JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

THE GOVERNMENT OF THE FEDERAL DISTRICT
THE UNITED MEXICAN STATES

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THE STUDY ON SOLID WASTE MANAGEMENT FOR MEXICO CITY IN THE UNITED MEXICAN STATES

FINAL REPORT
VOLUME V

ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

MAY 1999

KOKUSAI KOGYO CO., LTD.

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The Study on Solid Waste Management for Mexico City in the United Mexican States

List of Volumes

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Volume V(S)	EIA Report (Spanish Version)

This is the EIA Report.

In this report, the project cost is estimated by using the September 1998 price and an exchange rate of 1 US$ = 135.00 Japanese Yen = 9.10 Pesos.

Introduction

This "Environmental Impact Assessment Report" was prepared by the JICA team for the GDF in regard to the two projects namely "composting plant project" and "Bordo Poniente Etapa V landfill project". The report is divided into two parts:

Part A EIA for the Composting Plant Project.

Part B EIA for the Bordo Poniente Etapa V Landfill Project.

These projects were derived from the Solid Waste Management Master Plan which has been elaborated also by the JICA team for the GDF. In view of the urgency and importance, they are considered to be of high priority and environmental impact assessment as well as feasibility study are required.

It must be noted that the present EIA report should be used as reference for further detailed discussion by the GDF and other relevant parties. The finalization and submission of the EIA report is the responsibility of the GDF, which is the proponent of the both projects.

Part A

EIA for
the Composting Plant Project

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Description of the Proposed Project

1 Description of the Proposed Project

1.1 Characteristic of the Project

The Bordo Poniente Composting Plant Project is to construct and operate a composting plant with productively engineered process. Organic waste is treated by a controlled aerobic decomposition to produce compost product which is used as soil conditioner and/or cover soil for waste landfill. In other words, the plant is the one not only for waste treatment plant but also material production from waste. The product, i.e. compost, will be used as cover soil at the landfill or soil conditioner to facilitate the nature enhancement.

1.1.1 Background

The project of the composting plant is to be implemented within the scope of the M/P targeting the year of 2010. Since the intermediate waste treatment is merely one component of the whole SWM system, its requisites and conditions are directly subject to the M/P. Consequently, the outline of the M/P should be presented.

It is necessary, however, to review the background of the M/P which is closely linked with the composting plant project.

1.1.1.1 Introduction of Sub-System

The waste collection in the DF has been implemented by the collection crews, who constitute a group called Section 1 belonging to the delegations, and their affiliated workers. However, the GDF and the Section 1 signed an agreement in July 1998 that the Section 1 would withdraw its waste collection service from primary schools, parks and markets in 1999.

As a result, a new type of waste collection, sub-system, is to be established in SWM of the GDF, which allows the GDF to strategically alter the collection system. In consideration of the existence of large organic waste dischargers, i.e. *Central de Abasto* and other general markets, in the sub-system, the separate collection of organic waste within the sub-system was judged to be feasible, and decided to be implemented.

1.1.1.2 Outline of the M/P

The following table summarizes the M/P.

Table 1-1: Outline of the M/P

	Data of 1997	Phase 1 (1999 - 2001)	Phase 2 (2002 - 2004)	Phase 3 (2005 - 2010)
Population	8,610,000	8,654,000-8,747,000	8,796,000-8,896,000	8,946,000-9,206,000
Waste generation amount (ton/year)				
Household	1,926,000	1,946,000-1,965,000	1,976,000-1,998,000	2,009,000-2,072,000
Commercial	1,210,000	1,217,000-1,223,000	1,229,000-1,236,000	1,244,000-1,267,000
Service	636,000	642,000-649,000	652,000-657,000	659,000-669,000
Special	130,000	131,000-134,000	134,000-136,000	136,000-140,000
Others	267,000	268,000-270,000	271,000-275,000	276,000-282,000

		Data of 1997	Phase 1 (1999 - 2001)	Phase 2 (2002 - 2004)	Phase 3 (2005 - 2010)
Total		4,169,000	4,201,000-4,241,000	4,262,000-4,302,000	4,324,000-4,430,000
Discharge/Storage					
	Sub System	-	Introduction of source separation	Introduction of source separation	Maintaining source separation
	Delegation	Mixed	Mixed	Introduction of source separation	Introduction of source separation
Collection					
Amount (ton/year)	Sub System	-	853,000-858,000	861,000-867,000	870,000-884,000
	Delegation	4,169,000	3,293,000-3,325,000	3,342,000-3,376,000	3,395,000-3,485,000
Method	Sub System	-	Introduction of separate collection	Introduction of separate collection	Maintaining separate collection
	Delegation	Mixed	Mixed	Introduction of separate collection	Introduction of separate collection
Transfer Station and Transport					
Transfer Station and Transport			• Installation of weighbridges for every station. • Utilization of a single common format for data compilation	• Utilization of the transport monitoring and control system (for 5 flows[1]) based on the accurate incoming/outgoing weight measuring • Efficient transport allocation by the monitoring and control system	
Transfer amount (ton/year)		3,123,000	3,725,000-3,757,000	3,776,000-3,812,000	3,830,000-3,922,000
O&M cost(US/year)		43,547,000	51,941,000-52,387,000	52,652,000-53,154,000	53,405,000-54,688,000
Intermediate Treatment					
Selection plant			• Experiment of operation modification to incorporate an objective of quantity oriented picking. • Experiment of "storage system" for recovered materials to cope with market prices fluctuation.	• Implementation of operation control with 2 objectives of: - revenue oriented picking; -quantitative picking. • Establishment of "storage system" for recovered materials to cope with market prices fluctuation, in view of experiment results.	• Implementation of operation control with the major objective of "quantity oriented picking". • Utilization of the optimum "storage system" for recovered materials to cope with market prices fluctuation.
Input amount (ton/year)	Mixed	1,794,000	1,650,000-1,546,000	1,288,000- 725,000	567,000 - 0
	Recyclable	-	0 - 98,000	210,000-438,000	504,000-844,000
Recycle amount(t/y)		182,000	166,000-224,000	277,000-380,000	409,000-591,000
Recovery rate (%)		10.0	10.0-13.6	18.5-32.7	38.2-70.0
O&M cost (US$ 1,000)		11,232	10,565 - 10,537	9,857 - 8,296	7,867 - 6,809
Composting plant		-	Design and construction	Starting operation	Operation and maintenance
Input amount (ton/year)		-	-	253,000 - 424,000	425,000 - 431,000
Compost production amount (ton/year)		-	-	34,000 - 57,000	57,000 - 58,000
Investment (US$)		-	3,959,000	1,345,000	1,334,000
O&M cost(US$/year)		-	0 - 33,000	1,185,000 - 1,343,000	1,343,000 - 1,343,000
Final Disposal					
Final Disposal Site		BP "Etapa IV" Santa Catarina	BP "Etapa IV" vertical expansion Design & construction of BP "Etapa V"	Operation of BP "Etapa V"	Operation of BP "Etapa IV" & "Etapa V"
Disposal amount (ton/year)	GDF	3,489,000	3,619,000 - 3,592,000	3,325,000 - 3,101,000	3,089,000 - 2,994,000
	Edo. Mexico	262,000	284,000	284,000	284,000

[1] 5 flows refer to current waste flows (from the transfer stations to the S/Ps, from the transfer stations to the final disposal sites, and from the S/Ps to the final disposal site) and additional flows from the transfer stations to the NIT and the NIT to the final disposal site.

		Data of 1997	Phase 1 (1999 - 2001)	Phase 2 (2002 - 2004)	Phase 3 (2005 - 2010)
	Total	3,751,000	3,903,000-3,876,000	3,609,000-3,385,000	3,373,000-3,278,000
Investment (US$)		-	12,708,000	-	-
O&M cost (US$/year)	Bordo Poniente	9,925,694	8,570,000 (2001)	9,400,000 (2003)	4,072,000 (2005)
	Santa Catarina	?	-	-	-
Others					
Street sweeping	Length (km/day)	1,273.4	1,285-1,296	1,303-1,316	1,323-1,357
	O&M cost (US$/y)	3,293,000	3,323,000-3,352,000	3,369,000-3,403,000	3,421,000-3,509,000

In regard to the composting plant, what should be reminded is that the composting plant receive not the mixed waste but only organic waste separated in the sub-system.

1.1.2 Objectives of the Project

The prime objective of the project is **to reduce the amount of waste which otherwise has to be disposed of at the final disposal site in the most appropriate method which can be realized by the GDF within their competence in terms of engineering, finance and management without causing any unacceptable environmental impacts.**

It should be emphasized that this project is one of the essential components of the Master Plan (M/P) of the solid waste management (SWM) in the DF which was prepared by the JICA team for the DGSU. The objectives of the M/P, which consequently the composting plant project is supposed to aim at, are as follows.

- The improvement of public health and the reduction of health hazards in and around the city, in order to promote the well-being of citizens.
- The implementation of the sustainable and cost-effective SWM services required as the duty and mandate of the GDF through technical, institutional, legislative improvement and appropriate administration.
- The achievement of the environmental conservation through SWM by encouraging the public acknowledgment on the waste matter, promoting "reduction", "recycling" and "recovery" of waste and, with particular importance for the present project, operating treatment and disposal facilities which do not degrade the environment.

In order to achieve those objectives, the contribution by the composting plant project is expected to be the following.

- Volume reduction of organic waste, and thus extension of the service life of the final disposal site, which is vital for sustainable urban life.
- Conversion of organic waste, which is highly active in municipal waste and is the causal component to produce aggressive leachate if disposed of in the landfill, into compost, which is useful for the environment.
- Raising the peoples' awareness in regard to the waste recycle.

- Accomplishment by the GDF, as the responsibility of the governmental body as established by the National Program of Urban Development 1995-2000, to provide infrastructure necessary for the sound urbanization.

1.1.3 Justification of the project

In Mexico City, more than 11,000 tons of wastes are daily generated (or 4.169 million tones per year in 1997), which has to be collected, stored, transported, and disposed of in the most appropriate way in order to avoid possible negative impacts on the social and natural environment.

As well known, solid wastes are the result of the human activities. Generation is largely influenced by the socioeconomic level, the consumption habits and the season of the year. The JICA team estimates the waste generation amount in the DF to be 4.430 million tons in the year 2010. Therefore, for the period from 1997 to 2010, the annual waste generation rate is on average worked out to be about 0.5%. To manage such large volume of wastes represents a great challenge for the GDF.

1.1.3.1 Legal Justification

Starting with the effective legal framework, the Public Administration of the DF is responsible for the service of urban sanitation, in which the final disposal of the solid wastes is included. In regards to environmental protection, the General Law of the Ecological Balance and Protection of the Environment (LGEEPA) specifies in the Art. 9 that preservation of the ecological balance and protection to the environment are to be looked after by the GDF, pursuant to the legal provisions issued by the Legislative Assembly of the DF and the powers referred to in articles 7 and 8 of this Law.

