UNIVERSITY OF CALGARY

Groundwater Flow System and Water Quality in a Coastal Plain Aquifer in Northwestern Nicaragua

By

Valeria Delgado Quezada

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
SCIENCE

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

CALGARY, ALBERTA

JUNE, 2003

UNIVERSITY OF CALGARY

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled “Groundwater Flow System and Water Quality in a Coastal Plain Aquifer in Northwestern Nicaragua” submitted by Valeria Delgado Quezada in partial fulfillment of the requirements for the degree of Master of Science.

Supervisor, Dr. Cathryn Ryan – Dept. of Geology and Geophysics

Internal Examiner, Dr. J.M. Maillol – Dept. of Geology and Geophysics

External Examiner, Dr. M. Reid – Dept. of Biological Sciences

MSc. Dave Bethune – Dept. of Geology and Geophysics

Date

ABSTRACT

The Departments of León and Chinandega in northwestern Nicaragua are agricultural regions that were under cotton cultivation for almost thirty years (1950's-1980's), and more recently mainly under sugarcane. Water supply for the population of almost 700,000 inhabitants comes mainly from groundwater. The principal aquifer in the region is a shallow unconfined alluvial unit underlain by fractured volcanic rocks. Several hydrogeological and chemical studies have identified significant water quality impacts by pesticides and nitrate, but none of the studies have investigated the depth of impact in the aquifer. This information is important in order to ensure new potable water supply wells are drilled deep enough and to ensure the unimpacted deeper aquifer is protected in the long-term. Monitoring wells were installed at five different depths at three locations roughly along the groundwater flow direction. Precipitation, groundwater, and surface water samples were collected during two sampling events. Agrochemical impact in the aquifer was observed at depths of up to 12 m below the water table at all three sites and originates mostly from the historical application of pesticides in the cultivation of cotton. Isotope composition confirmed that in general groundwater at increasing depth in the aquifer is recharged at increasingly higher elevations although some mixing of local and regional flow systems is evident. This has important implications in terms of aquifer protection and management strategies.

ACKNOWLEDGMENTS

This study was supported by the Central American Water Resource Management Network (CARA), which is funded by the Canadian International Development Agency (CIDA). The study is a joint effort by Nicaraguan Aquatic Resources Research Center (CIRA) from the Nicaraguan National Autonomous University and the Geology and Geophysics Department at the University of Calgary.

Special thanks to Dr. Cathy Ryan and David Bethune, who made this project possible with their support, encouragement, and orientation.

Special thanks to Dr. Katherine Vammen and Dr. Salvador Montenegro for all your support, encouragement, orientation, and guidance.

Special thanks to Dr. Jiri Krásný, Dr. Marcelino Losilla, Dr. Adrián Ortega, Lic. Jorge Guatemala, Lic. Karla Sarria, Lic. Marvin Corriols, Eng. Gustavo Salgado, MSc. Marvin Valle, Eng. Armando Ulloa, MSc. Martha Espinoza, Eng. Enoc Castillo, Eng. Francisco Ortega, Eng. Heyddy Calderón, MSc. Víctor Martínez, Eng. Wilber Cuadra, Matthew Nelson, and Jason McCullough.

Thanks to all the personnel from CIRA for all their support and backup during the realization of this thesis. Thanks to all the personnel from Isotope Science Laboratory at the University of Calgary.

Special thanks to United States International Development Agency (USAID), Save the Children León, Ingenio San Antonio –Nicaraguan Sugar Estate Limits, Cooperative El Trianón, Fam. García Soto, Nicaraguan Terrestrial Studies Institute (INETER), Nicaraguan Ministry of Cattle, Forest, and Agriculture (MAGFOR).

To my beloved parents and family, with all my heart for all their love and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

APHA	American Public Health Association
CARA	Central American Water Resource Management Network
CEPIS	Pan American Sanitation Engineering Centre
CIDA	Canadian International Development Agency
CIRA	Nicaraguan Aquatic Resources Research Centre
DIPS	Danish Institute of Plant and Soil Science
ECE	European Community
FAO	Food and Agriculture Organization
IAEA	International Atomic Energy Agency
ICAITI	Central American Research and Industrial Technology Institute
INEC	Nicaraguan Institute of Census and Statistics
INETER	Nicaraguan Institute for Terrestrial Studies
INTA	Nicaraguan Institute of Agriculture-Farming Technology
ISA/NSEL	San Antonio Sugar Mill/Nicaraguan Sugar Estate Limit
MAGFOR	Agriculture, Livestock and Forestry Ministry
MARENA	Agriculture and Natural Resources Ministry
MEL	Marine Environment Laboratory
NAQUA	National Water Quality
OIEA	International Atomic Energy Organization
PAN	Pesticides Action Network
UN	United Nations
UNAN	Nicaraguan National Autonomous University
USAID	United States International Development Agency
US-EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WHO	World Health Organization

1. INTRODUCTION

1.1 Background

Nicaragua is naturally blessed by a humid tropical climate and plentiful water resources, including the region's two largest lakes, numerous mountain-fed rivers and deep aquifers. The most reliable water supply for Nicaragua's nearly 5 million people is groundwater, which provides 80-90% of the potable water supply for Nicaragua (Losilla et al., 2001). Surface waters are either unreliable (due to a distinct 4-month dry season), too far from population centers, or have become contaminated. Recent decades of rapid population growth and associated intensive agricultural, urban, and industrial land-use have already led to water quality degradation of surface waters with increasing contamination emanating from urban, industrial and agricultural land-uses. This has further increased the demand for groundwater supplies. While aquifers are generally less vulnerable than surface waters to pollution, there is increasing evidence of water quality impacts to Nicaraguan aquifers (Bethune et al, 1995; Briemberg, 1995; INETER, 1998; INETER/OIEA, 1997; Lacayo, 1997; Cruz, 1997; CIRA/MEL/DIPS, 1997; Alvarez, 1994; CIRA/IAEA, 1999; CIRA, 1999; Centro Humboldt, 2002; Dahlberg and Odebjer, 2002).

Agriculture is the mainstay of the Nicaraguan economy and the large (approximately 10,000 km^2) agricultural plain of northwestern Nicaragua is by far the largest agricultural area of the country. This area of approximately 687,000 inhabitants is comprised of two political departments: León and Chinandega (populations about 337,000 and 350,000 respectively). The inhabitants are mainly low-income agricultural workers or sustenance farmers. The largest urban centers are the cities of León and Chinandega (populations about 162,000 and 117,000 respectively; INEC, 1995).

This area was mainly under cotton cultivation from the 1950’s to the 1980’s, after which a global decline in demand led to its gradual decline. Other crops such as sugarcane and bananas have emerged, but not on the scale of the former cotton cultivation. Aside from small research stations in Posoltega and in nine private farms, cotton is not currently cultivated in the region. These research stations are part of a recent study to assess the re-introduction of organic cotton culture in the zone in the future pending market forces and other factors (INTA, 2001).

Agrochemicals and their Application in León-Chinandega

The 1950’s also coincides with the introduction of agrochemicals (fertilizers and pesticides) worldwide. Cotton cultivation in León-Chinandega became significantly more productive with the application of organochlorine pesticide compounds such as toxaphene, dieldrin, and DDT.

Organochlorine pesticides are highly persistent in the environment (a.k.a. “persistent organic pollutants”; POP’s) and highly toxic to human and ecosystems. In addition to their slow or negligible rate of natural degradation to less toxic compounds, POP’s have low solubilities and thus tend to persist in the non-aqueous phase and remain attached to soil particles and geologic materials. While concentrations in groundwaters rarely exceed 0.1 mg/L (Barbash and Resek, 1996), the high toxicity of these compounds has led to low drinking water standards (e.g. US-EPA standard for DDT is 0.01 mg/L). This means that shallow aquifers may be easily contaminated above drinking water standards and this contamination can persist for decades or longer. In highly permeable aquifers, dissolved contamination may travel large distances, impact shallow wells, and eventually discharge to surface water (creek, stream, lake, or ocean).

The toxicity of POP's (individually and in combination) is not fully understood but these compounds have been linked to various acute and chronic health problems such as cancer, endocrine system disruption, and learning disabilities (UN/ECE, 1996). The combination of environmental persistence and toxicity led to their near worldwide ban in 1979 (Barbash and Resek, 1996). While their application in Nicaraguan cotton cultivation in the 1980's decreased, there are reports of continued availability and application, through a black market, in the 1980's and 1990's (PAN, 1999).

Although few studies have been conducted in León-Chinandega on the effects of POP's on human health (Rugama et al., 1993; Lacayo, M., 1995; Cruz, A., 1995; Cruz, A. et al., 1997), there is some evidence that higher levels of these compounds are found in the inhabitants of the León-Chinandega region compared to inhabitants of industrialized countries (Lacayo, M., 1995). A comparison of Lacayo's study and studies conducted in other countries (Table 1) show that according to breast feeding time, DDE average concentrations detected in Lacayo's study are higher in Nicaraguan's mothers than the ones reported in Middle East, North American, and European countries [Alawi et al. (1992), Rogan et al. (1986), Larsen et al. (1994) and Bates et al. (1994)]; meanwhile DDT average concentrations were higher than the ones reported from Bates et al. (1994).

León-Chinandega Aquifer and Water Quality Degradation by Agrochemicals

The principal aquifer in the León-Chinandega region is a shallow unconfined alluvial unit underlain by fractured volcanic materials with lower hydraulic conductivity. Although the majority of wells are located in the alluvial aquifer, there are some wells tapping into the volcanic aquifer where the alluvial aquifer is either non-existent or too thin for exploitation. These aquifers provide all of the potable water supply for the region’s inhabitants, as local surface water is either polluted or unreliable. Large quantities of irrigation water are also pumped from the aquifers. Although the alluvium is highly heterogeneous and contains a significant amount of silt and clay size materials, it is shallow, and poorly protected from contamination. In the León-Chinandega region, such contamination principally emanates from agriculture, municipal/domestic sewage and solid waste.

A number of water well surveys indicate pesticides and nitrate have degraded the water quality of the shallow aquifer throughout most of the region (UN, 1974; INETER/OIEA, 1997; CIRA/IAEA, 1999; CIRA, 1999; INETER, 2000; Centro Humboldt, 2002; Dahlberg and Odebjer, 2002). These studies have been primarily based on water well surveys which sampled existing dug and drilled wells. Unfortunately these wells are unreliable sources of information about the state of the aquifer as they are often poorly protected from direct surface water contamination and also draw water from a various different depths in the aquifer. For example, UN (1974) observed that in dug and drilled wells, nitrate concentrations tend to increase during dry season, and decrease during wet season (Table 2). However, in some drilled wells, this tendency is inverted due to the recharge arrival time to groundwater deposit. And CIRA-UNAN (1999) sampled dug and drilled wells in seven communities in the Posoltega area and found all the dug wells were impacted by bacteriological contamination likely resulting from polluted surface water directly entering the wells. Care must be taken in the interpretation of such data as wells may be impacted by dispersed “non-point” source contamination (e.g. regular pesticide and fertilizer application) or from distinct “point-source” contamination (e.g. latrines, local pesticide/fertilizer storage facilities). In León-Chinandega, INETER/OIEA (1997) report that some of their results may have resulted from the proximity of the well to local pesticide storage facilities.

Table 1. Summary results from different studies of organochlorine pesticides in mother's milk.

Source: Lacayo, M., 1995.

Reference	Country	Number of Samples	Time of breast feeding	Pesticides detected	Pesticides Concentrations Detected • g/g)	
					pp-DDE	pp-DDT
Lacayo, M., 1995	Nicaragua	202	4 - 8 weeks	pp-DDE, pp-DDT, -BHC, lindane, dieldrin, endrin, heptachlor, heptachlor epoxide	2.8	0.129
Beretta et al., 1994	Brazil	30	nr	pp-DDE, pp-DDT, -BHC, lindane, dieldrin, heptachlor epoxide	2.53	0.12
Larsen et al., 1994	Italy	64	4 - 8 weeks	pp-DDE, pp-DDT, -BHC	2.10	0.15
Bates et al., 1994	New Zealand	38	8 weeks	pp-DDE, pp-DDT, dieldrin	1.95	0.07
Ustumbas et al., 1994	Turkey	51	nr	pp-DDE, pp-DDT, b-BHC, lindane, dieldrin, heptachlor, heptachlor epoxide	2.389	0.41
Rogan et al., 1986	United States	868	1 day - 1.5 yr	pp-DDE	2.43 – 1.29	n.a.
Furst et al., 1994*	Germany	1405	nr	pp-DDE, pp-DDT, -BHC, lindane, dieldrin	0.893	0.085
Gonzalez, 1970	Guatemala	46	nr	Total DDT, total BHC, heptachlor epoxide	nr	nr

*Furst et al., carried out their study from 1984 to 1991. nr: not reported. n.a.: not analyzed.

Cont. Table 1. Summary results from different studies of organochlorine pesticides in mother's milk.

Source: Lacayo, M., 1995.

Reference	Country	Number of Samples	Time of breast feeding	Pesticides detected	Pesticides Concentrations Detected • g/g)	
					pp-DDE	pp-DDT
Stevens et al., 1993	Australia	128	2 - 6 weeks	p-DDT, dieldrin, heptachlor	n.a.	0.8
Vuori et al., 1977	Finland	49	X= 41.4 days	p-DDT,	n.a.	0.41
Andersen et al., 1981	Denmark	50	4 -113 days	pp-DDE, pp-DDT, -BHC, dieldrin	1.04	0.11
Rugama et al., 1993	Nicaragua	20	Nr	Total DDT, -BHC, lindane, dieldrin, heptachlor, heptachlor epoxide	nr	nr
Spicer et al., 1993	Papua, New Guinea	40	Nr	pp-DDE, pp-DDT, heptachlor epoxide	0.45	0.41
Quinsey et al., 1995	Australia	60	6 weeks	pp-DDE, pp-DDT, -BHC, lindane, dieldrin, endrin, heptachlor epoxide	1.002	0.218
Bouwman et al., 1992	KwaZulu-South Africa	23	Nr	pp-DDE, pp-DDT	8.7	6.74
Bordet et al., 1993	France	20	2 – 90 days	pp-DDE, pp-DDT, -BHC, lindane, dieldrin, endrin, heptachlor epoxide	2.183	0.079

*Furst et al., carried out their study from 1984 to 1991. nr: not reported. n.a.: not analyzed.

Cont. Table 1. Summary results from different studies of organochlorine pesticides in mother's milk.

Source: Lacayo, M., 1995.

Reference	Country	Number of Samples	Time of breast feeding	Pesticides detected	Pesticides Concentrations Detected • g/g)	
					pp-DDE	pp-DDT
Savage et al., 1981	United States	1436	Nr	Dieldrin, heptachlor epoxide	n.a	n.a
Alawi et al., 1992	Jordan	59	1 – 4 weeks	pp-DDE, pp-DDT, -BHC, lindane, dieldrin, endrin, heptachlor, heptachlor epoxide	2.04	0.45
Dillon et al., 1981	Canada	154	3 – 6 days	pp-DDE, pp-DDT, lindane	0.883	0.204
Johansen et al., 1994	Norway	28	3 – 5 days	Total DDT, total BHC	n.a	n.a
Krauthacker et al., 1980	Yugoslavia	71	3 – 5 days	pp-DDE, pp-DDT	1.55	0.55
Jonsson et al., 1977	United States	51	7 – 56 days	pp-DDE, pp-DDT, total BHC, dieldrin, heptachlor, heptachlor epoxide	0.035	0.008
Hernández et al., 1993	Spain	51	0 – 20 days	pp-DDE, pp-DDT, total BHC, lindane, dieldrin, heptachlor, heptachlor epoxide	0.604	0.012

*Furst et al., carried out their study from 1984 to 1991.

nr: not reported.

n.a.: not analyzed.

Table 2. Extreme and Average Nitrate Concentrations (mg NO_3^- - N/L) in Waters from the Study Area (UN, 1974).

	Groundwater					
	Dug Wells			Drilled Wells		
	Min	Max	Average	Min	Max	Average
Nitrate	0.9	21.7	6.3	< 0.1	9.9	2.7

The water well surveys do, however, provide a general indication of the health of the aquifer and of what the inhabitants are drinking and, if carefully interpreted, they can prove insightful. The most comprehensive study to date was conducted by Briemberg (1995) who conducted a water quality survey of most of the major rural and peri-urban municipalities of western and central Nicaragua and found significantly higher frequency of pesticide detections in the León-Chinandega region compared to the other areas in the country (Table 3). The study sampled 147 wells in the León-Chinandega region and found that 37% had detections of 10 different organochlorine pesticides and one organophosphate pesticide. The most frequently detected compound was dieldrin.

Other studies involved a smaller number of wells but nonetheless consistently detected several organochlorine pesticides and slightly elevated nitrate levels. INETER/OIEA (1997) found organochlorine (-BHC, -BHC, lindane, heptachlor, heptachlor-epoxide, dieldrin, endrin, pp-DDE, pp-DDD, pp-DDT, and toxaphene) pesticides in 50%, and organophosphate (diazinon, methyl-parathion, malathion, fenthion, zolone, and co-ral) pesticides in 22%, of the 50 sampled sites (14 dug wells, 34 drilled wells –including piezometers, and 2 rivers). Nitrate concentrations varied from 0.05 mg-N/L to 7.75 mg-N/L in 20 sampled wells; and the WHO and EPA’s drinking water guidelines value for nitrate (10 mg/L as N) was not exceeded, even though some of the results were close to this value. Seventy five percent of the wells had nitrate concentrations above the estimated background concentration in groundwater of 2 mg-N/L (Mueller and Helsel, 1996). This study (INETER/OIEA, 1997) included the installation of three shallow piezometers in each of three locations extending from the water table to depths from 2.5 to 10 meters. Each installation was sampled two times, with the detection of a number of organochlorine (-BHC, lindane, heptachlor, dieldrin, aldrin, endrin, pp-DDE, pp-DDD, pp-DDT, and toxaphene) and organophosphate (terbufos, diazinon, ethyl-parathion, malathion, fenthion, ethion, guthion, zolone, and co-ral) pesticides. None of the piezometer points sampled was free from pesticides. Nitrate concentrations in the piezometers ranged from 3.0 mg-N/L to 49.0 mg-N/L (14 mg-N/L as average concentration and 13.5 standard deviation in 16 samples), with 50% of the samples exceeding the 10 mg NO_3-N/L guideline established by the EPA and WHO. Groundwater quality degradation by pesticides was particularly severe in León and Chinandega.

Two sampling campaigns were conducted in the Atoya River watershed in Chinandega Department (31 and 32 water samples, respectively). During the first sampling, pp-DDE, pp-DDD, pp-DDT, toxaphene, aldrin, endrin, dieldrin, and lindane were detected, and pp-DDE, pp-DDD, pp-DDT, toxaphene, aldrin, endrin, dieldrin, lindane, and hepthachlor were detected in the second campaign. Organophosphate pesticides (naled, malathion, methyl-parathion, ethyl-parathion, ethion, and zolone) were detected in 32 water samples (12 surface water samples, and 20 wells). Of 28 river sediments sampled, pp-DDT (39.3%), pp-DDD (32.1%), pp-DDE (85.7%), and toxaphene (35.7%) were detected; meanwhile aldrin, endrin, dieldrin, lindane, alpha-endosulphan and beta-endosulphan were detected in less frequency (Alvarez, 1994).

Table 3. Number of wells with detections* of organochlorine pesticides in Nicaraguan water wells. Percentage is shown in brackets (from Briemberg, 1995).

Compound	León	Chinandega	Estelí	Masaya	Granada	Diriamba
-BHC	8 [13.6]	3 [3.3]	0	0	0	0
-BHC	0	3 [3.3]	4	0	0	0
Lindane	13 [22]	16 [17.4]	3 [5.9]	0	0	0
-BHC	3 [5.1]	2 [2.2]	0	0	0	0
Heptachlor	7 [11.9]	2 [2.2]	1 [1.9]	0	0	0
Aldrin	21 [35.6]	23 [25]	0	6 [35.3]	0	6 [33.3]
Heptachlor-epoxide	12 [20.3]	7 [7.6]	0	0	0	0
alpha-endosulphan	7 [11.9]	4 [4.3]	0	0	0	0
Dieldrin	34 [57.6]	21 [22.8]	0	5 [29.4]	0	5 [27.8]
pp-DDE	21 [35.6]	11 [12]	3 [5.9]	0	0	1 [5.6]
Endrin	18 [30.5]	14 [15.2]	1 [1.9]	0	0	0
Beta-endosulphan	3 [5.1]	3 [3.3]	1 [1.9]	0	0	0
pp-DDD	8 [13.6]	6 [6.5]	1 [1.9]	0	0	1 [5.6]
pp-DDT	16 [27.1]	10 [10.9]	1 [1.9]	0	0	0
Toxaphene	13 [22]	27 [29.3]	2 [3.9]	0	0	0
# of samples analyzed	**59**	**92**	**51**	**17**	**9**	**18**

* “Detection” is defined as above the particular method detection limit for each compound.

Thirty samples from Posoltega region (22 dug wells, 5 drilled wells, 2 rivers and one spring) had nitrate levels ranging from 0.6 mg-N/L to 15.1 mg-N/L (average concentration of 7 mg-N/L with a standard deviation of 3.23 in 30 samples), where ninety three percent of wells sampled exceeded 5.65 mg-NO_3/L (1.27 mg-N/L) which were considered by the authors to indicate anthropogenic sources (Centro Humboldt, 2002). In addition, organochlorine -dieldrin, endrin, -BHC, pp-DDE, pp-DDD, pp-DDT, and toxaphene- and organophosphates -fenthion, ethyl-parathion, ethion, and clorfenvifos- pesticides in 3 and 2 dug wells, respectively, were detected.

In the area of León-Chinandega, nitrate concentrations from 0.27 mg-N/L to 1.24 mg-N/L (average of 0.70 mg-N/L) were detected in samples collected from 9 drilled wells; meanwhile nitrate concentrations on samples from 14 dug wells ranged from 0.09 mg-N/L to 3.59 mg-N/L (average of 1.61 mg-N/L). Pesticides analyses were conducted on samples from 6 drilled wells, 8 dug wells, and 4 springs. Organochlorine pesticides (dieldrin, pp-DDE, pp-DDD, pp-DDT, endrin, toxaphene, -BHC, and lindane) were detected in 57.1% of the samples and no organophosphate pesticides were detected (Dahlberg and Odebjer, 2002).

A summary of wells with organochlorine and organophosphates pesticides, and nitrate detections in Nicaraguan waters from León-Chinandega, as well as a comparison of the above studies to large-scale water well surveys in the United States (Table 4) shows that, in general, the frequency of detection and percent above EPA drinking water standards is significantly greater in León-Chinandega compared to the United States EPA’s National Pesticide Survey and on-going programs, the USGS’s National Water Quality Assessment (NAQUA, 1997), and various ongoing studies conducted in Canada (Agriculture Canada, 1992; Miller et al., 1994; Lampman, 1995; Briggins and Moerman, 1995). Pesticide concentrations in most of these studies, although fairly frequently found, are low (well below the drinking water limit), and spatially and temporally variable (Barbash and Resek, 1996). Thus, the water quality degradation in León-Chinandega aquifer is relatively severe.

Two wells, Picacho I and Picacho II, located in close proximity to Picacho airstrip in Chinandega, were closed in May 1992 and in April 1993, respectively because of high pesticides levels detected. This airstrip was used for aerial spraying, storage and formulation of pesticides mixed during cotton cultivation, and currently it is still being used as an aerial spraying (in minor scale) and as an airport. A visual site inspection, revealed evidence of heavy pesticide spills in its area. In Chichigalpa, in early 1993, a well located in Barrio Erick Ramírez was closed. This well has been subsequently decommissioned, as well as the well located in Pan Brand, in Chinandega.

The relatively severe groundwater impacts in the León-Chinandega aquifer are the result of a number of factors. Geologically, the aquifer is highly vulnerable to contamination because of its shallow depth and high permeability. In addition, tropical cultivation is typically continuous (as opposed to temperate regions where cultivation occurs only in summer) with commensurate increases in rates of agrochemical application. Further, pests proliferate in monocultural crops and warm temperatures. Application of particularly high rates of pesticides are permitted in cotton-growing regions since cotton is not a food crop and pesticide residue regulations do not apply.

Table 4. Summary of surveys of detections* of organochlorine and organophosphate pesticides, and nitrates above drinking water quality guidelines in Nicaraguan water wells from previous studies in León and Chinandega and the United States. Percentage is shown in brackets. Standard deviation is shown in parentheses.

Study	N	Number of Wells with Pesticides Detections	% above EPA Pesticides drinking water standard	n	Average NO_3-N Concentration (mg/L) in Wells	Number of Wells with NO_3-N (mg/L)**	Number of Wells with NO_3-N (mg/L)***
Alvarez, 1994	63	37 [58.7]	100	n.a.	n.a.	n.a.	n.a.
Briemberg, 1995	60^1	27^1 [45]^1	33.3	n.a.	n.a.	n.a.	n.a..
INETER/OIEA, 1997	23	23 [100]	100	37	8.4 (11.0)	9 [24.3]	31 [83.8]
CIRA/IAEA, 1999	70	41 [58.6]	51.4	36	7.5 (9.6)	10 [27.8]	27 [75.0]
CIRA, 1999	17	13 [76.5]	70.6	17	8.1 (3.4)	7 [41.2]	17 [100]
Centro Humboldt, 2002	9	7 [77.8]	77.8	27	7.0 (3.2)	6 [22.2]	26 [96.3]
Dahlberg and Odebjer, 2002	23	14 [60.9]	60.9	23	5.5 (4.1)	2 [8.7]	18 [78.3]
United States							
California (Mackay and Smith, 1990)	>11,000	18	n/a	n/a	n/a	n/a	n/a
National Pesticide Survey (EPA, 1990)	1300	4.2^2/10.4^3	0.6	n/a	n/a	n/a	n/a

N: total number of wells sampled for pesticides

n: total number of wells sampled for nitrates

n.a.: not analyzed, ^{1} including samples collected at the distribution system, ^{2} domestic wells, ^{3} community wells

n/a = information not available

* “Detection” is defined as above the particular method detection limit for each compound.

**Above EPA/WHO water guidelines (10 mg/L as N).

***Above background concentration in groundwater, 2 mg-N/L (Mueller and Helsel, 1996).

1.2. Thesis Rationale and Objectives

Clear evidence of water quality impacts by agricultural pesticides and nitrate is indicated by previous well water studies in the León-Chinandega aquifer. To date groundwater quality investigations have consisted almost entirely of well water surveys, which are inherently unreliable as indicators of the actual degree of contamination of the aquifer. It is not yet understood whether the widespread groundwater quality degradation is due to standard agricultural practices, or results from poor well construction and protection, or poor well location (i.e. down gradient from nearby “point-sources” such latrines, solid waste and, agri-chemical storage/transfer areas). Some of the contaminated wells surveyed appear to be impacted by nearby pesticide storage and transfer areas, however, the impacts to the vast majority of wells cannot be explained by point sources suggesting a predominantly “non-point” or regional source of contamination resulting from the routine agricultural application. There is also little understanding of how deeply the aquifer has been impacted, the mechanisms of contaminant attenuation, and the time required for natural remediation. If contamination is limited to the shallow water table, un-impacted drinking water supplies may be successfully developed in the deeper aquifer.

Such understanding is necessary to produce a viable aquifer management plan for the region and will meet the dual needs of: a) protecting the aquifer for potable water supply and ecosystem health and b) maintaining agriculture as a primary economic activity in the region.

The overall goal of this thesis is to better understand the hydrogeology and agrochemical water quality degradation of the León-Chinandega aquifer and propose a management and protection strategy based on this understanding. This is accomplished through the following objectives:

1. Conduct a thorough review of the hydrogeology of the region and improve the understanding through a drilling and sampling program.
2. Install piezometers at various depths below the water table to measure hydraulic gradients and chemical concentrations (natural species and contaminants). Measure the types and depth of contamination in the aquifer.
3. Describe the types of contaminants and their concentrations in the aquifer.
4. Propose strategies for the management and protection of the aquifer based on natural aquifer vulnerability to contamination, actual contamination, and multiple aquifer usage.

This thesis, while clearly relevant to Nicaragua, is also of scientific interest. Most of the ongoing and past pesticides-in-groundwater investigations in North America and Europe (e.g. the EPA's National Pesticide Survey and on-going programs, the USGS's National Water Quality Assessment (NAQUA, 1997) and similar studies conducted in Canada (Agriculture Canada, 1992; Miller et al., 1994; Lampman, 1995; Briggins and Moerman, 1995) have been conducted in temperate climates. There have been few studies of this nature conducted in tropical climates with the associated crops and extended growing seasons.

The present thesis was designed to compliment the theses of two other students, Wilber Cuadra (MSc. Student, CIRA-UNAN) and Heyddy Calderon (MSc. Student, University of Calgary), whose theses were conducted in the same time period (2000-2003). Mr. Cuadra's thesis focused on measuring pesticide levels in the soil zone and Ms. Calderon's thesis involves numeric modeling of the aquifer to assess the impacts of various water supply and irrigation pumping scenarios.

2. STUDY AREA DESCRIPTION

2.1. Introduction

The study area lies within a large agricultural plain comprised of the Departments of León and Chinandega (Figure 1), which include 23 municipalities (PROTIERRA/MARENA, 1997). The two Departments have a total area of 10,279 km^2, and a combined population of 687,206 (INEC, 1995; Tables 5 and 6).

Table 5. Demographic Data for Department of León

LEÓN	Surface (km²)	Altitude (m.a.s.l.)	Population
Department	5,457.0	0 - 1,400	336,894
City of León	820.2	109	161,530
Quezalguaque	85.7	90	7,754
Telica	393.7	119	22,779
Larreynaga	1,099.2	115	29,798
El Sauce	693.0	163	25,973
Achuapa	416.2	331	13,186
Santa Rosa del Peñón	227.6	180	9,129
El Jicaral	431.5	116	10,036
La Paz Centro	691.6	67	27,509
Nagarote	598.4	76	14,609

Source**:** INEC, 1995.

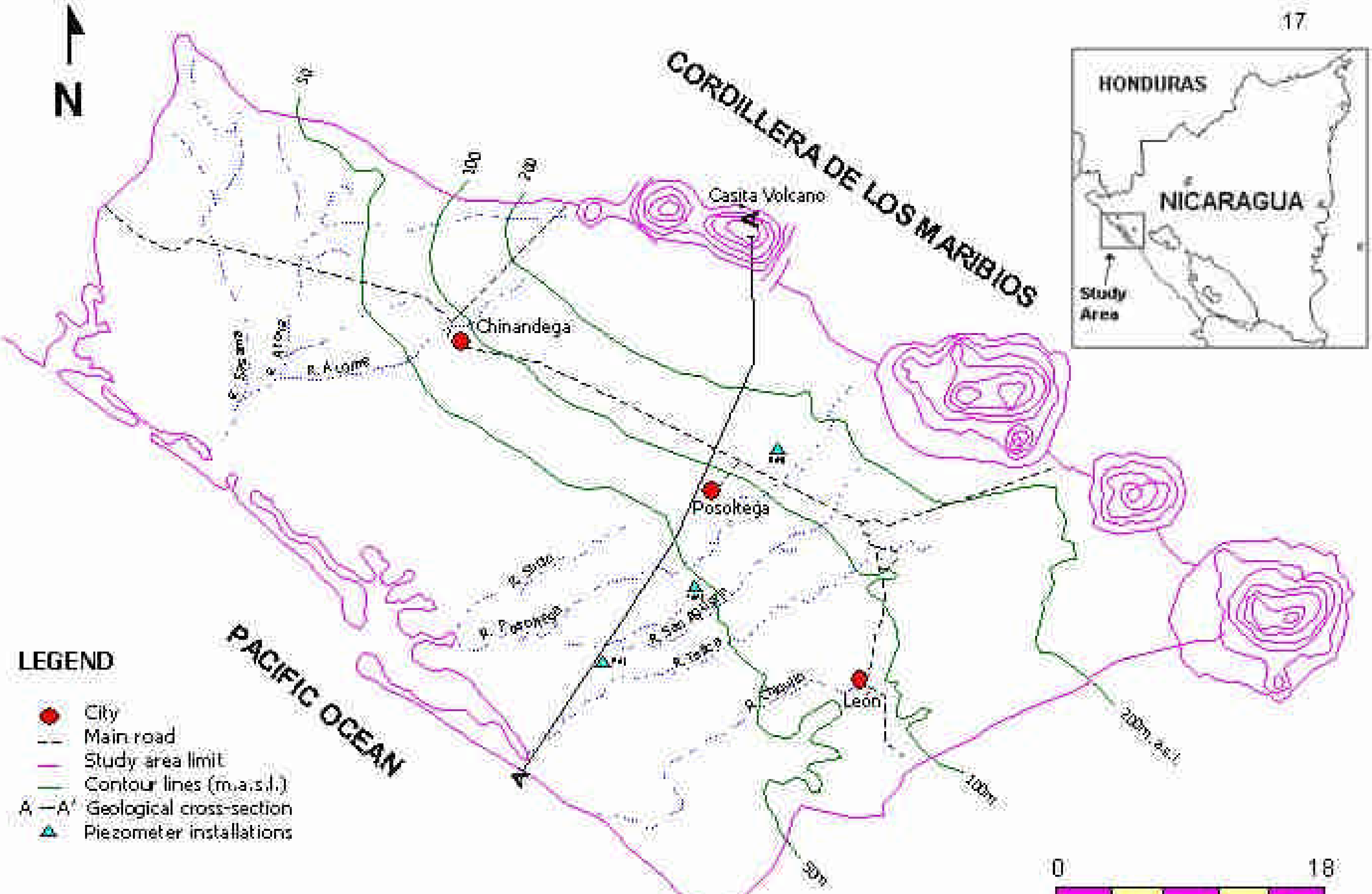


Figure 1. Study Area.

Table 6. Demographic Data for Department of Chinandega

CHINANDEGA	Surface (km^2)	Altitude (m.a.s.l.)	Population
Department	4,822	0 - 1,745	350,212
City of Chinandega	686	70	117,037
El Viejo	1,275	43	69,055
Chichigalpa	223	85	41,903
Posoltega	149	71	15,331
El Realejo	105	12	8,154
Corinto	71	3	17,177
Puerto Morazán	517	30	11,411
Somotillo	725	41	24,767
Villanueva	780	60	22,341
Cinco Pinos	60	400	6,220
Santo Tomás del Norte	40	180	6,788
San Pedro del Norte	72	500	4,048
San Francisco del Norte	120	396	5,980

Source: INEC, 1995.

2.1.1 Regional Economic Activities, Employment, and Income

The major economic activity is cultivation of export crops, including sugarcane, banana, peanut, and sesame seed cultures. Fruits, coffee, basic grains (rice, beans, and wheat), and improved and natural grasses for cattle feed are also cultivated. Minor economic activities also include mining, fishery, tourist and commerce industries (PROTIERRA/MARENA, 1997). A general economic downturn, combined with less labor-intensive cultivation, has led to high rates of unemployment in the region (66.2% for Leon and 67.5% for Chinandega; INEC, 1995). In 1999, the average per capita income for the Leon-Chinandega region was only US$460, and the gross domestic product was $2,268 million dollars (INEC, 1995).

2.1.2 Physiography

Geologically the study area consists of marine deposits, which were uplifted. Sand, lava and ash from volcanic eruptions from the peninsula of Cosigüina Volcano and Tamarindo Plateus were subsequently deposited on top of the uplifted marine deposits (PROTIERRA/MARENA, 1997).

The León-Chinandega region is characterized by a large plain extending from the Los Maribios volcanic chain to the Pacific Ocean. The only relief on the plain is small hills comprised of older underlying volcanic rocks. Some rivers in the region: Chiquito, Telica, Posoltega, San Agustín, Sucio, Acome, Atoya, and Sasama, among others (Figure 1).

2.1.3 Climate

Weather

A tropical savanna climate predominates in the whole Pacific region of Nicaragua (based on Köppen classification, 1936). The climate is characterized by distinct wet (June-November) and dry (December-May) seasons. There is typically a one-month break in the rainy season from mid-July to mid-August known as the “*Canícula*” (literally meaning “dog days”). During the dry season, weather systems originate from the east and thus have traveled over a considerable landmass leading to very dry conditions. During the wet season, moist winds blow mostly from the Pacific Ocean providing almost daily (afternoon) rainstorms (PROTIERRA/MARENA, 1997). During September and

October, larger tropical storms and hurricanes may emanate from the Atlantic Ocean leading to high amounts of precipitation often over several days.

Precipitation

Average annual precipitation varies from 1400 mm to 1800 mm (Figure 2). Average years monthly precipitation values recorded at El Polvón rain gauge station property of San Antonio Sugar mill and distillery (ISA/NSEL, Field Division, 1990-2002) are included in Table 7.

Temperature

The mean annual temperature varies from 27 °C to 29.5 °C with slight variation related to the monthly average measurements that do not exceed 3.5 °C of the annual average. Maximum absolute values recorded on the low zones of the Pacific region record temperatures between 35 °C and 40 °C (PROTIERRA/MARENA, 1997; Fenzl, 1989).

2.1.4 Soils

Soils in the study area are very fertile, mainly loamy, loamy-clayey, or loamy-sandy which make them highly suitable for agriculture (MAGFOR 1996-1997; Figure 3). The soils are derived from ancient and recent volcanic ashes, volcanic rocks, alluvial and lake sediments. In the coastal zone, the soils are poorly drained with abundant swamps, mud holes, and marshes. About 68,000 hectares (42.9%) are suitable for irrigation and 23,600 hectares (14.9%) are not suitable for irrigation in 1974 (UN, 1974).

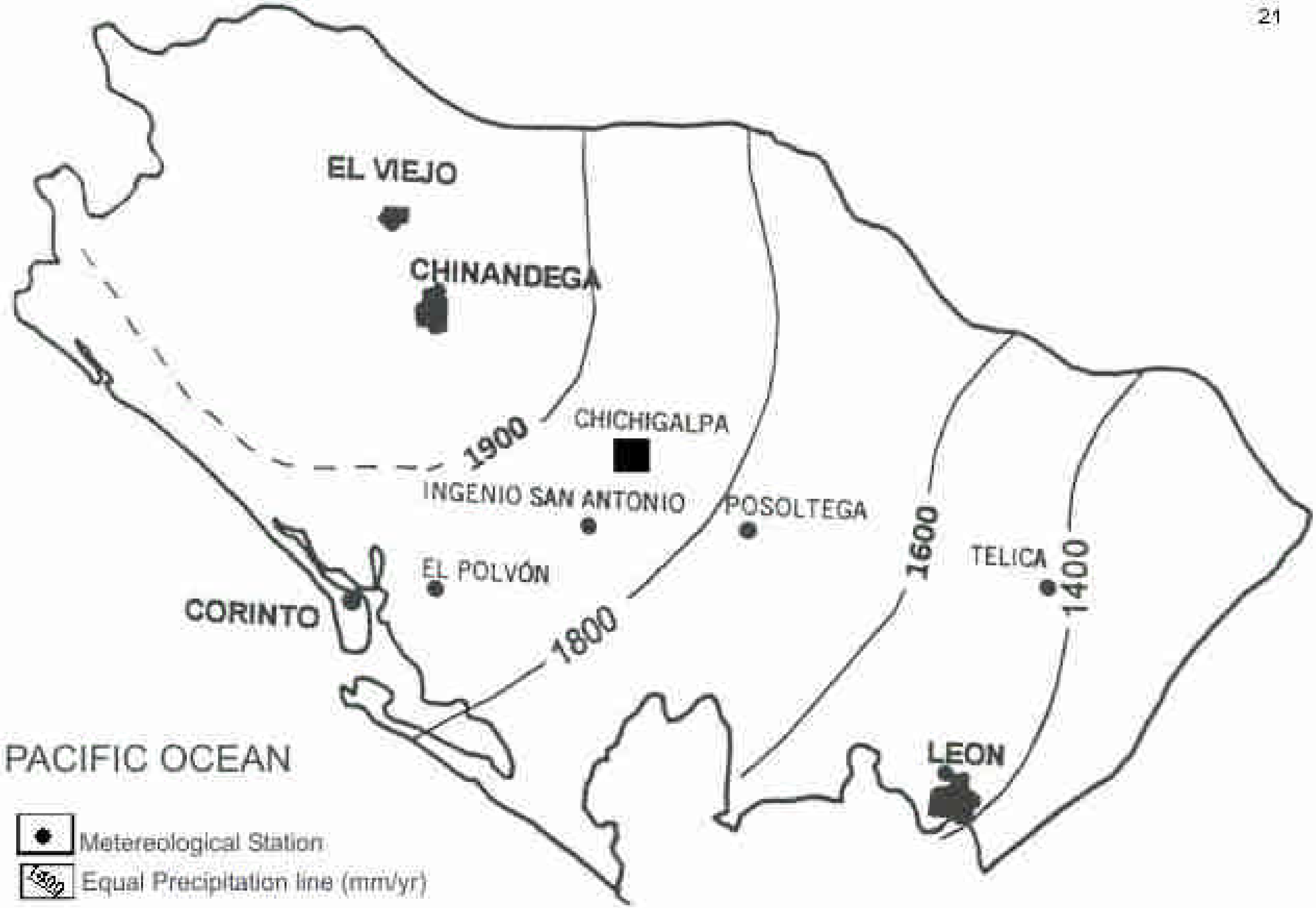


Figure 2. Average Annual Precipitation Distribution in the Study Area. From CIRA/AEA, 1999.

Table 7. Precipitation Values (mm) at El Polvón

Year	Jan	Feb	March	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
1990	0.0	0.0	0.0	3.2	6.4	6.7	5.8	7.2	15.5	14.8	6.0	0.3	**65.8**
1991	0.0	0.0	0.0	0.3	9.5	10.2	3.3	9.0	9.5	8.9	0.9	0.1	**51.6**
1992	0.0	0.6	0.0	0.0	4.6	7.7	5.1	9.0	21.0	1.3	1.5	0.3	**51.2**
1993	0.1	0.0	0.0	0.9	19.7	11.9	2.8	10.4	29.8	6.8	1.5	0.0	**83.9**
1994	0.0	0.0	0.0	2.1	6.5	2.8	2.2	8.5	14.6	7.5	9.2	0.0	**53.4**
1995	0.0	0.0	1.9	1.1	5.2	10.5	12.6	17.6	18.3	23.5	1.2	1.3	**93.1**
1996	1.0	0.0	0.0	0.3	9.7	11.9	18.6	8.5	15.7	18.6	16.2	0.0	**100.5**
1997	0.0	0.0	0.0	0.1	1.4	17.2	3.4	1.1	8.0	6.7	3.0	0.0	**41.0**
1998	0.0	0.0	0.1	0.7	2.0	4.8	7.5	10.3	17.9	81.6	6.7	0.4	**131.9**
1999	0.0	0.0	0.0	0.4	5.8	8.1	6.3	10.0	47.9	12.4	4.6	0.1	**95.7**
2000	0.0	0.0	0.0	0.2	4.6	7.3	5.8	5.2	32.4	13.1	2.8	0.3	**71.7**
2001	0.0	0.0	0.4	0.0	14.3	2.7	6.0	8.7	20.3	8.4	2.6	1.8	**65.1**
2002	0.0	0.0	0.0	0.0	19.2	14.6	3.3	7.0					

Source: ISA/NSEL, Field Division, 1990-2002.

2.1.5 Land Use

Historic Land-Use

In 1968-1969, 62.6% of 158,390 hectares in the study area were cultivated mainly with cotton and sugarcane (Table 8), representing about half of the national cotton and sugarcane production. This illustrates the economic importance of this zone. In the study area 46,922 hectares were grass, bushes, and forests, and 12,302 hectares are swamps, shores, and estuaries close to the coast and with low agricultural value (UN, 1974).

In 1995-1996, 8,173 hectares were cultivated with cotton (Table 9; PROTIERRA/MARENA, 1997).

Current Land Use

In 1997, most of the region's land area was cultivated. In order of percentage of land area the major crops were: sugarcane, banana, cotton, peanut, rice, and sesame seed. In the northwestern mountainous soils, coffee and large quantities of basic grains are grown, as well as other annual cultures. In some instances accelerated soil degradation occurs due to cultivation on very steep slopes and deforestation (PROTIERRA/MARENA, 1997).

Currently crops in the western zone of the Department of León include basic grains (beans, rice, and wheat), sesame seed, sorghum, and fruits. The main crops in the Department of Chinandega include banana, coffee, and sugarcane. Other economic activities in this region are livestock, industry, commerce and services, shrimp ponds (INEC, 1995), and rum production at San Antonio Sugar Mill and Distillery, Nicaraguan Sugar Estate Limit (ISA/NSEL).

