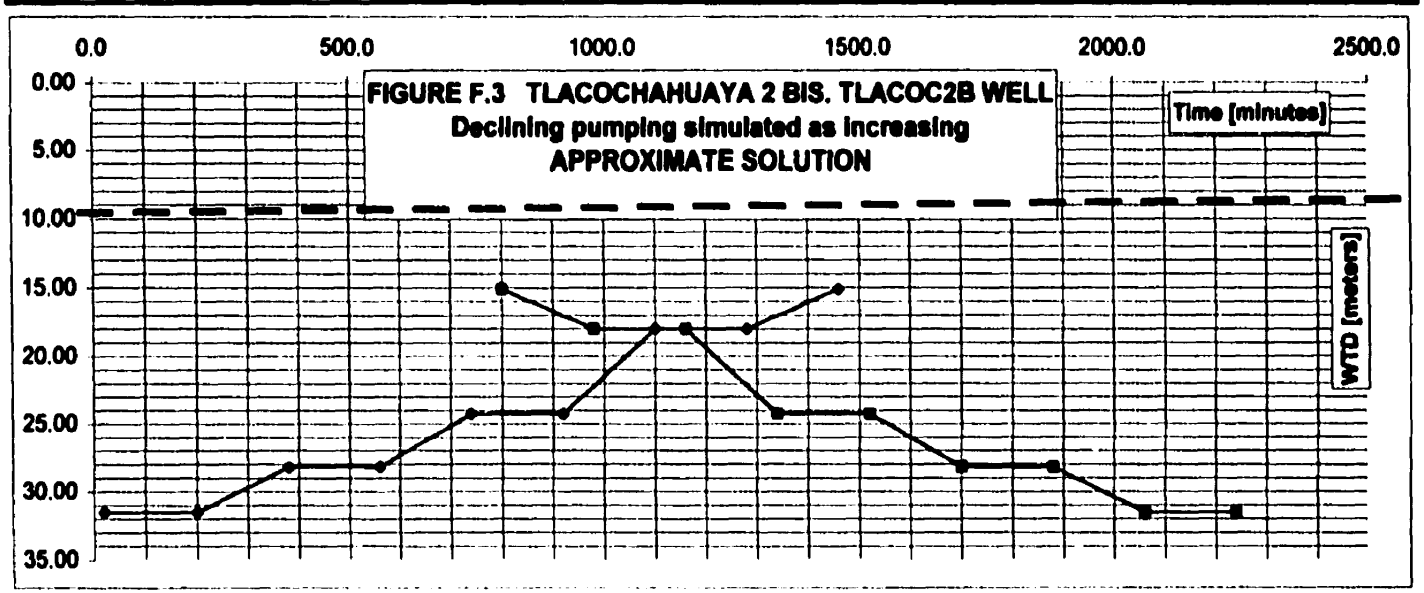


TABLE F.6 CALCULATIONS OF T and S for various SIMULATED STARTING TIME

r_w = >	0.19 s_{corr}/Q versus log (t/r_w =	0.20 m					min	min	t/r^2	Log (t/r^2)	s/Q
D	72.5 TLACOCHAHUAYA 2B TEST DATA ANALYSIS							Late	min/m^2		m^2/min
t_{ini}	R2	slope	intercept	T	T	S	time	time	52078.3	4.72	14.16
(min)				(m^2/min)	(m^2/d)		(min)	(days)	47092	4.67	14.16
800.0	0.9318	6.4	-15.6	0.029	41	0.1592	5	634	42105.8	4.62	13.79
90	0.9046	2.1	4.5	0.085	123	-0.4006	-4	214	37119.5	4.57	13.79
30	0.8515	1.5	7.3	0.123	177	-1.3648	-10	148	32133.2	4.51	12.69
400	0.9357	4.2	-5.0	0.044	63	0.1180	2	418	27146.9	4.43	12.69
600	0.9344	5.3	-10.4	0.035	50	0.1525	4	528	22160.7	4.35	11.93
700	0.9331	5.8	-13.0	0.031	45	0.1577	5	582			
800	0.9318	6.4	-15.6	0.029	41	0.1592	5	634			
900	0.9304	6.9	-18.2	0.027	38	0.1587	5	686			
1000	0.9291	7.4	-20.8	0.025	36	0.1568	6	738			
1200	0.9267	8.4	-26.0	0.022	31	0.1512	6	840			
3000	0.9146	17.4	-73.6	0.010	15	0.0996	9	1739			

Figure F.4. The solution with unique S and T values. TLACOC2B.

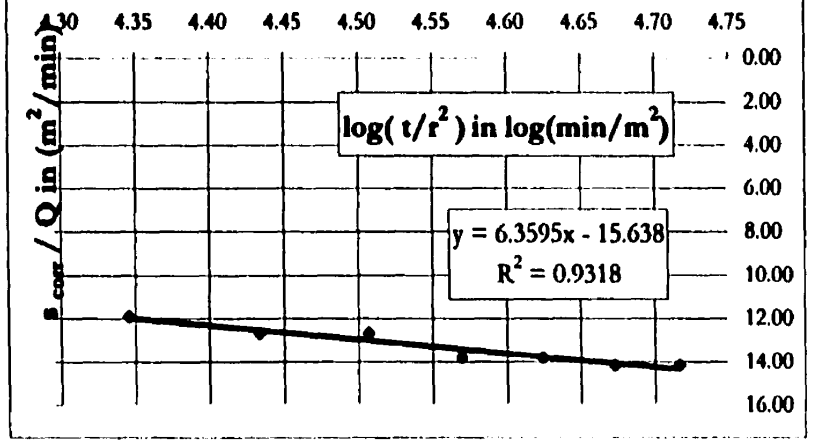
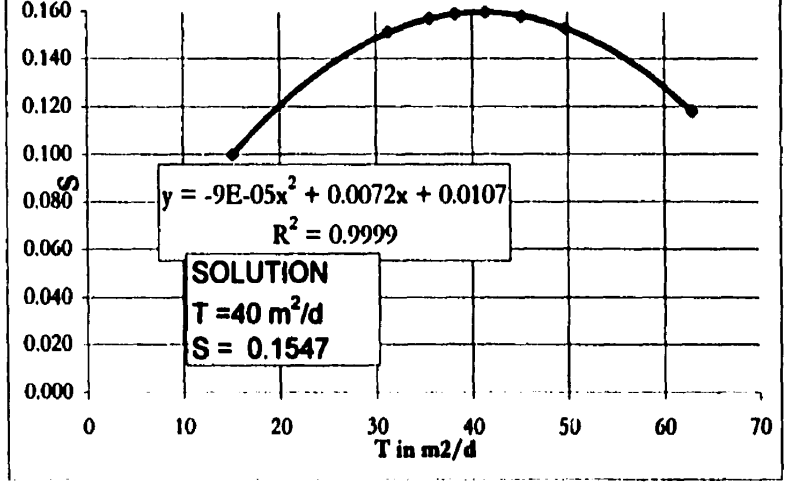


Figure F.5. Possible solutions of S and T. TLACOC2B WELL TEST



APPENDIX G. TRANSIENT FLOW IN UNCONFINED AQUIFERS

Ignoring well losses and delayed specific yield , Boulton's equation as reported by Bouwer (1979) for the drawdown s of a well pumping in transient flow in unconfined aquifers can be written as :

$$s = \frac{Q}{2\,\Pi\,K\,H}(1 + C_k) \times V(t', r') \qquad \text{(G.1)}$$

where C_k is a correction factor and V (t', r') is Boulton's well function of t' and r' . The variables t' and r' are defined as;

$$t' = \frac{K\,t}{SH} \qquad \text{(G.2)}$$

where K is the saturated thickness, [m/d]

t is the time since pumping started. [d]

S is the specific yield, [ ]

H is the saturated height (or saturated depth), [m].

$$r' = \frac{r}{H} \qquad \text{(G.3)}$$

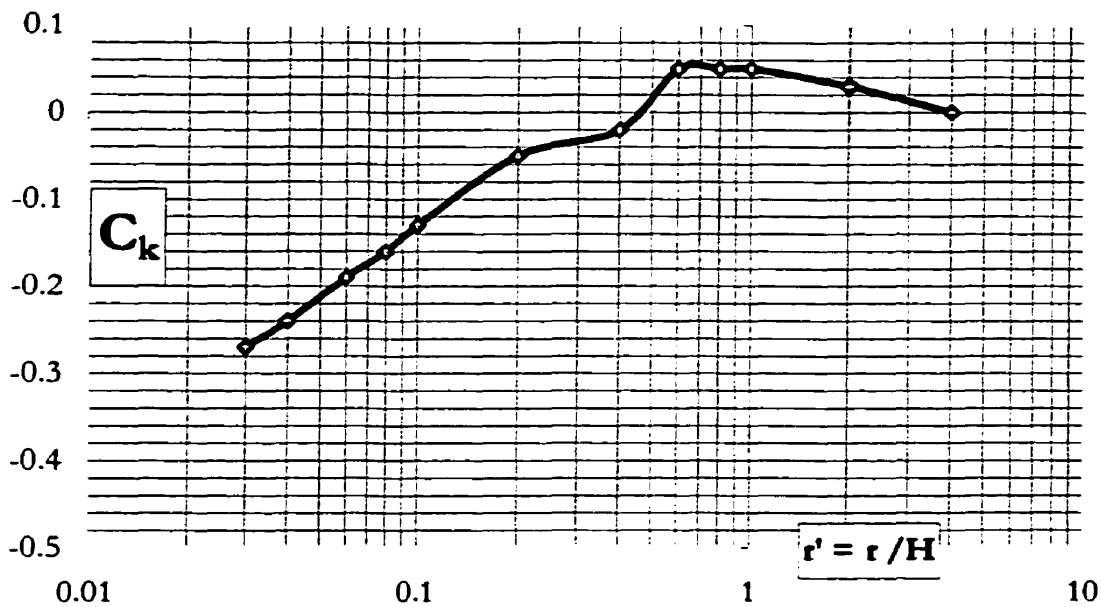
where r is the radius of influence (m) and

H was defined previously

The correction factor C_k

- may be taken as equal to zero when $0{,}05 < t' < 5$ with an anticipated error less than 6%. THIS WAS THE CASE FOR ALL HISTORICAL well tests reported for this this research.
- WHEN $t' > 5$ THEN $C_k = f(r')$ and can be obtained from the graph shown on Figure below

FIGURE (G.1) Boulton's correction Factor C_k when Kt/SH > 5



Limits of The Dupuit formula .

The Dupuit formula fails to give an accurate description of the drawdown near the well where the strong curvature of the watertable contradicts Dupuit's assumptions. These assumptions as noted by Kruseman and De Ridder (194, 2nd edition) ignore the existance of the a seepage face at the well and the influence of the vertical velovity components which reach their maximum in the viscinity of the well.

APPENDIX H

Boulton's analysis for transient flow in an unconfined aquifer.

Typical Example Of Compilation : The Well TLACOC2B .

Boulton's analysis for transient flow in an unconfined aquifer can be applied to the well pumping test identified as TLACOC2B . The profile of the unconfined aquifer as reported the driller's log is reproduced as T-2 profile.

The top four meters of the profile is a clay material that has impervious nature but its action on the aquifer is not confining the water since the static water level is at 9,50 meters that is four meters below it. This aquifer is therfore assumed to have a free response within the radius of influence of the well.

Given

H	Total Initial Water Depth = 72,5m so 0,5 H = 36,25 m.
s_{max}	Maximum drawdown = 22,0m .
r_w	hydraulic radius = 0,19m .
[1] h_w**min**	Minimum Water depth = 72,5 - 22,0 = 49,5m >> 36,0 m so Boulton's equation may be used.
Q	Well pumping discharge = 2531 m^3/d.

Let us define

s_w	Drawdown just outside the well envelope in (m)
s_{iw}	Drawdown inside the well in (m)
seepage	Seepage along the well envelope in (m)

---

[1] This is an estimate only $h_{iw} < h_w$. Actual value will be evaluated when the seepage is known.

$s_{iw} = s_w + \text{seepage}$

When expressed in terms of head we get

$h_w = H - s_w$ **and** $h_{iw} = H - s_{iw}$

$H = h_w + s_w = h_{iw} + \text{seepage} + s_w$

First estimate of T and K using Walton's graph .

First estimate **of T and K** is obtained using **Walton (1970.)**'s graph which has been reproduced. as Figure 1. Four lines are obtained for each boundary limits of:

S = 0,20 and pumping time of 8 hours

S = 0,0001 and pumping time of 8 hours

S = 0,20 and pumping time of 24 hours

S = 0,0001 and pumping time of 24 hours

in equation form are given in Table 3.

We need an estimate of S the specific yield. This is obtained by the layers superposition approach shown in Talbe 1. S = 0,15 is then estimated

Table 1. Estimating the specific yield . The layers syperposition approach.

LAYER	1	2	3	4	5	6	7	8	9	10
Assumed $S = \Sigma(S_i)$	0,03	0,10	0,15	0,20	0,25	0,25	0,25	0,10	0,03	0,00
Thickness (d_i) in m.	4	2	10	6	10	4	4	10	8	24
$S_i \times d_i$	0,12	0,20	1,5	1,2	2,5	1,0	1,0	1,0	2,4	0,0

$$S = \frac{\Sigma(S_i) \times d_i}{\Sigma(d_i)} = \frac{8,76}{58} = 0,15$$

we have $Q / S_{max} = 2531/22 =$ after 24 hours of pumping and our estimate of $S = 0,15$.

Table 4 shows the factors to convert Q/s of a well of a given r_w to the standard r_w = 150 mm. whereas Table 5 shows the factors to convert the transmissivity T obtained from Walton's standard graphs derived for a specific yield of S = 0,20 to the actual specific yield of the material under consideration. An example will show the procedure

After 24 hours of pumping $Q/s_w = 2531/22 = 115\ m^2/d$ and $S = 0,20$.

We get $\log(T) = 1,104 \log (115) - 0,3556.$

$\text{Log (T)} = 2.2750 - 0,3556 = 1,9194$

$\Rightarrow \quad T = 83\ m^2/d$

To get the transmissivity for a value of S = 0,15 we have:

$$T_{(\text{for } S = 0,15)} = (A \times T_{(\text{for } S = 0,20)}) + B$$

A and B are obtained from Table 4 .

$A = (1 + 1,35093) / 2 = 1,1755$

$B = (0 + 8,41171) / 2 = 4,2059$

$$T_{(\text{for } S = 0,15)} = (A \times T_{(\text{for } S = 0,20)}) + B$$

$$T_{(\text{for } S = 0,15)} = (1,1755 \times 83) + 4,2059 = 102\ m^2/d$$

$$K = \frac{T}{H} = \frac{102}{72,5} = 1,40\ m/d.$$

Calculate t' and r' .

$$t' = \frac{(Kt)}{(SH)} = \frac{1{,}40 \times (24/24)}{0{,}15 \times 72{,}5} = 0{,}13$$

$$r' = r/H = 0{,}19 / 72{,}5 = 0{,}0026$$

We have the following tabulated values of V (t',r') for the values of t' and r' approaching the calculated values of t' = 0,13 and r' = 0,0026.

Linear Interpolation to find V (t' = 0,13 ; r' = 0,0026)

t' \ r' ->	**0,002**	**0,003**	**0,0026**
0,10	4,54	4,14	4,30
0,20	5,15	4,78	4,93
0,13	4,72	4,33	***4,49***

We find by linear Interpolation V(0,13 ; 0,0026) = 4,49

V (t', r') can be found from the simple regression equation of V(t',r') versus r' and t'.

$$V(t', r') = ((-1{,}5305\,(r/H)) + 0{,}7728)\ln(t') + \ldots$$
$$\ldots + (-0{,}9757 \ln(r/H) + 0{,}1553).$$

We have r / H = 0,0026 and t' = 0,13

we find **V (t', r') = 4,4** compared to 4,49 by linear interpolation.

Calculate h_{iw}.

t' = 0,13 and therefore 0,05 < t' < 5 in which case we have:

$$h_{iw} = H - \frac{Q}{2\pi KH}\left(m + \ln\left(\frac{H}{r_w}\right)\right)$$

m is function of t' = (K t) / (SH). From Figure 4 we get m = 0,03. We note Ln $(H/r_w) >> m$

$$h_{iw} = H - \frac{Q}{2\pi K H}(5{,}9443 + 0{,}0300) \approx H - \frac{Q}{2\pi K H}(5{,}97)$$

RECALL **that the drawdown outside the well** may be obtained from , Boulton's equation (G.1) for transient flow in unconfined aquifers as reported by Bouwer (1979). This was done earlier and t' was calculated = 0,13 . This satisfies $0{,}05 < t' < 5$ in which case C_k the correction factor may be taken as equal to zero with an anticipated error less than 6% (Bouwer, 1979). Boulton's well function of t' noted as V (t', r') was found to be = **4,4**

In equation form this is written as:

$$s = \frac{Q}{2\,\Pi\,K\,H}(1 + C_k) \times V(t', r') = s = \frac{Q}{2\,\Pi\,K\,H}(1 + C_k).x.(4{,}4) = s_w$$

by definition the **seepage** = $H - h_{iw} - s_w$ and Therefore

$$\textbf{seepage} = H - h_{iw} - s_w = \frac{Q}{2\,\Pi\,K\,H}(5{,}97 - 4{,}40) = \frac{Q}{2\,\Pi\,K\,H}(1{,}57)$$

The seepage can be expressed in terms of the drawdown measured outside the well which represents the drawdown upstream of the water seep front. The ratio (seepage/ s_w) = (5,97 - 4,40)/ 4,40) = 0,36 . The seepage amounts to 36% of s_w .

$h_{iw} = H - s_w$ - seepage $= H - s_w - 0{,}36\ s_w$

$h_{iw} = H - s_{iw} = H - 1{,}36\ s_w$

double check

$h_w = h_{iw}$ + seepage $= H - 1{,}36\ s_w + 0{,}36\ s_w = H - s_w = h_w$ ok!

So we have $s_{iw} = 1{,}36\ s_w = 22m / 1{,}36 = 16{,}7m$

Inside the well the drawdown siw was found to be equal to

$$s_{iw} = \frac{Q}{2 \Pi K H}(5,97) = 22,0\text{m}$$

from which KH = 2531 x 5,97 / (2 π x22) = 109,3 m^2/d

Outside the well the drawdown was found to be equal to

$$s_{iw} = \frac{Q}{2 \Pi K H}(4,4) = 16,7\text{m}$$

from which KH = 2531 x 4,49 / (2 π x16,7) = 108,3 m^2/d

WALTON.xls

TABLE 2 WALTON's (1972) graph values LOG(Q/s) vs LOG (T)

Q/s (m3/d)/m	LOG (Q/s)	T (m3/d)/m	Log (T)	Pumping Hours	rw (m)
20.5706101	1.3132472	12.42236025	1.09420412	8	0.15
10732.4922	4.0307006	12422.36025	4.09420412		
10.3747425	1.0159773	12.42236025	1.09420412		
7154.99482	3.8546093	12422.36025	4.09420412		
17.887487	1.2525493	12.42236025	1.09420412	24	0.15
9838.11787	3.992912	12422.36025	4.09420412		
9.83811787	0.992912	12.42236025	1.09420412		
6439.49533	3.8088518	12422.36025	4.09420412		

TABLE 3 WALTON's (1972) graphs Log(Q/s) versus Log (T) in equation form

ALL for -> r_w = 15 cms		Q/s	Log (T)	T
EQUATIONS of the 2 extreme values	CURVE	$(m^3/d)/m$		$(m^3/d)/m$
Log (T) = 1.104log (Q/s) - 0.3556	A	21	1.094225	12.42294731
S = 0,2 t =8 hours		10732.5	4.094294	12424.92542
Log (T) = 1.0568Log (Q/s) + 0.0205	C	10.3747	1.094183	12.42175498
S=0,0001 t = 8 hours		7155	4.094051	12417.99457
Log (T) = 1.0947Log (Q/s) - 0.277	B	17.88749	1.094166	12.4212629
S = 0,2 t = 24 hours		9838.118	4.094041	12417.68932
Log (T) = 1.0654Log (Q/s) + 0.0364	D	9.838118	1.094248	12.42362883
S=0,0001 t = 24 hours		6439.495	4.094351	12426.5549

TABLE 4 FACTORS TO CONVERT Q/s of a well of a given r_w to Q/s equivalent for a well of r_w = 15cms. S = 0,05

r_w in cms.	15	20	25	30	41	T in m2/d
c	1	1.05034722	1.092014	1.13021	1.19271	100
c	1	1.0467461	1.086159	1.12099	1.17965	200

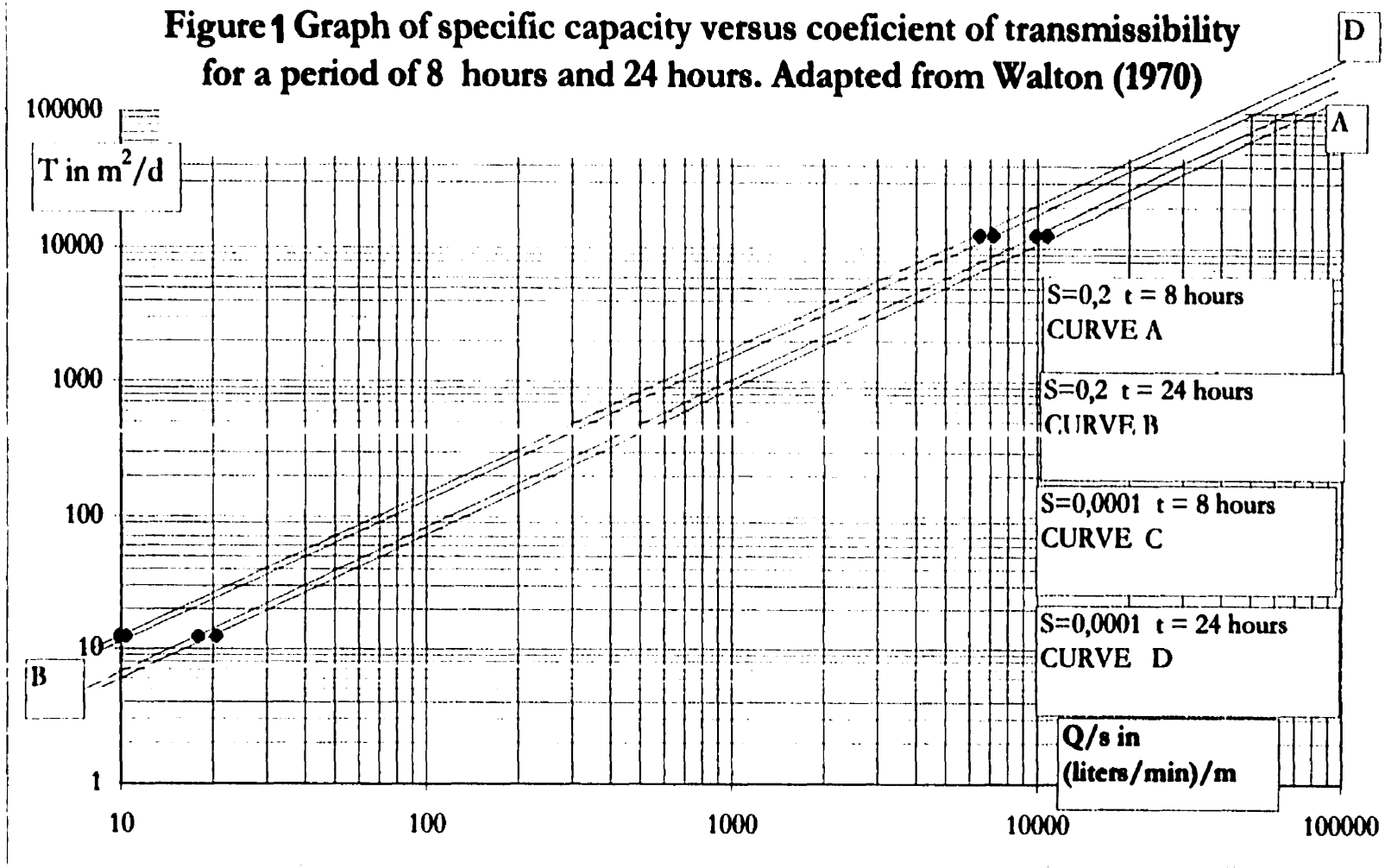
Q/s for r_w =15 cms = (Q/s) / c

TABLE 5 FACTORS TO CONVERT T (in m^2/d) FOUND FOR S = 0,2 curve to T for a given S $T_S = (A \times T_{S=0,2}) + B$

S -->	0.0001	0.001	0.01	0.1	0.2
A -->	1.7015	1.69834167	1.666758	1.35093	1
B -->	16.815	16.7392946	15.98224	8.41171	0

based on Linear Regression on Walton's (1972) curves Log(Q/s) vs Log(T) for t=8 and 24 hours S = 0,2 vs S = 0,0001 R^2 = 0,9987

Figure 1 Graph of specific capacity versus coeficient of transmissibility for a period of 8 hours and 24 hours. Adapted from Walton (1970)



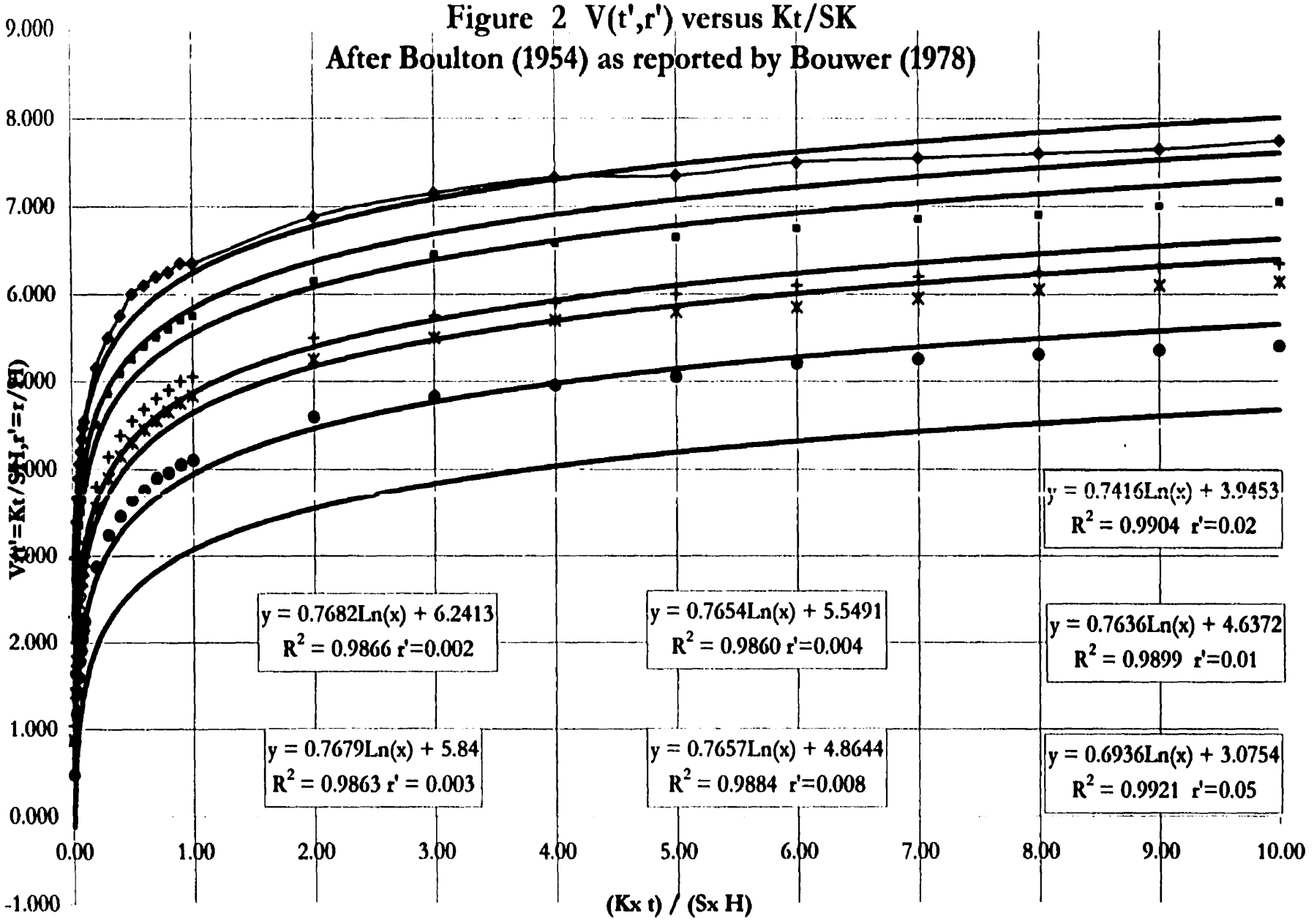

Figure 2 V(t',r') versus Kt/SK
After Boulton (1954) as reported by Bouwer (1978)
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
-1.000
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
V(t',r')=Kt/SH,r'=r/H)
(Kx t) / (Sx H)
y = 0.7416Ln(x) + 3.9453
R2 = 0.9904 r'=0.02
y = 0.7682Ln(x) + 6.2413
R2 = 0.9866 r'=0.002
y = 0.7654Ln(x) + 5.5491
R2 = 0.9860 r'=0.004
y = 0.7636Ln(x) + 4.6372
R2 = 0.9899 r'=0.01
y = 0.7679Ln(x) + 5.84
R2 = 0.9863 r' = 0.003
y = 0.7657Ln(x) + 4.8644
R2 = 0.9884 r'=0.008
y = 0.6936Ln(x) + 3.0754
R2 = 0.9921 r'=0.05

Figure 3 V(t',r') versus Kt/SK. Boulton (1954) as per Bouwer (1978).

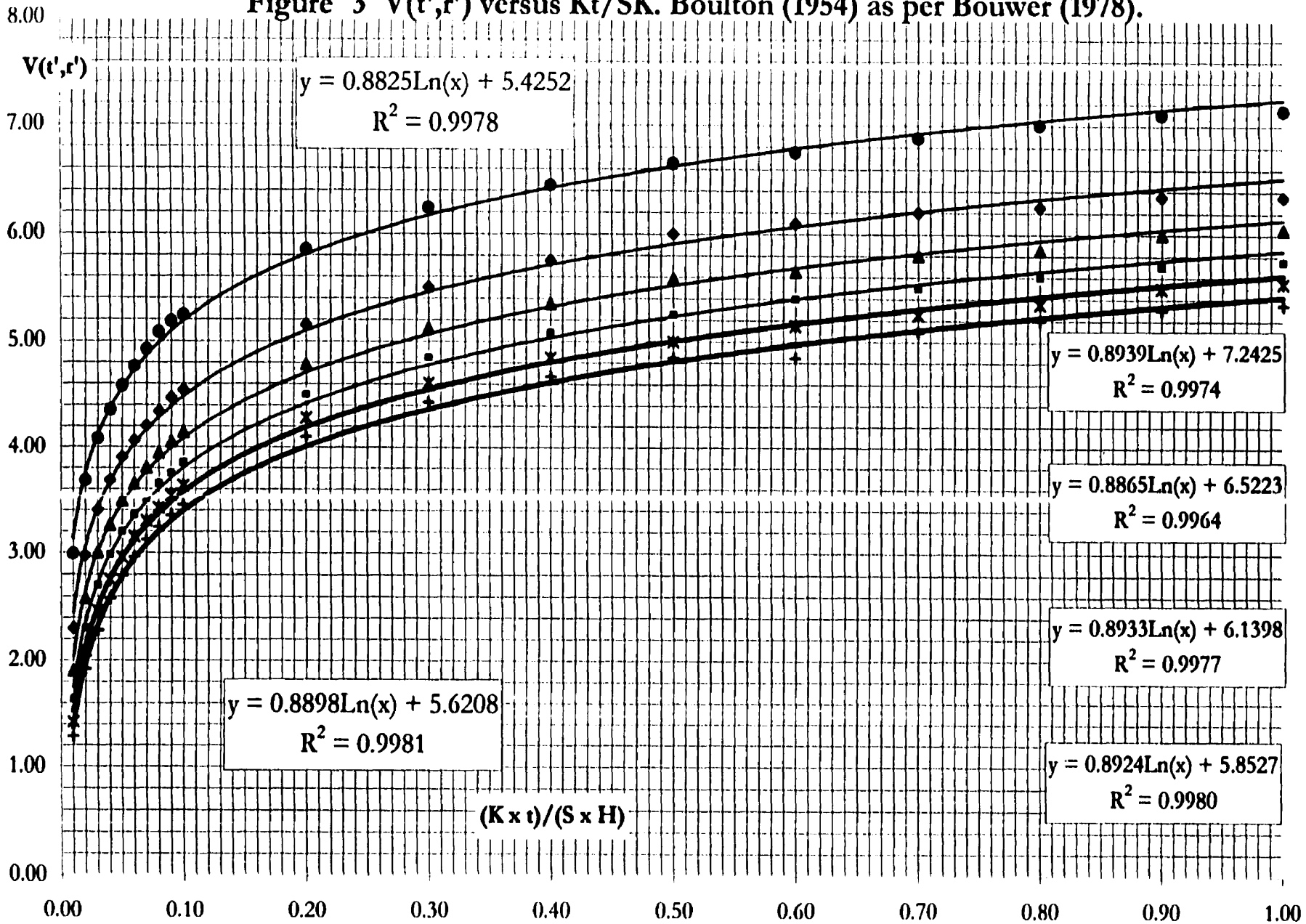
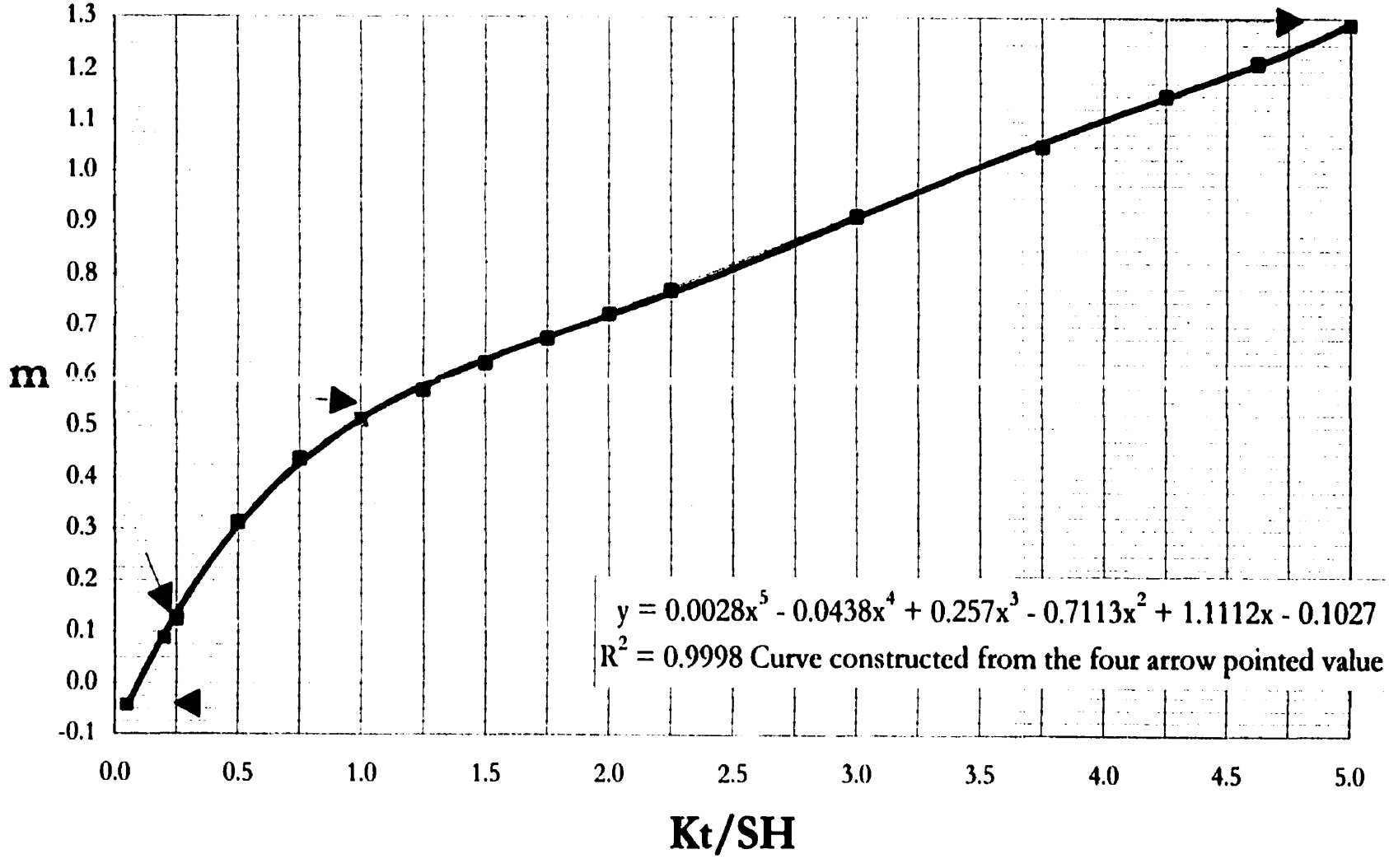
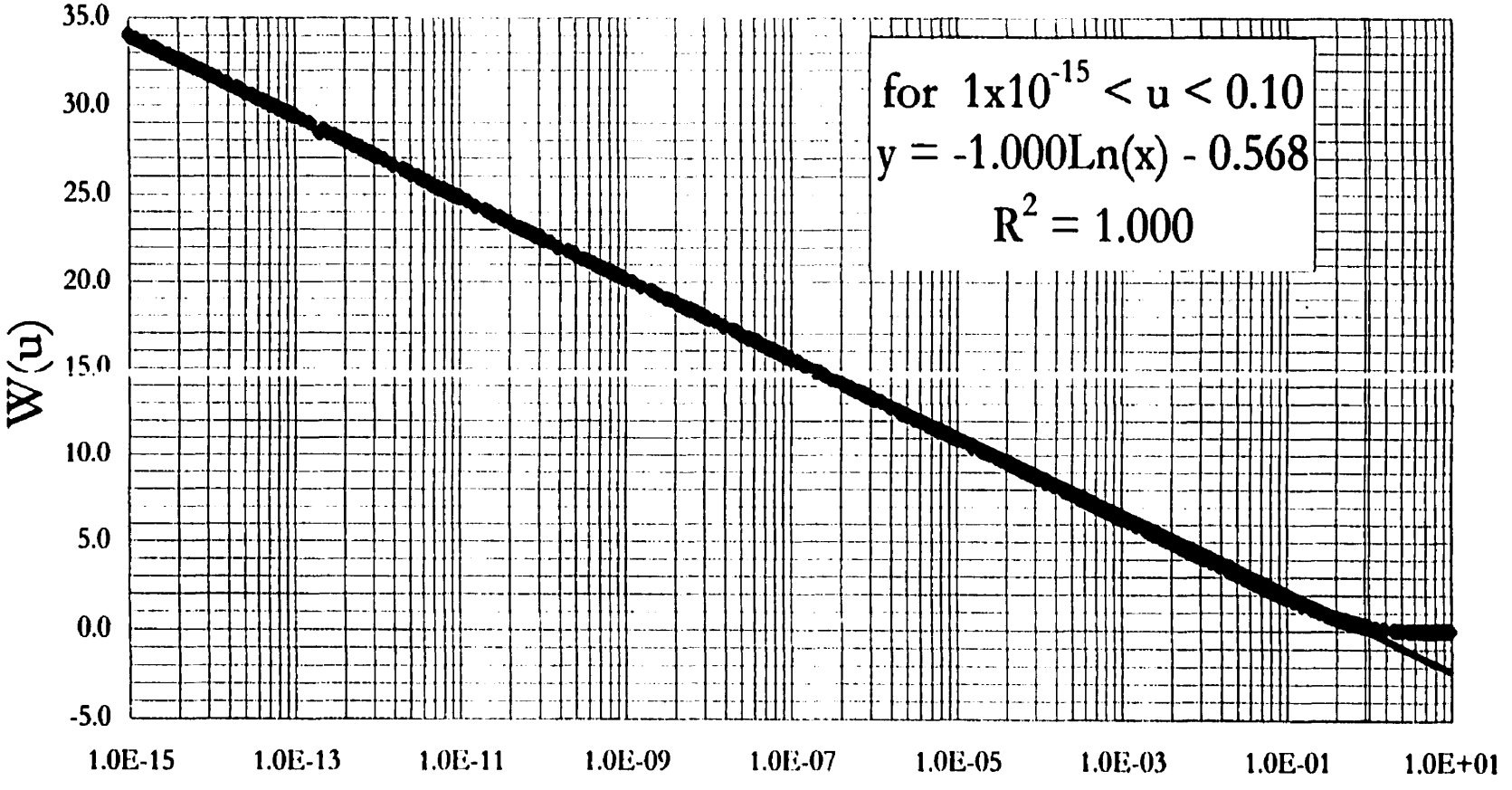


FIGURE 4 " m " versus " Kt/SH "
from Boulton (1954) as reported by Bouwer (1978)



File: W(u)final.xls

FIGURE 5 Values of " W(u) " for different values of "u"
Source Ferris et al.,1962 as tabulated by Bouwer (1978)



APPENDIX J

ESTIMATION OF K and T FROM GRAIN SIZE DISTRIBUTION .		**ESTIMATION OF S** FROM GRAIN SIZE
TABLE 1.	TLACOC4.	TABLE 20.
TABLE 2.	TLACOC6B.	TABLE 21.
TABLE 3.	TLACOC6.	TABLE 22.
TABLE 4.	TLACOC2B.	TABLE 23.
TABLE 5.	POB-6.	TABLE 24.
TABLE 6.	POB-1. Yagul.	TABLE 25.
TABLE 7.	POB-2. Santa Cruz Papalutla	TABLE 26.
TABLE 8.	PODOB-15. Diaz Ordaz.	TABLE 27.
TABLE 9.	POMB-35. Macuixochitl.	TABLE 28.
TABLE 10.	PORCB-54. Rijas de Cuauhtemoc.	TABLE 29.
TABLE 11.	POAB-59. San Sebastian Abasolo	TABLE 30
TABLE 12.	POCPB-60 . Santa Cruz Papalutla	TABLE 31
TABLE 13.	POTO-61. Tanivet	TABLE 32
TABLE 14.	POMIB-62. Mitla	TABLE 33
TABLE 15	POCPB-64.Santa Cruz Papalutla	TABLE 34
TABLE 16	POTB-66 Santa Maria El Tule	TABLE 35
TABLE 17	POMB-71. Mitla	TABLE 36
TABLE 18	POMB-72. Mitla	TABLE 37
TABLE 19	POMB-73. Mitla	TABLE 38

When compared with our results from well tests, the weighted mean values for the transmissivity is always larger. This was expected because the conductivity is function not only of the size of the pores but also of their disposition.