Art. 7 fraction VI stipulates that the DF has the following authority: "regulation of the systems of collection, transport, storage, handling, treatment and final disposal of the solid wastes and non-hazardous industrial waste in conformity with that prepared for the article 137 of the present law".

Article 8 stipulates that the GDF will have the following authority: "application of the relative juridical dispositions for the prevention and control of the effects on the environment caused by the generation, transport, storage, handling, treatment and final disposal of the solid wastes and non-hazardous industrial waste in conformity with article 137 of the LGEEPA.

Also, article 137 states that the operation of the systems of collection, storage, transport, lodging, reuse, treatment and final disposal of the municipal solid wastes is subject to the authorization of the municipalities or the DF, according to their applicable local laws the Mexican official norms.

In the Environmental Law of the DF published in the Federal Official Newspaper of 9 July of 1996, regarding the handling of municipal solid wastes and the benefit of services, the following is settled down:

Art. 15 for the Secretary of the environment of the DF concerning:

XIV. In coordination with the DGSU, to prevent and to control the contamination of the soil, as well as the contamination originated from the generation and handling of wastes in the area not reserved to the Federation.

XV. In coordination with the DGSU, to settle down or to authorize the establishment of the places dedicated to the management of waste which is out of the control of the Federation, as well as to propose the promotion of the arrangements that regulate their handling, observing the official norms.

XXIII In coordination with the other competent authorities, to observe and to fulfill the official norms in the benefit of the public services, including those related with the supply of water, drainage and sewer system, treatment and reuse of residual waters, conservation of pluvial waters, cleansing, markets and central market, vaults, slaughterhouses and local transports.

XXVIII. To regulate, to prevent and to control environmentally risky activities outside of the mandate or the Federation.

XXX. To participate with the Federation in the analysis, approval and application of the programs of prevention and control of derived accidents of the realization of highly risky activities for the environment in the DF.

XXXI. To participate, in the environment of their attributions, in the regulation and application of the urgent measures that are required to safeguard the integrity of the environment, in the event of accidents, escapes or spills of materials or wastes.

Art. 16 The DF will participate in the terms settled down by the Political Constitution of the Mexican United States and the Statute of GDF, in the planning and execution of actions coordinated with the Federation, States and Municipalities in the areas of co-urbanized with Mexico City, in matters of protection of the environment, and preservation and restoration of the ecological balance. For these purposes, they will subscribe agreements for the creation of the corresponding Commission where they will attend and participate according to their own laws.

Art. 18. Through this Commission, the following will be established:

I. The bases for the celebration of agreements, in the headquarters of the Commission, according to what was agreed about the territorial environments and functions regarding the execution and operation of works, benefit of services or realization of actions in the matters indicated in Art. 16.

Art. 57. Those who cause contamination or deterioration are forced to restore the soil, underground, aquifer and the other affected natural resources in accordance with the present Law and the official norms.

Art. 93. Regarding the wastes and in the terms of the official norms, people are forced:

I. To prevent waste generation;
II. To minimize the generation of wastes that cannot be prevented;
III. To recycle or to reuse wastes that are generated;

IV. To treat them prior to their disposal final, when they cannot be recycled or to be reused, in order to eliminate or to minimize their danger and volume, and

V. To dispose of the treated wastes finally.

Art. 94. It is assumed, unless otherwise verified, that the owners or possessors of wastes are responsible for their damages and injuries, according to the case. Those who manage residuals are considered as possessors during the time when they have the waste under their custody or responsibility. The responsibility of the non dangerous waste will correspond to the Public Administration the DF once they are collected by its cleansing service.

The Ordinance by means of which the Internal Code for the Public Administration of the DF was reformed, and issued in the Official Gazette of the Federation on December 1st, states in its Art. 33 that the attributions are pointed out for the DGSU as regards to the municipal waste management as follows.

- In coordination with the competent authorities, to settle down approaches and technical norms for the activities of minimization, collection, transfer, treatment and final disposal of solid waste, to restore contaminated places, as well as to establish the systems of recycling and treatment of waste.
- To carry out the studies, projects and the construction, conservation and maintenance of infrastructure works for SWM, transfer stations, selection plants and utilization, as well as final disposal sites;
- To organize and to carry out the treatment and final disposal of solid waste, as well as the operation of the transfer stations;
- To receive the new works that require urban services and executed by other DF agencies, administrative units and decentralized bodies.

In realizing this project, the entity responsible for SWM, i.e. DGSU, will fulfill their responsibility which is established in the Political Constitution of the Mexican United States, the LGEEPA, as well as the Environmental Law of the DF.

1.1.3.2 Social Justification

Secondly, it is possible to point out justification of the project from the view point of social needs. Social justification of the project is directly reflected by the difficulty of perpetual waste disposal, since the projected work seeks to give countermeasure to a demand generated by the necessity to grant a public service appropriate to the inhabitants of the DF and of some co-urbanized municipalities of the State of Mexico.

At present more than 11,000 tons of wastes have been generated everyday in the DF, and that nearly 10,000 tons, collected in the DF and part of the State of Mexico are disposed of in Bordo Poniente Etapa IV. This quantity of waste that is necessary to be disposed of will increase in the same manner as the population growth, unless satisfactory efforts are made. Although it is planned to dispose of the waste for the coming decade by vertically expanding the Etapa IV and starting a new landfill at Etapa V, it is getting certain that to secure land for waste disposal in or around the metropolis becomes increasingly difficult.

Accordingly, there is a strong need to reduce waste disposal amount in the DF's society and the composting plant is considered to be the best available solution for this matter.

1.2 Site Selection and Current Land Use

The site is near the junction of two main roads and the Etapa (stage) 4 of the Bordo Poniente Final Disposal Site.

Importantly the site is well located in respect to transporting of material. Because the raw material to be composted is currently be deposited at the Bordo Poniente Final Disposal Site, no additional transportation cost is required to bring the raw material to the site. Moreover the site is favorably located if it is assumed that the end product is to be used at the Bordo Poniente landfill or for soil improvement of the ex-Lake Texcoco area.

Also negative impacts of the proposed compost site will be significantly lessened because of the existing many large open drainage canals (such as Rio Churubusco) which conduct wastewater through the zone. These produce a significant problems in the area, in excess of what can be expected from a well operated composting plant.

Besides, it should be emphasized that the land is at present not used for any purpose and there is no specific plan to use it in near future. The project, therefore, makes the best of the currently abandoned land for the productive activity.

The location of the project site is shown in the following figure.

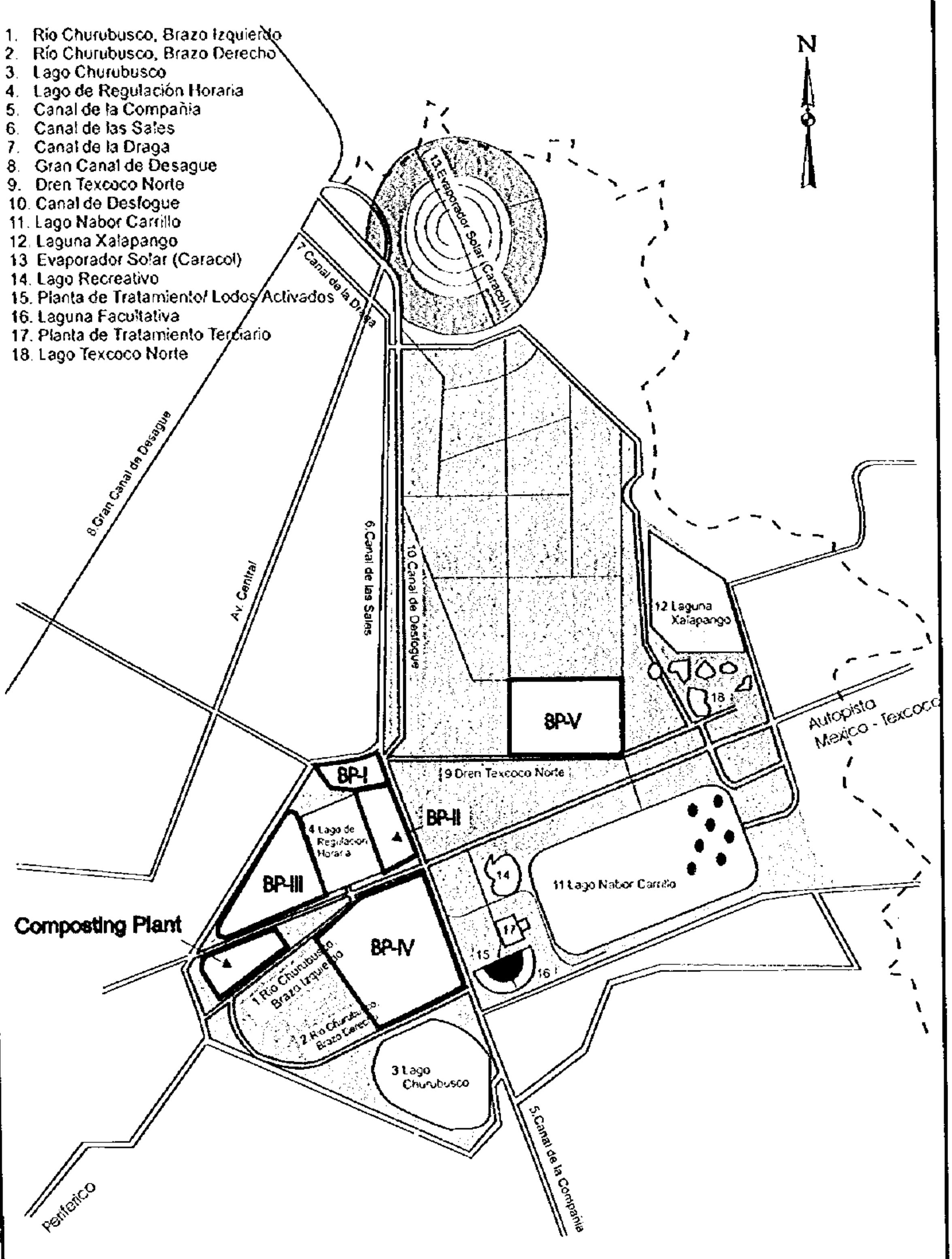

Figure 1-1:
Location of the Project

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1.3 Description of the Work

1.3.1 Examination of Design Condition

1.3.1.1 Design Capacity

Capacity of the composting plant is set out under the condition that the whole amount of organic waste generated in the sub-system are to be delivered and fed into the plant.

It is planned that the separate collection in the sub-system is introduced in the year 2000 and its total diffusion (100%) will be achieved in the year 2004. The estimation of organic wastes input amount for the composting plant until 2010 is shown in Table 1-3.

The operation of the composting plant is planned to start in the year 2002 and the organic waste separation in the year will be still about 60%, while the plant has to receive 100% of separated organic waste from the sub-system in the year 2004. Therefore, the plant should be constructed from 2001 to 2003 to improve its capacity in a stepwise manner, in order to meet the increase in the organic waste separation rate.