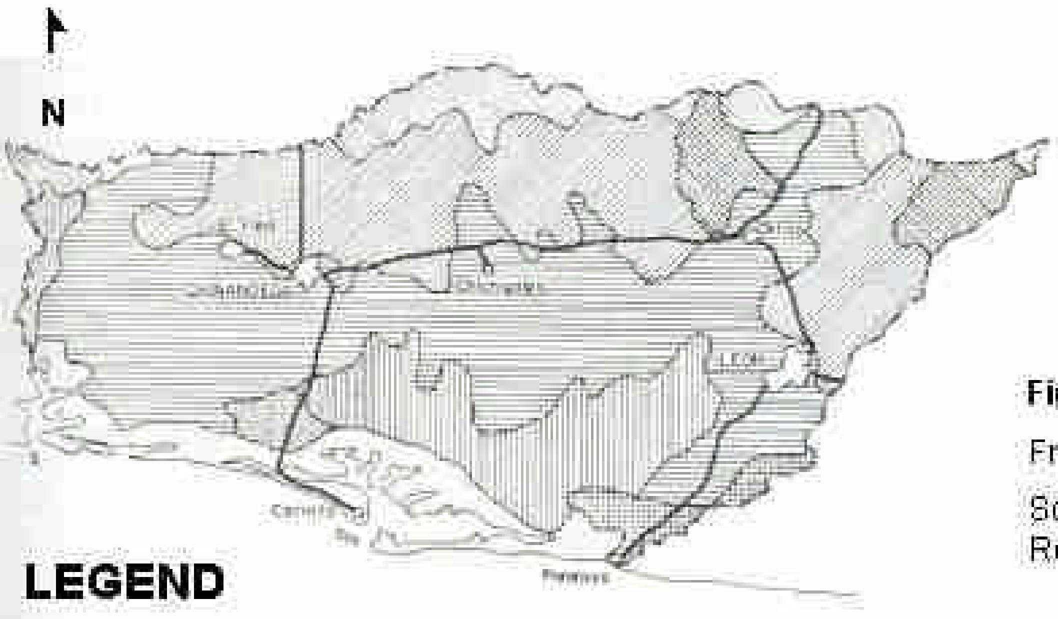


Figure 3. Types of Soil in the Study Area.

From: UN, 1974.

Source: Cadestre and Inventory of Natural Resources.

LEGEND

▤	Loam, deep, well drained. Slope from 0 – 15%
▨	Sandy-loam, deep, well drained. Slope from 0 – 15%
▥	Loam, deep, well drained. Associated to soils from poor to excessive drainage. Slope from 0 – 15%
▩	Loam-clayey, well drained, associated to vertisols, sandy soils, and miscellaneous terrains with grass and forests potential. Slope from 0 – 15%
░	Well-drained. Associated to vertisols and broken miscellaneous terrains with grass and forests potential. Slope from 1.5 – 30%
☐	Vertisols. Bad drainage. Associated to agriculture potential soils. Slope from 0 – 4%
▦	Vertisols-Miscellaneous. Bad drainage. Slopes from 0 – 30%, and even more
▧	Broken miscellaneous terrains. Soils in high elevation terrains with diverse textures and depths. Slope from 4 – 75% and more
☐	Marshes and mangles

Table 8. Land Use in the Study Area 1968-1969

	Surface (ha)				
	Irrigated	**Percentage**	**Unirrigated**	**Percentage**	**Total**
Cultivated Zone					
Sugarcane	8,310	54	7,003	46	15,313
Cotton	-	-	54,055	100	54,055
Banana	2,206	80	534	20	2,740
Grain	163 [a]	1	17,114	99	17,277
Improved pastures	1,058	11	8,283	89	9,341
Coffee	-	-	372	100	372
Fruits	-	-	59	100	59
Vegetables	-	-	1	100	1
Total	11,737	12	87,421	88	**99,158**
Non-Cultivated Zone					
Grass, under bushes, weed					23,250
Non-agricultural (villages, rocky zones, industries, lava flows)					3,612
Forests					20,060
Total					**46,922**
Marshes, sandy shores, and flood zones					
Marshes					7,280
Sandy shores					584
Swamps					616
Estuaries					3,822
Total					**12,302**

Source: United Nations, 1974

a: Rice cultured under irrigation

Potential Land-Use Classification

Potential land-use is a classification based on what the land is suitable for, considering a combination of climate, soils, topography, etc. This classification establishes the percentage of soils that are being used in accordance to their maximum development.

The study area is constituted by soils suitable for cattle grazing, cattle, and forest purposes, comprising 81% of the area of the region, where the remaining 19% of the region can not be economically used. Twenty-six percent of the soils are suitable for grazing. The most limited soils occur in the Pacific plain (Figure 4, MAGFOR, 1995; Table 10; PROTIERRA/MARENA, 1997).

Table 9. Cultivated Area per Municipality (in hectares), 1995-1996.

Municipality	Cotton	Sugarcane	Banana	Sesame Seed	Peanut	Soy	Corn	Sorghum (Industrial)	Rice
Telica	1,226.2	-	-	2,021.2	314.5	917.7	1,461.0	533.6	8.7
La Paz Centro	279.6	524.2	-	4,780.5	55.9	968.0	1,372.6	838.7	-
León	1,790.6	69.9	-	6,986.5	499.7	2,473.7	2,309.9	984.0	190.1
Larreynaga	551.1	-	-	4,874.8	14.0	605.2	940.7	489.2	167.7
Nagarote	-	-	-	615.0	-	-	985.4	954.0	-
El Jicaral	-	-	-	334.1	-	-	742.9	274.3	5,592.2
Santa Rosa del Peñón	-	-	-	32.2	-	-	630.4	34.9	-
El Sauce	-	-	-	1,453.7	-	-	1,020.4	139.8	-
Achuapa	-	-	-	454.3	-	-	506.7	48.9	-
Quezalguaque	1,185.3	384.4	-	540.9	88.1	1,293.0	1,296.5	-	31.4
Chinandega	2,295.2	3,564.4	-	3,672.0	4,714.1	3,639.9	549.3	267.0	1,701.8
Chichigalpa	-	1,949.6	-	1,016.2	-	838.7	308.9	65.7	1,796.2
El Realejo	-	-	448.7	-	1,876.5	-	-	-	-
El Viejo	482.2	7,475.4	1,397.8	3,106.6	-	1,097.3	660.5	230.6	917.7
Villanueva	-	-	-	2,158.2	-	-	3,633.6	271.2	74.1
Somotillo	-	-	-	1,654.3	-	178.2	3,449.8	260.7	-
San Francisco	-	-	-	131.4	-	-	355.7	-	-
Santo Tomás	-	-	-	97.8	-	-	821.2	-	-
Cinco Pinos	-	-	-	51.0	-	-	577.3	41.9	-
San Pedro	-	-	-	1.4	-	-	826.1	-	-
Puerto Morazán	209.7	-	-	-	-	-	-	-	-
Posoltega	153.4	803.7	-	422.1	1,346.1	851.9	854.8	55.9	454.3
Corinto	-	-	-	-	-	-	-	-	-
Total	**8,173.3**	**14,789.6**	**1,846.5**	**34,404.2**	**8,908.9**	**12,863.6**	**23,303.7**	**5,490.4**	**10,934.2**

Source: (PROTIERRA/MARENA, 1997).

Cont. Table 9. Cultivated Area per Municipality (in hectares), 1995-1996

Municipality	Bean	Coffee	Sorghum	Melon	Yucca	Watermelon	Mango	Cultivated Area
Telica	680.7	83.9	-	-	-	-	-	7,247.5
La Paz Centro	-	-	349.5	-	-	-	-	9,169.0
León	62.9	-	63.1	-	638.4	-	-	16,068.8
Larreynaga	520.7	-	16.8	-	-	-	-	8,180.2
Nagarote	-	-	449.4	90.9	-	-	-	3,094.7
El Jicaral	256.8	-	349.5	214.8	-	-	349.5	8,114.1
Santa Rosa del Peñón	517.2	-	328.5	-	-	-	-	1,543.2
El Sauce	572.4	-	153.8	-	-	-	-	3,340.1
Achuapa	405.4	-	90.9	-	-	-	-	1,506.2
Quezalguaque	94.4	-	-	-	-	-	-	4,914.0
Chinandega	195.7	-	-	-	-	-	-	20,599.4
Chichigalpa	123.7	37.0	-	-	-	-	-	6,136.0
El Realejo	-	-	-	-	-	-	-	2,325.2
El Viejo	-	-	-	-	-	-	-	15,368.1
Villanueva	468.3	-	349.5	-	-	-	-	6,954.9
Somotillo	237.6	-	244.6	-	-	104.8	-	6,130.0
San Francisco	265.6	14.0	209.7	-	-	-	-	976.4
Santo Tomás	-	-	419.3	-	-	-	-	1,338.3
Cinco Pinos	153.8	21.0	209.7	-	-	-	-	1,054.7
San Pedro	459.2	10.5	279.6	-	-	-	-	1,576.8
Puerto Morazán	-	-	-	-	-	-	-	209.7
Posoltega	213.9	513.7	-	-	-	-	-	5,669.8
Corinto	-	-	-	-	-	-	-	-
Total	**5,228.3**	**680.1**	**3,513.9**	**305.7**	**638.4**	**104.8**	**349.5**	**131,517.1**

Source: (PROTIERRA/MARENA, 1997).

Table 10. Potential Land Use (ha), 1997

Category	Total	% (1)	Chinandega	% (2)	León	% (2)
Forests	252,981	36.9	96,377	38.1	156,604	61.9
Cattle grazing	176,602	25.7	95,412	54.0	81,190	46.0
Cattle	124,413	18.1	55,879	50.0	68,534	50.1
Preservation	73,687	10.7	61,656	84.0	12,031	16.3
Agro forestry	39,758	5.8	19,958	50.2	19,800	49.8
Silvopastoril	5,857	0.9	1,770	30.2	4,087	69.8
Other purposes	13,016	1.9	4,876	37.5	8,140	62.5
Total	**686,314**	**100**	**335,928**	**49.0**	**350,386**	**51.0**

Source: PROTIERRA/MARENA (1997)

(1) Percentage based in the total region.

(2) Percentage based in the total of the potential purpose category.

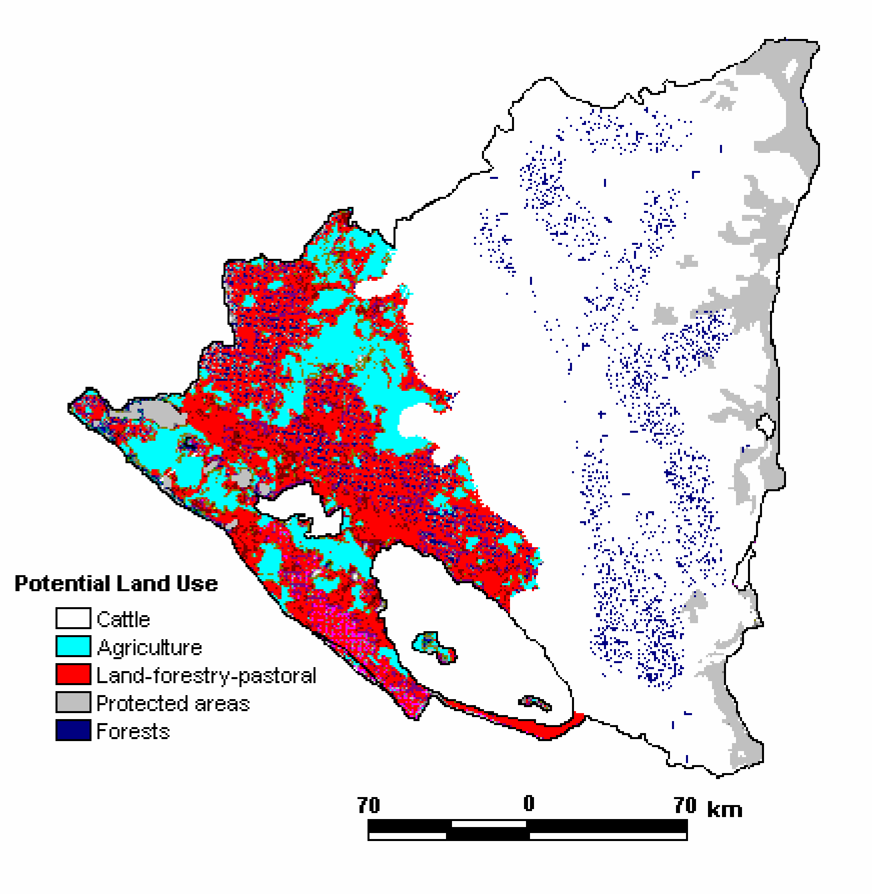


Figure 4. Map of Potential Soil Use. Source: MAGFOR, 1995.

2.1.6 Annual Agricultural Cycle

The agricultural cycle in Nicaragua includes two harvests and is typically divided into four agricultural periods:

- First Planting and Growing Season (Wet Season: May-July)
- First Harvest (Short dry spell (*Canícula*)*:* mid-July to mid-August)
- Second Planting, Growing Season and Harvest (Wet Season (*Postrera*): August-December)
- Irrigation (Dry Season: December-April)

The extended winter season (between November and February) at higher altitudes is referred to as *Apante*. During this time, crops such as beans and corn are harvested. During the short first harvest of winter the crops that are grown are primarily corn, beans, wheat, and sorghum for local food supplies. All the major export crops, such as cotton, are produced during the *Postrera*. Cotton is normally cultivated from August or September until January. During the dry season, the number of producers is reduced due to the capital investment that is required to purchase and maintain irrigation equipment. During this season, rice and banana are the principal crops. Coffee is a permanent crop with December. All other major crops are seasonal.

2.1.7 Irrigation in the Region

Surface water is mainly used for irrigation during the dry season (November-May) and sometimes during the *Canícula* (July-August) in the study area. Surface water is used for industrial processes in lower quantities. In 1970-1971, surface water was extracted from its natural rivers and streams and stored in nineteen reservoirs (with storage capacities ranging from 15,000 m^3 to 250,000 m^3); from which 130 x 10^6 m^3 were distributed that year (UN, 1974).

Currently the most important sugar mill in Nicaragua (ISA/NSEL) has 9,659 ha cultured with sugarcane, of which 95% (9,175 ha) are irrigated. This represents 10% of the total area in the country under irrigation. The volume of water used at ISA/NSEL increases to 261 x 10^6 m^3 per year, from which 199 x 10^6 m^3 are from rivers, and 62 x 10^6 m^3 extracted from groundwater. Of the river supply, 146x10^6 m^3 are used to irrigate sugarcane culture, and 53 x10^6 m^3 are used to wash the sugarcane before it is processed. From the volume of groundwater extracted, 53x10^6 m^3 are used for irrigation, 9 x10^6 m^3 for industrial processing, and 0.18 x10^6 m^3 for human consumption (Aguilar and Amador, 1998).

The groundwater geochemistry data (U.S. Salinity Laboratory Diagram, 1954) indicate the groundwater has low sodium concentrations and moderate salinity and meets standards for industrial uses with the exception of chloride concentrations, which are > 20 ppm. In general the groundwater complies with international drinking water guidelines (Aguilar and Amador, 1998).

2.1.8 History of Cotton Cultivation in the Region

The following history of cotton cultivation is based mainly on the final report of a study on the Environmental and Economic Consequences from Pesticides Use in Cotton Production in Central America (ICAITI, 1977).

Early 1900's

Cotton cultivation was initiated at a commercial scale in Central America in the early 1900's. Encouraged by the success of this crop in the U.S., Central American farmers began by importing cotton and agricultural techniques from the southern U.S.

Cotton grows well in deep, fertile soils with good drainage. It requires a minimum precipitation of 650 mm during the development and fruit stages, and absence of rain during maturity and harvest stages. Major plant development is obtained between 25 °C and 30 °C, and the plant needs sunlight for more than 50% of time. The León and Chinandega regions are very suitable for cotton cultivation (PROTIERRA/MARENA 1997).

During it first stage, the culture is in its subsistence phase, and the use of pesticides is scarce. Pests were historically controlled with calcium arseniate, sulfur, or tobacco leaf infusion. More “progressive” farmers used these procedures. Most of the crops required natural control and manual collection of the insects. The principal pests during this era were cotton-boll weevil (Anthonomus grandis Boh.), cotton leafworm (Alabama argillacea), and cotton-grasshopper (Schistocerca parenensis Bum).

1950’s – 1970’s: Increasing Yields but Environmental Impacts

By the end of Second World War, a successful campaign to exterminate the cotton-grasshopper was waged. As result only the cotton-boll weevil and cotton leafworm remained. These two insects are the only ones that have an ecological potential to grow as cotton pests in Central America. Cotton-boll weevil originated from this part of the world and evolved with cotton plant evolution. Hence, cotton leafworm, has a migration character apparently following sunlight, and its favorite food is cotton leaf.

According to some older cotton producers, there were no “worms” in their cotton plants before pesticides use; they thus only worried about collecting cotton-boll weevil. Cotton yield per unit area was not very high, its maximum value was around 2,000 kg of cotton with seed per hectare.

In 1950's and 1960s, cotton cultivation increased significantly in the region as intensive agricultural machinery and agrochemicals were introduced. The use of synthetic pesticides revolutionized. Average cotton yield production increased from 1,550 kg of cotton with seed per hectare to 2,270 kg and the amount of land under cotton cultivation grew rapidly.

In the 1950's, cotton cultivation had its "boom" in Nicaragua and the Departments of León and Chinandega, formerly cultivated with citrus crops, became home of cotton. In 1977 and 1978, there were 194,563 hectares of cotton cultivated (MAG, 1977-1978). By 1982-1983 the land area under cotton cultivation decreased to 21,957 hectares (MAG, 1982-1983). The pesticides applied during cotton cultivation were mainly pp-DDT, BHC, and toxaphene. These are three well-known organochlorine pesticides with high toxicity and environmental persistence. These compounds were applied in a pure form, as a mixture between them, or in some cases, mixed with sulfur. On average, pesticides were applied eight times per season. In the mid fifty's, organophosphates pesticides appeared, showing a major efficiency in pest control.

The increasing use of organo-synthetic pesticides brought an increase in the number of injurious pest species. About the middle of the decade, three new species were added to the former two: cotton-budworm (Heliothis spp), cotton-aphid (Aphis gossypii), and false pink bollworm (Sacadodes pyralis.

In the next decade (1960-1970) a great variety of organo-synthetic pesticides appeared in the Central American market, especially organophosphates and carbamates. The scant governmental restrictions related to the agricultural use of pesticides turned Central America into an experimental field for pesticides productive companies. Many of the pesticides that were applied in Central America for cotton production did not have a commercial-sale approval in the source country. The inadequate regulations related to pesticides, and the belief that mixing several of them increase their efficiency for pest control, edged on cotton producers in situations in which they can choose among fifty or more options of products and mixtures for pest chemical control.

By that time, pesticides were mainly applied according to a calendar schedule (as opposed to responses to pest infestation). This schedule was based on a perceived need to keep certain toxic levels in the culture, and to protect new parts of the plant. The average number of applications increased to twenty-eight per season. From the five important pest species in the past decade, the false pink bollworm was no longer a threat, the cotton-aphid became less important, and the four most serious pests included black cutworm (Prodenia spp), whitefly (Bemisia tabaci), cabbage loopers (Trichoplusia ni), and cotton armyworm (Spodoptera spp).

New pest appearance and their resistance to pesticides forced cotton farmers to used higher quantities of pesticides and more frequently applications. Costs for pests control reached 50% of production costs. The decrease in cotton prizes internationally caused its culture to be abandoned in the marginal lands. In the early 1970's, Nicaragua began an integrated cotton pest control program, which facilitated decreased pesticide use.

Toxaphene was produced in Nicaragua in a factory named HERCASA. HERCASA began operations in 1974, and its first production was of 9,500 metric tons. In the year 1976 the factory produced 5,700 metric tons of toxaphene. Since that year the production has been varying, with a tendency to decline; in 1985 the production was 2,140 metric tons and in the year 1989 it was 300 metric tons. From the year 1985, all the production was sold in Nicaragua. In 1991 the factory was working very irregularly, and since June 1991 it has been out of production. Its production went down with the years until it closed in 1991

(Matus and Beck, 1991). In 1974, 27,300 tons of pesticides were applied in Guatemala, Honduras, El Salvador, and Nicaragua. Nicaragua had the third highest rate of pesticides consumption in the region (ICAITI, 1997; Table 11).

A source of pesticide contamination is the washing out of pesticide application after aerial application when precipitation occurred soon after application (ICAITI, 1997). The departments of Chinandega and León also served as the principal centers for the formulation, distribution, and spraying of pesticides using a number of minor airstrips. During the period from 1973 – 1981, 70,270 metric tones of pesticides, including herbicides, fungicides, insecticides, etc. were applied. Eighty percent of this amount was used in the cultivation of cotton (Briemberg, 1995).

1980's-present

The 1980's were characterized by economic depression in the region caused mainly by drastic reductions in cotton prices. New agricultural crops were assessed, with none as profitable as cotton (PROTIERRA/MARENA 1997).

This situation was mainly extended into the nineties, although land use planning resulted in some improvement. In the study area, extensive soil erosion and deforestation occurred, and surface water bodies have received solid and liquid wastes from industrial, agro-industrial, and domestic activities; and sediments deposition from soil erosion (PROTIERRA/MARENA 1997).

Table 11. Pesticides Application in Nicaragua 1972-1974

Description	1972	1973	1974
Total amount of pesticides applied (kg)	7,123,657	7,809,774	4,859,079
Total amount of pesticides applied per surface unit (kg/km^2)	60.2	66.0	41.0
Average amount of pesticides applied during cotton production (kg/ha)	51.2 (1972/1973)	44.1 (1973/1974)	49.8 (1974-1975)
DDT application for cotton production (lb/ha)	--	--	13.9 (1974-1975)
DDT application for cotton production (kg/ha)	--	--	6.3 (1974-1975)

Source: (ICAITI, 1977)
--: Not available

Sugarcane cropping has been historically concentrated in one region (~9000 ha in 1974; UN, 1974) belonging to San Antonio Sugar mill and Distillery, Nicaraguan Sugar Estate Limit (ISA/NSEL), The ISA/NSEL currently owns 9,575 hectares, of which 9,095 hectares are irrigated (equivalent to 10% of the total irrigated area in the country). The total annual volume of water used in sugarcane production (including cultivation and rinsing prior to processing), is above 261 millions of cubic meters (Aguilar and Amador, 1998).

In 1992, thirteen percent of the economically active population of the country was involved in agriculture. In that year, the principal commercial agricultural products were coffee, cotton, and bananas.

The 1996-1997's MAGFOR study showed that 782,777 hectares are suitable for cotton cultivation; the same land area is also suitable for soy, peanut, and sesame seed; meanwhile sorghum has a suitability of 138,846 hectares of land. The production in 2000 in the country was: sugarcane (four million tons), corn (363,636 tons), fruits -notably orange, banana, and pineapple (256,636 tons), and rice (285,315 tons).

2.1.9 Other Sources of Pesticide Contamination

Another source of pesticide contamination is the control of human disease vectors. This consists mainly of insecticide applications in urban areas to reduce the types of mosquitoes that transmit Malaria (Anopheles) and dengue virus (Aedes aegipti). In 1990, the program for control of Malaria used a total of 174,275 kg/L of deltametrin, fenitrotion, 40 WP, and fenthion; and in the same year, the program for control of Dengue used a total of 263,575 kg of temephos and malathion (Briemberg, 1995).

Domestic use of insecticides is common in Nicaragua for the control of cockroaches, mosquitoes, flies, and rodents (Briemberg, 1995).

2.2 Regional Geology

The following description of the regional geology summarizes the detailed geologic mapping conducted by a United Nations study (UN, 1974).

2.2.1 Introduction

The León-Chinandega region is located within the Nicaraguan Depression, one of the four geological provinces in which the country is divided. The Depression consists of a large graben created in the Pliocene-Pleistocene by tensional tectonics associated with subduction zones. Bounded by normal faults running sub-parallel to the Pacific coast, the valley is shallow but very broad extending as wide as 550 km. (UN, 1974).

A more recently active fault system, perpendicular to the main faults, generates a mosaic of angular blocks and is the source of frequent earthquakes. The fault systems, as well as the moderate folding in the adjacent formations to the Depression, reflect the varied character of the regional deformation. This Depression with an approximate length of 550 km, starts at the Fonseca Gulf and ends in the valley of San Juan River. The Depression comprises the Cordillera de los Maribios of the León-Chinandega region and the Lakes Xolotlán (a.k.a. Lake Managua) and Cocibolca (a.k.a. Lake Nicaragua).

2.2.2 Geomorphology.

The study area is divided into four geomorphologic zones: the Maribios Cordillera, the Volcanic Foothills, the Plain, and the Hills (*prominences*).

The ***Los Maribios Cordillera*** has an area of approximately 160 km^2, oriented northwest to southeast, and it is comprised of a series of volcanic cones, some of them currently active (Figs. 5, 6a, and 6b; Table 12). These mountains provide a natural watershed divide (surface water and groundwater). In the study area the San Cristóbal, Telica, and Rota volcanoes constitute the northeastern limit. The flanks of the cones become increasingly steep with altitude with maximum slopes ranging from 36 to 71%. The cones have varying size craters on top depending on the degree of pyroclastic collapse, and have small crater lakes.

The ***Volcanic Foothills*** is a strip of land between 100 and 300 masl, between the Cordillera de los Maribios and the Plain. It has an area of approximately 430 km^2, and an average slope of 3%.

Table 12. Volcanic Chain Cone Altitudes, and Status

Volcano	Altitude in m.a.s.l. (Activity status)
Chonco	1105 (*)
San Cristóbal	1745 (active)
Casita	1405 (*)
Telica	1010 (active)
Santa Clara	834 (*)
San Jacinto	900 (*)
Rota	836 (*)
Las Pilas	938 (*)
Cerro Negro	635 (active)

Source: UN, 1974
(*): Not active

The ***Plain*** occupies an area of about 900 km^2, between the Pacific coast (0 masl) and the Foot of the Volcanics (100 masl). The average topographic gradient is very low (0.6%). Near the ocean, the rivers and estuaries are strongly affected by tides bringing salt water many kilometers inland in several locations and mangle shrubs dominate vegetation.

The ***Hills*** (or *prominences)* are a series of highly eroded volcanic “basement” rocks of the *Tamarindo Formation* (Figs. 5, 6a, and 6b) rising above the more recent alluvial materials of the plain. Their altitude varies from a few meters to 300 meters above sea level. Some isolated hills are found near the coastline, and they tend to align in a more regular chain form to the west of León, west and northwest of El Viejo. The hills occupied a total area of approximately 90 km^2.

2.2.3 Geologic Units

Within the study area, the following stratigraphic units have been differentiated, according to their ascending order (Figures 5, 6a and 6b). The map including the geological units is based on UN (1974) map.

Tamarindo Formation (Miocene, ~ 5.3 and 23.8 million years ago)

The *Tamarindo Formation* is the oldest geologic unit in the area and is comprised of Miocene volcanic materials including pyroclastic deposits (mostly tuffs and ignimbrites) and lava flows (basalts, and andesites). The formation outcrops, often as prominences (Figs. 5, 6a, and 6b) near the coast as well as in the northwestern, western, and eastern extremes of the area. Otherwise, it is only found at depth below more recent volcanic formations and alluvial materials. The tuffs are present in white, pink or gray color, and are occasionally completely welded, forming ignimbrites. The lavas have a dark gray to blue-black color with minor oxidation layers. The maximum thickness of this formation in the study area is 300 meters.

Magma Intrusions (Miocene-Pliocene, ~ 1.8 and 23.8 million years ago)

There are two magma intrusions into the *Tamarindo Formation*. The most important is the Monterrosa Hill, which consists of augitic-diorite. The other intrusion is a porphyry andesitic unit that outcrops in the community of Ceilán. These intrusions, along with a third one located outside of the study area, constitute an alignment oriented north to south.

Los Maribios Cordillera (Pliocene-Pleistocene, ~ 11,000 years to 5.3 million years ago)

The *Los Maribios Cordillera* is the northeastern boundary of the study area, and includes four volcanoes: San Cristóbal, Telica, Rota, and El Hoyo. Their ages are upper Pliocene to recent Pliocene, with andesitic, normal basaltic, dacites, and olivine basaltic lavas. The olivine basalts are the youngest lavas in the Cordillera, partially covering the alluvial deposits.

From petrographic study, it was observed that it is a narrow correspondence between geomorphology, chronology, and lithology in the volcanic groups of this Cordillera. Three volcanic groups can be differentiated: Volcanic Group I, probably from a Pliocene-Pleistocene age, characterized by a semi-destroyed structure due to erosion and tectonics. Volcanic Group II, probably from Pleistocene age, characterized by the presence of semi-destroyed volcanic rock structure that shows prolonged erosion activity. Well-formed volcanic cones, not affected by erosion processes with a recent to historical activity, characterize Volcanic Group III.

The volcanoes from the Cordillera were most active in the early Quaternary and since then have emitted large quantities of pyroclastic materials. These materials have been transported long distances throughout the Pacific region of Nicaragua by air and water.

Las Sierras Formation (Pliocene-Pleistocene, ~ 11,000 years to 5.3 million years ago)

The *Las Sierras Formation* has a maximum known thickness of 220 meters in the study area and outcrops to the east of León, west of Chinandega, and east of Chichigalpa. This Formation is comprised of older pyroclastic deposits that lie discordant over the *Tamarindo Formation*. These deposits vary in size from silts to well-rounded fine gravels and include compacted aglomerate tuffs, soft lithic tuff, lapilli, pumice, and ash.

A layer of plastic clay (which probably corresponds to an alteration of *Tamarindo Formation*) has been observed at the contact between the *Las Sierras and Tamarindo Formations*.

Recent Pyroclastic Deposits and Alluvial Materials (Upper Pleistocene, ~11,000 years to 1.8 million years)

The alluvial materials lie unconformably over *Las Sierras Formation* and *Tamarindo Formation* (in some sectors of the coastal zone) with a thickness ranging from a few meters to 120 meters (near Chinandega). These materials thin out in the coastal zone, and in the west and northwest extremes of the region. They are comprised of unconsolidated silts, fine to coarse sands, granules, and fine gravel; all deposited by air and water.

The recent pyroclastic deposits are comprised of volcanic dust, fine to coarse ashes, lapilli, and pumice, found sporadically in thin layers. During volcanic eruptions, the coarser pyroclastic materials tend to settle closer to the volcanoes, whereas, prevailing winds have dispersed the fine pyroclastic deposits (medium size lapilli to volcanic dust) across the entire plain.

Silts, gravels, and cobbles that have undergone a limited transportation process comprise the alluvial deposits. Near the coast, some open and buried riverbeds show some sorting classification. Some lava flows are intercalated within the pyroclastic deposits at the base of the Cordillera.

Recent historic pyroclastic deposits (volcanic dust and ash) cover a large part of the Plain. Due to its position and hydrogeological characteristics, the recent pyroclastic deposits and alluvial deposits constitute along with *Las Sierras Formation* the most important geological units. This unit is referred to as “infill” in this thesis.

Marshy Deposits

These deposits are characterized by the presence of silty, color gray clayey sands, in some sectors covered with salt granules. The thickness of this layer is several meters or less.

Coastal Deposits

Coastal deposits mainly consist of materials ocean delta materials. They consist of a mixture of quartz, feldspars, rock micro fragments, iron-magnesium minerals, and with some organic origin contamination. The thickness of this layer may vary from centimeters to a few meters.

Composition, Texture, and Structure of Aquifer Materials

Within the “infill” materials, there are lenses of higher granular size, mainly consist of pumice, sand, lapilli, and gravel with thickness from 1.5 to 20 meters. The thickness of the pumice lenses varies from 0.10 to 5.0 meters, and they are characterized by a light predominant color with quartz, feldspars, and impregnated with little mafic rocks.

The sands, with thickness from a few centimeters to several meters, are in some cases lightly welded in pure composition or as a mixture of sands, gravels, and silt. Occasionally, they present edges or intercalations of finer materials layers, and they may also present cross bedding stratification. This characteristic is variable for these materials according to their oxidation level.

Lapilli is present in granular size, generally in dark colors and contains scorial fragments. The thickness of this layer is similar to the sand layer. The gravels are less frequent than the other materials described, and generally are present as fine, sub-rounded clastics formed by aphanitic, porphyritic or vesicular types dark lavas. These gravel layers have low thickness, and sometimes they are mingled with sands and silts.

Coyol Formation (Miocene-Pliocene ~ *1.8 and 23.8 million years ago)*

The *Coyol Formation* is volcanic of similar composition to the *Tamarindo Formation* and its thought to be contemporaneous (Miocene-Pliocene), but formed further away from the Pacific (Ehrenborg, 1999). The rocks from *Coyol Formation* lie undiscordantly over the *Tamarindo Formation* and outcrop at the northwest extreme of the aquifer. This *Formation* is represented by basalt lava flows and agglomerated lenses at the base (CIRA/IAEA, 1999)

2.3 Hydrogeology

The aquifer of León-Chinandega is composed by a shallow unconfined alluvial aquifer, whose depth is estimated to be 120 meters, and by a deeper volcanic aquifer with depths greater than 200 meters, both considered to be regional aquifers.

In some sector of the aquifer, there are random lenses of pumice, lapilli and gravel with thicknesses that range from 0.5 m to 40 m, Also, some lenses of low permeability material are found as well as some dense lava flows (mainly in the higher elevation zones closed to the volcanic chain) that cause perched aquifers to occur locally (CIRA/IAEA, 1999).

Figure 5. Stratigraphic Column of the Study Area

ERA	PERIOD	UNIT	APPROXIMATE THICKNESS (m)	LITHOLOGY
QUATERNARY	Recent	Coastal Deposits	Some centimeters to some meters	Sands, gravels, pebbles
		Marshy Deposits	Few meters	Clayey or silty sands
	Recent to Pleistocene	Pyroclastic and Alluvial Deposits	Some meters to 120 meters	Volcanic dust, ashes, lapilli, pumice, silt, gravel, pebbles, some lava flows, minor clay -
		Las Sierras Formation Los Maribios Cordillera	Few meters to 250 meters ?	Tuffs, pumice, lapilli, arenaceous tuff, basaltic and andesitic lavas, pyroclasts
TERTIARY	Pliocene	Magma Intrusions	?	Augitic diorite, porphyritic andesites
		Coyol Formation*	?	Basalt-lava flows, and agglomerate lenses at the base.
	Miocene	Tamarindo Formation	300	Intercalation of tuffs, ignimbrites, basalts and andesites

Source: UN, 1974. * Source: INETER, 2000

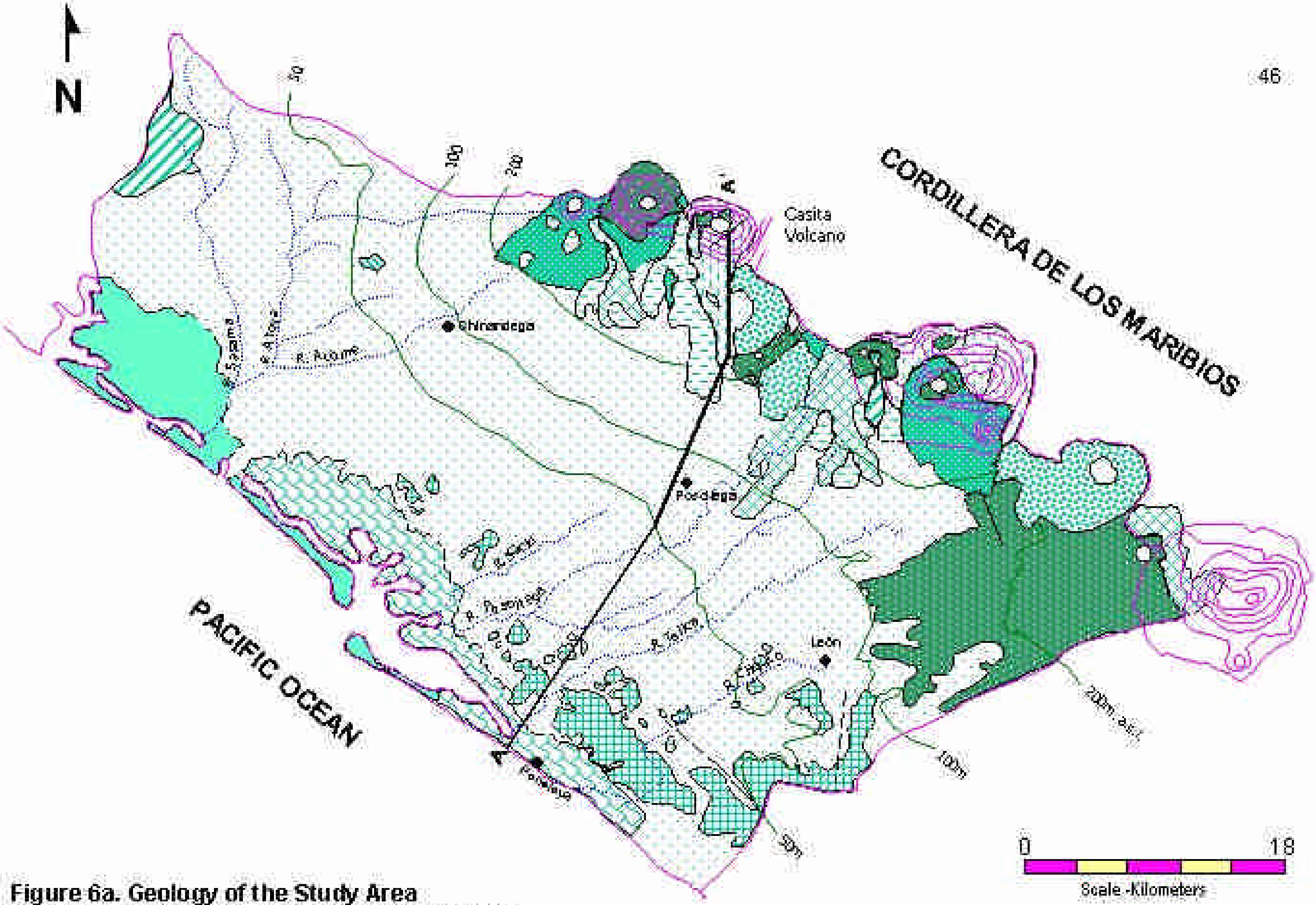


Figure 6a. Geology of the Study Area
Modified from Nicaraguan Pacific Coast Groundwater Research Project. United Nations, 1974
Elevation contours in m.a.s.l.

LEGEND

Quaternary		Coastal Deposits	🟩	Coarse sands, gravels, and pebbles. Centimeters to meters tick.
		Marsh Deposits	▒	Silty sands and clayey sands. Few meters thick.
		Pyroclastics Deposits and Alluvial	☐	Lapilli, ash, pumice,volcanic dust, sands, gravels, silts and clays. Few meters thick.
		Las Sierras Formation	▓	Tuffs, pumice, lapilli, ashes
	Volcanic Chain	Volcanic Group III	▓	Recently pyroclasts
			░	Volcanic cones, pyroclastics, and lavas
			▨	Very recently historical lavas
			▩	Recently low covered lavas
			▤	Semi buried lavas
			▒	Lava domes
		Volcanic Group II	░	Volcanic cones, lavas and pyroclastics
		Volcanic Group I	░	Volcanic cones, lavas and pyroclastics
Tertiary		Magma Intrusions	▧	Diorites and Phorphyrics
		Coyol Formation	▨	Basalt-lava flows, agglomerated lenses
		Tamarindo Formation	▦	Tuffs, ignimbrites, basalts and andesites
			⬭	Craters, and calderas
			A—A'	Geological cross-section
			●	City or Town
			—	Faults
			- - -	Supposed Faults

Figure 6b. Geology of the Study Area Legend (UN, 1974).

Almost the entire León-Chinandega region is underlain by a shallow alluvial aquifer, which extends over an area of 1300 km^2 (including 200 km^2 of coastal marsh; CIRA/IAEA, 1999). To the northwest, the aquifer is bounded by geological contact with the ignimbrites and basalts of the *Coyol Formation*. The north-northeastern limit is associated with the regional groundwater divide along the length of the volcanic chain. The *Tamarindo Formation* and the Pacific Ocean represent the southwestern boundary (CIRA/IAEA, 1999).

Several hydrogeological studies have been conducted on the shallow alluvial aquifer, which supplies all the drinking water for both the rural and urban population of León and Chinandega Departments. The majority of these studies emphasized water quality and the aquifer potential for domestic, agricultural and industrial uses. Most of these studies had been carried out in a specific cross section through the aquifer, or in specific areas of it –mainly related to aquifer use and exploitation for agricultural and industrial processes. A brief summary of these studies follows.

United Nations (1974) conducted an extensive hydrogeological study including the chemical quality of surface water and groundwater; cultivation zones, type of culture and irrigation zones, groundwater potential, and groundwater extraction costs. This study concluded that groundwater is found under storage or running off, under confined, unconfined and semi-confined conditions in the alluvial pyroclastics deposits that infill the depression. The groundwater average depth is 13 meters below ground surface (mbgs), and it is found at ground surface level near the coast and below 100 mbgs near the *Los Maribios Cordillera*. Chemical characteristics among surface waters and groundwaters are similar; and groundwaters characteristics are almost similar to the base flow river waters. Most of the waters in the study area are useful for irrigation, industrial use and human consumption.

From 1986 to 1990, INETER conducted the *Hydrogeological Study of the Pacific Region of Nicaragua,* which included hydrogeological, hydrochemical and irrigation maps. The hydrogeological map shows the most important discharge zones, geological formations, relations between the different hydrogeological units and the risk of contamination of groundwater bodies. Hydrochemical and irrigation maps classified the type of groundwater (INETER, 1986).

The *Hydrological Evaluation of Atoya River Watershed* provided the water balance for this watershed and information related to its further use and exploitation (Gutiérrez, 1993). In 1996, Peña and Rodríguez worked on the *Evaluation of Groundwater at Monte Rosa Sugar Mill.* This study provided an update in the hydrogeology of the watersheds of El Viejo River and Atoya River.

From 1997 to 1999, CIRA-UNAN-Managua in collaboration with IAEA carried out the *Isotopic and Contamination Study of León-Chinandega Aquifer, Nicaragua.* This study concluded that the groundwater average lineal velocity is 0.2 m/day, and a low cationic exchange in most of the groundwater path. It could be observed that the increase in nitrate concentration in shallow waters is due to anthropogenic source.

In 1998, Aguilar and Amador, worked on the *Hydrogeological Actualization of the San Antonio Sugar Mill Area.* Their thesis work estimated that the safe exploitation rate of the aquifer is 309×10^6 m^3 per year. The groundwater is classified based on the U.S. Salinity Laboratory as low sodium concentration and medium salinity, and according to the international water guidelines, it is concluded that the groundwater in the system is suitable for human consumption.

From 1998 to 2000, INETER conducted a *Hydrologic and Hydrogeological Studies in the Region of Chinandega-León-Nagarote (Western Aquifer).* As result of these studies, the country has updated information about the hydrological and hydrogeological balances, as well as water chemistry in the aquifer.

2.3.2 Deeper Volcanic Aquifer

The deeper aquifer is dominated by the presence of a deep graben of tectonic origin, whose deep base is located to the height of Chichigalpa and Posoltega, and between León and Telica. This graben is composed of *Tamarindo Formation*, which is identified as the impermeable bottom of the aquifer system. This graben is mainly filled with quaternary alluvial deposits and recent pyroclasts, and in lower amount by pyroclastic flows from *Las Sierras Formation*. This zone is known as the “infill”. However, according to United Nations study (1974), thick clay deposits can perform the same function, especially in the deepest zones in the depression (INETER, 2000).

The depth of the aquifer in the region between the Pan-American Highway and the volcanic chain is believed to be more than 200 m (CIRA/IAEA, 1999). INETER (2000) reported that the aquifer has an asymmetrical geometry, with the greatest depths between Quezalguaque and Chichigalpa, ranging from 300 to 400 meters below ground surface.

This bottom of the aquifer is basically a structural wedge depression which thinner extreme connects with the coastal zone at depths about 20 to 30 meters below sea level. It has a fixed limit by the system of normal faults that run northwest southeast and northeast southwest, where basement crops out can be observed (INETER, 2000).