TABLE 1. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION TLACOC4.

TLACOC4	0.1 cl	0.3 cs	70 sg	100 bsg	150 bg	2 Tf	<- K_j Kb_i
depth (m)	4						0.2
depth (m)		6					1.8
depth (m)	2						0.1
depth (m)			3				210
depth (m)			7				490
depth (m)			6				420
depth (m)				4			400
depth (m)					6		900
depth (m)						6	12
SUM OF	Kb_i						2432
DEPTH OF CONFINED AQUIFER Properties							32
AVERAGE ESTIMATED K (m/d)							76
T (m^2/d)							2432

		Assumed K (m/d)	
cl	clay	0.05	CONF
cs	Plastic clay + Sands	0.3	CONF
sg	Small Gravels + Sand	70	Conf
bsg	Boulders + small gra	100	Conf
bg	Boulders + small gra	150	Conf
Tf	Fractured Rhyolite T	2	

TABLE 2. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION TLACOC6B

TLACOC6B	100 gs	1 sc	100 bg	0 cbT	2 bT	0 LU	Kb_i
depth (m)	6						600
depth (m)		2					2
depth (m)			10				1000
depth (m)				8			16
Confining layer			26	10			0.005
depth (m)						16	0
depth (m)						36	0
SUM OF	Kb_i						1618
DEPTH WITH AQUIFER PROPERTIES (m)							26
AVERAGE ESTIMATED K (m/d)							62
T (m^2/d)							1618

		Assumed K (m/d)	
gs	Gravels, Small Gr +	100	
sc	Sand with little cla	1	
bg	Boulders derived fro	100	
cbT	Clay with few boulde	0.0005	CONF
bT	Boulders derived fro	2	
LU	Lutita CLAYSTONE	0	

TABLE 3. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION TLACOC6

TLACOC6	100 gs	200 g	5 gc	50 bTQ	0 cl	50 bT	0.1 Lub					Assumed K (m/d)	
depth(m)	2							200	gs	Gravels, Small Gr +		100	Phreati
depth(m)		4						800	g	Gravels and Smal Gra		200	Phreati
depth(m)			2	2				110	gc	Gravels with little		5	Phreati
depth(m)		8						1600	bTQ	Boulders from Tuff R		50	Phreati
depth(m)						4		200	cl	Plastic Clay		1E-06	CONF
CLAY CONFINING LAYER 1					2			0.000002	bT	Boulders fderived fr		50	
depth(m)						14		700	Lub	Claystone Lutita fra		0.1	
depth(m)							43	4.3					
								81					
								44.620988					
TOP PHREATIC LAYER 1													
DEPTH OF PHREATIC AQUIFER								18					
AVERAGE ESTIMATED K (m/d)								162					
T								2910					
CLAY CONFINING LAYER 2													
SUM OF Kb_i								704					
DEPTH OF CONFINED AQUIFER Properties								57					
AVERAGE ESTIMATED K (m/d)								12					
T (m^2/d)								704					

TABLE 4. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION TLACOC2B

TLACOC2b	0.1 cl	70 sg	100 gs	100 ggb	bT	bG	Gf	G					K (m/d)	S %
depth(m)	4								0.2		cl	clay, plastic clay.	0.05	CONFININ
depth(m)		10							3		sg	Sands and small gravels	70	CONF
depth(m)			6						420		gs	Gravels + Small Gravels	70	Conf
depth(m)				10		10			1020		ggb	Gravels and Boulders + s	100	Conf
depth(m)					4				600		bT	Boulders derived from Tu	150	Conf
depth(m)						10			20		bG	Boulders derived from gr	20	Conf
depth(m)							8		0		Gf	Fractured granite.	10	
depth(m)								24	0		G	Healthy granite.	0	Aquitard
SUM OF	Kb_i								2063					
DEPTH OF	CONFINED	AQUIFER	Properties						58					
AVERAGE	ESTIMATED	K	(m/d)						35.569					
T (m^2/d)									2063					

TABLE 5. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION POB-6.

POB-6	10 20 gs	0.1 10 sgc	0.1 2 Gf	0 0 G	0	0	0	<- K_j Kb_i	<- S Sbi			K (m/d)	S %
depth(m)	20							200	400	gs	gravels and sands	10	20
depth(m)		83						8.3	830	sgc	sand+gravels+clay	0.1	10
depth(m)			7					0.35	14	Gf	Granite fractured	0.05	2
depth(m)				9				0	0	G	Granite	0	0
depth(m)								0					
depth(m)								0					
depth(m)								0					
SUM OF	Kb_i							208.65	1244				
DEPTH OF	UNCONFINED	AQUIFER	Properti					119	119				
AVERAGE	ESTIMATED	K	(m/d)					1.8	10.5		<- Average S % of phreatic zone		
T (m^2/d)								208.7					

TABLE 6. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION POB-1. YAGUL.

POB-1	10 gc	0 Tlu	0 gcc	0	0	0	0	<- K_j Kb_i			Assumed K (m/d)
depth(m)	28							280	gc	Gravels + clay	10
depth(m)		##						2.66	Tlu	Tuff and Lutita(clay	0.01
depth(m)			##					0	gcc	Gravels + plastic c	0
depth(m)								0	0		
depth(m)								0	0		
depth(m)								0	0		
depth(m)								0	0		
depth(m)								0	0		
depth(m)								0			
SUM OF	Kb_i							282.66			
DEPTH OF UNCONFINED AQUIFER Properti								294			
AVERAGE ESTIMATED K (m/d)								1.0			
T (m^2/d)								282.7			

TABLE 7. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION POB-2. Sta Cruz Papalutla

POB-2	10 sg	10 gs	0 R	0 Rc	0	0	0	0	<- K_j Kb_i			Assumed K (m/d)
depth(m)	22								220	sg	Sands and Small Grav	10
depth(m)		28							280	gs	Samall gravels and S	10
depth(m)			10						0	R	Rhyolite dense.	0
depth(m)				19					0	Rc	Rhyolite and clay in	0
depth(m)									0			
depth(m)									0			
depth(m)									0			
depth(m)									0			
depth(m)									0			
SUM OF	Kb_i								500			
DEPTH OF UNCONFINED AQUIFER Properti									79.5			
AVERAGE ESTIMATED K (m/d)									6.3			
T (m^2/d)									500			

TABLE 8. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION . PODOB-15 DIAZ ORDAZ.

PODOB-15	10	0	0	0	0	0	0	0	<- K_j			Assumed K
	s								Kb_i			(m/d)
depth(m)	40								400	s	Sands.	10
depth(m)									0	0	AQUITARD NOT REACHED	
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0			
SUM OF	Kb_i								400			
DEPTH OF	UNCONFINED		AQUIFER		Properti				40			
AVERAGE	ESTIMATED		K	(m/d)					10			
T (m^2/d)									400			

TABLE 9. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION . POMB-35 Macuilxochitl

POMB-35	2	0.1	0	0	0	0	0	0	<- K_j			Assumed K
	ND	Li	gcc						Kb_i			(m/d)
depth(m)	3								6	ND	Not defined. Vegetal	2
depth(m)		##							18.85	**Li**	**Limestone**	**0.1**
depth(m)									0	gcc	Gravels + plastic c	0
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
SUM OF	Kb_i								24.85			
DEPTH OF	UNCONFINED		AQUIFER		Properti				191.5			
AVERAGE	ESTIMATED		K	(m/d)					0.129765			
T (m^2/d)									24.85			

TABLE 10.ESTIMATING K & T from GRAIN SIZE DISTRIBUTION.PORCB-54 Rojas de Cuahutemoc.

PORCB-54	10	0.1	0	0	0	0	0	0	<- K_j			Assumed K
	ND	Sc	Lu						Kb_i			(m/d)
depth(m)	4								40	ND	Not defined. Vegetal	2
depth(m)		51							5.1	Sc	Fine sand 90% Clay 1	0.1
depth(m)			10						0	Lu	Claystone. Gray colo	0
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
SUM OF	Kb_i								45.1			
DEPTH OF UNCONFINED AQUIFER Properti									65			
AVERAGE ESTIMATED K (m/d)									0.6938462			
T (m^2/d)									45.1			

TABLE11.ESTIMATING K & T from GRAIN SIZE DISTRIBUTION.POAB-59 San Sebastian Abasolo.

POAB-59	100	0.1	0.1	0	0	0	0	0	<- K_j			Assumed K
	bLi	sT	LuS						Kb_i			(m/d)
depth(m)	1								100	bLi	Boulders derived fro	100
depth(m)		10							1	sT	fine granular deived	0.1
depth(m)			##						29	LuS	Claystone Lutita and	0.1
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
SUM OF	Kb_i								130			
DEPTH OF UNCONFINED AQUIFER Properti									301			
AVERAGE ESTIMATED K (m/d)									0.4318937			
T (m^2/d)									130			

TABLE12.ESTIMATING K and T from GRAIN SIZE DISTRIBUTION.POCPB-60 Sta Cruz Paplutla.

POCPB-60	0.1	0.1	0.5	5	0.5	1	0	0	<- K_j			Assumed K
	ND	sf	sA	sg	sA	s?			Kb_i			(m/d)
depth(m)	1								0.05	ND	Not defined. Vegetal	0.1
depth(m)		24							2.4	sf	Fine sands.	0.1
depth(m)			24						12	sA	volcanic ashes, fine	0.5
depth(m)				22					110	sg	**sands and gravel**	5
depth(m)					24				12	sA	volcanic ashes, fine	0.5
depth(m)						7			7	s?	Sand derived from ?	1
depth(m)									0	0	AQUITARD NOT REACHED	
depth(m)									0	0		
depth(m)									0			
SUM OF	Kb_i								143.45			
DEPTH OF UNCONFINED AQUIFER Properti									101.5			
AVERAGE ESTIMATED K (m/d)									1.4			
T (m^2/d)									143.5			

TABLE 13. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION . POTO-61 Tanivet

POTO-61	1	0	0	0	0	0	0	0	<- K_j			Assumed K
	S	Lu							Kb_i			(m/d)
depth(m)	24								24	S	Sandstone little fra	1
depth(m)		##							2.76	Lu	Lutita(claystone).	0.01
depth(m)									0	0		0
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
SUM OF	Kb_i								26.8			
DEPTH OF UNCONFINED AQUIFER Properti									300			
AVERAGE ESTIMATED K (m/d)									0.09			
T (m^2/d)									26.8			

TABLE 14. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION . POMIB-62 MITLA.

POMIB-62	1	10	0.2	0	0	0	0	0	<- K_j			Assumed K
	ND	s	TR						Kb_i			(m/d)
depth (m)	5								5	ND	Not defined. Vegetal	1
depth (m)		39							390	s	Sands	10
depth (m)			##						51.2	TR	Rhyolite Tuff	0.2
depth (m)									0	0		
depth (m)									0	0		
depth (m)									0	0		
depth (m)									0	0		
depth (m)									0	0		
SUM OF	Kb_i								446.2			
DEPTH OF UNCONFINED AQUIFER Properti									300			
AVERAGE ESTIMATED K (m/d)									1.5			
T (m^2/d)									446.2			

TABLE 15. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION. POCPB-64 Sta Cruz Paplutla.

POCPB-64	0	0.1	0.2	2	0.2	0.1	0	0	<- K_j			Assumed K
		s	Ta	sT	Ta	sc			Kb_i			(m/d)
depth (m)		30							3			
depth (m)			52						10.4	s	Sands fine	0.1
depth (m)				22					44	Ta	Tuff andesitic	0.2
depth (m)					34				6.8	sT	Grains medium size.	2
depth (m)						34			3.37	Ta	Andesitic Tuff	0.2
depth (m)									0	sc	Sands fine and mediu	0.1
depth (m)									0	0		
depth (m)									0	0		
depth (m)									0			
SUM OF	Kb_i								67.57			
DEPTH OF UNCONFINED AQUIFER Properti									171.7			
AVERAGE ESTIMATED K (m/d)									0.4			
T (m^2/d)									67.6			

TABLE 16.ESTIMATING K and T from GRAIN SIZE DISTRIBUTION.POTB-66 Sta Maria El Tule.

POTB-66	1	2	0	0	0	0	0	0	<- K_j			Assumed K
	ND	sLi	s?	Sl					Kb_i			(m/d)
depth (m)	6								6	ND	Not defined. Vegetal	1
depth (m) ->		22							44	sLi	Sands fine and medim	2
depth (m) ->			58						0	s?	sands derived from ?	0
depth (m) ->				12					0	Sl		
depth (m) ->									0	0		
depth (m) ->									0	0		
depth (m) ->									0	0		
depth (m) ->									0	0		
SUM OF	Kb_i								50			
DEPTH OF UNCONFINED AQUIFER Propertie									86			
AVERAGE ESTIMATED K (m/d)									0.6			
T (m^2/d)									50.0			

TABLE 17. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION . POMB-71 MITLA.

POMB-71	10	0	0	0	0	0	0	0	<- K_j			Assumed K
	sR								Kb_i			(m/d)
depth(m)	31								310	sR	Granular like hetero	10
depth(m)									0	0		
depth(m)									0	0	AQUITARD NOT REACHED.	
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
depth(m)									0	0		
SUM OF	Kb_i								310			
DEPTH OF UNCONFINED AQUIFER Propertie									31			
AVERAGE ESTIMATED K (m/d)									10.0			
T (m^2/d)									310.0			

TABLE 18. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION . POMB-72 MITLA.

PMB-72	10	0	0	0	0	0	0	0	<- K_j				Assumed K
	sR								Kb_i				(m/d)
depth(m)	28								280	sR	Granular like hetero		10
depth(m)									0	0			
depth(m)									0	0	AQUITARD NOT REACHED.		
depth(m)									0	0			
depth(m)									0	0			
depth(m)									0	0			
depth(m)									0	0			
depth(m)									0	0			
depth(m)									0				
SUM OF	Kb_i								280				
DEPTH OF	UNCONFINED	AQUIFER	Properti						28				
AVERAGE	ESTIMATED	K	(m/d)						10.0				
T (m^2/d)									280.0				

TABLE 19. ESTIMATING K and T from GRAIN SIZE DISTRIBUTION . POMB-73 MITLA.

PMB-73	0.5	0	0	0	0	0	0	0	<- K_j				Assumed K
	R								Kb_i				(m/d)
depth(m)	86								43	R	Rhyolite. Volcanic r		0.5
depth(m)									0	0			0
depth(m)									0	0			0
depth(m)									0	0			
depth(m)									0	0			
depth(m)									0	0			
depth(m)									0	0			
depth(m)									0	0			
depth(m)									0				
SUM OF	Kb_i								43				
DEPTH OF	UNCONFINED	AQUIFER	Properti						86				
AVERAGE	ESTIMATED	K	(m/d)						0.5				
T (m^2/d)									43.0				

TABLE 20. ESTIMATING S from depth of confined aquifer TLACOC4. Tlacochahuaya

TLACOC4	1 cl	12 cs	25 sg	30 bsg	30 bg	1 Tf	<- S_j Sb_i
depth(m)	4						4
depth(m)		6					72
depth(m)	2						2
depth(m)			3				75
depth(m)			7				175
depth(m)			6				150
depth(m)				4			120
depth(m)					6		180
depth(m)						6	6
SUM OF Sb_i							706
DEPTH OF CONFINED AQUIFER							32
AVERAGE ESTIMATED S in %							**22.1**
IF CONFINED Storage Coeff.							9.22E-04

		Assumed S %	
cl	clay	1	**CONF**
cs	Plastic clay + Sands	12	**CONF**
sg	Small Gravels + Sands	25	conf
bsg	Boulders + small gravels +san	30	conf
bg	Boulders + small gravels	30	conf
Tf	Fractured Rhyolite Tuff.	1	conf
	LEVEL ?		
	STORAGE COEEFICIENT		**St Coeff**
	$S=1.8\times10^{-5}(d_2-d_1) + 8.6\times10^{-4}(d_2^{0.5}-d_1^{0.5})$ =		9.22E-04
		d2	d1
		44	12

TABLE 21. ESTIMATING S from GRAIN SIZE DISTRIBUTION TLACOC6B

TLACOC6E	25 gs	10 sc	30 bg	10 cbT	15 bT	0 LU	<- S_j Sb_i
depth(m)	6						150
depth(m)		2					20
depth(m)			10				300
depth(m)					8		120
Confining layer			26	10			100
depth(m)						16	0
depth(m)						36	0
SUM OF Sb_i							590
DEPTH OF CONFINED AQUIFER							26
AVERAGE ESTIMATED S in %							**22.7**

		Assumed S %	
gs	Gravels, Small Gr + Sand	25	UNCONF
sc	Sand with little clay binding	10	UNCONF
bg	Boulders derived from Gravel	30	UNCONF
cbT	Clay with few boulders from T	10	LEAKY
bT	Boulders derived from Tuff(To	15	leaky
LU	Lutita CLAYSTONE	0	

TABLE 22. ESTIMATING S from GRAIN SIZE DISTRIBUTION TLACOC6

TLACOC6	25 gs	25 g	10 gc	10 bTQ	0.1 cl	10 bT	1 Lub	<- S_j Sb_i
depth(m)	2							50
depth(m)		4						100
depth(m)			2	2				40
depth(m)		8						200
depth(m)						4		40
CLAY CONFINING LAYER 1					**2**			0.2
depth(m)						14		140
depth(m)							43	43
								81
TOP PHREATIC LAYER 1								
DEPTH OF PHREATIC AQUIFER								18
AVERAGE ESTIMATED S in %								**23.9**
CLAY CONFINING LAYER 2								
SUM OF Sb_i								183
DEPTH OF CONFINED AQUIFER Properties								57
AVERAGE ESTIMATED S in %								1.93E-03

		Assumed S %	
gs	Gravels, Small Gr + Sand	25	UNCONF
g	Gravels and Small Gravels	25	UNCONF
gc	Gravels with little clay	10	UNCONF
bTQ	Boulders from Tuff Rhyo +Quar	10	UNCONF
cl	Plastic Clay	0.1	CONF
bT	Boulders fderived from Tuff R	10	conf
Lub	Claystone Lutita fractured wi	1	conf

STORAGE COEEFICIENT **St Coeff**

$S=1.8x10^{-6}(d_2-d_1) +8.6x10^{-4}(d_2^{0.3}-d_1^{0.3})$ = 1.93E-03

d2	d1
57	2

TABLE 23. ESTIMATING S from GRAIN SIZE DISTRIBUTION TLACOC2B TLACOCHAHUAYA

TLACOC2E	1	30	100	20					<- S_j			Maybe Leaky, confined or unco	Assumed S	
	cl	sg	gs	ggb	bT	bG	Gf	G	Sb_i			depending on SEASON (WTD)	%	
depth (m)	4								4	cl	clay, plastic clay.		1	**CONF**
depth (m)		12							144	sg	Sands and small gravels		30	conf
depth (m)			6						150	gs	Gravels + Small Gravels +sand		30	Conf
depth (m)				10		10			310	ggb	Gravels and Boulders + small		20	Conf
depth (m)					4				120	bT	Boulders derived from Tuff.		25	Conf
depth (m)						10			10	bG	Boulders derived from granite		5	Conf
depth (m)							8		0	Gf	Fractured granite.		1	Conf
depth (m)								24	0	G	Healthy granite.		0	**Aquitard**
SUM OF	Sb_i								734		STORAGE COEEFICIENT			**St Coeff**
DEPTH OF	AQUIFER								60		$S=1.8x10^{-5}(d_2-d_1) + 8.6x10^{-4}(d_2^{0.5}-d_1^{0.5})$		=	1.73E-03
AVERAGE	ESTIMATED	S if Unconfined						i	12.2				d2	d1
AVERAGE	ESTIMATED	Storage Coeff.							1.73E-03				60	4

TABLE 24. ESTIMATING S from GRAIN SIZE DISTRIBUTION POB-6. ZAACHILA

POB-6	25	15	5	0	0	0	0	<- S_j			Assumed S	
	gs	sgc	Gf	G				Sb_i			%	
depth (m)	20							500	gs	gravels and sands	25	UNCONF
depth (m)		83						1245	sgc	sand+gravels+clay	15	UNCONF
depth (m)			7					35	Gf	Granite fractured	5	UNCONF
depth (m)				9				0	G	Granite sound	0	AQUITARD
depth (m)								0				
depth (m)								0				
depth (m)								0				
SUM OF	Sb_i							1780				
DEPTH OF	AQUIFER							119				
AVERAGE	ESTIMATED	S in %						15.0				

TABLE 25. ESTIMATING S from GRAIN SIZE DISTRIBUTION POB-1. YAGUL.

POB-1	10	1	1	0	0	0	0	<- S_j			Assumed S	
	gc	Tlu	gcc					Sb_i			%	
depth(m)	28							280	gc	Gravels + clay	10	UNCONF
depth(m)		266						266	Tlu	Tuff and Lutita(claystone).	1	UNCONF
depth(m)			113					112.6	gcc	Gravels + plastic clay. Ceme	1	AQUITARD
depth(m)								0	0			
depth(m)								0	0			
depth(m)								0				
SUM OF Sb_i								658.6				
DEPTH OF AQUIFER								294				
AVERAGE ESTIMATED S in %								2.2				

TABLE 26. ESTIMATING S from GRAIN SIZE DISTRIBUTION POB-2.Sta Cruz Papalutla

POB-2	30	30	0	0	0	0	0	0	<- S_j			Assumed S	
	sg	gs	R	Rc					Sb_i			%	
depth(m)	22								660	sg	Sands and Small Gravels	30	UNCONF
depth(m)		28							840	gs	Small gravels and Sands.	30	UNCONF
depth(m)			10						0.1	R	Rhyolite dense.	0.01	AQUITARD
depth(m)				19					0	Rc	Rhyolite and clay interlayers		
depth(m)									0				
SUM OF Sb_i									1500.1				
DEPTH OF AQUIFER									79.5				
AVERAGE ESTIMATED S in %									18.9				
									1500.1				

TABLE 27. ESTIMATING S from GRAIN SIZE DISTRIBUTION . PODOB-15 DIAZ ORDAZ.

PODOB-15	20	0	0	0	0	0	0	0	<- S_j			Assumed S	
	s								Sb_i			%	
depth (m)	40								800	s	Sands.	20	UNCONF
depth (m)									0		AQUITARD NOT REACHED		
depth (m)									0				
depth (m)									0				
SUM OF Sb_i									800				
DEPTH OF AQUIFER									40				
AVERAGE ESTIMATED S in %									20.0				
									800				

TABLE 28. ESTIMATING S from GRAIN SIZE DISTRIBUTION . POMB-35 Macuilxochitl

POMB-35	10	2	5	0	0	0	0	0	<- S_j			Assumed S	
	ND	Li	qcc						Sb_i			%	
depth (m)	3								30	ND	Not defined. Vegetal cover.	10	UNCONF
depth (m)		189							377	**Li**	**Limestone**	**2**	UNCONF
depth (m)									0	gcc	Gravels + plastic clay. Ceme	5	AQUITARD
depth (m)									0				
SUM OF Sb_i									407				
DEPTH OF AQUIFER									191.5				
AVERAGE ESTIMATED S in %									2.1				

TABLE 29. ESTIMATING S from GRAIN SIZE DISTRIBUTION.PORCB-54 Rojas de Cuahutemoc.

PORCB-54	10	15	0.1	0	0	0	0	0	<- S_j			Assumed S	
	ND	sc	Lu						Sb_i			%	
depth(m)	4								40	ND	Not defined. Vegetal cover.	10	UNCONF
depth(m)		51							765	sc	Fine sand 90% Clay 10%	15	UNCONF
depth(m)			10						1	Lu	Claystone. Gray color	0.1	AQUITARD
depth(m)									0				
SUM OF	Sb_i								806				
DEPTH OF	AQUIFER								65				
AVERAGE	ESTIMATED	S	in %						12.4				

TABLE 30. ESTIMATING S from GRAIN SIZE DISTRIBUTION.POAB-59 San Sebastian Abasolo.

POAB-59	15	15	0.5	0	0	0	0	0	<- S_j			Assumed S	
	bLi	sT	LuS						Sb_i			%	
depth(m)	1								15	bLi	Boulders derived from Limesto	15	UNCONF
depth(m)		10							150	sT	fine granular deived from vol	15	UNCONF
depth(m)			290						145	LuS	Claystone Lutita and Sandston	0.5	AQUITARD
depth(m)									0				
SUM OF	Sb_i								310				
DEPTH OF	AQUIFER								301				
AVERAGE	ESTIMATED	S	in %						1.0				

TABLE 31. ESTIMATING S from GRAIN SIZE DISTRIBUTION. POCPB-60 Sta Cruz Paplutla.

POCPB-60	10	15	5	25	5	10	0	0	<- S_j			Assumed S	
	ND	sf	sA	sg	sA	s?			Sb_i			%	
depth(m)	0.5								5	ND	Not defined. Vegetal cover.	10	UNCONF
depth(m)		24							360	sf	Fine sands.	15	UNCONF
depth(m)			24						120	sA	Volcanic ashes, fine sand tex	5	LEAKY
depth(m)				22					550	sg	**Sands and gravel**	25	leaky
depth(m)					24				120	sA	Volcanic ashes, fine sand tex	5	LEAKY
depth(m)						7			70	s?	Sand derived from ?	10	leaky
depth(m)									0	0	AQUITARD NOT REACHED		
depth(m)									0	0			
depth(m)									0				
SUM OF	Sb_i								1225				
DEPTH OF	AQUIFER								101.5				
AVERAGE	ESTIMATED	S	in %						12.1				

TABLE 32. ESTIMATING S from GRAIN SIZE DISTRIBUTION . POTO-61 Tanivet

POTO-61	5	0.1	0	0	0	0	0	0	<- S_j			Assumed S	
	S	Lu							Sb_i			%	
depth(m)	24								120	S	Sandstone little fractured	5	UNCONF
depth(m)		276							27.6	Lu	Lutita(claystone).	0.1	AQUITARD
depth(m)									0	0			
SUM OF	Sb_i								147.6				
DEPTH OF	AQUIFER								300				
AVERAGE	ESTIMATED	S	in %						0.5				

TABLE 33. ESTIMATING S from GRAIN SIZE DISTRIBUTION . POMIB-62 MITLA.

POMIB-62	10	20	1	0	0	0	0	0	<- S_j			Assumed S	
	ND	s	TR						Sb_i			%	
depth (m)	5								50	ND	Not defined. Vegetal cover.	10	UNCONF
depth (m)		39							780	s	Sands	20	UNCONF
depth (m)			256						256	TR	Rhyolite Tuff	1	UNCONF
depth (m)									0				
SUM OF	Sb_i								1086				
DEPTH OF	AQUIFER								300				
AVERAGE	ESTIMATED	S	in %						3.6				

TABLE 34. ESTIMATING S from GRAIN SIZE DISTRIBUTION.POCPB-64 Sta Cruz Papalutla.

POCPB-64	0	20	5	15	2	10	0	0	<- S_j			Assumed S	
		sf	Ta	sT	Ta	sc			Sb_i			%	
depth (m)		30							600				
depth (m)			52						260	sf	Sands fine	20	UNCONF
depth (m)				22					330	Ta	Tuff andesitic	5	UNCONF
depth (m)					34				68	sT	Grains medium size.Volcanic	15	UNCONF
depth (m)						34			337	Ta	Andesitic Tuff	2	UNCONF
depth (m)									0	sc	Sands fine and medium with cl	10	UNCONF
depth (m)									0		AQUITARD NOT REACHED ?		
SUM OF	Sb_i								1595				
DEPTH OF	AQUIFER								171.7				
AVERAGE	ESTIMATED	S	in %						9.3				

TABLE 35. ESTIMATING S from GRAIN SIZE DISTRIBUTION.POTB-66 Sta Maria El Tule.

POTB-66	10	15	15	0	0	0	0	0	<- S_i			Assumed S	
	ND	sLi	s?	Sl					Sb_i			%	
depth (m	6								60	ND	Not defined. Vegetal cover.	10	UNCONF
depth (m)->		22							330	sLi	Sands fine and medium calcare	15	UNCONF
depth (m)->			58						870	s?	Granular material obtained fr	15	UNCONF
depth (m)->				12					0		AQUITARD NOT REACHED ?		
depth (m)->									0				
SUM OF Sb_i									1260				
DEPTH OF AQUIFER									86				
AVERAGE ESTIMATED S in %									14.7				

TABLE 36. ESTIMATING S from GRAIN SIZE DISTRIBUTION . POMB-71 MITLA - Tanivet.

POMB-71	15	0	0	0	0	0	0	0	<- S_i			Assumed S	
	sR								Sb_i			%	
depth(m)	31								465	sR	Granular like heterogeneous s	15	UNCONF
depth(m)									0				
depth(m)									0		AQUITARD NOT REACHED.		
depth(m)									0				
SUM OF Sb_i									465				
DEPTH OF AQUIFER									31				
AVERAGE ESTIMATED S in %									15.0				

TABLE 37. ESTIMATING S from GRAIN SIZE DISTRIBUTION . POMB-72 MITLA- Tanivet.

PMB-72	15	0	0	0	0	0	0	0 <- S_j			Assumed S	
	sR							Sb_i			%	
depth(m)	28							420	sR	Granular like heterogeneous s	15	UNCONF
depth(m)								0				
depth(m)								0		AQUITARD NOT REACHED.		
depth(m)								0				
SUM OF Sb_i								420				
DEPTH OF AQUIFER								28				
AVERAGE ESTIMATED S in %								15.0				

TABLE 38. ESTIMATING S from GRAIN SIZE DISTRIBUTION . POMB-73 MITLA - Tanivet.

PMB-73	5	0	0	0	0	0	0	0 <- S_j			Assumed	UNCONF
	R							Sb_i			%	
depth(m)	86							430	R	Rhyolite. Volcanic rock	5	UNCONF
depth(m)								0				
depth(m)								0				
SUM OF Sb_i								430				
DEPTH OF AQUIFER								86				
AVERAGE ESTIMATED S in %								5.0				

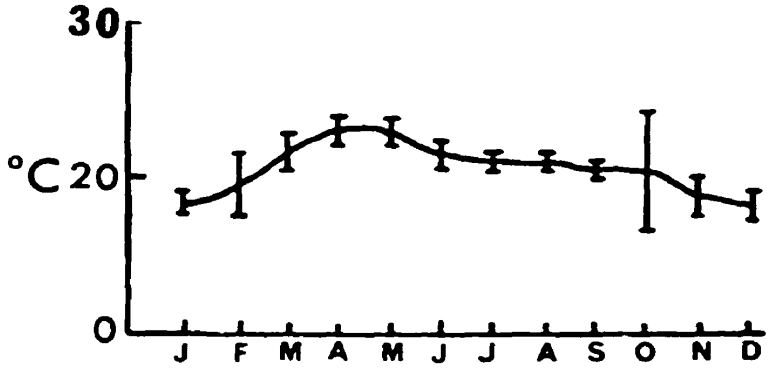
APPENDIX K

This Appendix contains one Table and five Figures reproduced from Kirkby (1973) . A summary of Kirkby's (1973) description of the four physiographic zones in the research area is also given. These Figures, Tables and notes are included because they contain basic observations on the research area which are used with observations made by the author as the basis of discussions in this thesis.

TABLE K1 CLIMATIC VARIATION WITH ALTITUDE AND WITHIN THE VALLEY FLOOR OF OAXACA VALLEYS.

Station	Altitude (m)	Mean Annual Temperature (°C)	Mean Annual Precipitation R (mm)	Total Degree-days above 6 °C (per annum)	Potential Evapo-transpira-tion (ET_0) (mm)	$\frac{R}{ET_0}$ (year)	$\frac{R}{ET_0}$ (3 summer months)	Frost-Free Period (months)	Natural Vegetation
TABLE (K1a) CLIMATIC VARIATION WITH ALTITUDE IN THE CENTRAL VALLEYS OF OAXACA.									
Cuajimoloyas	3110	8	1000	1000	340	2.9	6.9	0	pine
Tejocotes	2500	13	800	2500	720	1.1	3	0	pine-oak
Ixtepeji	2000	16	860	3600	1080	0.8	1.6	6.5	oak
Oaxaca	1540	21	630	5000	1890	0.34	0.81	12	mesquite grassland
TAB:E (K1b) CLIMATIC VARIATION WITHIN THE VALLEY FLOOR.									
Etla	1660	19	650	5000	1670	0.39	0.92	10	mesquite grassland
Tlacolula	1620	18	550	4500	2020	0.26	0.50	10	" "
Oaxaca	1540	21	630	5000	1890	0.34	0.81	12	" "
Ocotlán	1520	20	740	5000	1900	0.39	0.93	12	" "

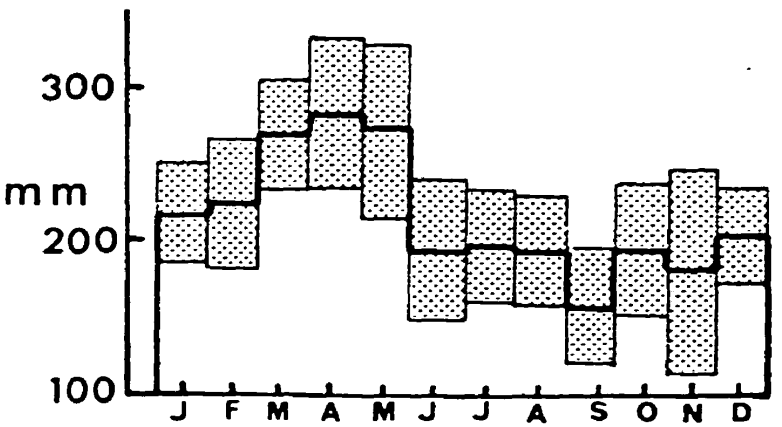
(After Kirby, 1973). *: Data have been corrected to include additional historical climatic data since Kirby (1973).