Table 1-2: Separate Discharge and Collection Plan

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Separate Discharge and Collection Plan	Mixed Discharge					100%		Separate Discharge				

Table 1-3: Organic Waste Collection Amount

unit : 1,000 ton/year

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Organic waste	0	84	168	253	338	424	425	426	428	429	430	431

1.3.1.2 Waste Composition

Composition of organic waste applied to the plant design is assumed as shown in Table 1-4, based on the future waste amount and composition trends assumed in the M/P framework. Source separation compliance rate is set out as 90% with reference to the 92% compliance recorded in the DGSU's pilot projects for source separation.

The design moisture content can be assumed to be:

- about 78%, which is calculated from the DGSU's empirical data for respective composition items, and from a set of empirical data recorded in Japan; and
- about 68%, which is the moisture content obtained in the field investigation of waste composition by the team.

Therefore, the design moisture content is set out between the **maximum 78%** and **minimum 68%**.

Table 1-4: Organic Waste Composition

Composition	Organic matter contents (%)	Moisture contents of each components (%)	Moisture contents (%)
Organic waste			
Vegetable fiber	2.29	*68	1.56
Bone	1.02	*68	0.69
Food waste	78.38	**90	70.54
Garden waste	8.3	***40	3.32
Organic total (a)	**90**	-	**76.11**
Recyclable waste			
Cardboard	0.99	***24	0.24
Synthetic fiber	0.19	***17	0.03
Vinyl	0.04	***17	0.01
Cans	0.27	***4	0.01
Metal	0.41	***4	0.02
Nonferrous metal	0.05	***4	0
Paper	0.46	***24	0.11
News paper	0.83	***24	0.2
Plastic film	0.77	***17	0.13
Hard plastic	0.67	***8	0.05
Color glass	0.34	***8	0.03
Transparent glass	0.58	***8	0.05
Recyclable total (b)	**5.58**	-	**0.88**
Non-recyclable waste			
Spatula	0	-	-
Cotton	0.23	***19	0.04
Leather	0.01	***9	0
Paper container	0.43	***24	0.1
Gauze	0	-	-
Disposable syringe	0	-	-
Ceramics	0.05	***8	0
Wood	0.33	***24	0.08
Construction waste	0.38	***8	0.03
Toilet paper	1.09	***24	0.26
Disposable diaper	0.25	***80	0.2
X-ray film	0	-	-
Polyurethane	0.02	***17	0
Foamed polyurethane	0.12	***17	0.02
Sanitary napkin	0	-	-
Rags	0.23	***19	0.04
Bandage	0	-	-
Fine fraction	0.92	***24	0.22
Others	0.35	***24	0.08
Non-recyclable total (c)	**4.42**	-	**1.07**
Total (a+b+c)	**100**	-	78.06

* : results of the waste composition survey

** : Harina Vegetal a Partir de Residuos Organicos, LUGARDA ARACELI SANTOS PEREZ, MARGARITA GUTIERREZ ROJAS, VICTOR MANUEL FLORES VALENZUELA, DGSU

*** : Design guideline for municipal solid waste treatment facilities in Japan 1978(editorial supervision by ministry of health and welfare, JAPAN)

1.3.1.3 Geological Condition

Geological survey data in the composting plant candidate site is absent, however, the candidate site is located near the Bordo Poniente Etapa-IV, and its geological data (see Figure 1-2) is used for examining the design of the composting plant.

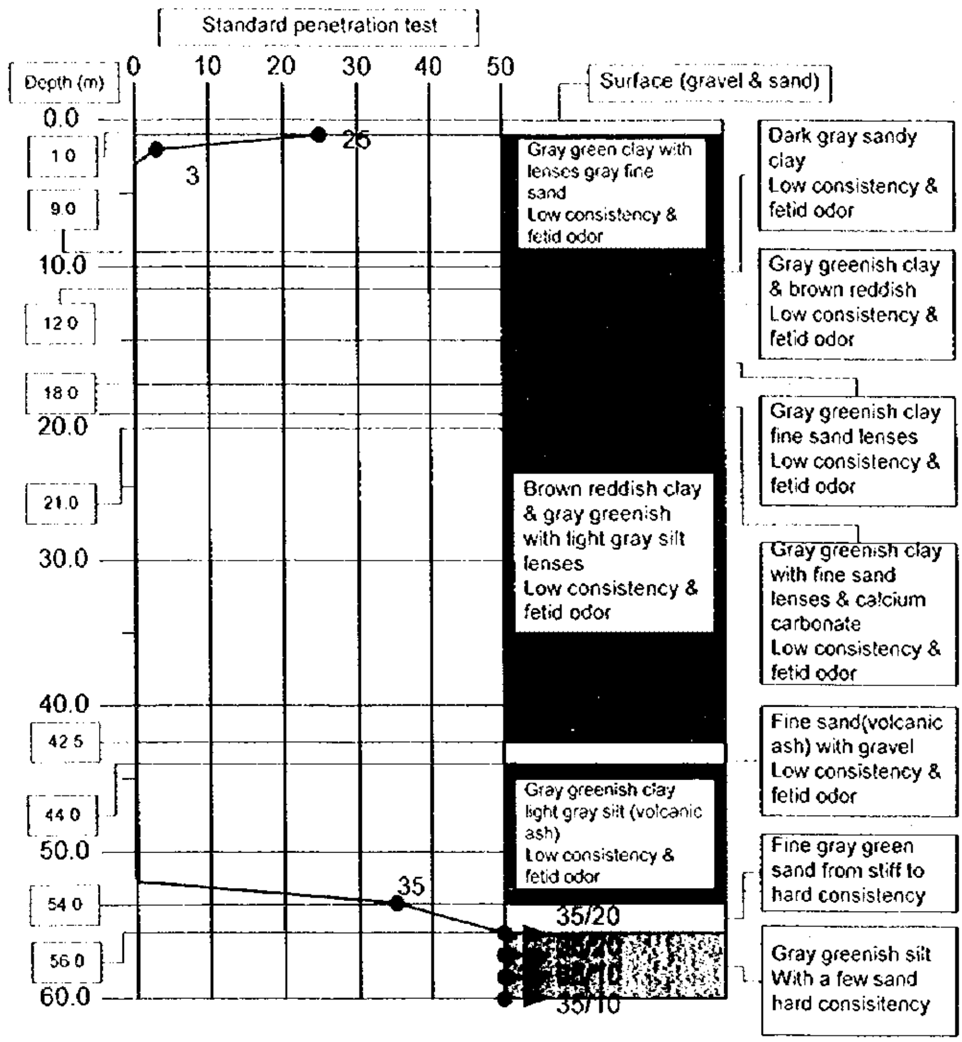


Figure 1-2: Results of "Etapa IV " Core Boring (SM-8)

1.3.2 Examination of Technical Alternative

1.3.2.1 Basic Alternative

There are basically two types of composting process for organic fraction of municipal solid waste: "aerobic process" and "anaerobic process". Table 1-5 shows the comparison of the two processes.

Table 1-5: Comparison of Aerobic and Anaerobic Composting for Organic Fraction of Municipal SW

Characteristic	Aerobic process	Anaerobic process
Energy use	Net energy consumer	Net energy producer
End products	Humus, CO_2, H_2O	Sludge, CO_2, CH_4
Volume reduction	Up to 50%	Up to 50%
Processing time	20 to 30 days	20 to 40 days
Curing time	30 to 90 days	30 to 90 days
Primary goal	Volume reduction	Energy production
Secondary goal	Compost production	Volume reduction, waste stabilization

source : Integrated Solid Waste Management, McGraw-Hill

As the composting plant is selected as one of the priority projects in the M/P with the prime objective of "minimization of final disposal amount", the aerobic process is selected for the design of this project.

1.3.2.2 Examination of Technical Alternative

Aerobic composting can be operated by either: windrow composting; static pile composting; or in-vessel composting. Furthermore, the windrow composting has two types: minimal technology windrow; and high-rate windrow. Table 1-6 shows comparison of those composting methods.

In view of the present situation where the DGSU has attained practical experiences and know-how of high-rate windrow method through the on-going project of composting pruned branches, and the land area available in the candidate site is wide enough for establishing high-rate windrow method, this project will be designed in line with the high-rate windrow method.

Table 1-6: Comparison of Composting Method

	Minimal technology windrow	High-rate windrow	Static pile	In-vessel
Outline	The minimal window technology approach involves forming large windrows (e.g. around 3.5m height by 7.3m width) that are turned only once a year with a front-end loader.	A high-rate windrow composting system employs windrow with smaller cross section, typically 1.5 to 2.0 m height by 4 to 5m width. The dimensions of the windrows depend on the type of equipment that will be used to turn the composting waste. Waste is turned twice per week while the temperature is maintained at around 55 Centigrade.	An aerated static pile system consists of a grid of aeration or exhaust piping over which the processed organic fraction of municipal solid waste is placed. Typical pile heights are 2 to 2.5 m. A layer of screened compost is often placed on top of the newly formed pile for insulation and odor control.	In-vessel composting contains an enclosed container vessel inside. The system can be divided into two major categories: plug flow and dynamic (agitated bed). In the plug flow system, the relationship between particles in the composting mass stays the same throughout the process, and system operates on first-in, first-out principle. In the dynamic system, the composting material is mixed mechanically during the processing.
Odors	Probably emit objectionable odors	Often release offensive odors (accompanied turning)	Controllable	Less than static pile and controllable

	Minimal technology windrow	High-rate windrow	Static pile	In-vessel
Degradation period	Three to five years	Three to four weeks (composting) Three to four months (curing)	Three to four weeks (composting) Three to four months (curing)	One to two weeks (composting) Four to twelve weeks (curing)
Required area	Very large	Large	Large	Small
Construction cost	Very cheap	Cheap	Intermediate	High
O & M cost	Very cheap	Cheap	Intermediate	High

source : Integrated Solid Waste Management, McGraw-Hill

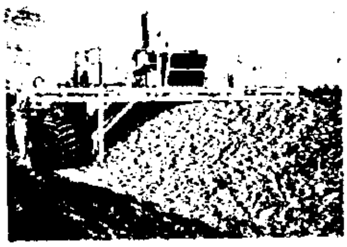
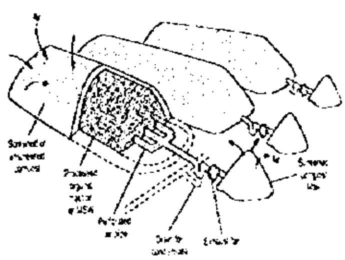
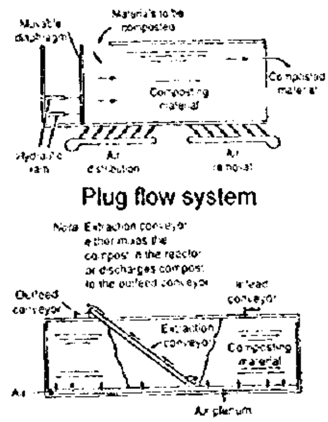
High-rate Windrow	Static Pile	In-vessel
		 Dynamic system

Figure 1-3: Major Composting System

1.3.3 Conceptual Design and Cost Estimation

1.3.3.1 Outline

The composting plant is planned to be located within a triangular shaped area of about 85 hectares enclosed by (refer to Figure 1-6):

- the left branch of the Rio Churubusco adjacent to the Bordo Poniente Final Disposal Site-Etapa IV;
- the Mexico-Texcoco Toll Road; and
- the Mexico City Peripheral Ring-Road.