2.3.3 Groundwater Recharge

Payne and Yurtsever (1974) used environmental isotopes (^{18}O and ^{2}H) and the radioisotope tritium, to understand groundwater recharge in the León-Chinandega area and found a clear "altitude effect" or correlation between altitude and isotope concentration. The study demonstrated that the aquifer below the agricultural plain is mainly recharged in the upper elevations (greater than 280 masl) on the slopes of the volcanoes. Although evidence of direct recharge from the agricultural plain was found, it was less significant than the regional higher altitude recharge. These results were confirmed by CIRA/IAEA (1999).

Given the unconfined characteristic of the aquifer, precipitation constitutes the main source of recharge. Therefore, a direct correlation can be established between precipitation and groundwater levels. Seasonal, annual or inter-annual variations in wells' water levels are the result of variations in the natural recharge of the aquifer between the dry and wet seasons, water extraction, and evapotranspiration (INETER, 2000). Four recharge zones have been defined according to soil characteristics, which are shown in Table 13. Recharge values are expressed as percentages related to annual average precipitation (INETER, 2000).

Table 13. Recharge Percentages in the Study Area.

Code	Type of Soil	Average Annual Recharge %	Average Annual Recharge Mm
RZ1	Sandy-loam, or coarser textures	38 – 46	593 – 881
RZ2	Loam, and loam-sandy	20 – 35	316 – 678
RZ3	Loam, and loam-clayey	0 – 10	0 – 146
RZ4	Coastal Zone, swamps, lateral recharge zone, and rejected recharge zone.	0.0	0.0

Source: INETER, 2000.

2.3.4 Groundwater Flow Direction and Transit Time

Since the upper aquifer is unconfined, the watertable is it upper boundary, and equipotential lines mimic the topography. Groundwater flows predominantly from Northeast to Southwest towards the ocean. However, there are other flow directions as a consequence of a natural hydraulic divide located east of León city, which results in two shallow groundwater flow systems. This divide is comprised of the ignimbrites of *Tamarindo Formation* (INETER, 2000).

The bottom of the aquifer forms the lower boundary of the aquifer and the groundwater flow system. According to the mathematical model, upward vertical flows are produced in the region of low elevation, causing groundwater to discharged from rivers as base flow between 30 and 70 meters above sea level (INETER, 2000). The average linear groundwater velocity was estimated to be 0.2 m/d (CIRA/IAEA, 1999).

2.3.5 Aquifer Transmissivity and Storage

Transmissivity varies according to geological conditions reflected in the lithostratigraphy, grain size, consolidation level, and degree of fracturing. As consequence, the aquifer has several hydrogeological zones characterized by type of aquifer bottom, volcanic chain, type and texture of soils -mainly.

INETER (2000) reports that the capacity of the aquifer (transmissivity) to allow flow, storage and transmission of water is higher in the area of the volcanic chain (*Los Maribios Cordillera*) where the aquifer is deeper and larger grain sizes and lower consolidation levels characterize the saturated porous media. The potential transmissivities reported range from 500 to 7,000 m^2/d from 20 masl to 200 masl. The most transmissive zones are located near of Chinandega, Posoltega, Telica, Las Chácaras Community, and La Paz Centro-Nagarote.

Storage coefficient decreases from 0.1 to 0.01 from west to east sector of the aquifer (INETER, 2000).

2.3.6 Natural Groundwater Chemistry

The groundwater chemistry is mainly a bicarbonate-calcium-magnesium type (UN, 1974; INETER, 1997; Aguilar and Amador, 1998; Dahlberg, and Odebjer, 2002). CIRA/IAEA (1999) classified the groundwater as two types: bicarbonate-calcium-magnesium and bicarbonate-magnesium-calcium. Meanwhile, INETER (2000) classified the water chemistry in bicarbonate-calcium-magnesium in the higher and medium elevation zones, and as bicarbonate-calcium-sodium in the lower areas of the eastern zone of the aquifer. In the western zone of the aquifer, the types of groundwater chemistry are: bicarbonate-calcium and bicarbonate-calcium-magnesium for the higher and medium elevation zones, and bicarbonate-calcium-sodium in the lower zones. In the coastal zone of Chinandega and Nagarote, chloride-calcium-sodium groundwater type is found.

2.3.7 Saline Intrusion

In 1982 and 1983 the Nicaraguan Institute of Terrestrial Studies (INETER) studied the saline intrusion in the coastal aquifers in the León-Chinandega region. The results show three zones with different grades of saline intrusion risk, being the zone closest to the sea with a certain level of contamination. INETER (1989) reported that the saline intrusion constitutes a threat for the groundwater along the coast of the Chinandega-Nagarote aquifer (this aquifer includes Chinandega-León and León-Nagarote aquifers) due to the excessive groundwater extraction near the coast.

2.3.8 Groundwater Discharge

Groundwater discharge mechanisms have two principal components: natural (which is climate dependent), and water extraction for several uses – mainly from drilled wells. The first component influences the recharge system – water volume that discharges towards the sea carried away by groundwater flow and discharged as river base flow. It should be mentioned that in the lowest zone, rainfall undergoes direct runoff and is evapotranspirated at a higher rate due to soil saturation (INETER, 2000).

3. MATERIALS AND METHODS

3.1 Site Selection

Although the León-Chinandega regional aquifer covers a very large area (1,300 km^2), a smaller study area was selected using the following criteria:

1. The availability of existing hydrogeological cross-sections (INETER, 1996):

    a) From Sta. Clara Volcano to Pacific Ocean, crossing through León city to Poneloya.
    b) From Casita Volcano to Pacific Ocean, crossing through Posoltega to Doña Paula Estuary.
    c) From Chonco Volcano to Pacific Ocean, crossing through Chinandega city to Paso Caballos Estuary.

    These cross-sections produced valuable information about the geology and hydrogeology (groundwater table, depth of the aquifer, natural hydraulic divisions, aquifer boundaries, etc.) of the aquifer.

    From these cross-sections, sections a) and b) have reasonably good data and geologic consistency.

2. A study area with:
    a) Cotton historic cultivation
    b) Recent and historical land agricultural use
    c) Available water well logs for subsurface information
    d) Pesticide application

e) Recent hydrogeological information (INETER, 2000; CIRA/IAEA, 1999)
f) Recent pesticide assessments in the zone (CIRA/IAEA, 1999; CIRA, 1999; Centro Humboldt, 2002; Dahlberg, C. and Odebjer, W., 2002)

Based on the above criteria the cross section from Casita Volcano (A') to the Pacific Ocean (A) was selected (see location of the cross section in Figure 6a). This cross section is located in the central part of the aquifer.

Once the cross section was selected, sites for groundwater monitoring well installation were selected based on the following criteria:

- Sites at various elevations. One site in lowland close to the coast, a site at moderate elevation located in the Chinandega Plain, and the third one at the upper topographic limit of agricultural land use. Selection of the sites at different altitude would allow assessing the groundwater flow system and water quality in the aquifer.
- The site should be located in the selected cross section line or as close as possible to it.
- Cooperative landowners and a minimal chance of vandalism.
- Sites not located near to point contaminant sources (e.g. airstrips, agrochemical storage warehouse).

The selected sites through the cross section are Calle Real del Bosque (at 139 m.a.s.l.), El Trianón (at 42 m.a.s.l.), and El Polvón (at 17 m.a.s.l.), all of them with a significant agricultural land use (Figure 7).

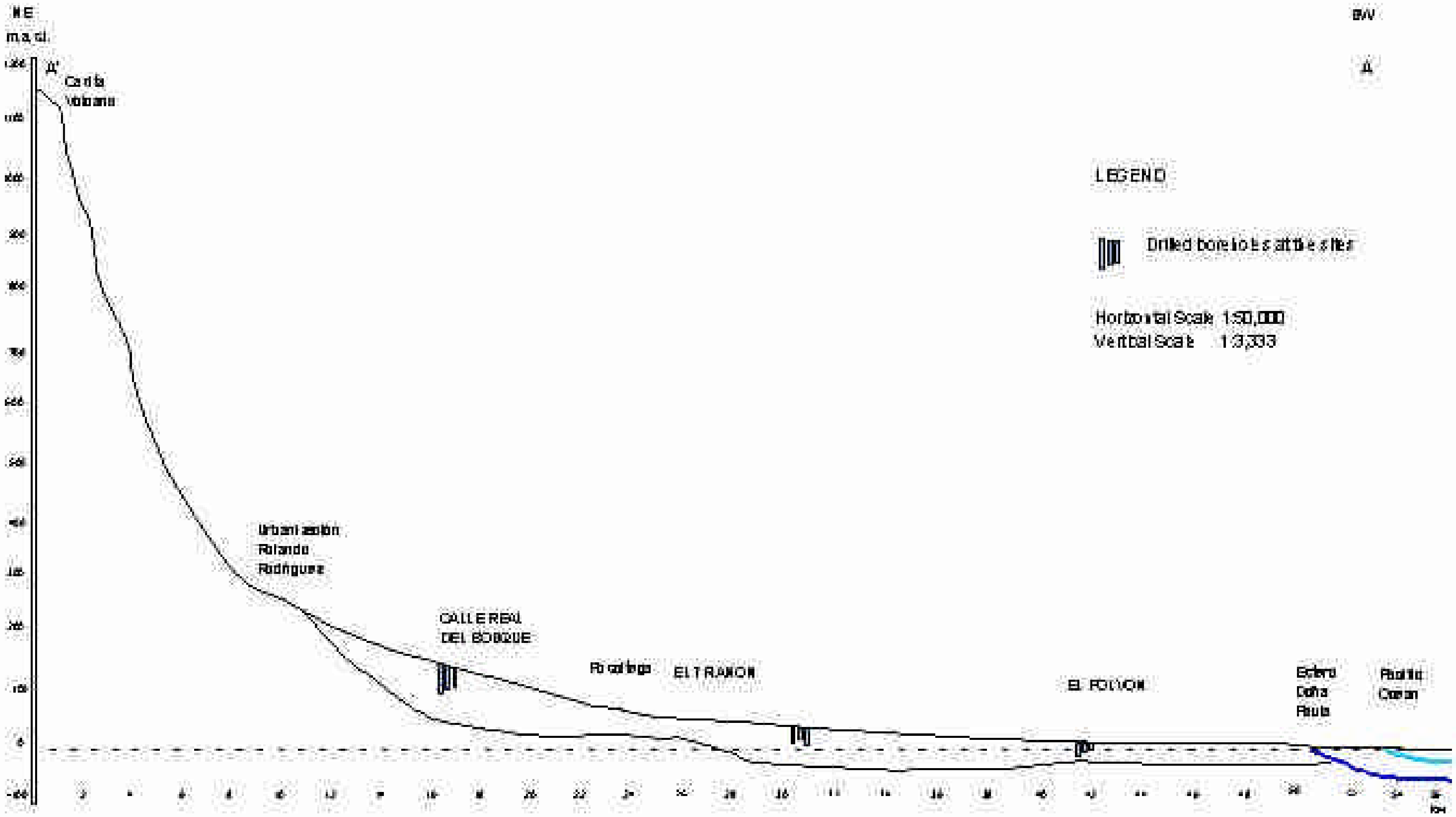


Figure 7. Selected Sites Location at the Vertical Cross-Section with location of Drilled Boreholes.

The site at Calle Real del Bosque [B(H); H for higher elevation], is a private property with historic cotton cultivation and more recently with yucca and corn. The site at El Trianón [T(M); M for medium elevation], belongs to a farm and business co-operative, which uses surrounding lands for sugarcane, corn, banana, sesame seed, and sorghum cultures. Cotton was also grown at this site historically. Finally, the site at El Polvón [P(L); L for low elevation] is located in the property of Ingenio San Antonio (ISA/NSEL.), the biggest sugarcane mill and distillery in the country.

3.2 Site Instrumentation

3.2.1 Drilling and Geologic Sampling

Fifteen monitoring wells were installed at the three selected sites. Drilling was conducted on November 14-20, 2001. At each of the three sites, three boreholes were drilled.

The drilling rig was an Ingersoll Rand (model TH-10-LM) air-rotary using a down-hole percussion bit. Compressed air was blown down inside of the drill pipe with an air compressor (Ingersoll Rand, model XHP-750-CAT) with a mass flux of 750 cubic feet per meter and 350 pounds per square inch of pressure. The air then blows the drill cuttings (or chips) up the annular space to the ground surface. The drilling process included the installation of a surface casing through any unconsolidated material. A six-inch diameter down-hole percussion bit with tungsten carbide buttons was used to drill through unconsolidated and bedrock formations at different pressures according to the geological strata. When water was encountered, the water blown out of the drill stem by the air provided a crude estimation of the depth of the water table and water-bearing units, as well as their yields. Water was used as necessary in the drilling process.

Drill cuttings from the nine boreholes were collected from ground surface to the bottom of the borehole. These cuttings were collected from around the borehole using a shovel. Dried and wet sediment samples were taken. The dried samples contain the entire cuttings including the consolidated and unconsolidated materials. The unconsolidated material was washed out of the wet sample. In total, 67 sediment samples were collected at Calle Real del Bosque, 27 samples at El Trianón, and 37 samples at El Polvón.

3.2.2 Monitoring well Construction and Installation

At each of the three sites five monitoring wells were installed in the three boreholes. Two monitoring wells were installed in each of two boreholes and one monitoring well was installed in the third borehole. In each borehole the monitoring wells were installed at the following depths: at the water table, 2, 4, 8, and 12 meters below the water table (see Appendix A).

The monitoring wells were constructed with 6-meter lengths of 3/4" diameter Schedule 17 polyvinyl chloride (PVC). The lengths were connected with PVC joints of 3/4" external diameter and 1/2" inner. Monitoring well screens were constructed by drilling 66 (for small screens) and 98 (for larger screens in the water table wells) 3/16" diameter holes. All the screens were covered with 210-micron nytex screen. The screen length for all monitoring wells is 0.5 meters except for the water table monitoring wells, which are 1.5 meters. A 3/4" PVC bottom cap was placed at the bottom of each screen. All monitoring well screens were packed with clean medium to coarse-grained sand. The sand was obtained from El Motastepe Hill (Department of Managua) where no pesticides have ever been applied. The filter pack material extends from the bottom of the well screen to 0.5 meters above of the well screen. Due to the high cost of powdered bentonite in Nicaragua the annular space in all boreholes was filled with cement.

Only one borehole at Calle Real del Bosque has a small amount of bentonite in the annular space.

To prevent surface water entering the borehole or monitoring well and protect against vandalism, the monitoring wells were finished with steel or PVC casings and a protective cover pipe with a pad-locked cap. These protective casings were installed at approximately from 0.8 meter to 1.0 meter above ground surface, and were set from 0.5 meter to 0.8 meter below ground surface into a surface sand-cement grout seal. In addition to the protective steel and PVC casings, concrete ground bases were built for each borehole protective casing.

3.2.3 Monitoring well Development

Groundwater monitoring well development was conducted with an open bailer, a peristaltic pump, and compressed air. In addition, an external eight horsepower pump was used to purge the wells at El Trianón and El Polvón. The average rate of pumped discharge from El Trianón wells was 60 L/min, and 40L/min at El Polvón.

The narrow inner diameter of the PVC piping (~3/8 inch) and depth of the water table, made well development difficult at Calle Real del Bosque. For these monitoring wells, a Waterra® check-valve pump was used. The average rate of discharge at this site was approximately 0.3 L/hr.

3.3 Hydraulic Conductivity, Water Levels and Hydraulic Gradients

In-situ hydraulic conductivity tests (a.k.a. *slug tests* or in-situ monitoring well response tests) were conducted to estimate hydraulic conductivity of the saturated materials around to the well screen. *Slug tests* were conducted in twelve monitoring wells, three at El Polvón, five at El Trianón and four at Calle Real del Bosque and analyzed using the Hvorslev method (Fetter, 1994; Appendix B).

Water level measurements at the monitoring wells were taken when possible, and water levels from dug wells in the region were measured to provide information about the water table (Appendix C). In addition, water levels from an additional monitoring well, “T(M) – I” were measured. The T(M)-I installation, located 6 meters northeast of the El Trianón monitoring wells installed for this study, was installed on February 7th, 2000 for the INETER/MAGFOR Project. It has a total depth of 147 meters below ground surface, and possesses 50 meters of non-continuous screen installations located between 40-50 m, 60-70 m, 90 – 105 m, and 120 – 135 m.

Topographic surveys were conducted at all three sites, and vertical and horizontal hydraulic gradients estimated (Appendix D).

3.4 Sampling Procedure for Chemical, Isotope and Pesticide Analyses

Water samples for isotopic and chemical analyses were collected directly from the above-described piezometers and additional domestic water wells following sample protocols, and using materials and resources provided by the laboratories of Nicaraguan Aquatic Resources Research Center (CIRA-UNAN-Managua). These water samples were collected between November 2000 and September 2002.

Twenty-five groundwater samples from 6 dug wells and 8 drilled wells (with samples from drilled wells were collected at different screen depths while no pumping was occurring), and 5 seawater samples were collected in November 2000. Fourteen samples from the monitoring wells, 5 surface water samples taken from rivers, one spring sample were collected during December 2001- May 2002 sampling period. Precipitation samples were collected on a monthly basis from June to September 2002.

The equivalent of three times the volume of standing water in each well was removed prior to sample collection to ensure the sample was representative of the groundwater and not stagnant water in the well casing. The peristaltic pump was used to purge and collect samples from monitoring wells at the middle and lower elevation sites. A Waterra check-valve pump was used to pump the deeper monitoring wells at the highest elevation site.

Chemical analyses (major and minor ions), bacterial analyses, and pesticides –organochlorine and organophosphorus- were conducted at CIRA-UNAN-Managua laboratories. Isotopes analyses were carried out at Stable Isotope Laboratory of University of Calgary. In addition, pH, electrical conductivity, temperature, total and phenolphthalein alkalinities, oxidation-reduction (redox) potential, and dissolved oxygen were measured in the field, after sampling. Temperature and pH were measured using an Orion pH-meter, model 230 with pH probe model 9106. Electrical conductivity was measured using an Orion Conductimeter model 105 with conductivity probe model 011050. Total and phenolphthalein alkalinities were measured using a HACH field alkalinity kit. Redox potential was measured with an Orion 250A plus model with a platinum electrode model 967800. Dissolved oxygen was measured using an YSI oxygen meter model 57.

Major and minor ions and microbiological parameters were analyzed only in groundwater samples collected from each monitoring well installation at the three sites. Pesticides were analyzed in groundwater samples, and in a sample from the Posoltega River. Isotopes were analyzed in groundwater, surface water, and precipitation samples.

Precipitation samples were collected at stations located at Calle Real del Bosque, El Trianón (both property of CIRA-UNAN-Managua) and El Polvón (property of ISA/NSEL). Precipitation samples were collected on a monthly basis; each sample is a subsample of a composite of monthly precipitation.

As part of Cuadra, W. (2002; MSc. Thesis, UNAN) thesis *"Risk Management of Soil Contamination by Organochlorine Pesticides used in Cotton Culture in Posoltega Watershed, Chinandega"*, soil samples were taken at the three sites and further analyzed for grain size analyses, and organochlorine pesticides. One test pit was hand-dug at each site; the dimensions of the pits at each site were 1 m width x 1.5 m length x 2 m depth.These results will be presented in Chapter 4, sections 4.2.1.1 and 4.3.3, respectively.

3.4.1 Sampling Procedure for Chemical Analyses

Water samples for major and minor ions analyses were collected with a low-flow peristaltic pump to collect a sample with as little sediment as possible. At Calle Real del Bosque, a Waterra check-valve pump was used to collect samples. Each monitoring installation was purged before collecting the sample. Peristaltic pump and its tubing, as well as the Waterra check-valve pump and its tubing were cleaned between each installation sampled. Four liters of sample at each installation were collected in an opaque plastic container, sealed with double plastic cap for major and minor ion analyses. An additional one-liter sample for ammonium analyses was collected in an opaque plastic container and acidified with 1 mL of H_2SO_4. Samples were kept on ice during transport to the laboratory.

3.4.2 Sampling Procedure for Bacterial Analyses

Samples were analyzed for total coliforms, fecal coliforms, fecal streptococcus, and *Escherichia Coli* analyses.

Sampling equipment was cleaned with alcohol immediately prior to sample collection for bacterial analyses. Peristaltic pump and the Waterra check-valve pumps were used to sample the installations. The tubing bottoms and check-valve were cleaned with cotton wet in alcohol, and the sterilized sealed plastic and/or dark glass container was not opened until the sample was coming out of the tubing. One liter of sample was collected. Samples were kept under refrigeration until they arrived at the lab. Samples for bacterial analyses were analyzed within 6 hours of their collection.

3.4.3 Sampling Procedure for Isotope Analyses

A total of 39 groundwater samples, 5 surface water samples, 5 seawater, one spring sample, and 8 precipitation samples were collected for oxygen 18 (^{18}O) and deuterium (^{2}H). Isotope analyses were collected in 25 mL plastic containers sealed with double cap using the peristaltic pump and the Waterra check-valve pump.

3.4.4 Sampling Procedure for Pesticide Analyses

Groundwater Samples

Five liters of sample were required for pesticide analyses. The use of plastic sampling materials and insect repellant were avoided during sampling. The peristaltic pump, Waterra check-valve pump, and an open bailer were used. Five liters crystal Pyrex glass bottles with Teflon seal caps are used to contain the sample. Samples were preserved with 50 mL of pesticide grade hexane and kept under refrigeration until analysis was conducted within 24 hours after collection.

Soil Samples

One kilogram of soil was collected, using a metallic spatula, in a metallic tray previously covered with aluminum foil. The sample was then wrapped with the aluminum foil, and double packed in HDPE bags until their arrival at the lab. The metallic spatula and tray were cleaned between samplings with pesticide grade hexane.

3.5 Analytical Methods and Techniques

In this section, analytical methods for the analyses are mentioned briefly since this is not the purpose of this thesis. A brief description on each analyses technique is mentioned in Appendix E.

3.5.1 Chemical Analyses

Major and minor ions were analyzed following the methodology from the Standard Methods for the Examination of Water and Wastewater of the American Public Health Association (APHA, 1999), and Freshwater, Wastewater and Seawater Analyses (Rodier, 1981). A list with methodology number is provided in Appendix E - Description of Analytical Techniques.

Major and minor ions analyses include pH, electrical conductivity, total dissolved solids, calcium, magnesium, sodium, potassium, chloride, nitrate, nitrite, ammonium, sulfate, carbonate, bicarbonate, total hardness, total and phenolphthalein alkalinities, dissolved silica, fluoride, and total iron.

Most of the major and minor ions analyses were analyzed by ion chromatography, spectrophotometry, and titration techniques, and specific field devices probe measurements. Electrical conductivity was measured using a Crison conductivity meter Model 522, and pH was measured with a Knic digital pH meter, Model 646. Anions (chloride, fluoride, nitrate, and sulfate) were analyzed on an ion DX100 ion chromatograph with an Ion Pac AS4A analytical column and Ion Pac AG4A guard column. Ammonium, total iron, nitrites, silica, and sodium were analyzed spectrophotometrically at 640 nm, 510 nm, 543 nm, 410 nm, and 589 nm wavelengths respectively using a Varian SpectrAA-20. Sodium was analyzed under acetylene flame emission mode. Alkalinity (total and phenolphthalein), calcium and total hardness are quantified by titration. Potassium was analyzed under flame photometry or atomic absorption spectrometry in flame emission mode. Total dissolved solids (APHA Standard Method 1030 F) and magnesium are calculated with chemical formulas.

3.5.2 Bacterial Analyses

Bacterial analyses were analyzed according to methods 9222 B (total coliforms), 9222 D (fecal coliforms), 9222 G (escherichia coli), and 9230 C (fecal streptococcus) from Standard Methods for the Examination of Water and Wastewater from APHA (1999) and CEPIS (2000).

3.5.3 Stable Isotope Analyses

Stable isotopes were analyzed with a gas source Mass Spectrometer Micro Mass 903 operated in dual mode (November 2000 set of samples) and Micromass SIRA II (2001-2002 set of samples) for ^{18}O, and a gas source Mass Spectrometer Micro Mass 602 for ^{2}H.

Mass Spectrometer Micro Mass 903 is a triple collector mass spectrometer, for the masses 44, 45, and 46 of the CO_2 gas. The error of this mass spectrometer is 0.2‰. The Micro Mass 602 is a double collector spectrometer operated in a dual mode for masses 2 and 3 of hydrogen gas. The deviation for the results in this mass spectrometer is about 2 or 3 ‰.

3.5.4 Pesticide Analyses

Organochlorine and organophosphate pesticides in water samples were analyzed using liquid-liquid extraction and gas chromatography technique. Organochlorine pesticides were analyzed with the analytical method from IAEA (1995) and organophosphate pesticides were analyzed following analytical method from FAO (1983). A Varian 3300 gas chromatograph with electron capture detector (ECD) with a DB05 capillary column is used for these analyses. The complete description of the analytical technique and equipment is provided in Appendix E.

Organochlorine pesticides in soil samples were analyzed using solid-liquid extraction in a soxhlet distillation column and gas chromatography technique. The analytical method is from IAEA (1995).

Fifteen organochlorine pesticides and thirteen organophosphate pesticides were analyzed. The organochlorine pesticides analyzed in water and soil samples were: alfa-BHC, beta-BHC, lindane, delta-BHC, heptachlor, aldrin, heptachlor-epoxide, alfa-endosulphan, dieldrin, pp-DDE, endrin, beta-endosulphan, pp-DDD, pp-DDT, and toxaphene. Organophosphate pesticides analyzed in water samples included: mocap, naled, terbufos, diazinon, methyl-parathion, malathion, fenthion, ethyl-parathion, DEF, ethion, guthion, zolone, and Co-Ral.

4. RESULTS AND DISCUSSION

4.1 Introduction

An understanding of the physical hydrogeology of the alluvial aquifer is key to understanding the groundwater quality issues and ensuring measures are taken to manage and protect the aquifer and watershed. Physical hydrogeology consists of understanding the underlying geology and its hydraulic properties and dynamics of groundwater flow. Physical hydrogeologic results are thus presented first followed by geochemical and isotope data. Geochemical data are also useful in understanding physical groundwater behavior. Natural and anthropogenic groundwater quality impacts are subsequently discussed in light of the natural flow system to provide a holistic assessment of the state of the groundwater and the measures necessary to manage and protect it over the long-term.

As explained in Chapter 3, P(L) refers to the nest of groundwater piezometers at the lower elevation, El Polvón. T(M) refers to the nest of groundwater piezometers at the middle elevation, El Trianón. B(H) refers to the nest of groundwater piezometers at the higher elevation, Calle Real del Bosque.

4.2 Soils and Subsurface Geologic Materials

4.2.1 Soils

Grain size analyses conducted in a parallel thesis project (Cuadra, 2002; Table 14) indicates sand or silt-size materials consistently dominate the upper 1-2 meters of soil. At B(H), the soil consists entirely of silty sand. At T(M), the soil consists mostly of sandy silt with clayey silt in the deepest horizon. At P(L), the soil consists of silty sand with sandy silt in the deepest horizon.

Table 14. Grain Size Analyses from Shallow Soil Samples from León-Chinandega (from Cuadra, 2002)

Type of material		Sand (%)				Silt (%)				Clay (%)	Total (%)	Soil Type
Code	**Depth (mbgs)**	**Fine** 0.063-0.2 mm	**Medium** 0.2-0.6 mm	**Coarse** 0.6-2.0 mm	**Total % in sample**	**Fine** 0.063-0.2 mm	**Medium** 0.2-0.6 mm	**Coarse** 0.6-2.0 mm	**Total % in sample**	**<0.002 mm**		
B(H)-Sup	0– 0.05	37	10	12	59	7	10	18	35	6	100	Silty sand
B(H)-A	0.05-0.35	18	15	20	53	8	14	21	43	4	100	Silty sand
B(H)-B	0.35-0.80	17	20	33	70	2	10	16	28	2	100	Silty sand
B(H)-C	0.80-1.40	22	19	20	61	3	16	17	36	3	100	Silty sand
T(M)-Sup	0-0.05	13	10	5	31	11	12	24	47	22	100	Sandy silt
T(M)-1-sub	0.05-0.30	16	12	8	36	8	14	21	43	21	100	Sandy silt
T(M)-A	0.30-0.60	15	11	11	37	10	23	13	46	17	100	Sandy silt
T(M)-B	0.60-1.0	14	5	2	21	15	17	17	49	30	100	Clayey silt
P(L)-Sup	0-0.05	21	19	5	45	4	18	16	38	17	100	Silty sand
P(L)-A	0.05-0.40	13	11	22	46	14	20	2	36	18	100	Silty sand
P(L)-B	0.40-0.55	16	18	15	49	8	21	11	40	11	100	Silty sand
P(L)-C	0.55-0.90	16	10	14	40	12	28	14	54	6	100	Sandy silt

4.2.2 Subsurface Geologic Materials

Full descriptions of the geologic logs from B(H), T(M) and P(L) and a log from a nearby borehole (T(M)-I; INETER, 2000) are found in Appendix A. These and other logs are all plotted on a geologic cross-section (Figure 8) providing a sub-surface interpretation of the major geologic contacts and distribution of geologic materials. The composition of the alluvial material to depths of about 12 meters below the water table is primarily provided by the logs obtained at B(H), T(M) and P(L).

To define the contact between the deeper *Las Sierras* (Q_{ps}) and *Tamarindo* (T_{mt}) volcanic formations and the overlying alluvial formation (Q_{al}), well T(M)-I and nearby boreholes (88, 57, 20, 118, 8, and 7) from INETER (2000) were used. The inferred contact depth varies from 78 to 8 m.a.s.l., decreasing in elevation with increasing distance from the coast. The contact between Q_{al} and Q_{ps} was not identified due to the homogeneous lithology present in these wells, very similar to recent not consolidated sedimentary volcanic deposits; which indicates that the predominant rocks in the aquifer in this zone are from Q_{al} formation.

Overall, the alluvial materials are comprised of mostly sand with minor silt and clay layers interwoven by minor layers of recent volcanic materials (ash, tuff, pumice and lava). At B(H) and T(M), there is a thin (2-3 meters) layer of clay at or near land surface. At T(M) and P(L), between 14 –16 m and 4 – 17 m respectively, the silt has been secondarily modified by iron mineralization producing the mineral limonite. Elevated iron is typical of volcanic rocks (Hem, 1985) and in this area the source appears to be the underlying *Tamarindo Formation*. The origin of the limonite will be discussed in a later section.

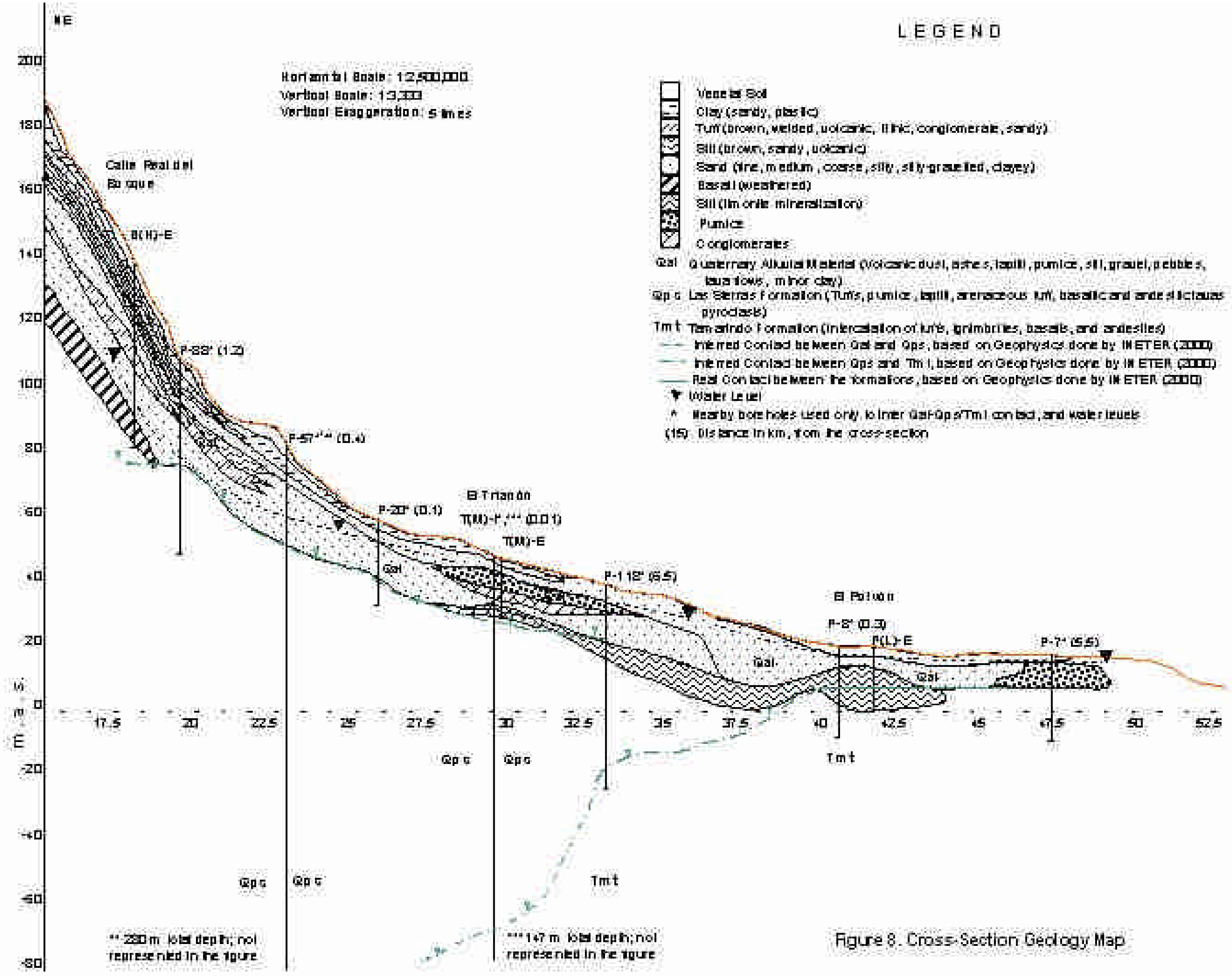


Figure 8. Cross-Section Geology Map

4.3 Physical Hydrogeology

4.3.1 Hydraulic Conductivity

Single well piezometer tests (a.k.a. *"slug tests"*) were conducted at the three sites to estimate hydraulic conductivity (K) of the saturated geologic materials immediately surrounding the piezometer screens (Appendix B; Table 15). At B(H), all screens are located in weathered basalt (see Appendix A) yet K values varied three orders of magnitude ($1.4x10^{-6}$ - $2.7x10^{-9}$ m/s) suggesting the influence of fracturing. At T(M), the screens are located in alluvial sands, silt and conglomerates and the K values varied less ($2.2x10^{-6}$ - $6.9x10^{-8}$ m/s). At P(L) all screens are set in limonite (mineralized silt) and K values are very similar ($3.4x10^{-6}$ - $6.4x10^{-6}$ m/s). These K values are low to moderate and indicate the upper materials in the alluvial aquifer are not highly conductive or suitable for high production pumpage, but are likely suitable for small domestic wells.

Table 15. In-Situ Hydraulic Conductivity Test Results

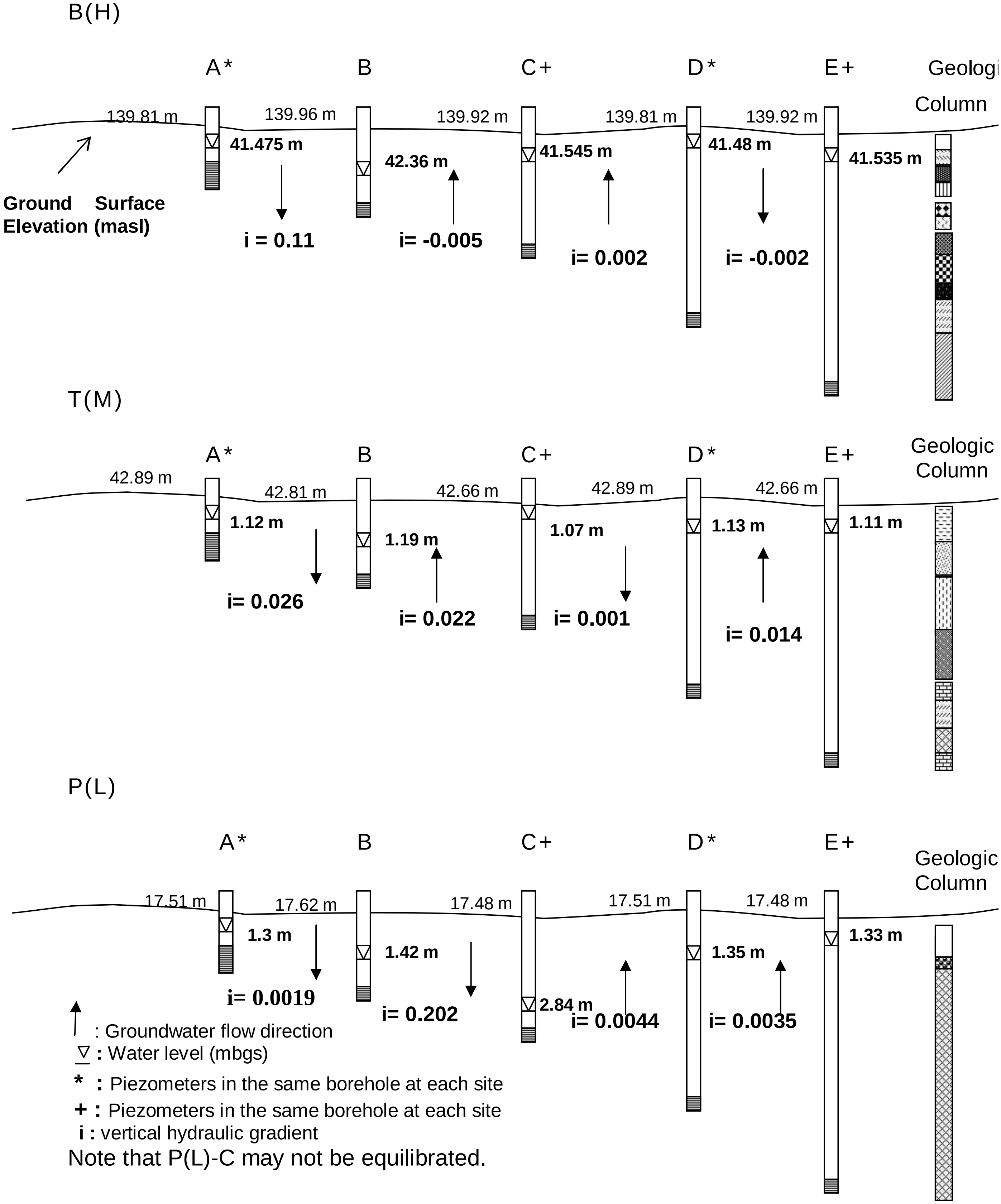
Code	Screen Depth (mbgs)	Calculated K Value (m/s)	Geologic Material Adjacent to Screen From well logs
B(H)-A	47	$2.7x10^{-9}$	Weathered basalt
B	48	Not conducted	Weathered basalt
C	50	$3.4x10^{-7}$	Weathered basalt
D	54	$2.8x10^{-6}$	Weathered basalt
E	58	$1.4x10^{-6}$	Weathered basalt
T(M)-A	6	$6.9x10^{-8}$	Clayey sand
B	7	$2.2x10^{-6}$	Clayey sand
C	9	$2.3x10^{-6}$	Pumice with minor silt
D	13	$5.2x10^{-6}$	Silty graveled sand
E	17	$8.8x10^{-7}$	Conglomerates
P(L)-A	6	Not conducted	Limonite
B	7	$6.4x10^{-6}$	Limonite
C	9	Not conducted	Limonite
D	13	$4.8x10^{-6}$	Limonite
E	17	$3.4x10^{-6}$	Limonite

4.3.2 Hydraulic Gradients

Vertical hydraulic gradients measured between monitoring wells or piezometers in a single nest were consistently downward between the shallowest piezometers (directly below the water table) at each of the three sites indicating a component of local groundwater recharge (Figure 9). However, the deeper piezometers show both downward and upward gradients indicating either groundwater discharge from deeper flow systems and/or the influence of low-permeability layers. The geologic cross-section (Figure 8) does not indicate the existence of an extensive low-K layer, but rather, a heterogeneous layering of materials of varying K and limited lateral extent.

Horizontal hydraulic gradients were estimated using the hydraulic heads for the deepest piezometer at each site and vary from 0.006 (between B(H) and T(M)) to 0.003 (between (T(M) and P(L)).

Groundwater flow is thus interpreted to be generally horizontal from the volcanic chain towards the coast, with discharge zones located around the coastal estuaries. The geologically layered, or aquifer-aquitard, system apparently has significant vertical gradient and gradient reversals in any given vertical profile.



Note that P(L)-C may not be equilibrated.

4.3.3 Equipotentials

Hydraulic heads estimated from 78 wells in the alluvial aquifer were plotted on a map to obtain a contour map (Figure 11) of the water table, showing lines of equal hydraulic head (equipotentials). These wells are mostly dug to just a meter or two below the water table; however, several are drilled and screened at depth further below the water table (Appendix C).

The interpreted groundwater flow direction approximately follows the topographic gradient flowing in a southwesterly direction from the volcanic mountains towards the coast. A notable exception to this pattern is in the southern part of the study area where small hills representing outcrops of the underlying (and less conductive) *Tamarindo Formation* (see Figs. 6a and 6b) cause a local groundwater mound.