Temperature (°C)

Period of record 38yrs
Mean annual temperature
= 20·6°C
σ = 0·63
V = 3·1%

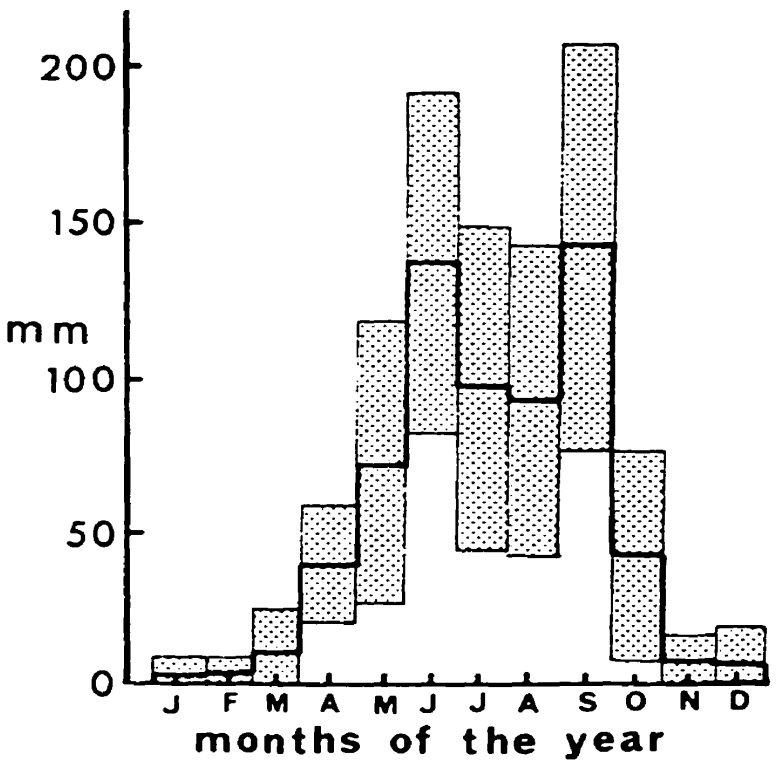
K1A



Mean monthly evaporation

Period of record 19yrs
Mean annual evaporation
= 2544mm
σ = 271
V = 10·6%

K1B



Mean monthly precipitation

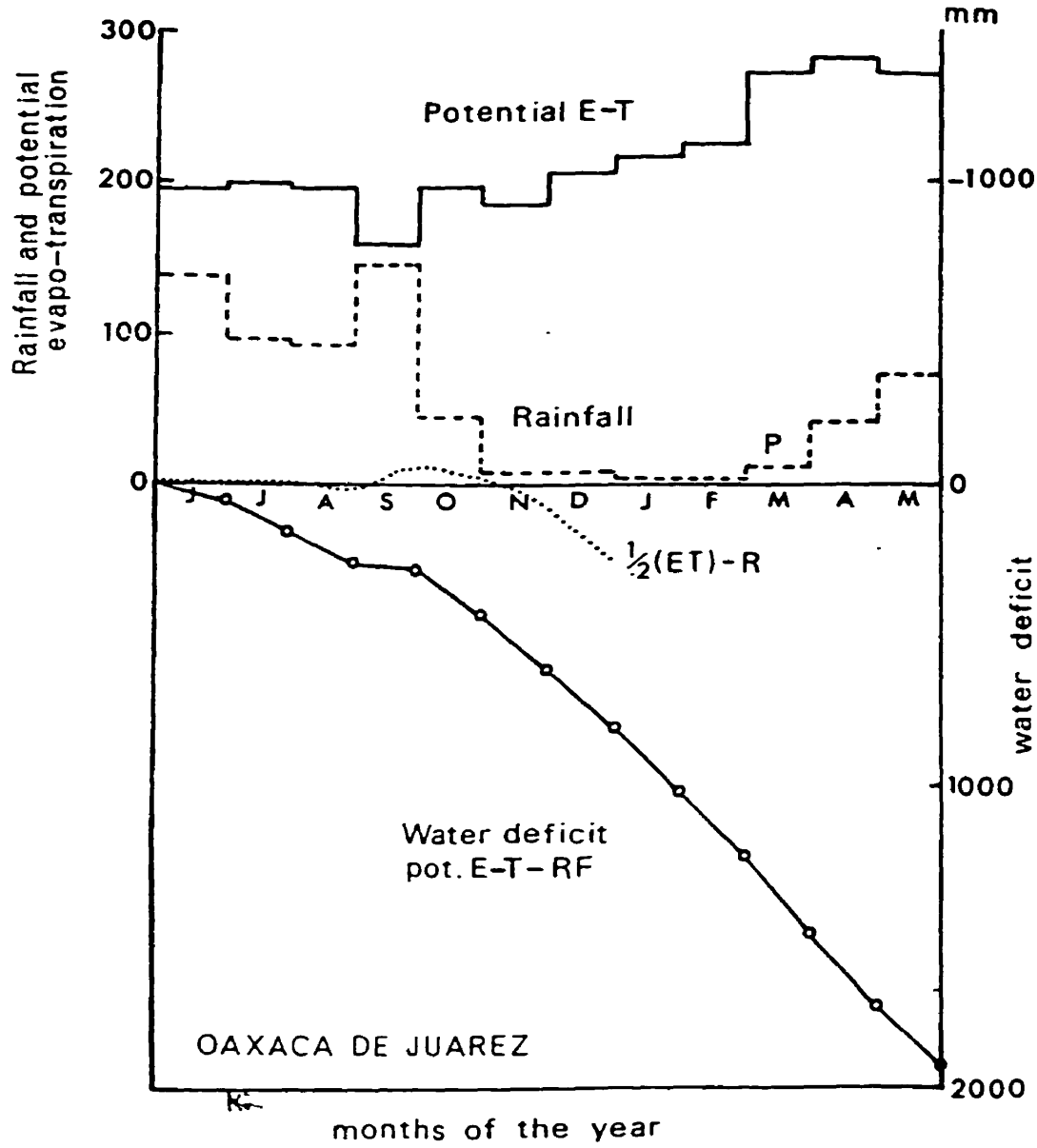
Period of record 40yrs
Mean annual precipitation
= 631·4 mm
σ = 134·1
V = 21·2%

Bars and shaded areas show one standard deviation above and below the mean.

K1C

OAXACA DE JUAREZ Altitude : 1540m

Fig K1 Climatic data for Oaxaca de Juárez: mean monthly values and one standard deviation of temperature, evaporation and rainfall. **From Kirby (1973).**



K2

Fig. Pattern of annual water deficit for Oaxaca de Juárez.
From Kirby (1973).

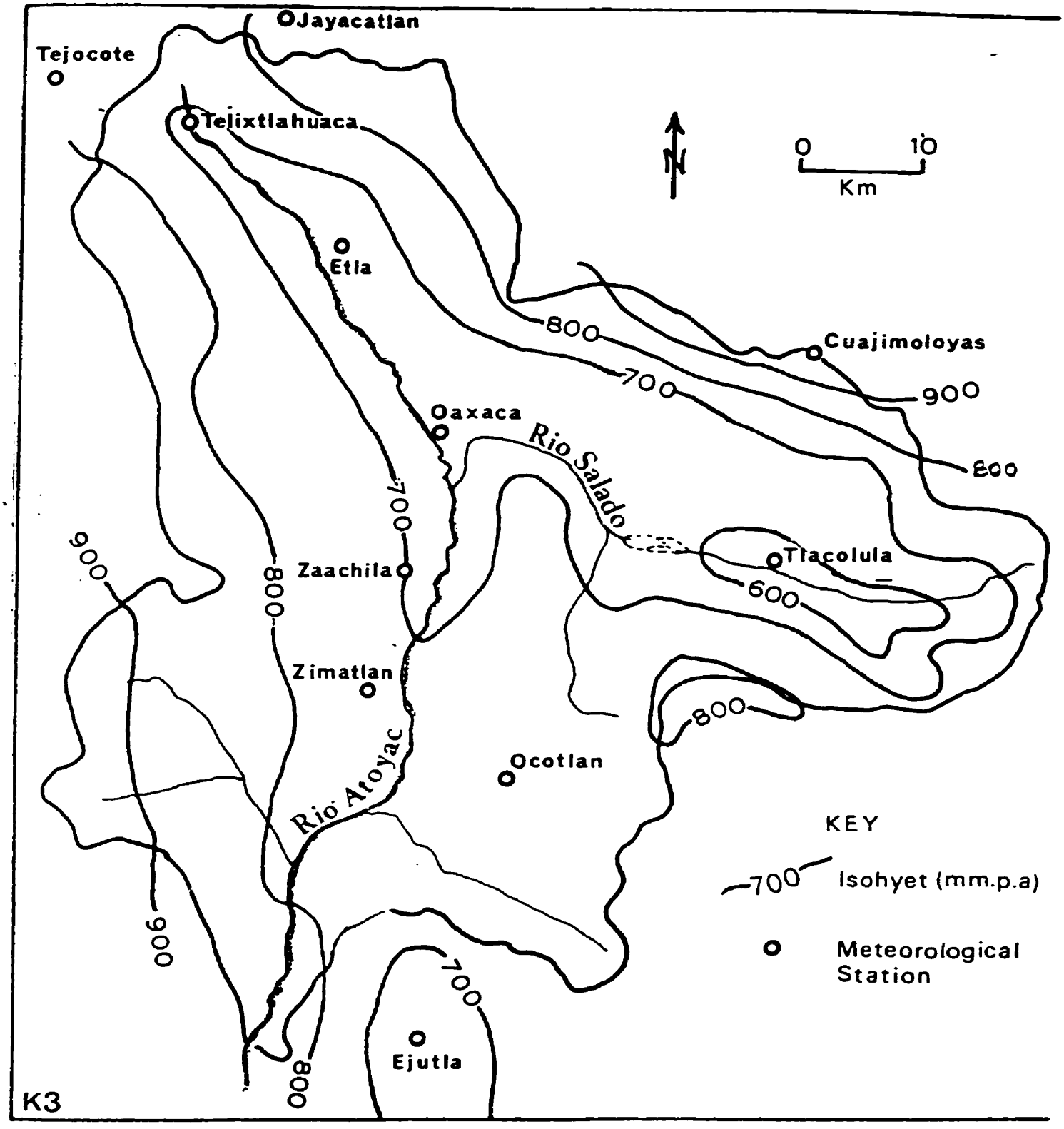


Fig. Rainfall map of the Valley of Oaxaca based on all available records and interpolation with respect to altitude. **From Kirby (1973).**

Notes TAKEN FROM PREHISTORY AND HUMAN ECOLOGY OF THE VALLEY OF OAXACA, MEXICO. Kirkby (1973).

[1]Land

According to Kirkby(1973), the most important criteria for distinguishing land for agriculture are gradient, altitude and soil. The type and density of natural vegetation were important in the past, but now the valley floor is continually under cultivation and clearing is only an important task in the mountains. On the basis of these criteria, the valley is divided into four physiographic zones: mountain, piedmont, high alluvium, and low alluvium.

The Mountain Zone

The mountain zone, with its lower temperatures and steep slopes is the least important agriculturally. Whatever the bedrock, soils in the mountains tend to be red in colour, very stony and variable in depth. Except near the villages, shifting agriculture is practiced. Terracing is not used, even on slopes steeper than 39 degrees. The mountains are used more as a collecting area for wood and wild fruits and making prepared charcoal than for cultivation. They are covered with high pine and oak forests which show a zonation of dominant species with increasing altitude from a broad-leafed oak woodland at 2000 to 2500 meters, to a mixed pine-oak forest at 2500 to 2700 meters, to a pine forest at altitudes above 2700 meters. CNA(1

The Piedmont

On the south side of the Tlacolula Valley the piedmont is wide and forms a continuous surface with gullies cut 20 meters into it rather than a series of separate spurs. The average slope of the piedmont from mountain to alluvium is 1 to 2 degrees with later dissection producing side slopes with gradients up to 20 to 30 degrees. The soils developed on the piedmont are poor for agriculture, mainly because they are very stony; and where the surface is cut on bedrock, there are commonly thin with out-crops of rock scattered over the slopes. Soils are usually red-brown in color, coarse textured and free draining.

---

[1] Piedmont.doc

Typical mechanical compositions range between 5 and 15 percent gravel, and 40 to 90 percent sand with 10 to 30 percent of the ground surface covered by stones greater than 25 mm in diameter. in some areas notably near Mitla in the Tlacolula Valley, where over 90 percent of the surface is covered by stones greater than 25 mm in diameter, surface stoniness makes agriculture impractical. Despite its inferiority to the valley alluvium for agriculture, the piedmont is extensively cultivated and, even more important, grazed by domestic animals so that the natural vegetation is partly or wholly destroyed.

It is typically more open today than the natural vegetation of either the alluvium or the mountains; so the piedmont may have been one of the easiest areas of the Valley for early cultivators to clear. Between 1800 to 2000 meters, however, the open mesquite grassland does give way to a thorn forest which is almost impenetrable when well developed, with several species of cactus and Agape. Above 2000 meters, piedmont vegetation is again more open with the thorny species giving way to narrow- and broad-leafed oaks which are easy to clear and not as well developed as the oak zone in the mountains proper.

Low Alluvium

The main rivers of the Valley are generally incised into the high alluvium to a depth of 1 to 3 meters, although below dams downcutting has reached 6 to 7 meters and at this lower level a new flood plain is presently forming. This flood plain, or low alluvium, is very restricted in area, occurring as a distinct geomorphic unit along less than 50 percent of the courses of the Río Atoyac and Río Salado, and attaining a maximum width of only 2.5 kilometers (in the Zaachila Valley). incision leading to the formation of the low alluvium did not begin until after A.D.1500 in the Zaachila Valley and as late as A.D.1800 upstream in the Etla Valley near Huitzo. Throughout most of the period of agriculture, therefore, the low alluvium does not exist.

Where the rivers are incised and the low alluvium is absent, the channel bed is bordered by a steep, sometimes near-vertical bank cut in the deposits of the high alluvium. Where the low alluvium is present, the 1 to 3 meter high difference between

the two levels is normally occupied by a gentle slope, degraded by natural slope processes and ploughing.

Soils of the low alluvium are similar to the sand soils of the high alluvium with pH of approximately 8.0 and little or no detectable profile development. Surface stoniness (greater than 25 mm diameter) increases towards the present river channels, and concentrations of gravel on or just below the surface indicate recent former positions of the bed. The river beds and most recent areas of deposition are usually pure sand and gravel and are locally excavated for these materials. The value of the low alluvium for agriculture depends primarily on its water resources rather than on its land characteristics since it is restricted in area, has poor soils and is liable to crop damage from flooding during the summer growing season.

High Alluvium

The high alluvium forms the main part of the valley floor and is the most important zone for agriculture both in quantity and quality. It varies in total with from 1 kilometer just north of Oaxaca de Juárez to 17 kilometers near Ocotlán (Fig.3). Within the high alluvium, the value of land for agriculture (apart from the consideration of water availability) varies with soil texture and with topography, principally in its effect on ground frost frequency.

In contrast with the mountain and piedmont zones, soils on the valley floor are always greater than 1 meter in depth, and soil thickness is nowhere a limiting factor for agriculture. Throughout the valley floor, soil profiles are poorly developed and retain their alluvial structure almost unaltered below the A horizon. Some salts accumulation is found in the B horizon, especially in the widest parts of the Valley where low gradients allow shallow depressions to contain standing water for several days or weeks after storms in the summer months.

The alluvial soils are always alkaline (pH 8.0-8.7) and low in humus and nutrients. Soil color is generally brown and tends toward red-brown in the better drained gravels and grey-brown in the more arid parts of the Valley. The general uniformity of the young valley soils in thickness, chemical composition and profile development has emphasized the importance to agriculture of textural differences; grain size largely

determines the water-holding characteristics of soil and therefore influences the amount of water available for crops from both groundwater and irrigation water.

The distribution of soil types by texture is shown in Figure 5. Generally grain size increases from the outer edge of the floor to the main river courses. The transition from piedmont fan soil to high alluvium soil is therefore commonly marked by an abrupt change in soil texture from stony sand in the piedmont to fine clay in the alluvium, and in the valley centre the course of the Rio Atoyac is outlined by a band of sand soils.

In detail the pattern is more complicated becasue the larger distributaries, which rise in the mountains and cross the piedmont, deposit aprons of gravels and sands on the outer edge of the high alluvium. These deposits may be sufficiently extensive to produce a continuous band of sandy soil along the outer edge of the alluvium as occurs, for example, on the western side of the valley near Zaachila.

In the central part of the Tlacolula Valley, the high alluvium soils are entirely fine grained; the usual band of sandy soil following the river course is absent. This is caused by the unusual hydrology if the area, During most summers, the Rio Salado does not flow in a single channel to join the Atoyac, but spreads across a wide area between San Juan Guelavia and San Sebastián Abasolo in a complicated pattern of braided channels and slowly moving sheets of water, producing a seasonal swamp in which clays are deposited (Pl.3.)

Silt soils are not widespread and occur in narrow discontinuous bands between the areas of sand and clay soils. Along major tributary valleys a characteristic sequence of decreasing grain size downstream is observed going from gravel soils to clay soils within a distance of 10 to 15 kilometers.

Gradients on the high alluvium are less than 1 degree so that topography is an important factor for agriculture only in that the overall downwards gradient from north to south results in an altitudinal difference between the floors of the Etla and Tlacolula Valleys on the one hand and the Zaachila Valley on the other. Also, some areas in the valley centre form depressions into which cold air drains. These topographic differences

affect crops in terms of frost frequency. Within the elevation range found in the valley floor (1500 to 1670 meters), two agriculturally distinct areas may be defined:

1) a higher, cooler zone including all of the Etla and Tlacolula Valleys, where absolute minimum temperatures recorded are -8°C. The probability of air frosts is once every three years, and ground frosts are likely every year so that the average length of the frost-free period is 10 months.

2) a lower, warmer zone including all of the Zaachila Valley, where absolute minimum temperatures are +1°C. The probability of air frosts is less than 1 in 20 to 40 years. Ground frosts are reported not to occur, and in any case their probability is so low that frost sensitive plants are not excluded; the average length of the frost-free period is therefore 12 months. Oaxaca de Juárez, at 1540 meters and with no air frosts in 40 years of records, lies close to the elevation that divides the valley floor into frost-free and non frost-free areas.

The 3 to 6 meters of alluvium which separate the present high alluvium surface from the present river level have all been deposited since about 800 B.B.-200B.C. By the time of the Spanish Conquest in the sixteen century, the rivers had finished aggrading throughout most if the valley, and rapid downcutting was initiated which appears to be continuing today.

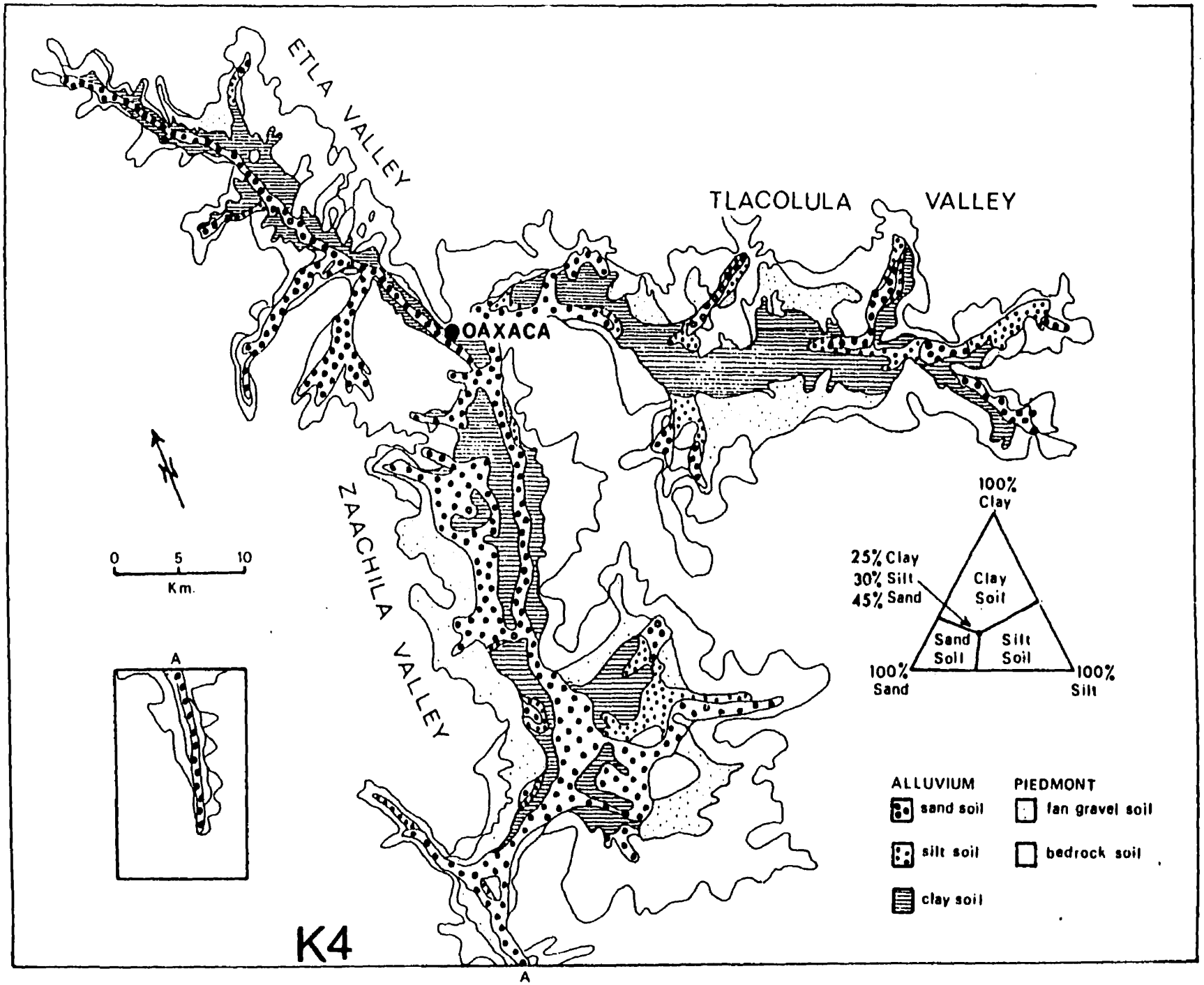


Fig. Map of Valley of Oaxaca to show soils of the valley floor and piedmont.

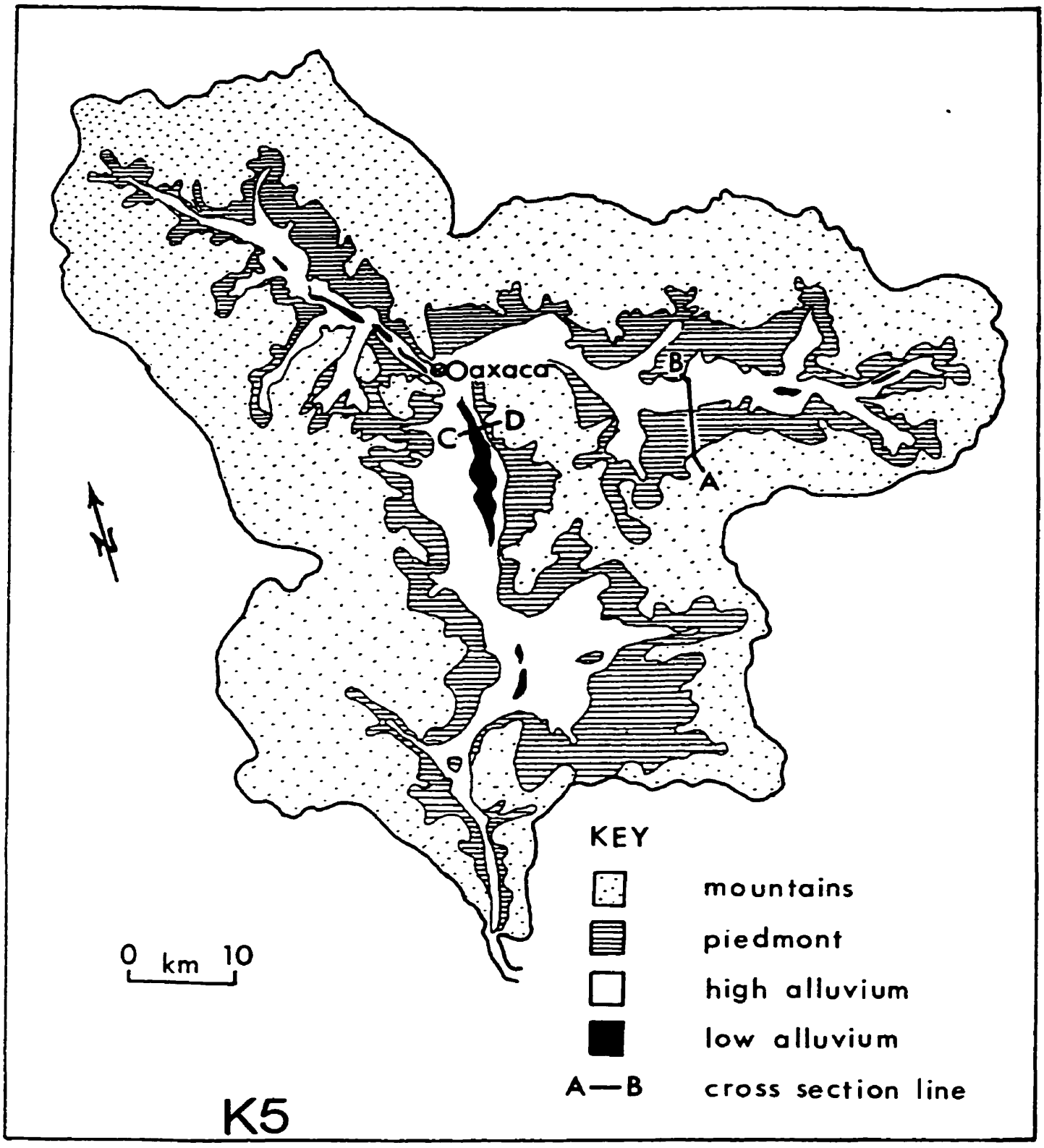


Fig. Map of the Valley of Oaxaca to show main physiographic zones.

APPENDIX S.

POLYGON SURVEY DATA. **TABLES 1 TO 7.**

GROUNDWATER MONITORING C.N.A 1972-1973. **TABLE 8.**

DATES OF INVENTORY AND DATES OF MEASUREMENTS OF WATER TABLE DEPTH TAKEN FROM WELLS INVESTIGATED FOR ESTABLISHING A GROUNDWATER OBSERVATION NETWORK **TABLES 9A to 9F.**

MEASUREMENTS OF WATER TABLE DEPTH TAKEN FROM WELLS INVESTIGATED FOR ESTABLISHING A GROUNDWATER OBSERVATION NETWORK **TABLES 10A to 10F.**

LIST OF OBSERVATION WELLS FOR WHICH X, Y COORDINATES WERE DIGITIZED FROM THE TOPOGRAPHIC MAP. **TABLE 11.**

DIGITIZED COORDINATES OF DEEP WELLS DRILLED AND TESTED BY S.A.R.H. **TABLE 12.**

DEEP WELLS DRILLED by S.A.R.H 1968-1995. **Figure 1**

TABLE 1 POLYGON San Francisco Lachigolo

Pi-0 is BN.156 of Elevation : 1609.0752 <PSIn =261,39,00

Station						D1	AZIMUTHS		Internal Angles	
	PID		BSID		FSID	m	degr.	min	Degr.	Min.
Pi 38	640	37	630	0	100	550	94	0		
Pi 0	100	38	640	1	110	178	247	39	333	39
Pi 1	110	0	100	2	120	580	252	57	185	18
Pi 2	120	1	110	3	130	350	264	16	191	19
Pi 3	130	2	120	4	140	240	196	02	111	46
Pi 4	140	3	130	5	150	155	198	04	182	2
Pi 5	150	4	140	6	160	335	195	55	177	51
Pi 6	160	5	150	7	170	165	15	00	135	5
Pi 7	170	6	160	8	180	410	195	17	224	17
Pi 8	180	7	170	9	190	128	280	26	265	9
Pi 9	190	8	180	10	200	190	183	20	82	54
Pi 10	200	9	190	11	210	200	170	16	166	56
Pi 11	210	10	200	12	220	175	145	42	155	26
Pi 12	220	11	210	13	230	250	158	47	193	5
Pi 13	230	12	220	14	240	76	100	45	121	58
Pi 14	240	13	230	15	250	230	196	25	275	40
Pi 15	250	14	240	16	260	120	200	20	183	55
Pi 16	260	15	250	17	270	230	196	12	175	52
Pi 17	270	16	260	18	280	258	284	02	267	50
Pi 18	280	17	270	19	290	305	320	43	216	41
Pi 19	290	18	280	20	300	180	320	43	180	0
Pi 20	300	19	290	21	310	178	013	16	232	33
Pi 21	310	20	300	22	320	220	012	50	179	34
Pi 22	320	21	310	23	330	165	018	40	185	50
Pi 23	330	22	320	24	340	304	01	35	172	55
Pi 24	340	23	330	25	350	48	017	05	185	30
Pi 25	350	24	340	26	360	75	284	40	87	35
Pi 26	360	25	350	27	370	185	013	11	268	31
Pi 27	370	26	360	28	380	59	358	07	164	56
Pi 28	380	27	370	29	390	195	00	00	182	53
Pi 29	390	28	380	30	400	240	020	07	199	7
Pi 30	400	29	390	31	410	110	013	26	173	19
Pi 31	410	30	400	32	420	260	313	15	119	49
Pi 32	420	31	410	33	430	102	305	30	172	15
Pi 33	430	32	420	34	440	120	007	22	241	52
Pi 34	440	33	430	35	450	305	010	51	183	29
Pi 35	450	34	440	36	460	262	00	26	170	35
Pi 36	460	35	450	37	470	390	09	22	269	56
Pi 37	470	36	460	38	480	800	096	12	184	50
Pi 38	480	37	470	0	100	550	094	05	177	53
Compiled by : Etienne Perraton									7357.00	1385.00
Length of circuit (metr 9145								Allow.	562 seconds	
#of sides : 39								Actual	300 seconds	

alferez.xls

TABLE 2 Polygon : EL ALFEREZ Survey Data SPREADSHEET

Station		Back-Sight		Fore Sight		D1	Azimuths	External Angles		
	PID		BSID		FSID	m	Decimal	Decimal	Degr.	Min.
PI 26	360	PI 25	350	PI - 0	100	190	101.22			
PI 0	100	PI 26	300	PI - 1	110	159	171.57	250.35	250	21
PI 1	110	PI 0	100	PI - 2	120	44	166.35	174.78	174	47
PI 2	120	PI 1	110	PI - 3	130	70	152.93	166.58	166	35
PI 3	130	PI 2	120	PI - 4	140	193	179.43	206.50	206	30
PI 4	140	PI 3	130	PI - 5	150	231	206.85	207.42	207	25
PI 5	150	PI 4	140	PI - 6	160	120	201.52	174.67	174	40
PI 6	160	PI 5	150	PI - 7	170	111	196.88	175.37	175	22
PI 7	170	PI 6	160	PI - 8	180	600	186.73	169.85	169	51
PI 8	180	PI 7	170	PI - 9	190	290	195.57	188.83	188	50
PI 9	190	PI 8	180	PI - 10	200	37	301.47	285.90	285	54
PI 10	200	PI 9	190	PI - 11	210	108	32.38	270.92	270	55
PI 11	210	PI 10	200	PI - 12	220	202	15.13	162.75	162	45
PI 12	220	PI 11	210	PI - 13	230	250	7.10	171.97	171	58
PI 13	230	PI 12	220	PI - 14	240	224	5.78	178.68	178	41
PI 14	240	PI 13	230	PI - 15	250	44	313.28	127.50	127	30
PI 15	250	PI 14	240	PI - 16	260	131	18.53	245.25	245	15
PI 16	260	PI 15	250	PI - 17	270	212	9.20	170.67	170	40
PI 17	270	PI 16	260	PI - 18	280	270	43.78	214.58	214	35
PI 18	280	PI 17	270	PI - 19	290	406	344.35	120.57	120	34
PI 19	290	PI 18	280	PI - 20	300	442	246.43	82.08	82	5
PI 20	300	PI 19	290	PI - 21	310	156	240.90	174.47	174	28
PI 21	310	PI 20	300	PI - 22	320	216	40.23	339.33	339	20
PI 22	320	PI 21	310	PI - 23	330	49	6.73	146.50	146	30
PI 23	330	PI 22	320	PI - 24	340	94	110.82	284.08	284	5
PI 24	340	PI 23	330	PI - 25	350	57	11.17	80.35	80	21
PI 25	350	PI 24	340	PI - 26	360	137	80.53	249.37	249	22
PI 26	360	PI 25	350	PI - 0	100	190	101.22	200.68	200	41

Compiled by : Etienne Perraton		SUM ---->	5205.00 900.00
Length of circuit (metres) : 4984		Allowable Ang. Err	8 minutes
#of sides : 27		Actual Ang. error	0 minutes

TABLE 3 THE COORDINATES , BSIGHT , FSIGHT Direc. Angles of DIAZ ORDAZ POLYGON

NON CORR		CORRECTED			FSID	FSID	STAT	BSID	Bsight	Fsight	Angle	
X in (m)	Y in (m)	X in (m)	Y in (m)		PI #	ID #	ID #	ID #	(m)	(m)	Degr	Min
24663	15438	24652	15442	PI	1	110	4	4	131	78	19	58
24663	15438	24697	15565	PI	0	100	4	4	131	78	19	58
24711	15641	24717	15640	PI	16	260	100	110	131	78	175	11
24835	15988	24871	15975	PI	15	250	260	100	78	370	189	19
24924	15946	24956	15925	PI	14	240	250	260	370	99	275	43
24975	15915	25004	15890	PI	13	230	240	250	99	59	185	54
25092	15894	25119	15859	PI	12	220	230	240	59	119	158	39
25158	15498	25151	15458	PI	11	210	220	230	119	400	250	41
25045	15285	25019	15256	PI	10	200	210	220	400	240	217	39
25050	15187	25015	15158	PI	9	190	200	210	240	98	149	9
25020	15029	24972	15003	PI	8	180	190	200	98	160	193	22
25013	14991	24962	14966	PI	7	170	180	190	160	38	179	57
24974	15065	24929	15043	PI	6	160	170	180	38	84	321	25
24847	15163	24812	15151	PI	5	150	160	170	84	160	155	49
24699	15202	24667	15203	PI	4	140	150	160	160	154	157	1
24531	15174	24498	15190	PI	3	130	140	150	154	170	155	52
24530	15217	24500	15233	PI	2	120	130	140	170	43	277	31
24663	15439	24652	15442	PI	1	110	120	130	43	260	212	26
24697	15565	24697	15565	PI	0	100	110	120	260	131	164	11
0	0	0.00				0	0	0	0	0	0	0

rojas.xls

TABLE 4 POLYGON Rojas de Cuauhtemoc								Xpi-22 = 4976.04		
Pi-22 is from Polygon 13: <PSIn = 193,14,05 ->200.52 d1=44								Ypi-22 = 16857.23		
Station		Back-Sight		Fore-Sight		D1	Azimuths			
	PID		BSID		FSID	m	Decimal	Degr.	Min.	Sec.
Pi 22	320	26	960	1	700	445	193.23			
Pi 1	700	22	320	2	710	160	114.08	100	50	50
Pi 2	710	1	700	3	720	145	100.68	166	36	0
Pi 3	720	2	710	4	730	62	104.99	184	18	20
Pi 4	730	3	720	5	740	158	200.31	275	19	20
Pi 5	740	4	730	6	750	23	168.42	148	6	30
Pi 6	750	5	740	7	760	35	201.56	213	8	20
Pi 7	760	6	750	8	770	80	285.32	263	45	30
Pi 8	770	7	760	9	780	31	196.60	91	17	15
Pi 9	780	8	770	10	790	35	344.47	327	52	15
Pi 10	790	9	780	11	800	118	279.60	115	7	35
Pi 11	800	10	790	12	810	185	193.06	93	27	30
Pi 12	810	11	800	13	820	115	103.50	90	26	45
Pi 13	820	12	810	14	830	27	211.52	288	1	0
Pi 14	830	13	820	15	840	59	173.57	142	2	55
Pi 15	840	14	830	16	850	145	189.64	196	4	20
Pi 16	850	15	840	17	860	158	329.66	320	1	0
Pi 17	860	16	850	18	870	92	340.07	190	24	30
Pi 18	870	17	860	19	880	91	328.61	168	32	30
Pi 19	880	18	870	20	890	38.5	317.83	169	13	0
Pi 20	890	19	880	21	900	165	329.88	192	3	30
Pi 21	900	20	890	22	910	198	325.26	175	22	30
Pi 22	910	21	900	23	920	285	330.32	185	3	30
Pi 23	920	22	910	24	930	137.5	104.28	313	57	30
Pi 24	930	23	920	25	940	88	104.58	180	18	0
Pi 25	940	24	930	26	950	93	126.43	201	51	30
Pi 26	950	25	940	22	320	417	37.60	91	10	0
Pi 22	320	26	950	1	700	445	193.27	335	40	0
Compiled by : Etienne Perraton								5210	592	595
Length of circuit (m) :			3476	SUMAN			5220.03	Allowable	468 sec.	
#of sides :			27	TITANC			5220.00	Actual Er	115 sec.	
Note: We start the comp. identification of PI-' at 700 because this polygon ties to the Guendulain polygon where the comp. ID goes from 100 to 680.										

sanjuan2.xls

TABLE 5 POLYGON San Juan de Teitipac attached to San Sebastian.

Pi-0 is of Elevation : <PSIn = 178,51,30

	Station						D1 AZIMUTHS				Internal Angles	
		PID		BSID		FSID	m	grad	min	seg	Degr.	
#	Pla 35	450	22	820	1	610	146	178	51	30		
1	Pla 1	610	35	450	2	620	388	176	29	30	177	38
2	Pla 2	620	1	610	3	630	270	171	46	30	175	17
3	Pla 3	630	2	620	4	640	240	176	13	30	184	27
4	Pla 4	640	3	630	5	650	240	166	11	30	169	58
5	Pla 5	650	4	640	6	660	122	124	55	30	138	44
6	Pla 6	660	5	650	7	670	83	091	41	30	146	46
7	Pla 7	670	6	660	8	680	150	094	09	30	182	28
8	Pla 8	680	7	670	9	690	108	090	44	30	176	35
9	Pla 9	690	8	680	10	700	20	355	11	30	84	27
10	Pla 10	700	9	690	11	710	30	130	56	30	315	45
11	Pla 11	710	10	700	12	720	190	090	58	30	140	1
12	Pla 12	720	11	710	13	730	109	143	26	30	232	28
13	Pla 13	730	12	720	14	740	45	121	38	30	158	12
14	Pla 14	740	13	730	15	750	61	004	33	30	62	56
15	Pla 15	750	14	740	16	760	35	270	10	30	85	37
16	Pla 16	760	15	750	17	770	320	355	53	30	265	43
17	Pla 17	770	16	760	18	780	140	277	01	30	101	8
18	Pla 18	780	17	770	19	790	63	286	01	30	189	0
19	Pla 19	790	18	780	20	800	350	319	19	30	213	18
20	Pla 20	800	19	790	21	810	375	331	09	30	191	50
21	Pla 21	810	20	800	22	820	270	356	43	30	205	34
22	Pla 22	820	21	810	35	450	293	313	59	30	137	16
23	Pla 35	450	22	820	1	610	378	178	48	30	44	49
											3768.00	717.00

Compiled by : Etienne Perraton — **Surveyed by :** C.N.A/Oax.

Length of circuit (metres) : 3892 — SUMANG (degr 3779.95 — Error Act. -180

#of sides : 23 — TITANG (degree 3780.00 — Error Perm 432

Note. Internal angles because we proceed in a counterclockwise sequential order in compiling the angles from the azimuths.

SUMANG: Actual Sum of All polygon Angles. — TITANG : Theoretical Sum of angles.