Treatment capacity of the proposed plant is projected to be 1,250 ton/day, i.e.:

- by the Master Plan target year of 2010, 431,000 ton/year of organic waste is treated; and
- the proposed plant operates for 350 days per year.

While compost production is planned to be about 166 ton/day, or about 58,000 ton/year.

Main processes of the proposed facility comprise (refer to Figure 1-4):

- the composting process;
- the curing process; and
- the separation process.

The process times are assumed for the purpose of the preliminary design to be 28 days for composting and 120 days for curing.

Auxiliary facilities of the plant comprise:

- truck scale;
- waste reception areas;
- temporary storage areas;
- machine/equipment maintenance workshop; and
- site office and laboratory.

1.3.3.2 Definition of Terms

- **Raw material**: the material to be fed into the composting facility. Source separated organic wastes from the sub-systems is designated as the raw material.
- **Composting**: the controlled biological decomposition of organic solid waste materials under aerobic conditions. The product of this process is defined as **young compost**.
- **Composting period**: the period of decomposition of the raw material. For this preliminary design it is assumed to be **28 days**.
- **Turning**: action of agitating the windrows in order to maintain aerobic conditions inside the windrow.
- **Curing**: time for stabilization of young compost. The product of this process is defined as **mature compost**.
- **Curing Period** is defined as the maturation period. For this preliminary design the curing period is assumed to be **120 days**.
- **Separation**: the process of removing large-size particles, and non-compostables (e.g., plastics, glass, cans, metal, etc.) and not-yet-decomposed materials (e.g., paper and wood). Mature compost is passed through a trommel removing the large particles, then ferrous metal is removed with a magnetic separator.
- **Compost Product**: the end product resulting from the composting, curing, and separation processes.

1.3.3.3 Composting Facility Design Parameters

a. Design Principals

- It is planned that the composting plant starts operating in the year 2002, when separate collection of MSW from subsystems is projected to reach about 60%. The required composting capacity at this time will be 750 ton/day. Separate collection is estimated to further increase to 80% by 2003, and to 100% by 2004.

- The implementation schedule for this design comprises phase 1 (a 750 ton/day windrow yard and a 240 ton/day curing yard in year 2001) and phases 2 and 3, in 2002 and 2003 respectively (each consisting of a 250 ton/day windrow yard and a 80 ton/day curing yard). It is planned that the total composting capacity reaches 1,250 ton/day in 2004, and this capacity is maintained until 2010.

- Since stepwise improvement of the separation facility is neither practicable nor rational, it is planned to construct the 100% capacity separation facility in the year 2001.

- Considering that the proposed facility is to be constructed on highly compressible ground (in the ex-Lake Texcoco region), it is proposed that all machinery and equipment are mobile, and buildings are lightweight, so that problems of ground subsidence will be reduced.

b. Main Design Parameters

b.1 Operation Time of Composting Plant

Operational conditions of the facility are proposed as follows:

- The composting plant is to be operated 24 hours a day, to minimize the cost and size of planned processing machinery.

- Receiving of raw materials will correspond with the collection program. Therefore, raw materials will be received for 12 hours per day.

- Annual operation time for the composting and curing sections is 350 days per year. 15 days are set aside for overall maintenance and national holidays.

- For the composting section operating for 24 hours a day, 20 hours is for operation and 4 hours is for routine maintenance for machinery and time required for shift changes, etc. Works in this section will be undertaken in 3 shifts.

- For the curing section operating for 16 hours a day, 14 hours is for operation and 2 hours is for routine maintenance for machinery and time required for shift change, etc. Works in this section will be undertaken in 2 shifts.Because the volume of material handled in the separation section is substantially less than in the other two sections, an operation time of 350 day/year, 16 hour/day is proposed for the separation section, with work done in 2 shifts.

b.2 Design Assumptions

Design assumptions for the preliminary design are listed below. However, it is strongly recommended that these assumptions be re-examined and verified through pilot projects undertaken before the final detailed design (in 2000) is formulated.

- **Composting Period:** In general practice, the composting period is in the order of 20 to 30 days. This preliminary design proposes a period of 28 days be allowed for the composting period. Thus including a margin of safety that allows for variations in moisture content of the raw material.

- **Turning Frequency:** It is assumed to carry out a total 5 turnings during the 28-day composting period, with an interval between turning of 5 or 6 days. Transferring the young compost to the curing area on the 28th day is counted as the 5th turning. When higher moisture contents are found in raw materials delivered to the facility, an additional turning to accelerate evaporation may be carried out 1 or 2 days after forming the raw material into windrows. Table 1-7 shows the proposed work schedule for the composting process. The design assumes a windrow temperature of 55 °C.

Table 1-7: Work Schedule in the Composting Process

1st day	Windrow formation
5th day	1st turning
10th day	2nd turning
16th day	3rd turning
22nd day	4th turning
28th day	Young compost transported to curing area (5th turning)

- **Curing Period:** This is generally in the order of 30 to 90 days. The preliminary design assumes a 120-day period in order to provide sufficient maturation time. The yard reserved for the 120-day curing period also serves as an on-site storage for mature compost.

- **Bulk Density and C/N ratio:** Bulk density and the C/N ratio obtained during the Team's field investigation of organic wastes in September 1998 are employed as the figures for the raw material. While, the figures (i.e., bulk density) for young compost and mature compost are derived from empirical values recorded in Japan.

- **Moisture Content:** The design moisture content is assumed to be between 78% to 68%. Seventy-eight percent (78%) is derived from the DGSU's empirical data, whereas 68% is from the Team's field investigation results. Design moisture contents for young compost and mature compost are derived from empirical values recorded in Japan.

- **Compostable Content:** DGSU analysis classifies the raw material into 35 categories. These 35 categories are further classified into compostables and non-compostables for the preliminary design, with the compostables grouped into fast-rate compostables (putrescible); and slow-rate compostables (paper and wood) (see Table 1-8).

Table 1-8: Categorization of Raw Material

Grouping of Raw Materials	The 35 categories include
Fast-rate compostables (putrescible)	vegetable fiber, food waste, garden waste, etc.
Slow-rate compostables (paper and wood)	cardboard, paper, newspaper, wood, toilet paper, etc.
Metal (metal)	cans, ferrous and non-ferrous metal, etc.
Non-compostable	others

The solid content of respective waste groupings (putrescible, paper and wood, metals, and others) are listed for three moisture contents: 68%, 78%, and the average of two (73%). Moisture contents for food wastes are also included in Table 1-9.

Table 1-9: Composition of Raw Material

Component (% by weight)	Moisture Content 1	Moisture Content 2	Moisture Content 3
Moisture content of raw material	68.00	73.00	78.00
Putrescible	23.61	18.61	13.61
Paper and wood	2.81	2.81	2.81
Metal	0.65	0.65	0.65
Non-compostable	4.93	4.93	4.93
Total	100.00	100.00	100.00
Moisture content of food wastes	77.16	83.54	89.92

Obtained from Table 1-4.

b.3 Summary of Design Parameters

Table 1-10 summarizes design parameters based on the design assumptions established above.

Table 1-10: Design Parameters

Composting section				
Raw Material (Organic Waste)	Amount	431,000 ton/year	
	Compostable content	16.4 to 26.4 (% by wt.)	
	Moisture content	68 to 78 (% by wt.)	
	Bulk density	280 kg/m³	
	C/N ratio	20 - 27	
Operation		350 day/year 24 hour/day	
Treatment Capacity	Total	1,250 ton/day	
	Year 2002	750 ton/day	
	Year 2003	1,000 ton/day	
	Year 2004 and onward	1,250 ton/day	
Windrow		Trapezoidal shape	*1
	Width (bottom)	5.0 m	*1
	Width (top)	3.0 m	*1
	Height	1.5 m	*1
	Cross section area	6.0 m²	*1
Composting Period		28 days	
Turning Frequency		1 time/5 - 6 days	
Windrow Temperature		55°C	
Curing section			
Operation		350 day/year 16 hour/day	
Treatment Capacity	Young compost production	400 ton/day (max.)	*2
	Year 2002	240 ton/day	
	Year 2003	320 ton/day	
	Year 2004 and onward	400 ton/day	
	Moisture content	45 %	
	Bulk density	600 kg/m³	
Curing Period		120 days	
Separation			
Operation		350 day/year 16 hour/day	
Treatment Capacity	Mature compost production	300 ton/day (max.)	*2
	Moisture content	30 %	
	Bulk density	600 kg/ m³	

*1 :These figures are referred to the specification of the turning machine used by the DGSU for composting green waste from public parks and gardens.

*2 :These figures are calculated from the *1 figures based on the conditions given in the section c.5 "Materials Balance".

c. Quantity and Quality of Compost Product

Table 1-11 shows the target quality and quantity of the compost product in the preliminary design.

- Moisture content of the compost product is kept as low as possible (approx. 30%), for the purpose of mitigating the impact of odor on the surrounding environment.
- A water truck is included in the plant machinery plan in order to adjust the moisture level of the final product. There is the possibility that a compost product with a higher moisture content is demanded by the market. The water truck is also utilized for windrow moistening.