4.3.4 Hydraulic Head Variation Over Time

Hydraulic head variations with time for each of the three piezometer nests (Tables 16 to 18, Figure 10) and water levels from the observation well, T(M) – I (located six meters from wells T(M)-A and T(M)-D) , in general, gradually decline over the dry season as expected. There are insufficient data at B(H) to observe temporal variations. A significant exception is at P(L)-C which shows a gradual ascending pattern with time approaching the levels of the other piezometers. This may indicate the piezometer was very slowly approaching static equilibrium as it is screened in materials of very low hydraulic conductivity and/or insufficiently developed (fine materials removed) following installation

Table 16. Recorded Water Levels (masl) at Calle Real del Bosque

Date	B(H) – A	B(H) - B	B(H) - C	B(H) - D	B(H) - E
14-16/Nov/2001	98.66	98.72	98.68	98.66	98.68
31/Jan/2002	98.29	95.30	98.33	98.30	98.36
06/Feb/2002	98.33	98.35	98.35	98.30	98.36
12/Mar/2002	98.06	98.03	98.14	98.06	98.14

masl= meters above sea level

Table 17. Recorded Water Levels (masl) at El Trianón

Date	T(M) - A	T(M) - B	T(M) - C	T(M) - D	T(M) - E	T(M) - I
16-17/Nov/2001	41.75	41.67	41.52	41.75	41.52	nm
23/Nov/2001	42.13	41.99	41.74	42.14	41.90	nm
31/Jan/2002	41.74	41.71	41.46	41.73	41.48	42.22
06/Feb/2002	41.86	41.67	41.48	41.85	41.48	42.31
07/Feb/2002	41.87	41.67	41.69	41.85	41.69	42.31
23/Feb/2002	41.87	41.68	41.49	41.85	41.51	42.30
11/Mar/2002	41.69	41.55	41.37	41.69	41.36	42.12
24/Mar/2002	41.64	41.46	nm	41.64	42.21	41.99
05/Apr/2002	41.54	41.35	41.22	41.51	41.24	41.91
21/May/2002	41.61	41.46	41.27	41.61	41.28	nm

masl= meters above sea level **ET(M)-I = INETER'S Monitoring Well**

nm= not measured

Table 18. Recorded Water Levels (masl) at El Polvón

Date	P(L) - A	P(L) - B	P(L) - C	P(L) - D	P(L) - E
20/Nov/2001	15.68	15.79	15.65	15.68	15.65
24/Nov/2001	15.62	nm	15.65	15.68	15.67
31/Jan/2002	16.29	16.24	16.24	16.29	16.21
06/Feb/2002	16.43	16.35	16.49	16.39	16.41
07/Feb/2002	16.24	16.37	10.67	16.42	16.44
12/Mar/2002	16.29	16.55	12.04	16.49	16.51
24/Mar/2002	nm	16.27	15.98	16.32	16.31
05/Apr/2002	17.1	15.96	13.59	15.99	16.00
20/May/2002	16.04	16.10	15.48	16.17	16.11

masl= meters above sea level **nm= not measured**

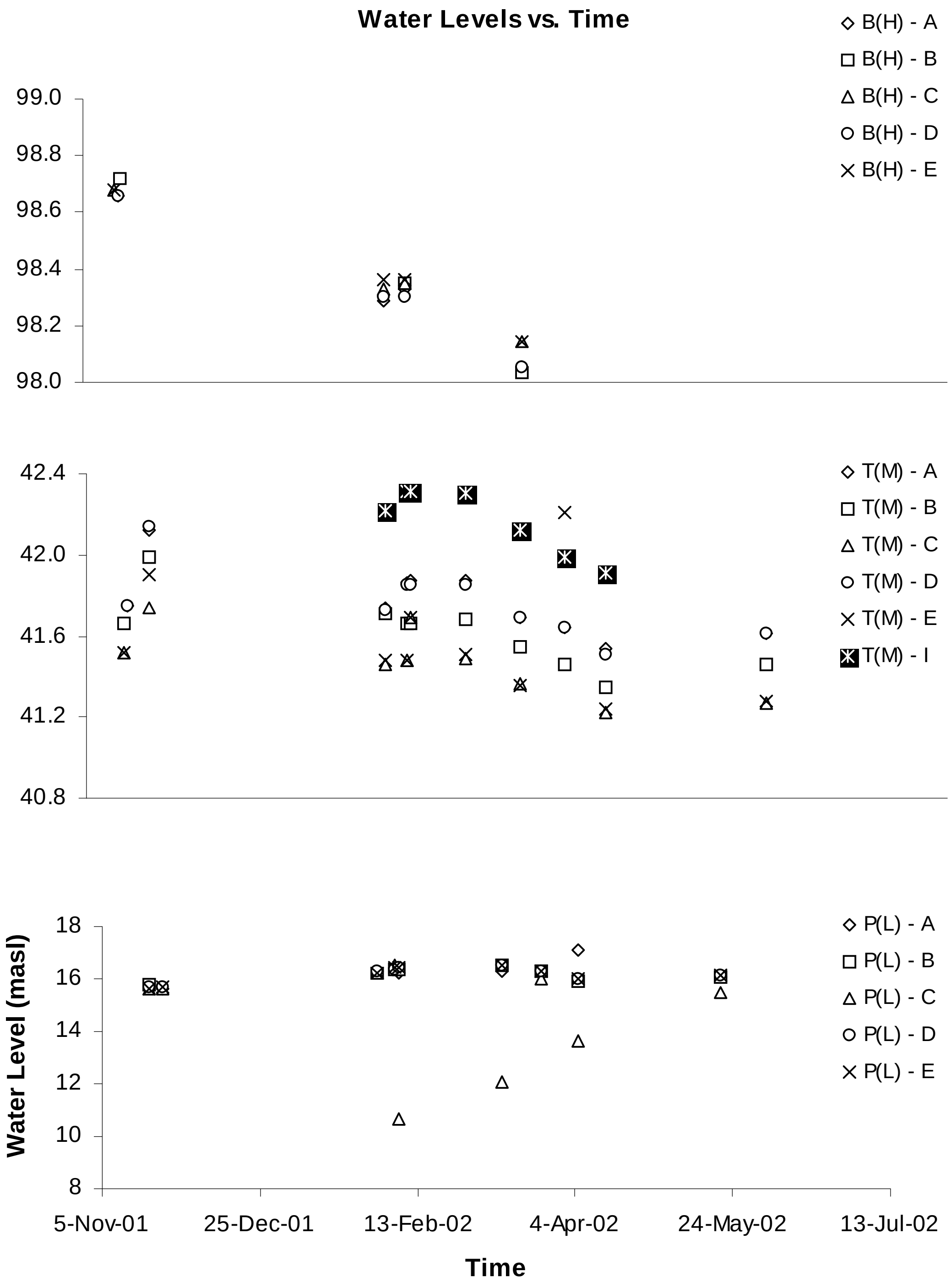


Figure. 10. Water Levels vs. Time at the Three Monitoring Installation Sites.

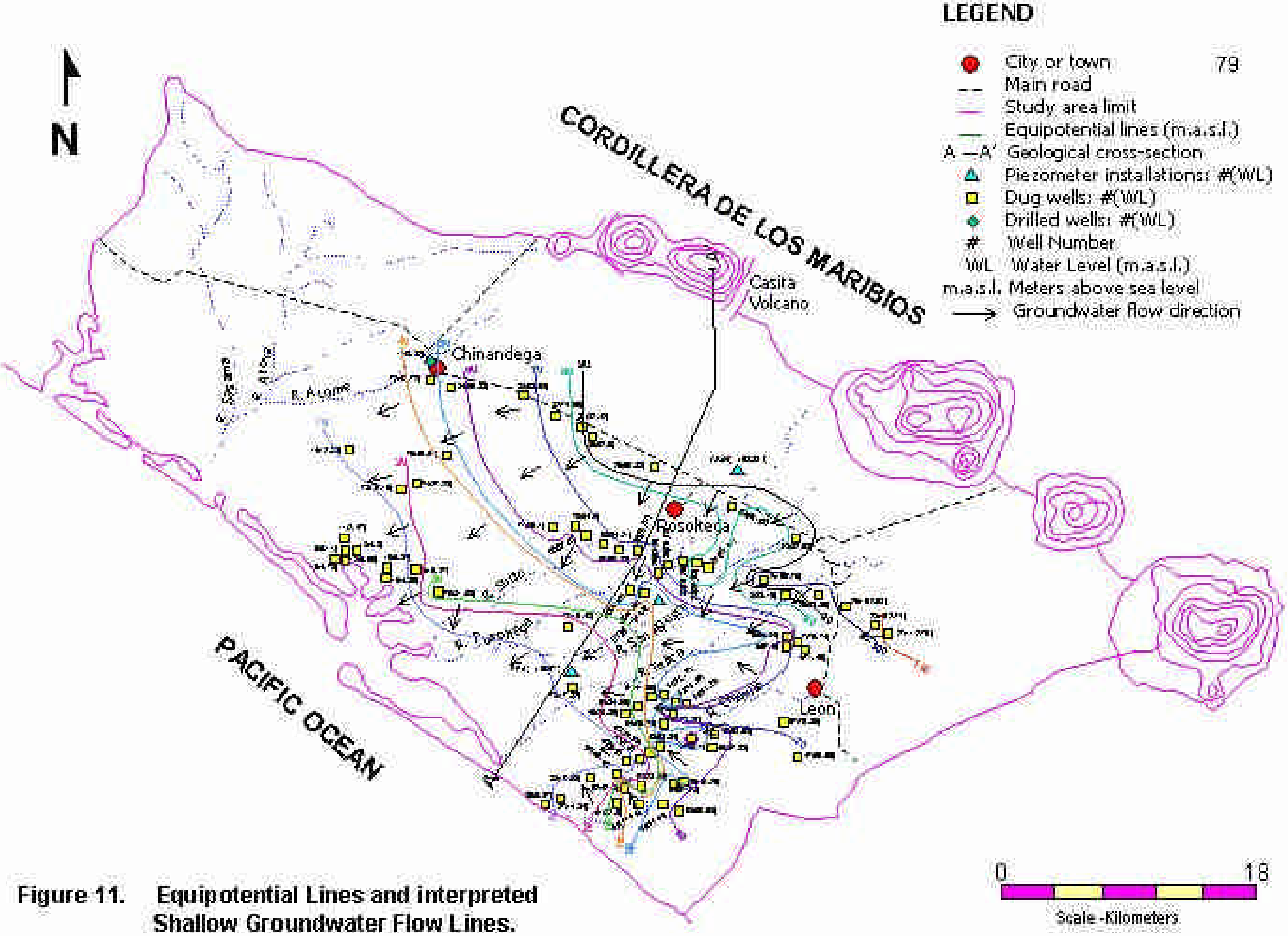


Figure 11. Equipotential Lines and interpreted Shallow Groundwater Flow Lines.

4.4 Aqueous Geochemistry

4.4.1 Major Ions

Major ion characterization of the waters (Table 19, Figure 12) indicates the water is mainly bicarbonate-calcium-magnesium type. The only significant exception is P(L)-E which has relatively low concentrations of calcium, magnesium, bicarbonate, alkalinity, total dissolved solids and electrical conductivity. This suggests the water originates from a different geologic unit compared to the other piezometers. Total iron concentrations are above the aesthetic guideline value (0.3 mg/L) at all sampling points indicating the influence of geothermal activity. The highest iron level is T(M)-B where the level is 15.6 mg/L. The limonite mineralization noted in the geologic profiles (Section 4.2.2) likely results from interaction of geologic materials with iron-rich water. Higher silica concentrations at T(M) installations suggest groundwater at this point has had a relatively long groundwater residence time with consequently more rock-water interaction.

4.4.2 ^{18}O and ^{2}H in Precipitation and Groundwater

The purpose of collecting samples for ^{18}O and ^{2}H in precipitation and groundwater is to estimate the elevation (in the volcanic highlands) at which groundwater below the agricultural plain is recharged. The isotopic composition of precipitation is characterized by high spatial and temporal variability resulting from numerous meteorological factors such as humidity, temperature, amount and source of storm events (Clark and Fritz, 1997). Monthly, seasonal and annual variations are common and demonstrate the need to collect precipitation data over several years. By contrast, groundwater represents a mix of many years of precipitation events and thus represents a long-term average isotopic value.

AQUI VA LA TABLA 19 CON MAJOR/MINOR IONS RESULTS

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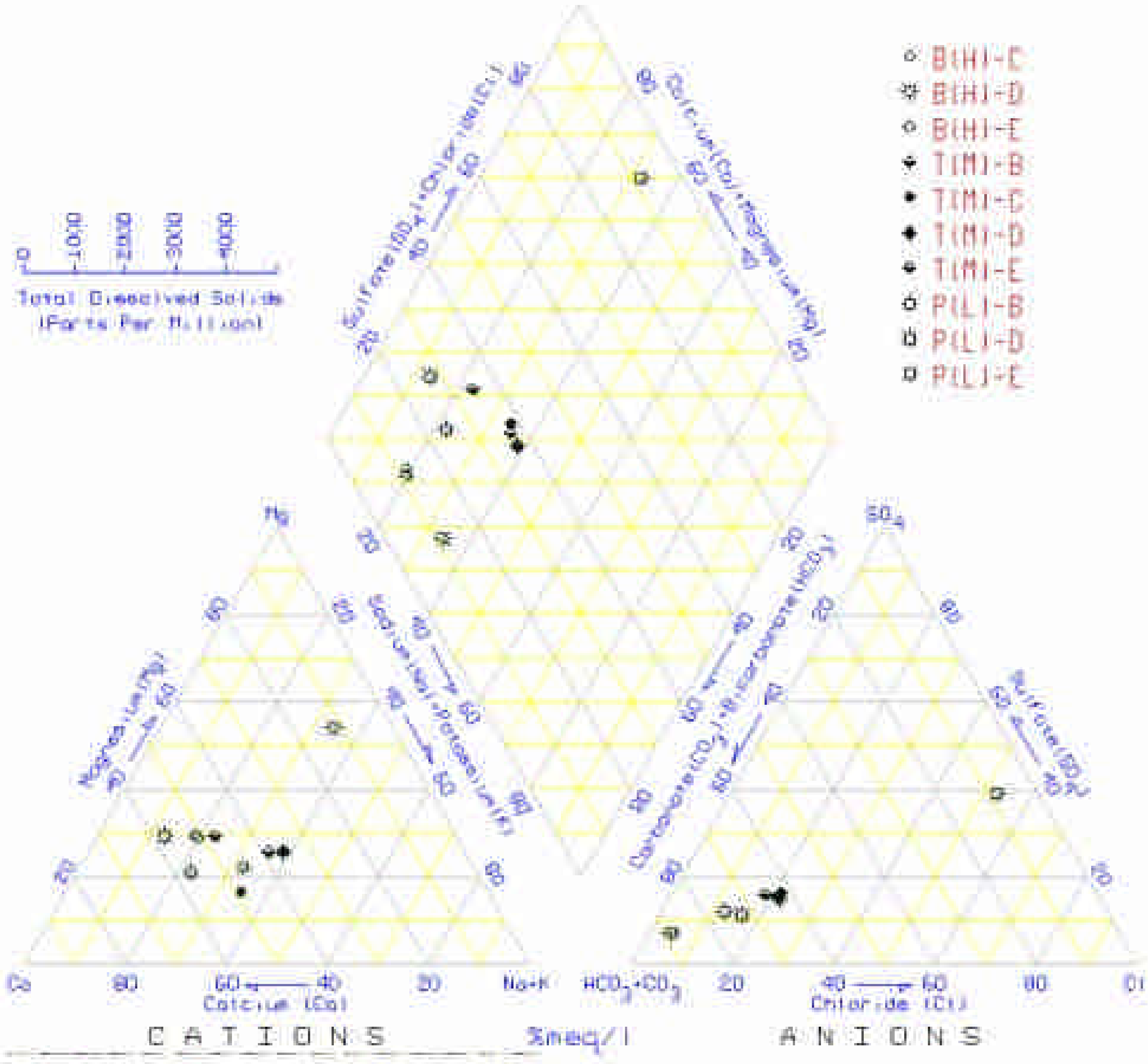

Figure 12. Piper Plot of Major Ions in Groundwater.

Since dispersion (groundwater mixing; Freeze and Cherry, 1979) causes groundwater isotope values to be less variable than precipitation, they are useful as an approximation of the long-term isotopic composition of precipitation and groundwater recharge (Clark and Fritz, 1997). The stable isotope composition of water sampled from the headwaters of rivers, or springs, are also to estimate the mean isotopic composition of spring.

Precipitation

Isotope precipitation data (Table 20) from all three sites shows a wide variation in ^{18}O and ^{2}H values with ^{18}O varying from –0.5 to –10.3‰, and ^{2}H varies from –17 to -74.3‰. Based on an amount weighted-average for the limited time period available, P(L) appears to be slightly more depleted than B(H) or T(M). A possible seasonal effect is also observed at B(H) and P(L) where both ^{18}O and ^{2}H enrich slightly as rainfall decreases.

Table 20. Isotope Precipitation Data from the three Sites.

	Rainfall amount (mm)			d^{18}O (‰)			d^{2}H (‰)		
	B(H)	**T(M)**	**P(L)**	**B(H)**	**T(M)**	**P(L)**	**B(H)**	**T(M)**	**P(L)**
Elev (masl)	139	66	19						
Jan-02	nr	nr	0.00	--	--	--	--	--	--
Feb-02	0.20	nr	0.00	--	--	--	--	--	--
Mar-02	0.00	nr	0.00	--	--	--	--	--	--
Apr-02	0.00	nr	0.00	--	--	--	--	--	--
May-02	265.95	nr	19.17	--	--	--	--	--	--
Jun-02	306.23	249.00	14.63	-8.1	-7.1	-10.3	-55.9	-50.5	-74.3
Jul-02	40.20	100.12	3.27	-3.3	-2.1	--	-43.0	-18.0	--
Aug-02	169.20	104.80	7.01	-0.5	-5.0	-8.5	-17.0	-45.0	-70.0
Sep-02	368.00	844.40	na	-3.8	-8.2	-3.9	-35.0	-30.0	-65.0
Oct-02	94.55	173.20	na	--	--	--	--	--	--
Nov-02	9.16	22.50	na	--	--	--	--	--	--
Dec-02	na	na	na	--	--	--	--	--	--
Average annual isotope composition (volume weighted average)				-4.62	-7.27	-9.73	-39.15	-34.21	-72.89

nr= not recorded, because rain gauges were not installed yet

na= not available -- = not sampled

The high monthly variation observed is common and demonstrates the need to use precipitation data collected over at least an entire year. In addition, slight variations from year to year likely depend on the amount, type and source of rainfall events. Precipitation isotope data from two previous studies (Payne and Yurtsever, 1974; and CIRA/IAEA, 1999) are thus combined with the data collected in this study to provide a longer-term data set (Figure 13, Appendix G). These data are plotted as the Local Meteoric Water Line (LMWL; Figure 13), which has a slightly different slope on ^{18}O versus ^{2}H from the Global Meteoric Water Line (GMWL), reflecting the meteoric conditions at each sampling time.

The combined data show a trend of isotopic depletion with increasing altitude (Figure 14). While lower elevation groundwater tends to have ^{18}O values over a large range, the upper elevation values tend to be depleted. This could be because the groundwater that occurs at lower elevation could be a mix of groundwaters that recharged at both lower and higher elevations, while those at higher elevations were recharged exclusively at high elevations.

Groundwater

Stable isotope ratios were measured on groundwater samples from 6 dug and 8 drilled wells, 3 springs, 3 rivers, and the three piezometers sites (B(H), T(M) and P(L); Table 21). A plot of ^{18}O versus ^{2}H including Payne and Yurtsever (1974) data (Figure 15) shows groundwaters isotope composition from both studies are within the same ^{18}O range (-5.5‰ to -8.0‰), meanwhile ^{2}H composition for drilled wells from this study is slightly depleted compare to the Payne and Yurtsever (1974) data. Tidal marshes samples are much enriched, which is consistent with waters that undergo evaporation. Only T(M) samples show ^{18}O depletion with depth (Table 19).

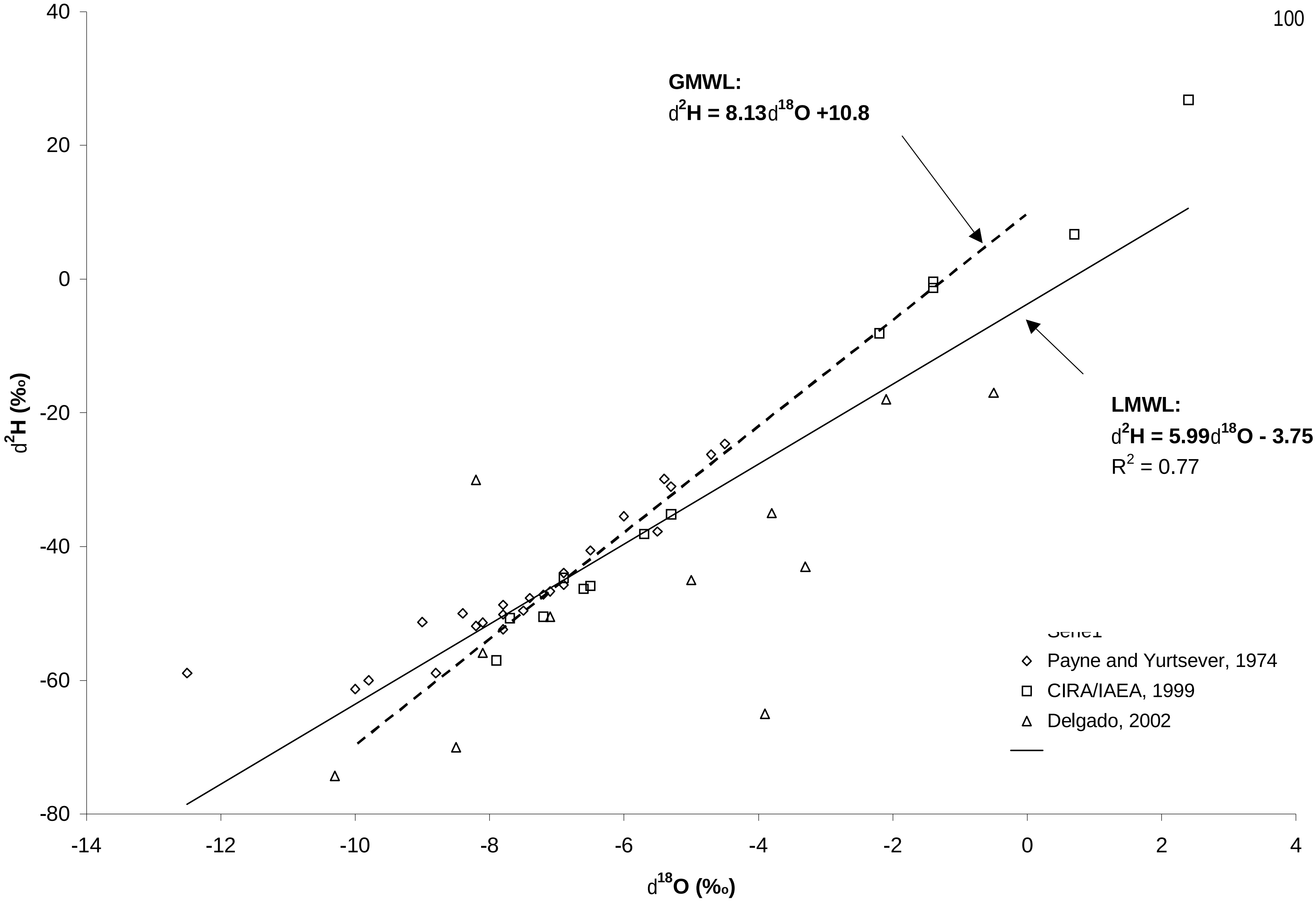

Figure 13. Stable Isotope Composition of Precipitation from León-Chinandega.
The Local Meteoric Water Line (LMWL) is estimated based on all three studies shown.

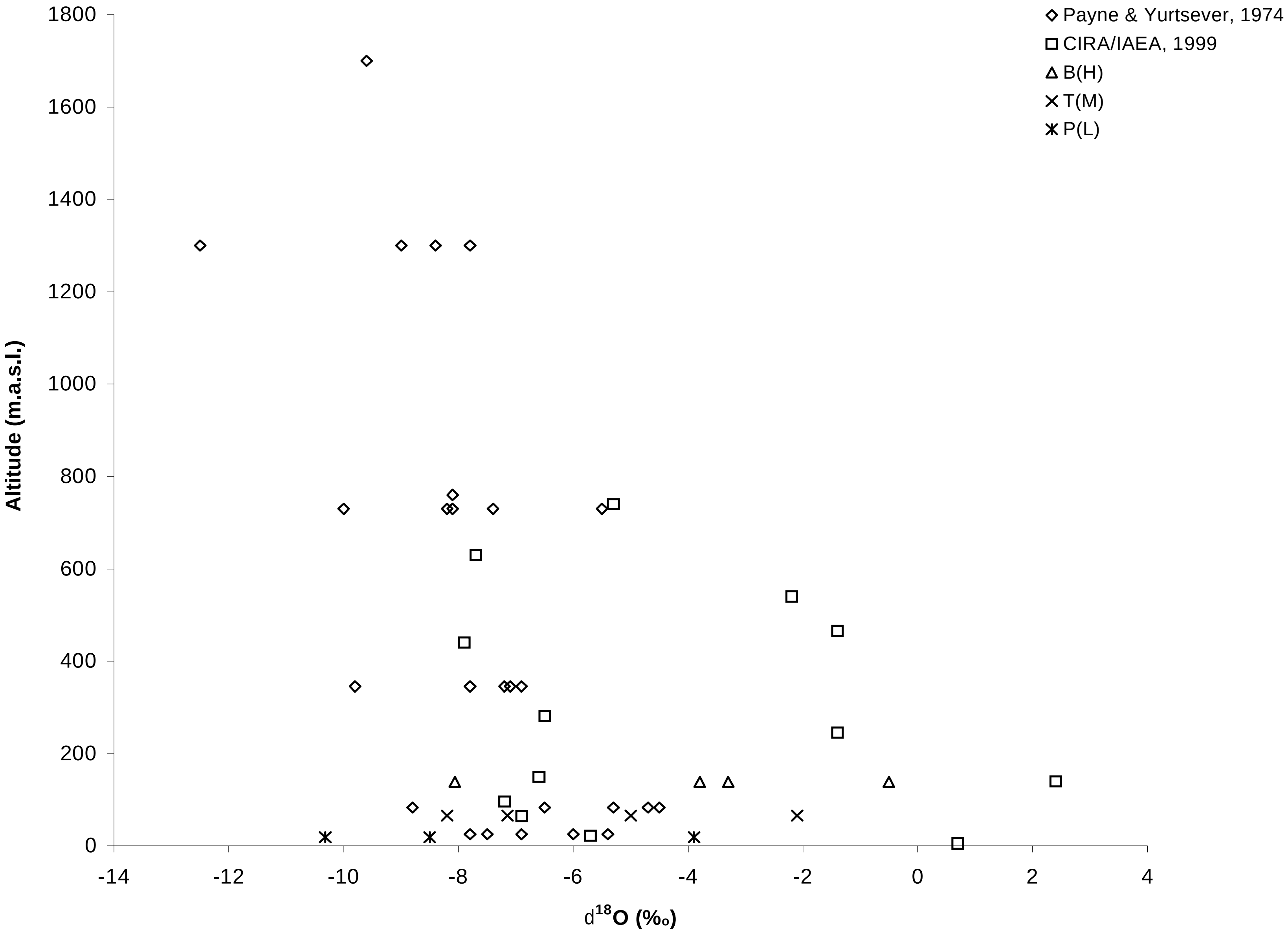

Figure 14. Altitude Effect in Precipitation from León-Chinandega.

Table 21. Groundwater Isotope Data

Code	Sampling Date	Altitude (masl)	Distance[1] (km)	Depth (mbgs)	^{18}O (‰)	^{2}H (‰)
PE-1	02-Nov-00	5	5	2.0	-7.1	-59.0
PE-1-DUP	02-Nov-00	5	5	2.0	-7.1	-53.3
PE-4	02-Nov-00	7	6	2.5	-6.7	-48.9
PP-76 N1	01-Nov-00	7	6	8.0	-6.6	-55.5
PP-76 N2	01-Nov-00	7	6	18.0	-6.8	-50.6
PE-2	02-Nov-00	17	--	1.5	-7.1	-53.4
PE-3	02-Nov-00	23	10	4.0	-7.1	-49.0
PP-129 N1	01-Nov-00	28	11	14.0	-6.8	-54.4
PP-129 N2	01-Nov-00	28	11	35.0	-6.9	-49.6
PP-129 N3	01-Nov-00	28	11	43.0	-6.9	-36.7
PP-129 N4	01-Nov-00	28	11	55.0	-6.8	-48.6
PP-130	02-Nov-00	29	11	Surface	-6.8	-45.3
PP-133 N1	03-Nov-00	66	15	32.0	-7.4	-50.2
PP-133 N1 DUP	03-Nov-00	66	15	32.0	-7.4	-48.5
PP-133 N2	03-Nov-00	66	15	47.0	-7.4	-50.6
PP-133 N3	03-Nov-00	66	15	63.0	-7.8	-45.0
PP-133 N4	03-Nov-00	66	15	70.0	-7.4	-55.5
PE-6	02-Nov-00	112	18	23.0	-5.9	-43.5
PE-5	02-Nov-00	140	19	32.5	-6.8	-45.6
PPNSL-N1	02-Nov-00	156	20	74.0	-7.5	-57.3
PPNSL-N2	02-Nov-00	156	20	84.0	-7.6	-50.9
PPNSL-N3	02-Nov-00	156	20	94.0	-7.6	-50.0
PPMN-N1	02-Nov-00	180	21	Surface	-7.0	-51.1
PPMS-N1	02-Nov-00	200	18	Surface	-7.0	-51.5
PPLB-N1	02-Nov-00	229	22	Surface	-6.8	-54.0
B (H) - A**	21-Jul-02	139.808	36.75	47.0	-6.4	-44.0
B (H) - C**	07-Sep-02	139.921	36.75	50.0	-5.5	-48.0
B (H) - D**	07-Sep-02	139.781	36.75	54.0	-6.3	-46.0
B (H) - E**	07-Sep-02	139.909	36.75	58.0	-5.8	-47.0
T (M) - A**	12-Dic-01	42.89	20.85	6.0	-6.6	-40.0
T (M) - B**	12-Dic-01	42.81	20.85	7.0	-7.6	-45.0
T (M) - C**	12-Dic-01	42.66	20.85	9.0	-7.5	-45.0
T (M) - D**	12-Dic-01	42.89	20.85	13.0	-7.6	-45.0
T (M) - E**	12-Dic-01	42.65	20.85	17.0	-8.1	-46.0
P (L) - A**	15-Jun-02	17.510	10.3	6.0	-7.1	-41.0
P (L) - B**	12-Dic-01	17.619	10.3	7.0	-6.4	-43.0
P (L) - C**	15-Jun-02	17.482	10.3	9.0	-5.6	-41.0
P (L) - D**	12-Dic-01	17.508	10.3	13.0	-6.5	-43.0
P (L) - E**	15-Jun-02	17.484	10.3	17.0	-6.6	-41.0
FCA-S-PEDRO*		440	31	Surface	-7.6	-52.0
MW-1***		0	5.45	0.5	-1.4	-16.4
MW-2***		0	3.05	0.5	-0.9	-13.7
MW-3***		0	1.65	0.5	-1.2	-21.4
MW-4***		0	2.65	0.5	-2.4	-26.2
MW-5***		0	1.6	0.5	-1.5	-24.7
Río Posoltega****		47.64	20.70	0.5	-6.2	-45.1
Naciente R. Posoltega*		73.91	25.50	Surface	-6.1	-45.0
Río Corvado****		46.53	19.65	0.5	-5.5	-42.2
Naciente R. San Agustín*		78.67	19.75	0.2	-6.0	-44.8
Presa San Jerónimo****		60.00	16.75	0.6	-6.0	-44.1

PP = Drilled Well
PE = Dug Well
DUP = Duplicate
-- = not applicable
1 = From the Pacific Coast
N = Level
*** = Spring**
****= monitoring well**
*****=sea water**
******= river**

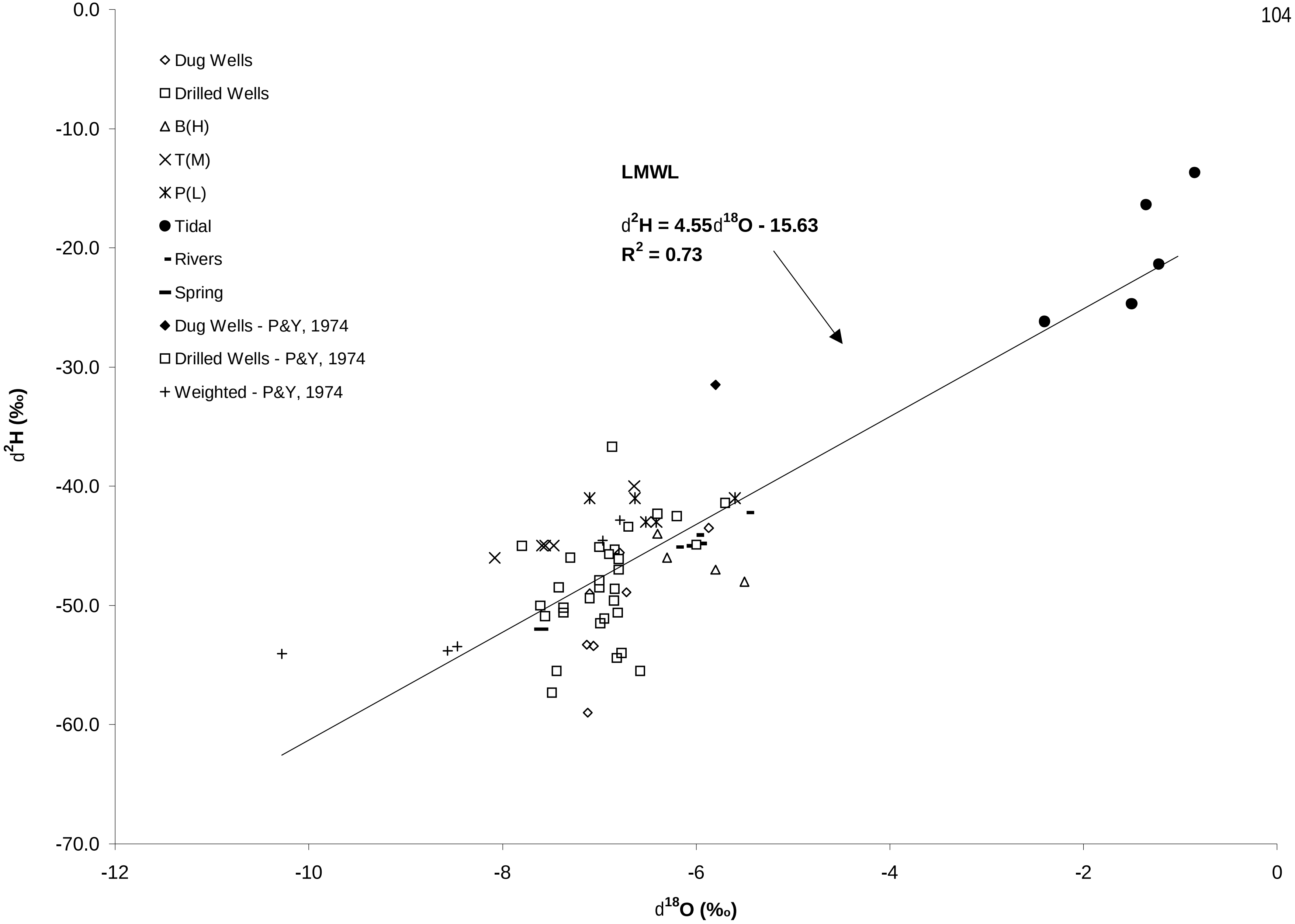

Figure 15. Isotope Composition in Groundwater, Surface Water, and Precipitation Sampled in León and Chinandega

Estimated Groundwater Recharge Elevations

Due to the high temporal variability in precipitation isotope values, Payne and Yurtsever (1974) used the isotopic composition of groundwater at different elevations to calculate the following relation between elevation and ^{18}O of recharge; ^{18}O = -5.653 – 0.0026E, where E = elevation in meters above mean sea level. This relation is used to estimate the recharge elevation of groundwater samples collected in this study.

Groundwater ^{18}O values are plotted versus elevation (Figure 16). The relation calculated with Payne and Yurtsever (1974) data between ^{18}O of recharge and elevation is also plotted. Estimated recharge elevations are also indicated each piezometer nest based on Payne and Yurtsever's (1974) relation. It can be seen that B(H) recharges between 139 m and 598 m, average at 380 m; T(M) recharges between 42 m and higher than 1200 m, average at >1200 m; and P(L) recharges between 17 m and 1140 m, with average at 730 m.

These estimated recharge elevations are shown on a regional cross-section from the topographic high point (Casita volcano) to the Pacific coast (Figure 17). For the upper two-piezometer nests, the estimated recharge elevations are connected to the nest by approximating the groundwater flowlines. The highest recharge elevations were estimated for piezometer nest at moderate elevation (T(M)). This suggests a deeper flow system consistent with conventional conceptual understanding of groundwater flow (Freeze and Cherry, 1979). This is also consistent with a longer flow path suggested by the slightly elevated silica concentrations. The high range in recharge elevations observed in the lowest piezometer nest (P(L)) is consistent with a heterogeneous flow system. Although we have some insight into vertical heterogeneity here, we have little insight into horizontal heterogeneity. Given volcanic aquifer and aquifers can be deposited as discrete lava flows and or alluvial processes (with limited aerial extent) and also through the air (with larger aerial extents possible), the resulting deposits can be geologically heterogeneous. In addition, groundwater flow directions interpreted from water well data (Figure 11) suggest the lowest piezometer nest receives groundwater from different directions. The isotope data also suggest that this nest receives groundwater recharge from the widest range of elevations.

4.5 Mixing of Regional Flow System and Shallow Recharge

It is apparent that the groundwater sampled in the study area represents a mix of regional, intermediate and local flow systems. Mixing of groundwaters recharged in different elevations is common in mountainous watersheds and this process is likely exacerbated with this particular flow system given the tendency to concentrate groundwater flow in the more conductive alluvial aquifer (Qal).

Evidence of this mixing is given by the correlation between ^{18}O (indicator of regional flow) and tritium (indicator of modern recharge), as well as ^{18}O and nitrate (indicator of shallow recharge), ^{18}O and chloride (indicator of mixing trends, and geochemical processes in the subsurface). Correlation between ^{18}O and tritium from Payne and Yurtsever (1974) groundwater results (Appendix G; Figure 18) mainly shows two groups, in the first group where most (<80%) the wells have groundwaters considered as regional flow that have mixed with shallow modern groundwaters in the discharge zone or within boreholes; meanwhile the second group with tritium units (TU) >~20 indicates recharge during the 1960's (Clark and Fritz, 1997). As mentioned before in section 4.3.2, the vertical hydraulic gradients measured at the monitoring wells at each of the three sites, indicate a downward flow in the shallowest groundwater (Figure 9). At each site, vertical gradients alternate between upwards and downwards in the deep point. This indicates there is upward and downward groundwater flow, which could contribute to the mixing between local and regional groundwater systems.

4.6 Groundwater Quality Impacts

Water quality impacts related to both natural (volcanism) and anthropogenic sources are presented and discussed in the context of the physical groundwater flow system.

4.6.1 Volcanism-Related Impacts

The impacts of local volcanism are evident by very high iron levels (up to 15.6 mg/L) in all groundwater samples (Table 19).

When igneous rock minerals whose iron content is relatively high, react with water, the iron that may be released is generally reprecipitated nearby as sedimentary species. In oxidizing environments the sedimentary species will be ferric oxides or oxyhydroxides (Hem, 1985). The mineral limonite ($2Fe_2O_3.3H_2O$) is a very common material in the oxidized zones of iron-bearing deposits of secondary origin; it is produced by the decomposition of many iron minerals, particularly goethite (-FeOOH), with water being retained in varying amounts, or for alteration of silica rock in subtropical climate. Limonite has been known to pseudomorph other minerals such as pyrite (FeS_2), and as a result is often finely disseminated, mixed with clays and other minerals, or found in massive amorphous lumps. In the study area, silts near the coast appear to have been most significantly altered by limonite mineralization as can be observed in the geologic log at P(L).

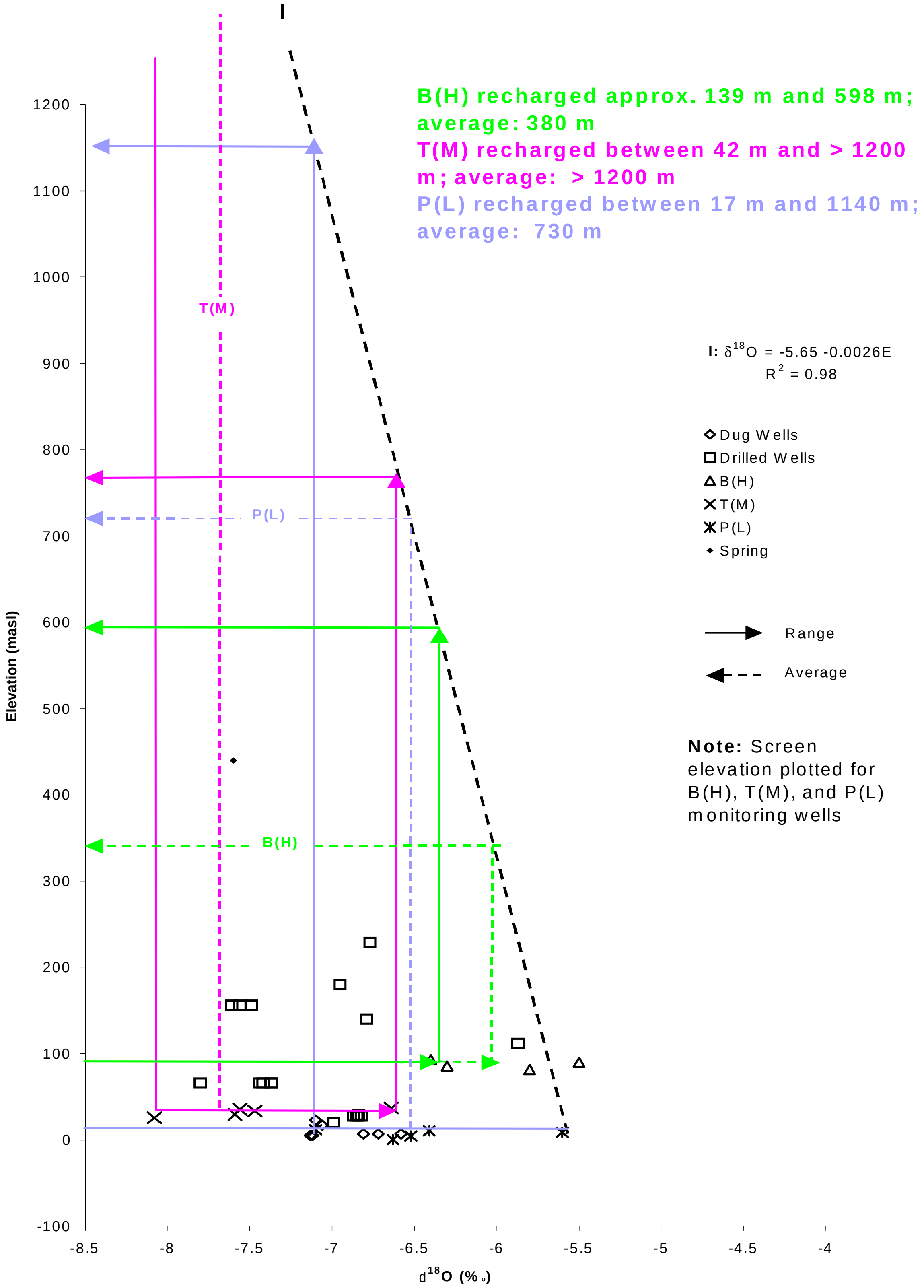

Fig. 16. Predicted Recharge Elevation, based on Payne and Yurtsever Relation (1974) between ^{18}O and Elevation of Recharge

AQUI VA LA FIG. 17: X-SECTION CON VALORES ISOTOPICOS

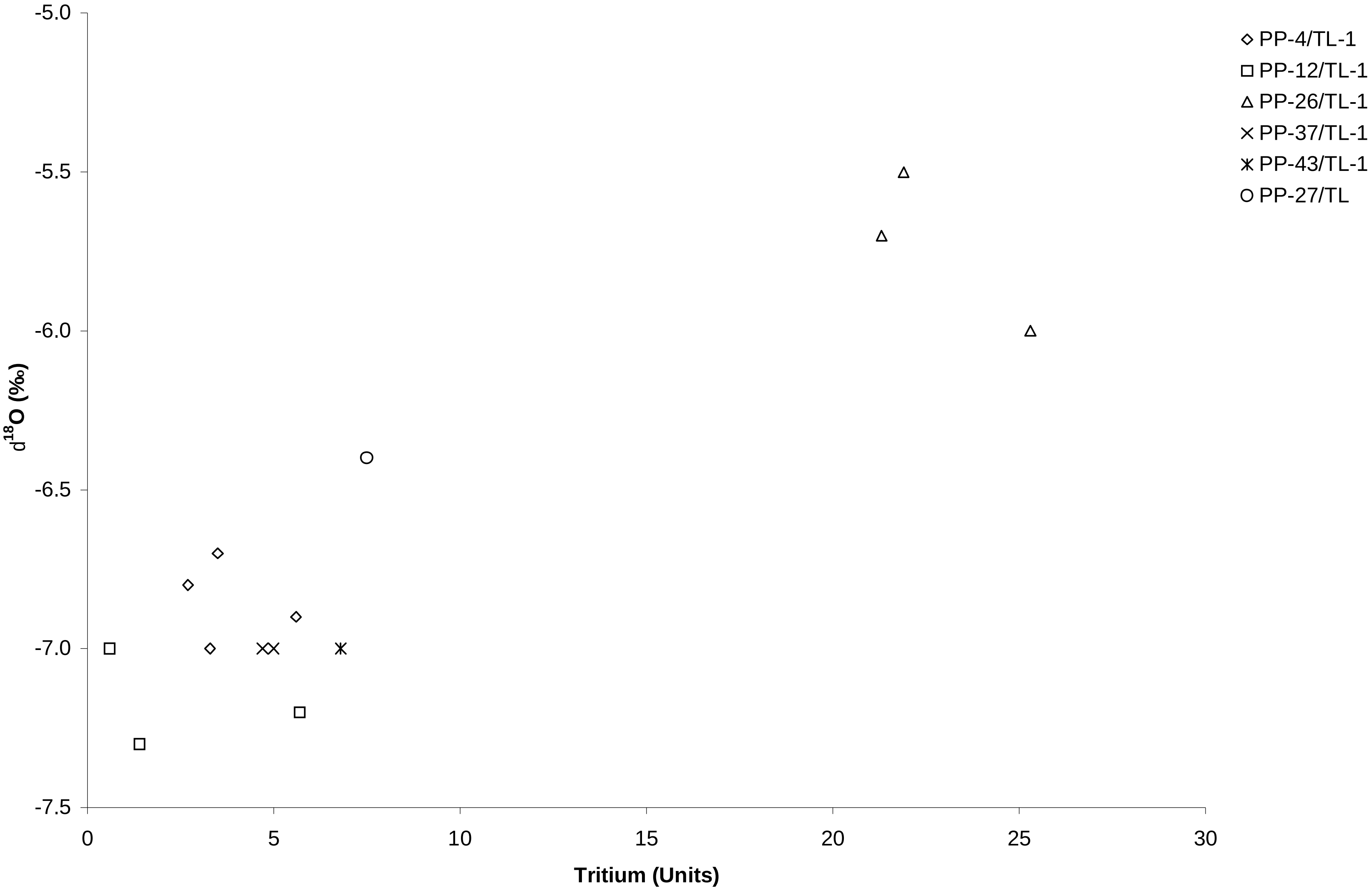

Figure 18. Oxygen 18 vs. Tritium in Groundwater Samples from Payne and Yurtsever (1974)

Volcanic spring waters of the calcium-bicarbonate type are believed to attain their character at relatively low temperature through the mixing in limestone beds of a little volcanic water with very abundant meteoric water (White, 1957). Volcanic groundwaters are expected based on the relatively higher Na and K concentrations, compared to the carbonated groundwaters, which are instead typified by higher Ca and Mg concentrations (Stetzenbach et al., 2001). For those groundwaters that interact with the volcanic rocks, large amounts of highly soluble Na may be dissolved that would in effect mask a carbonate groundwater signature that would be dominated by Ca and Mg (Stetzenbach et al., 2001), which is the case at T(M) where Na concentrations are as high as Ca concentrations; meanwhile at B(H) and P(L) Na is equal and/or higher than Mg. This enrichment in Na at the expense of Ca indicates the release of Na mainly from the glassy matrix in the alkaline volcanics and their sedimentary derivatives; another feature is the significant enrichment in Mg/Ca ratio representing the weathering of the mafic minerals (Edmunds et al., 2002).