Error Act.: Actual closing angle error — Error Perm. Permissible Ang. error

sansebas.xls

TABLE 6. A	POLYGON San Sebastian de Teitipac									
Pi-0 is of Elevation :				<PSIn = 174,21,00		Xpi-0, Ypi-0 =				
Station		Back-Sight		Fore Sight		D1	Azimuths	Internal Angles		
	PID		BSID		FSID	m	Decimal	Degr.	Min.	Sec.
PI 0	100	PI - 46	560	PI - 1	110	244	174.35			
PI 1	110	PI - 0	100	PI - 2	120	153	191.73	197	23	5
PI 2	120	PI - 1	110	PI - 3	130	122	149.25	137	31	0
PI 3	130	PI - 2	120	PI - 4	140	32	162.31	193	3	15
PI 4	140	PI - 3	130	PI - 5	150	21	207.18	224	52	35
PI 5	150	PI - 4	140	PI - 6	160	66	178.45	151	16	15
PI 6	160	PI - 5	150	PI - 7	170	77	90.12	91	40	0
PI 7	170	PI - 6	160	PI - 8	180	278	219.08	308	57	25
PI 8	180	PI - 7	170	PI - 9	190	16	193.66	154	34	50
PI 9	190	PI - 8	180	PI - 10	200	46	253.01	239	20	55
PI 10	200	PI - 9	190	PI - 11	210	78	225.09	152	5	10
PI 11	210	PI - 10	200	PI - 12	220	22	197.27	152	10	25
PI 12	220	PI - 11	210	PI - 13	230	100	123.99	106	43	20
PI 13	230	PI - 12	220	PI - 14	240	313	126.07	182	4	60
PI 14	240	PI - 13	230	PI - 15	250	174	153.57	207	29	40
PI 15	250	PI - 14	240	PI - 16	260	440	180.17	206	36	30
PI 16	260	PI - 15	250	PI - 17	270	132	144.35	144	10	40
PI 17	270	PI - 16	260	PI - 18	280	198	129.10	164	44	40
PI 18	280	PI - 17	270	PI - 19	290	94	119.18	170	5	0
PI 19	290	PI - 18	280	PI - 20	300	230	154.07	214	53	30
PI 20	300	PI - 19	290	PI - 21	310	249	185.57	211	29	40
PI 21	310	PI - 20	300	PI - 22	320	123	129.08	123	30	40
PI 22	320	PI - 21	310	PI - 23	330	139	183.61	234	32	5
PI 23	330	PI - 22	320	PI - 24	340	134	193.29	189	40	30
PI 24	340	PI - 23	330	PI - 25	350	205	168.17	154	53	5
PI 25	350	PI - 24	340	PI - 26	360	45	154.92	166	45	0
PI 26	360	PI - 25	350	PI - 27	370	36	215.51	240	35	30
PI 27	370	PI - 26	360	PI - 28	380	30	277.80	242	17	10
PI 28	380	PI - 27	370	PI - 29	390	80	205.65	107	51	20
PI 29	390	PI - 28	380	PI - 30	400	40	155.42	129	45	60
PI 30	400	PI - 29	390	PI - 31	410	235	192.35	216	55	40

sansebas.xls

TABLE 6.B POLYGON San Sebastian de Teitipac

Pi-0 is of Elevation : <PSIn = 174,21,00 Xpi-0, Ypi-0 =

Station	PID	Back-Sight	BSID	Fore Sight	FSID	D1 m	Azimuths Decimal	Internal Angles Degr.	Min.	Sec.
PI 31	410	PI-30	400	PI-32	420	178	188.15	175	47	60
PI 32	420	PI-31	410	PI-33	430	161	196.33	188	11	0
PI 33	430	PI-32	420	PI-34	440	13	184.83	168	30	0
PI 34	440	PI-33	430	PI-35	450	202	95.01	90	10	30
PI 35	450	PI-34	440	PI-36	460	390	8.77	93	45	60
PI 36	460	PI-35	450	PI-37	470	180	10.47	181	41	60
PI 37	470	PI-36	460	PI-38	480	670	5.39	174	54	60
PI 38	480	PI-37	470	PI-39	490	85	1.89	176	30	0
PI 39	490	PI-38	480	PI-40	500	590	3.22	181	20	0
PI 40	500	PI-39	490	PI-41	510	201	323.94	140	43	0
PI 41	510	PI-40	500	PI-42	520	500	332.96	189	0	60
PI 42	520	PI-41	510	PI-43	530	400	333.87	180	55	0
PI 43	530	PI-42	520	PI-44	540	342	332.72	178	50	60
PI 44	540	PI-43	530	PI-45	550	420	332.07	179	21	0
PI 45	550	PI-44	540	PI-46	560	155	0.92	208	50	60
PI 46	560	PI-45	550	PI-0	100	138	307.99	127	4	0
PI 0	100	PI-46	560	PI-1	110	244	174.37	46	22	50
Survey supervised and Compiled by : E. Perraton								8075	1480	1275

Length of circuit (metres) :	8624	Allowable	617 seconds
#of sides :	47	Actual An	75 seconds

Note. Internal angles because we proceed in a counterclockwise sequential order in compiling the angles from the azimuths.

Surveyed by C.N.A/Oaxaca. 1994.

guelavia.xls

TABLE 7A POLYGON Guelavia (obs.Wells #108,109,110,111,112..,121

Pi-0 is of Elevation : <PSIn = 282,42,00 BS:203.0

Station		Back-Sight		Fore Sight		D1	Azimuths	Internal Angles	
	PID		BSID		FSID	m	Decimal	Degr.	Min.
Pi 55	640	Pi 54	630	Pi 1	100	52	12.10		
Pi 1	100	Pi 55	650	Pi 2	110	201	180.48	348	23
Pi 2	110	Pi 1	100	Pi 3	120	103	234.13	233	39
Pi 3	120	Pi 2	110	Pi 4	130	269	274.13	220	0
Pi 4	130	Pi 3	120	Pi 5	140	304	246.30	152	10
Pi 5	140	Pi 4	130	Pi 6	150	500	193.40	127	6
Pi 6	150	Pi 5	140	Pi 7	160	400	194.43	181	2
Pi 7	160	Pi 6	150	Pi 8	170	426	201.80	187	22
Pi 8	170	Pi 7	160	Pi 9	180	180	154.15	132	21
Pi 9	180	Pi 8	170	Pi 10	190	117	221.97	247	49
Pi 10	190	Pi 9	180	Pi 11	200	490	193.77	151	48
Pi 11	200	Pi 10	190	Pi 12	210	77	109.67	95	54
Pi 12	210	Pi 11	200	Pi 13	220	163	267.42	337	45
Pi 13	220	Pi 12	210	Pi 14	230	28	129.45	42	2
Pi 14	230	Pi 13	220	Pi 15	240	62	137.18	187	44
Pi 15	240	Pi 14	230	Pi 16	250	228	191.95	234	46
Pi 16	250	Pi 15	240	Pi 17	260	121	198.15	186	12
Pi 17	260	Pi 16	250	Pi 18	270	11	114.25	96	6
Pi 18	270	Pi 17	260	Pi 19	280	245	193.18	258	56
Pi 19	280	Pi 18	270	Pi 20	290	120	185.03	171	51
Pi 20	290	Pi 19	280	Pi 21	300	39	180.15	175	7
Pi 21	300	Pi 20	290	Pi 22	310	180	194.02	193	52
Pi 22	310	Pi 21	300	Pi 23	320	20	82.63	68	37
Pi 23	320	Pi 22	310	Pi 24	330	82	178.73	276	6
Pi 24	330	Pi 23	320	Pi 25	340	80	186.00	187	16
Pi 25	340	Pi 24	330	Pi 26	350	145	171.22	165	13
Pi 26	350	Pi 25	340	Pi 27	360	30	183.30	192	5
Pi 27	360	Pi 26	350	Pi 28	370	11	122.53	119	14
Pi 28	370	Pi 27	360	Pi 29	380	27	201.78	259	15
Pi 29	380	Pi 28	370	Pi 30	390	21	237.08	215	18
Pi 30	390	Pi 29	380	Pi 31	400	38	288.58	231	30
Pi 31	400	Pi 30	390	Pi 32	410	89	248.58	140	0
Pi 32	410	Pi 31	400	Pi 33	420	71	318.92	250	20
Pi 33	420	Pi 32	410	Pi 34	430	260	10.32	231	24

guelavia.xls

TABLE 7 B	POLYGON Guelavia (obs.Wells #108,109,110,111,112..,121									
Pi-0 is of Elevation :				<PSIn = 282,42,00 BS:203.0						
Station		Back-Sight		Fore Sight			D1	Azimuths	Internal Angles	
	PID		BSID		FSID		m	Decimal	Degr.	Min.
Pi 34	430	Pi 33	420	Pi 35	440		210	298.18	107	52
Pi 35	440	Pi 34	430	Pi 36	450		83	292.93	174	45
Pi 36	450	Pi 35	440	Pi 37	460		208	15.70	262	46
Pi 37	460	Pi 36	450	Pi 38	470		110	283.20	87	30
Pi 38	470	Pi 37	460	Pi 39	480		150	29.20	286	0
Pi 39	480	Pi 38	470	Pi 40	490		82	18.98	169	47
Pi 40	490	Pi 39	480	Pi 41	500		222	30.58	191	36
Pi 41	500	Pi 40	490	Pi 42	510		97	17.85	167	16
Pi 42	510	Pi 41	500	Pi 43	520		70	116.43	278	35
Pi 43	520	Pi 42	510	Pi 44	530		335	4.88	68	27
Pi 44	530	Pi 43	520	Pi 45	540		300	29.73	204	51
Pi 45	540	Pi 44	530	Pi 46	550		300	22.35	172	37
Pi 46	550	Pi 45	540	Pi 47	560		260	18.93	176	35
Pi 47	560	Pi 46	550	Pi 48	570		380	12.12	173	11
Pi 48	570	Pi 47	560	Pi 49	580		780	6.12	174	0
Pi 49	580	Pi 48	570	Pi 50	590		230	41.58	215	28
Pi 50	590	Pi 49	580	Pi 51	600		297	63.95	202	22
Pi 51	600	Pi 50	590	Pi 52	610		221	64.73	180	47
Pi 52	610	Pi 51	600	Pi 53	620		179	100.02	215	17
Pi 53	620	Pi 52	610	Pi 54	630		22	160.03	240	1
Pi 54	630	Pi 53	620	Pi 55	640		90	104.12	124	5
Pi 55	640	Pi 54	630	Pi* 1	100		52	12.08	87	58
Compiled by :		Etienne Perraton							10236.00	1439.00
Length of circuit (metres) :						9615	Angle allowed Error (seconds)			667
#of sides :						55	Actual Ang. error (seconds)			-60
Note. * This circuit was closed as BS(Pi-55)-Station(Pi-1)--FS(PI-2) witth an with an Azimuth of 180°28' for an Error of closure of one (1) minute '.										

PIEZOMETRIA.xls

TABLE **8A** GROUNDWATER MONITORING C.N.A 1972-1973. all in (m)

	Coordinates Xp	Yp	8-10th of March. 72	17-18th of April 72.	11th of May 72.	25-28th of July 72.	22-25th of Aug. 72.
Y	1821.9	24226.8	1592.17	1592.15	1592.62	1594.40	1594.11
A	30765.6	229.7	1711.97	1711.75	1711.74	1712.32	1712.18
AA	-2770.0	22996.2	1545.04	1544.74	1544.84	1546.00	1546.16
B	36394.3	5306.0	1739.83	1739.55	1739.60	1740.25	1740.00
C	33194.8	7921.1	1682.61	1682.05	1682.05	1682.19	1682.15
D	24633.2	7459.6	1641.24	1641.34	1641.49	1641.99	1641.96
E	20189.4	11305.3	1640.24	1639.94	1640.00	1640.27	1640.34
F	18263.8	1614.2	1740.81	1740.61	1740.93	1740.91	1741.31
G	21463.3	4383.1	1696.70	1695.92	1696.32	1696.90	1696.87
H	25610.8	16166.2	1702.97	1702.97	1704.16	1705.90	1705.17
I	21078.2	15458.6	1664.50	1664.20	1664.38	1666.30	1666.17
J	13523.8	11243.8	1591.76	1591.69	1591.70	1591.38	1591.50
K	12042.5	5306.0	1766.28	1766.03	1766.25	1767.15	1767.09
L	18115.7	5521.4	1737.80	1738.00	1738.45	1738.40	1738.37
LL	13879.3	17458.4	1628.53	1627.93	1627.83	1629.92	1630.42
M	15745.6	19150.5	1669.58	1669.38	1669.58	1669.95	1669.97
N	9080.0	16996.9	1587.07	1586.96	1586.56	1587.80	1587.82
N	11094.5	19150.5	1641.92	1641.77	1641.80	1642.36	1642.37
O	8546.8	15612.5	1580.13	1579.73	1579.68	1580.69	1580.59
P	8635.6	11151.5	1586.21	1586.11	1586.34	1586.76	1586.95
Q	6710.0	7921.1	1632.42	1632.24	1632.19	1632.96	1632.40
R	5969.4	10843.8	1601.15	1600.78	1600.88	1601.19	1601.21
S	4784.4	17304.6	1572.36	1572.30	1572.45	1572.56	1572.77
T	6650.8	16689.3	1570.39	1570.27	1570.22	1570.76	1570.68
U	7302.5	17766.1	1569.70	1567.25	1567.20	1570.66	1570.27
V	5969.4	18689.0	1563.79	1563.29	1563.42	1563.45	1563.92
W	4458.5	22627.0	1581.99	1581.59	1581.09	1584.12	1584.32
X	3747.5	21304.1	1567.23	1566.91	1566.41	1566.97	1567.03
Z	-1051.8	22688.5	1545.65	1544.70	1544.66	1545.81	1545.58

SOURCE: CNA\ OAXACA, OAX. MEXICO AGUAS SUBTERRANEAS.

Coordinates estimated by E.Perraton... 1997.

1) Typing Errors detected and corrected

2) Errors suspected but not corrected .

PIEZOMETRIA.xls

TABLE **8B** GROUND WATER ELEVATION IN METERS.

	Coordinates Xp	Yp	18-19th of Jan. 73.	14-16th of Feb. 73.	26-27th of March 73.	2-3rd of April 73.	6-7th of May 73.
Y	1821.9	24226.8	1592.40	1592.30	1591.51	1591.41	1591.54
A	30765.6	229.7	1711.41	1711.26	1711.04	1710.89	1711.20
AA	-2770.0	22996.2	1546.15	1546.00	1545.77	1545.32	1545.56
B	36394.3	5306.0	1739.54	1739.50	1739.45	1739.39	1739.40
C	33194.8	7921.1	1682.15	1681.54	1682.15	1682.13	1682.48
D	24633.2	7459.6	1641.66	1641.62	1641.55	1641.46	1641.62
E	20189.4	11305.3	1639.92	1639.89	1639.75	1639.61	1639.53
F	18263.8	1614.2	1740.65	1740.51	1740.51	1740.47	1740.48
G	21463.3	4383.1	1696.40	1696.42	1695.82	1696.18	1696.26
H	25610.8	16166.2	1703.33	1703.49	1701.80	1702.32	1702.86
I	21078.2	15458.6	1664.38	1664.22	1664.16	1664.02	1663.97
J	13523.8	11243.8	1590.79	1590.68	1590.56	1590.37	1590.24
K	12042.5	5306.0	1767.12	1767.06	1767.02	1767.05	1767.08
L	18115.7	5521.4	1737.89	1737.77	1736.56	1737.28	1737.75
LL	13879.3	17458.4	1628.77	1628.22	1627.63	1627.18	1626.60
M	15745.6	19150.5	1669.74	1669.47	1669.34	1669.18	1669.08
N	9080.0	16996.9	1589.12	1588.98	1588.67	1588.74	1588.46
N	11094.5	19150.5	1642.00	1641.90	1641.55	1641.76	1641.66
O	8546.8	15612.5	1579.96	1579.74	1579.49	1579.28	1579.17
P	8635.6	11151.5	1586.32	1586.25	1586.17	1585.63	1585.79
Q	6710.0	7921.1	1632.24	1632.17	1631.94	1631.92	1631.83
R	5969.4	10843.8	1601.13	1601.09	1600.94	1600.82	1600.72
S	4784.4	17304.6	1572.48	1572.36	1572.34	1572.16	1572.07
T	6650.8	16689.3	1570.39	1570.33	1570.12	1569.97	1569.85
U	7302.5	17766.1	1566.62	1565.50	1567.33	1566.62	1566.56
V	5969.4	18689.0	1563.40	1563.35	1563.17	1563.04	1562.91
W	4458.5	22627.0	1581.70	1581.30	1580.71	1580.09	1579.58
X	3747.5	21304.1	1567.09	1566.99	1566.82	1566.61	1566.43
Z	-1051.8	22688.5	1544.90	1544.76	1545.59	1544.51	1544.38

SOURCE: CNA\ OAXACA, OAX.

Coordinates estimated by E.Perraton...

1) Typing Errors detected and corrected

2) Errors suspected but not corrected .

TABLE 9 A Date of Inventory and Preliminary Monitoring OF POTENTIAL OBSERVATION WELLS.

X	Y	Well #.		Z rim	Z ground						
(m)	(m)			(m)	(m)						
		P	1	NoSurvey		21-Jul-94					
1112	23151	P	2	NoSurvey		21-Jul-94					
12464	17627	P	3	NoSurvey		21-Jul-94					
12747	17856	P	4	NoSurvey		21-Jul-94					
13274	17691	P	5	NoSurvey		21-Jul-94					
15241	16573	P	6	NoSurvey		22-Jul-94	04-Oct-94	10-Aug-95			
15189	16662	P	7	NoSurvey		22-Jul-94	04-Oct-94	10-Aug-95			
14906	16866	P	8	NoSurvey		22-Jul-94	04-Oct-94	10-Aug-95			
14984	18389	P	9	NoSurvey		22-Jul-94	04-Oct-94	10-Aug-95			
15151	18453	P	10	NoSurvey		22-Jul-94	04-Oct-94	10-Aug-95	22-Aug-95		
15626	18593	P	11	NoSurvey		22-Jul-94	04-Oct-94	10-Aug-95			
14765	16180	P	12	NoSurvey		22-Jul-94	04-Oct-94	10-Aug-95			
14701	16116	P	13	NoSurvey		22-Jul-94	04-Oct-94	10-Aug-95			
14778	15685	P	14	NoSurvey		22-Jul-94	04-Oct-94	10-Aug-95			
14456	13780	P	15	NoSurvey		22-Jul-94	22-Sep-94	14-Aug-95	22-Aug-95		
33959	7595	P	16	1704.28	1703.9	29-Jul-94	30-Aug-94	23-Sep-94	02-Aug-95	01-Sep-95	
35591	8002	P	17	1718.53	1716.93	29-Jul-94	30-Aug-94	23-Sep-94	02-Aug-95		
34190	7748	P	18	1704.48	1705.23	29-Jul-94	30-Aug-94	23-Sep-94	02-Aug-95	01-Sep-95	
32545	7189	P	19	1685.57	1685.57	29-Jul-94	30-Aug-94	23-Sep-94	02-Aug-95	01-Sep-95	
31298	7126	P	20	1673.84	1673.32	29-Jul-94	30-Aug-94	23-Sep-94	02-Aug-95	01-Sep-95	
30398	7151	P	21	1667.02	1666.61	29-Jul-94	30-Aug-94	23-Sep-94	02-Aug-95	01-Sep-95	
29806	7037	P	22	1661.80	1661.02	29-Jul-94	30-Aug-94	23-Sep-94	02-Aug-95	01-Sep-95	
29382	7024	P	23	1659.55	1659.05	29-Jul-94	30-Aug-94	23-Sep-94	02-Aug-95	01-Sep-95	
29524	7049	P	24	1657.55	1658.05	29-Jul-94	30-Aug-94	23-Sep-94	02-Aug-95	01-Sep-95	
29395	7202	P	25	1658.98	1658.11	29-Jul-94	30-Aug-94	23-Sep-94	02-Aug-95	01-Sep-95	
27647	7443	P	26	1649.06	1648.55	29-Jul-94	23-Sep-94	03-Aug-95			
31092	624	P	27	NoSurvey	NoSurvey	29-Jul-94					
31233	268	P	28	1750.84	1750.34	02-Aug-94	30-Aug-94	28-Sep-94	02-Aug-95	01-Sep-95	

TABLE 9 B Date of Inventory and Preliminary Monitoring OF POTENTIAL OBSERVATION WELLS.

X	Y	Well #.		Z rim	Z ground						
(m)	(m)			(m)	(m)						
		P	29	1736.62	1736.19	02-Aug-94	30-Aug-94	28-Sep-94	02-Aug-95	01-Sep-95	
30899	1145	P	30	1730.36	1729.95	02-Aug-94	30-Aug-94	28-Sep-94	02-Aug-95	01-Sep-95	
30321	2021	P	31	1714.85	1714.46	02-Aug-94	28-Sep-94	02-Aug-95	01-Sep-95		
30398	1386	P	32	1719.02	1718.50	02-Aug-94	30-Aug-94	28-Sep-94	02-Aug-95	01-Sep-95	
29986	395	P	33	1698.90	1698.68	02-Aug-94	28-Sep-94	02-Aug-95			
30089	319	P	34	1699.20	1699.00	02-Aug-94	28-Sep-94	02-Aug-95			
28366	7151	P	35	1653.87	1653.19	02-Aug-94	30-Aug-94	23-Sep-94	02-Aug-95	01-Sep-95	
		PM	35	1710.48	1709.72						
6087	19075	P	36	1572.07	1572.00	03-Aug-94	22-Sep-94	31-Jul-95	15-Aug-95	16-Aug-95	17-Aug-95
6010	19088	P	37	-1.00	1571.16	03-Aug-94	22-Sep-94	15-Aug-95			
6216	19075	P	38	NoSurvey	NoSurvey	03-Aug-94	22-Sep-94	31-Jul-95			
6074	18665	P	39	1567.53	1567.10	03-Aug-94	22-Sep-94	31-Jul-95	15-Aug-95		
		P	39a	1568.81	1568.601	31-Jul-95	15-Aug-95	17-Aug-95			
5560	16916	P	40	1555.74	1555.53	03-Aug-94	22-Sep-94	31-Jul-95	15-Aug-95	16-Aug-95	17-Aug-95
5766	17056	P	41	NoSurvey	NoSurvey	03-Aug-94					
5715	18529	P	42	-1.00	1559.88	03-Aug-94	22-Sep-94	31-Jul-95	15-Aug-95	16-Aug-95	
8016	13945	P	43	1567.51	1567.27	03-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95	18-Aug-95	
8440	14732	P	44	1571.79	1571.44	03-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95		
6923	18364	P	45	1571.50	1570.51	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95		
6949	18466	P	46	1572.59	1572.33	04-Aug-94	21-Sep-94				
6974	18326	P	47	1571.13	1570.54	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95		
6897	18326	P	48	1570.55	1570.05	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95		
6833	17653	P	49	1562.98	1562.44	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95	18-Aug-95	
7064	17475	P	50	1561.64	1561.46	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95	18-Aug-95	
7077	17500	P	51	1561.97	1561.69	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95		
6923	17297	P	52	1561.77	1561.47	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95		
7064	17246	P	53	1562.13	1562.04	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95	18-Aug-95	
7026	17170	P	54	1562.55	1562.18	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95	18-Aug-95	

TABLE 9C Date of Inventory and Preliminary Monitoring OF POTENTIAL OBSERVATION WELLS.

X	Y	Well #.		Z rim	Z ground						
(m)	(m)			(m)	(m)						
6936	16967	P	**55**	1562.47	1562.43	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95		
6897	16726	P	56	1563.41	1563.16	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95	18-Aug-95	
6794	16472	P	57	1563.35	1563.28	04-Aug-94	21-Sep-94	01-Aug-95	16-Aug-95	18-Aug-95	
		P	57	1677.74	1677.29						
		P	58	1701.58	1700.74	05-Aug-94	04-Oct-94	10-Aug-95	21-Aug-95		
26768	7453	P	59	1700.73	1700.47	05-Aug-94	04-Oct-94	10-Aug-95	21-Aug-95		
26768	7415	P	**60**	1690.98	1690.30	05-Aug-94	10-Aug-95	21-Aug-95			
26691	7466	P	61	1689.64	1689.60	05-Aug-94	04-Oct-94	10-Aug-95	21-Aug-95		
26748	7295	P	62	1689.87	1689.65	05-Aug-94	04-Oct-94	10-Aug-95	21-Aug-95		
26851	6812	P	63	1688.86	1688.44	05-Aug-94	04-Oct-94	10-Aug-95	21-Aug-95		
26890	7091	P	64	1695.22	1694.45	05-Aug-94	04-Oct-94	10-Aug-95	21-Aug-95		
26870	7193	P	**65**	1644.13	1643.83	05-Aug-94	04-Oct-94	10-Aug-95	21-Aug-95		
26864	7777	P	66	1609.89	1609.62	05-Aug-94	28-Sep-94	04-Aug-95	10-Aug-95		
26768	7453	P	67	1645.43	1645.04	10-Aug-94	23-Sep-94	03-Aug-95			
26768	7415	P	68	1644.04	1644.14	10-Aug-94	23-Sep-94	03-Aug-95			
26691	7466	P	69	1645.55	1645.04	10-Aug-94	23-Sep-94	03-Aug-95			
26748	7295	P	**70**	1645.81	1644.86	10-Aug-94	23-Sep-94	03-Aug-95			
26851	6812	P	71	1667.45	1656.42	10-Aug-94	03-Aug-95				
26890	7091	P	72	1667.45	1667.25	10-Aug-94	23-Sep-94	03-Aug-95			
26870	7193	P	73	1657.88	1657.27	10-Aug-94	23-Sep-94	03-Aug-95			
26864	7777	P	74	1644.48	1644.25	10-Aug-94	28-Sep-94	03-Aug-95			
26035	8209	P	**75**	NoSurvey	NoSurvey	10-Aug-94	28-Sep-94	03-Aug-95			
		P	76	NoSurvey	NoSurvey	10-Aug-94	28-Sep-94	03-Aug-95			
		P	77	NoSurvey	NoSurvey	10-Aug-94	28-Sep-94	03-Aug-95			
		P	78	NoSurvey	NoSurvey	28-Sep-94	03-Aug-95				
		P	79	NoSurvey	NoSurvey						
		P	**80**	NoSurvey	NoSurvey	28-Sep-94	03-Aug-95				
		P	81	NoSurvey	NoSurvey	28-Sep-94	03-Aug-95				

TABLE 9D Date of Inventory and Preliminary Monitoring OF POTENTIAL OBSERVATION WELLS.

X	Y	Well #.		Z rim	Z ground				
(m)	(m)			(m)	(m)				
		P	82	1606.33	1605.90	11-Aug-94	22-Sep-94	03-Aug-95	01-Sep-95
		P	82a			03-Aug-95			
		P	83	1607.06	1606.69	11-Aug-94	22-Sep-94	03-Aug-95	01-Sep-95
		P	84	1607.37	1607.22	11-Aug-94	22-Sep-94	03-Aug-95	01-Sep-95
		P	85	1607.44	1607.15	11-Aug-94	22-Sep-94	03-Aug-95	01-Sep-95
		P	86	1609.09	1608.93	11-Aug-94	03-Aug-95	01-Sep-95	
		P	87	1609.72	1609.08	11-Aug-94	04-Aug-95		
		P	88	1611.89	1611.30	11-Aug-94	04-Aug-95		
		P	89	1613.25	1613.00	11-Aug-94	04-Aug-95		
		P	90	1632.88	1632.45	11-Aug-94	04-Aug-95	01-Sep-95	
		P	91	NoSurvey	NoSurvey	11-Aug-94	04-Aug-95		
5715	21145	P	92	NoSurvey	NoSurvey				
5817	21170	P	93	NoSurvey	NoSurvey				
		P	94	NoSurvey	NoSurvey				
		P	95	NoSurvey	NoSurvey				
		P	96	NoSurvey	NoSurvey				
		P	97	NoSurvey	NoSurvey				
		P	98	NoSurvey	NoSurvey				
		P	99	NoSurvey	NoSurvey				
		P	100	1713.43	1713.28	04-Aug-95			
		P	101	1655.15	1654.05	04-Aug-95			
		P	102	1706.87	1706.36	04-Aug-95			
		P	103	1702.29	1702.02	04-Aug-95			
				1700.29	1698.55				
		P	104	NoSurvey	NoSurvey	04-Aug-95			
		P	105	NoSurvey	NoSurvey	04-Aug-95			
		P	106	1640.57	1640.35	04-Oct-94	10-Aug-95	21-Aug-95	
		P	107	1650.65	1650.22	04-Oct-94	10-Aug-95	21-Aug-95	

TABLE 9E				Date of Inventory and Preliminary Monitoring OF POTENTIAL OBSERVATION WELLS.							
X	Y	Well #.		Z rim	Z ground						
(m)	(m)			(m)	(m)						
13004	12281	P	108	1579.52	531.12	22-Sep-94	14-Aug-95				
13171	12065	P	109	1579.50	530.90	22-Sep-94	14-Aug-95	22-Aug-95			
12824	11646	P	**110**	NoSurvey	NoSurvey	22-Sep-94	14-Aug-95	22-Aug-95			
12978	11557	P	111	-1.00	534.68	22-Sep-94	14-Aug-95	22-Aug-95			
12862	11507	P	112	1582.98	534.30	22-Sep-94	14-Aug-95	22-Aug-95	04-Sep-95		
12785	11532	P	113	1582.66	533.88	22-Sep-94	14-Aug-95	22-Aug-95	04-Sep-95		
12850	11202	P	114	1587.82	539.44	30-Aug-94	22-Sep-94	14-Aug-95	22-Aug-95	01-Sep-95	
12682	10783	P	**115**	1592.83	544.29	30-Aug-94	22-Sep-94	14-Aug-95	22-Aug-95	01-Sep-95	
12644	10567	P	116	NoSurvey	NoSurvey	22-Sep-94	14-Aug-95	22-Aug-95	04-Sep-95		
12618	10643	P	117	1595.48	547.05	22-Sep-94	14-Aug-95	22-Aug-95	04-Sep-95		
12760	10364	P	118	NoSurvey	NoSurvey	14-Aug-95	22-Aug-95				
12824	10478	P	119	NoSurvey	NoSurvey	14-Aug-95	22-Aug-95				
12592	10288	P	**120**	1601.10	552.58	14-Aug-95	22-Aug-95				
12464	10300	P	121	1601.18	552.71	14-Aug-95	22-Aug-95				
12541	10364	P	122			14-Aug-95	22-Aug-95				
		P	123	-1	552.35	14-Aug-95					
		P	124	NoSurvey	NoSurvey						
7797	12751	P	**125**	NoSurvey	NoSurvey	21-Sep-94	01-Aug-95	16-Aug-95	18-Aug-95		
7861	12535	P	126	NoSurvey	NoSurvey	21-Sep-94	01-Aug-95	16-Aug-95	18-Aug-95		
7887	10808	P	127	NoSurvey	NoSurvey	01-Aug-95	16-Aug-95				
		P	128	1619.31	1618.95	31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95		
		P	129	1626.65	1625.95	31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95		
		P	**130**	1618.41	1618.34	31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95		
		P	131	1618.40	1618.31	31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95		
		P	131a			31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95		
5560	10745	P	132	1601.714	1601.498	31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95		
5740	10808	P	133	NoSurvey	NoSurvey	31-Jul-95					
5727	10872	P	134	1599.00	1598.74	31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95		

TABLE 9 F Date of Inventory and Preliminary Monitoring OF POTENTIAL OBSERVATION WELLS.

X	Y	Well #.		Z rim	Z ground						
(m)	(m)			(m)	(m)						
5779	10999	P	135	1598.53	1598.09	31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95		
4982	13145	P	136	1619.34	1618.83	04-Oct-94	31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95	
5110	13513	P	137		1617.35	04-Oct-94	31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95	
5303	13323	P	138	-1.00	1614.66	04-Oct-94	31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95	
5342	13399	P	139	1600.29	1599.79	04-Oct-94	31-Jul-95	15-Aug-95	17-Aug-95	22-Aug-95	
		P	140	-1.00	1572.51	22-Sep-94	31-Jul-95	15-Aug-95	17-Aug-95	21-Aug-95	
5277	16523	P	141	1602.16	1601.62	22-Sep-94	31-Jul-95				
5303	16599	P	141a	NoSurvey	NoSurvey	15-Aug-95					
		P	142	1566.66	1566.25	22-Sep-94	31-Jul-95				
		P	142A	1569.94	1569.60						
					Counts ->	136.00	119.00	101.00	69.00	31.00	456.00

TABLE 10A Water Table Depth measured from Z(rim) in 1994 and 1995.
Use Table 9 for date of measurements

X (m)	Y (m)	Well #.		Z rim (m)	Z ground (m)					
		P	1	NoSurvey		11.85				
1112	23151	P	2	NoSurvey		3.15				
12464	17627	P	3	NoSurvey		5.50				
12747	17856	P	4	NoSurvey		3.50				
13274	17691	P	5	NoSurvey		14.50				
15241	16573	P	6	NoSurvey		12.57	13.60	12.70		
15189	16662	P	7	NoSurvey		10.62	11.07	10.44		
14906	16866	P	8	NoSurvey		0.60	0.75	0.60		
14984	18389	P	9	NoSurvey		6.69	6.52	5.00		
15151	18453	P	10	NoSurvey		7.58	7.60	6.34	1.65	
15626	18593	P	11	NoSurvey		7.35	7.17	6.38		
14705	16180	P	12	NoSurvey		19.00	17.43	16.05		
14701	16116	P	13	NoSurvey		19.31	18.22	17.52		
14778	15685	P	14	NoSurvey		6.80	7.17	5.58		
14456	13780	P	15	NoSurvey		8.00	6.04	6.52	6.42	
33959	7595	P	16	1704.28	1703.9	7.45	7.30	7.52	7.95	6.30
35591	8002	P	17	1718.53	1716.93	1.00	0.95	Bordo de M	1.20	
34190	7748	P	18	1704.48	1705.23	7.44	6.63	7.27	7.54	6.73
32545	7189	P	19	1685.57	1685.57	8.43	8.28	8.50	8.00	7.65
31298	7126	P	20	1673.84	1673.32	8.84	8.23	8.01	Esta esca	8.37
30398	7151	P	21	1667.02	1666.61	7.18	7.00	6.79	7.81	7.55
29806	7037	P	22	1661.80	1661.02	8.25	5.01	5.00	5.77	5.48
29382	7024	P	23	1659.55	1659.05	8.00	7.72	7.76	8.44	8.41
29524	7049	P	24	1657.55	1658.05	8.00	7.60	10.35	8.30	8.19
29395	7202	P	25	1658.98	1658.11	8.50	8.20	8.22	9.01	8.88
27647	7443	P	26	1649.06	1648.55	7.63	7.85	8.03		
31092	624	P	27	NoSurvey	NoSurvey	9.16				
31233	268	P	28	1750.84	1750.34	17.27	17.45	16.84	17.25	16.37

TABLE 10 B Water Table Depth measured from Z(rim) in 1994 and 1995.
Use Table 9 for date of measurements

X (m)	Y (m)	Well #.		Z rim (m)	Z ground (m)						
		P	29	1736.62	1736.19	11.00	10.54	10.64	11.83	bombeando	
30899	1145	P	30	1730.36	1729.95	10.00	9.90	10.00	10.38	No tomamos	
30321	2021	P	31	1714.85	1714.46	8.50	Muestra	9.04		No tomamos	
30398	1386	P	32	1719.02	1718.50	9.18	9.03	8.86	9.20	9.00	
29986	395	P	33	1698.90	1698.68	7.65	no datos	No fuimos			
30089	319	P	34	1699.20	1699.00	7.65	7.31	No fuimos			
28366	7151	P	35	1653.87	1653.19	8.33	8.50	7.35	8.56	8.35	
		PM	35	1710.48	1709.72						
6087	19075	P	36	1572.07	1572.00	15.26	10.92	14.09	11.23	11.00	10.83
6010	19088	P	37	-1.00	1571.16	18.73	14.32	16.88			
6216	19075	P	38	NoSurvey	NoSurvey	13.65	12.55	no lo encontramos en la milpa			
6074	18885	P	39	1567.53	1567.10	11.17	10.59	esta seco	seco		
		P	39a	1568.81	1568.601	12.37	12.04	11.99			
5560	16916	P	40	1555.74	1555.53	14.80	4.19	6.97	5.48	5.42	5.35
5766	17056	P	41	NoSurvey	NoSurvey	cerrado	11.74	11.71			
5715	18529	P	42	-1.00	1559.88	12.30	12.11	11.85	3.57	3.57	
8016	13945	P	43	1567.51	1567.27	5.00	4.70	4.65	6.47		
8440	14732	P	44	1571.79	1571.44	5.80	5.46	6.60	9.44		
6923	18364	P	45	1571.50	1570.51	10.80	9.72	11.45			
6949	18466	P	46	1572.59	1572.33	10.00	11.32				
6974	18326	P	47	1571.13	1570.54	9.00	8.51	9.77	8.00		
6897	18326	P	48	1570.55	1570.05	9.30	8.80	10.13	8.88		
6833	17653	P	49	1562.98	1562.44	10.40	12.58	7.14	3.94	4.83	
7064	17475	P	50	1561.64	1561.46	5.40	5.28	6.48	5.61	5.57	
7077	17500	P	51	1561.97	1561.69	7.30	6.32	5.97	5.46		
6923	17297	P	52	1561.77	1561.47	6.50	6.48	7.17	6.94		
7064	17246	P	53	1562.13	1562.04	5.70	5.72	6.88	6.36	6.22	
7026	17170	P	54	1562.55	1562.18	6.00	5.94	12.06	24.82	6.67	

TABLE 10C Water Table Depth measured from Z(rim) in 1994 and 1995.
Use Table 9 for date of measurements

X	Y	Well #.		Z rim	Z ground					
(m)	(m)			(m)	(m)					
6936	16967	P	55	1562.47	1562.43	5.55	5.47	5.94	5.59	
6897	16726	P	56	1563.41	1563.16	5.05	5.38	6.04	5.86	5.88
6794	16472	P	57	1563.35	1563.28	5.30	4.24	6.00	5.67	5.68
		P	57	1677.74	1677.29					
		P	58	1701.58	1700.74	7.60	no datos	7.07	4.46	
		P	59	1700.73	1700.47	7.60	7.13	7.44	4.51	
		P	60	1690.98	1690.30	5.10	3.70	1.94		
		P	61	1689.64	1689.60	5.80	5.54	4.60	2.43	
		P	62	1689.87	1689.65	5.35	5.05	4.43	2.29	
		P	63	1688.86	1688.44	4.50	4.27	3.61	1.62	
		P	64	1695.22	1694.45	6.00	5.85	6.32	3.76	
		P	65	1644.13	1643.83	7.40	7.69	7.47	5.84	
		P	66	1609.89	1609.62	5.65	5.72	7.64	6.82	
26768	7453	P	67	1645.43	1645.04	4.45	4.36	4.87		
26768	7415	P	68	1644.04	1644.14	4.25	4.10	4.81		
26691	7466	P	69	1645.55	1645.04	4.70	4.55	5.12		
26748	7295	P	70	1645.81	1644.86	4.55	4.41	5.03		
26851	6812	P	71	1667.45	1656.42	8.40	seco			
26890	7091	P	72	1667.45	1667.25	22.60	22.81	22.81		
26870	7193	P	73	1657.88	1657.27	12.90	12.67	13.06		
26864	7777	P	74	1644.48	1644.25	3.35	3.28	3.77		
26035	8209	P	75	NoSurvey	NoSurvey	2.85	1.19	3.39		
		P	76	NoSurvey	NoSurvey	9.85	9.14	9.50		
		P	77	NoSurvey	NoSurvey	8.00	8.00	8.20		
		P	78	NoSurvey	NoSurvey	8.56	8.67			
		P	79	NoSurvey	NoSurvey					
		P	80	NoSurvey	NoSurvey	7.68	8.21			
		P	81	NoSurvey	NoSurvey	7.10	7.10			