Table 1-11: Quantity and Quality of Compost Product

Quantity		166 ton/day 58,000 ton/year
Quality	Moisture Content Bulk Density C/N ratio	30% by wt 600 kg/m^3 < 15

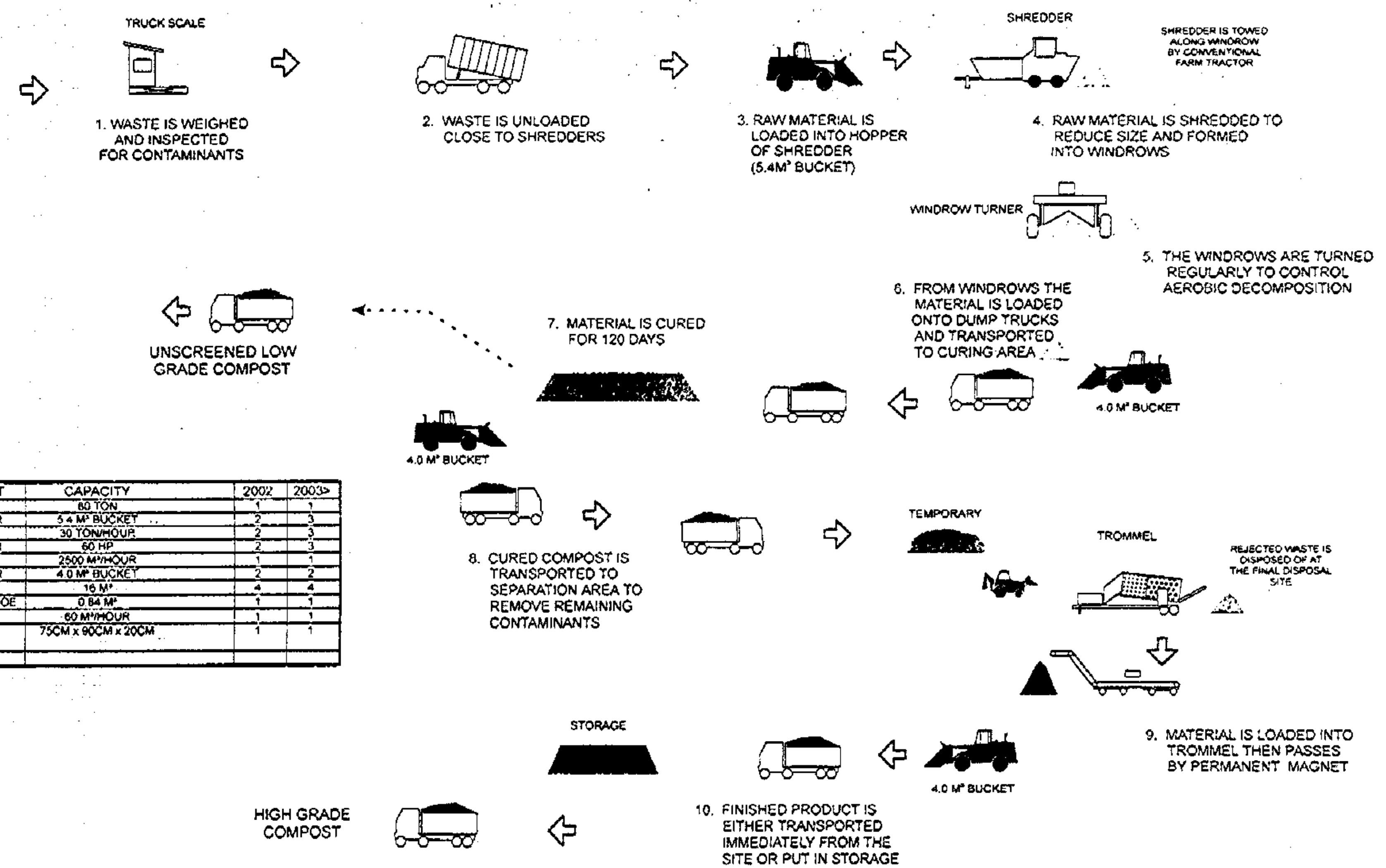
1.3.3.4 Flow of Composting Process

Figure 1-4 shows the flow of the proposed composting process.

- Summarizing the order of processes: first is the composting process (shredding, formation of windrows, and turning of the raw material); second, the curing process (formation of piles and curing for 128 days); and third, the separation process (removal of objects larger than 25 mm in size with a trommel and magnetic separation).
- Alternative sequence of the processes (e.g., having the separation process first or second) are not recommended for the following reasons.

    1) It is anticipated that most non-compostables will be separated at the generation source. Namely, separate collection of organic waste in the sub-system is considered to be primary separation procedure in the composting process.

    2) Any non-compostables in the material provide voids within the windrow. Thus improving the supply of oxygen and assisting aerobic decomposition.



EQUIPMENT	CAPACITY	2002	2003>
TRUCK SCALE	60 TON	1	1
WHEEL LOADER	5.4 M³ BUCKET	2	3
SHREDDER	30 TON/HOUR	2	3
FARM TRACTOR	60 HP	2	3
TURNER	2500 M³/HOUR	1	1
WHEEL LOADER	4.0 M³ BUCKET	2	2
DUMP TRUCK	16 M³	4	4
LOADER/BACKHOE	0.84 M³	1	1
TROMMEL	60 M³/HOUR	1	1
PERMANENT MAGNET	75CM x 90CM x 20CM	1	1

Figure 1-4: Flow Sheet of Proposed Composting Facility

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3) Separation of mature compost is more efficient than separation of young compost because, a) the moisture content of mature compost is lower than that of young compost making mature compost less cohesive and thus easier to separate, and b) the average size of mature compost particles is smaller than that of young compost, so less organic material will be rejected.

4) The quantity of mature compost is less than that of young compost, the separation facility can be smaller to save some costs.

1.3.3.5 Material Balance

Figure 1-5 shows the material balance in the proposed composting facility for the case of 73% moisture content. 60% of decomposition rate for the fast-rate compostable materials and 40 % for the slow-rate compostable materials were assumed in this material balance on the basis of the experience in Japan.

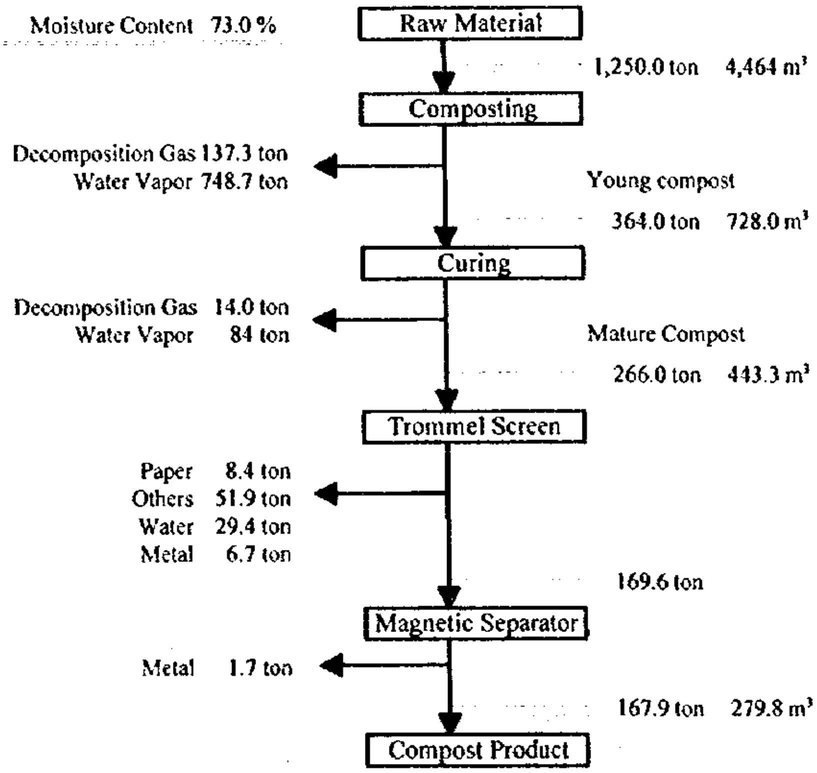

Figure 1-5: Materials Balance of Composting Facility

1.3.3.6 Layout of Proposed Composting Facility

The proposed layout of the composting facility was prepared taking the following into account.

- To avoid damaging the canal structures, the proposed facility is off-set at least 60 meters from the bank of a canal *Río Churubusco Brazo Izquierdo*.

- The composting windrow area accounts for a large portion of the total facility area. Therefore, the layout pays attention to: primarily the layout of the windrows, and subsequently the layout of the curing and separation areas to attain efficient on-site transport.
- Although the proposed site is located next to the Bordo Poniente Disposal Site-Etapa IV and the selection plant, the Rio Churubusco lies between these and the proposed composting plant. Therefore, direct transport routes (i.e., construction of bridges) between these sites is considered to be prohibitively expensive and is thus not included in the preliminary design.
- In order to mitigate odors and noise resulting from windrow formation and turning, at least 100 meters is maintained between the proposed windrows and nearby major roads.
- As strong winds often occur in the vicinity, the layout plan incorporates tree planting to act as a wind break. This buffer zone will also work as noise buffer and improve the appearance of the facility.

Figure 1-6 shows the proposed layout of the composting facility, and Figure 1-7 presents its cross section.

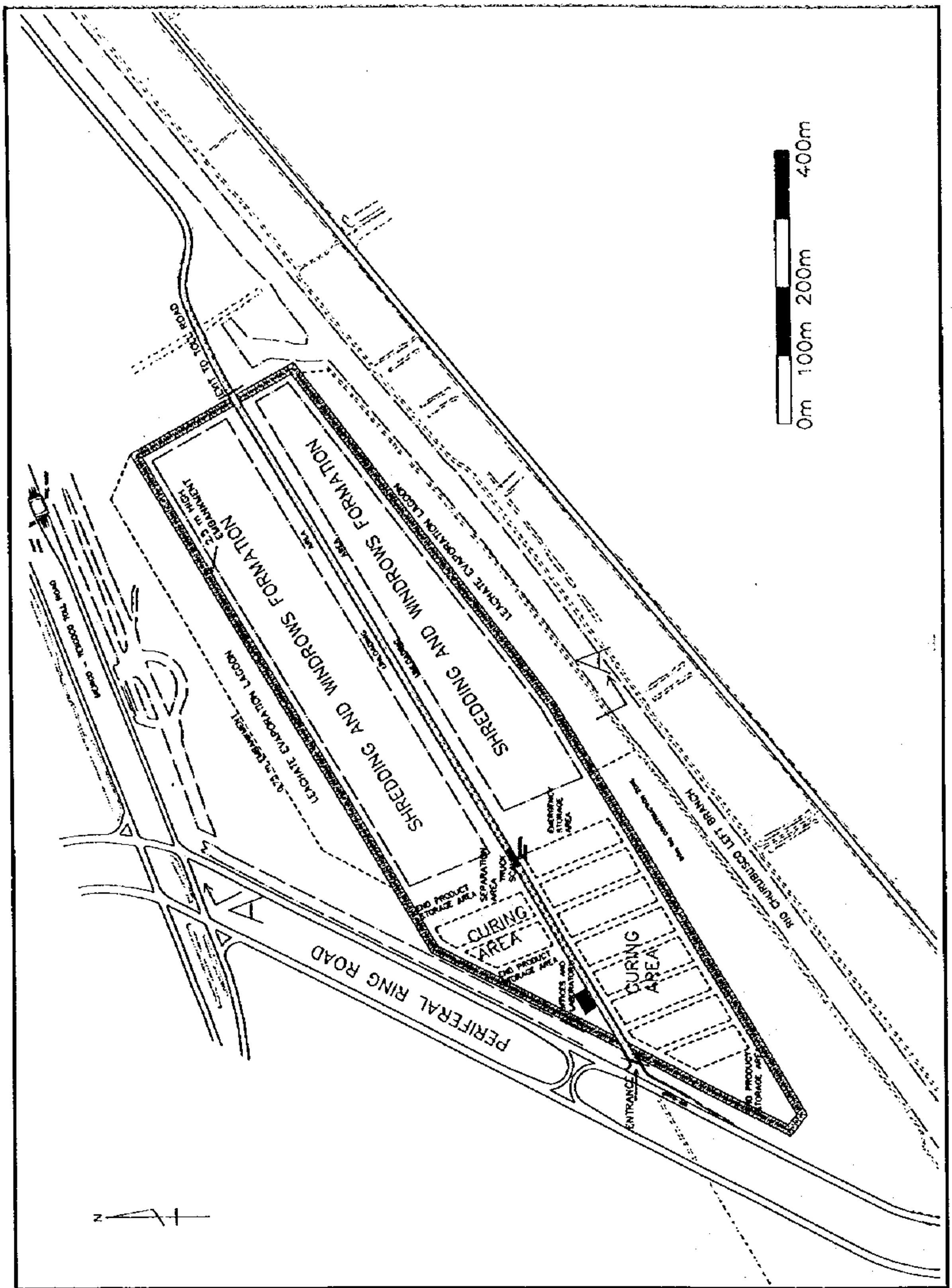

Figure 1-6:

Layout of Proposed Composting Facility

SCALE (m)
0 100 200 300

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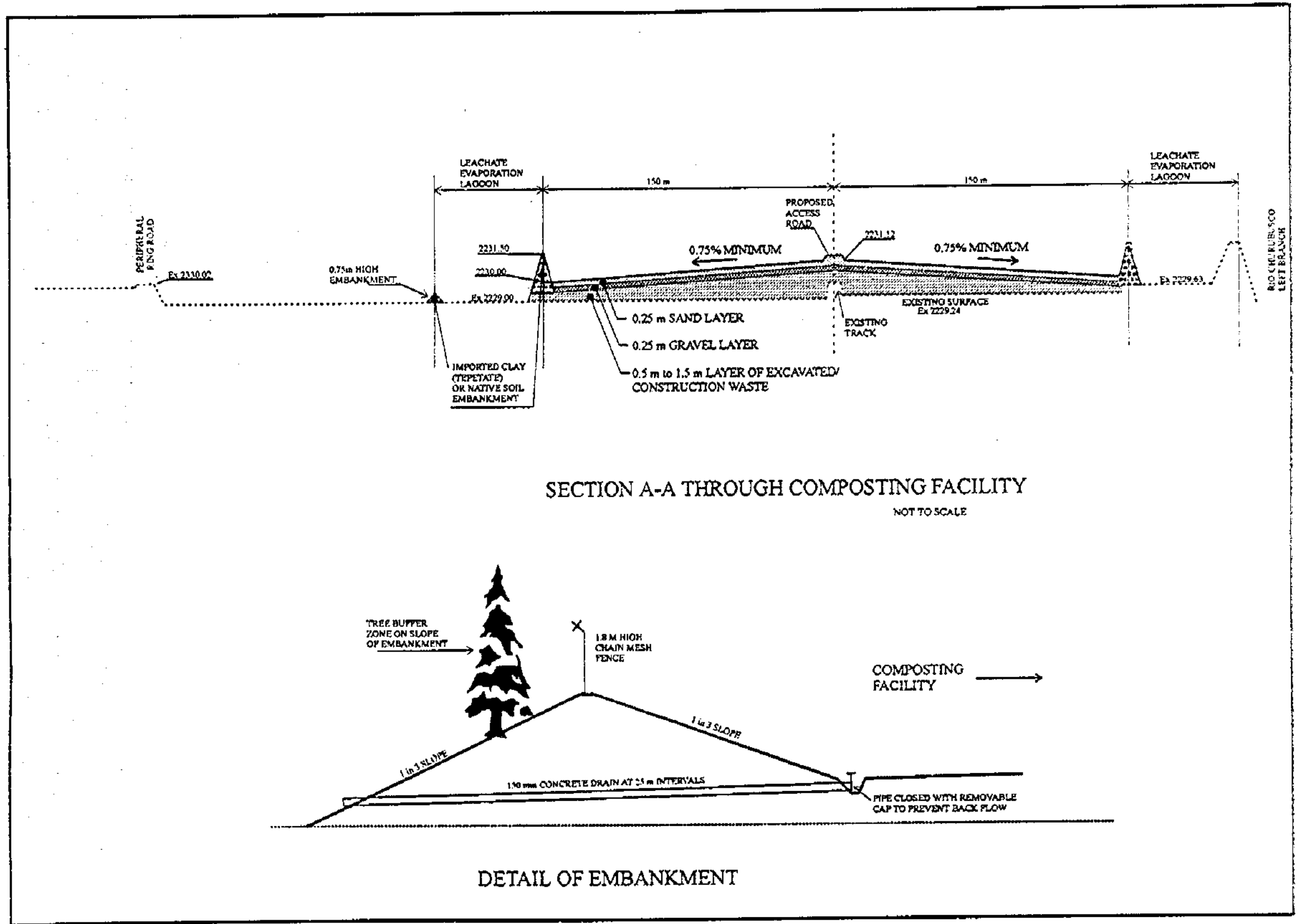

Figure 1-7: Cross Section A-A of Proposed Composting Facility

1.3.3.7 Construction Schedule

Table 1-12 shows the construction schedule of the composting plant.

Table 1-12: Construction Schedule of Composting Facility

Year	2001	2002	2003	2004	2010
Required Capacity (ton/day)	---	750	1,000	1,250	1,250
Composting Section (ton/day)	750	250	250	---	---
Curing Section (ton/day)	240	80	80	---	---
Separation Section (ton/day)	300	---	---	---	---

1.3.3.8 Operation Plan

The proposed operation plan is as follows.

a. Truck Scale

A truck scale measures the quantities of: raw material waste entering, compost product leaving the site, ferrous materials recovered, and rejected waste to be disposed of.

b. Composting Section

Raw material input at 1,250 ton/day results in a total windrow length of 800 meters per day.

- Raw material delivered to the site is unloaded near the planned windrow location.
- A wheel loader and a mobile shredder are shifted to the windrow yard. The wheel loader is used to load the temporarily stockpiled raw material into the shredder. Windrows are formed by a conveyor connected to the shredder's outlet and shaped with the wheel loader and manual workers.
- Turning of windrows is carried out in accordance with the schedule mentioned in the prior section. Cleaning of the area and windrow re-shaping is undertaken with a wheel loader and manual workers.
- Temperature and moisture content of all windrows is periodically monitored and controlled.
- Young compost after the 28-day composting period is loaded onto a dump truck, with a wheel loader, to be transported to the curing yard. The windrow yard from which the young compost is removed is prepared, with a wheel loader and manual workers, to receive new shredded raw material.

c. Curing Section

Considering the young compost amount to be handled daily and the work efficiency expected, it is designed to allocate two curing yards.

- Young compost transported from composting yard is temporarily unloaded near the curing yard.

- Unloaded young compost is then formed into 3-meter high piles with a wheel loader.
- Temperature and moisture content of the all curing piles at different heights is periodically monitored and controlled.
- Mature compost after the 120-day curing period is loaded onto dump trucks with a wheel loader and transported to the separation yard. The curing yard from which the mature compost is removed is then prepared, with wheel loader and manual workers, to again receive young compost.

d. Separation Section

- Mature compost unloaded from dump trucks is fed (with small wheal loader) into a hopper, which feeds the mature compost to a trommel. Staff is necessary for the feeding control and maintenance and cleaning of the separation yard.
- The trommel has screen sizes of 8mm and 25mm, classifying the fed mature compost into: high quality compost (8 mm and under); normal quality compost (8-25 mm) and the rejected material (over 25 mm).
- Compost after trommelling is transported to a compost product stock yard on a conveyor belt, passing a magnetic separator, which removes ferrous metal from the compost. Removed metal is periodically cleaned from the magnet and stored in the yard.
- Rejected waste (over 25 mm) is moved to another stock yard by a conveyor for disposal at the final disposal site.
- The compost product is loaded onto dump trucks with a wheel loader and delivered to users.

1.3.3.9 Staffing Schedule

Table 1-13 is the staffing schedule for the proposed composting facility. The number of operators and manual workers is derived from the volume of material processed and facility operation capacity. It is planned that by 2003, when facility capacity is 80%, the number of staff will reach its maximum. It is estimated that from the year 2003, 93 persons will be working in the proposed facility. Biological, physical and chemical analyses of compost for controlling the process and product's quality are to be conducted in the laboratory at San Juan de Aragon and/or others.

Table 1-13: Staffing Schedule

Position	2002				2003 -			
	Shift			total	Shift			total
	1	2	3		1	2	3	
ADMINISTRATION								
Site director	1	-	-	1	1	-	-	1
Finance and product promotion	1	-	-	1	1	-	-	1
Secretary	2	-	-	2	2	-	-	2
General helper	1	-	-	1	1	-	-	1
Driver	2	-	-	2	2	-	-	2
sub totals	7	0	0	7	7	0	0	7
OPERATION								
Sub-director process	1	-	-	1	1	-	-	1
Shredding supervisor	1	1	1	3	1	1	1	3
Turning and curing supervisor	1	-	-	1	1	-	-	1
Shredder operators	2	2	2	6	3	3	3	9
Loader operators	4	4	2	10	5	5	3	13
Tractor drivers	2	2	2	6	3	3	3	9
Small loader operators	1	1	-	2	1	1	-	2
Turner operator	1	-	-	1	1	-	-	1
Dump truck drivers	3	3	-	6	4	4	-	8
Waste inspectors	1	1	-	2	1	1	-	2
Traffic controllers	3	3	-	6	3	3	-	6
General Laborers	9	6	2	17	10	7	3	20
Truck scale attendant	1	1	-	2	1	1	-	2
Water truck driver	1	-	-	1	1	-	-	1
Security	2	2	2	6	2	2	2	6
sub totals	33	26	11	70	38	31	15	84
MAINTENANCE								
mechanics	1	1	-	2	1	1	-	2
sub totals	1	1	0	2	1	1	0	2
Totals	41	27	11	79	46	32	15	93

Part A
Chapter 2

Natural and Socioeconomic Environment

2 Natural and Socioeconomic Environment

2.1 Natural Environment

2.1.1 Introduction

This chapter describes the environmental aspects of the project site in the ex-Lake Texcoco and its area of influence, stressing those items which might be affected by the implementation of the project.

2.1.2 Area of Influence

The area of study of the composting plant project is located at the eastern part of Mexico City in the ex-Lake Texcoco. The site is in the west half of an triangle zone limited by the Autopista Mexico Texcoco, the Periferico and Brazo Izquierdo Río Churubusco. There is no productive activity carried out in the surroundings of the site.

The area of influence of the composting plant project is located in the physiographic zone of the *Eje Neovolcanico* axis in the sub-province of the Anahuac lakes and volcanoes, in the Mexico Valley basin. From a hydrological point of view, the project is located in the hydrological region of Panuco river, in the Moctezuma river basin.

Construction and operation of the composting plant encompass earthworks and carriage of organic wastes, which implies the vehicle traffic from the Periferico.