The silica content of volcanic springs of the calcium-bicarbonate type is commonly as low as 50 or 60 mg/L (White, 1957).

Volcanic activity is an important source of F to the atmosphere, mainly in the form of hydrofluoric acid (HF). A significant release of F is also associated with persistent non-eruptive degassing. Due to these huge emissions, meteoric recharge is thought to be the main F source of the groundwater system (Aiuppa et al., 2003).

4.6.2 Anthropogenic Impacts

Anthropogenic impacts emanate from human waste and/or land-use activities. In the study area, the main sources of contamination are household/community sewage (and other waste), and agrochemicals (fertilizers and pesticides).

Chloride

Chloride in water is a common indicator of human or animal sewage or fecal waste. Chloride is not a significant component of most nitrogen fertilizer compositions, but is usually applied with potassium, which is normally formulated as KCl. Elevated chloride levels (compared to background) are not a health-risk but indicate the potential for finding sewage-related pathogens.

Chloride levels in all piezometers at B(H), T(M) and P(L) are below the drinking water guideline value of 250 mg/L. It can be observed that chloride levels are slightly higher at T(M) and P(L) compared to B(H). This is indicative of a gradual increase in the impact of human and/or animal waste on the aquifer. Chloride does not appear to be associated with deeper hydro thermally altered groundwaters in this area (Feth and Hem, 1963). Sodium-chloride waters of hydrothermal origin are fairly common in the world but distinguishable by relatively high lithium, fluorine, silica, boron, sulfur, CO_2, arsenic, and antimony; by relatively low calcium and magnesium (White, 1957).

Correlation between ^{18}O and chloride shows a weak tendency for higher elevation recharge groundwater to have higher chloride; and the same behavior is observed when comparing these parameters for the different studies in the zone (Figure 19).

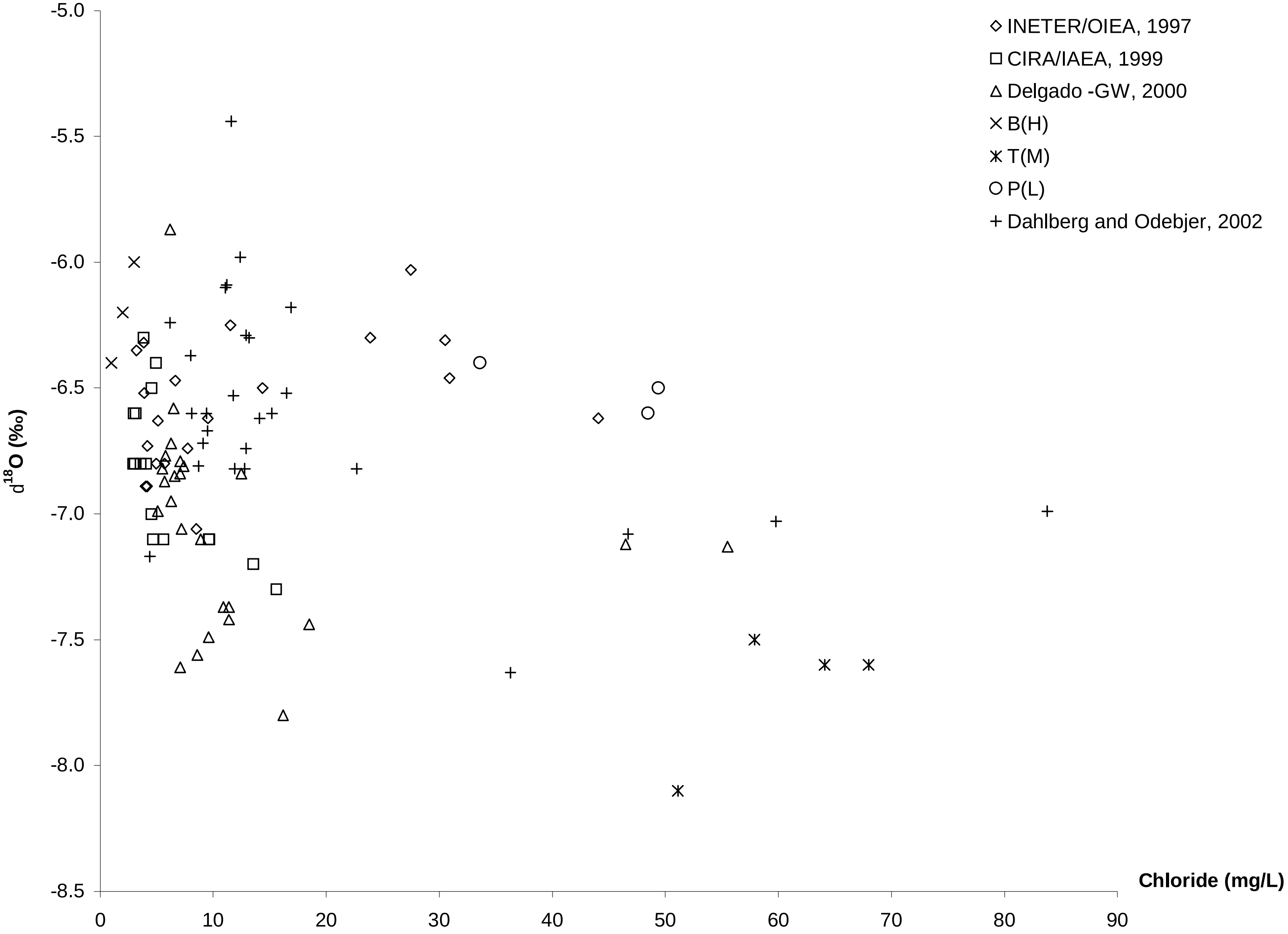

Figure 19. Oxygen 18 vs. Chloride in Groundwater from León-Chinandega, Several Studies

Nitrate

Nitrate emanates from natural sources, human sewage, and agricultural fertilizers. Nitrate concentrations in groundwater from all piezometers were all below drinking water guidelines (10 mg/L as N). The highest concentrations were detected at B(H). In the U.S., a typical background nitrate concentration in groundwater of 2 mg-N/L has been reported (Mueller and Helsel, 1996). Seventy percent of the samples have a nitrate concentration above this background nitrate concentration. Nitrite and ammonium levels are also below drinking water guidelines.

Correlations between nitrate and sulfate, and nitrate and bicarbonate (Figure 20) indicate that at lower nitrate concentrations there is an increase in both sulfate and bicarbonate concentrations. This could indicate that nitrate is potentially being denitrified with sulphide and/or organic carbon oxidation. United Nations (1974; Table 2) observed that in dug and drilled wells, nitrate concentrations tend to increase during dry season, and decrease during wet season; however, in some drilled wells this trend is inverted due to the recharge arrival time to the groundwater aquifer. Probably, some of the nitrates and nitrites present in the waters from the area come from commercial fertilizers such as urea, sulfates, and ammonium nitrates. In cotton and sugarcane culture, for example, approximately 27,425 tons of commercial fertilizer were use/applied in a normal year. In some years, these applications were done three times (UN, 1974).

It can be observed, comparing nitrate concentrations from dug and drilled wells from this study and UN study (1974; Table 22), that nitrate concentrations may have decreased slightly.

Table 22. Nitrate Concentration (mg NO_3^- -N/L) during two study periods in the study area (2002-2003 data from this study; 1974 data from UN study).

	Dug Wells		Drilled Wells	
	2002-2003	**1974**	**2002-2003**	**1974**
Average	4.9	6.3	2.4	2.7
Minimum	2.9	0.9	0.5	<0.1
Maximum	8.2	21.7	6.2	9.9
Std. Dev.	2.2	n.a.	1.7	n.a.
n	7	n.a.	28	n.a.

n.a.: not available

Nitrate can also be naturally produced in volcanic fumarole deposits (Dolgoff, 1998). There is a decrease in nitrate concentrations as chloride concentrations increase (Figure 20) suggesting potential denitrification is occurring; meanwhile increase in chloride concentrations suggest that human activities may be the principal cause in chloride circulation.

A cross plot of ^{18}O and nitrate among the different studies in the zone (Appendixes F and G; Figure 21) suggests that groundwaters in the zone are mainly a mix of more regional flow and less shallow recharge. The highest nitrate concentrations tend to occur in water with more enriched $\delta^{18}O$ values (from –5.44‰ to –6.62‰), indicating waters predominantly recharged at lower elevations of significant agricultural activity (from 17 to 70 masl).

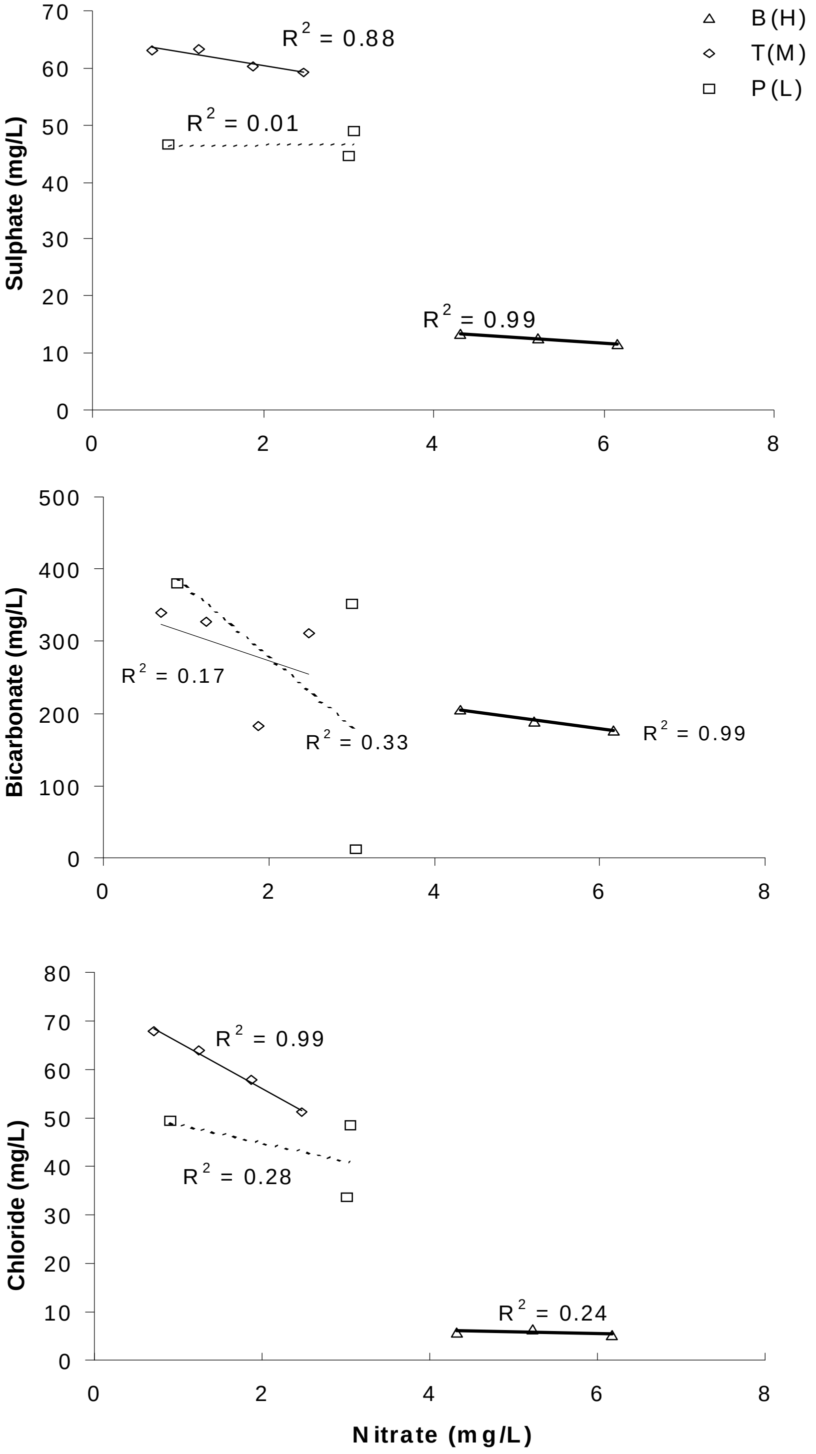

Figure 20. Correlations for the three Sites

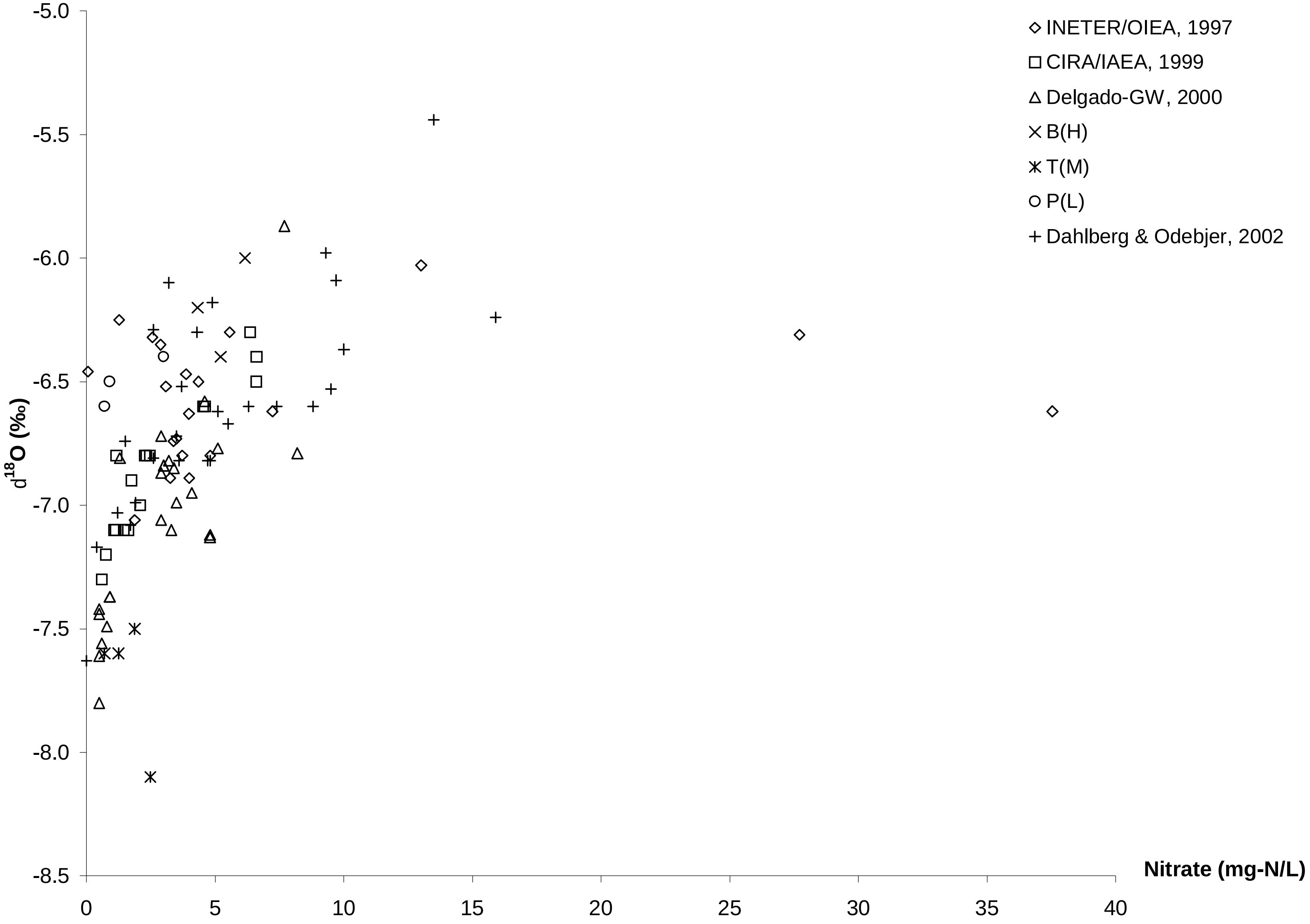

Figure 21. Oxygen 18 vs. Nitrate in Groundwater from León-Chinandega from Several Studies.

Bacteria

The presence of certain types of bacteria indicates the water has been impacted by human or animal waste. Bacteria measured in this study are total coliforms, fecal coliforms, fecal streptococcus and E. Coli and their presence is used as an indicator of pathogenic organisms (viruses, parasites, protozoa, etc).

Although only about half the piezometers were tested for bacteria, the results (Table 19) indicate both the intermediate (T(M)) and lower (P(L)) elevation piezometers are impacted. The shallowest piezometer at T(M) and the deepest piezometer at P(L) tested positively for bacteria. The levels are particularly high at T(M). The only sample taken from B(H) was at the deepest piezometer and no bacteria were detected.

The ratio of fecal coliforms to fecal streptococcus (FC/FS ratio) can be used to differentiate between human and animal sources of bacteria (Glynn and Heinke, 1996). A ratio of 4.0 or more suggests the bacteria emanates from human waste, whereas a ratio below 0.7 indicates the sources is animal wastes. For the two piezometers (one at T(M) and one at P(L)) that tested positive for bacteria, the FC/FS ratios are 4.66 and 5.0, respectively, suggesting that the source of pollution is human wastes. This is consistent with the lack of intensive cattle operations in the area.

Pesticides

Organochlorine and organophosphate pesticides were detected (Table 19) at all piezometers except the deepest point at T(M). In all, seven organochlorine (-BHC, lindane, dieldrin, pp-DDE, endrin, pp-DDD, and toxaphene) and two organophosphate (fenthion, ethyl-parathion) pesticides were detected. The concentrations of dieldrin, pp-DDD, and toxaphene are above drinking water guidelines were detected. Pesticide levels were highest at the deepest piezometer at the lower elevation site (P(L)). At this location, the toxaphene concentration was two orders of magnitude higher that EPA's guideline value (0.73 ng/L). Lindane, and pp-DDE were detected in both the Posoltega River and T(M); meanwhile pp-DDD was detected at the deepest piezometer in P(L) and Posoltega River nearby T(M).

4.7 Extent of Water Quality Impacts

Based on the information presented thus far, an interpretation can be made of the depth of anthropogenic water quality impacts in the alluvial aquifer. Isotopic data indicate groundwater sampled at the deepest (17 meters) piezometer at T(M) originates at a significantly higher elevation than the other sampling points, and groundwater from this site is consistent with volcanic signature. Above this depth, groundwater is clearly impacted by anthropogenic contamination (Figure 22). Intensive land use (from 17 up to 600 masl) is reflected in clearly anthropogenic impacts from pesticide application (Table 19) at the 3 sites, especially at T(M) and deepest piezometer in P(L).

4.8 Potential for Natural Remediation

It is apparent that some of the detected pesticides persist in the shallow soil zone long after their application and represent a long-term source of groundwater contamination. As discussed in Chapter 2, it is known that BHC, pp-DDT and toxaphene were applied in the cultivation of cotton from the 1950s to the 1980's but after that time, these compounds were only applied sporadically at best as they could only be purchased illegally. A study by Cuadra (2002; see Appendix I) found pp-DDT (and/or its daughter products pp-DDD and pp-DDE) and toxaphene in the upper 1-2 meters of soil at the three-piezometer locations (B(H), T(M) and P(L)). The pesticide pp-DDE was detected in 83% of the samples, pp-DDT in 75%, pp-DDD in 33% and toxaphene in 25% of the samples during the first sampling, meanwhile during the second sampling, organochlorine pesticides (DDT and its daughter products, dieldrin, endrin, and heptachlor-epoxide) were detected only at T(M).

4.9 Aquifer Vulnerability to Contamination

It is clear the shallow alluvial aquifer in the study area is, in general terms, highly vulnerable to contamination. This is concluded based partly on the fact that it is contaminated but also due to the shallowness of the water table and lack of substantive low permeability protective layers (especially clay). Shallow groundwater (near water table) at lower elevations is particularly vulnerable and observed water quality impacts in this area are evidence of this vulnerability. As indicated by the geologic cross-section (Figure 8), the aquifer is protected only slightly by a thin clay layer that appears to extend only over the middle elevations (B(H) and T(M)) but not to the lower elevations (P(L)).

Aquifer vulnerability can also be interpreted at any given location according to the depth of any particular groundwater flow path. In general, shallow groundwater (near the water table) emanates from local recharge and, as you go progressively deeper in the aquifer, groundwater has traveled increasing distances, originating from further and further up gradient. This means deeper groundwater, that may be highly suitable as a potable water supply, is vulnerable to land-use activities at higher elevations. In other words, land-use activities at progressively higher elevations tend to impact groundwater at progressively greater depths, and at lower elevations tend to impact shallow groundwaters. Limiting land-use activities at higher elevations and facilitating the drilling of deeper water supply wells (which is not trivial for a rural population) may be the best method to provide potable groundwater supplies.

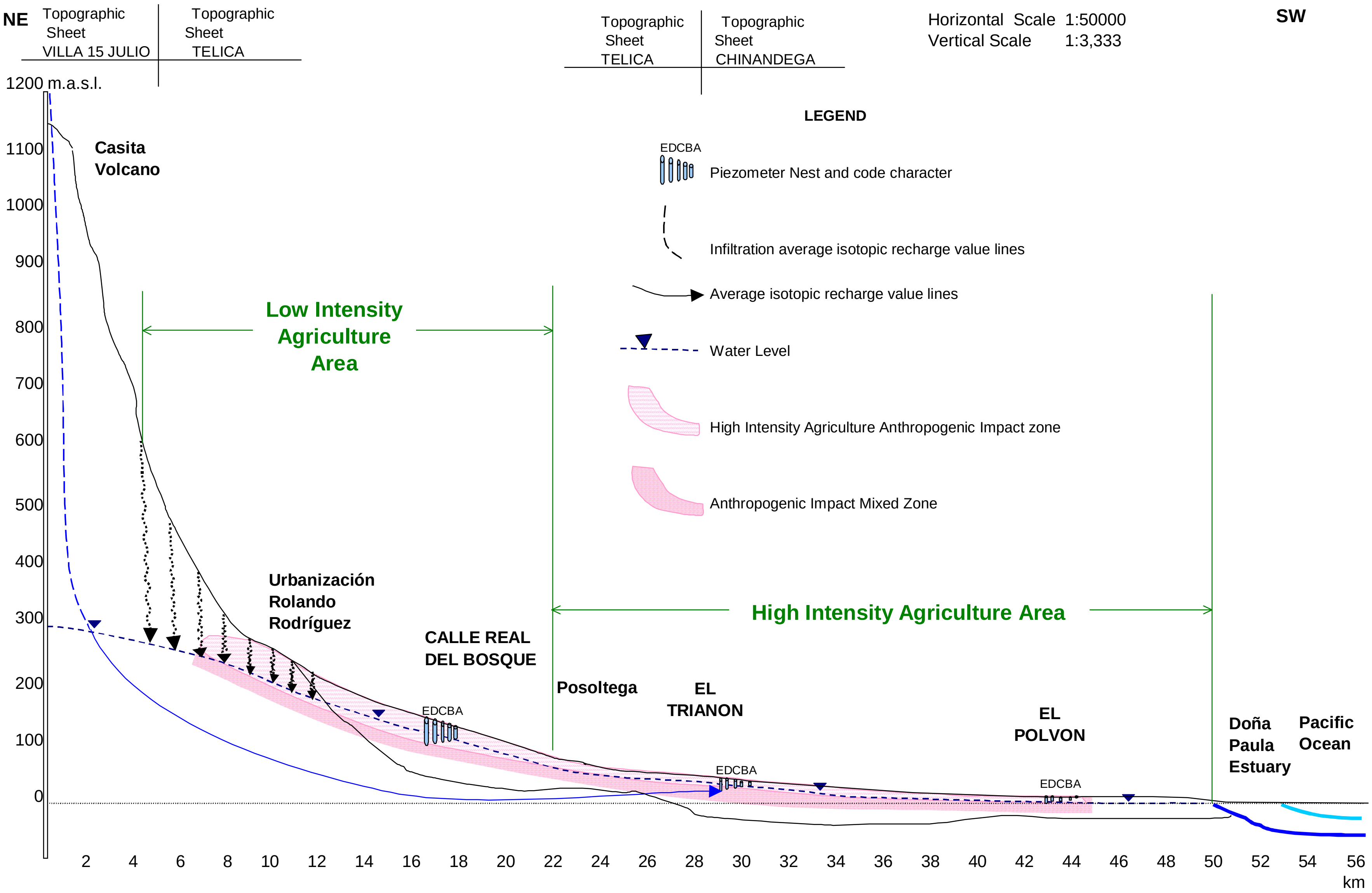

Figure 22. Depth of Anthropogenic Water Quality Impacts

4.10 Origin of Water Quality Impacts

The observed water quality impacts emanate from both human and/or animal wastes and agrochemicals. Human and/or animal wastes are indicated by the presence of fecal coliform bacteria; as well as, some chloride and nitrate concentrations. Chloride concentrations could have an indicative of volcanic influence in the study area, but another chloride source could be human activities. Nitrate and numerous pesticides indicate agrochemical sources (600 masl is the maximum elevation of significant agricultural activity in the study area). Leaching of agrochemicals to the water table has been documented in numerous recent studies, as presented in chapter 2.

4.11 Implications for Aquifer as Long-Term Source of Drinking Water Supply

Since groundwater is the only source for drinking water supply for the Departments of León-Chinandega, there is the need to drill and screen wells below the zone of anthropogenic contamination (see Figure 22) in order to extract groundwater with good quality.

Based on mathematical modeling (MODFLOW) of groundwater in order to assess negative pumping impacts, it has been recommended that the water extraction volume should be 664.5 $x10^6$ m^3/year in order to assure a maximum supply of water in ideal quality and quantity (INETER, 2000). Based on electrical resistivity measurements, major ions analyses, and mathematical modeling with MODFLOW, the effect of groundwater extraction in the coastal zone close to the 10 masl, does not evidence saline intrusion into the aquifer. Even though, the zones more vulnerable to saline intrusion are the estuaries, and the zones with geological faults (INETER, 2000).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Hydrogeology

The León-Chinandega aquifer is the sole source of water supply for a population of almost 700,000 inhabitants living in a vast agricultural plain in northwestern Nicaragua. The aquifer also supplies irrigation water to numerous commercial and domestic farming operations. The aquifer is comprised of layered alluvial materials eroded from the Los Maribios volcanic chain with minor interwoven volcanic lavas and pyroclastic materials. The alluvial materials are mostly sand with minor silt and clay with limonite mineralization predominant near the coast. The aquifer is generally unconfined with evidence of semi-confining conditions in some places due the presence of a thin discontinuous clay layer. Hydraulic Conductivity ranges from $1.4\text{x}10^{-6}$ to $2.7\text{x}10^{-9}$ m/s and the average horizontal linear groundwater flow velocity is 0.004 m/day.

Geochemically, the aquifer is characterized as a bicarbonate-calcium-magnesium with the exception of the deepest piezometer at P(L), which is sulfate-calcium-magnesium suggesting this water may have come from a geochemically distinct formation such as the deeper Tamarindo Formation. Natural concentrations of dissolved iron in the aquifer are high (up to 15.6 mg/L) and this has lead to secondary limonite (iron hydroxide) mineralization of alluvial materials near the coast.

The aquifer is recharged throughout the plain (i.e. from the coast to 300 masl), however, recharge significantly increases with higher elevation in the volcanic highlands (300-1200 masl). This produces a classic groundwater flow system comprised of local (shallow), intermediate and regional (deep) flow systems, however, the boundaries between these systems are not distinct due to natural mixing of young (local recharge) and older (regional recharge) groundwater. Vertical gradient reversal within each of the piezometer nests is also consistent with mixing. Isotopes (^{18}O and ^{2}H) in precipitation and groundwater indicate groundwater at any given depth below the water table is comprised of a mix of water recharged locally and regionally (higher elevations). In general, with greater depth below the water table the groundwater is recharged from higher and higher elevations and has flowed along a longer (distance and time) groundwater flow path. Groundwater from B(H) is the most enriched suggesting groundwater from this zone emanates mostly from local recharge between 83 masl and 280 masl. Groundwater from T(M) is the most depleted (especially the deepest piezometer, T(M)-E), indicating a higher elevation recharge zone (300-1200 masl). Groundwater from P(L) is intermediate isotopically indicating it is recharged between 25 m and 83 m.

At T(M), a positive correlation between chloride and sodium is observed suggesting the influence of deeper hydrothermal groundwaters and/or seawater intrusion (at depth).

Groundwater Quality Impacts

Groundwater mixing is evident by isotope values and vertical hydraulic gradients, which alternate between upwards and downwards in the deep point at each site indicating upward and downward groundwater flow, contributing to the mixing between local and regional groundwater systems.

Evidence of anthropogenic impacts to aquifer water quality is given by various parameters. Fecal coliform bacteria were detected at two sites [T(M) and P(L)]. Nitrate concentrations are slightly above natural levels (<2 mg-N/L) at 70% of the sampled wells but below the drinking water guideline value (10 mg-N/L).

Nitrate levels tend to decrease with depth in P(L), and a correlation between nitrate (and nitrite and ammonium) concentrations and redox measurements (Eh and dissolved oxygen) indicate that denitrification is likely occurring.

Pesticides detected in groundwater at all three piezometer locations are dieldrin, pp-DDT, pp-DDE, pp-DDD, and toxaphene. Pesticide levels exceed drinking water guidelines at T(M) and P(L) but not B(H). Dieldrin was not detected at the piezometers at T(M), but it was detected at T(M)-I (shallowest well screen located within 40-50 mbgs) suggesting water quality impacts are potentially very deep. Dieldrin, pp-DDD, pp-DDT and toxaphene were also detected in the soils adjacent to each of the three-piezometer sites indicating the soil zone continues to be a source of pesticide contamination.

At P(L)-E, where there is isotopic evidence of deeper regional recharge, fecal coliform and pesticides were also detected suggesting the groundwater at this depth is also impacted by locally recharged groundwater.

The above water quality impacts appear to be related primarily to agricultural activity and secondarily to human settlement. The fecal coliform may be related to human or cattle waste, however, there is some evidence the detected levels are related to human waste. This is consistent with a lack of intensive livestock operations in the area. Nitrate can emanate from human/cattle waste or agricultural fertilizer.

5.2. Recommendations

Future Hydrogeologic Studies

Monitoring wells should be installed at greater depths to more accurately define the depth of water quality impacts. Monitoring wells should be at least 2 inch in diameter to facilitate sampling. Future sampling should include the Casita Volcano and Bella Vista springs.

Ongoing Monitoring

The aquifer should be monitored on an ongoing basis for various parameters including water levels, and various indicator parameters such as coliform bacteria, nitrate, pesticides, and chloride. A continuous record, monitoring and isotopic analysis of precipitation samples in the study area through Increase the number of precipitation monitoring stations through the study area, especially at higher elevation zones. Keep continuous record and monitoring of the wells. As well as a geochemistry and isotope composition monitoring program for these wells and other drilled wells located in the study area.

Aquifer Protection and Management

The León-Chinandega aquifer is clearly highly vulnerable to contamination emanating from land-use activities on the plain and the volcanic highlands. Vulnerability is highest at the water table directly below the plain and decreases with depth below the plain and also with increasing distance from the coast.

At present the aquifer appears to be contaminated to a depth of at least 17 meters below ground surface at T(M). The depth of water quality impacts is unknown at B(H) and P(L). The current contamination will not likely abate or naturally remediate in the near future (especially the highly persistent pesticides). Thus, aquifer protection strategies should focus on: a) ensuring the shallow aquifer does not become more contaminated and b) protection of the apparently still pristine deeper aquifer.

Such aquifer protection/management strategies should include:

- Control of land-use activities to ensure they do not pollute the aquifer. Depending on a particular land areas location in the watershed, certain activities should be permitted, some activities should only be permitted with strict controls and others should not be permitted. Large commercial agricultural operations and larger settlements should conduct local hydrogeologic studies to ensure they do not pollute the aquifer. High elevations are the most important for groundwater protection, since groundwater recharge to the plain and the coast comes mainly from the mountains.

- Control water taking from the aquifer to ensure water taking (especially from the deeper aquifer) does not cause water quality impacts to migrate deeper and also ensure the aquifer is not over-pumped locally and that competing demands (e.g. drinking water and irrigation) are met fairly. Any applications for new or increased water taking should be accompanied by a hydrogeologic study to ensure there are not adverse impacts from the water taking. In some cases, ongoing monitoring of aquifer levels and water quality may be required.

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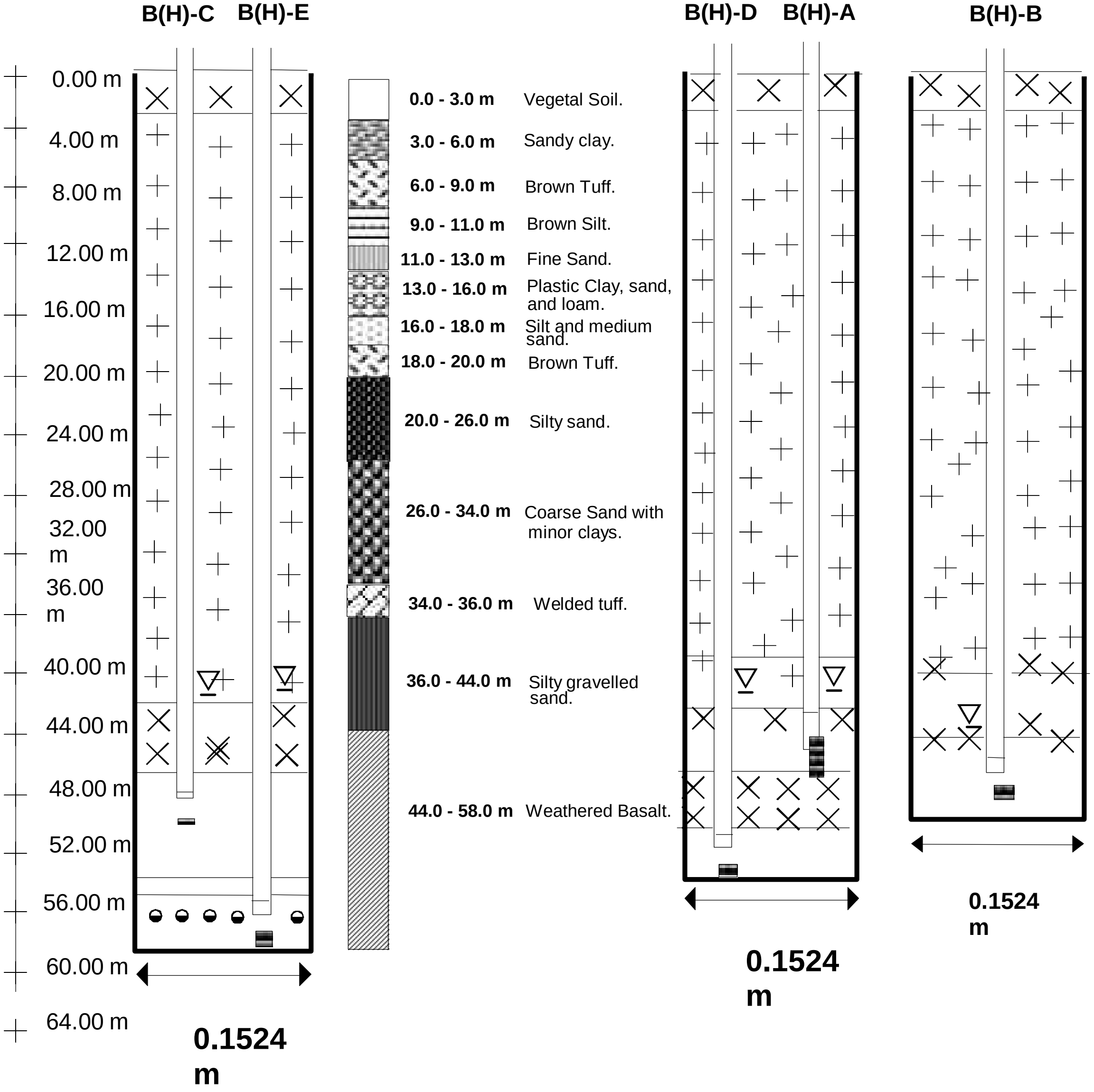
7 APPENDIX A WELL LOGS



CIRA-UNAN-Managua

Well Code: B(H)-A, B(H)-B, B(H)-C, B(H)-D, B(H)-E
Site: Hcda. Calle Real del Bosque
Community: El Bosque
Municipality: Posoltega
Department: Chinandega
Coordinates: N 12º 35' 7.6" W 86º 56' 29"
Drilling Date: November 14th, 15th, and 16th, 2001.

THESIS:
Groundwater Flow System and Water Quality in a Coastal Plain Aquifer in Northwestern Nicaragua.

by Valeria Delgado Quezada.

WELL CONSTRUCTION

☐	Sandpack and Backfill.
+ +	Natural backfill.
◒ ◒	Bentonite Seal
× ×	Neat-cement seal.

LEGEND

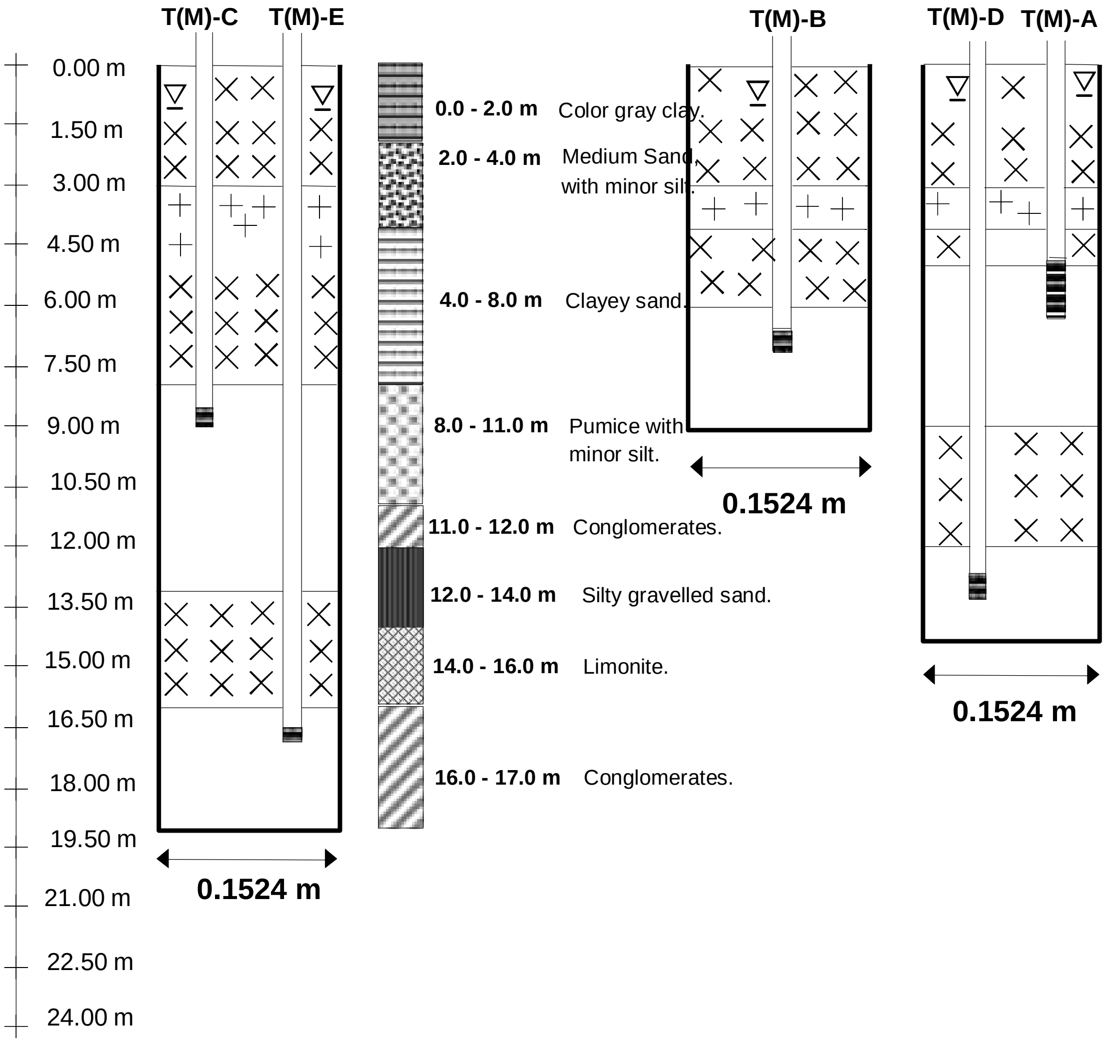
▽ Static Water Level (mbgs)
31-Jan-2002

(A) 41.52 mbgs (B) 44.66 mbgs
(C) 41.59 mbgs (D) 41.51 mbgs
(E) 41.56 mbgs

mbgs Meters below ground surface

▤ Well Screen

7 APPENDIX A WELL LOGS



CIRA-UNAN-Managua

Well Code: T(M)-A, T(M)-B, T(M)-C, T (M)-D, T(M)-E.

Site: Hcda. El Trianón.

Community: El Trianón.

Municipality: Posoltega

Départment: Chinandega

Coordinates: N - 12º 30' 44"
W - 86º 59' 35"

Drilling Date: November 17th and 18th, 2001.

THESIS:

Groundwater Flow System and Water Quality in a Coastal Plain Aquifer in Northwestern Nicaragua.

by Valeria Delgado Quezada.