TABLE 10D Water Table Depth measured from Z(rim) in 1994 and 1995.
Use Table 9 for date of measurements

X (m)	Y (m)	Well #.		Z rim (m)	Z ground (m)				
		P	82	1606.33	1605.90	3.40	3.46	3.81	3.39
		P	82a			11.69			
		P	83	1607.06	1606.69	4.48	4.48	4.86	4.64
		P	84	1607.37	1607.22	4.18	4.07	4.56	4.30
		P	85	1607.44	1607.15	4.21	4.16	4.36	4.34
		P	86	1609.09	1608.93	2.60	2.80	2.53	
		P	87	1609.72	1609.08	3.95	4.40		
		P	88	1611.89	1611.30	6.10	esta bombeando		
		P	89	1613.25	1613.00	7.17	ya no sirve		
		P	90	1632.88	1632.45	15.25	15.10	15.06	
		P	91	NoSurvey	NoSurvey	13.00	no entramos		
5715	21145	P	92	NoSurvey	NoSurvey				
5817	21170	P	93	NoSurvey	NoSurvey				
		P	94	NoSurvey	NoSurvey				
		P	95	NoSurvey	NoSurvey				
		P	96	NoSurvey	NoSurvey				
		P	97	NoSurvey	NoSurvey				
		P	98	NoSurvey	NoSurvey				
		P	99	NoSurvey	NoSurvey				
		P	100	1713.43	1713.28	6.00			
		P	101	1655.15	1654.05	2.94			
		P	102	1706.87	1706.36	11.06			
		P	103	1702.29	1702.02	6.57			
				1700.29	1698.55				
		P	104	NoSurvey	NoSurvey	A fuera de los limites			
		P	105	NoSurvey	NoSurvey	A fuera de los limites			
		P	106	1640.57	1640.35	10.37	10.35	10.39	
		P	107	1650.65	1650.22	12.28	12.30	11.13	

TABLE 10 E Water Table Depth measured from Z(rim) in 1994 and 1995.
Use Table 9 for date of measurements

X	Y	Well #.		Z rim	Z ground					
(m)	(m)			(m)	(m)					
13004	12281	P	108	1579.52	531.12	1.89	1.73			
13171	12065	P	109	1579.50	530.90	2.62	2.35	2.32		
12824	11646	P	110	NoSurvey	NoSurvey	4.04	3.28	3.18		
12978	11557	P	111	-1.00	534.68	5.89	5.69	5.52		
12862	11507	P	112	1582.98	534.30	6.30	6.40	6.18	6.08	
12785	11532	P	113	1582.66	533.88	5.93	5.98	5.86	5.65	
12850	11202	P	114	1587.82	539.44	1594.00	10.31	10.01	10.00	9.79
12682	10783	P	115	1592.83	544.29	1585.00	11.27	11.67	11.56	11.55
12644	10567	P	116	NoSurvey	NoSurvey	Not poss	13.52	13.42	13.48	
12618	10643	P	117	1595.48	547.05	12.42	13.14	13.08	12.93	
12760	10364	P	118	NoSurvey	NoSurvey	13.15	12.64			
12824	10478	P	119	NoSurvey	NoSurvey	SCW	seco			
12592	10288	P	120	1601.10	552.58	11.86	11.47			
12464	10300	P	121	1601.18	552.71	12.58	12.38			
12541	10364	P	122			11.55	11.54			
		P	123	-1	552.35	11.86				
		P	124	NoSurvey	NoSurvey					
7797	12751	P	125	NoSurvey	NoSurvey	1.60	2.00	1.23	1.23	
7861	12535	P	126	NoSurvey	NoSurvey	2.35	2.77	2.32	2.32	
7887	10808	P	127	NoSurvey	NoSurvey	6.37	no se tupo			
		P	128	1619.31	1618.95	en la escu	escuela	4.29	cerrrado	
		P	129	1626.65	1625.95	4.57	1.15	1.16	1.17	
		P	130	1618.41	1618.34	3.61	2.58	2.48	2.46	
		P	131	1618.40	1618.31	7.89	7.25	7.06	6.24	
		P	131a			6.61 nuevo	6.25	6.27	6.29	
5560	10745	P	132	1601.714	1601.498	12.43	12.32	12.08	11.94	
5740	10808	P	133	NoSurvey	NoSurvey	lo cerraron	10.00			
5727	10872	P	134	1599.00	1598.74	10.15	seco	9.89	9.83	

TABLE 10 F Water Table Depth measured from Z(rim) in 1994 and 1995.
Use Table 9 for date of measurements

X	Y	Well #.		Z rim	Z ground						
(m)	(m)			(m)	(m)						
5779	10999	P	135	1598.53	1598.09	8.89	2.45	seco	seco		
4982	13145	P	136	1619.34	1618.83	2.84	3.84	2.45	2.46		
5110	13513	P	137		1617.35	12.76	14.68	13.80	13.36	13.10	
5303	13323	P	138	-1.00	1614.66	12.00	12.38	seco	seco	seco	
5342	13399	P	139	1600.29	1599.79	18.41	18.50	18.43	18.51	18.42	
		P	140	-1.00	1572.51	13.07	13.55	13.65	13.57	13.53	
5277	16523	P	141	1602.16	1601.62	13.13	seco				
5303	16599	P	141a	NoSurvey	NoSurvey	17.12					
		P	142	1566.66	1566.25	12.96	seco				
		P	142A	1569.94	1569.60						
					Counts ->	128.00	108.00	95.00	62.00	26.00	2.00

wellsmissinç.xls

TABLE 11 LIST OF OBSERVATION WELLS				
with X , Y coordinates Digitized from 1:50000				
Topo Map. All Z elevations compiled from Surveys.				
		SURVEYED		OBS
x digitized	x digitized	Z rim *	Z ground **	WELL
m	m	m	m	ID#
31104	624	1736.62	1736.2 P	29
27620	7456	1649.07	1648.6 P	26
25050	15900	1700.73	1700.5 P	58
24934	15735	1700.73	1700.5 P	59
24807	14925	1690.98	1690.3 P	60
24743	14925	1689.64	1689.6 P	61
24820	14925	1689.87	1689.6 P	62
24769	14875	1688.86	1688.4 P	63
24396	15071	1695.22	1694.5 P	64
24780	9081	NO SURVEY	P	76
24471	9056	NO SURVEY	P	77
24278	9335	NO SURVEY	P	80
23661	9640	NO SURVEY	P	81
18618	7669	NO SURVEY	P	91
5906	21423	NO SURVEY	P	94
20977	4990	1713.43	1713.3 P	100
16253	7663	1655.15	1654.0 P	101
15611	6749	1706.87	1706.4 P	102
15617	6634	1702.29	1702.0 P	103
15341	5930	1700.29	1698.5 P	104
15354	5860	NO SURVEY	P	105
20563	14935	1650.65	1650.2 P	107
12163	6644	1761.91	1761.9 P	123
10868	5771	NO SURVEY	P	124
6293	8522	1619.31	1618.9 P	128
6023	8776	1626.65	1626.0 P	129
5997	8764	NO SURVEY	P	130
5702	8802	NO SURVEY	P	131
Error estimate on x,y :+/- radius 50m (3 pixels)				
Error estimate on Z rim : +/- 0,02m. (2x the closure error)				
Error estimate on Z ground: +/- 0,10m.				
Surveys conducted by C.N.A in 1995 Supervised by E. Perraton.				

WELLSDP1

TABLE 12. DIGITIZED COORDINATES OF DEEP WELLS DRILLED and TESTED BY S.A.R.H

X in (m)	Y in (m)	Deep Wells Id.
3696	20497	POTB - 66
5277	17399	R - 2
4802	16739	R - 3
5483	16688	I
5766	17056	I I
5946	16700	I I I
5445	16827	I V
4172	15710	P
7591	10402	PORCB - 54
8157	10745	POCPB - 64
8980	11811	POCPB - 60
8221	14834	POB - 2
9263	14491	POAB - 59
9327	15634	T - 6
8671	16091	V I
8119	16358	V
9700	16281	I V
8916	16358	I I
10600	16954	T - 4
10124	17119	V I I
10188	17412	T - 3
12682	17627	FIRCO - T 2
15369	18212	POMB - 35



Figure 1. Deep Wells drilled in the Research Area. 1968-1995.

APPENDIX AA.

CLIMATIC DATA TABLES.

TABLE 1 Monthly Precipitation in (mm) STATION: CUAJIMOLOYAS

Año / Year. ->	---- 1968 ----		---- 1969 ----		---- 1970 ----		---- 1971 ----		---- 1972 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	59.5	73.8	16.5	15.1	4.0	4.9	2.0	2.7	20.5	25.9
FEB./FEB.	12.5	15.5	20.5	18.7	15.5	19.0	1.0	1.3	1.5	1.9
MAR./MAR.	2.5	3.1	27.5	25.1	0.0	0.0	8.5	11.3	35.5	44.9
APR./ABR.	47.0	58.3	75.0	68.6	28.5	35.0	22.0	29.3	57.5	72.7
MAY/MAYO	176.5	219.0	53.5	48.9	62.5	76.6	59.5	79.3	66.5	84.1
JUNE/JUNIO	265.5	329.5	120.5	110.2	204.0	250.2	112.0	149.3	324.5	410.5
JULY/JULIO	69.0	85.6	182.0	166.4	122.0	149.6	99.4	132.5	138.0	174.6
AUG./AGO.	84.5	104.9	475.5	434.7	271.0	332.3	181.0	241.4	66.0	83.5
SEPT./SEPT	138.0	171.3	210.0	192.0	222.0	272.3	203.5	271.4	76.5	96.8
OCT./OCT.	66.5	82.5	112.5	102.9	41.5	50.9	94.0	125.3	62.0	78.4
NOV./NOV.	34.5	42.8	16.5	15.1	7.5	9.2	64.5	86.0	94.5	119.6
DEC./DIC.	11.0	13.7	2.5	2.3	0.0	0.0	52.5	70.0	5.5	7.0
TOTAL	967.0	1200.0	1312.5	1200.0	978.5	1200.0	899.9	1200.0	948.5	1200.0
AVERAGE	80.6	100.0	109.4	100.0	81.5	100.0	75.0	100.0	79.0	100.0

TABLE 2 Monthly Precipitation in (mm) STATION: CUAJIMOLOYAS

Año / Year. ->	---- 1973 ----		---- 1974 ----		---- 1975 ----		---- 1976 ----		---- 1977 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	0.0	0.0	18.5	16.4	19.0	19.2	9.0	10.1	0.0	0.0
FEB./FEB.	0.0	0.0	2.0	1.8	8.5	8.6	0.0	0.0	22.0	25.4
MAR./MAR.	1.5	1.4	87.5	77.4	2.0	2.0	0.0	0.0	0.0	0.0
APR./ABR.	70.0	63.2	100.0	88.4	36.0	36.5	67.5	75.6	68.0	78.4
MAY/MAYO	98.0	88.5	185.5	164.0	197.0	199.5	181.0	202.7	46.0	53.1
JUNE/JUNIO	262.5	237.1	270.0	238.8	173.5	175.7	271.5	304.1	191.0	220.3
JULY/JULIO	242.5	219.0	185.5	164.0	162.5	164.6	166.0	185.9	165.7	191.2
AUG./AGO.	255.0	230.3	47.0	41.6	187.0	189.4	78.0	87.4	185.0	213.4
SEPT./SEPT	252.5	228.1	392.5	347.1	217.0	219.7	134.0	150.1	149.0	171.9
OCT./OCT.	137.5	124.2	61.0	53.9	146.0	147.8	69.5	77.8	78.5	90.6
NOV./NOV.	9.0	8.1	7.5	6.6	19.5	19.7	95.0	106.4	66.0	76.1
DEC./DIC.	0.0	0.0	0.0	0.0	17.0	17.2	0.0	0.0	69.0	79.6
TOTAL	1328.5	1200.0	1357.0	1200.0	1185.0	1200.0	1071.5	1200.0	1040.2	1200.0
AVERAGE	110.7	100.0	113.1	100.0	98.8	100.0	89.3	100.0	86.7	100.0

TABLE 3 Monthly Precipitation in (mm) **STATION:** CUAJIMOLOYAS

Año / Year. ->	---- 1978 ----		---- 1979 ----		---- 1980 ----		---- 1981 ----		---- 1982 ----		---- 1983 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	0.0	0.0	4.5	4.3	15.5	20.0	4.0	3.7	2.0	3.0	12.5	18.4
FEB./FEB.	5.0	4.3	24.5	23.1	0.0	0.0	7.0	6.5	36.2	55.0	88.3	130.3
MAR./MAR.	62.0	53.7	10.0	9.4	6.5	8.4	35.4	32.7	35.5	53.9	39.5	58.3
APR./ABR.	48.0	41.6	99.0	93.5	48.0	62.0	53.4	49.4	68.8	104.5	0.0	0.0
MAY/MAYO	122.0	105.7	71.0	67.1	89.0	115.0	146.6	135.5	95.2	144.5	7.8	11.5
JUNE/JUNIO	303.6	263.0	106.0	100.2	125.0	161.5	454.1	419.8	76.8	116.6	116.1	171.3
JULY/JULIO	228.0	197.5	236.0	223.0	71.5	92.4	175.7	162.4	96.8	147.0	220.8	325.8
AUG./AGO.	117.3	101.6	213.0	201.3	252.0	325.5	203.4	188.0	16.5	25.1	64.5	95.2
SEPT./SEPT	343.0	297.1	378.5	357.6	270.5	349.4	152.8	141.3	155.6	236.2	139.4	205.7
OCT./OCT.	112.4	97.4	93.0	87.9	39.5	51.0	53.2	49.2	191.1	290.1	26.8	39.5
NOV./NOV.	24.6	21.3	15.0	14.2	7.0	9.0	10.0	9.2	15.9	24.1	53.0	78.2
DEC./DIC.	19.6	17.0	19.5	18.4	4.5	5.8	2.5	2.3	0.0	0.0	44.5	65.7
TOTAL	1385.5	1200.0	1270.0	1200.0	929.0	1200.0	1298.1	1200.0	790.4	1200.0	813.2	1200.0
AVERAGE	115.4583	100	105.8333	100	77.41667	100	108.175	100	65.9	100.0	67.8	100.0

TABLE 4 Monthly Precipitation in (mm) **STATION:** CUAJIMOLOYAS

Año / Year. ->	---- 1984 ----		---- 1985 ----		---- 1986 ----		---- 1987 ----		---- 1988 ----		* *Sum of %	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Sum	%
JAN./ENE.	0.0	0.0	0.0		0.0	0.0	0.0	0.0	1.0		217.6	11.5
FEB./FEB.	0.0	0.0	12.5		28.5	31.7	10.0	13.1	0.0		356.3	18.8
MAR./MAR.	57.0	62.2	6.5		3.5	3.9	77.0	101.2	25.5		549.0	28.9
APR./ABR.	3.3	3.6	127.6		46.5	51.7	62.0	81.5	73.0		1093.9	57.6
MAY/MAYO	179.8	196.2	77.4		224.0	249.2	80.5	105.8	93.5		2346.4	123.5
JUNE/JUNIO	208.4	227.4	122.9		187.0	208.1	261.5	343.7	216.5	231.8	4437.1	233.5
JULY/JULIO	161.0	175.7	139.5		189.5	210.8	219.5	288.5	169.1	181.0	3456.5	181.9
AUG./AGO.	148.4	161.9	108.2		133.0	148.0	69.5	91.3	292.5		3296.7	173.5
SEPT./SEPT	325.4	355.0	166.1	230.6	167.5	186.4	118.5	155.8	186.0		4405.0	231.8
OCT./OCT.	5.5	6.0	61.5	85.3	63.5	70.7	5.5	7.2	38.5		1633.4	86.0
NOV./NOV.	6.0	6.5	26.7	37.1	34.5	38.4	8.0	10.5	5.0		701.3	36.9
DEC./DIC.	5.0	5.5	15.7	21.8	1.0	1.1	1.0	1.3	20.4	21.8	306.8	16.1
TOTAL	1099.8	1200.0	864.6		1078.5	1200.0	913.0	1200.0	1121.0		22800.0	1200.0
AVERAGE	91.7	100.0			89.9	100.0	76.1	100.0			1900.0	100.0

TABLE 5 Monthly Precipitation in (mm) **STATION:** Oaxaca de Juarez

Año / Year. ->	---- 1968 ----		---- 1969 ----		---- 1970 ----		---- 1971 ----		---- 1972 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	26.8	54.4	14.9	24.6	2.0	3.1	0.0	0.0	0.0	0.0
FEB./FEB.	12.1	24.6	0.9	1.5	2.0	3.1	0.0	0.0	0.0	0.0
MAR./MAR.	11.8	24.0	18.4	30.4	0.0	0.0	3.2	5.9	16.0	24.8
APR./ABR.	22.7	46.1	11.8	19.5	4.5	7.0	2.5	4.6	69.2	107.2
MAY/MAYO	138.7	281.6	48.3	79.8	41.8	64.7	93.1	170.7	67.1	103.9
JUNE/JUNIO	236.8	480.8	103.9	171.7	227.6	352.0	85.7	157.1	332.1	514.4
JULY/JULIO	40.5	82.2	113.5	187.6	139.3	215.5	53.6	98.3	47.0	72.8
AUG./AGO.	74.6	151.5	352.1	581.9	195.2	301.9	118.7	217.6	37.3	57.8
SEPT./SEPT	15.3	31.1	44.8	74.0	129.1	199.7	207.1	379.7	131.2	203.2
OCT./OCT.	8.5	17.3	13.5	22.3	28.3	43.8	85.5	156.7	10.4	16.1
NOV./NOV.	3.0	6.1	4.0	6.6	6.0	9.3	4.2	7.7	63.5	98.4
DEC./DIC.	0.2	0.4	0.0	0.0	0.0	0.0	1.0	1.8	0.9	1.4
TOTAL	591.0	1200.0	726.1	1200.0	775.8	1200.0	654.6	1200.0	774.7	1200.0
PROMEDIO	49.3	100.0	60.5	100.0	64.7	100.0	54.6	100.0	64.6	100.0

TABLE 6 Monthly Precipitation in (mm) **STATION:** Oaxaca de Juarez

Año / Year. ->	---- 1973 ----		---- 1974 ----		---- 1975 ----		---- 1976 ----		---- 1977 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	0.0	0.0	2.6	3.2	0.3	0.4	0.0	0.0	0.0	0.0
FEB./FEB.	0.5	0.6	0.0	0.0	14.6	21.2	0.0	0.0	3.0	7.8
MAR./MAR.	16.9	20.5	45.4	55.7	15.5	22.5	0.0	0.0	0.0	0.0
APR./ABR.	48.2	58.5	78.6	96.4	3.7	5.4	166.2	265.2	36.0	94.0
MAY/MAYO	117.3	142.5	142.8	175.1	109.6	158.8	81.8	130.5	12.7	33.2
JUNE/JUNIO	197.0	239.2	182.4	223.7	159.9	231.7	121.1	193.2	149.9	391.5
JULY/JULIO	184.9	224.6	157.3	192.9	192.9	279.5	242.4	386.8	20.0	52.2
AUG./AGO.	109.2	132.6	103.5	126.9	56.1	81.3	48.2	76.9	98.7	257.8
SEPT./SEPT	238.8	290.0	264.6	324.5	250.0	362.2	60.4	96.4	73.6	192.2
OCT./OCT.	68.8	83.6	0.4	0.5	24.9	36.1	21.5	34.3	51.5	134.5
NOV./NOV.	6.5	7.9	1.0	1.2	0.0	0.0	10.5	16.8	11.6	30.3
DEC./DIC.	0.0	0.0	0.0	0.0	0.8	1.2	0.0	0.0	2.5	6.5
TOTAL	988.1	1200.0	978.6	1200.0	828.3	1200.0	752.1	1200.0	459.5	1200.0
PROMEDIO	82.3	100.0	81.6	100.0	69.0	100.0	62.7	100.0	38.3	100.0

TABLE 7 Monthly Precipitation in (mm) **STATION:** Oaxaca de Juarez

Año / Year. ->	---- 1978 ----		---- 1979 ----		---- 1980 ----		---- 1981 ----		---- 1982 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	0.0	0.0	0	0.0	1.9	2.7	0.0	0.0	0.0	0.0
FEB./FEB.	3.2	5.9	14.9	21.4	0.9	1.3	26.8	28.8	33.3	69.0
MAR./MAR.	14.0	25.8	0.5	0.7	6	8.7	30.3	32.5	15.0	31.1
APR./ABR.	18.6	34.3	106.5	152.8	27.2	39.3	16.2	17.4	76.8	159.2
MAY/MAYO	43.3	79.9	85.5	122.7	111.3	160.8	87.4	93.8	89.6	185.7
JUNE/JUNIO	231.2	426.4	71.3	102.3	139.8	202.0	330.9	355.1	106.3	220.3
JULY/JULIO	105.0	193.7	93	133.4	165.8	239.5	283.7	304.5	93.5	193.8
AUG./AGO.	66.2	122.1	130.7	187.5	219.6	317.2	181.1	194.3	47.4	98.3
SEPT./SEPT	130.7	241.1	290.8	417.2	134.9	194.9	126.3	135.5	91.0	188.6
OCT./OCT.	35.5	65.5	35.4	50.8	16.6	24.0	35.3	37.9	20.6	42.7
NOV./NOV.	2.5	4.6	7.8	11.2	6.7	9.7	0.2	0.2	5.4	11.2
DEC./DIC.	0.4	0.7	0	0.0	0	0.0	0.0	0.0	0.0	0.0
TOTAL	650.6	1200.0	836.4	1200.0	830.7	1200.0	1118.2	1200.0	578.9	1200.0
PROMEDIO	54.2	100	69.7	100	69.225	100	93.18333	100	48.2	100.0

TABLE 8 Monthly Precipitation in (mm) **STATION:** Oaxaca de Juarez

Año / Year. ->	---- 1983 ----		---- 1984 ----		---- 1985 ----		---- 1986 ----		---- 1987 ----		---- 1988 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	0.3	0.6	5.2	7.6	0	0.6	3.5	5.7	0.0	0.0	0.0	0.0
FEB./FEB.	32.2	63.0	3.2	4.7	0.1	63.0	4.8	7.8	2.5	5.3	0.0	0.0
MAR./MAR.	18.6	36.4	20.5	29.8	4.3	36.4	0.0	0.0	10.7	22.6	0.0	0.0
APR./ABR.	0.0	0.0	0.0	0.0	69.5	0.0	34.0	55.5	25.8	54.6	11.7	18.2
MAY/MAYO	24.4	47.8	133.2	193.7	46.9	47.8	88.1	143.8	98.8	208.9	68.5	106.5
JUNE/JUNIO	87.6	171.5	214.6	312.1	173.6	171.5	182.4	297.8	142.4	301.1	227.9	354.4
JULY/JULIO	145.2	284.2	63.7	92.7	113.3	284.2	119.1	194.4	92.4	195.4	120.1	186.8
AUG./AGO.	101.7	199.1	109.9	159.9	119	199.1	109.3	178.4	100.0	211.5	238.5	370.9
SEPT./SEPT	123.9	242.5	265.0	385.5	114.5	242.5	135.0	220.4	94.3	199.4	88.2	137.2
OCT./OCT.	12.4	24.3	9.7	14.1	31.6	24.3	50.4	82.3	0.6	1.3	16.8	26.1
NOV./NOV.	48.5	94.9	0.0	0.0	0.5	94.9	5.4	8.8	0.0	0.0	0.0	0.0
DEC./DIC.	18.2	35.6	0.0	0.0	5.8	35.6	3.0	4.9	0.0	0.0	0.0	0.0
TOTAL	613.0	1200.0	825.0	1200.0	679.1	1200.0	735.0	1200.0	567.5	1200.0	771.7	1200.0
PROMEDIO	51.1	100.0	68.8	100.0	56.6	100.0	61.3	100.0	47.3	100.0	64.3	100.0

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TABLE 9 Monthly Precipitation in (mm) **STATION:** AYUTLA

Año / Year. ->	---- 1968 ----		---- 1969 ----		---- 1970 ----		---- 1971 ----		---- 1972 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	30.4	29.3	6.1	3.8	6.0	4.5	0.0	0.0	49.3	38.6
FEB./FEB.	13.4	12.9	10.2	6.3	1.6	1.2	1.4	1.2	6.2	4.9
MAR./MAR.	3.7	3.6	33.5	20.8	1.6	1.2	92.5	76.3	85.0	66.6
APR./ABR.	43.7	42.2	35.5	22.0	23.9	18.1	0.0	0.0	71.9	56.4
MAY/MAYO	114.5	110.5	62.7	38.9	59.5	44.9	17.2	14.2	18.9	14.8
JUNE/JUNIO	284.1	274.3	170.2	105.6	173.4	131.0	199.8	164.8	323.5	253.5
JULY/JULIO	243.6	235.2	421.7	261.7	344.3	260.0	291.9	240.8	240.6	188.6
AUG./AGO.	182.6	176.3	674.3	418.5	426.0	321.8	392.7	323.9	241.7	189.4
SEPT./SEPT	196.3	189.5	370.8	230.1	362.9	274.1	243.5	200.8	278.1	218.0
OCT./OCT.	62.1	60.0	65.3	40.5	113.8	86.0	141.3	116.5	141.3	110.7
NOV./NOV.	26.5	25.6	64.2	39.8	61.7	46.6	45.9	37.9	45.9	36.0
DEC./DIC.	42.1	40.6	19.0	11.8	14.1	10.6	28.7	23.7	28.7	22.5
TOTAL	1243.0	1200.0	1933.5	1200.0	1588.8	1200.0	1454.9	1200.0	1531.1	1200.0
PROMEDIO	103.6	100.0	161.1	100.0	132.4	100.0	121.2	100.0	127.6	100.0

TABLE 10 Monthly Precipitation in (mm) **STATION:** AYUTLA

Año / Year. ->	---- 1973 ----		---- 1974 ----		---- 1975 ----		---- 1976 ----		---- 1977 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	15.3	18.6	18.3	12.8	17.0	16.3	13.8	12.8	6.2	7.0
FEB./FEB.	21.1	25.6	0.0	0.0	14.5	13.9	36.0	33.4	21.0	23.9
MAR./MAR.	0.0	0.0	0.0	0.0	3.0	2.9	10.0	9.3	0.0	0.0
APR./ABR.	14.2	17.2	23.9	16.7	15.9	15.3	44.0	40.8	32.0	36.4
MAY/MAYO	19.0	23.1	120.3	83.9	110.8	106.3	47.7	44.3	98.6	112.0
JUNE/JUNIO	242.4	294.1	299.1	208.6	56.3	54.0	291.1	270.1	197.1	223.9
JULY/JULIO	153.6	186.4	189.6	132.2	234.9	225.3	214.4	198.9	91.1	103.5
AUG./AGO.	233.2	282.9	157.4	109.8	270.7	259.7	146.4	135.8	219.9	249.8
SEPT./SEPT	241.5	293.0	718.3	500.8	235.0	225.4	246.9	229.1	147.2	167.2
OCT./OCT.	3.4	4.1	117.4	81.9	192.9	185.1	128.7	119.4	108.8	123.6
NOV./NOV.	25.2	30.6	65.6	45.7	42.0	40.3	79.1	73.4	77.5	88.1
DEC./DIC.	20.2	24.5	11.1	7.7	57.9	55.5	35.3	32.7	56.8	64.5
TOTAL	989.1	1200.0	1721.0	1200.0	1250.9	1200.0	1293.4	1200.0	1056.2	1200.0
PROMEDIO	82.4	100.0	143.4	100.0	104.2	100.0	107.8	100.0	88.0	100.0

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TABLE 11 Monthly Precipitation in (mm) **STATION:** AYUTLA

Año / Year. ->	---- 1978 ----		---- 1979 ----		---- 1980 ----		---- 1981 ----		---- 1982 ----		---- 1983 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	3.9	2.8	19.6	16.2	9.8	8.6	35.5	24.0	15.3	17.4	13.0	10.0
FEB./FEB.	41.7	30.2	9.8	8.1	8.0	7.0	34.8	23.5	26.6	30.2	57.8	44.3
MAR./MAR.	34.3	24.8	50.7	41.9	0.7	0.6	26.5	17.9	16.2	18.4	15.0	11.5
APR./ABR.	0.0	0.0	81.0	66.9	59.1	52.0	27.0	18.2	25.4	28.9	11.2	8.6
MAY/MAYO	87.4	63.3	105.6	87.2	109.4	96.3	66.8	45.1	98.3	111.7	24.1	18.5
JUNE/JUNIO	483.4	350.0	122.2	100.9	222.7	196.0	473.1	319.2	137.2	155.9	111.1	85.2
JULY/JULIO	300.0	217.2	163.1	134.7	253.5	223.1	283.2	191.1	192.7	218.9	594.3	456.0
AUG./AGO.	210.0	152.0	374.5	309.3	213.5	187.9	344.2	232.2	127.6	144.9	260.6	199.9
SEPT./SEPT	261.5	189.3	411.5	339.8	320.7	282.3	260.8	176.0	250.9	285.0	340.0	260.9
OCT./OCT.	179.9	130.2	38.2	31.5	105.0	92.4	147.0	99.2	65.6	74.5	81.5	62.5
NOV./NOV.	16.0	11.6	49.1	40.5	37.0	32.6	58.6	39.5	66.5	75.5	17.9	13.7
DEC./DIC.	39.4	28.5	27.8	23.0	24.0	21.1	21.1	14.2	34.1	38.7	37.6	28.8
TOTAL	1657.5	1200.0	1453.1	1200.0	1363.4	1200.0	1778.6	1200.0	1056.4	1200.0	1564.1	1200.0
PROMEDIO	138.125	100	121.0917	100	113.6167	100	148.2167	100	88.0	100.0	130.3	100.0

TABLE 12 Monthly Precipitation in (mm) **STATION:** AYUTLA

Año / Year. ->	---- 1984 ----		---- 1985 ----		---- 1986 ----		---- 1987 ----		---- 1988 ----		* *Sum of %	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Sum	%
JAN./ENE.	25.5	18.5	9.2	8.0	11.5	12.8	0.0	0.0	13.2	10.2	230.4	12.8
FEB./FEB.	9.1	6.6	4.5	3.9	38.8	43.2	7.0	10.2	17.0	13.1	253.2	14.1
MAR./MAR.	11.5	8.4	0.0	0.0	25.0	27.9	51.5	74.9	2.0	1.5	368.4	20.5
APR./ABR.	5.2	3.8	48.0	42.0	36.5	40.7	78.6	114.3	24.0	18.5	562.0	31.2
MAY/MAYO	249.6	181.5	141.9	124.0	32.1	35.8	50.5	73.4	45.3	34.9	1278.3	71.0
JUNE/JUNIO	283.0	205.8	293.9	256.9	180.8	201.4	50.5	73.4	280.8	216.5	3615.7	200.9
JULY/JULIO	312.4	227.2	260.4	227.6	202.2	225.3	242.3	352.4	250.3	193.0	4049.5	225.0
AUG./AGO.	251.5	182.9	206.9	180.9	218.4	243.3	170.1	247.4	599.3	462.2	4372.0	242.9
SEPT./SEPT	402.6	292.8	182.2	159.3	214.1	238.6	108.0	157.1	143.6	110.7	4326.8	240.4
OCT./OCT.	30.9	22.5	152.2	133.1	68.2	76.0	16.3	23.7	93.4	72.0	1365.0	75.8
NOV./NOV.	33.9	24.7	13.0	11.4	33.0	36.7	27.9	40.6	25.5	19.7	660.0	36.7
DEC./DIC.	34.6	25.2	60.5	52.9	16.4	18.3	22.4	32.6	61.7	47.6	518.7	28.8
TOTAL	1649.8	1200.0	1372.7	1200.0	1077.0	1200.0	825.1	1200.0	1556.1	1200.0	21600.0	1200.0
PROMEDIO	137.5	100.0		100.0	89.8	100.0	68.8	100.0		100.0	1800.0	100.0

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TABLE 13 **Monthly Precipitation in (mm)** **STATION: MITLA**

Correction Factor from Double Mass Curve: 0.511 CORRECTED GENERATED DATA (1968-1980)

Año / Year. ->	---- 1978 ----		---- 1979 ----		---- 1980 ----		---- 1981 ----		---- 1982 ----		---- 1983 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	0.5	0.8	3.7	7.0	5.8	13.5	4.5	17.0	0.5	1.8	0.0	0.0
FEB./FEB.	6.9	12.3	9.7	18.6	1.1	2.5	9.2	34.2	18.9	66.4	35.8	104.8
MAR./MAR.	23.3	41.7	9.2	17.6	2.6	5.9	8.8	32.7	2.6	9.0	52.8	154.7
APR./ABR.	19.8	35.5	49.3	94.3	23.8	55.1	4.2	15.8	10.2	35.9	0.0	0.0
MAY/MAYO	50.0	89.4	42.1	80.5	50.3	116.4	60.9	227.0	117.5	412.6	0.5	1.5
JUNE/JUNIO	170.1	304.3	52.6	100.6	77.6	179.5	70.5	262.8	32.7	114.8	111.4	326.5
JULY/JULIO	112.9	201.9	96.9	185.3	68.9	159.3	67.7	252.6	65.4	229.6	102.7	301.0
AUG./AGO.	66.2	118.5	120.5	230.4	120.8	279.3	55.2		3.6	12.6	2.0	6.0
SEPT./SEPT	143.6	256.9	188.7	360.6	130.6	302.0	22.3		38.3	134.5	74.1	217.1
OCT./OCT.	57.9	103.6	34.9	66.6	26.0	60.0	14.8		15.8	55.6	11.8	34.4
NOV./NOV.	9.2	16.5	11.1	21.3	7.3	16.8	3.6		33.2	116.6	8.2	24.0
DEC./DIC.	10.4	18.6	9.0	17.2	4.2	9.8	0.0		3.1	10.8	10.2	30.0
TOTAL	670.9	1200.0	627.8	1200.0	519.0	1200.0	321.7		341.9	1200.0	409.5	1200.0
PROMEDIO	55.90766	100	52.31363	100	43.24763	100	26.80876		28.5	100.0	34.1	100.0

TABLE 14 **Monthly Precipitation in (mm)** **STATION: MITLA**

Año / Year. ->	---- 1984 ----		---- 1985 ----		---- 1986 ----		---- 1987 ----		--- 1988 * ---		* *Sum of %	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Sum	%
JAN./ENE.	0.5		0.0	0.0	0.0	0.0	14.3	83.0	25.0		84.8	17.0
FEB./FEB.	9.8	34.2	0.0	0.0	0.0	0.0	0.0	0.0	11.1		171.2	34.2
MAR./MAR.	1.5		0.0	0.0	0.0	0.0	0.0	0.0	9.7		163.7	32.7
APR./ABR.	0.0		7.7	43.4	0.0	0.0	0.0	0.0	3.3		79.2	15.8
MAY/MAYO	30.0		51.1	289.1	64.4	354.9	13.3	77.0	49.4		1135.1	227.0
JUNE/JUNIO	91.2		57.2	323.8	7.7	42.3	87.4	506.7	79.2	262.8	1314.0	262.8
JULY/JULIO	41.4		23.0	130.1	69.0	380.3	38.3	222.2	76.1	252.6	1263.2	252.6
AUG./AGO.	15.8		34.2	193.7	7.2	39.4	42.9	248.9	30.2	100.1	500.6	100.1
SEPT./SEPT	153.3		20.4	115.6	63.9	352.1	10.7	62.2	53.1	176.3	881.6	176.3
OCT./OCT.	0.0		17.4	98.3	3.6	19.7	0.0	0.0	12.5	41.6	208.1	41.6
NOV./NOV.	0.0		0.6	3.2	1.0	5.6	0.0	0.0	9.0	29.9	149.4	29.9
DEC./DIC.	0.0		0.5	2.9	1.0	5.6	0.0	0.0	3.0	9.8	49.2	9.8
TOTAL	343.6		212.1	1200.0	217.7	1200.0	207.0	1200.0	361.6		6000.0	1200.0
PROMEDIO			17.7	100.0	18.1	100.0	17.2	100.0			500.0	100.0

*** Deducted from average monthly rainfall for the period of (1981-1987)**

**** Sum of % for complete years**

TABLE 15 **Monthly Precipitation in (mm)** **STATION: MITLA**

Correction Factor from Double Mass Curve: 0.511 CORRECTED GENERATED DATA (1968-1980)

Año / Year. ->	---- 1968 ----		---- 1969 ----		---- 1970 ----		---- 1971 ----		---- 1972 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	23.5	54.4	7.0	12.2	2.1	4.5	0.6	1.3	12.0	26.3
FEB./FEB.	6.4	14.9	7.2	12.6	4.8	10.4	0.5	1.1	1.2	2.6
MAR./MAR.	1.8	4.3	13.9	24.2	0.2	0.4	14.2	33.6	22.3	49.0
APR./ABR.	21.1	48.9	26.9	47.0	11.5	24.8	6.5	15.4	32.4	71.3
MAY/MAYO	78.7	182.4	28.0	48.8	29.5	63.7	28.7	67.9	28.2	62.0
JUNE/JUNIO	135.2	313.4	66.1	115.3	103.0	222.6	65.5	155.0	166.6	366.7
JULY/JULIO	54.0	125.2	115.8	202.0	91.8	198.3	69.9	165.6	73.9	162.7
AUG./AGO.	54.4	126.1	255.2	445.1	150.1	324.3	115.3	273.0	55.4	122.0
SEPT./SEPT	65.2	151.1	110.3	192.4	121.5	262.4	109.5	259.2	69.7	153.4
OCT./OCT.	27.5	63.7	41.4	72.3	28.8	62.3	53.1	125.7	36.4	80.1
NOV./NOV.	13.4	31.0	13.1	22.8	10.4	22.5	24.5	58.0	42.0	92.3
DEC./DIC.	36.5	84.6	3.1	5.3	1.7	3.8	18.6	44.1	5.2	11.5
TOTAL	517.6	1200.0	688.0	1200.0	555.4	1200.0	506.7	1200.0	545.2	1200.0
PROMEDIO	43.1	100.0	57.3	100.0	46.3	100.0	42.2	100.0	45.4	100.0

TABLE 16 **Monthly Precipitation in (mm)** **STATION: MITLA**

Correction Factor from Double Mass Curve: 0.511 CORRECTED GENERATED DATA (1968-1980)

Año / Year. ->	---- 1973 ----		---- 1974 ----		---- 1975 ----		---- 1976 ----		---- 1977 ----	
MONTH/MES	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%	Pr. / R	%
JAN./ENE.	1.9	3.8	7.8	13.3	7.6	15.7	4.2	9.4	0.8	1.9
FEB./FEB.	2.7	5.3	0.5	0.9	5.7	11.9	4.4	9.8	9.1	22.9
MAR./MAR.	2.1	4.3	29.5	50.6	2.6	5.3	1.2	2.7	0.0	0.0
APR./ABR.	26.6	53.0	39.5	67.7	12.6	26.1	41.8	92.4	27.0	67.4
MAY/MAYO	42.3	84.2	82.4	141.2	81.0	168.4	65.8	145.5	29.5	73.7
JUNE/JUNIO	125.0	248.9	132.7	227.4	72.8	151.3	125.8	278.2	97.3	243.3
JULY/JULIO	107.1	213.1	92.5	158.5	95.2	197.8	98.8	218.5	60.5	151.1
AUG./AGO.	113.2	225.4	43.6	74.7	92.5	192.3	45.3	100.2	90.1	225.2
SEPT./SEPT	126.4	251.6	228.1	390.8	116.7	242.4	75.0	165.7	68.2	170.5
OCT./OCT.	46.6	92.8	32.0	54.8	68.0	141.3	38.0	83.9	41.1	102.8
NOV./NOV.	6.3	12.6	10.4	17.8	10.8	22.4	37.9	83.8	29.6	73.9
DEC./DIC.	2.5	5.0	1.4	2.4	12.1	25.2	4.4	9.7	26.9	67.3
TOTAL	602.8	1200.0	700.3	1200.0	577.6	1200.0	542.7	1200.0	480.1	1200.0
PROMEDIO	50.2	100.0	58.4	100.0	48.1	100.0	45.2	100.0	40.0	100.0

TABLE 17 NOTES for TABLES (1 to 12).
Campos Aranda's (1984) Rational Deductive Method.