2.1.3 Climatology

Regarding the information required to analyze the climatic features of the site concerned, data of the meteorological station in the "Benito Juarez" International Airport and from the station located in the Nezahualcoyotl municipal hall in the State of Mexico was gathered, as well as the information obtained from Bordo Poniente's meteorological station.

Weather

The predominant climate in the region is dry steppe-type and cold, with rainfall during the summer (BKS'w). Taking the ex-lake as a central point, when climbing up to the eastern and western zone, the weather changes to temperate (Cwb), and in the higher zones of the sierra, to a cold temperate climate (Cwc).

Temperature

The annual average temperature in the region ranges between 12-20° C, being January, February, November and December with the lowest temperature. In the hottest months (May and June) the temperature reaches mean averages between 18-19 °C.

Table 2-1 shows the temperature behavior for the period of 1970-1989, whereas Figure 2-1 for 1994-1997. As can be perceived, the monthly average at a surface level during the last 4 years shows a cyclical behavior between 12.5° and 20° C, with maximum values in May and the minimum ones in January.

During the 1970-1989 period, the maximum annual extreme temperature was between 28° and 31°C, being March, April and June the months with the highest values (Table 2-2).

Regarding the monthly extreme temperatures for the 1994-1997 period, the highest temperature recorded during those years was 33° C in May (Figure 2-2).

The minimum extreme temperature for the months of January, February, March, November and December ranged between 0°C and 2°C (Table 2-3).

Relative moisture

Figure 2-3 shows the relative moisture for the 1994-1997 period.

This average relative humidity pattern illustrates a stage of the year with low relative moisture between January-April, whereas the high relative humidity stage takes place from July to September. It is important to point out that the high relative humidity level presents a gradual reduction of its average level in 1994-1997, with levels of 72% and 63% relatively.

According to a micro-location scale in the ex-Lake Texcoco, the highest humidity is found in the lacustrian zone with superficial water bodies, and the lowest humidity is found towards the zone of the project.

Precipitation

In general terms, rainfall in this region ranges between 500 and 600 mm. This fact classifies the area into one of the zones with the lowest precipitation in the Mexico Valley.

The precipitation behavior for the 1979-1988 period is shown in Table 2-4.

Most of the annual rainfall took place between May and October, in which almost 90% of total precipitation is accumulated.

During the period of 1994-1997, it is observed that the rain season is more intense between July and October (Figure 2-4), due to the presence of tropical humid air coming from the Pacific Ocean and the Gulf of Mexico. The lowest precipitation levels are found in the area of study.

Table 2-1: Average Temperature

Station: Airport of Mexico City

unit: °C

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970	12.0	13.1	15.9	20.2	17.8	17.2	16.8	17.3	16.5	16.2	12.9	12.5
1971	13.4	14.4	16.5	21.0	19.4	16.9	16.6	16.8	16.9	16.0	14.7	12.8
1972	13.2	13.6	15.6	18.8	18.2	17.8	16.4	16.8	17.1	16.5	14.6	12.6
1973	13.0	14.5	18.0	18.0	18.1	21.6	15.8	15.8	16.6	14.2	13.7	10.6
1974	12.9	13.9					15.1	16.5	16.1	15.2	13.0	12.9
1975	11.7	14.2	17.7	19.3	17.4	17.0	15.2	16.4	15.3	15.2	16.8	11.3
1976	11.4	11.8	16.3	16.9	17.2	17.3	16.1	15.4	16.6	15.6	13.5	13.3
1977	13.8	14.2	17.8	16.1	17.9	17.2	16.4	17.4	17.1	16.2	14.0	12.9
1978	13.1	13.6	15.7	18.9	19.2	17.0	16.7	17.5	16.6	15.3	15.1	14.3
1979	13.3	14.2	17.0	18.3		17.8	17.3	16.5	15.8	15.9	13.9	13.2
1980	12.9	14.1	18.2	17.2	19.2	18.3	17.9	17.3	17.0	16.2	14.1	12.3
1981	11.3	14.2	16.9	17.8	18.7	18.1	17.0	17.5	17.3	16.9	13.9	14.0
1982	14.5	15.2	17.9	20.1	18.8	19.4	17.0	17.5	17.8	16.1	14.5	13.6
1983	12.6	13.3	16.4	19.6	21.4	20.2	17.5	17.6	17.0	16.1	15.5	13.9
1984	13.2	14.7	17.7	20.3	17.4	17.7	16.6	16.5	15.9	17.2	13.9	12.9
1985	13.1	14.5	16.9	16.4	18.4	17.6	16.7	17.3	17.1	16.3	14.9	13.6
1986	11.5	14.8	15.2	18.0	18.5	17.4	16.9	17.3	17.7	16.3	15.4	14.0
1987	13.6	15.3	17.1	17.8	18.2	17.9	17.5	18.0	18.5	15.1	15.1	14.8
1988	12.7	15.2	16.5	19.2	19.7	18.6	17.6	17.8	17.2	15.9	15.4	13.4
1989	14.3	14.5	15.4	17.0	19.3							
Average	**12.9**	**14.2**	**16.8**	**18.5**	**18.6**	**18.1**	**16.7**	**17.0**	**16.8**	**15.9**	**14.5**	**13.1**

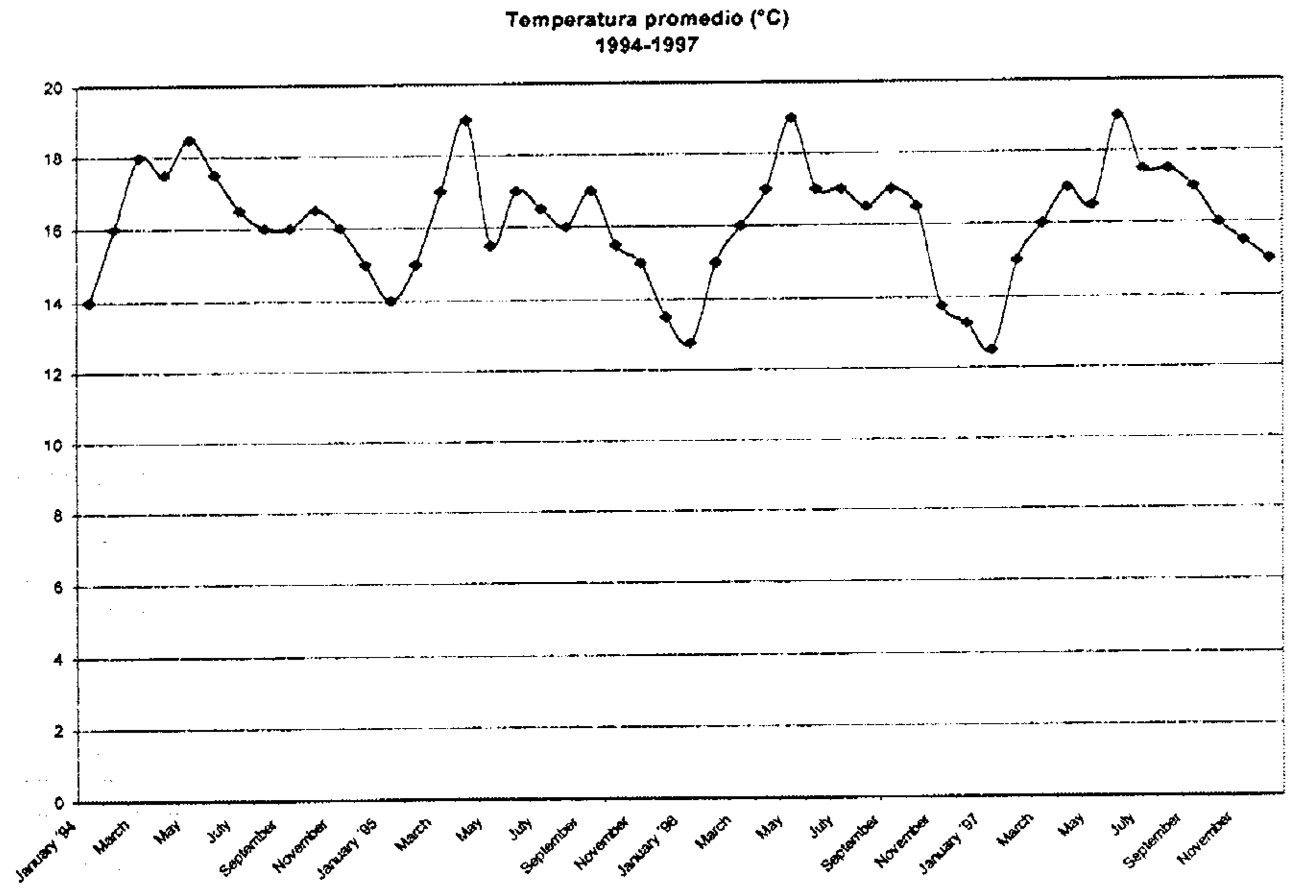

Figure 2-1: Average Temperature (°C) (1994-1997)

Table 2-2: Maximum Temperature

Airport of Mexico City

unit: °C

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970	25.7	21.2	31.4	33.5	32.0	30.5	27.5	27.4	26.5	26.8	25.6	19.2
1971	27.0	29.4	29.0	31.8	30.6	28.0	26.8	25.5	26.8	26.3	26.3	24.7
1972	25.0	27.4	28.5	31.0	31.7	30.4	27.3	26.6	28.1	27.6	27.6	25.3
1973	28.4	27.8	31.2	31.0	31.7	30.8	25.1	24.5	25.7	25.5	26.2	24.2
1974	34.3						24.9	26.7	25.8	25.1	24.5	26.3
1975	23.9	27.4	30.5	30.5	30.5	27.0	24.9	24.5	25.5	26.5	25.5	24.5
1976	24.0	26.3	29.4	28.7	29.4	28.5	24.5	25.6	25.5	25.5	25.3	25.5
1977	27.5	26.6	32.2	30.7	30.3	26.4	26.6	26.9	27.3	27.8	25.5	25.4
1978	25.7	27.4	29.3	31.7	31.8	28.5	26.0	27.2	26.6	26.3	25.3	25.2
1979	27.3	26.1	30.1	30.0		28.0	26.6	25.1	24.5	27.5	26.2	24.5
1980	25.6	29.0	30.7	30.5	33.5	29.6	28.2	25.8	25.6	26.0	23.5	24.3
1981	25.0	27.5	29.1	30.5	29.7	27.8	25.8	26.7	27.2	26.6	24.8	25.5
1982	27.0	26.6	31.4	31.4	29.6	32.2	26.3	28.1	28.3	27.1	25.9	26.0
1983	24.7	27.7	31.0	33.1	34.7	31.0	27.3	27.2	27.3	27.0	25.1	25.0
1984	24.2	27.8	31.0	32.6	30.1	27.5	25.7	25.4	25.3	27.6	26.4	24.6
1985	25.0	26.4	30.0	29.2	31.4	28.0	25.7	26.5	26.6	26.7	26.8	25.6
1986	24.6	27.4	29.1	30.8	31.7	26.7	26.7	27.8	27.1	27.0	28.7	25.9
1987	28.4	29.0	31.5	30.5	30.0	28.8	27.2	27.9	29.0	27.0	26.4	27.0
1988	25.3	30.6	29.7	32.0	31.5	24.5	27.4	27.2	27.5	18.4	27.6	25.7
1989	26.6	27.6	29.6	29.8	32.5							
Average	**26.3**	**27.3**	**30.2**	**31.0**	**31.3**	**28.6**	**26.3**	**26.5**	**26.6**	**26.2**	**26.0**	**25.0**