WELL CONSTRUCTION

☐	Sand Backfill and Packfill
+ +	Natural Filling
✕ ✕	Neat-cement grout and sand seal

LEGEND

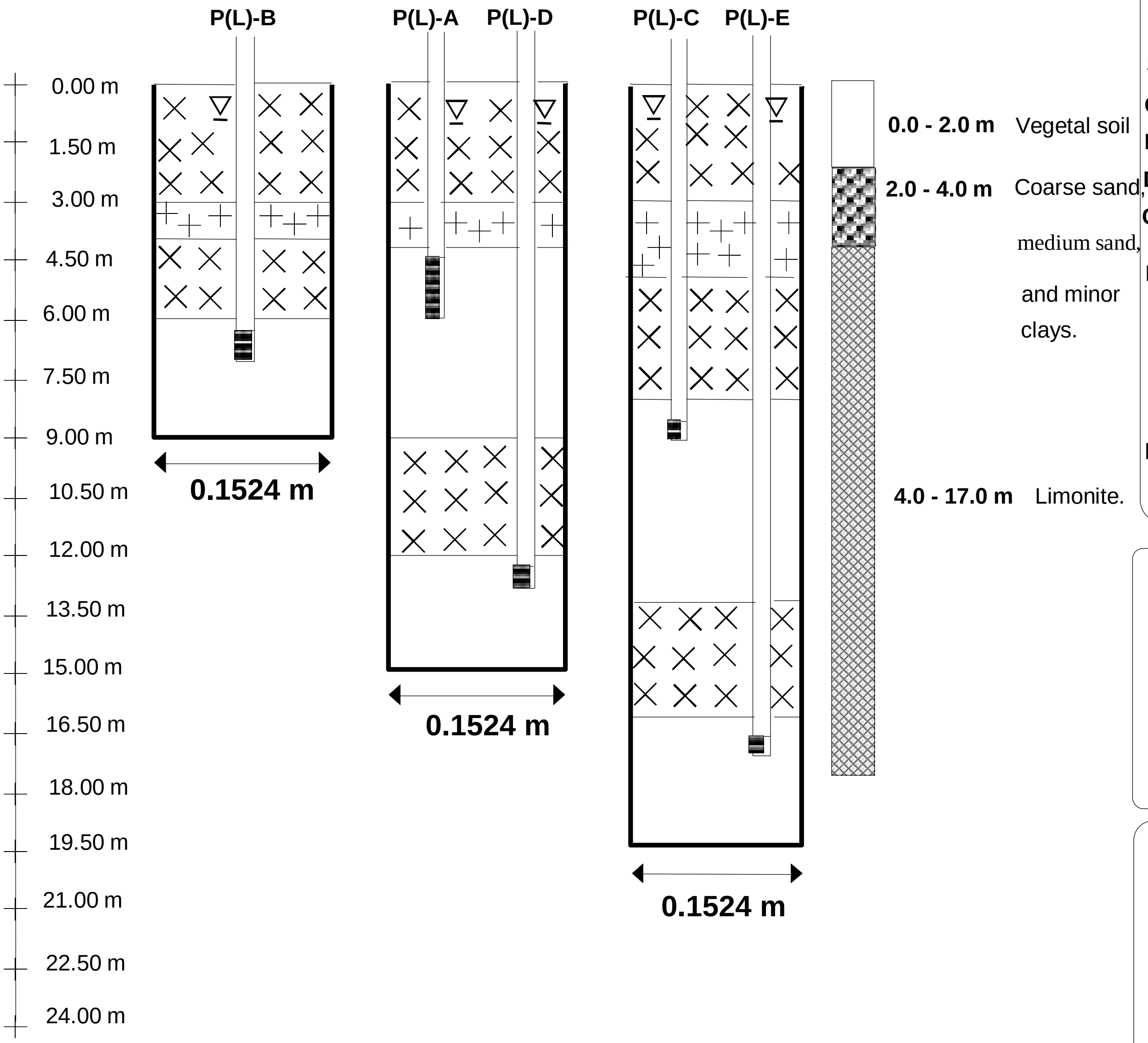
∇ Static Water Level (31-Jan-2002)

(A) 1.15 mbgs (B) 1.10 mbgs
(C) 1.20 mbgs (D)1.16 mbgs
(E) 1.18 mbgs

mbgs meter below ground surface.

▤ Well Screen

7 APPENDIX A WELL LOGS



CIRA-UNAN-Managua

Well Code: P(L)-A, P(L)-B, P(L)-C, P(L)-D, P(L)-E.

Site: Hcda. El Polvón.

Community: Ingenio San Antonio.

Municipality: Chichigalpa.

Départment: Chinandega

Coordinates: N - 12º 27' 59"
W - 87º 2' 51"

Drilling Date: November 20th, 2001.

THESIS:

Groundwater Flow System and Water Quality in a Coastal Plain Aquifer in Northwestern Nicaragua.

by Valeria Delgado Quezada.

WELL CONSTRUCTION

☐	Sandpack and Backfill.
+ +	Natural backfill.
× ×	Neat-cement seal.

LEGEND

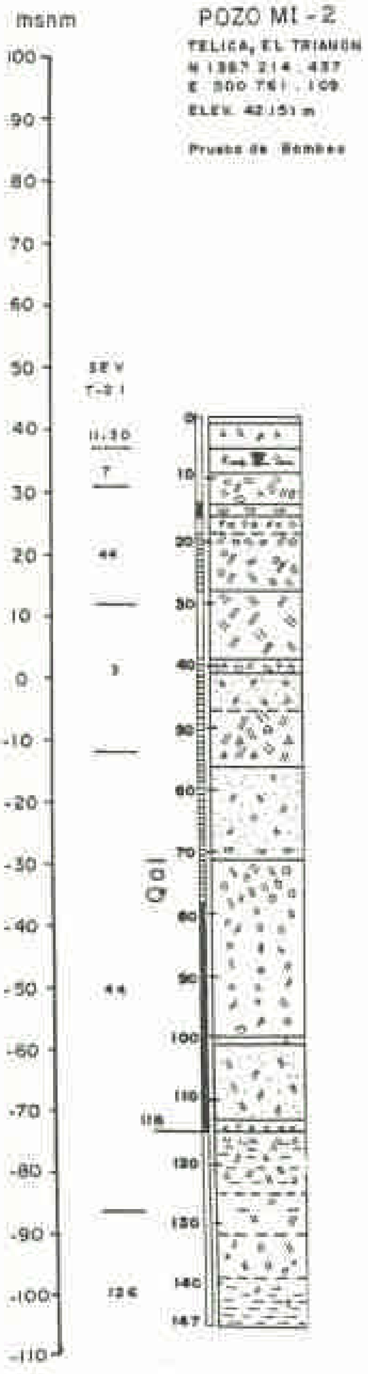
▽ Static Water Level (31-Jan-2002)

(A) 1.22 mbgs (B) 1.38 mbgs
(C) 1.24 mbgs (D) 1.22 mbgs
(E) 1.27 mbgs

mbgs meter below ground surface

▤ Well Screen

7 APPENDIX A WELL LOGS



INETER

Well Code: T(M)-I

Site: Hda. El Trianón

Community: El Trianón

Municipality: Posoltega

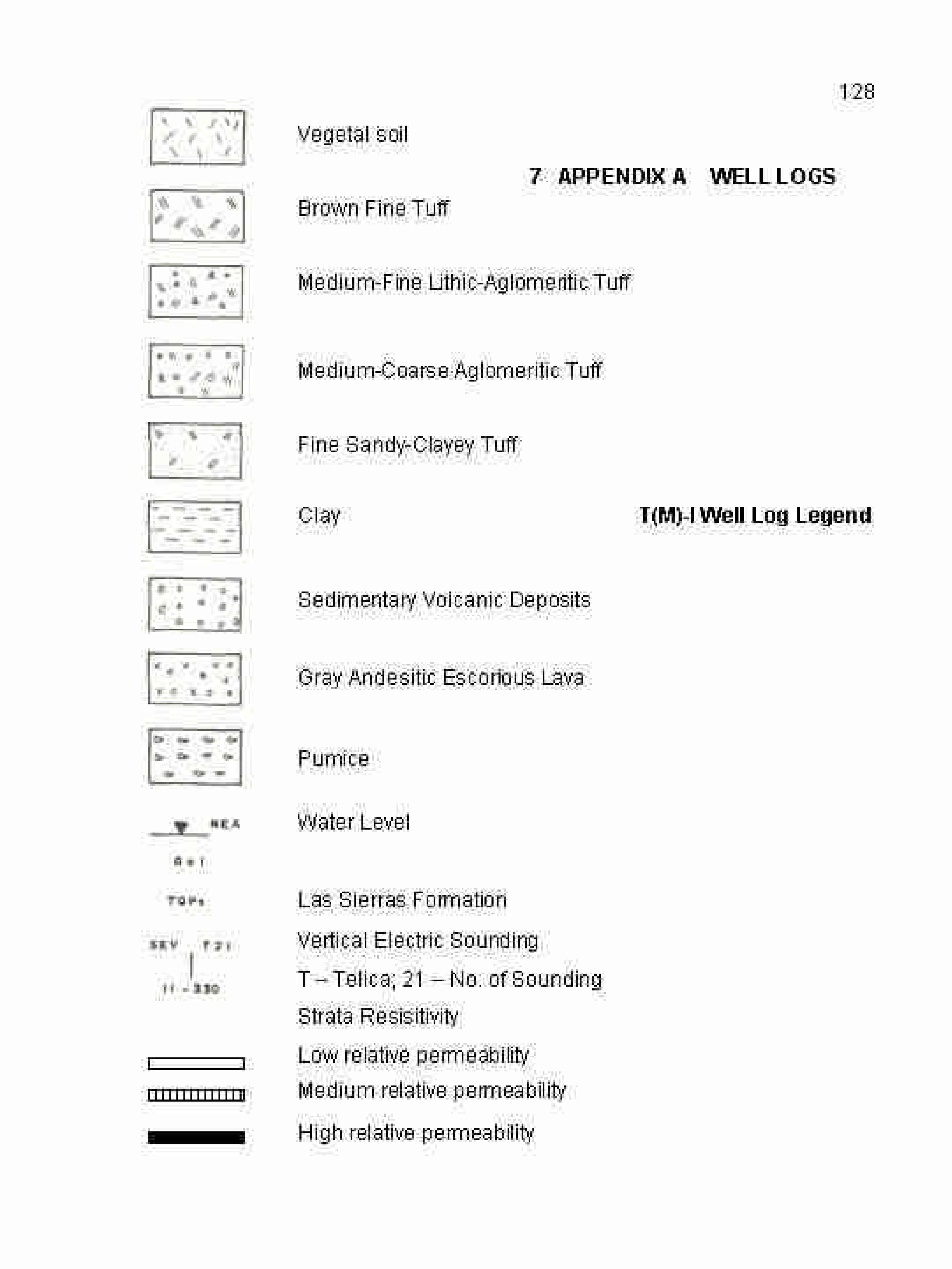
Department: Chinandega

Coordinates: N 1383 214 .437
W 500 761 . 109

Elevation: 42.151 m

Drilling Date: February 7th, 2000

Project: MAGFOR – INETER, 2000



7. APPENDIX A WELL LOGS

T(M)-I Well Log Legend

Vegetal soil

Brown Fine Tuff

Medium-Fine Lithic-Aglomeritic Tuff

Medium-Coarse Aglomeritic Tuff

Fine Sandy-Clayey Tuff

Clay

Sedimentary Volcanic Deposits

Gray Andesitic Escorious Lava

Pumice

Water Level

Las Sierras Formation

Vertical Electric Sounding

T – Telica; 21 – No. of Sounding

Strata Resisitivity

Low relative permeability

Medium relative permeability

High relative permeability

8 APPENDIX B SLUG TEST RESULTS

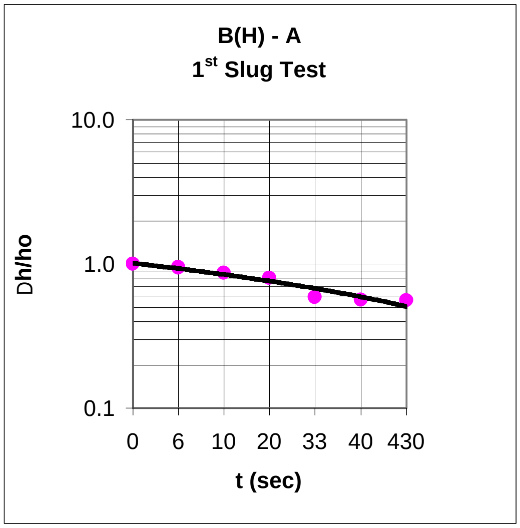
B(H) - A
First Test

Water Level (m) 41.9
Dho (m) = 13.11 **ho (m) =** 28.79

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	1310.6	13.11	28.79	1.00
6	1463.0	14.63	27.27	0.95
10	1676.4	16.76	25.14	0.87
20	1889.8	18.9	23.00	0.80
33	2499.4	24.99	16.91	0.59
40	2560.3	25.6	16.30	0.57
430	2575.6	25.76	16.14	0.56

L (m) = 11
R (m) = 0.08
r (m) = 0.01
To (sec)* = 7840
K (m/s) = 2.7E-09

*** :** value obtained extrapolating



B(H) - A
Second Test**

Water Level (m)
Dho (m) = **ho (m) =**

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho

**: The second test could not be run due to fact that the well did not recovered its initial water level

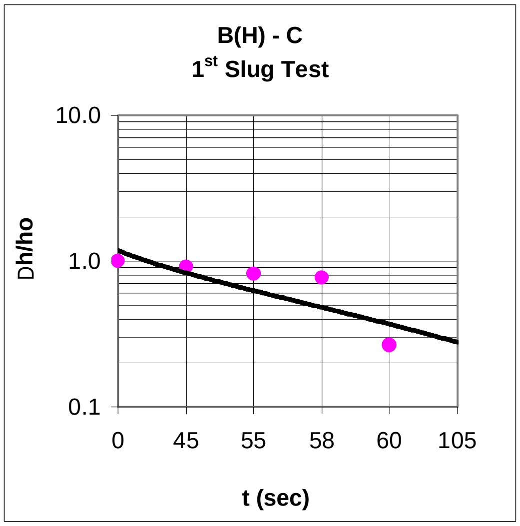
8 APPENDIX B SLUG TEST RESULTS

B(H) - C
First Test

Water Level (m) 41.34
Dho (m) = 34.75 **ho (m) =** 6.59

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	3474.7	34.75	6.59	1.00
45	3535.7	35.36	5.98	0.91
55	3596.6	35.97	5.37	0.82
58	3627.1	36.27	5.07	0.77
60	3960.0	39.60	1.74	0.26
105	4170.0	41.70	-0.36	0.00
121	4260.0	42.60	-1.26	0.00
140	4270.0	42.70	-1.36	0.00
334	4280.0	42.80	-1.46	0.00
551	4290.0	42.90	-1.56	0.00

L (m) = 12
R (m) = 0.08
r (m) = 0.01
To (sec) = 59.57
K (m/s) = 3.4E-07

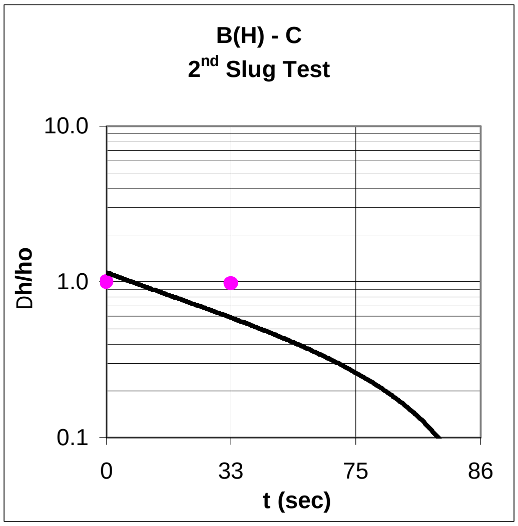

B(H) - C
1st Slug Test

B(H) - C
Second Test

Water Level (m) 41.34
Dho (m) = 17.68 **ho (m) =** 23.66

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	1767.8	17.68	23.66	1.00
33	1828.8	18.29	23.05	0.97
75	4000.0	40.00	1.34	0.06
86	4140.0	41.40	-0.06	0.00
93	4160.0	41.60	-0.26	0.00
96	4170.0	41.70	-0.36	0.00
116	4250.0	42.50	-1.16	0.00
123	4260.0	42.60	-1.26	0.00
143	4270.0	42.70	-1.36	0.00
391	4280.0	42.80	-1.46	0.00

L (m) = 12
R (m) = 0.08
r (m) = 0.01
To (sec) = 60.692
K (m/s) = 3.3E-07


B(H) - C
2nd Slug Test

B(H) - D
First Test

Water Level (m) 41.3
Dho (m) = 6.71 **ho (m) =** 34.59

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	670.56	6.71	34.59	1.00
22	3048.0	30.48	10.82	0.31
26	3535.7	35.36	5.94	0.17
51	4270.0	42.70	-1.40	0.00
61	4280.0	42.80	-1.50	0.00
83	4290.0	42.90	-1.60	0.00

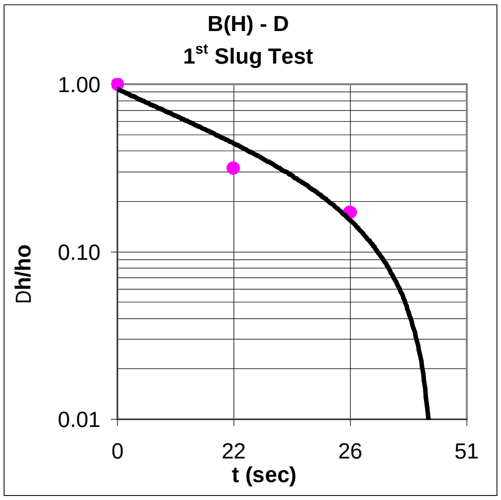
L (m) = 3
R (m) = 0.08
r (m) = 0.01
To (sec) = 20.09
K (m/s) = 2.9E-06

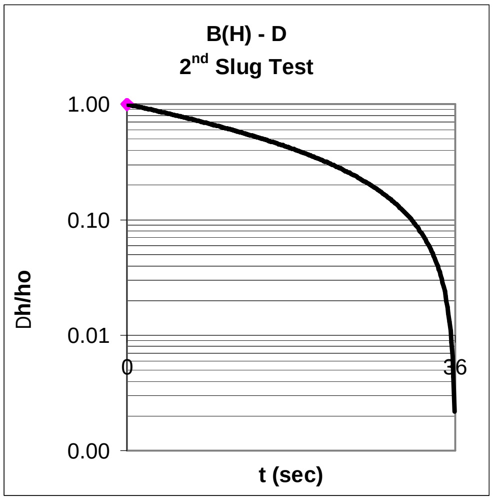
B(H) - D
Second Test

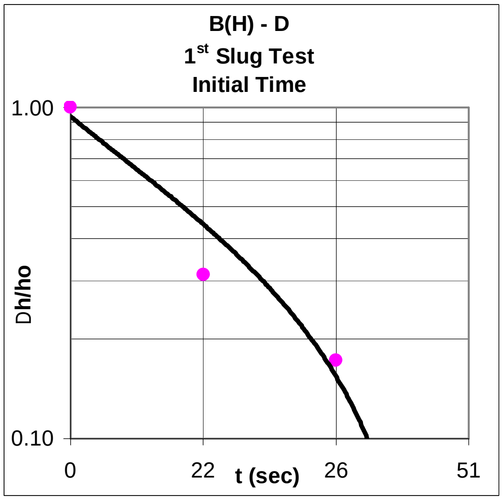
Water Level (m) 41.3
Dho (m) = 8.53 **ho (m) =** 32.77

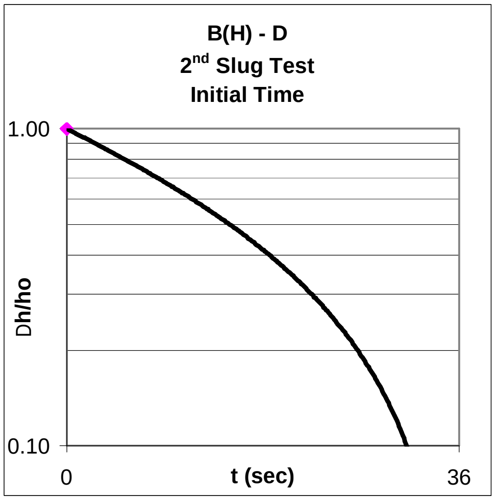
t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	853.44	8.53	32.77	1.00
36	4250.0	42.50	-1.20	0.00
39	4260.0	42.60	-1.30	0.00
53	4270.0	42.70	-1.40	0.00
64	4280.0	42.80	-1.50	0.00
99	4285.0	42.85	-1.55	0.00
261	4290.0	42.90	-1.60	0.00

L (m) = 3
R (m) = 0.08
r (m) = 0.01
To (sec) = 22.68
K (m/s) = 2.6E-06









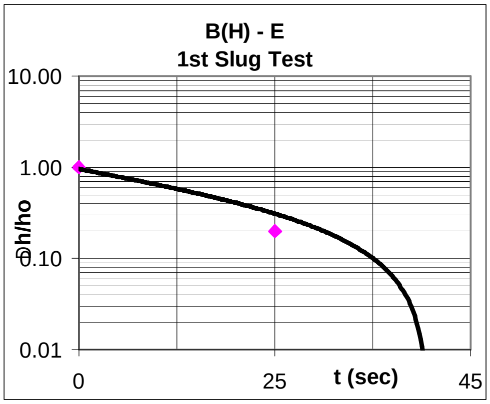
8 APPENDIX B SLUG TEST RESULTS

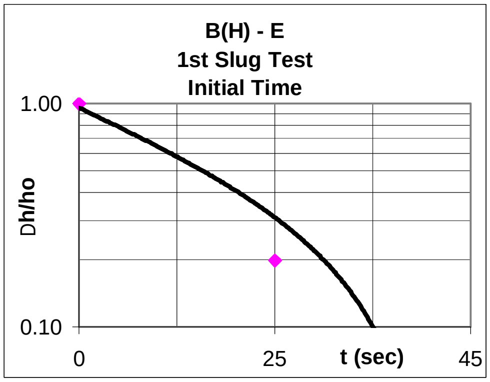
B(H) - E
First Test

Water Level (m) 41.33
Dho (m) = 17.37 **ho (m) =** 23.96

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	1737.4	17.37	23.96	1.00
25	3657.6	36.58	4.75	0.20
45	4280.0	42.8	-1.47	0.00
97	4290.0	42.9	-1.57	0.00

L (m) = 4
R (m) = 0.08
r (m) = 0.01
To (sec) = 19.69
K (m/s) = 2.4E-06



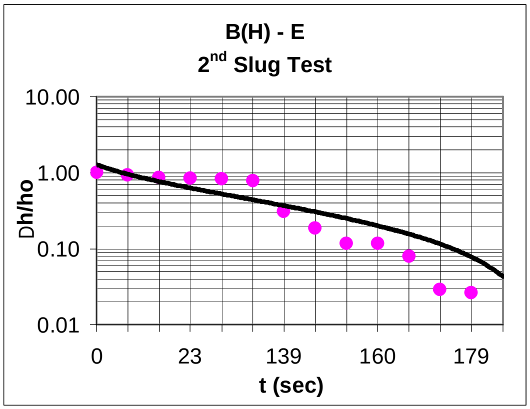


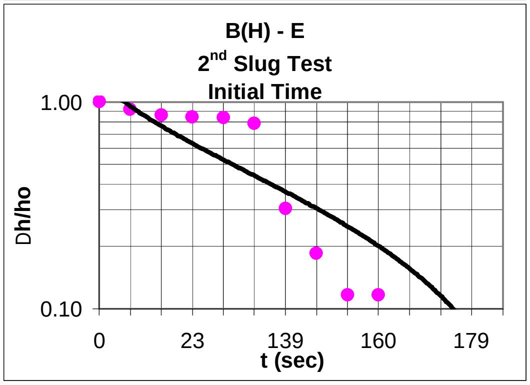
B(H) - E
Second Test

Water Level (m) 41.33
Dho (m) = 5.79 **ho (m) =** 35.54

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	579.1	5.79	35.54	1.00
6	853.4	8.53	32.80	0.92
11	1066.8	10.67	30.66	0.86
23	1127.8	11.28	30.05	0.85
98	1158.2	11.58	29.75	0.84
110	1341.1	13.41	27.92	0.79
139	3048.0	30.48	10.85	0.31
146	3474.7	34.75	6.58	0.19
150	3718.6	37.19	4.14	0.12
160	3720.0	37.20	4.13	0.12
169	3850.0	38.50	2.83	0.08
177	4030.0	40.30	1.03	0.03
179	4040.0	40.40	0.93	0.03
196	4170.0	41.70	-0.37	0.00

L (m) = 4
R (m) = 0.08
r (m) = 0.01
To (sec) = 135.38
K (m/s) = 3.5E-07





8 APPENDIX B SLUG TEST RESULTS

T(M) - A
First Test

Water Level (m)	2.24
Dho (m) =	0.1
ho (m) =	2.14

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	10	0.10	2.14	1.00
38	20	0.20	2.04	0.95
58	25	0.25	1.99	0.93
77	30	0.30	1.94	0.91
84	35	0.35	1.89	0.88
100	40	0.40	1.84	0.86
115	45	0.45	1.79	0.84
131	50	0.50	1.74	0.81
150	55	0.55	1.69	0.79
161	60	0.60	1.64	0.77
183	65	0.65	1.59	0.74
200	70	0.70	1.54	0.72
221	75	0.75	1.49	0.70
241	80	0.80	1.44	0.67
263	85	0.85	1.39	0.65
283	90	0.90	1.34	0.63
305	95	0.95	1.29	0.60
330	100	1.00	1.24	0.58
353	105	1.05	1.19	0.56
370	110	1.10	1.14	0.53
410	115	1.15	1.09	0.51
437	120	1.20	1.04	0.49
472	125	1.25	0.99	0.46
502	130	1.30	0.94	0.44
532	135	1.35	0.89	0.42
571	140	1.40	0.84	0.39
610	145	1.45	0.79	0.37
649	150	1.50	0.74	0.35
691	155	1.55	0.69	0.32
734	160	1.60	0.64	0.30
785	165	1.65	0.59	0.28
854	170	1.70	0.54	0.25
906	175	1.75	0.49	0.23
992	180	1.80	0.44	0.21
1064	185	1.85	0.39	0.18
1156	190	1.90	0.34	0.16
1200	195	1.95	0.29	0.14
1395	200	2.00	0.24	0.11
1550	205	2.05	0.19	0.09
1756	210	2.10	0.14	0.07
1989	215	2.15	0.09	0.04
2414	220	2.20	0.04	0.02

T(M) - A
Second Test

Water Level (m)	2.24
Dho (m) =	0.1
ho (m) =	2.14

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	10	0.10	2.14	1.00
4	20	0.20	2.04	0.95
30	25	0.25	1.99	0.93
45	30	0.30	1.94	0.91
71	35	0.35	1.89	0.88
76	40	0.40	1.84	0.86
87	45	0.45	1.79	0.84
104	50	0.50	1.74	0.81
121	55	0.55	1.69	0.79
140	60	0.60	1.64	0.77
156	65	0.65	1.59	0.74
172	70	0.70	1.54	0.72
190	75	0.75	1.49	0.70
210	80	0.80	1.44	0.67
233	85	0.85	1.39	0.65
253	90	0.90	1.34	0.63
272	95	0.95	1.29	0.60
297	100	1.00	1.24	0.58
320	105	1.05	1.19	0.56
344	110	1.10	1.14	0.53
372	115	1.15	1.09	0.51
399	120	1.20	1.04	0.49
429	125	1.25	0.99	0.46
455	130	1.30	0.94	0.44
486	135	1.35	0.89	0.42
518	140	1.40	0.84	0.39
552	145	1.45	0.79	0.37
591	150	1.50	0.74	0.35
632	155	1.55	0.69	0.32
677	160	1.60	0.64	0.30
720	165	1.65	0.59	0.28
780	170	1.70	0.54	0.25
827	175	1.75	0.49	0.23
899	180	1.80	0.44	0.21
977	185	1.85	0.39	0.18
1048	190	1.90	0.34	0.16
1125	195	1.95	0.29	0.14
1277	200	2.00	0.24	0.11
1377	205	2.05	0.19	0.09
1538	210	2.10	0.14	0.07
1711	215	2.15	0.09	0.04
2034	220	2.20	0.04	0.02

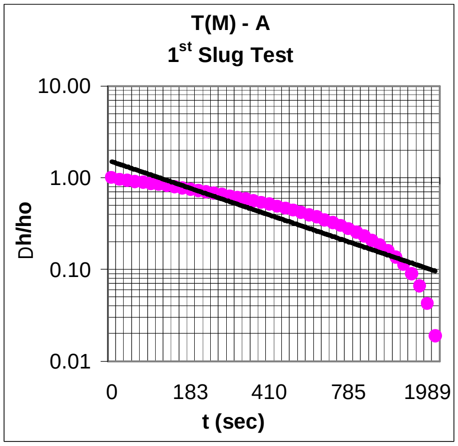
8 APPENDIX B SLUG TEST RESULTS

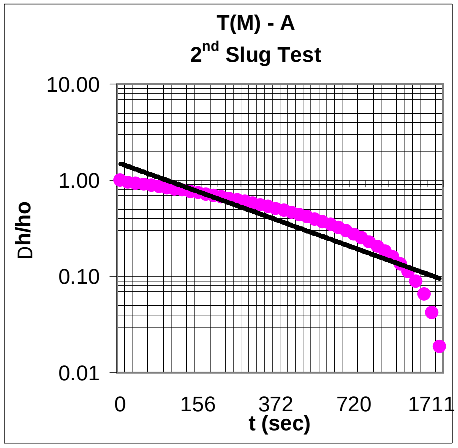
T(M) - A
First Test

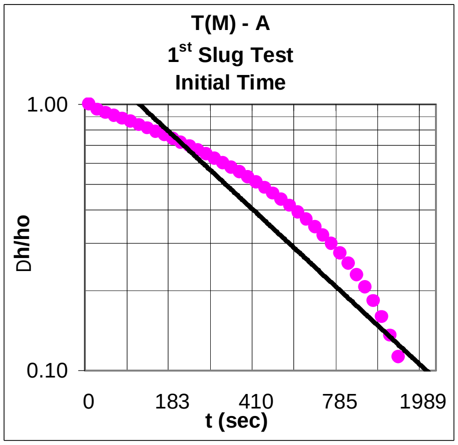
L (m) = 5
R (m) = 0.08
r (m) = 0.01
To (sec) = 610
K (m/s) = 6.5E-08

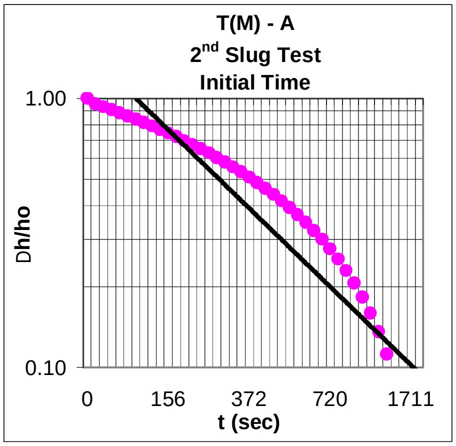
T(M) - A
Second Test

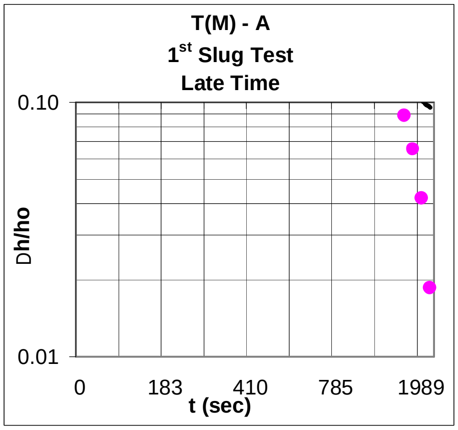
L (m) = 5
R (m) = 0.08
r (m) = 0.01
To (sec) = 552
K (m/s) = 7.2E-08

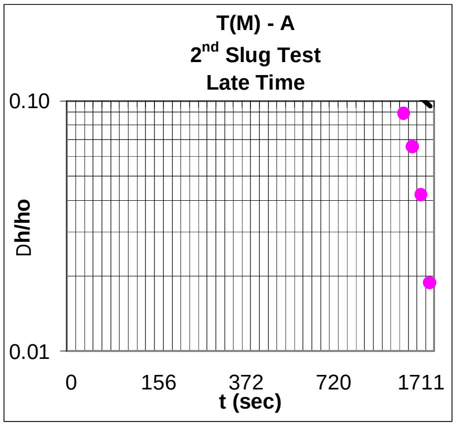












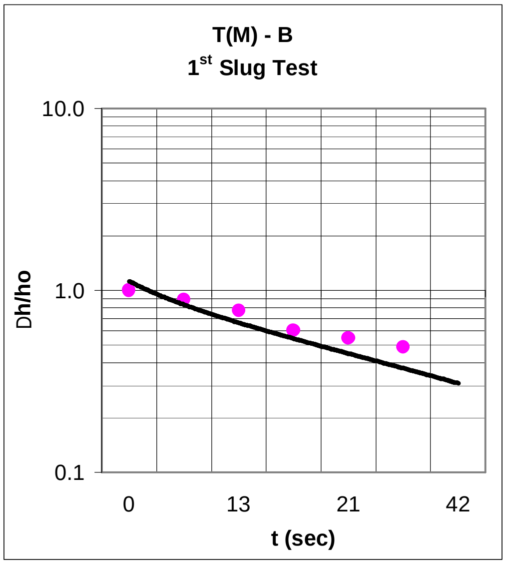
8 APPENDIX B SLUG TEST RESULTS

T(M) - B
First Test

Water Level (m) 2.18
Dho (m) = 1.3 **ho (m) =** 0.88

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	130	1.30	0.88	1.00
7	140	1.40	0.78	0.89
13	150	1.50	0.68	0.77
15	165	1.65	0.53	0.60
21	170	1.70	0.48	0.55
24	175	1.75	0.43	0.49
42	218	2.18	0.00	0.00

L (m) = 3
R (m) = 0.08
r (m) = 0.01
To (sec) = 28.41
K (m/s) = 2.0E-06

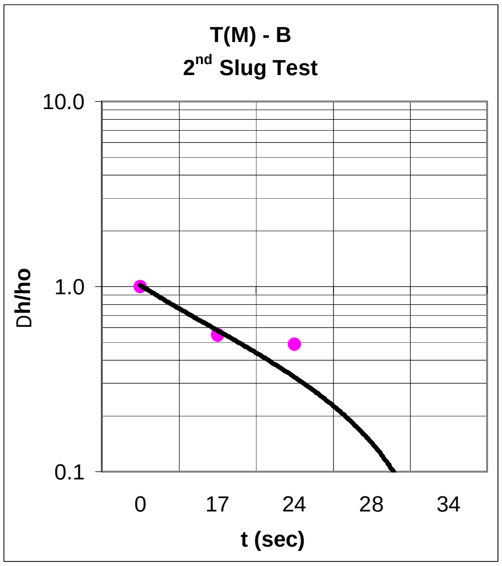


T(M) - B
Second Test

Water Level (m) 2.18
Dho (m) = 1.3 **ho (m) =** 0.88

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	130	1.30	0.88	1.00
17	170	1.70	0.48	0.55
24	175	1.75	0.43	0.49
28	215	2.15	0.03	0.03
34	218	2.18	0.00	0.00

L (m) = 3
R (m) = 0.08
r (m) = 0.01
To (sec) = 25.04
K (m/s) = 2.3E-06



8 APPENDIX B SLUG TEST RESULTS

T(M) - C
First Test

Water Level (m) 2.05
D**ho (m) =** 1.6 **ho (m) =** 0.45

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	160	1.60	0.45	1.00
10	170	1.70	0.35	0.78
15	190	1.90	0.15	0.33
20	195	1.95	0.10	0.22
33	200	2.00	0.05	0.11
46	205	2.05	0.00	0.00

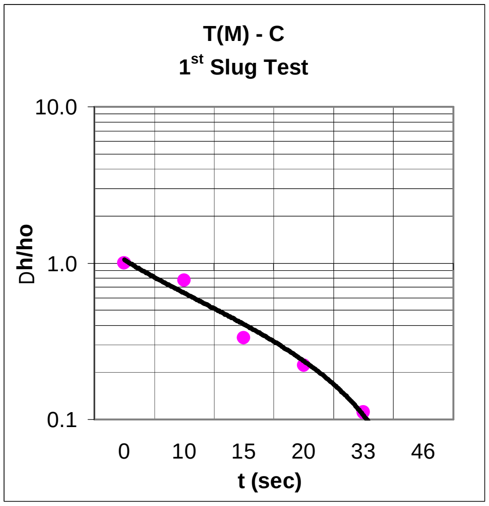
L (m) = 5
R (m) = 0.08
r (m) = 0.01
To (sec) = 14.56
K (m/s) = 2.7E-06

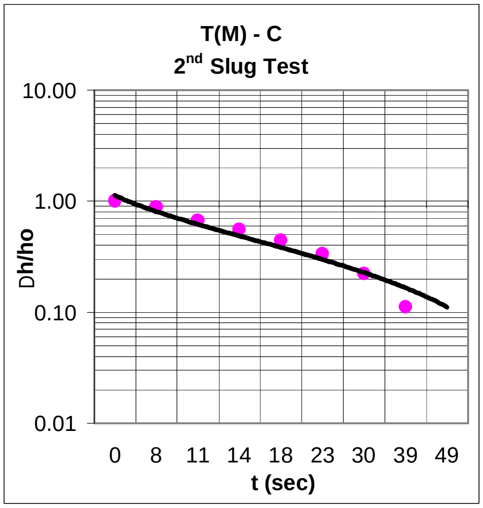
T(M) - C
Second Test

Water Level (m) 2.05
D**ho (m) =** 1.6 **ho (m) =** 0.45

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	160	1.60	0.45	1.00
8	165	1.65	0.40	0.89
11	175	1.75	0.30	0.67
14	180	1.80	0.25	0.56
18	185	1.85	0.20	0.44
23	190	1.90	0.15	0.33
30	195	1.95	0.10	0.22
39	200	2.00	0.05	0.11
49	205	2.05	0.00	0.00

L (m) = 5
R (m) = 0.08
r (m) = 0.01
To (sec) = 21.18
K (m/s) = 1.9E-06





8 APPENDIX B SLUG TEST RESULTS

T(M) - D
First Test

Water Level (m) 2.24
Dho (m) = 1.35 **ho (m) =** 0.89

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	135	1.35	0.89	1.00
15	190	1.90	0.34	0.38
29	195	1.95	0.29	0.33
38	200	2.00	0.24	0.27
42	205	2.05	0.19	0.21
48	210	2.10	0.14	0.16
53	215	2.15	0.09	0.10
62	220	2.20	0.04	0.04
85	224	2.24	0.00	0.00

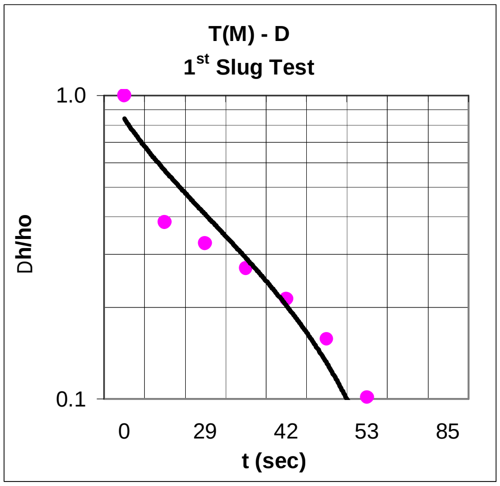
L (m) = 2
R (m) = 0.08
r (m) = 0.01
To (sec) = 17.80
K (m/s) = 4.4E-06

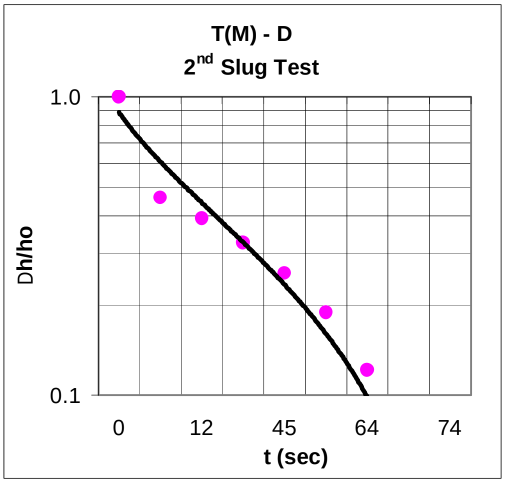
T(M) - D
Second Test

Water Level (m) 2.24
Dho (m) = 1.5 **ho (m) =** 0.74

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	150	1.50	0.74	1.00
6	190	1.90	0.34	0.46
12	195	1.95	0.29	0.39
16	200	2.00	0.24	0.32
45	205	2.05	0.19	0.26
53	210	2.10	0.14	0.19
64	215	2.15	0.09	0.12
70	220	2.20	0.04	0.05
74	224	2.24	0.00	0.00

L (m) = 2
R (m) = 0.08
r (m) = 0.01
To (sec) = 13.14
K (m/s) = 5.9E-06





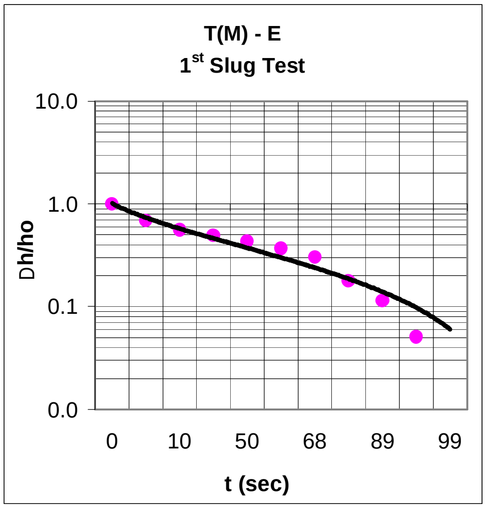
8 APPENDIX B SLUG TEST RESULTS

T(M) - E
First Test

Water Level (m)	2.04			
Dho (m) =	1.25		**ho (m) =**	0.79

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	125	1.25	0.79	1.00
7	150	1.50	0.54	0.68
10	160	1.60	0.44	0.56
40	165	1.65	0.39	0.49
50	170	1.70	0.34	0.43
61	175	1.75	0.29	0.37
68	180	1.80	0.24	0.30
82	190	1.90	0.14	0.18
89	195	1.95	0.09	0.11
94	200	2.00	0.04	0.05
99	204	2.04	0.00	0.00

L (m) = 3
R (m) = 0.08
r (m) = 0.01
To (sec) = 61.00
K (m/s) = 9.5E-07

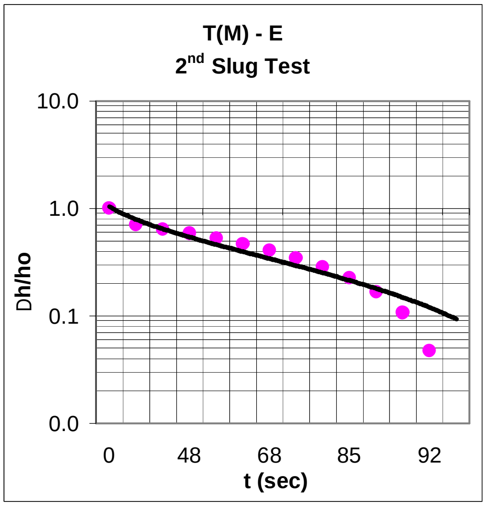


T(M) - E
Second Test

Water Level (m)	2.04			
Dho (m) =	1.2		**ho (m) =**	0.84

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	120	1.20	0.84	1.00
5	145	1.45	0.59	0.70
27	150	1.50	0.54	0.64
48	155	1.55	0.49	0.58
52	160	1.60	0.44	0.52
59	165	1.65	0.39	0.46
68	170	1.70	0.34	0.40
76	175	1.75	0.29	0.35
81	180	1.80	0.24	0.29
85	185	1.85	0.19	0.23
88	190	1.90	0.14	0.17
90	195	1.95	0.09	0.11
92	200	2.00	0.04	0.05
94	204	2.04	0.00	0.00

L (m) = 3
R (m) = 0.08
r (m) = 0.01
To (sec) = 72.80
K (m/s) = 8.0E-07



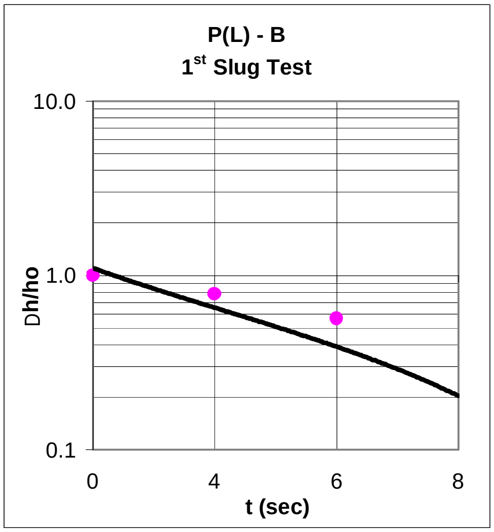
8 APPENDIX B SLUG TEST RESULTS

P(L) - B
First Test

Water Level (m) 2.33
Dho (m) = 2.1 **ho (m) =** 0.23

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	210	2.10	0.23	1.00
4	215	2.15	0.18	0.78
6	220	2.20	0.13	0.57
8	233	2.33	0.00	0.00