Pr_i = (Sum of Pr / (1200 - Sum of S_i)) * S_i

Ri : Unknown monthly rainfall en each incomplete year

i : each of the unknown months, (max of 11)
Sum of Si: Sum of the % of the monthly % for which the monthly rainfall is inknown
Sum of R: Sum of monthly rainfall that are known in the incomplete years.
Si: Average % assigned to each of the unknown months (or missing)

Period of 1968-1980

Only the the station of Ayutla has missing data for the months of July 1975 and january 1976

Period of 1981-1988

Cuajimoloyas: Missing data in Sept, Oct, Nov and Dec 1985.
Missing data in June, july, and december of 1988
Total of Missing monthly tot 7 out of 25 Percentage of completion : 97%

Ayutla: Missing data in July, aughust, sept, oct and november 1986.
Total of Missing monthly tot 5 out of 25 Percentage of completion : 98%

Mitla: Missing data in January, Feb, March, April, May, June and july 1981.
Missing data in August, sept, oct, nov and december 1988
Missing Months 1981-1988 12 out of 96 Percentage of completion : 95%
Missing Months 1961-1988 168 out of 25 Percentage of completion : 33%

TABLE 18 MONTHLY PRECIPITATION . TLACOLULA DE MATAMOROS

Data from: SECRETARIA DE RECURSOS HIDRAULICOS (S.A.R.H)
SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS

S. A. R. H
compiled by : E. Perraton 1996.

Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1950				43.0	131.5	36.5	82.5	58.0	55.5	125.5			532.5
1951			0.0	10.0	79.0	193.0	60.5	108.0	81.0	44.0			575.5
1952	0.0	0.0	10.0	19.0	161.0	190.5	113.5	56.5	165.5	13.0	10.0	0.0	739.0
1953	0.0			10.0	7.0	104.5	46.0	8.0	36.0	40.0		6.0	257.5
1954				90.5	118.5	101.0	81.5	20.5	214.0	82.5			708.5
1955						68.0	208.0		216.0	14.5			506.5
1956	0.0	0.0	0.0	13.0	126.5	160.5	50.0	43.5	99.0	0.0	0.0	0.0	492.5
1957	0.0	12.0	9.0	19.5	76.5	191.5	64.5	27.5	113.5	5.5	0.0	0.0	519.5
1958	71.5	58.0	0.0	31.0	29.0	210.0	99.5	128.5	161.5	24.5	42.0	13.0	868.5
1959												0.0	
1960	0.0	0.0	0.0	49.0	24.0	162.5	82.0	159.5	59.0	51.5	2.0	0.0	589.5
1961	0.0	0.0	13.5	0.0	40.0	150.0	116.0	6.0	51.0	0.0	34.5	0.0	411.0
1962	0.0	0.0	0.0	44.0	12.0	134.5	23.0	137.0	82.0	42.0	0.0	0.0	474.5
1963	0.0	0.0	9.0	10.5	57.5	132.5	114.0	92.5	160.5	0.0	0.0	0.0	576.5
1964		0.0	0.0	30.5	85.0	103.5	64.0	40.5	93.4	1.0	0.0	0.0	417.9
1965	0.0	0.0	0.0	17.0	27.5	120.0	50.0	30.0	45.5	64.0	0.0	0.0	354.0
1966	0.0	0.0	23.0	62.5	73.0	123.0	55.5	124.0	100.0	88.0	0.0	0.0	649.0
1967	0.0	0.0	18.0	72.5	36.0	134.0	15.5	28.0	61.5	30.5	35.5	0.0	431.5
1968	20.0	2.5	0.0	11.0	75.0	207.0	89.0	67.5	46.5	3.0	6.0	0.0	527.5
1969	0.0	5.0	14.0	22.0	25.0	108.5	74.5	302.5	97.5	12.5	2.0	0.0	663.5
1970	0.0	4.0	0.0	0.0	42.5	167.0	33.0	159.5	83.0	18.0	0.0	0.0	507.0
1971	0.0	0.0	0.0	18.0	37.0	103.0	31.0	145.0	115.0	40.0	0.0	0.0	489.0
1972	0.0	0.0	9.0	90.0	17.5	271.5	37.5	63.0	28.0	0.0	16.5	0.0	533.0
1973	0.0	0.0	0.0	17.0	55.0	65.5	79.4	131.0	89.0	25.0	4.5	0.0	466.4
1974	0.0	0.0	29.5	27.5	212.5	152.5	101.5	32.5	186.0	5.0	0.0	0.0	747.0
1975	7.0	11.0	0.0	17.0	40.0	67.0	118.5	53.5	147.0	25.0	0.0	0.0	486.0
1976	0.0	0.0	0.0	23.0	88.0	90.5	95.0	48.5	37.0	36.0	21.0	0.0	439.0
1977	0.0	0.0	0.0	50.0	20.0	52.5	0.0	84.5	48.5	23.2	13.0	13.0	304.7
1978	0.0	0.0	21.0	24.0			47.0						
1984	0.0	0.0	0.0	0.0	66.0	134.0	51.0	86.0	166.0	0.0	0.0	0.0	503.0
1985	0.0	0.0	9.0	34.0	43.0	52.0	76.0	86.0	33.0	29.0	0.0	0.0	362.0
1986	0.0	0.0	0.0	23.0	94.0	121.0	108.0	31.0	48.0	32.0	0.0	0.0	457.0
1987	0.0			0.0		222.0	38.0	0.0	34.0		0.0		

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL
Average	3.6	3.6	6.1	28.3	65.5	133.2	72.0	78.6	95.3	29.2	7.2	1.2	519.6
nb	27	26.0	27.0	31.0	29.0	31.0	32.0	30.0	31.0	30.0	26.0	27.0	30.0
Std	14.1	11.6	8.7	24.3	48.1	56.0	40.1	63.5	55.9	29.8	12.5	3.6	134.2
C.V	388%	325%	142%	86%	73%	42%	56%	81%	59%	102%	174%	303%	26%

19A TABLE MONTHLY PRECIPITATION

Oaxaca de Juarez.

Data from: SECRETARIA DE RECURSOS HIDRAULICOS (S.A.R.H)

SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS

Years	Jan.	Feb.	Mar.	Apr.	dry months November - April			
					TOTAL	Avg	STD	C.V
	mm	mm	mm	mm	mm	mm	mm	%
1951	0.0	0.0	3.5	62.3	65.8	16.5	30.6	186%
1952	0	6.8	33.0	77.6	117.4	46.4	35.2	137%
1953	0.0	0.0	4.0	11.1	15.1	3.8	5.2	139%
1954	0.0	8.1	1.5	41.9	51.5	12.9	19.7	153%
1955	1.8	0.0	11.7	13.4	26.9	6.7	6.8	101%
1956	0.8	0.0	9.0	31.0	40.8	10.2	14.5	142%
1957	0.0	0.0	1.0	79.4	80.4	20.1	39.5	197%
1958	68.8	19.2	0.0	29.1	117.1	29.3	29.0	99%
1959	0.0	0.0	3.8	89.5	93.3	23.3	44.2	189%
1960	0.0	0.0	39.5	9.1	48.6	12.2	18.7	154%
1961	0.0	0.0	13.8	0.0	13.8	3.5	6.9	200%
1962	0.0	0.9	0.0	24.3	25.2	6.3	12.0	191%
1963	0.0	3.0	1.0	18.4	22.4	5.6	8.6	154%
1964	0.0	4.6	0	13.3	17.9	4.5	6.3	140%
1965	1.8	0.0	0.4	8.1	10.3	2.6	3.8	146%
1966	0.0	9.9	24.9	73.1	107.9	27.0	32.4	120%
1967	0.0	0.0	11.3	51.1	62.4	15.6	24.3	156%
1968	26.8	12.1	11.8	22.7	73.4	18.4	7.6	41%
1969	14.9	0.9	18.4	11.8	46.0	11.5	7.6	66%
1970	2.0	2.0	0.0	4.5	8.5	2.1	1.8	87%
1971	0.0	0.0	3.2	2.5	5.7	1.4	1.7	117%
1972	0.0	0.0	16.0	69.2	85.2	21.3	32.8	154%
1973	0.0	0.5	16.9	48.2	65.6	16.4	22.6	138%
1974	2.6	0.0	45.4	75.6	123.6	30.9	36.4	118%
1975	0.3	14.6	15.5	3.7	34.1	8.5	7.7	90%
1976	0.0	0.0	0.0	166.2	166.2	41.6	83.1	200%
1977	0.0	3.0	0.0	36.0	39.0	9.8	17.6	180%
1978	0.0	3.2	14.0	18.6	35.8	9.0	8.8	98%
1979	0.0	14.9	0.5	106.5	121.9	30.5	51.2	168%
1980	1.9	0.9	6.0	27.2	36.0	9.0	12.3	137%
1981	0.0	26.8	30.3	16.2	73.3	18.3	13.6	74%
1982	0.0	33.3	15.0	76.8	125.1	31.3	33.3	106%
1983	0.7	32.2	18.6	0.0	51.5	12.9	15.5	120%
1984	5.2	3.2	20.5	0.0	28.9	7.2	9.1	126%
1985	0.00	0.1	4.3	69.5	73.9	18.5	34.1	184%
1986	3.5	4.8	0.0	34.0	42.3	10.6	15.7	149%
1987	0.00	2.5	10.7	25.8	39.0	9.8	11.6	119%
1988	0.00	0.0	11.7	68.5	80.2	20.1	32.8	163%
1989	0.00	1.3	5.2	44.8	51.3	12.8	21.4	167%
1990	0.00	17.1	7.1	33.1	57.3	14.3	14.3	100%
1991	2.90	0.0	0.0	0.2	3.1	0.8	1.4	183%
1992	22.60	12.0						
1993			50.8	12.3	63.1	31.6	27.2	86%
1994	0.00	0.0		58.9	58.9	19.6	34.0	173%
1995	0.00	14.3	3.4	121.6	139.3	34.8	58.2	167%
1996								

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19B TABLE MONTHLY PRECIPITATION Oaxaca de Juarez.						
Data from: S. A. R. H						
compiled by : E. Perraton 1996.						
Years	**May**	**June**	**July**	**Aug.**	**Sep.**	**Oct.**
	mm	mm	mm	mm	mm	mm
1951	56.2	114.5	75.0	69.9	112.4	22.8
1952	160.8	115.6	55.9	199.5	17.3	0.8
1953	53.3	202.3	101.4	47.2	40.4	28.5
1954	92.3	104.7	89.2	25.0	117.1	101.4
1955	3.9	80.2	181.3	147.9	236.7	41.5
1956	194.2	97.0	62.3	72.3	142.3	0.0
1957	101.0	245.4	87.1	71.7	151.6	27.1
1958	90.5	131.2	139.8	120.8	166.6	89.7
1959	41.3	220.2	108.6	106.8	92.8	97.8
1960	64.7	114.4	151.8	159.4	184.6	67.7
1961	25.2	215.4	299.2	27.1	107.7	24.4
1962	80.9	188.0	43.0	140.0	98.4	31.8
1963	66.2	121.7	199.1	113.3	141.6	38.5
1964	128.8	154.1	73.2	42.4	90.1	9.3
1965	36.6	226.7	54.1	125.3	40.4	40.2
1966	85.6	131.1	131.7	115.7	141.3	127.6
1967	36.9	149.8	28.5	102.3	53.2	105.8
1968	138.7	236.8	40.5	74.6	15.3	8.5
1969	48.3	103.9	113.5	352.1	44.8	13.5
1970	41.8	227.6	139.3	195.2	129.1	28.3
1971	93.1	85.7	53.6	112.7	207.1	85.5
1972	67.1	332.1	47.0	37.3	131.2	10.4
1973	117.3	197.0	184.9	109.2	236.8	68.8
1974	142.8	162.4	157.3	103.5	264.6	0.4
1975	109.6	159.9	192.9	56.1	250.0	24.9
1976	81.8	121.1	242.4	48.2	60.4	21.5
1977	12.7	149.9	20.0	98.7	73.6	51.5
1978	43.3	231.2	105.0	66.2	130.7	35.5
1979	85.5	71.3	93.0	130.7	290.8	35.4
1980	111.3	139.8	165.8	219.6	134.9	16.6
1981	87.4	330.9	283.7	181.1	126.3	35.3
1982	89.6	106.3	93.5	47.4	91.0	20.6
1983	24.4	87.6	145.2	101.7	129.3	12.4
1984	133.2	214.6	63.7	109.9	265.0	9.7
1985	46.9	173.6	113.3	119.0	114.5	31.6
1986	88.1	182.4	119.1	109.3	135.0	50.4
1987	98.8	143.4	92.4	100.0	94.3	0.6
1988	227.9	120.1	238.5	88.2	16.8	0.0
1989	60.9	323.9	96.9	166.0	153.1	17.1
1990	26.2	139.7	110.4			
1991	134.7	250.0	96.7	61.8	125.8	186.3
1992						
1993	140.8	355.6	103.6	60.4	78.2	11.0
1994	82.4	201.1	76.4	101.6	31.1	40.7
1995	189.6	74.0	78.4	303.2		
1996						

19c TABLE MONTHLY PRECIPITATION
Oaxaca de Juarez.

Data from: S. A. R. H

compiled by : E. Perraton 1996.

Years	wet months May - October				Nov.	Dec.	TOTAL
	TOTAL	Avg	STD	C.V			
	mm	mm	mm %		mm	mm	mm
1951	450.8	75.1	34.8	46%	0.0	0.0	516.60
1952	549.9	91.7	80.1	87%	0.0	0.0	667.30
1953	473.1	78.9	65.4	83%	0.0	7.0	495.20
1954	529.7	88.3	32.5	37%	3.8	0.0	585.00
1955	691.5	115.3	88.6	77%	7.2	22.5	748.10
1956	568.1	94.7	67.4	71%	3.2	0.0	612.10
1957	683.9	114.0	76.0	67%	0.0	0.0	764.30
1958	738.6	123.1	29.7	24%	28.7	4.8	889.20
1959	667.5	111.3	58.8	53%	0.0	0.0	760.80
1960	742.6	123.8	50.0	40%	0.0	1.0	792.20
1961	699.0	116.5	116.7	100%	29.2	6.3	748.30
1962	582.1	97.0	59.3	61%	0.0	5.7	613.00
1963	680.4	113.4	56.7	50%	0.0	0.0	702.80
1964	497.9	83.0	53.6	65%	11.7	0.0	527.50
1965	523.3	87.2	76.1	87%	0.0	0.0	533.60
1966	733.0	122.2	19.7	16%	2.4	0.2	843.50
1967	476.5	79.4	47.5	60%	7.4	7.4	553.70
1968	514.4	85.7	88.0	103%	3.0	0.2	591.00
1969	676.1	112.7	123.3	109%	4.0	0.0	726.10
1970	761.3	126.9	79.9	63%	6.0	0.0	775.80
1971	637.7	106.3	52.9	50%	4.2	1.0	648.60
1972	625.1	104.2	118.8	114%	**63.5**	0.9	774.70
1973	914.0	152.3	63.6	42%	6.5	0.0	986.10
1974	831.0	138.5	86.2	62%	1.0	0.0	955.60
1975	793.4	132.2	85.0	64%	0.0	0.8	828.30
1976	575.4	95.9	79.2	83%	10.5	0.0	752.10
1977	406.4	67.7	51.6	76%	11.6	2.5	459.50
1978	611.9	102.0	73.0	72%	2.5	0.4	650.60
1979	706.7	117.8	90.2	77%	7.8	0.0	836.40
1980	788.0	131.3	67.3	51%	6.7	0.0	830.70
1981	1044.7	174.1	114.6	66%	0.2	0.0	1118.20
1982	448.4	74.7	33.2	44%	5.4	0.0	578.90
1983	500.6	83.4	54.4	65%	**48.5**	18.2	618.80
1984	796.1	132.7	94.5	71%	0.0	0.0	825.00
1985	598.9	99.8	52.3	52%	0.5	5.8	679.10
1986	684.3	114.1	44.5	39%	5.4	3.0	735.00
1987	529.5	88.3	47.0	53%	0.0	0.0	568.50
1988	691.5	115.3	101.6	88%	0.0	0.0	771.70
1989	817.9	136.3	107.5	79%	4.5	0.0	873.70
1990	276.3	92.1	58.9	64%			incomplete
1991	855.3	142.6	67.0	47%	15.8	0.0	874.20
1992							incomplete
1993	749.6	124.9	121.0	97%	4.5	0.0	incomplete
1994	533.3	88.9	61.0	69%	5.7	0.2	incomplete
1995	645.2	161.3	108.7	67%			incomplete
1996							

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TABLE 20A MONTHLY RAINFALL

SECRETARIA DE RECURSOS HIDRAULICOS

SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS

CUAJIMOLOYAS STATION

Years	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
	mm	mm	mm	mm	mm	mm
1955	33.5	46.2				0.6
1956	29.8	9.5	15.7	5.7	5.0	7.5
1957	7.5	2.0	4.8	19.5	66.0	45.7
1958	88.0	29.0	98.0	60.5	0.0	36.8
1959	13.5	0.0	23.0	52.0	7.5	116.5
1960	28.5	4.0	3.0	0.0	0.0	36.0
1961	136.0	10.5	5.0	0.0	60.0	23.5
1962	12.5	9.0	0.0	9.0	27.5	68.0
1963	5.0	5.0	0.0	9.5	5.5	29.0
1964	75.0	32.5	2.5	0.0	14.0	9.5
1965	9.5	5.0	3.0	0.5	1.5	24.5
1966	8.5	3.5	1.5	18.5	79.0	134.5
1967	15.5	13.0	2.5	2.5	19.5	102.0
1968	34.5	11.0	59.5	12.5	2.5	47.0
1969	16.5	2.5	16.5	20.5	27.5	75.0
1970	7.5	0.0	4.0	15.5	0.0	28.5
1971	64.5	52.5	2.0	1.0	8.5	22.0
1972	94.5	5.5	20.5	1.5	35.5	57.5
1973	9.0	0.0	0.0	0.0	1.5	70.0
1974	7.5	0.0	18.0	2.0	87.5	101.0
1975	19.5	17.0	19.0	8.5	2.0	36.0
1976	95.0	0.0	9.0	0.0	0.0	67.5
1977	66.0	69.0	0.0	22.0	0.0	68.0
1978	24.5	19.3	0.0	5.0	62.0	48.0
1979	15.0	19.5	4.5	24.5	10.0	99.0
1980	7.0	4.5	15.5	0.0	6.5	48.0
1981	10.0	2.5	4.0	7.0	35.4	53.6
1982	15.9	0.0	2.0	36.2	35.5	68.8
1983	53.0	12.2	12.5	88.3	39.5	0.0
1984	6.0	5.0	0.0	0.0	57.0	3.3
1985			0.0	12.5	6.5	127.6
1986	34.5	1.0	0.0	28.5	3.5	46.5
1987	8.0	1.0	0.0	10.0	77.0	62.0
1988	5.0		1.0	0.0	25.5	73.0
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Average	32.0	12.2	10.5	14.3	24.5	54.0
nb	33.0	32.0	33.0	33.0	33.0	34.0
Std	30.7	19.7	7.4	21.1	28.0	32.0
C.V	96%	161%	70%	147%	114%	59%

	DRY SEASON	
	NOVEMBER -MARC	NOVEMBER -APRIL
MONTHS ->	5	6
Avg	18.8	24.8
nb	164	198.0
Std	25.2	30.3
C.V	135%	122%

TABLE 208 CUAJIMOLOYAS

SECRET

SUBSECRE	CUENCA	CORRIENTE	STATION
	Rio. ATOYAC	Rio. SALADO	CUAJIMOLOYAS

Years	May	June	July	Aug.	Sep.	Oct.
	mm	mm	mm	mm	mm	mm
1955	13.2	84.9	381.7	170.8	381.8	124.7
1956	178.9	295.1	124.2	126.0	180.7	27.2
1957	119.0	117.9	102.4	92.5	173.4	34.0
1958	93.2	167.0	216.0	175.4	241.0	80.0
1959	26.5	296.5	206.0	183.5	65.5	310.3
1960	102.0	195.5	165.5	276.5	191.5	107.5
1961	50.0	165.5	249.5	68.0	153.5	33.0
1962	19.5	119.5	90.0	161.0	169.0	63.0
1963	75.5	205.5	246.0	117.5	211.5	31.5
1964	153.5	189.5	94.0	81.0	95.0	65.0
1965	54.0	189.0	95.0	59.0	109.5	113.0
1966	163.0	203.0	166.0	111.0	145.5	216.0
1967	52.0	266.5	65.5	94.0	216.5	127.5
1968	176.5	265.5	69.0	84.5	138.0	66.5
1969	53.5	120.5	182.0	475.5	210.0	112.5
1970	62.5	204.0	122.0	271.0	222.0	41.5
1971	59.5	112.0	99.4	181.0	203.5	94.0
1972	66.5	324.5	138.0	66.0	76.0	62.5
1973	98.0	262.5	242.5	255.0	252.5	137.5
1974	185.5	270.0	185.5	47.0	392.5	61.0
1975	197.0	173.5	162.5	187.0	217.0	146.0
1976	181.0	271.5	166.0	78.0	134.0	69.5
1977	46.0	191.0	165.7	185.0	149.0	78.5
1978	122.0	303.5	228.0	117.0	343.8	112.4
1979	71.0	106.0	236.0	213.0	378.5	93.0
1980	89.0	125.0	71.5	252.0	270.5	39.5
1981	146.3	454.1	175.7	203.4	152.9	53.2
1982	95.2	76.8	96.8	16.5	155.6	191.1
1983	7.8	116.1	220.9	64.5	139.4	26.8
1984	179.9	207.4	161.0		325.4	
1985	77.4	122.9	139.5	108.2		
1986	224.0	187.0	189.5	133.0	167.5	63.5
1987	80.5	261.5	219.5	69.5	118.5	5.5
1988	93.5			292.5	186.0	38.5
	May	June	July	Aug.	Sep.	Oct.
Average	100.4	201.5	165.8	152.0	199.0	88.3
nb	34.0	33.0	33.0	33.0	33.0	32.0
Std	59.4	96.5	50.3	85.5	93.1	47.6
C.V	59%	48%	30%	56%	47%	54%

		WET SEASON	
	APR. +OCT	MAY-SEP.	MAY-OCT.
MONTHS ->	2	5	6
Avg	70.6	163.4	151.2
nb	66.0	166.0	198.0
Std	53.3	86.4	87.4
C.V	75%	53%	58%

TABLE 20C CUAJIMO LOYAS

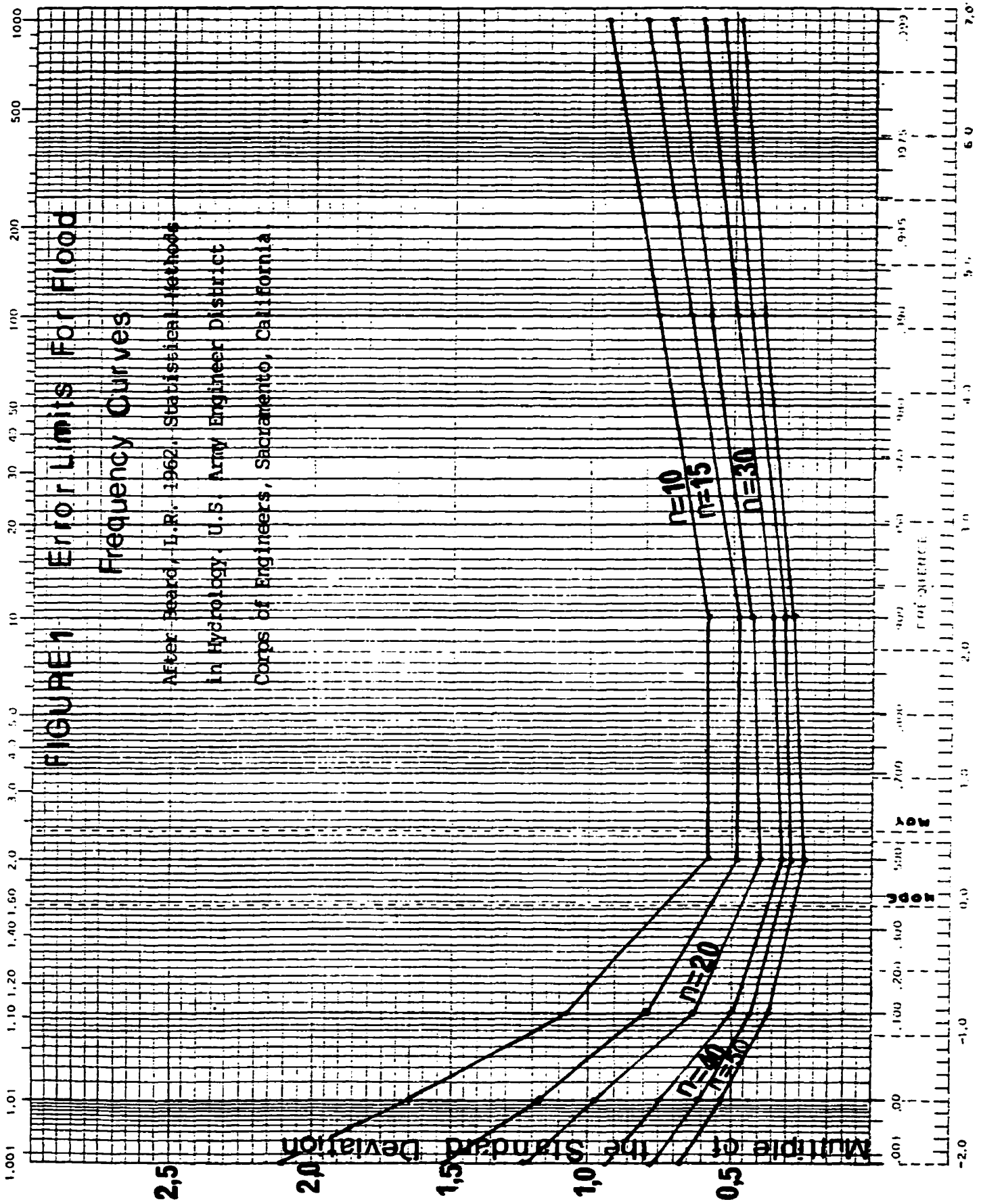
SECRET

SUBSECRE

Years	dry season Nov. - April				wet season May - October				YEAR
	Total	average	STD	C.V	Total	average	STD	C.V	TOTAL
	mm	mm	mm	%	mm	mm	mm	%	mm
1955									
1956	73.2	12.2	9.4	77%	932.1	155.4	88.3	57%	1005.3
1957	145.5	24.3	26.0	107%	639.2	106.5	45.2	42%	784.7
1958	312.3	52.1	37.3	72%	972.6	162.1	64.5	40%	1284.9
1959	212.5	35.4	43.6		1088.3	181.4	116.5	64%	1300.8
1960	71.5	11.9	16.0	134%	1038.5	173.1	64.7	37%	1110.0
1961	235.0	39.2	52.1	133%	719.5	119.9	83.8	70%	954.5
1962	126.0	21.0	24.7	118%	622.0	103.7	57.8	56%	748.0
1963	54.0	9.0	10.3	114%	887.5	147.9	85.7	58%	941.5
1964	133.5	22.3	28.3	127%	678.0	113.0	48.0	42%	811.5
1965	44.0	7.3	9.0	123%	619.5	103.3	48.9	47%	663.5
1966	245.5	40.9	54.2	133%	1004.5	167.4	38.2	23%	1250.0
1967	155.0	25.8	38.0	147%	822.0	137.0	86.4	63%	977.0
1968	167.0	27.8	22.7	82%	800.0	133.3	77.9	58%	967.0
1969	158.5	26.4	25.2	95%	1154.0	192.3	149.3	78%	1312.5
1970	55.5	9.3	11.1	120%	923.0	153.8	92.6	60%	978.5
1971	150.5	25.1	27.2	108%	749.4	124.9	55.5	44%	899.9
1972	215.0	35.8	35.3	99%	733.5	122.3	103.1	84%	948.5
1973	80.5	13.4	27.9	208%	1248.0	208.0	71.3	34%	1328.5
1974	216.0	36.0	45.8	127%	1141.5	190.3	130.0	68%	1357.5
1975	102.0	17.0	11.6	68%	1083.0	180.5	25.3	14%	1185.0
1976	171.5	28.6	41.9	146%	900.0	150.0	74.7	50%	1071.5
1977	225.0	37.5	34.0	91%	815.2	135.9	59.8	44%	1040.2
1978	158.8	26.5	24.3	92%	1226.7	204.5	102.7	50%	1385.5
1979	172.5				1097.5	182.9	117.0	64%	1270.0
1980	81.5	13.6	17.6		847.5	141.3	97.1	69%	929.0
1981	112.5	18.8	20.9	112%	1185.6	197.6	135.5	69%	1298.1
1982	158.4	26.4	26.0	98%	632.0	105.3	61.3	58%	790.4
1983	205.5	34.3	33.0	96%	575.5	95.9	79.3	83%	781.0
1984	71.3	11.9	22.2	187%					
1985									
1986	114.0	19.0	20.1	106%	964.5	160.8	56.2	35%	1078.5
1987	158.0	26.3	34.0	129%	755.0	125.8	96.9	77%	913.0
1988									

	dry season Nov. - April			wet season May - October			TOTAL
Average	147.8	24.8		895.2	151.2		1049.1
nb	31.0	198.0		30.0	198.0		28.0
Std	51.1	30.3		200.1	87.4		214.2
C.V	35%	122%		22%	58%		20%

	TRANSITION MONTHS
MONTHS ->	
Avg	
nb	
Std	
C.V	


FIGURE 1
Error Limits For Flood
Frequency Curves
After Beard, L.R., 1962, Statistical Methods
in Hydrology, U.S. Army Engineer District
Corps of Engineers, Sacramento, California
n=10
n=15
n=20
n=30
n=40
n=50
Multiple of the Standard Deviation
INTERVALLE DE RÉCURRENCE
VARIABLE RÉDUITE
012-0016/RN-300(11)

APPENDIX AB.

CALIBRATION OF MOLINET TABLE 1.

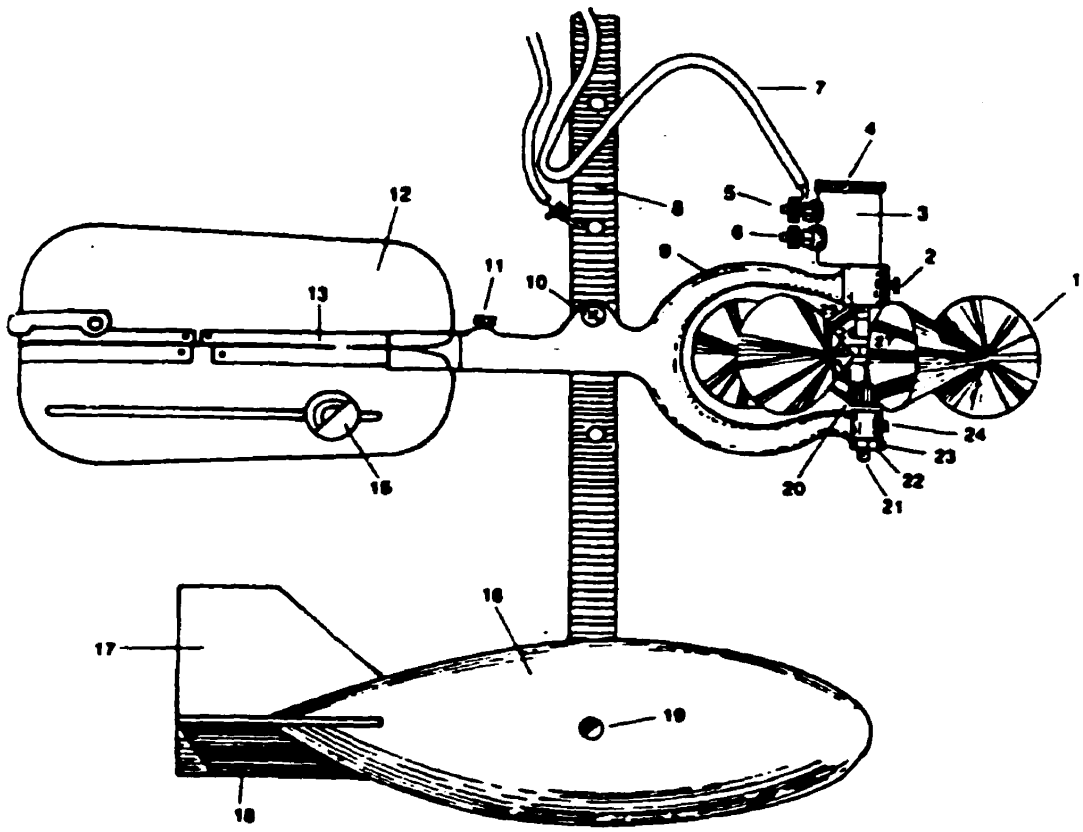
FIGURE 1.

HYDROMETRIC DATA TABLES 2 to 9.

AFOROS1.xls DIAORDAVEL

TABLE 1 Linear Regression to establish the linear relationship between the Number of Revolutions per second as measured with the Molinet of type Price and the corresponding Average fluid velocity (m/s).

SUMMARY OUTPUT			Coefficients		
Regression Statistics			Avg.		Standard Error
Multiple	0.9999	Intercept	0.0160		0.0020
R Squar	0.9999	X Variable 1	0.6785		0.0013
Adjuste	0.9999		Lower 95%	Upper 95%	t Stat
Standar	0.0064	Intercept	0.0119	0.0201	7.9
Observa	39	X Variable 1	0.6760	0.6811	536.6
			Lower 99.0%	Upper 99.0%	P-value
		Intercept	0.0105	0.0215	1.70E-09
ANOVA		X Variable 1	0.6751	0.6820	1.34E-73
	df	SS	MS	F	Significance F
Regress	1	11.66	11.66	287941.39	1.34E-73
Residua	37	0.00	4.05E-05		
Total	38	11.66			



MOLINET USEI

Fig 1

AÑO	SECRETARIA DE RECURSOS HIDRAULICOS											
1978	SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS											
2	DIVISION			CUENCA		CORRIENTE			ESTACION			
	TEHUANTEPEC			Rio. ATOYAC		Rio. SALADO			OAXACA			
	DIRECCION DE HIDROLOGIA.											
DIA	ENE.	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
1		0.120	0.038	0.029	0.023	0.113	0.890	0.614	0.162	1.791	0.213	0.252
2	0.040	0.043			0.020	0.105		0.586	0.159	1.197	0.090	0.246
3	0.039	0.042		0.029	0.018	0.961	0.315	0.383		0.917	0.086	
4	0.039	0.046		0.034	0.018	1.757	0.320	0.196	0.158	0.702	0.091	0.238
5	0.040			0.026	0.019	10.388	0.295	0.192	0.543	0.654		0.087
6	0.036	0.123		0.012	0.020	9.906	0.257		4.255	0.649	0.096	0.086
7	0.037	0.123		0.013		6.189	0.260	0.182	0.712	0.444	0.177	0.085
8		0.122		0.012	0.020	20.138	0.251	0.179	0.496		0.121	0.089
9	0.036	0.124			0.018	17.177		0.459	1.449	0.718	0.127	
10	0.036	0.125		0.012	0.018	10.932	0.584	0.189	1.595	0.652	0.135	0.087
11	0.035	0.067		0.011	0.019	11.811	0.308	0.189	1.243	0.656	0.184	0.097
12	0.033			0.012	0.020	2.770	0.228	0.177	0.639	2.233		0.097
13	0.076	0.080		0.021	0.019	1.085	0.222		0.624	6.825	0.240	0.035
14	0.077	0.081		0.021		0.695	0.219	0.168	0.625	5.923	0.078	0.035
15		0.033		0.075	0.020	0.457	0.227	0.230	0.335	3.119	0.108	0.035
16	0.123	0.035			0.288	0.418		0.149	0.236	2.449	0.103	0.036
17	0.126	0.042		0.062	0.052	0.422	0.225	0.147		1.816	0.101	
18	0.075	0.042		0.062	0.054		0.223	0.145	0.310	1.223	0.089	0.038
19	0.123			0.080	0.068	0.415	0.219	0.162	0.250	1.016		0.038
20	0.062	0.033	0.030	0.078	0.066	0.410	0.271		0.264	0.449	0.091	0.035
21	0.125	0.042	0.025	0.010		0.111	0.199	0.172	0.550	0.143	0.001	0.043
22		0.042	0.025	0.019	0.084	0.238	0.216	0.136	1.951		0.091	0.048
23	0.053	0.032	0.025		0.279	0.232		0.134	23.707	0.462	0.090	0.044
24	0.114	0.063	0.026	0.037	0.216	0.236	0.245	0.135	33.896	0.525	0.089	
25	0.113	0.064	0.026	0.036	0.121		0.223	0.132	21.457	0.469	0.089	0.189
26	0.111			0.037	0.122	0.192	0.306	0.158	14.011	0.468		0.151
27	0.189	0.121	0.122	0.046	0.099	0.908	0.304		6.963	0.377	0.090	0.150
28	0.056	0.038	0.029	0.034		0.295	4.938	0.161	5.631	0.282	0.093	0.150
29			0.031	0.022	0.080	0.692	4.486	0.133	4.162		0.094	0.097
30	0.042		0.026		0.086	0.696	1.127	1.149	2.997	0.221	0.261	0.102
31	0.121		0.027				1.225	0.223		0.219		
1	0.120	0.038	0.029	0.023	0.113	0.890	0.614	0.162	1.791	0.213	0.252	0.190
MAXIMO	0.189	0.125	0.122	0.080	0.288	20.138	4.938	1.149	33.896	6.825	0.261	0.252
MINIMO	0.033	0.032	0.025	0.011	0.018	0.105	0.198	0.132	0.158	0.219	0.078	0.035
MEDIO	0.075	0.070	0.036	0.034	0.072	3.573	0.688	0.255	4.621	1.318	0.120	0.100
COUNT	27	25	13	26	27	29	28	28	29	29	27	27
avg	0.077	0.069	0.035	0.034	0.073	3.481	0.686	0.252	4.523	1.280	0.125	0.103
std	0.043	0.037	0.026	0.021	0.077	5.574	1.171	0.218	8.270	1.590	0.056	0.069
cv	55.580%	53.178%	74.472%	62.742%	105.184%	160.139%	170.782%	86.662%	182.846%	124.247%	44.991%	67.486%

AÑO	SECRETARIA DE RECURSOS HIDRAULICOS											
1980	SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS											
3	DIVISION TEHUANTEPEC			CUENCA Rio. ATOYAC			CORRIENTE Rio. SALADO			ESTACION OAXACA		
	DIRECCION DE HIDROLOGIA.											
DIA	ENE.	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
1	0.153	0.078		0.068	0.021		0.171	0.516	1.443	24.327	0.520	0.276
2	0.265	0.081		0.048	0.022	0.126	0.172	0.221	1.309	19.129		0.197
3	0.167			0.049	0.022	0.102	0.174		13.764	9.987	0.461	0.189
4	0.113	0.102		0.020		0.102	0.173	0.425	18.684	8.654	0.300	0.184
5	0.112	0.173		0.020	0.118	0.129	0.169	0.405	10.603		0.359	0.184
6		0.171			0.122	0.432		0.689	3.305	4.420	0.346	0.185
7	0.137	0.205		0.023	0.998	0.119	0.132	0.565		3.048	0.371	0.186
8	0.134	0.172		0.131	0.245		0.141	0.233	2.060	2.735	0.373	0.147
9	0.155	0.093		0.126	0.198	0.085	0.134	43.777	1.195	2.618		0.186
10	0.097			0.099	0.199	0.082	0.131	18.932	1.656	2.180	0.283	0.171
11	0.136	0.094		0.118		0.086	0.134	11.446	1.648	2.004	0.277	0.156
12	0.136	0.094		0.117	0.160	0.084	0.138	15.435	1.236		0.329	0.144
13		0.095			0.155	0.085		65.800	1.189	1.551	0.312	0.130
14	0.163	0.128		0.085	0.145	0.083	0.126	53.313		1.374	0.315	0.184
15	0.152	0.129		0.092	0.099		0.130	90.877	0.907	1.346	0.325	0.197
								69.506				
16	0.147	0.102		0.085	0.113	0.087	0.112	25.913	1.070	1.022		0.201
17	0.155			0.139	0.092	0.086	0.119	12.921	0.981	0.926	0.323	0.189
18	0.152	0.106		0.090		0.141	0.597	5.701	0.953	0.899	0.322	0.174
19	0.159	0.106		0.091	0.123	0.483	32.017	4.278	0.952		0.269	0.191
20		0.111			0.105	2.312	1.855	2.840	0.788	0.586	0.285	0.185
21	0.200	0.145		0.093	0.216	3.467	0.792	1.969		0.573	0.329	0.194
22	0.199	0.144		0.024	0.101	1.066	0.404	1.785	0.617	0.612	0.326	0.203
23	0.198	0.136		0.025	0.103	0.407	0.244	1.307	0.536	0.608		0.291
24	0.149			0.029	0.274	0.284	0.239		0.543	0.600	0.337	0.238
25	0.149	0.079		0.078		0.272	0.410	0.953	3.342	0.567	0.172	0.255
26	0.150	0.081		0.022	0.345	0.182	0.295	1.272	19.108		0.276	0.247
27		0.080			0.321	0.179	0.284	2.717	35.582	0.604	0.280	0.239
28	0.153	0.074		0.021	0.154	0.172	0.455	1.068	97.140	0.607	0.277	0.219
29	0.078			0.020	0.147		0.224	1.756	59.873	0.490	0.283	0.199
30	0.079			0.070	0.122	0.177	0.230	1.087	35.521	0.524	0.280	0.172
31	0.077		0.066		0.130		0.226			0.518		0.190
1	0.078		0.066	0.021	0.128	0.171	0.516	1.443	24.327	0.520	0.276	0.201
MAXIMO	0.265	0.205	0.066	0.139	0.998	3.467	32.017	90.877	97.140	24.327	0.520	0.291
MINIMO	0.077	0.074	0.066	0.020	0.021	0.082	0.112	0.221	0.536	0.490	0.172	0.130
MEDIO	0.147	0.117	0.066	0.069	0.183	0.417	1.394	15.093	11.703	3.423	0.320	0.196
COUNT	28		2	27	28	27	30	30	28	28	27	32
avg	0.144		0.067	0.067	0.181	0.407	1.365	14.638	12.154	3.319	0.318	0.196
std	0.042		0.001	0.040	0.179	0.761	5.799	24.497	21.999	5.736	0.065	0.036
cv	29.003%		2.111%	60.605%	98.642%	186.791%	424.891%	167.345%	181.002%	172.839%	20.350%	18.637%

AÑO	SECRETARIA DE RECURSOS HIDRAULICOS											
1981	SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS											
	DIVISION			CUENCA			CORRIENTE			ESTACION		
4	TEHUANTEPEC			Río. ATOYAC			Río. SALADO			OAXACA		
	DIRECCION DE HIDROLOGIA.											
DIA	ENE.	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
1	0.201		ND	0.027	0.076	2.212	6.170	7.174	25.154	8.208		0.485
2	0.180	0.160	ND	0.030	0.074	3.181	11.961		22.982	3.979	1.195	0.493
3	0.186	0.189	ND	0.037		3.577	12.609	4.292	19.678	4.076	0.943	0.505
4		0.185	ND	0.032	0.022	4.617	6.968	4.259	22.959		1.151	0.475
5	0.181	0.173	ND		0.138	10.836		3.535	23.252	3.391	1.130	0.474
6	0.188	0.131	ND	0.029	0.091	17.108	4.805	3.349		3.064	1.110	
7	0.184	0.137	ND	0.030	0.076	6.867	10.203	3.470	21.381	2.270	0.997	0.574
8	0.194		ND	0.030	0.107	9.048	10.661	3.407	14.906	2.181		0.594
9	0.198	0.132	ND	0.034	0.129	59.456	7.410		10.357	2.617	0.934	0.611
10	0.200	0.137	ND	0.035		42.321	5.822	7.220	8.956	8.102	0.932	0.584
11		0.137	ND	0.034	0.132	12.729	5.501	6.873	7.679		0.951	0.538
12	0.128	0.142	ND		0.133	7.199		4.072	6.364	2.268	0.901	0.494
13	0.178	0.131	ND	0.021	0.109	4.740	4.030	3.491		2.176	0.699	
14	0.110		ND	0.029	0.137	12.823	5.957	3.118	4.841	2.075	0.715	0.536
15	0.102		ND	0.065	0.129	69.980	29.818	4.805	4.702	2.023		0.423
16	0.018		ND	0.066	0.119	102.249	13.614		4.848	2.922	0.808	0.550
16						49.325						
17	0.026		ND	0.069		116.132	13.707	3.594	4.584	2.912	0.805	0.492
17						82.860						
18			ND	0.058	0.103	93.716	12.516	14.376	4.994		0.779	0.252
19	0.022		ND		0.095	35.302		7.355	9.530	1.438	0.773	0.232
20	0.023		ND	0.102	0.083	12.007	7.357	6.731		1.407	0.650	
21	0.043		ND	0.093	0.084		7.377	6.406	2.385	1.359	0.689	
22	0.024		ND	0.106	0.074	10.597	28.987	14.330	2.449	1.365		0.340
23	0.020		ND	0.100	0.077	14.148	13.912		2.324	1.339	0.680	0.317
24	0.021		ND	0.084		7.627	9.347	8.043	2.900	1.379	0.676	0.315
25			ND	0.088	1.239	16.187	11.288	7.671	2.869		0.672	0.312
26	0.029		ND		0.268	36.271		14.155	2.446	1.139	0.474	0.313
27	0.028		ND	0.141	0.272	13.156	25.354	35.797		1.129	0.476	
28	0.032		ND	0.134	0.434		15.152	58.043	3.660	1.121	0.398	0.304
29	0.030		ND	0.134	0.187	7.457	9.755	49.940	3.719	1.109		0.290
30	0.071		ND	0.079	0.705	6.230	7.269	45.959	5.147	1.195	0.490	0.390
31	0.059		ND				7.668	28.142		1.693		0.247
1	0.110		0.027	0.076	2.210	6.170	7.174	25.154	8.208		0.485	0.244
MAXIMO	0.201	0.189		0.141	1.239	116.132	29.818	58.043	25.154	8.208	1.195	0.611
MINIMO	0.018	0.131		0.021	0.022	2.212	4.030	3.118	2.324	1.109	0.398	0.232
MEDIO	0.099	0.150		0.065	0.196	29.002	11.304	13.319	9.426	2.516	0.801	0.428
COUNT	27		1	26	26	30	27	27	26	26	26	26
avg	0.096			0.067	0.278	29.134	11.342	13.985	8.774	2.297	0.789	0.419
std	0.073			0.037	0.468	32.916	6.782	15.854	7.251	1.478	0.226	0.126
cv	76.186%			55.594%	168.517%	112.980%	59.800%	113.366%	82.648%	64.342%	28.641%	30.087%

ANO	SECRETARIA DE RECURSOS HIDRAULICOS											
1982	SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS											
	DIVISION			CUENCA			CORRIENTE			ESTACION		
	TEHUANTEPEC			Rio. ATOYAC			Rio. SALADO			OAXACA		
	DIRECCION DE HIDROLOGIA.											

DIA	ENE.	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
1	0.244	ND	ND	0.094	0.347	1.139	0.386		ND	0.352	0.073	0.024
5 2	0.243					0.677	0.314	0.263	ND	0.291	0.095	0.025
3				0.093	0.335	0.534	0.301	0.239			0.124	0.022
4	0.326				0.360	0.489		0.238		0.324	0.105	0.023
5	0.325			0.091	0.364	0.480	0.333	0.262		0.309	0.171	
6	0.319			0.092	0.357		0.322	0.258		0.374	0.137	0.021
7	0.318			0.096	0.289	0.444	0.325	0.210		0.376		0.025
8	0.313			0.096	0.293	0.468	0.316			0.363	0.159	0.023
9	0.310			0.097	0.292	0.397	0.295	0.218		0.304	0.152	0.023
10				0.177	0.290	0.462	0.295	0.211			0.147	0.025
11	0.267				0.288	0.410		0.202		0.299	0.122	0.024
12	0.264			0.266	0.284	0.421	0.284	0.172		0.328	0.114	
13	0.273			0.164	0.316		0.283	0.168		0.326	0.109	0.026
14	0.266			0.166	0.279	0.380	0.291	0.411		0.249		0.025
15	0.238			0.172	0.300	0.378	0.252			0.243	0.140	0.028
16	0.235			0.171	0.300	0.418	0.285	0.255		0.245	0.137	0.026
17				0.173	0.300	0.391	0.275	0.205			0.138	0.025
18	0.300				0.296	0.393		0.140		0.259	0.125	0.026
19	0.296			0.162	0.400	0.350	0.502	0.140		0.254	0.127	
20	0.288			0.165	0.758		0.485	0.138		0.227	0.122	0.024
21	0.285			0.867	0.534	0.516	0.370	0.139		0.140		0.025
22	0.285			0.648	1.766	0.441	0.356			0.149	0.040	0.028
23	0.279			0.388		0.905	0.348	0.263		0.127	0.032	0.051
24				0.357	2.218	0.397	0.444	0.192			0.034	0.053
25	0.229				29.209	0.392	0.334	0.172		0.177	0.029	0.057
26	0.231			0.382	2.671	0.377		0.172		0.165	0.033	
27	0.229			0.416	1.105		0.334	0.146		0.132	0.031	0.055
28	0.229			0.484	0.681	0.360	0.348	0.143		0.131		0.058
29				0.395	1.138	0.366	0.342			0.072	0.028	0.040
30				0.328		0.388	0.328	0.142		0.064	0.024	0.060
31					3.248		0.310	0.139				0.054
1	0.078			0.347	1.139	0.386		0.147		0.073	0.024	0.051
MAXIMO	0.326			0.867	29.209	1.139	0.502	0.411		0.376	0.171	0.060
MINIMO	0.229			0.091	0.279	0.350	0.252	0.138		0.064	0.024	0.021
MEDIO	0.275			0.262	1.751	0.477	0.335	0.201		0.242	0.098	0.033
COUNT	25.000			26.000	29.000	27.000	27.000	27.000		27.000	27.000	28.000
avg	0.267			0.265	1.730	0.473	0.335	0.199		0.236	0.095	0.034
std	0.051			0.192	5.342	0.175	0.060	0.062		0.098	0.050	0.014
cv	19.301%			72.556%	308.881%	37.004%	17.851%	31.171%		41.710%	52.959%	41.511%

AÑO	SECRETARIA DE RECURSOS HIDRAULICOS											
1983	SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS											
	DIVISION			CUENCA		CORRIENTE				ESTACION		
6	TEHUANTEPEC			Rio. ATOYAC		Rio. SALADO				OAXACA		
	DIRECCION DE HIDROLOGIA.											
DIA	ENE.	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
1	0.051	0.063	ND	no runoff	ND	0.035	0.182	0.209	0.108	0.104	0.033	0.269
2		0.066	ND	no runoff	ND	0.043	0.408	0.139	0.110		0.034	0.146
3	0.025	0.068	ND	no runoff	ND	0.047		0.129	0.127	0.104	0.034	0.081
4	0.028	0.061	ND	no runoff	ND	0.045	0.366	0.222		0.084	0.033	
5	0.029	0.063	ND	no runoff	ND		0.609	0.166	0.323	0.095	0.033	0.037
6	0.028		ND	no runoff	ND	0.044	0.252	0.172	0.185	0.073		0.054
7	0.027	0.065	ND	no runoff	ND	0.335	0.168		0.224	0.072	0.036	0.052
8	0.021	0.073	ND	no runoff	ND	0.131	0.148	0.137	0.290	0.078	0.034	0.050
9		0.069	ND	no runoff	ND	0.065	0.148	0.115	0.204		0.035	0.051
10	0.028	0.075	ND	no runoff	ND	0.062		0.187	0.345	0.076	0.035	0.051
11	0.031	0.065	ND	no runoff	ND	0.055	0.045	0.399		0.069	0.037	
12	0.034	0.071	ND	no runoff	ND		0.046	0.166	0.687	0.029	0.036	0.050
13	0.032		ND	no runoff	ND	0.079	0.153	1.291	0.416	0.044		0.050
14	0.034	0.055	ND	no runoff	ND	0.073	0.047		0.349	0.042	0.037	0.050
15	0.052	ND	ND	no runoff	ND	0.069	0.156	0.361	0.453	0.042	0.035	0.048
16		ND	ND	no runoff	ND	0.066	1.813	0.183	0.554		0.037	0.046
17	0.068	ND	ND	no runoff	ND	0.054		0.148	0.444	0.039	0.037	0.046
18	0.070	ND	ND	no runoff	ND	0.078	1.350	0.147		0.035	0.035	
19	0.050	ND	ND	no runoff	ND		0.534	0.129	0.603	0.072	0.036	0.118
20	0.047	ND	ND	no runoff	ND	0.067	1.349	0.134	0.382	0.064		0.062
21	0.067	ND	ND	no runoff	ND	0.079	2.068		0.260	0.053	0.035	0.052
22	0.043	ND	ND	no runoff	ND	0.777	0.993	0.132	0.215	0.054	0.034	0.050
23		ND	ND	no runoff	ND	0.427	0.567	0.130	0.132		0.034	0.049
24	0.040	ND	ND	no runoff	ND	0.696		0.113	0.134	0.048	0.034	0.049
25	0.041	ND	ND	no runoff	0.081	0.353	0.469	0.116		0.039	0.035	
26	0.042	ND	ND	no runoff	0.100		0.609	0.117	0.112	0.040	0.035	0.037
27	0.063	ND	ND	no runoff	0.095	0.989	0.486	0.116	0.115	0.039		0.037
28	0.063	ND	ND	no runoff	0.041	0.209	0.470		0.111	0.039	0.034	0.040
29	0.054	ND	ND	no runoff		0.193	0.230	0.037	0.110	0.037	0.110	0.040
30		ND	ND	no runoff	0.038	0.184	0.216	0.117	0.105		0.084	0.040
31	0.064	ND	ND	no runoff	0.034			0.122		0.037		0.038
1	0.063		ND	no runoff	0.035	0.182	0.209	0.108	0.104	0.033	0.269	0.038
MAXIMO	0.070	0.075		0.000	0.100	0.989	2.968	1.291	0.687	0.104	0.110	0.269
MINIMO	0.021	0.055		0.000	0.034	0.035	0.045	0.037	0.105	0.029	0.033	0.037
MEDIO	0.044	0.066			0.065	0.202	0.569	0.201	0.273	0.058	0.040	0.063
COUNT	27				7	27	27	28	27	27	27	28
avg	0.044				0.061	0.201	0.555	0.198	0.267	0.057	0.048	0.062
std	0.015				0.030	0.249	0.653	0.226	0.171	0.023	0.047	0.047
cv	34.989%				49.573%	123.653%	117.644%	114.254%	64.060%	39.547%	98.126%	76.349%

ANO	SECRETARIA DE RECURSOS HIDRAULICOS											
1984	SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS											
7	DIVISION TEHUANTEPEC			CUENCA Rio. ATOYAC		CORRIENTE Rio. SALADO			ESTACION OAXACA			
	DIRECCION DE HIDROLOGIA.											
DIA	ENE.	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
1		SE	EL		0.000	0.214		0.321	1.156	3.636	0.437	
2	0.038	ENVIO	MOLINETE	0.044		0.152	1.542	0.316		3.295	0.444	0.163
3	0.037	EL	a	0.043			0.469	0.390	2.612	2.660	0.441	0.154
4	0.036	MOLINETE	MEXICO	0.043		0.327	0.399	0.315	2.548	2.372		0.154
5	0.035	a	PARA	0.043	0.079	0.151	0.508		2.755	2.327	0.258	0.151
6	0.034	MEXICO	SU	0.042		1.548	0.678	0.234	23.772	2.213	0.255	0.152
7	0.035	PARA	TARA	0.043	0.076	0.814	0.626	0.234	21.165		0.254	0.151
8		SU	EL		0.685	1.480		0.328	14.336	1.789	0.252	0.165
9	0.040	TARA	MOLINETE	0.043	0.100	4.709	0.754	1.576		1.784	0.253	
10	0.039	ND	a	0.041	0.078		0.848	1.633	4.751	1.765	0.250	0.134
11	0.038	ND	MEXICO	0.040	0.049	5.850	0.824	0.562	3.012	1.270		0.136
12	0.041	ND	ND	0.040	0.049	5.110	3.875		4.755	1.226	0.165	0.135
13	0.041	ND	1.108	0.040		1.446	29.325	0.466	17.439	1.023	0.166	0.125
14	0.044	ND	0.119	0.038	0.726	3.625	4.464	0.447	17.538		0.166	0.153
15		ND	0.054	0.000	19.023	2.003		0.446	11.007	0.931	0.160	0.122
16	0.044		0.054	0.000	3.589	0.832	2.204	1.573		0.908	0.160	
17	0.042		0.051	0.000	1.218		1.207	0.579	12.669	0.916	0.163	0.120
18	0.042			0.000	0.233	1.480	1.157	0.404	9.137	0.915		0.121
19	0.042		0.043	0.000	0.194	2.109	1.124		31.625	0.88	0.221	0.118
20	0.040		0.060	0.000		1.085	1.123	2.319	74.049	0.866	0.223	0.119
21	0.037		0.059	0.000	0.234	0.807	1.094	3.123	59.457		0.225	0.120
21									60.284			
22			0.060	0.000	0.216	0.594		1.927	30.080	0.754	0.217	0.121
23	0.040		0.059	0.000	1.252	0.591	0.383	1.334		0.755	0.214	
24	0.040		0.060	0.000	0.628		0.361	1.270	13.105	0.728	0.215	0.120
25	0.041			0.000	0.153	0.548	0.360	0.766	9.010	0.713		0.136
26	0.043		0.044	0.000	0.135	0.533	0.339		12.878	0.710	0.171	0.135
27	0.046		0.045	0.000		0.683	0.318	0.409	9.139	0.707	0.166	0.135
28	ND		0.044	0.000	0.085	0.372	0.314	1.116	5.971		0.166	0.136
29	ND		0.046	0.000	0.146	0.365		0.421	5.136	0.447	0.167	0.135
30	ND		0.046	0.000	0.110	0.348	0.247	0.356		0.447	0.165	
31	ND		0.045		0.136		0.239	0.351		0.480		0.120
1	ND		0.044	0.000	0.214		0.321		3.636	0.437		0.120
MAXIMO	0.046		1.108	0.044	19.023	5.850	29.325	3.123	74.049	3.636	0.444	0.165
MINIMO	0.034		0.043	0.000	0.000	0.151	0.239	0.234	1.156	0.447	0.160	0.118
MEDIO	0.040		0.117	0.018	1.225	1.445	2.121	0.860	17.630	1.352	0.230	0.136
COUNT	23		18	29	25	26	27	27	27	28	26	27
avg	0.040		0.113	0.017	1.184	1.445	2.055	0.860	17.112	1.319	0.230	0.135
std	0.003		0.249	0.021	3.790	1.599	5.546	0.745	18.997	0.879	0.086	0.015
cv	7.947%		219.563%	121.312%	320.052%	110.637%	269.920%	86.633%	111.016%	66.601%	37.332%	11.107%

AÑO		SECRETARIA DE RECURSOS HIDRAULICOS											
1986		SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS											
		DIVISION			CUENCA		CORRIENTE			ESTACION			
8		TEHUANTEPEC			Rio. ATOYAC		Rio. SALADO			OAXACA			
				DIRECCION DE HIDROLOGIA.									
DIA	ENE.	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC	
1	0.137	0.108	CALIBRAR	ND	0.109		0.261	0.318	0.165	0.667	0.504	0.036	
2	0.147		MOLINETE	ND	0.099	1.091	0.251	0.310	0.155	1.825		0.036	
3	0.143	0.111	CALIBRAR	ND	0.092	22.678	0.509		0.156	0.569	0.508	0.036	
4	0.144	0.110	MOLINETE	ND		2.672	0.509	0.131	0.236	0.487	0.503	0.036	
5		0.120	CALIBRAR	ND	0.091	0.807	0.319	0.124	0.235		0.501	0.034	
6	0.139	0.109	MOLINETE	ND	0.088	0.426		0.119	0.252	0.383	0.498	0.034	
7	0.134	0.106	CALIBRAR	ND	0.088	1.062	1.164	0.120		0.382	0.499		
8	0.141	0.106	MOLINETE	ND	0.205		1.415	0.112	0.215	0.385	0.496	0.034	
9	0.141		CALIBRAR	ND	0.141	1.960	0.550	0.115	0.215	0.270		0.034	
10	0.143	0.109	MOLINETE	ND	0.206	2.264	0.388		0.214	0.268	0.494	0.034	
11	0.143	0.108	CALIBRAR	ND		3.296	0.392	0.115	0.210	0.270	0.032	0.035	
12		0.108	MOLINETE	ND	0.124	0.927	0.694	0.110	0.208		0.037	0.035	
13	0.140	0.116	CALIBRAR	ND	0.137	0.538		0.109	0.207	0.288	0.037	0.035	
14	0.139	CALIBRAR	MOLINETE	ND	0.103	0.511	0.421	0.102		0.282	0.036		
15	0.132	MOLINETE	CALIBRAR	ND	0.109		0.364	0.102	0.085	0.290	0.035	0.031	
16	0.134	MOLINETE	CALIBRAR	ND	0.108	0.323	0.362	0.102	0.083	0.291		0.031	
17	0.130	CALIBRAR	MOLINETE	ND	0.104	0.335	0.212		0.083	0.293	0.033	0.031	
18	0.135	MOLINETE	CALIBRAR	ND		0.318	0.206	0.106	0.081	0.263	0.035	0.031	
19		CALIBRAR	MOLINETE	ND	0.412	0.317	0.200	0.106	0.082		0.036	0.031	
20	0.110	MOLINETE	CALIBRAR	ND	0.263	0.305		0.100	0.084	0.290	0.034	0.031	
21	0.110	CALIBRAR	MOLINETE	ND	0.145	0.292	0.193	0.099		0.262	0.035		
22	0.109	MOLINETE	CALIBRAR	0.105	0.249		0.189	0.097	0.054	0.269	0.036	0.031	
23	0.109	CALIBRAR	MOLINETE		0.201	0.128	0.172	0.139	0.045	0.246		0.036	
24	0.109	MOLINETE	CALIBRAR	0.051	0.409	0.132	0.182		0.042	0.244	0.034	0.036	
25	0.108	CALIBRAR	MOLINETE	0.078		0.132	1.682	0.170	0.042	0.243	0.035	0.037	
26		MOLINETE	CALIBRAR	0.079	0.429	0.132	3.422	0.161	0.041	2.275	0.033	0.037	
27	0.116	CALIBRAR	MOLINETE		0.266	0.130		0.124	0.041	0.541	0.034	0.037	
28	0.118	MOLINETE	CALIBRAR	0.081	0.203	0.269	0.562	0.160		0.517	0.036		
29	0.106	CALIBRAR	MOLINETE	0.079	0.195		0.504	0.384	0.043	0.504	0.037	0.037	
30	0.108	MOLINETE	CALIBRAR	0.116	0.232	0.270	0.321	0.210	0.274	0.507		0.037	
31	0.108	CALIBRAR	MOLINETE		0.196		0.317			0.504		0.037	
1	0.108	MOLINETE		0.109		0.261	0.318	0.165	0.667	0.504	0.036	0.037	
MAXIMO	0.147	0.120		0.116	0.429	22.678	3.422	0.384	0.274	2.275	0.508	0.037	
MINIMO	0.106	0.106		0.051	0.088	0.128	0.172	0.097	0.041	0.243	0.032	0.031	
MEDIO	0.127	0.110		0.084	0.185	1.653	0.584	0.148	0.136	0.486	0.184	0.034	
COUNT	28			8	27	26	28	27	27	29	26	28	
avg	0.126			0.087	0.185	1.599	0.574	0.149	0.156	0.487	0.178	0.035	
std	0.015			0.021	0.101	4.383	0.669	0.074	0.129	0.454	0.219	0.002	
cv	12.012%			24.465%	54.561%	274.086%	116.483%	49.853%	82.899%	93.208%	122.893%	6.709%	

AÑO	SECRETARIA DE RECURSOS HIDRAULICOS											
1988	SUBSECRETARIA DE PLANEACION. - DIRECCION GENERAL DE ESTUDIOS											
9	DIVISION TEHUANTEPEC			CUENCA Rio. ATOYAC		CORRIENTE Rio. SALADO			ESTACION OAXACA			
	DIRECCION DE HIDROLOGIA.											
DIA	ENE.	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
1						0.203	4.145	0.373	103.870	3.434	0.609	0.304
2					6.487	0.194	1.762	0.374	147.009		0.593	0.303
2									157.483			
3						0.190		0.326	156.618	3.406	0.594	0.301
4						0.189	1.290	0.324		2.094	0.598	
5							0.467	0.317	103.604	2.093	0.600	0.306
6						8.297	0.362	0.317	70.207	2.098		0.305
7						0.267	0.410		199.541	2.087	0.600	0.303
8						0.147	0.407	0.329	122.050	2.074	0.608	0.313
9						1.796	0.406	0.486	48.790		0.608	0.300
10						0.227		5.481		2.059	0.605	0.298
11						0.216	0.389	3.868	38.747	2.054	0.599	
12							1.001	3.721	8.576	2.052	0.597	0.243
13						0.149	0.477	7.899	7.316	2.047		0.243
14						0.147	0.473		6.697	2.050	0.593	0.244
15						0.150	0.460	67.462	6.444	2.040	0.592	0.247
16					1.661	0.623	1.007	121.371	6.322		0.601	0.243
17					0.258	0.265		57.044	6.307	2.034	0.602	0.245
18					0.253	6.993	0.542	51.000		2.032	0.594	
19					0.247		0.239	48.539	6.284		0.591	0.247
20					0.243	5.908	104.410	8.446	3.406			0.245
21						0.680	0.469		3.384	0.695	0.593	0.245
22						0.441	5.443	7.812	3.364	0.694	0.608	0.249
23						1.784	2.317	3.975	3.354		0.606	0.249
24						2.888		3.188	3.415	0.687	0.607	0.248
25						51.786	0.711	2.273		0.690	0.598	
26							0.682	1.822	3.119	0.594	0.597	0.249
27						2.689	0.669	1.479	2.125	0.595		0.253
28					0.210	1.029	0.670		2.118	0.596	0.300	0.252
29						1.226	0.668	3.245	2.125	0.612	0.307	0.247
30					0.211	7.706	0.669	7.922	3.437		0.303	0.248
31					0.216			48.667		0.612		0.246
1					0.203	4.145	0.373	103.870	3.434	0.609	0.304	
MAXIMO					6.487	51.786	104.410	121.371	199.541	3.434	0.609	0.313
MINIMO					0.210	0.147	0.230	0.317	2.118	0.594	0.300	0.243
MEDIO					1.087	3.699	5.020	16.953	45.400	1.643	0.566	0.266
COUNT					10	26	26	27	27	24	26	26
avg					0.999	3.850	4.875	20.786	41.680	1.525	0.554	0.264
std					1.980	10.102	20.328	33.595	61.623	0.812	0.109	0.027
cv					198.234%	262.377%	416.997%	161.622%	147.848%	53.270%	19.676%	10.196%

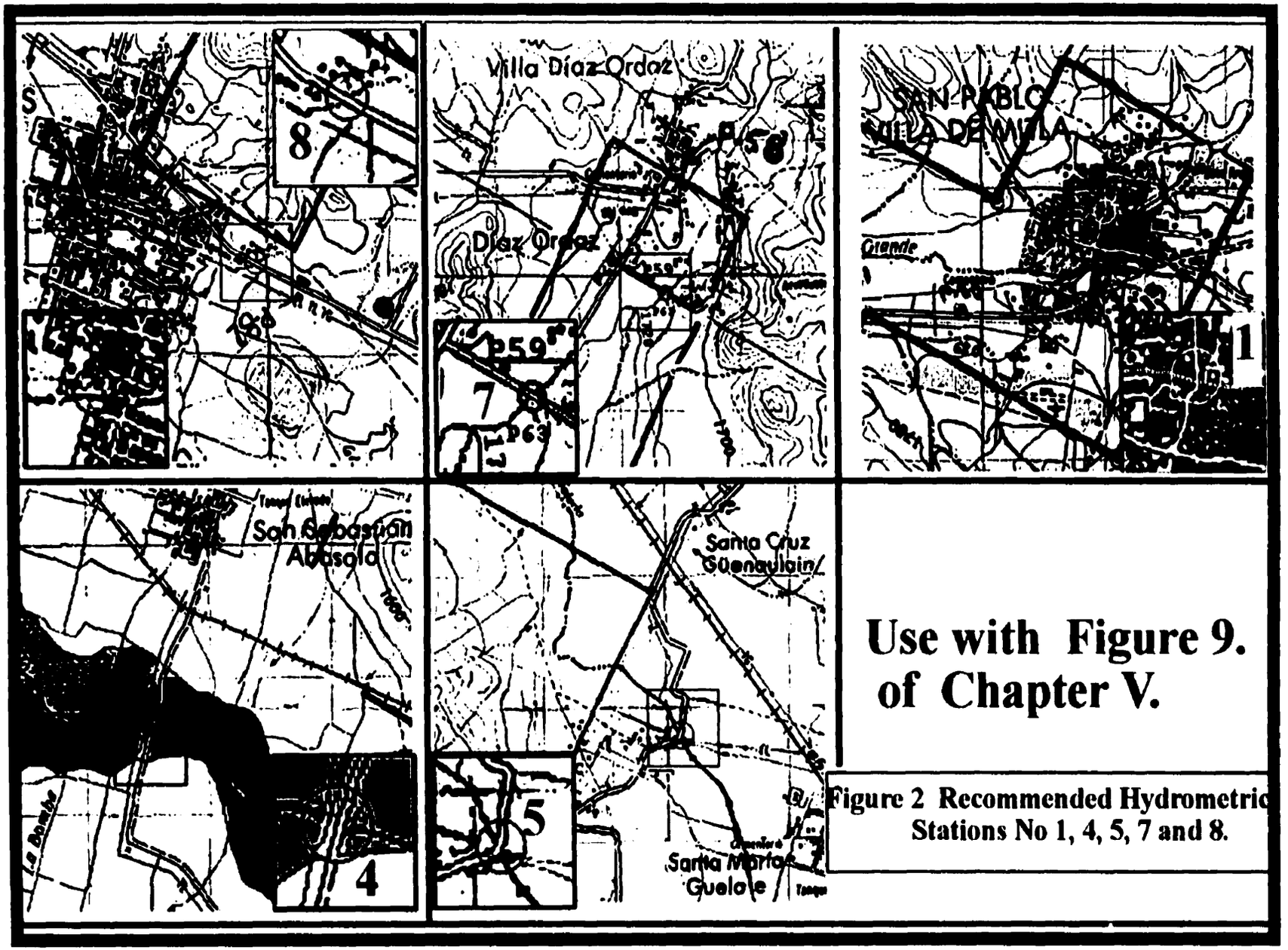


Figure 2 Recommended Hydrometric Stations No 1, 4, 5, 7 and 8.

APPENDIX AC.

GROUND WATER QUALITY DATA .

CHEMICAL ANALYSIS PERRATON 1994 SURVEY.

Columns B to Y

Columns AA to AN

Columns AO to AU

CHEMICAL ANALYSIS PERRATON 1995 SURVEY.

Columns B to Y

Columns AA to AN

Columns AO to AU

CHEMICAL ANALYSIS GEOCA 1979 SURVEY. 1 - 30.

Columns B to Y

Columns AA to AN

Columns AO to AU

CHEMICAL ANALYSIS GEOCA 1979 SURVEY. 31 - 53.

Columns B to Y

Columns AA to AN

Columns AO to AU

CHEMICAL ANALYSIS PERRATON 1994 SURVEY.