L (m) = 3
R (m) = 0.08
r (m) = 0.01
To (sec) = 6.70
K (m/s) = 8.7E-06

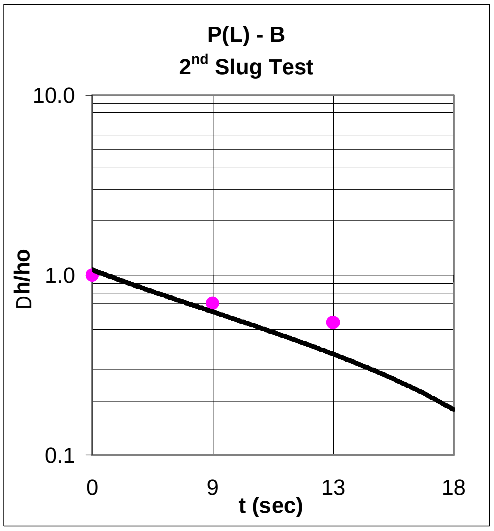


P(L) - B
Second Test

Water Level (m) 2.33
Dho (m) = 2 **ho (m) =** 0.33

t (sec)	h (cm)	h (m)	Dh (m)	Dh/ho
0	200	2.00	0.33	1.00
9	210	2.10	0.23	0.70
13	215	2.15	0.18	0.55
18	233	2.33	0.00	0.00

L (m) = 3
R (m) = 0.08
r (m) = 0.01
To (sec) = 14.6364
K (m/s) = 4.0E-06



8 APPENDIX B SLUG TEST RESULTS

P(L) - D
First Test

Water Level (m) = 2.2

D**ho (m) =** 0.72 ho (m) = 1.48

t (sec)	h (cm)	h (m)	D**h (m)**	D**h/ho**
0	72.0	0.72	1.48	1.00
5	82.5	0.83	1.38	0.93
8	107.0	1.07	1.13	0.76
10	121.0	1.21	0.99	0.67
13	133.0	1.33	0.87	0.59
18	139.0	1.39	0.81	0.55
20	157.0	1.57	0.63	0.43
22	165.0	1.65	0.55	0.37
24	172.5	1.73	0.48	0.32
27	173.5	1.74	0.47	0.31
31	182.0	1.82	0.38	0.26
33	187.0	1.87	0.33	0.22
35	192.0	1.92	0.28	0.19
38	194.0	1.94	0.26	0.18
41	196.0	1.96	0.24	0.16
44	198.0	1.98	0.22	0.15
47	201.0	2.01	0.19	0.13
50	203.5	2.04	0.17	0.11
55	206.0	2.06	0.14	0.09
57	208.0	2.08	0.12	0.08
58	209.5	2.10	0.11	0.07
59	209.5	2.10	0.11	0.07

L (m) = 2
R (m) = 0.08
r (m) = 0.01
To (sec) = 22
K (m/s) = 3.5E-06

P(L) - D
Second Test

Water Level (m) = 2.2

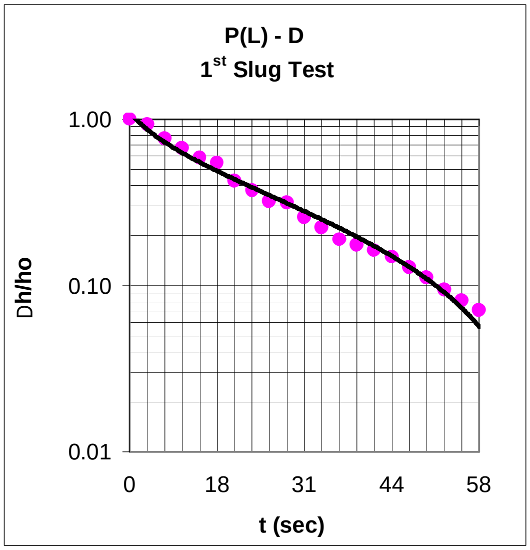
D**ho (m) =** 0.305 ho (m) = 1.90

t (sec)	h (m)	h (m)	D**h (m)**	D**h/ho**
0	30.5	0.31	1.90	1.00
4	67.5	0.68	1.53	0.80
7	120.0	1.20	1.00	0.53
9	130.5	1.31	0.90	0.47
10	133.0	1.33	0.87	0.46
11	140.0	1.40	0.80	0.42
13	149.0	1.49	0.71	0.37
14	156.0	1.56	0.64	0.34
17	164.0	1.64	0.56	0.30
19	170.5	1.71	0.50	0.26
21	179.0	1.79	0.41	0.22
24	183.0	1.83	0.37	0.20
25	187.0	1.87	0.33	0.17
27	192.0	1.92	0.28	0.15
29	194.0	1.94	0.26	0.14
31	197.5	1.98	0.23	0.12
33	199.0	1.99	0.21	0.11
35	201.2	2.01	0.19	0.10
37	204.0	2.04	0.16	0.08
39	207.0	2.07	0.13	0.07
41	208.0	2.08	0.12	0.06
44	210.0	2.10	0.10	0.05
45	211.0	2.11	0.09	0.05
48	212.0	2.12	0.08	0.04
49	213.0	2.13	0.07	0.04
53	214.0	2.14	0.06	0.03
56	214.0	2.14	0.06	0.03
60	217.0	2.17	0.03	0.02
63	218.0	2.18	0.02	0.01
66	219.0	2.19	0.01	0.01
80	220.0	2.20	0.00	0.00
86	220.0	2.20	0.00	0.00
93	220.0	2.20	0.00	0.00
95	220.0	2.20	0.00	0.00

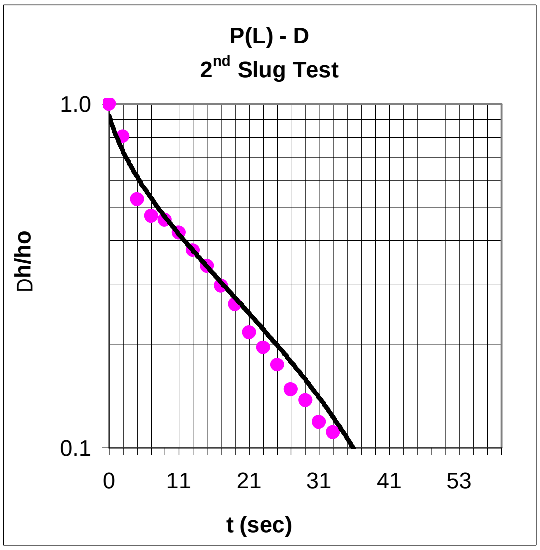
L (m) = 2
R (m) = 0.08
r (m) = 0.01
To (sec) = 13
K (m/s) = 6.0E-06

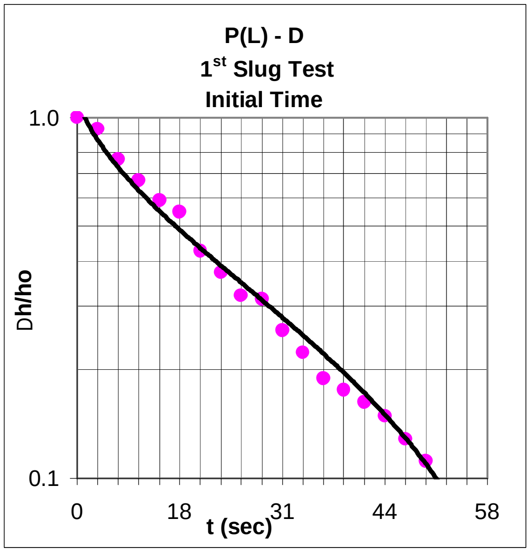
8 APPENDIX B SLUG TEST RESULTS

P(L) - D
First Test



P(L) - D
Second Test





P(L) - E
First Test

Water Level (m)	2.23			
D**ho (m) =**	1.65		**ho (m) =**	0.58

t (sec)	**h (cm)**	**h (m)**	D**h (m)**	D**h/ho**
0	165	1.65	0.58	1.00
6	170	1.70	0.53	0.91
8	185	1.85	0.38	0.66
17	220	2.20	0.03	0.05
25	220	2.20	0.03	0.05
27	223	2.23	0.00	0.00
30	223	2.23	0.00	0.00

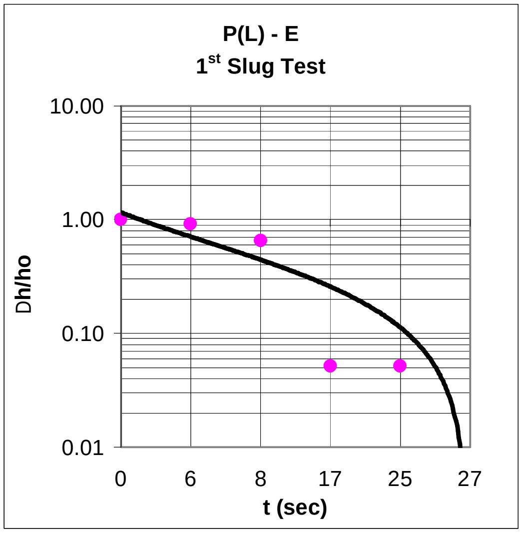
L (m) = 3
R (m) = 0.08
r (m) = 0.01
To (sec) = 12.28
K (m/s) = 4.7E-06

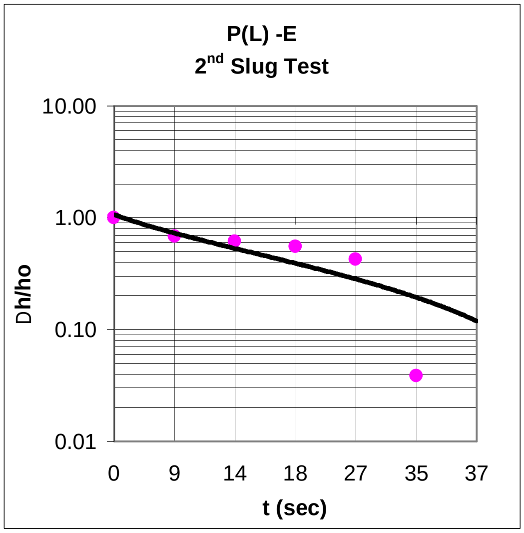
P(L) - E
Second Test

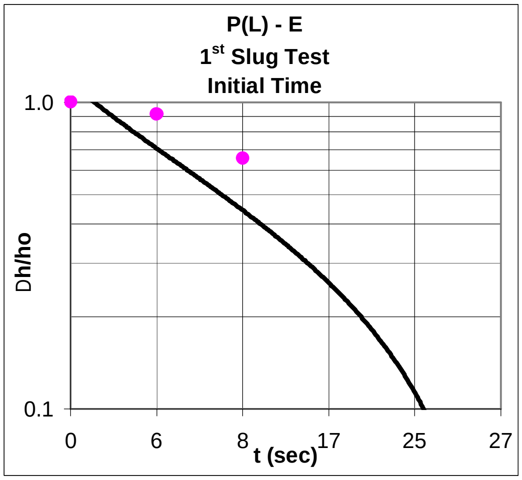
Water Level (m)	2.23			
D**ho (m) =**	1.45		**ho (m) =**	0.78

t (sec)	**h (cm)**	**h (m)**	D**h (m)**	D**h/ho**
0	145	1.45	0.78	1.00
9	170	1.70	0.53	0.68
14	175	1.75	0.48	0.62
18	180	1.80	0.43	0.55
27	190	1.90	0.33	0.42
35	220	2.20	0.03	0.04
37	223	2.23	0.00	0.00

L (m) = 3
R (m) = 0.08
r (m) = 0.01
To (sec) = 28.05
K (m/s) = 2.1E-06


P(L) - E
1st Slug Test


P(L) -E
2nd Slug Test


P(L) - E
1st Slug Test
Initial Time

9 APPENDIX C WATER LEVELS FOR EQUIPOTENTIAL MAP*

#	Name	Coordinates		Water Level	Elev	Water Level
		N	E	mbgs	masl	masl
1	Picacho	1396983	485419.0	13.60	62.42	48.82
2	Las Mercedes	1385667	510414.0	12.15	112.94	100.79
3	Puntarena	1383038	510820.6	12.99	96.15	83.16
4	La Estación	1382363	508883.6	12.20	83.66	71.46
5	San Antonio	1382189	506913.5	4.40	71.90	67.50
6	San Francisco	1381471	505131.0	4.12	63.46	59.34
7	Flor Verde	1382990	507704.6	6.20	76.94	70.74
8	Tesorero 1	1386291	489625.1	3.13	20.00	16.87
9	Amelia	1388322	479824.6	7.31	7.20	-0.11
10	San Carlos	1387201	479067.1	10.00	5.27	-4.73
11	San Rafael	1387840	481230.5	5.72	8.19	2.47
12	El Realejo	1386386	482457.6	2.44	8.43	5.99
13	Rosario	1388680	480866.4	3.97	8.77	4.80
14	Paraisito	1391898	481885.8	4.41	16.74	12.33
15	Mono Chingo 1	1385213	484226.5	12.92	8.56	-4.36
16	Mono Chingo 2	1385459	483731.0	3.29	8.63	5.34
17	Trianón 1	1383961	500741.4	2.77	50.00	47.23
18	Trianón 2	1385016	500888.4	0.90	56.76	55.86
19	Chico Mulapa	1386448	501556.8	5.18	67.18	62.00
20	Posoltega 1	1387991	502573.0	14.27	85.00	70.73
21	Posoltega 2	1388769	502939.1	19.70	98.89	79.19
22	El Roble	1388153	505007.9	21.42	101.95	80.53
23	Paciente 2	1386962	507566.6	24.33	106.86	82.53
24	Buenos Aires	1386525	508761.2	26.02	111.43	85.41
25	El Porvenir	1385001	511825.6	18.50	117.39	98.89
26	Los Cocos	1384567	512991.5	17.32	120.00	102.68
27	Santa Lucía	1383581	514590.7	7.21	120.00	112.79
28	San José de Telica	1382424	515033.1	22.26	125.00	102.74
29	Santa Gertrudis	1392673	495589.4	18.42	108.80	90.38
30	Cosmapa	1393151	494020.4	21.00	113.60	92.60
31	San Benito	1393612	492645.1	11.15	93.57	82.42
32	Santa Rosa	1393900	490827.9	10.35	85.00	74.65
33	San Benito 2	1394535	489327.8	11.32	80.00	68.68
34	Campana Sur	1394563	487876.0	10.45	69.78	59.33
35	Buenos Aires	1390093	500872.4	22.78	104.00	81.22
36	Poneloya	1367514	496547.0	2.03	2.90	0.87
37	San Roque	1368574	498717.4	5.66	20.00	14.34
38	El Toro	1369215	500934.2	4.47	20.00	15.53
39	San Jerónimo	1369505	502463.2	3.13	19.30	16.17

* Data proportioned by Corriols, M.; personal communication.

9 APPENDIX C WATER LEVELS FOR EQUIPOTENTIAL MAP*

#	Name	Coordinates		Water Level	Elev	Water Level
		N	E	mbgs	masl	masl
40	San Carlos	1370428	503686.4	5.00	8.30	3.30
41	El Marañón	1371741	504819.8	5.45	9.45	4.00
42	El Infiernito	1372595	506463.7	11.45	40.00	28.55
43	Santa Klelia	1373206	507706.0	21.16	80.00	58.84
44	Luisa Espinoza	1373501	509081.6	6.90	70.00	63.10
45	Hangar La Unión	1373875	510174.1	16.32	70.00	53.68
46	Félix P. Quiróz	1372757	510593.5	9.62	67.00	57.38
47	El Almendro	1371534	510195.6	8.44	68.50	60.06
48	Troílo	1376993	5000628.6	5.25	25.00	19.75
49	Quebrada Seca	1376156	503243.3	4.22	33.57	29.35
50	Yagualí	1375808	504741.6	5.95	40.00	34.05
51	Goyena 1	1376982	505590.9	4.20	46.15	41.95
52	Nueva Vida	1378815	505661.9	7.86	60.00	52.14
53	Goyena 2	1379837	505646.1	10.95	60.00	49.05
54	La Envidia	1379452	507557.2	6.81	62.10	55.29
55	La Cascada	1379097	509479.4	6.73	80.00	73.27
56	La Canela	1377698	510231.4	8.25	70.00	61.75
57	Roger Deshon	1375856	511691.9	19.14	90.00	70.86
58	Las Conchitas	1366754	508610.4	9.47	70.00	60.53
59	San Jerónimo 2	1367021	507455.8	2.38	60.00	57.62
60	San Sebastián	1368005	506444.3	15.96	60.00	44.04
61	Las Colinas	1368101	504812.7	7.40	40.00	32.60
62	La Ceiba	1370769	505584.6	17.20	60.00	42.80
63	Escuela	1371278	506812.9	11.35	40.00	28.65
64	El Obraje	1371635	508225.6	13.72	65.00	51.28
65	El Ojoche	1374701	509247.5	4.75	54.00	49.25
66	El Tanque	1384361	506159.9	3.90	73.57	69.67
67	San Gilberto	1385078	504986.9	5.53	74.86	69.33
68	El Porvenir	1386105	503310.0	8.01	72.22	64.21
69	San Francisco	1387976	500580.9	9.45	77.00	67.55
70	Valle Viejo 1	1389010	499104.5	11.10	75.70	64.60
71	Valle Viejo 2	1389686	497944.2	11.04	77.14	66.10
72	Chinandega	1395407	486007.3	11.28	60.00	48.72
73	La Cepa	1390192	483428.4	3.85	20.00	16.15
74	La Concepción	1391801	484787.1	4.51	31.79	27.28
75	Santa Lucía	1393539	485911.0	5.69	46.30	40.61
76	Zapatera	1386534	494184.3	3.32	34.40	31.08
77	Paso Hondo	1379847	494132.8	3.52	20.00	16.48
78	El Gobierno	1376977	494458.9	1.73	19.05	17.32

* Data proportioned by Corriols, M.; personal communication.

10 APPENDIX D TOPOGRAPHIC SURVEY

Topographer, Eng. Sergio Cordonero from INETER realized topographic survey at the sites, as follows:

Code	Ground Surface (masl)	Top of Casey Surveyed (masl)
B(H) – A	139.13	139.81
B(H) – B	139.21	139.96
B(H) – C	139.16	139.92
B(H) – D	139.13	139.81
B(H) – E	139.16	139.92
T(M) – A	41.97	42.89
T(M) – B	42.01	42.81
T(M) – C	42.01	42.66
T(M) – D	41.97	42.89
T(M) – E	42.01	42.66
T(M) – I	42.15	42.84
P(L) – A	16.66	17.51
P(L) – B	16.81	17.62
P(L) – C	16.65	17.48
P(L) – D	16.66	17.51
P(L) – E	16.65	17.48

masl: meters above sea level

11 APPENDIX E Description of Analytical Techniques

Major and Minor Ions

Major and minor ions analyses were carried out following the American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater, 20th Edition, Washington 1999.

Ammonium analyses were carried out following the procedure from Natural Water, Wastewater and Marine Water Analyses. Rodier, J. Omega Editions; Spain, 1981.

Table below enlists major ions analyses carried out with APHA standard methods, and the analytical technique and/or equipment for their measurement.

Analysis	Method	Analytical Tecnique or Equipment
PH	4500-H.B	Phmeter
Electrical Conductivity	2510.B	Conductimeter
Total Dissolved Solids (TDS)	1030.F	
Calcium	3500-Ca.D	Titration
Magnesium	3500-Mg.E	By difference
Sodium	3500-Na.B	
Potassium	3500-K.D	Flame Photometry / AA in flame emission mode
Chloride	4110.B	Ion Chromatography
Nitrate	4110.B	Ion Chromatography
Sulfate	4110.B	Ion Chromatography
Carbonate	2320.B	
Bicarbonate	2320.B	
Total Hardness	2340.C	Titration
Total Alkalinity	2320.B	Titration
Phenolphthalein Alkalinity	2320.B	Titration
Silica	4500-Si.D	Spectrometry
Nitrites	4500-NO2.B	Spectrometry
Fluoride	4500-F.D	Ion Chromatography
Total Iron	3500-Fe.D	Spectrometry

11 APPENDIX E Description of Analytical Techniques

For Ion Chromatography analyses, an ion DX100 chromatograph with Ion Pac AS4A analytical column and Ion Pac AG4A guard column is used.

Pesticides

Organochloride and organophosphorus pesticides are analyzed using liquid-liquid extraction and gas chromatography technique. Organochlorine pesticides are analyzed following the analytical procedure of J.P. Villeneuve Method (IAEA, 1995), and organophosphorus pesticides were analyzed following S. Jensen, et al. Method (FAO, 1983). A Varian 3300 gas chromatograph with electron capture detector (ECD) and DB05 capillary column with 0.25 m film thickness is used for these analyses. The carrier gas is hydrogen and make-up gas is nitrogen. The injector temperature is 250 °C and the ECD temperature is 350 °C. One µL of standard is injected with each set of samples. The volume of sample injected is 3 µL. Gas chromatograph oven profile conditions are specified below:

Initial Temperature	100 °C
Hold time	1 minute
Temperature 1	200 °C
Ramp rate 1	4 °C/minute
Hold time	0 minute
Temperature 2	230 °C
Ramp rate 2	3 °C/minute
Hold time	0 minute
Temperature 3	230 °C
Ramp rate 3	15 °C/ minute
Hold time	5 minute
Total time	42 minutes

11 APPENDIX E Description of Analytical Techniques

Bacteria

Bacterial analyses were analyzed according to methods 9222 B (total coliforms), 9222 D (fecal coliforms), 9222 G (escherichia coli), and 9230 C (fecal streptococcus) from American Public Health Association (APHA) Standard Methods. The operative normative procedures (OPN’s) from the Microbiology laboratory at CIRA-UNAN-Managua, are based on the following literature:

- Standard Methods for the Examination of Water and Wastewater, 19th Ed., American Public Health Association –APHA-, Washington, 1995.
- Standard Methods for the Examination of Water and Wastewater, 20th Ed., American Public Health Association –APHA-, Washington, 1999.
- CEPIS. Capacity Program for Quality Control and Quality Monitoring of Human Drinking Water Consumption Laboratories. *Determination of total coliforms in Potable Water by Multiple Tubes Method.* Inamine, A. Lima, Perú (2000).
- Panamerican Health Organization (OPS). *Guides for Potable Water Quality. Vol. 1,2,and 3.* 1985

Isotopes

Isotopes Analyses were carried out at the Isotope Science Laboratory from the Department of Physics and Astronomy of the University of Calgary, Canada.

The deuterium/hydrogen isotope analysis of water is determined by chromium reduction. Four mL of sample is injected into a chromium filled quartz reactor held at 960 °C and evacuated to $\sim 10^{-3}$ Torr. Hydrogen gas is produced and

11 APPENDIX E Description of Analytical Techniques

collected within 60 seconds, then sent to a dual inlet, isotope ratio mass spectrometer (Micromass 602) for analysis.

Internal lab standards are analyzed repeatedly within each sample set (1 standard per 5 samples) to guarantee quality control.

Accuracy and precision for d^2H_{H2O} of natural waters are generally better than plus minus 2.0 per mil (one standard deviation based on n=10 lab standards). For deuterium:

- Internal laboratory standards (CW: Calgary water, OS: "old SMOW", SWAT) are calibrated periodically using international standards (V-SMOW, V-SLAP, V-GISP).
- Isotopically enriched water samples are calibrated using additional standards with positive δ^2H values provided by the IAEA (e.g. IAEA 302 and 304).
- Corrected symbol
- $^2HH_2O$ values are reported in the per mil (‰) notation relative to V-SMOW.

The bibliographic material for this analysis is:

1. Coleman, M.L., Shepherd, T.J., Durham, J.J., Rouse, J.E., Moore, G.R., 1982, Reduction of water with zinc for hydrogen isotope analysis: Anal. Chem., v. 54, p. 993-995.
2. Friedman, I., 1953, Deuterium content of natural water and other substances: Geochim. Cosmochim. Acta, v. 4, p. 89-103.
3. Nelson, S.T., Dettman D., 2001, Improving hydrogen isotope ratio measurements for on-line chromium reduction systems: Rapid Communications in Mass Spectrometry, 2001; 15: 2301-2306.

11 APPENDIX E Description of Analytical Techniques

4. Gehre, M., Hoefling, R., Kowski, P., Strauch, G., 1996, Sample Preparation Device for Quantitative Hydrogen Isotope Analysis Using Chromium Metal: Anal. Chem., v. 68, p. 4414-4417.
5. Donnelly, T., Waldron, S., Tait, A., Dougans, J., Bearhop, S., 2001: Hydrogen isotope analysis of natural abundance and deuterium-enriched waters by reduction over chromium on-line to a dynamic dual inlet isotope-ratio mass spectrometer, 2001; 15: 1297-1303.

For ^{18}O analysis, the $^{18}O/^{16}O$ ratio of natural waters is determined using the common CO_2-H_2O equilibration technique in which millimole quantities of CO_2 are equilibrated with water samples under constant temperatures. Subsequently, the CO_2 is cryogenically purified and analyzed mass spectrometrically (Micromass SIRA II) for its $^{18}O/^{16}O$ ratio. Note that this technique measures the isotopic activity of ^{18}O and not the actual ^{18}O concentration.

The obtained "raw" $\delta^{18}O_{H2O}$ values are drift corrected and normalized using internal laboratory standards. Internal laboratory standards (CW: Calgary water, LWS2: close to seawater) are calibrated periodically using international standards (V-SMOW, V-SLAP, V-GISP). Isotopically enriched water samples are calibrated using additional standards with positive $\delta^{18}O$ values provided by the IAEA (e.g. IAEA 302 and 304).

Corrected $\delta^{18}OH_2O$ values are reported in the per mil (‰) notation relative to V-SMOW.

Accuracy and precision for $\delta^{18}O$ values of natural waters are generally better than ± 0.2‰ (one standard deviation based on n=50 lab standards).

The bibliographic material for this analysis is:

1. Epstein, S. and T. K. Mayeda, 1953, Variation of O18 content of waters from natural sources: Geochimica et Cosmochimica Acta, v. 4, p. 213-224.

11 APPENDIX E Description of Analytical Techniques

2. Horita, J., Wesolowski, D., and Cole, D., 1993, The activity-composition relationship of oxygen and hydrogen isotopes in aqueous salt solutions: I. Vapor-liquid water equilibration of single salt solutions from 50 to 100 oC.: Geochimica et Cosmochimica Acta, v. 57, p. 2797-2817.
3. O'Neil, J.R., Adami, L.H., Epstein, S., 1975, Revised value for the 18O fractionation factor between CO2 and water at 25oC: J. Res. U.S. Geol. Surv., v. 3, p. 623-624.
4. Sofer, Z.a.G.J.R., 1972, Activities and concentrations of oxygen-18 in concentrated aqueous salt solutions: analytical and geochemical implications: Earth Planet. Sci. Lett., v. 15, p. 232-238.

For more information related to these analyses, please refer to:

http://www.phas.ucalgary.ca/isl/VG_602_d2HH2O.htm

http://www.phas.ucalgary.ca/isl/GILSON_d18OH2O.htm

12 APPENDIX F PREVIOUS MAJOR/MINOR IONS STUDIES IN LEÓN AND CHINANDEGA

INETER/OIEA (1997), conducted two samplings at the piezometer installations, and the samples were further analyzed for major and minor ions. The study also conducted sampling at 39 dug and drilled wells, major and minor ions values are shown in Tables 23 and 24, respectively; and water chemical characterization from piezometer installations is shown in Piper plot in Figure 23. Data characterized groundwater from the aquifer of León and Chinandega mainly as sulfate-calcium-magnesium.

Table 23. Major/Minor Ions at Piezometer Installations-INETER/OIEA,1997

Code	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Total Fe	Cl^{-}	NO_3^{-}	SO_4^{2-}	HCO_3^{-}
PM-1.1-A	43	15	21	7	6	3	13	10	221
PM-1.1-B	38	16	22	7	13	5	16	9	222
PM-1.2-A	59	7	19	5	30	3	14	10	227
PM-1.2-B	42	12	18	5	8	5	16	9	215
PM-1.3-A	58	16	25	7	33	24	25	25	231
PM-1.3-B	69	31	42	17	10	32	72	30	326
PM-2.1-A	56	22	27	6	15	44	166	17	77
PM-2.1-B	16	3	9	3	1	7	30	5	42
PM-2.2-A	28	14	20	5	37	14	61	13	95
PM-2.2-B	59	24	26	6	27	51	217	13	70
PM-2.3-B	40	17	22	5	163	31	123	13	89
PM-3.1-A	32	14	24	6	14	14	19	13	143
PM-3.1-B	42	25	24	6	37	13	28	16	147
PM-3.2-A	61	30	48	2	36	33	51	33	275
PM-3.2-B	56	34	45	2	37	28	49	30	302
PM-3.3-B	53	32	42	2	8	27	58	30	281

All units in mg/L **A= First sampling**

PM= Monitoring Well **B= Second sampling**

12 APPENDIX F PREVIOUS MAJOR/MINOR IONS STUDIES IN LEÓN AND CHINANDEGA

Table 24. Major and Minor Ions at Dug and Drilled Wells - INETER/OIEA 1997*

CODE	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe Total	Cl^{-}	NO_3^{-}	SO_4^{2-}	HCO_3^{-}
PP-130	27.8	11.92	18	5	0.04	5.12	17.64	7.53	199.11
PP-62	38.51	21.17	28.3	5.75	0.08	7.74	14.99	15.53	283.44
PP-156	26.96	15.4	18	5.1	0.14	4.17	15.48	5.25	200.27
PP-110	37.3	16.84	16.8	4.85	0.08	6.65	17.13	9.2	228.4
PP-28	44.89	18.05	16.7	0.5	7.13	11.54	5.61	10.51	246.26
PP-103	30.08	15.36	29.6	8.35	0.04	8.52	8.3	13.64	216.71
PE-44	44.34	21.12	22.6	6.9	1.11	34.09	142	20.56	70
PE-B	38.69	15.04	16.7	0.8	0.79	3.86	11.36	8.74	205.83
PP-26	39.68	18.29	20	7.95	0.13	4.02	17.667	8.87	257.69
PP-12	38.1	14.44	16.8	5.9	0.17	9.19	10.05	13.75	211.37
PE-16	19.05	7.22	10	3.15	0.76	3.89	13.67	6.02	105.38
PE-6	96.83	26.08	12.5	4.2	0.08	4.75	34.3	5.75	391.75
PP-A	45.24	18.77	21.1	8.5	0.05	4.16	14.4	6.83	288.95
PP-29	19.05	10.68	15.8	5.35	0.09	4.97	16.48	6.78	131.19
LE/PP-134	30.16	15.4	13	2.8	0.04	9.53	32	13.85	161.64
PP-8	63.73	20.16	33.4	7.85	0.04	5.7	21.31	11.75	358.76
PPN-LE	24.6	8.42	17.8	5.4	0.04	5.37	23.66	6.6	125.3
PP-41	32.54	12.03	50	5.4	0.05	30.9	0.24	20.91	250.08
PE-A	22.22	9.42	11	3.95	2.4	4.27	3.95	5.27	113.01
PE-X	29.76	8.42	27	1.85	0.08	24.2	1.59	10.92	142.15

*All units in mg/L

12 APPENDIX F PREVIOUS MAJOR/MINOR IONS STUDIES IN LEÓN AND CHINANDEGA

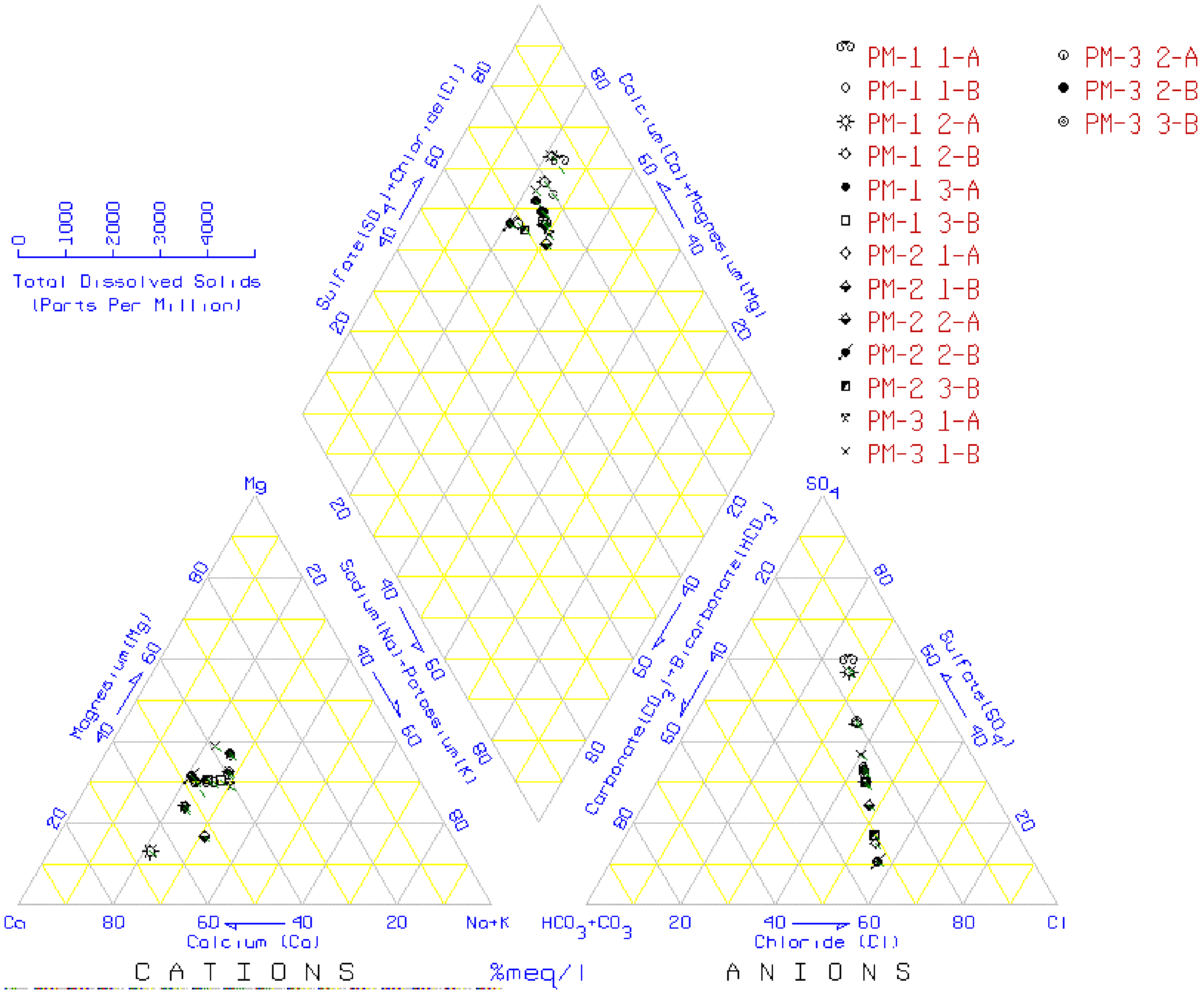


Figure 23. Piper Plot of Major Ions in Groundwater from Piezometer Installations. Source: INETER/OIEA, 1997

12 APPENDIX F PREVIOUS MAJOR/MINOR IONS STUDIES IN LEÓN AND CHINANDEGA

INETER (2000), reported major/minor ions data from samples collected in 159 dug and drilled wells in León and Chinandega. For the purpose of this thesis only the results from Posoltega region are going to be shown in Table 25, and water characterization (bicarbonate-calcium-magnesium) in Figure 24.

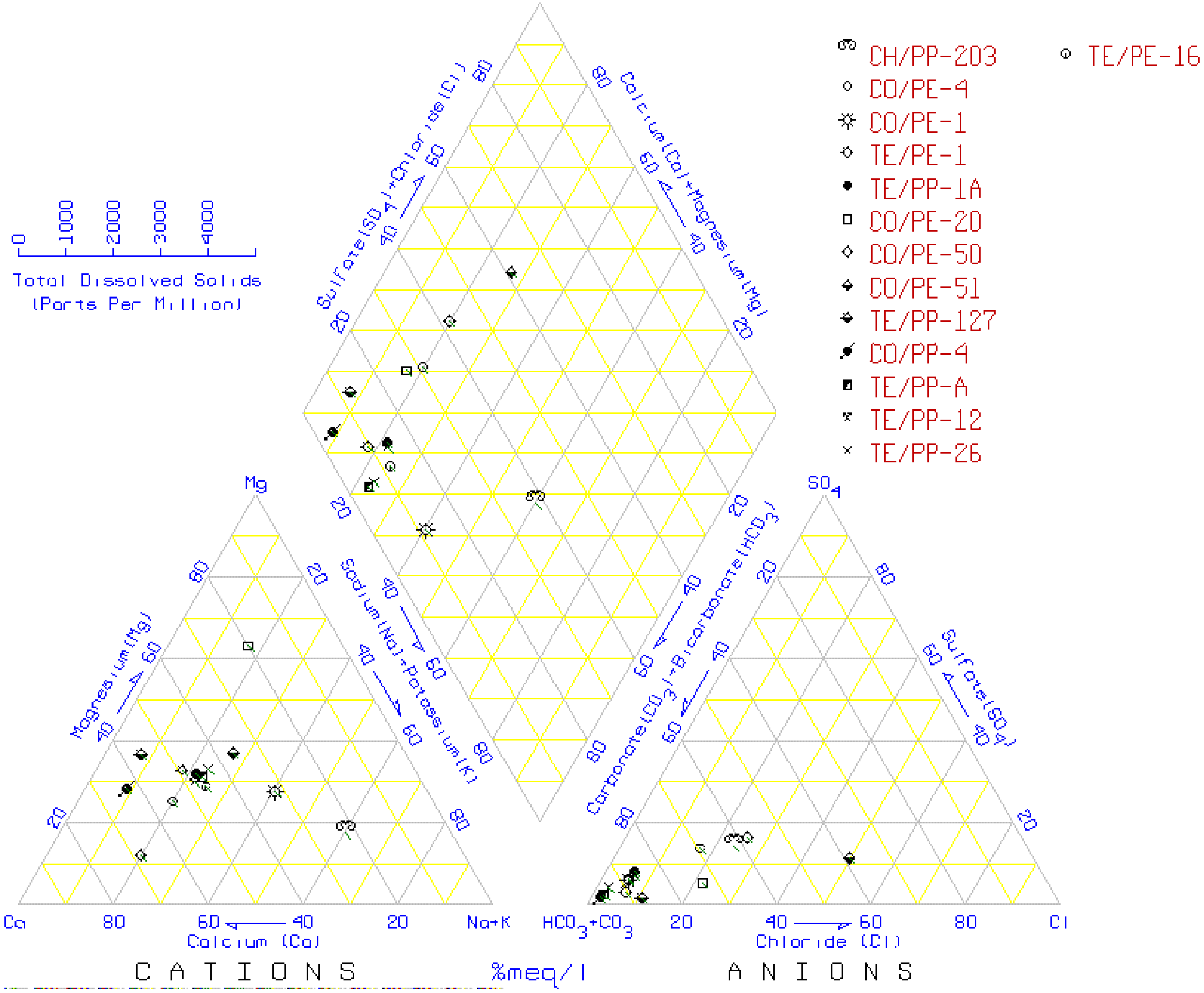


Figure 24. Piper Plot of Major Ions in Groundwater from Sampled Wells in Posoltega. Source: INETER, 2000.

12 APPENDIX F PREVIOUS MAJOR/MINOR ION STUDIES IN LEÓN AND CHINANDEGA

Table 25. Major Ions from Wells in Posoltega Region - INETER 2000

Code	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	CO_3^{2-}	SO_4^{2-}
CH/PP-203	131	20	46	22	81	362	0	65
CO/PE-4	32	14	97	27	52	362	0	56
CO/PE-1	31	29	33	17	9	228	0	12
TE/PE-1	20	7	57	23	11	253	0	6
TE/PP-1A	13	5	30	13	5	138	0	10
CO/PE-20	36	0	37	71	79	456	0	26
CO/PE-50	26	3	85	9	60	233	0	52
CO/PE-51	59	6	74	46	200	270	0	62
TE/PP-127	3	7	48	19	20	207	34	4
CO/PP-4	13	4	96	26	5	392	0	6
TE/PP-A	21	9	45	19	4	287	0	6
TE/PP-12	17	6	38	14	9	211	0	14
TE/PP-26	20	8	40	18	4	258	0	9
TE/PE-16	10	3	19	7	4	105	0	6

All units in mg/L	**CH= Chinandega**
PP= Drilled Well	**CO= Corinto**
PE= Dug Well	**TE= Telica**

12 APPENDIX F PREVIOUS MAJOR/MINOR IONS STUDIES IN LEÓN AND CHINANDEGA

CIRA/IAEA (1999) analyzed major and minor ions in dug and drilled wells from León and Chinandega. For the purpose of this thesis, only results from the Posoltega region wells sampled are shown in Table 26; and water characterization is presented in Piper plot in Figure 25.

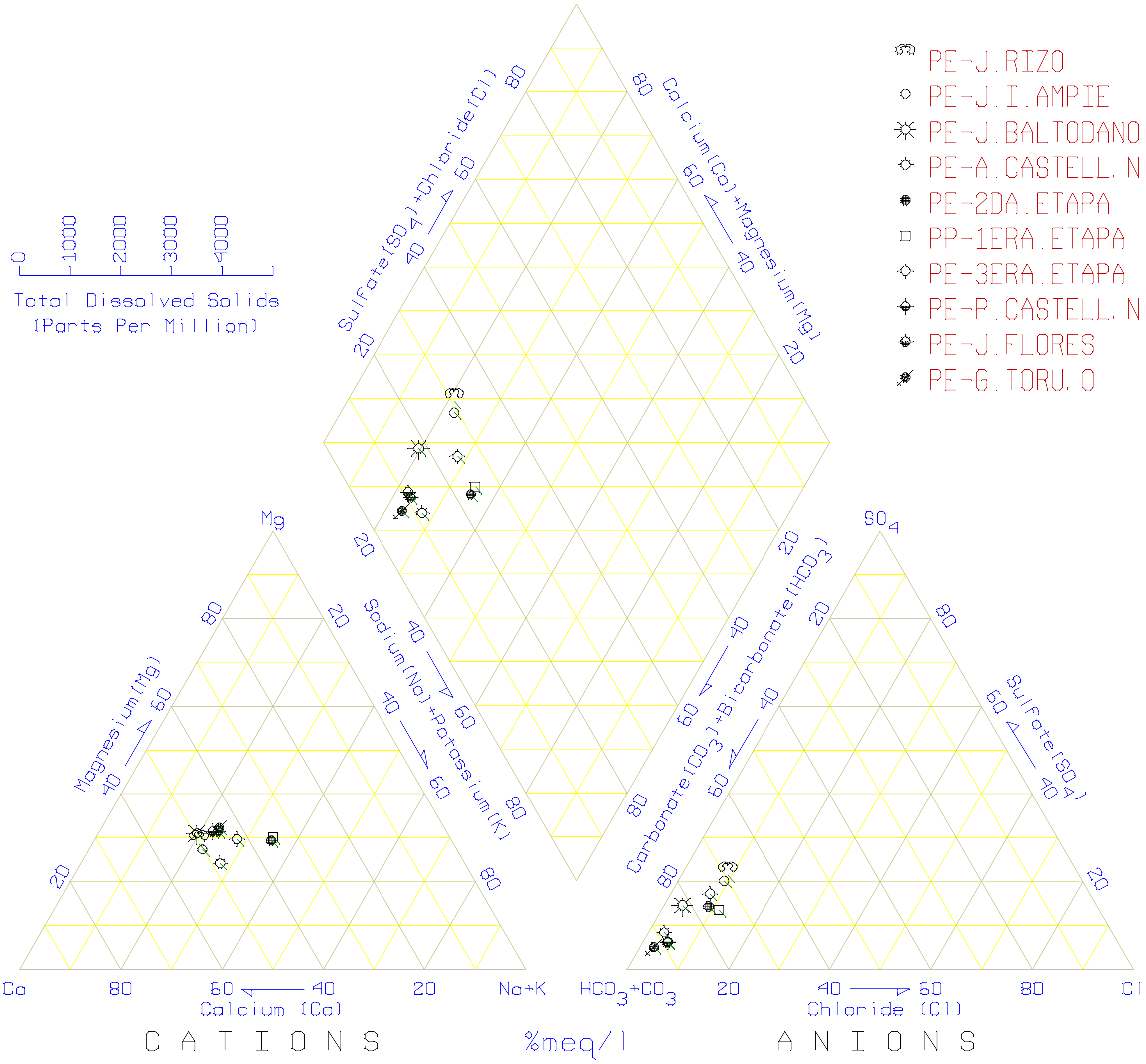


Figure 25. Piper Plot of Major Ions in Posoltega Groundwater. CIRA/IAEA (1999)

12 APPENDIX F PREVIOUS MAJOR/MINOR IONS STUDIES IN LEÓN AND CHINANDEGA

Table 26. Major and Minor Ions from Dug Wells in the Posoltega Region - ARCAL XXXI (CIRA/IAEA, 1999)

	Code	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	NO_3^-	SO_4^{2-}	Total Fe
El Tanque	PE-J.Rizo	13.00	5.10	33.10	11.36	13.13	65.99	51.46	41.17	1.01
	PE-J.I.Ampie	15.00	5.84	35.89	11.85	14.52	62.79	64.34	43.41	0.25
	PE-J.Baltodano	9.40	2.15	23.53	8.95	3.80	71.76	37.41	20.73	<ld
	PE-A.Castellón	10.80	4.66	20.74	6.29	3.04	65.35	41.44	11.16	<ld
Betesda	PE-2da. Etapa	37.50	9.59	38.28	19.10	17.59	198.60	30.70	38.33	0.21
	PP-1era. Etapa	47.00	10.70	46.26	24.18	26.89	276.80	13.14	42.95	<ld
	PE-3era. Etapa	21.00	7.81	33.55	14.30	12.75	112.50	48.99	38.33	0.14
Las Mayorgas	PE-P.Castellón	16.00	5.89	34.92	14.44	7.68	148.70	45.41	13.33	<ld
	PE-J.Flores	17.60	6.29	35.52	15.03	8.09	156.40	47.16	13.52	0.38
	PE-G.Toruño	12.50	4.76	25.39	11.19	2.93	138.30	15.64	7.32	<ld

PE: Dug Well

12 APPENDIX F PREVIOUS MAJOR/MINOR ION STUDIES IN LEÓN AND CHINANDEGA

Samples from dug and drilled wells from Posoltega region, as well as from the same spring sampled by Payne and Yutserver (1974) were sampled by Centro Humboldt (2002). Results and groundwater characterization are shown in Table 27 and Figure 26. Groundwater is characterized as bicarbonate-calcium-magnesium type.