Columns B to Y

Columns AA to AN

Columns AO to AU

	B	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Pozos	$EC_{corr}X10^6$	pH	Dissolved	Alcalinity	Dureza	Hardness	Hardness	*SATURATION EXTRACT DETERMINATIONS								Milliequivalents per l
2	Well	at 25 C		Solids	TOTAL	TOTAL	CALCIUM	Magnesio	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	SO_4^{-}	Cl^{-}	NO_3
3		nomhos		ppm	ppm	ppm	ppm	ppm	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l
4	8	355	8.2	253	49.5	144.2	103.0	NA	2.1	0.8	1.5	NA	0.18	0.81	0.30	0.13	3.22
5	9	448	7.4	320	47.3	216.3	138.0	NA	2.8	1.6	1.3	NA	0.00	0.95	0.63	0.46	0.43
6	15	1049	[illegible]	482	378.2	344.0	170.0	NA	3.4	3.5	7.7	NA	0.54	7.03	1.78	0.21	0.11
7	18	400	7.6	210	87.8	200.0	126.0	NA	2.5	1.5	1.0	NA	0.00	1.76	0.52	0.51	0.06
8	20	432	8.5	278	36.0	123.6	88.6	NA	1.8	0.7	3.2	NA	0.27	0.45	1.62	1.62	0.01
9	24	420	8.2	300	94.5	304.9	251.3	NA	5.0	1.1	0.0	NA	0.72	1.17	0.63	0.54	0.01
10	28	517	8.2	292	67.5	181.3	160.7	NA	3.2	0.4	2.6	NA	0.45	0.90	0.39	0.30	0.01
11	31	1080	8.2	586	141.8	372.9	257.5	NA	5.2	2.3	6.5	NA	0.45	2.39	3.34	1.02	1.14
12	34	641	8.2	436	78.8	244.0	172.0	NA	3.4	1.5	3.2	NA	0.18	1.39	0.97	0.27	0.03
13	42	1036	8.2	516	272.4	260.0	58.0	NA	1.2	4.1	10.5	NA	0.27	5.17	1.24	0.68	0.11
14	44	957	7.8	440	350.9	300.0	114.0	NA	2.3	3.7	7.9	NA	0.00	7.02	1.47	0.55	0.11
15	49	1144	8.2	488	281.4	198.0	84.0	NA	1.7	2.3	12.7	NA	0.81	4.81	2.35	1.44	0.21
16	56	999	7.6	544	308.4	326.0	210.0	NA	4.2	2.3	6.7	NA	0.00	6.17	1.58	0.47	0.12
17	63	1468	7.0	1390	96.8	484.4	329.6	NA	6.6	3.1	9.5	NA	0.00	1.93	1.95	10.67	0.42
18	64	418	7.4	298	49.5	183.3	78.3	NA	1.6	2.1	2.2	NA	0.00	1.00	0.95	0.19	0.09
19	65	3500	8.2	2486	117.1	342.0	100.9	NA	2.0	4.8	45.1	NA	0.18	2.16	8.39	25.61	0.15
20	66	4911	8.2	3508	117.1	432.6	88.6	NA	1.8	6.9	64.7	NA	0.54	1.80	9.99	37.93	0.67
21	66a	4802	8.2	3430	119.3	317.2	92.7	NA	1.9	4.5	64.9	NA	0.36	2.03	9.06	37.94	0.05
22	67	1000	8.2	452	103.6	321.4	214.2	NA	4.3	2.2	6.8	NA	0.36	1.71	1.95	2.53	0.01
23	76	589	8.2	386	63.0	201.9	80.3	NA	1.6	2.4	4.4	NA	0.18	1.08	0.13	0.67	0.09
24	77	1050	8.2	708	92.3	187.5	117.4	NA	2.3	1.4	11.0	NA	0.27	1.57	0.15	5.34	0.03
25	83	2829	8.2	1410	508.7	552.0	210.0	NA	4.2	6.9	30.3	NA	0.13	9.99	4.93	8.46	0.02
26	107	508	8.2	450	67.5	201.9	131.8	NA	2.6	1.4	2.5	NA	0.27	1.08	0.78	0.24	0.16
27	108	3870	8.5	2710	119.3	520.0	160.0	NA	3.2	7.2	46.9	NA	0.36	2.03	9.72	26.99	0.02
28	117	800	8.2	632	301.6	243.1	154.5	NA	3.1	1.8	5.9	NA	0.67	5.40	0.91	1.86	0.55
29	125	1000	8.2	658	177.8	278.1	164.8	NA	3.3	2.3	8.1	NA	0.18	3.37	0.40	4.26	0.02
30	136	509	7.0	436	72.0	243.1	154.5	NA	3.1	1.8	1.6	NA	0.00	1.44	0.32	0.16	0.04
31	139	2000	7.4	1444	56.3	716.9	436.7	NA	8.7	5.6	12.2	NA	0.00	1.44	3.09	12.13	2.20
32	141	1100	8.2	658	110.3	280.2	243.1	NA	4.86	0.74	8.5	NA	0.35	1.85	1.37	1.07	1.07
33	142	1500	8.2	1048	132.8	515.0	445.0	NA	8.90	1.40	7.9	NA	0.27	2.39	2.19	4.07	0.90
34	143	490	7.8	418	87.8	331.7	164.8	NA	3.30	3.35	0.0	NA	0.00	1.76	1.92	0.73	0.14
35																	
36																	

	B	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
1	Pozos	Residual	SAR		$(Ca^{++}+Mg^{++}+Na^{+})$		$(Ca^{++}+Mg^{++})$		$[CO_3+HCO_3]$		pH_c	$1+(8.4-pH_c)$		$(SAR)_i[1+(8.4-pH_c)]$		
2	Well	Na_2CO_3				$pk_2' - pk_c'$		$p(Ca^{++}+Mg^{++})$		p(Alk)			$(SAR)_i$	ADJUSTED SAR		
3		meq/l			meq/l		meq/l		meq/l							
4	8	0.00	1.29		4.44	2.2	2.89	2.8	0.99	3.0	8.1	1.3	1.3	1.7		
5	9	0.00	0.88		5.63	2.3	4.33	2.7	0.95	3.0	7.9	1.5	0.9	1.3		
6	15	0.68	4.17		14.63	2.3	6.89	2.5	7.57	2.1	6.9	2.5	4.2	10.4		
7	18	0.00	0.72		5.02	2.2	4.00	2.7	1.76	2.7	7.7	1.7	0.7	1.2		
8	20	0.00	2.90		5.69	2.3	2.47	2.9	0.72	3.1	8.3	1.1	2.9	3.2		
9	24	0.00	0.00		6.10	2.3	6.10	2.5	1.89	2.7	7.5	1.9	0.0	0.0		
10	28	0.00	1.91		6.19	2.3	3.62	2.7	1.35	2.9	7.9	1.5	1.9	2.9		
11	31	0.00	3.38		14.00	2.3	7.47	2.4	2.84	2.5	7.3	2.1	3.4	7.1		
12	34	0.00	2.08		8.14	2.3	4.89	2.6	1.57	2.8	7.7	1.7	2.1	3.6		
13	42	0.23	6.47		15.66	2.3	5.21	2.6	5.44	2.3	7.2	2.2	6.5	14.5		
14	44	1.01	4.53		13.87	2.3	6.01	2.5	7.02	2.1	7.0	2.4	4.5	10.9		
15	49	1.66	9.01		16.63	2.3	3.96	2.7	5.62	2.2	7.3	2.1	9.0	19.1		
16	56	0.00	3.73		13.25	2.3	6.52	2.5	6.17	2.2	7.0	2.4	3.7	8.9		
17	63	0.00	4.33		19.21	2.3	9.69	2.3	1.93	2.7	7.4	2.0	4.3	8.8		
18	64	0.00	1.64		5.89	2.3	3.67	2.7	1.00	3.0	8.0	1.4	1.6	2.3		
19	65	0.00	24.34		51.93	2.4	6.86	2.5	2.34	2.6	7.5	1.9	24.3	46.1		
20	66	0.00	31.07		73.41	2.5	8.68	2.4	2.34	2.6	7.4	2.0	31.1	61.2		
21	66a	0.00	36.39		71.25	2.4	6.36	2.5	2.39	2.6	7.6	1.8	36.4	67.2		
22	67	0.00	3.78		13.20	2.3	6.43	2.5	2.07	2.7	7.5	1.9	3.8	7.2		
23	76	0.00	3.10		8.47	2.3	4.05	2.7	1.26	2.9	7.9	1.5	3.1	4.8		
24	77	0.00	8.02		14.73	2.3	3.75	2.7	1.84	2.7	7.8	1.6	8.0	13.0		
25	83	0.00	12.89		41.36	2.4	11.06	2.2	10.12	2.0	6.6	2.8	12.9	35.5		
26	107	0.00	1.75		6.55	2.3	4.05	2.7	1.35	2.9	7.8	1.6	1.8	2.8		
27	108	0.00	20.55		57.35	2.4	10.43	2.3	2.39	2.6	7.3	2.1	20.5	42.7		
28	117	1.21	3.77		10.73	2.3	4.86	2.6	6.07	2.2	7.1	2.3	3.8	8.6		
29	125	0.00	4.87		13.70	2.3	5.57	2.5	3.55	2.4	7.3	2.1	4.9	10.2		
30	136	0.00	0.99		6.42	2.3	4.87	2.6	1.44	2.8	7.7	1.7	1.0	1.7		
31	139	0.00	4.57		26.60	2.4	14.35	2.1	1.44	2.8	7.3	2.1	4.6	9.4		
32	141	0.00	5.08		14.10	2.3	5.60	2.5	2.20	2.7	7.5	1.9	5.1	9.5		
33	142	0.00	3.48		18.20	2.3	10.30	2.3	2.66	2.6	7.2	2.2	3.5	7.7		
34	143	0.00	0.00		6.65	2.3	6.65	2.5	1.76	2.7	7.5	1.9	0.0	0.0		
35																
36																

Perraton Survey 1994. waterNEW.xls Appendix ____ Water Chemical Analysis Data.

	B	AO	AP	AQ	AR	AS	AT	AU
1	Pozos	Column #.	C S	S#				Residual Sodium Carbonate.
2	Well		Class	C #	S#	Conductivity	Sodium Hazard	Effect of [ ] on quality.
3								
4	8	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
5	9	4	21	2	1	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
6	15	6	33	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
7	18	4	21	2	1	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
8	20	4	21	2	1	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
9	24	4	21	2	1	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
10	28	4	21	2	1	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
11	31	6	32	3	2	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
12	34	4	21	2	1	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
13	42	6	34	3	4	HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
14	44	6	33	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
15	49	6	34	3	4	HIGH CONDUCTIVITY	VERY HIGH Na	1.25<RSC<2.5. => Marginal Water
16	56	6	32	3	2	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
17	63	6	32	3	2	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
18	64	4	21	2	1	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
19	65	8	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
20	66	8	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
21	66a	8	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
22	67	6	32	3	2	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
23	76	4	21	2	1	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
24	77	6	33	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
25	83	8	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
26	107	4	21	2	1	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
27	108	8	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
28	117	6	32	3	2	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
29	125	6	33	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
30	136	4	21	2	1	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
31	139	6	33	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
32	141	6	33	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
33	142	6	32	3	2	HIGH CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
34	143	4	21	2	1	MEDIUM CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
35								
36								

CHEMICAL ANALYSIS PERRATON 1995 SURVEY.

Columns B to Y

Columns AA to AN

Columns AO to AU

	B	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Pozos	$EC_{corr}X10^6$	pH	Dissolved	Alcalinity	Dureza	Hardness	Hardness	*SATURATION EXTRACT DETERMINATIONS Milliequivalents per l								
2	Well	at 25 C		Solids	TOTAL	TOTAL	CALCIUM	Magnesio	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	SO_4^{-}	Cl^{-}	NO_3
3		vomhos		ppm	ppm	ppm	ppm	ppm	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l
37																	
38																	
39	Pozos	$EC_{corr}X10^6$	pH	Dissolved	Alcalinity	Dureza	DUREZA	DUREZA	SATURATION EXTRACT DETERMINATIONS Milliequivalents								
40	Obs.W	at 25 C		Solids	TOTAL	TOTAL	CALCIUM	Magnesio	Ca^{++}	Mg^{++}	Na^{+}(see	K^{+}	CO_3^{-}	HCO_3^{-}	SO_4^{-}	Cl^{-}	NO_3
41					ppm	ppm	ppm	ppm									
42	66	4000	7.1	590	594.7	385.0	72.0	294.0	1.44	5.95	52.5		0.97	10.91	6.54	43.37	0.06
43	66B	200	7.9	188	77.9	76.0	58.0	18.0	1.16	0.36	1.0	NA	0.41	1.15	0.21	0.00	0.01
44	66C	1300	7.7	908	297.4	450.0	150.0	300.0	3.00	6.07	10.0	NA	0.41	5.54	6.12	1.98	0.12
45	83	2500	7.7	NA	447.8	516.0	230.0	286.0	4.60	5.79	25.7	NA	0.41	8.55	3.80	9.24	0.03
46	106	2500	7.4	1400	582.4	254.0	80.0	174.0	1.60	3.52	31.9	NA	0.73	10.91	0.39	10.82	0.11
47	108	4000	7.0	9950	568.1	1504.0	18.0	1485.0	0.35	30.07	35.1	NA	0.24	11.12	46.66	132.82	0.00
48	113	3000	7.5	2185	266.6	1900.0	900.0	1000.0	18.00	20.24	1.8	NA	0.24	5.09	3.69	17.62	0.00
49	114	1120	7.7	680	328.1	1000.0	300.0	700.0	6.00	14.17	0.0	NA	0.32	6.24	1.13	2.06	0.17
50	115	2500	8.2	NA	305.0	250.0	150.0	88.0	3.00	1.38	30.3	NA	0.00	6.11	0.93	0.84	0.00
51	116	880	7.7	506	268.7	1000.0	300.0	700	6.00	14.17	0.0	NA	0.24	5.13	0.82	1.90	0.09
52	144	1600	7.6	1048	254.3	458.0	234.0	224	4.68	4.53	13.2	NA	0.00	5.09	9.23	0.92	0.04
53	64	600	8.0	308	229.7	226.0	72.0	154	1.44	3.12	4.3	NA	0.49	4.10	0.63	0.08	0.11
54	64b	800	7.9	250	301.5	296.0	52.0	244	1.04	4.94	6.4	NA	1.06	4.96	1.39	0.65	0.03
55																	
56																	
57																	
58																	
59																	
60																	

	B	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
1	Pozos	Residual	SAR		$(Ca^{++}+Mg^{++}+Na^{+})$		$(Ca^{++}+Mg^{++})$		$[CO_3+HCO_3]$		pH_c	$1+(8.4-pH_c)$		$(SAR)_i[1+(8.4-pH_c)]$		
2	Well	Na_2CO_3				$pk_2' - pk_c'$		$p(Ca^{++}+Mg^{++})$		p(Alk)			$(SAR)_i$	ADJUSTED SAR		
3		meq/l			meq/l		meq/l		meq/l							
37																
38																
39	Pozos	Residual	SAR		$(Ca^{++}+Mg^{++}+Na^{+})$		$(Ca^{++}+Mg^{++})$		$[CO_3+HCO_3]$		pH_c	$1+(8.4-pH_c)$	$(SAR)_i$	$(SAR)_i[1+(8.4-pH_c)]$		
40	Obs.W	Na_2CO_3				$pk_2' - pk_c'$		$p(Ca^{++}+Mg^{++})$		p(Alk)				ADJUSTED SAR		
41																
42	66	4.49	27.30		59.86	2.4	7.39	2.4	11.88	1.9	6.8	2.6	27.3	71.6		
43	66B	0.04	1.10		2.48	2.2	1.52	3.1	1.56	2.8	8.1	1.3	1.1	1.4		
44	66C	0.00	4.71		19.10	2.3	9.07	2.3	5.95	2.2	6.9	2.5	4.7	11.8		
45	83	0.00	11.26		36.05	2.4	10.39	2.3	8.96	2.0	6.7	2.7	11.3	30.2		
46	106	6.52	19.94		37.03	2.4	5.12	2.6	11.64	1.9	6.9	2.5	19.9	49.7		
47	108	0.00	9.00		65.53	2.4	30.42	1.8	11.36	1.9	6.2	3.2	9.0	28.9		
48	113	0.00	0.41		40.02	2.4	38.24	1.7	5.33	2.3	6.4	3.0	0.4	1.2		
49	114	0.00	0.00		20.17	2.4	20.17	2.0	6.56	2.2	6.5	2.9	0.0	0.0		
50	115	0.93	16.84		35.50	2.4	9.10	2.0	8.11	2.2	7.2	2.2	16.6	41.6		
51	116	0.00	0.00		20.17	2.4	20.17	2.0	5.37	2.3	6.6	2.8	0.0	0.0		
52	144	0.00	6.15		22.41	2.4	9.21	2.3	5.09	2.3	7.0	2.4	6.1	14.9		
53	64	0.03	2.85		8.86	2.3	4.56	2.6	4.59	2.3	7.3	2.1	2.8	6.1		
54	64b	0.04	3.72		12.41	2.3	5.98	2.5	6.02	2.2	7.0	2.4	3.7	8.7		
55																
56																
57																
58																
59																
60																

Perraton Survey 1995. waterNEW.xls Appendix ____ Water Chemical Analysis Data.

	B	AO	AP	AQ	AR	AS	AT	AU
1	Pozos	Column #.	C S	S#				Residual Sodium Carbonate.
2	Well		Class	C #	S#	Conductivity	Sodium Hazard	Effect of [ ] on quality.
3								
37								
38								
39	Pozos	Column #.	C #	S#				Residual Sodium Carbonate.
40	Obs.W			C #	S#	Conductivity	Sodium Hazard	Effect of [ ] on quality.
41								**On the basis of the RSC**
42	66	8	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	RSC is HIGH => Not suitable for irrigation
43	66B	2	11	1	1	LOW CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
44	66C	6	33	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
45	83	8	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
46	106	8	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	RSC is HIGH => Not suitable for irrigation
47	108	8	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
48	113	8	41	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
49	114	6	31	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
50	115	8	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
51	116	6	31	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
52	144	6	34	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
53	64	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
54	64b	6	32	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
55								
56								
57								
58								
59								
60								

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Columns B to Y

Columns AA to AN

Columns AO to AU

	B	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Pozos	$EC_{corr}X10^6$	pH	Dissolved	Alcalinity	Dureza	Hardness	Hardness	*SATURATION EXTRACT DETERMINATIONS							Milliequivalents per l	
2	Well	at 25 C		Solids	TOTAL	TOTAL	CALCIUM	Magnesio	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	SO_4^{-}	Cl^{-}	NO_3
3		umhos		ppm	ppm	ppm	ppm	ppm	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l
61																	
62	Pozos	$EC_{corr}X10^6$	pH	Dissolved	Alcalinity	Dureza	DUREZA	DUREZA	SATURATION EXTRACT DETERMINATIONS							Milliequivalents per liter	
63	Obs.W	at 25 C		Solids	TOTAL	TOTAL	CALCIUM	Magnesio	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	SO_4^{-}	Cl^{-}	NO_3
64											measured						
65	1	950		923	375.0	130.0	60.0	70	1.19	1.39	9.59	NA	0.59	6.88	1.97	2.73	
66	2	600		683	405.0	220.0	170.0	50	3.39	0.98	4.59	NA	0.89	7.19	0.04	0.84	
67	3	370		357	195.0	140.0	110	30	2.19	0.57	1.86	NA	0.00	3.88	0.04	0.70	
68	4	240		335	172.0	120.0	80.0	40	1.59	0.74	2.03	NA	0.00	3.44	0.14	0.78	
69	5	620		634	367.0	270.0	100.0	170	1.99	3.37	2.99	NA	0.13	7.19	0.10	0.93	
70	6	740		810	457.0	40.0	10.0	30	0.19	0.57	9.43	NA	0.43	8.68	0.10	0.98	
71	7	600		734	435.0	290.0	100.0	190	1.99	3.78	3.77	NA	0.00	8.65	0.08	0.78	
72	8	600		674	360.0	270.0	220.0	50	4.39	0.98	3.31	NA	0.00	7.19	0.45	1.04	
73	9	600		697	360.0	300.0	140.0	160	2.59	3.20	3.59	NA	0.00	7.19	0.56	1.63	
74	10	495		613	315.0	270.0	160.0	110	3.19	2.11	2.82	NA	0.00	6.29	0.70	1.15	
75	11	220		275	135.0	40.0	25.0	15	0.49	0.24	2.83	NA	0.00	2.68	0.10	0.78	
76	12	590		579	322.0	250.0	190.0	60	3.79	1.15	2.58	NA	0.13	6.29	0.20	0.98	
77	13	660		725	390.0	250.0	150.0	100	2.99	1.97	4.47	NA	0.00	7.78	0.41	1.24	
78	14	700		760	412.0	310.0	180.0	130	3.59	2.96	3.68	NA	0.29	7.93	0.27	1.74	
79	15	800		748	330.0	330.0	200.0	130	3.99	2.55	4.01	NA	0.29	6.29	0.87	3.10	
80	16	1350		1204	450.0	420.0	240.0	180	4.79	3.53	9.09	NA	0.13	8.83	0.95	7.50	
81	17	550		566	300.0	260.0	120.0	110	2.39	2.79	2.37	NA	0.00	5.99	0.66	0.90	
82	18	785		750	352.0	410.0	270.0	140	5.38	2.79	2.09	NA	0.00	7.04	1.22	2.00	
83	19	2800		1653	375.0	1740.0	980.0	760	19.56	15.13	0.00	NA	0.00	7.49	5.51	10.01	
84	20	400		544	300.0	260.0	160.0	100	3.19	1.97	1.98	NA	0.00	5.99	0.31	0.84	
85	21	490		634	300.0	320.0	170.0	150	3.39	2.96	2.35	NA	0.00	5.99	1.22	1.49	
86	22	800		643	300.0	350.0	180.0	170	3.59	3.37	1.90	NA	0.00	5.99	1.37	1.55	
87	23	710		580	285.0	290.0	230.0	60	4.59	1.15	1.99	NA	0.00	5.68	0.70	1.35	
88	24	800		848	375.0	300.0	130.0	170	2.59	3.37	4.39	NA	0.00	7.49	1.66	1.10	
89	25	860		751	300.0	360.0	280.0	80	5.58	1.56	3.39	NA	0.00	5.99	1.16	3.38	
90	26	650		672	315.0	360.0	250.0	110	4.99	2.13	2.08	NA	0.00	6.29	0.83	2.08	
91	27	1150		1094	435.0	560.0	360.0	260	7.18	5.18	2.80	NA	0.00	8.68	4.99	1.49	
92	28	720		635	345.0	390.0	230.0	160	4.59	3.12	0.84	NA	0.00	6.88	0.49	1.18	
93	29	590		625	360.0	300.0	160.0	140	3.19	2.79	2.14	NA	0.00	7.19	0.20	0.73	
94	30	585		571	300.0	340.0	250.0	90	4.99	1.80	0.80	NA	0.00	5.99	0.72	0.98	

	B	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
1	Pozos	Residual	SAR		$(Ca^{++}+Mg^{++}+Na^{+})$		$(Ca^{++}+Mg^{++})$		$[CO_3+HCO_3]$		pH_c	$1+(8.4-pH_c)$		$(SAR)_i[1+(8.4-pH_c)]$		
2	Well	Na_2CO_3				$pk_2' - pk_c'$		$p(Ca^{++}+Mg^{++})$		$p(Alk)$			$(SAR)_i$	ADJUSTED SAR		
3		meq/l			meq/l		meq/l		meq/l							
61																
62	Pozos		SAR		$(Ca^{++}+Mg^{++}+Na^{+})$		$(Ca^{++}+Mg^{++})$		$[CO_3+HCO_3]$		pH_c	$1+(8.4-pH_c)$	$(SAR)_i$	$(SAR)_i[1+(8.4-pH_c)]$		
63	Obs.W	Na_2CO_3				$pk_2' - pk_c'$		$p(Ca^{++}+Mg^{++})$		$p(Alk)$				ADJUSTED SAR		
64																
65	1	4.89	8.44		12.17	2.3	2.58	2.9	7.47	2.1	7.3	2.1	8.4	17.6		
66	2	3.71	3.11		8.96	2.3	4.37	2.7	8.08	2.1	7.0	2.4	3.1	7.4		
67	3	1.12	1.58		4.62	2.2	2.76	2.9	3.88	2.4	7.5	1.9	1.6	3.0		
68	4	1.11	1.88		4.36	2.2	2.33	2.9	3.44	2.5	7.6	1.8	1.9	3.4		
69	5	1.96	1.83		8.35	2.3	5.36	2.6	7.32	2.1	7.0	2.4	1.8	4.4		
70	6	8.35	15.30		10.19	2.3	0.76	3.4	9.11	2.0	7.7	1.7	15.3	25.3		
71	7	2.88	2.22		9.54	2.3	5.77	2.5	8.65	2.1	6.9	2.5	2.2	5.6		
72	8	1.82	2.02		8.68	2.3	5.37	2.6	7.19	2.1	7.0	2.4	2.0	4.9		
73	9	1.40	2.11		9.38	2.3	5.79	2.5	7.19	2.1	7.0	2.4	2.1	5.1		
74	10	0.99	1.73		8.12	2.3	5.30	2.6	6.29	2.2	7.0	2.4	1.7	4.1		
75	11	1.95	4.68		3.56	2.2	0.73	3.4	2.68	2.6	8.2	1.2	4.7	5.6		
76	12	1.48	1.64		7.52	2.3	4.94	2.6	6.42	2.2	7.1	2.3	1.6	3.8		
77	13	2.82	2.84		9.43	2.3	4.96	2.6	7.78	2.1	7.0	2.4	2.8	6.8		
78	14	1.67	2.03		10.23	2.3	6.55	2.5	8.22	2.1	6.9	2.5	2.0	5.2		
79	15	0.04	2.22		10.55	2.3	6.54	2.5	6.58	2.2	7.0	2.4	2.2	5.4		
80	16	0.64	4.46		17.41	2.3	8.32	2.4	8.96	2.0	6.8	2.6	4.5	11.8		
81	17	0.81	1.47		7.55	2.3	5.18	2.6	5.99	2.2	7.1	2.3	1.5	3.4		
82	18	0.00	1.03		10.26	2.3	8.17	2.4	7.04	2.1	6.8	2.6	1.0	2.7		
83	19	0.00	0.00		34.69	2.4	34.69	1.8	7.49	2.1	6.3	3.1	0.0	0.0		
84	20	0.83	1.23		7.14	2.3	5.16	2.6	5.99	2.2	7.1	2.3	1.2	2.9		
85	21	0.00	1.32		8.70	2.3	6.35	2.5	5.99	2.2	7.0	2.4	1.3	3.2		
86	22	0.00	1.02		8.86	2.3	6.96	2.5	5.99	2.2	7.0	2.4	1.0	2.5		
87	23	0.00	1.17		7.73	2.3	5.74	2.5	5.68	2.2	7.1	2.3	1.2	2.8		
88	24	1.53	2.54		10.35	2.3	5.96	2.5	7.49	2.1	6.9	2.5	2.5	6.3		
89	25	0.00	1.79		10.53	2.3	7.14	2.4	5.99	2.2	7.0	2.4	1.8	4.4		
90	26	0.00	1.10		9.20	2.3	7.12	2.4	6.29	2.2	6.9	2.5	1.1	2.7		
91	27	0.00	1.13		15.16	2.3	12.36	2.2	8.68	2.1	6.6	2.8	1.1	3.2		
92	28	0.00	0.43		8.55	2.3	7.71	2.4	6.88	2.2	6.8	2.6	0.4	1.1		
93	29	1.21	1.24		8.12	2.3	5.98	2.5	7.19	2.1	6.9	2.5	1.2	3.0		
94	30	0.00	0.43		7.59	2.3	6.79	2.5	5.99	2.2	7.0	2.4	0.4	1.1		

GEOCA Survey 1979. waterNEW.xls Appendix ____ Water Chemical Analysis Data.

	B	AO	AP	AQ	AR	AS	AT	AU
1	Pozos	Column #.	C S	S#				Residual Sodium Carbonate.
2	Well		Class	C #	S#	Conductivity	Sodium Hazard	Effect of [ ] on quality.
3								
61								
62	Pozos	Column #.	C #	S#				Residual Sodium Carbonate.
63	Obs.W			C #	S#	Conductivity	Sodium Hazard	Effect of [ ] on quality.
64								**On the basis of the RSC**
65	1	6	34	3	3	HIGH CONDUCTIVITY	HIGH Na	RSC is HIGH => Not suitable for irrigation
66	2	4	22	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	RSC is HIGH => Not suitable for irrigation
67	3	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
68	4	2	11	1	1	LOW CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
69	5	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	1.25<RSC<2.5. => Marginal Water
70	6	4	24	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	RSC is HIGH => Not suitable for irrigation
71	7	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	RSC is HIGH => Not suitable for irrigation
72	8	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	1.25<RSC<2.5. => Marginal Water
73	9	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	1.25<RSC<2.5. => Marginal Water
74	10	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
75	11	2	11	1	1	LOW CONDUCTIVITY	LOW Na	1.25<RSC<2.5. => Marginal Water
76	12	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	1.25<RSC<2.5. => Marginal Water
77	13	4	22	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	RSC is HIGH => Not suitable for irrigation
78	14	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	1.25<RSC<2.5. => Marginal Water
79	15	6	32	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
80	16	6	33	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
81	17	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
82	18	6	31	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
83	19	8	41	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
84	20	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
85	21	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
86	22	6	31	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
87	23	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
88	24	6	32	3	3	HIGH CONDUCTIVITY	HIGH Na	1.25<RSC<2.5. => Marginal Water
89	25	6	32	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
90	26	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
91	27	6	31	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
92	28	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
93	29	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
94	30	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation

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Columns B to Y

Columns AA to AN

Columns AO to AU

	B	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Pozos	$EC_{corr}X10^6$	pH	Dissolved	Alcalinity	Dureza	Hardness	Hardness	*SATURATION EXTRACT DETERMINATIONS Milliequivalents per l								
2	Well	at 25 C		Solids	TOTAL	TOTAL	CALCIUM	Magnesio	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	SO_4^{-}	Cl^{-}	NO_3
3		umhos		ppm	ppm	ppm	ppm	ppm	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l
95	31	600		576	300.0	290.0	180.0	110	3.59	2.13	1.95	NA	0.00	5.99	0.58	1.10	
96	32	600		755	360.0	330.0	220.0	110	4.39	2.13	3.57	NA	0.00	7.19	1.35	1.55	
97	33	920		1088	562.0	430.0	290.0	140	5.78	2.79	5.83	NA	0.43	10.78	1.56	1.63	
98	34	650		653	352.0	350.0	250.0	100	4.99	1.97	1.82	NA	0.29	6.73	0.33	1.43	
99	35	590		976	367.0	370.0	240.0	130	4.79	2.87	5.75	NA	0.29	7.04	4.53	1.55	
100	36	400		454	255.0	270.0	150.0	120	2.99	2.38	0.93	NA	0.59	4.49	0.24	0.98	
101	37	430		503	285.0	230.0	160.0	70	3.19	1.39	2.05	NA	0.29	5.39	0.22	0.73	
102	38	650		672	375.0	350.0	220.0	130	4.39	2.55	1.84	NA	0.00	7.49	0.62	0.67	
103	39	510		527	285.0	280.0	220.0	60	4.39	1.15	1.36	NA	0.00	5.68	0.24	0.98	
104	40	460		522	300.0	380.0	210.0	120	2.19	2.38	2.25	NA	0.00	5.99	0.16	0.67	
105	41	420		462	255.0	230.0	150.0	80	2.99	1.56	1.51	NA	0.00	5.09	0.24	0.73	
106	42	900		946	450.0	360.0	270.0	90	3.58	1.80	5.47	NA	0.00	5.99	0.93	2.73	
107	43	8000		7321	1065.0	1300.0	500.0	800	9.98	15.95	93.31	NA	0.00	21.29	0.83	97.12	
108	44	540		590	270.0	240.0	200.0	40	3.99	0.74	3.27	NA	0.00	5.19	0.33	2.28	
109	45	640		604	300.0	240.0	200.0	140	3.99	2.79	1.39	NA	0.00	5.99	1.14	1.04	
110	46	470		513	292.0	300.0	150.0	150	2.99	2.96	0.96	NA	0.13	5.68	0.37	0.73	
111	47	460		554	300.0	340.0	170.0	170	3.39	3.37	0.73	NA	0.00	5.99	0.77	0.73	
112	48	595		560	300.0	360.0	150.0	210	2.99	4.19	0.44	NA	0.00	6.29	0.60	0.73	
113	49	315		348	195.0	240.0	130.0	110	2.59	2.13	0.00	NA	0.00	3.88	0.24	0.59	
114	50	260		342	195.0	250.0	100.0	240	1.99	2.96	0.00	NA	0.00	3.88	0.10	0.59	
115	51	220		233	127.0	130.0	60.0	70	1.19	1.39	0.66	NA	0.13	2.39	0.08	0.64	
116	52	2600		2300	735.0	520.0	380.0	140	7.58	2.79	23.41	NA	0.00	14.68	0.20	18.90	
117	53	2000		2288	750.0	280.0	100.0	180	1.99	3.53	26.35	NA	0.00	14.99	6.87	10.01	
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	B	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
1	Pozos	Residual	SAR		$(Ca^{++}+Mg^{++}+Na^{+})$		$(Ca^{++}+Mg^{++})$		$[CO_3+HCO_3]$		pH_c	$1+(8.4-pH_c)$		$(SAR)_i[1+(8.4-pH_c)]$		
2	Well	Na_2CO_3				$pk_2' - pk_c'$		$p(Ca^{++}+Mg^{++})$		p(Alk)			$(SAR)_i$	ADJUSTED SAR		
3		meq/l			meq/l		meq/l		meq/l							
95	31	0.27	1.15		7.67	2.3	5.72	2.5	5.99	2.2	7.0	2.4	1.2	2.7		
96	32	0.67	1.98		10.09	2.3	6.52	2.5	7.19	2.1	6.9	2.5	2.0	4.9		
97	33	2.64	2.82		14.40	2.3	8.57	2.4	11.21	1.9	6.6	2.8	2.8	7.8		
98	34	0.06	0.98		8.78	2.3	6.96	2.5	7.02	2.1	6.9	2.5	1.0	2.5		
99	35	0.00	2.94		13.41	2.3	7.66	2.4	7.33	2.1	6.9	2.5	2.9	7.5		
100	36	0.00	0.57		6.30	2.3	5.37	2.6	5.08	2.3	7.1	2.3	0.6	1.3		
101	37	1.10	1.35		6.63	2.3	4.58	2.6	5.68	2.2	7.1	2.3	1.4	3.1		
102	38	0.55	0.99		8.78	2.3	6.94	2.5	7.49	2.1	6.9	2.5	1.0	2.5		
103	39	0.14	0.82		6.90	2.3	5.54	2.5	5.68	2.2	7.1	2.3	0.8	1.9		
104	40	1.42	1.49		6.82	2.3	4.57	2.6	5.99	2.2	7.1	2.3	1.5	3.4		
105	41	0.54	1.00		6.06	2.3	4.55	2.6	5.09	2.3	7.2	2.2	1.0	2.2		
106	42	0.61	3.34		10.85	2.3	5.38	2.6	5.99	2.2	7.1	2.3	3.3	7.7		
107	43	0.00	25.91		119.24	2.5	25.93	1.9	21.29	1.7	6.0	3.4	25.9	87.3		
108	44	0.46	2.13		8.00	2.3	4.73	2.6	5.19	2.3	7.2	2.2	2.1	4.7		
109	45	0.00	0.75		8.17	2.3	6.78	2.5	5.99	2.2	7.0	2.4	0.8	1.8		
110	46	0.00	0.56		6.91	2.3	5.95	2.5	5.81	2.2	7.0	2.4	0.6	1.3		
111	47	0.00	0.40		7.49	2.3	6.76	2.5	5.99	2.2	7.0	2.4	0.4	1.0		
112	48	0.00	0.23		7.62	2.3	7.18	2.4	6.29	2.2	6.9	2.5	0.2	0.6		
113	49	0.00	0.00		4.72	2.2	4.72	2.6	3.88	2.4	7.3	2.1	0.0	0.0		
114	50	0.00	0.00		4.95	2.2	4.95	2.6	3.88	2.4	7.2	2.2	0.0	0.0		
115	51	0.00	0.58		3.24	2.2	2.58	2.9	2.52	2.6	7.7	1.7	0.6	1.0		
116	52	4.31	10.28		33.78	2.4	10.37	2.3	14.68	1.8	6.5	2.9	10.3	29.9		
117	53	9.47	15.86		31.87	2.4	5.52	2.6	14.99	1.8	6.8	2.6	15.9	41.9		
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GEOCA Survey 1979. waterNEW.xls Appendix ____ Water Chemical Analysis Data.

	B	AO	AP	AQ	AR	AS	AT	AU
1	Pozos	Column #.	C S	S#				Residual Sodium Carbonate.
2	Well		Class	C #	S#	Conductivity	Sodium Hazard	Effect of [ ] on quality.
3								
95	31	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
96	32	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
97	33	6	32	3	3	HIGH CONDUCTIVITY	HIGH Na	RSC is HIGH => Not suitable for irrigation
98	34	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
99	35	4	22	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
100	36	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
101	37	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
102	38	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
103	39	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
104	40	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	1.25<RSC<2.5. => Marginal Water
105	41	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
106	42	6	32	3	3	HIGH CONDUCTIVITY	HIGH Na	the RSC level is safe for irrigation
107	43	10	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	the RSC level is safe for irrigation
108	44	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
109	45	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
110	46	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
111	47	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
112	48	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
113	49	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
114	50	4	21	2	2	MEDIUM CONDUCTIVITY	MEDIUM Na	the RSC level is safe for irrigation
115	51	2	11	1	1	LOW CONDUCTIVITY	LOW Na	the RSC level is safe for irrigation
116	52	8	44	4	4	VERY HIGH CONDUCTIVITY	VERY HIGH Na	RSC is HIGH => Not suitable for irrigation
117	53	6	34	3	3	HIGH CONDUCTIVITY	HIGH Na	RSC is HIGH => Not suitable for irrigation
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APPENDIX AD.

NOTES FROM IDRISI FOR WINDOWS and ADOBE Photoshop.[0]

The following notes were extracted from the HELP environments of IDRISI For Windows and Adobe Photoshop. They are reproduced here because they show specific research efforts that were made to solve repeated software problems encountered during this research.

There were more problems encountered than the ones discussed here and most of the problems raised in these few pages have been solved by either Software company. IDRISI for Windows has now good macro capabilities, Adobe is now robust in Windows 95 environment etc... The importance of this section is not in the solution of these particular problems but in their nature. The following Software problems are discussed because they illustrate the nature of difficulties encountered in establishing an electronic base map system. Even if these difficulties are not related to the errors that are likely to occur in establishing a base mapping system and in that sense they do not affect the accuracy of the system, they do reflect however, computer problems that are being faced in water management and which can not be neglected.

INCOMPATIBILITIES .

Internal From A Version To Another.

Example: the case of Macro capabilities

In the MS-DOS version of IDRISI, macro capabilities are implemented by means of the MS-DOS batch utility and IDRISI's capability of running modules in a command line mode. Windows, however, has no batch processor.

With peripherical equipment.

Example. Mouse driver vs **The Adobe Photoshop .**

Incompatibilities exist which cause the Adobe Photoshop program and/or mouse to freeze, when the mouse driver being used is other than the "Microsoft, or IBM PS/2" version supplied with Microsoft Windows

Some mouse drivers and their program pointer.exe files are incompatible with the current version of Microsoft Win32s

With the Operating System .

The Win32s Subsystem and COMMDLG.DLL

The Adobe Photoshop Installer installs the latest version of COMMDLG.DLL to your WINDOWS\SYSTEM directory.

AdobeMouseBuffer=No

Setting the "AdobeMouseBuffer" line to "No" causes Adobe Photoshop to disable the use of ADOBEMSE.DRV under Win32s.

Data exchange structure system .

Example: ENVIRON Operation

ENVIRON allows to set an environment differently. Click on the down arrow next to the drive input box for a list of drives. Double click on the drive specified in your directories list to get a listing of all directories in that drive, or on specific directories, to get a listing of sub-directories.

ENVIRON Macro Comand

e.g., " environ x c:\exercise"

PREFERENCES

The Preferences dialog box controls the user-specified settings related to Language, User-defined applications, and the automatic output filename.

Creating Macros

In the MS-DOS version of IDRISI, macro capabilities are implemented by means of the MS-DOS batch utility and IDRISI's capability of running modules in a command line mode. Windows, however, has no batch processor. Therefore IDRISI has created one that is specially designed for the IDRISI for Windows system. With this initial release, IDRISI has chosen to make the macro processor capable of interpreting all MS-DOS batch calls of IDRISI modules and translating them to appropriate calls to the IDRISI for Windows module equivalents.

Creating and Running Macro Files

Macros with Display

The MACRO processor creates displays by creating map compositions and then displaying them with the normal display system. The current version understands the commands "COLOR" (the MS-DOS name for the closest equivalent module) and "DISPLAY" to be synonymous, both using the convention of the MS-DOS command line sequence.

Macro File Structure

The following is an example of a valid coomand line in an IML file:
OVERLAY x 3 soilsuit slopsuit suitland

Similar to the DOS batch language, IDRISI supports command line variables using the familiar %# format. For example, the above line could be modified to look like: OVERLAY x 3 %1 %2 %3

While Windows has a tendency to launch procedures asynchronously, IDRISI has tried to ensure that MACRO executes commands sequentially.

ENVIRON sets/changes the operating environment.

ENVIRON presents a summary of the current operating environment and allows setting it differently. Click on the down arrow next to the drive input box for a list of drives. Double click on the drive specified in your directories list to get a listing of all directories in that drive, or on specific directories, to get a listing of sub-directories.

IDRISI for Windows supports two syntactical forms for the ENVIRON module. The first is adopted from the DOS command line mode and is available here to facilitate support of DOS batch files. Running ENVIRON in this first batch mode requires three parameters:

1 : x (to indicate that batch mode is being used)

2 : option (1 = change drive / 2 = change path)

If option 1 (change drive) is chosen in parameter # 2:

3 : new drive (letter for the new drive, followed by a colon)

If option 2 (change path) is chosen in parameter # 2:

3 : new path (backslash followed by the entire path)

e.g., "environ x 1 c:", or e.g., "environ x 2 \exercise"

The second batch mode uses fewer parameters and is not compatible with DOS batch files. The same two parameters -- drive and path -- can be changed, but this is done through one command only. The following parameters are required:

1 : x (to indicate that batch mode is being used)

2 : new directory (the drive letter, followed by a colon, a backslash, and the path). e.g., " environ x c:\exercise"

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[0] NOTES FROM IDRISIand ADOBE.doc