In 2002, thirty groundwater samples from dug and drilled wells and springs were collected in León and Chinandega (Table 28; Dahlberg and Odebjer, 2002). Groundwater is characterized as bicarbonate-calcium-magnesium (Figure 27).

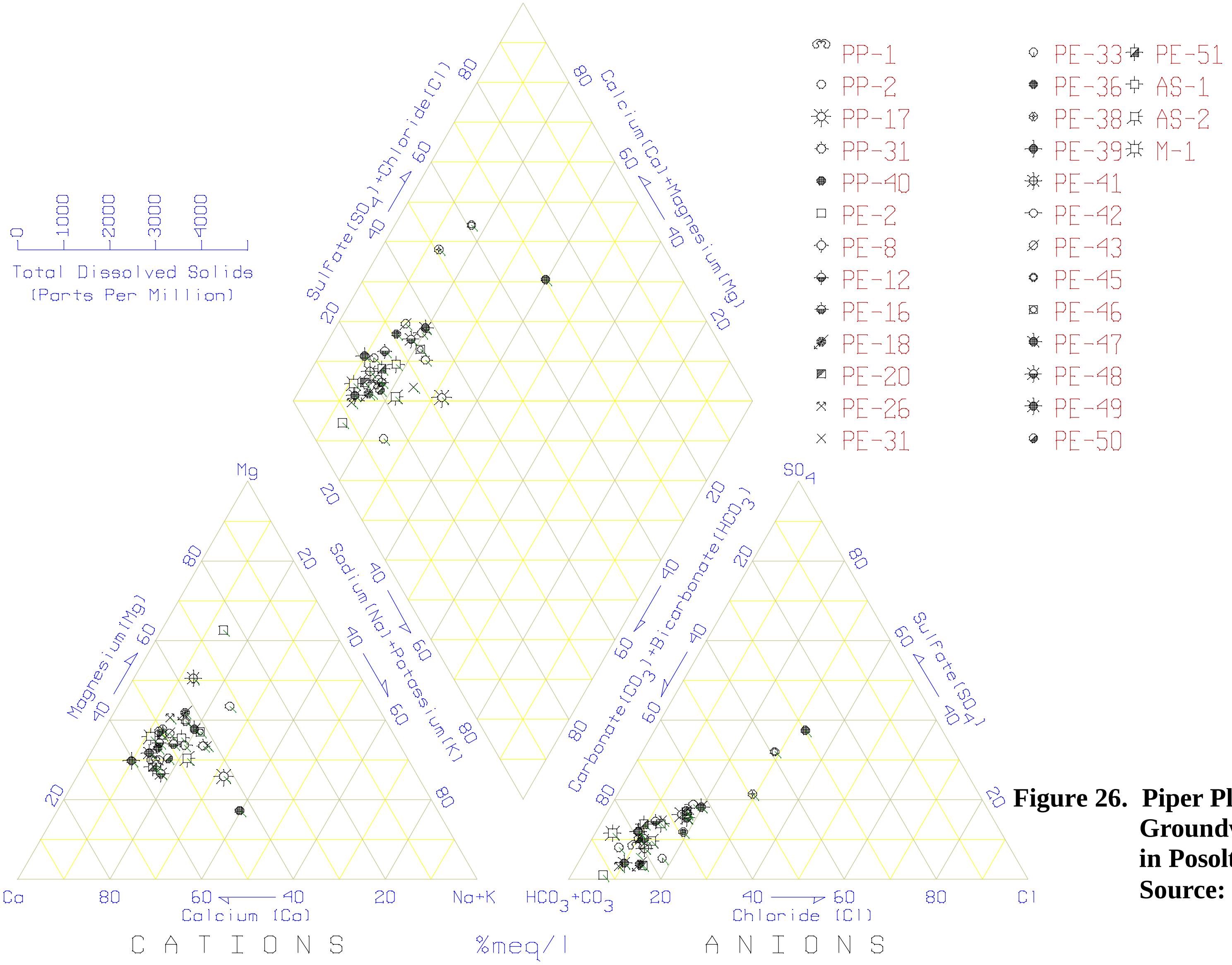


Figure 26. Piper Plot of Major Ions in Groundwater Characterization in Posoltega.
Source: Centro Humboldt, 2002

12 APPENDIX F PREVIOUS MAJOR/MINOR IONS STUDIES IN LEÓN AND CHINANDEGA

Table 28. Major and Minor Ions* in León-Chinandega. Dahlberg and Odebjer, 2002

Location	**Code / Type of Well**		**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**Total Fe**	**Cl^{-}**	**NO_3^{-}**	**SO_4^{2-}**	**HCO_3^{-}**
S. Cristobal	72	M	48.8	24.5	13.7	7.9	nr	36.3	0.0	182.9	34.7
Posolteguilla somero	22b	PE	12.4	11.1	6.9	2.9	nr	4.4	0.4	1.1	108.1
Cristo Rey	71	PP	47.1	89.8	41.9	16.4	nr	46.7	1.7	118.6	443.5
Sunwell	1	PP	73.9	40.3	36.4	14.4	0.2	59.8	1.2	103.1	344.5
Suroeste Esperanza prof.	38	PP	64.6	34.5	37.4	14.2	0.4	83.8	1.9	69.0	249.8
Fabrica de Mani	54	PP	23.6	24.9	31.0	9.9	nr	12.8	4.8	23.5	201.3
La Flor	61	PE	21.7	22.5	25.8	8.4	nr	11.9	3.6	31.8	186.9
SE El Trianon	46	PE	31.3	42.4	32.3	10.7	0.4	22.7	4.7	55.4	247.7
PPL-37	73	PP	15.9	8.4	18.4	7.9	nr	8.7	2.6	0.9	126.5
Las Mercedes	36	PP	11.9	6.6	10.7	5.1	0.2	12.9	1.5	14.1	62.5
S. Francisco	63	PP	15.5	20.6	14.3	7.1	nr	9.1	3.5	18.8	133.6
2 km. N Posoltega	48	PP	24.3	22.4	13.8	7.0	nr	9.5	5.5	12.7	202.0
Posolteguilla prof	22	PP	25.1	27.0	27.4	10.5	nr	14.1	5.1	30.8	219.4
S. Gilberto	5	M	19.9	22.1	14.1	7.7	nr	9.4	7.4	23.3	143.8
Chiquimula	12	M	24.0	24.6	12.1	6.2	nr	15.2	6.3	11.8	179.5
La Cascada	51	PE	15.6	14.5	9.4	1.1	0.1	8.1	8.8	13.5	121.0
El Tanque	4	PE	29.3	11.5	12.8	17.6	nr	11.8	9.5	21.1	119.8
S. Agustin	15	PE	20.7	27.2	22.3	5.3	1.1	16.5	3.7	36.0	166.4
La Fortuna	29	PE	18.0	17.8	11.2	8.6	nr	8.0	10.0	24.3	112.6
S. Agustin	16	M	21.2	28.0	20.0	7.0	nr	13.2	4.3	39.7	156.8
Rancho Grande	65	PE	41.4	17.0	16.5	4.9	nr	12.9	2.6	30.7	200.8
Guanacastal	70	PE	20.6	7.5	12.4	7.0	nr	6.2	15.9	6.6	62.3
La Esperanza	41	PE	28.5	4.2	13.8	3.7	0.2	16.9	4.9	26.9	106.5
Entre Quezalguaque y la Cascada	64	PE	29.7	10.5	10.4	2.2	0.2	11.1	3.2	18.9	125.5
La Virgen	35	PE	28.0	10.9	15.8	7.1	0.1	11.2	9.7	29.3	100.3
Sta. Elena	67	PE	29.2	11.0	28.0	4.9	0.3	12.4	9.3	27.6	133.5
El Tanque	49	PE	17.8	19.8	13.0	4.7	nr	11.6	13.5	35.9	76.6

All ions units in mg/L nr= not reported PP: Drilled Well PE: Dug Well M: Spring

12 APPENDIX F PREVIOUS MAJOR/MINOR IONS STUDIES IN LEÓN AND CHINANDEGA

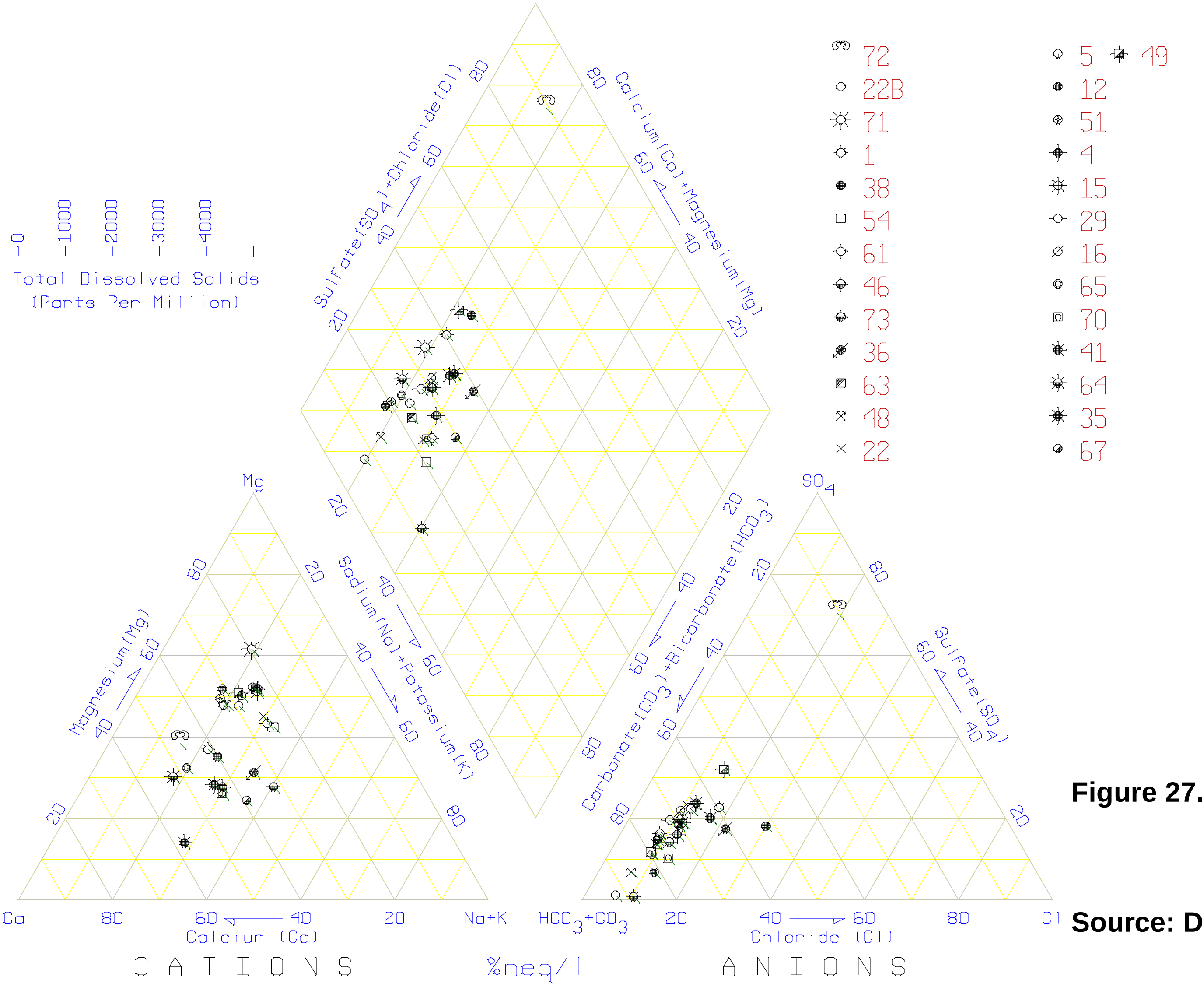


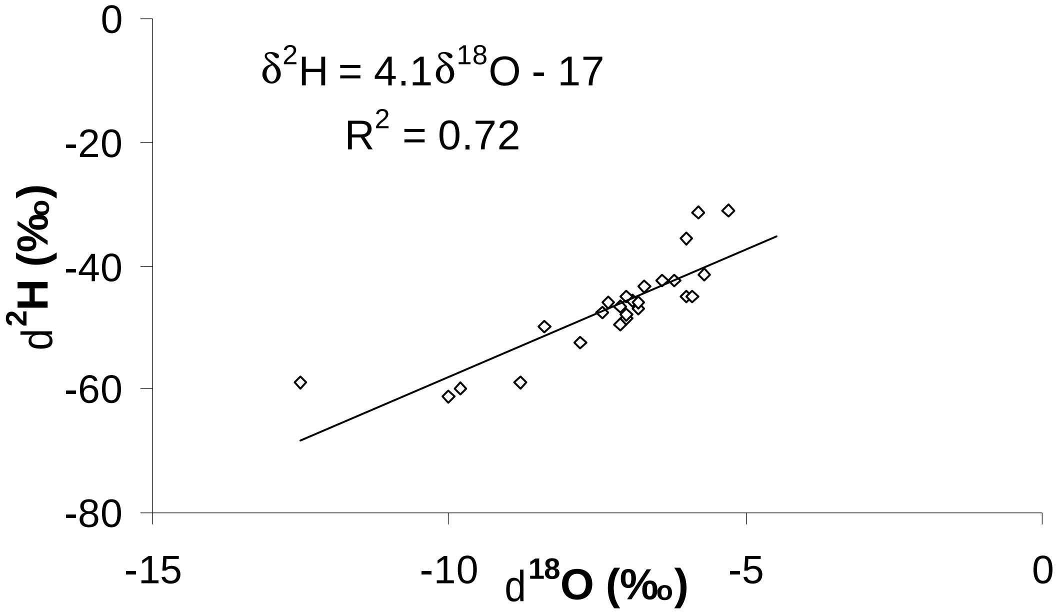
Figure 27. Piper Plot of Major Ions in Groundwater Characterization in León-Chinandega.

Source: Dahlberg and Odebjer, 2002

13 APPENDIX G PREVIOUS ISOTOPE STUDIES IN THE ZONE

In 1969 and 1970, Payne and Yurtsever, from IAEA Department of Research and Isotopes conducted an isotopic study in the zone. It was concluded that recharge to the deep aquifer from elevations higher tan 280 meters is more significant than recharge by precipitation on the plain. Tables 29 and 30 show the isotopic composition of precipitation and groundwater sampled in Nicaragua, respectively; and Figure 28 shows the relationship between ^{18}O and ^{2}H, as taken from the results (Payne and Yurtsever, 1974). Figure 29 shows the relationship between elevation and weighted volume in precipitation samples.

Figure 28. Variation in isotope composition in Water in Chinandega, 1959-1960. Source Payne and Yurtsever, 1974.



13 APPENDIX G PREVIOUS ISOTOPE STUDIES IN THE ZONE

Table 29. Isotope Composition of Precipitation Sampled in Nicaragua

Code	Date of Sampling	Altitude	d^{18}O	d^{2}H
Units		m	(‰)	(‰)
EL POLVON-1.1	23/09 - 22/10/69	25	-7.8	-52.4
EL POLVON-1.2	23/10 - 20/11/69		-6.0	-35.5
EL POLVON-1.3	20/06 - 20/07/70		-5.4	
EL POLVON-1.4	- 19/08/70		-7.5	
EL POLVON-1.5	22/09 - 22/10/70		-6.9	
POSOLTEGA-1.1	19/09 - 22/10/69	83	-8.8	-58.9
POSOLTEGA-1.2	22/10 - 20/11/69		-5.3	-31.0
POSOLTEGA-1.3	20/06 - 20/07/70		-6.5	
POSOLTEGA-1.4	- 19/08/70		-4.5	
POSOLTEGA-1.5	22/09 - 22/10/70		-4.7	
SANTA NARCISA-1.1	19/09 - 22/10/69	345	-9.8	-60.0
SANTA NARCISA-1.2	22/10 - 20/11/69		-7.1	-46.7
SANTA NARCISA-1.3	20/06 - 20/07/70		-7.8	
SANTA NARCISA-1.4	- 19/08/70		-7.2	
SANTA NARCISA-1.5	25/09 - 22/10/70		-6.9	
BELLA VISTA-1.1	19/09 - 22/10/69	730	-10.0	-61.3
BELLA VISTA-1.2	22/10 - 20/11/69		-7.4	-47.7
BELLA VISTA-1.3	20/06 - 20/07/70		-8.1	
BELLA VISTA-1.4	- 19/08/70		-8.2	
BELLA VISTA-1.5	25/09 - 23/10/70		-5.5	
VOLCAN CASITA-1.1	22/09 - 22/10/69	1300	-12.5	-58.9
VOLCAN CASITA-1.2	22/10 - 20/11/69		-8.4	-50.0
VOLCAN CASITA-1.3	20/06 - 20/08/70		-9.0	
VOLCAN CASITA-1.4	24/09 - 23/10/70		-7.8	
SAN CRISTOBAL	29/04 - 13/11/70	1700	-9.6	
VOLCAN TELICA	16/06 - 15/11/70	760	-8.1	

Source: Payne and Yurtsever, 1974

13 APPENDIX G PREVIOUS ISOTOPE STUDIES IN THE ZONE

Table 30. Isotopic Composition of Groundwater in Chinandega Plain

Code	Date of Sampling	Elevation	Total Depth	Static Level	d^{18}O	d^{2}H
Units		**m**	**m**	**m**	**(‰)**	**(‰)**
PP-4/TL-1	15/10/69	85	60	15	-6.8	-47.0
PP-4/TL-2	12/11/69				-6.7	-43.4
PP-4/TL-3	12/05/70				-6.9	-45.7
PP-4/TL-4	17/08/70				-6.8	
PP-4/TL-5	32/10/70				-7.0	
PP-12/TL-1	17/10/69	280	190	153	-7.3	-46.0
PP-12/TL-2	25/11/69				-7.1	-49.4
PP-12/TL-3	12/05/70				-7.0	-45.1
PP-12/TL-4	19/08/70				-7.2	
PP-12/TL-5	22/10/70				-7.3	
PP-26/TL-1	15/10/69	83	25	14	-6.2	-42.5
PP-26/TL-2	12/11/69				-6.0	-44.9
PP-26/TL-3	12/05/70				-5.7	-41.4
PP-26/TL-4	19/08/70				-6.0	
PP-26/TL-5	22/10/70				-5.5	
PP-37/TL-1	03/12/69		60	6	-7.0	-48.5
PP-37/TL-2	12/5/1970				-7.0	-47.9
PP-37/TL-3	21/12/70				-7.0	
PP-43/TL-1	03/12/69		45?		-6.8	-46.1
PP-43/TL-2	21/12/70				-7.0	
PP-27/TL	12/05/70		43	4	-6.4	-42.3
PC-19/TN	23/02/71	< 50			-5.8	-31.5
RIO ATOYA	23/02/71				-5.9	-45.0
BELLAVISTA	19/08/70				-8.5	

Source: Payne and Yurtsever, 1974 **PP= Drilled Well** **PC= Dug Well**

13 APPENDIX G PREVIOUS ISOTOPE STUDIES IN THE ZONE

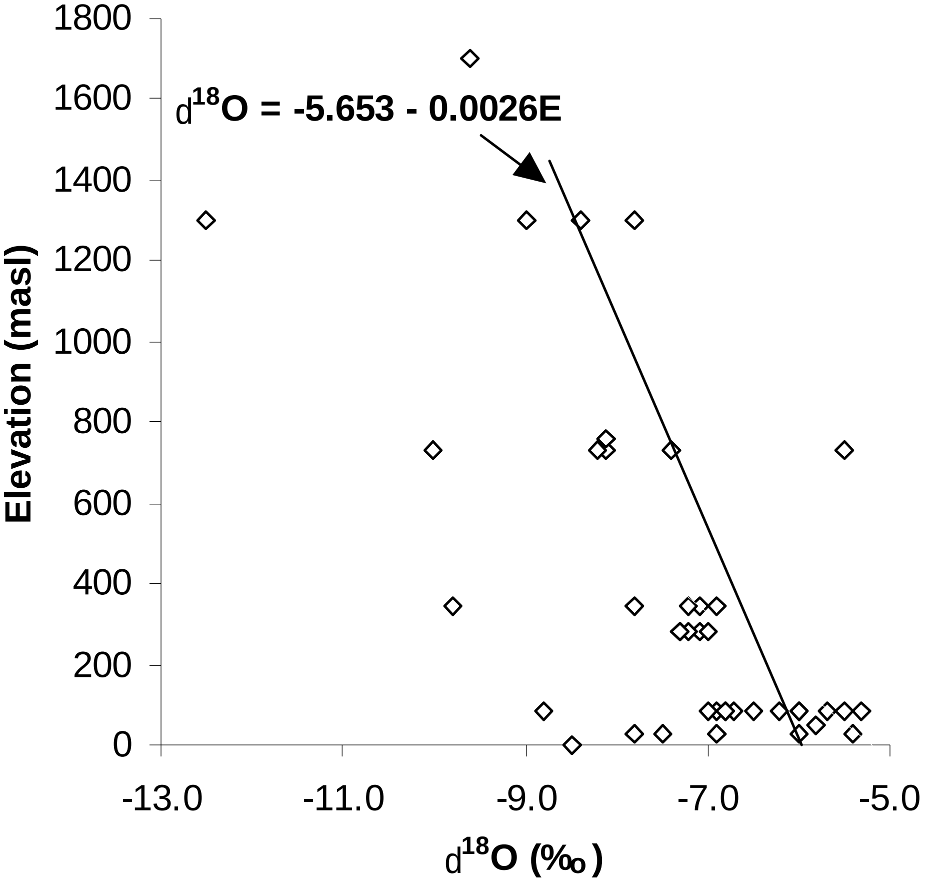


Figure 29. Relation between ^{18}O content of recharge and elevation. (Payne and Yurtsever, 1974)

The hydrogeological study carried out in 1995 and 1996 by INETER in cooperation with OIEA, involved isotopes analyses –^{18}O, ^{2}H, ^{13}C and ^{14}C- for drilled and dug wells, rivers, precipitation, and piezometers installations samples. For the purpose of this thesis, only ^{18}O and ^{2}H results were taken into account. Table 31 shows INETER's isotopic results from samples taken, and Figure 30 represents isotopic variation of the water in the study area (INETER/OIEA, 1997. Unpublished).

13 APPENDIX G PREVIOUS ISOTOPE STUDIES IN THE ZONE

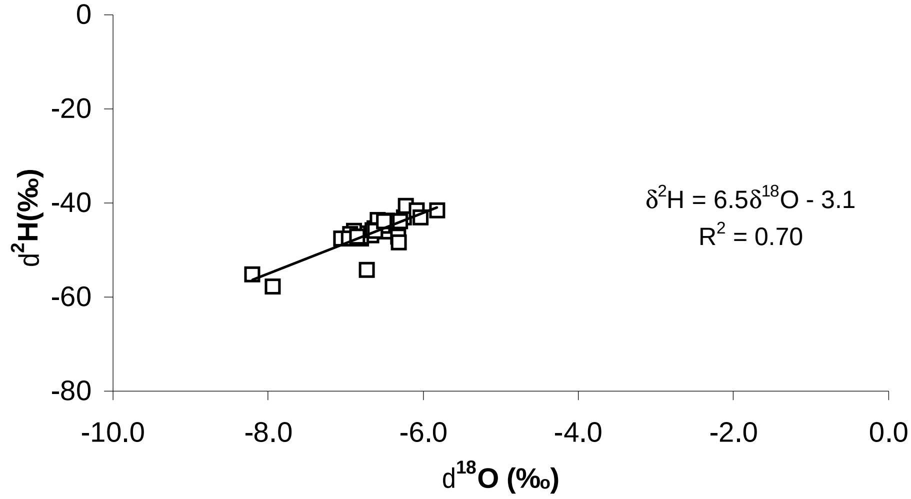


Figure 30. Isotope Composition in Water in León and Chinandega. Source: INETER/OIEA, 1997 (Unpublished).

Table 31. Isotope Composition

Code	d^{18}O	d^{2H}	Code	d^{18}O	d^{2H}
Units	(‰)	(‰)	Units	(‰)	(‰)
PP-130	-6.6	-45.4	TN/PP-8	-6.7	-46.8
PP-62	-6.7	-46.4	LN/PP29	-6.8	-47.1
PP-156	-6.7	-54.2	CH/PP-39	-6.6	-43.6
PP-110	-6.5	-46.1	LN/PP-INAA	-7.0	-47.6
PP-28	-6.3	-43.0	PP-203	-6.9	-47.1
PP-103	-7.1	-47.6	PP-118	-6.2	-40.6
PE-B	-6.3	-47.1	R.ATOYA	-6.1	-41.6
PP-26	-6.9	-45.9	RAIN	-7.9	-57.8
PE-16	-6.5	-44.8	R.POS	-6.7	-45.8
PP-A	-6.9	-47.1	VJ/M1	-8.2	-55.1
PP-29	-6.8	-47.1	PM-1.1	-6.4	-43.9
LE/PP-134	-6.6	-45.9	PM-1.3	-6.3	-43.9
PP-8	-6.8	-47.5	PM-2.1	-6.6	-45.9
PP-41	-6.5	-43.7	PM-2.3	-6.3	-48.4
PE-4	-5.8	-41.6	PM-3.1	-6.5	-43.9
TN/PP-12	-6.9	-46.6	PM-3.3	-6.0	-43.0

Source: INETER/OIEA, 1997 (Unpublished)

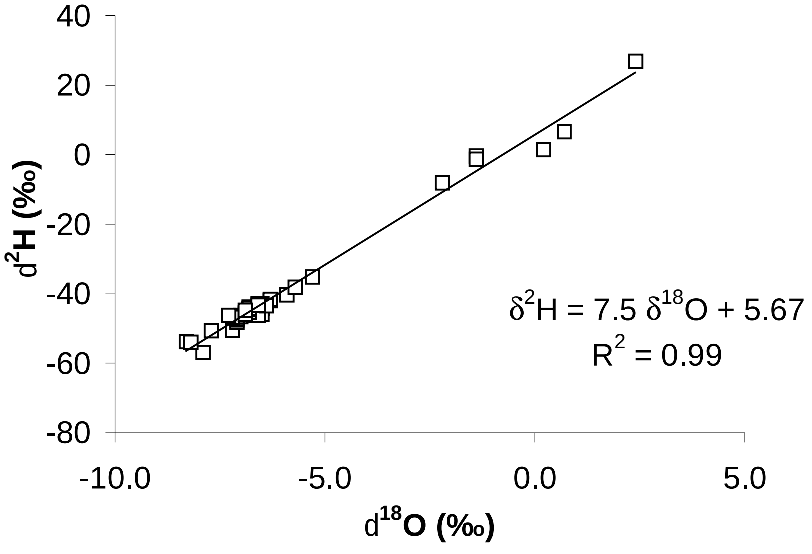
PP= Drilled Well
PE= Dug Well
PM= Piezometer Installation

LE= León
TN= Tonalá
CH= Chinandega

13 APPENDIX G PREVIOUS ISOTOPE STUDIES IN THE ZONE

In 1998 and 1999, CIRA-UNAN-Managua in cooperation with IAEA carried out an isotopic study in the aquifer of León and Chinandega. Groundwater, seawater, surface water, precipitation and spring samples were collected during the rainy season meanwhile groundwater, precipitation and spring samples were collected during the summer season. The study concluded that the results from spring samples are quite similar in both sampling periods and therefore it is considered that this zone represents the main recharge into the aquifer. The results for the other samples concluded that the enriched values they presented might be due to evaporation processes that undergo in those zones, emphasizing that the water from the zone experiments a low evaporation rate during rainy and dry season. It was also concluded that there is a recent recharge process in the zone, and that there is a considerable hydraulic connection between surface water and groundwater in the first 20 meters below ground surface in the low zone, and 60 meters below ground surface in the middle zone. Results from the two sampling periods are shown in Tables 32 and 33, and Figure 31 shows these results (CIRA/IAEA, 1999).

Figure 31. Isotopic Composition in Water in León and Chinandega.
Source: CIRA/IAEA, 1999.



13 APPENDIX G PREVIOUS ISOTOPE STUDIES IN THE ZONE

Table 32. Isotope Composition in León and Chinandega - Rainy Season

Code	^{18}O (‰)	^{2}H(‰)
MANI-1	-8.3	-53.8
M1-1	0.2	1.5
R1-1	-6.3	-42.1
R3-1	-6.8	-44.5
PE5-1	-5.9	-40.4
PE7-1	-6.5	-44.2
PE9-1	-6.5	-44.2
PE12-1	-6.9	-45.5
PE13-1	-6.8	-44.2
PP2-1	-6.8	-44.8
PP9-1	-7.0	-46.2
PP4-1	-6.8	-46.3
PP4-2-1	-6.4	-43.2
PV1-1	-7.9	-57.0
PV2-1	-7.7	-50.7
PV3-1	-6.5	-45.9
PV4-1	-6.6	-46.3
PV5-1	-7.2	-50.5
PV6-1	-5.7	-38.1

Source: CIRA, 1999

MANI= Spring
M= Seawater
R= River
PE= Dug Well
PP= Drilled Well
PV= Rain gauge

Table 33. Isotope Composition in León and Chinandega - Dry Season

Code	^{18}O (‰)	^{2}H(‰)
PP76-N1	-6.3	-41.6
PP76-N2	-6.5	-43.0
PP129-N1	-6.8	-45.3
PP129-N2	-7.0	-46.6
PP129-N3	-7.1	-48.3
PP129-N4	-7.1	-47.6
PP133-N1	-7.1	-47.1
PP133-N2	-7.1	-46.7
PP133-N3	-7.2	-46.8
PP133-N4	-7.3	-46.3
PPMN-N1a	-6.8	-43.9
PPMN-N1b	-6.8	-44.5
PPMN-N2	-6.8	-44.3
PPMN-N3	-6.9	-45.8
PPMS-N1	-6.4	-43.5
PPMS-N2	-6.6	-43.0
PPMS-N3	-6.6	-43.3
MANA-1	-8.2	-54.0
PVA-1	0.7	6.7
PVA-4	-6.9	-44.7
PVA-6	-1.4	-0.4
PVA-7	2.4	26.8
PVA-9	-1.4	-1.3
PVA-10	-5.3	-35.2
PVA-11	-2.2	-8.1

Source: CIRA, 1999

MANA= Spring
PP= Drilled Well
N= Level
PVA= Rain gauge

13 APPENDIX G PREVIOUS ISOTOPE STUDIES IN THE ZONE

Oxygen 18 results from dug and drilled wells, and springs from León-Chinandega collected during Dahlberg and Odebjer (2002) field campaign are presented in Table 34.

Table 34. ^{18}O in León-Chinandega. Dahlberg and Odebjer, 2002

Location	Code / Type of Well		^{18}O (‰)
S. Cristobal	72	M	-7.63
Posolteguilla somero	22b	PE	-7.17
Cristo Rey	71	PP	-7.08
Sunwell	1	PP	-7.03
Suroeste Esperanza prof.	38	PP	-6.99
Fabrica de Mani	54	PP	-6.82
La Flor	61	PE	-6.82
SE El Trianon	46	PE	-6.82
PPL-37	73	PP	-6.81
Las Mercedes	36	PP	-6.74
S. Francisco	63	PP	-6.72
R. Corvado	74	AS	-6.72
2 km. N Posoltega	48	PP	-6.67
Posolteguilla prof	22	PP	-6.62
S. Gilberto	5	M	-6.60
Chiquimula	12	M	-6.60
La Cascada	51	PE	-6.60
El Tanque	4	PE	-6.53
S. Agustin	15	PE	-6.52
La Fortuna	29	PE	-6.37
S. Agustin	16	M	-6.30
Rancho Grande	65	PE	-6.29
Guanacastal	70	PE	-6.24
La Esperanza	41	PE	-6.18
Entre Quezalguaque y la Cascada	64	PE	-6.10
La Virgen	35	PE	-6.09
Sta. Elena	67	PE	-5.98
El Tanque	49	PE	-5.44

PP: Drilled Well
PE: Dug Well
AS: Surface Water
M: Spring

14 APPENDIX H PRECIPITATION DATA FROM RAIN GAUGES

Site: Calle Real del Bosque* N: 1390913 E: 504618 Elev.: 139 m.a.s.l.

Day	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1			0.00	0.00	0.00	nr	0.00	0.00	0.00	44.00		
2			0.00	0.00	0.00	15.40	0.00	5.00	0.00	0.00		
3			0.00	0.00	0.00	56.50	0.00	0.00	13.60	0.00		
4			0.00	0.00	0.00	7.00	0.00	0.00	0.00	5.20		
5			0.00	0.00	0.00	48.53	0.00	0.00	2.80	0.00		
6			0.00	0.00	0.00	12.00	8.20	0.00	0.00	0.00		
7			0.00	0.00	0.00	8.40	0.00	0.00	4.80	1.40		
8			0.00	0.00	0.00	16.60	0.00	0.00	4.60	0.00		
9		0.20	0.00	0.00	0.00	26.75	0.00	0.00	16.80	1.20		
10		0.00	0.00	0.00	0.00	0.00	3.80	0.00	16.80	42.75		
11		0.00	0.00	0.00	0.00	39.75	nr	0.00	8.40			
12		0.00	0.00	0.00	0.00	13.60	5.00	0.00	15.20			
13		0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.40			
14		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
15		0.00	0.00	0.00	0.00	30.35	0.00	0.00	5.20			
16		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
17		0.00	0.00	0.00	0.00	0.00	0.00	5.20	41.45			
18		0.00	0.00	0.00	0.00	19.75	0.00	0.00	28.75			
19		0.00	0.00	0.00	0.00	0.00	4.00	0.00	40.75			
20		0.00	0.00	0.00	37.75	9.20	0.00	0.00	31.75			
21		0.00	0.00	0.00	29.95	0.00	8.20	34.75	30.70			
22		0.00	0.00	0.00	4.60	0.00	0.00	6.00	31.00			
23		0.00	0.00	0.00	6.20	0.00	0.00	0.00	21.00			
24		0.00	0.00	0.00	3.40	2.40	2.00	0.00	0.00			
25		0.00	0.00	0.00	4.00	0.00	0.00	5.20	0.00			
26		0.00	0.00	0.00	5.00	0.00	0.00	77.25	12.00			
27		0.00	0.00	0.00	20.75	0.00	9.00	24.00	8.00			
28		0.00	0.00	0.00	37.75	0.00	0.00	3.00	0.00			
29			0.00	0.00	91.75	0.00	0.00	8.20	20.00			
30			0.00	0.00	11.20	0.00	0.00	0.00	7.00			
31			0.00		13.60		0.00	0.60				
Total		**0.20**	**0.00**	**0.00**	**265.95**	**306.23**	**40.20**	**169.20**	**368.00**	**94.55**		

nr = not recorded

***Rain Gauge installed on February 9, 2002**

14 APPENDIX H PRECIPITATION DATA FROM RAIN GAUGES

Site: El Trianón* N: 1384634 E: 500870 Elev.: 66 m.a.s.l.

Day	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1							0.00	0.00	11.50	7.00		
2							0.00	0.00	1.00	11.40		
3						0.00	0.00	3.30	0.00	0.00		
4						16.00	0.00	0.00	3.10	0.00		
5						12.10	0.00	0.00	0.00	30.00		
6						15.00	3.62	0.00	4.00	0.00		
7						7.00	0.00	0.00	0.00	0.00		
8						2.50	0.00	0.00	1.30	0.00		
9						8.00	0.00	0.00	1.30	0.00		
10						0.00	0.00	0.00	7.60	0.00		
11						72.00	21.40	0.20	34.40	4.00		
12						10.30	5.00	0.00	3.60			
13						9.40	0.00	0.00	0.00			
14						0.00	10.00	0.00	0.00			
15						0.00	0.50	0.00	0.00			
16						20.00	0.00	0.00	16.20			
17						0.00	0.00	0.00	0.00			
18						9.30	0.40	5.00	524			
19						15.60	0.00	0.00	19.80			
20						0.00	48.00	0.00	49.80			
21						22.60	5.00	1.80	37.80			
22						0.00	0.00	6.90	15.00			
23						0.00	0.00	13.00	26.00			
24						0.00	0.00	0.00	16.20			
25						29.00	6.20	0.00	0.00			
26						0.00	0.00	3.20	0.00			
27						0.00	0.00	17.40	43.00			
28						0.00	0.00	36.00	17.60			
29						0.00	0.00	1.80	11.20			
30						0.20	0.00	16.00	0.00			
31							0.00	0.20				
Total						**249.00**	**100.12**	**104.80**	**844.40**	**52.40**		

nr = not recorded

***Rain Gauge installed on June 3, 2002**

14 APPENDIX H PRECIPITATION DATA FROM RAIN GAUGES

Site: El Polvón* N: 1378339 E: 494467 Elev.: 24 m.a.s.l.

Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
1990	0.00	0.00	0.00	3.20	6.40	6.69	5.79	7.17	15.47	14.75	6.00	0.31	**65.78**
1991	0.00	0.00	0.00	0.27	9.54	10.16	3.31	9.00	9.47	8.92	0.90	0.05	**51.62**
1992	0.00	0.58	0.00	0.00	4.58	7.73	5.09	8.95	21.04	1.32	1.54	0.34	**51.17**
1993	0.11	0.00	0.00	0.94	19.71	11.88	2.83	10.39	29.77	6.82	1.47	0.00	**83.92**
1994	0.00	0.00	0.00	2.05	6.53	2.79	2.22	8.48	14.63	7.54	9.17	0.00	**53.41**
1995	0.00	0.00	1.90	1.14	5.22	10.52	12.57	17.55	18.28	23.45	1.17	1.29	**93.09**
1996	1.00	0.00	0.00	0.28	9.67	11.93	18.56	8.46	15.74	18.63	16.22	0.00	**100.49**
1997	0.00	0.00	0.00	0.14	1.43	17.24	3.41	1.11	7.99	6.68	3.03	0.00	**41.03**
1998	0.00	0.00	0.07	0.69	2.01	4.79	7.48	10.30	17.93	81.58	6.65	0.35	**131.85**
1999	0.00	0.00	0.00	0.35	5.82	8.14	6.30	9.97	47.94	12.44	4.63	0.13	**95.72**
2000	0.00	0.00	0.00	0.20	4.63	7.26	5.83	5.19	32.35	13.10	2.83	0.34	**71.73**
2001	0.00	0.00	0.37	0.00	14.30	2.67	5.99	8.68	20.26	8.38	2.62	1.84	**65.11**
2002	0.00	0.00	0.00	0.00	19.17	14.63	3.27	7.01					
Average	**0.09**	**0.04**	**0.18**	**0.71**	**8.39**	**8.96**	**6.36**	**8.64**	**20.91**	**16.97**	**4.69**	**0.39**	**75.41**

Data proportioned by ISA-N.S.E.L.- Field Division

***Rain Gauge property of ISA-N.S.E.L.**

15 APPENDIX I PESTICIDES RESULTS IN SOILS

Data from Mr. Cuadra's thesis *"Risk Management of Soil Contamination by Organochlorine Pesticides used in Cotton Culture in Posoltega Watershed, Chinandega",* who kindly proportioned it (2002; MSc. Thesis, UNAN), is shown in this Appendix.

Two soil-sampling periods were carried out during March 7th to 9th, and November 5th to 7th, 2002 respectively at B(H), T(M), and P(L). The test pits were hand dug nearby the monitoring wells installed at each site, oriented west. During the first sampling period, 4 horizons were recognized at each hand-dug test pit, and eight organochlorine pesticides (Table 35) were detected at the three sites where presented in the four samples taken at each site. Meanwhile, during the second sampling period, the test pits had lower depth, and only two samples from each hand-dug test pit were taken at each site, and organochlorine pesticides were detected only at T(M) (Table 36) at horizon A1 (0.05 – 0.3 m) and horizon A2 (0.3 – 0.6 m).

15 APPENDIX I PESTICIDES RESULTS IN SOILS

Table 35. Organochlorine Pesticides in Soil Samples from León-Chinandega (from Cuadra, 2002)

	Organochlorine Pesticides (ng/g)*'**							
Code	Dieldrin	Endrin	Heptachlor	H-epox	pp-DDT	pp-DDE	pp-DDD	Toxaphene (mg/kg)
B(H)-Sup	0.96	nd	Nd	nd	51.48	11.52	nd	0.77
B(H)-A	21.05	63.58	Nd	nd	255.97	127.75	79.28	4.55
B(H)-B	0.43	nd	Nd	nd	5.38	15.45	2.86	0.08
B(H)-C	nd	nd	Nd	nd	nd	0.12	nd	nd
T(M)-Sup	0.97	nd	0.08	2.24	7.16	9.36	2.44	nd
T(M)-A1	0.75	nd	0.38	1.84	4.49	8.83	1.67	nd
T(M)-A2	0.57	nd	nd	nd	2.57	5.94	nd	nd
T(M)-B	1.02	nd	nd	nd	1.22	7.58	nd	nd
P(L)-Sup	nd	nd	nd	nd	0.49	1.23	nd	nd
P(L)-A	nd	nd	nd	nd	0.29	1.33	nd	nd
P(L)-B	nd	nd	nd	nd	nd	nd	nd	nd
P(L)-C	nd	Nd	nd	nd	nd	nd	nd	nd

***** Otherwise noticed**.** **H-epox:** heptachlor epoxide **nd:** not detected.

****** α-BHC, β-BHC, δ-BHC, lindane, aldrin, α-endosulphan, β-endosulphan were analyzed but not detected.

15 APPENDIX I PESTICIDES RESULTS IN SOILS

Table 36. Organochlorine Pesticides in Soil Samples from León-Chinandega – Second Sampling (from Cuadra, 2002)

Organochlorine Pesticides (ng/g)*

Code	Dieldrin	Endrin	H-epox	pp-DDT	pp-DDE	pp-DDD
B(H)-A1	nd	Nd	nd	nd	nd	nd
B(H)-A2	nd	Nd	nd	nd	nd	nd
T(M)-A1	1.301	0.525	2.669	7.307	42.198	1.959
T(M)-A2	0.467	0.160	0.664	3.661	27.811	0.727
P(L)-A1	nd	Nd	nd	nd	nd	nd
P(L)-A2	nd	Nd	nd	nd	nd	nd

H-epox: heptachlor epoxide **nd:** not detected.

***** α-BHC, β-BHC, δ-BHC, lindane, aldrin, heptachlor, α-endosulphan, β-endosulphan, and toxaphene were analyzed but not detected.