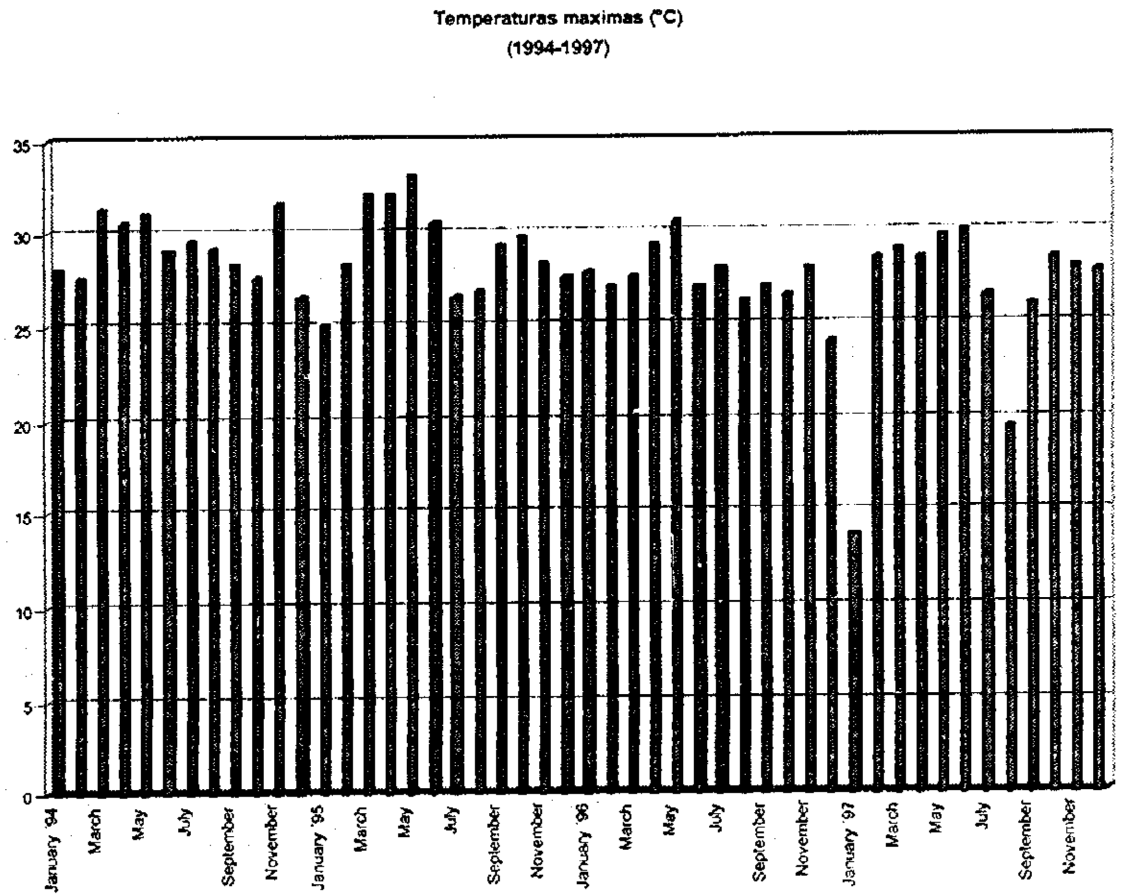

Figure 2-2: Maximum Temperature (°C) (1994-1997)

Table 2-3: Minimum Temperature (°C) (1994-1997)

Airport of Mexico City

unit: °C

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970	-1.2	-1.5	2.4	5.6	5.2	8.4	9.4	8.6	9.9	3.5	-1.6	-0.8
1971	0.5	0.4	2.0	1.0	7.3	7.9	9.2	8.4	9.9	4.1	3.0	-1.8
1972	0.5	-1.5	3.0	4.5	7.5	7.0	9.2	9.0	9.2	7.0	5.5	-2.0
1973	4.9	-0.5	1.6	3.3	6.5	7.0	8.9	9.2	8.5	6.5	0.0	-1.2
1974	1.1						6.4	7.7	2.2	2.0	-4.4	0.0
1975	-4.1	0.5	2.0	6.6	7.5	9.0	8.6	9.5	3.2	3.1	-1.0	-1.3
1976	-2.0	-5.5	3.4	6.2	6.8	8.1	10.0	8.3	9.0	7.7	4.1	3.4
1977	-0.5	0.6	0.5	1.6	4.8	5.6	8.7	8.8	7.7	3.6	0.8	-1.4
1978	-0.3	-1.4	0.0	5.3	3.5	6.4	7.5	8.3	5.6	5.0	5.8	11.5
1979	-2.0	1.9	2.0	5.9		3.6	6.7	8.9	2.0	2.4	-0.1	2.0
1980	-1.8	-2.6	3.0	4.2	6.4	7.2	6.0	10.0	6.4	5.4	1.8	-2.9
1981	-1.6	1.5	2.2	6.8	8.4	7.5	10.4	8.7	8.4	6.5	0.0	2.3
1982	1.5	-1.0	2.6	9.0	8.9	7.9	8.3	8.0	6.9	3.6	0.4	-1.5
1983	-2.5	-3.5	2.0	3.7	9.0	8.1	9.6	9.3	7.8	3.3	4.0	-1.8
1984	-0.6	-1.0	4.0	6.2	7.4	6.5	10.0	9.0	7.0	7.0	1.0	-1.0
1985	-1.0	1.2	4.6	2.9	7.0	8.5	7.3	9.3	6.8	5.0	3.0	-2.4
1986	-4.6	0.6	-1.5	7.0	8.0	11.2	8.2	8.7	8.8	3.0	13.2	0.5
1987	-2.8	-2.2	-1.9	5.3	8.0	10.8	1.2	11.0	9.3	21.5	1.5	1.8
1988	-3.7	3.2	2.6	7.4	9.0	9.5	11.6	10.0	4.8	4.5	1.2	-1.2
1989	1.8	-3.3	-2.0	4.8	7.0							
Average	**-0.9**	**-0.7**	**1.7**	**5.1**	**7.1**	**7.8**	**8.3**	**9.0**	**7.0**	**5.5**	**2.0**	**0.1**

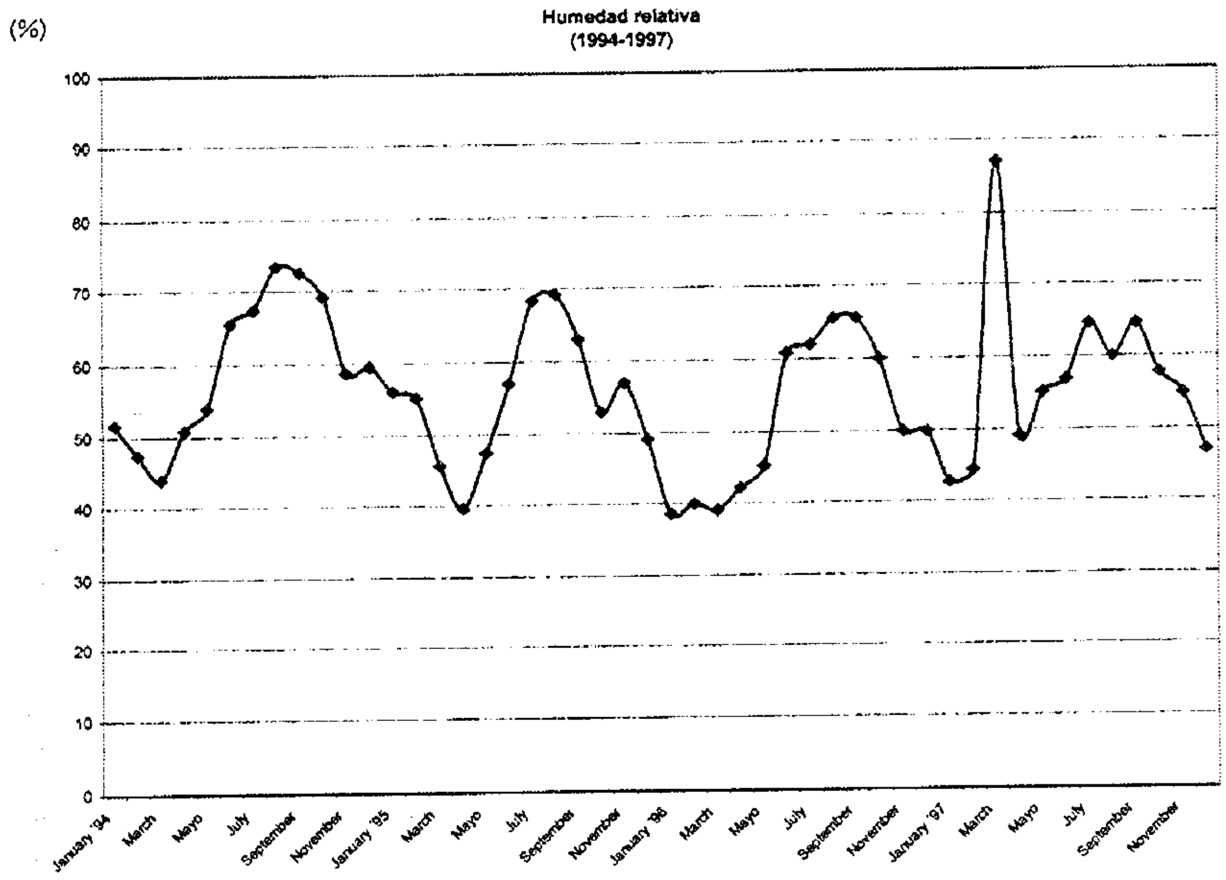

Figure 2-3: Relative Humidity (1994-1997)

Table 2-4: Total Precipitation (mm)

Station: Mexico City Airport

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1970	1.2	2.4	3.3	3.6	22.6	114.1	171.2	87.3	97.8	23.8	0.1	0.0	**527.4**
1971	0.5	1.1	14.0	6.6	17.5	158.3	110.1	105.8	99.4	93.2	7.5	5.6	**619.6**
1972	0.7	1.2	5.8	47.5	105.5	117.6	114.2	98.2	57.1	60.8	11.4	1.0	**621.0**
1973	0.3	4.5		43.6	33.5	59.9	166.9	147.5	58.1	28.7	28.8		**571.8**
1974	2.0	4.0					135.8	52.3	84.1	13.6		0.0	**291.8**
1975	35.7	3.7	0.0	16.6	78.1	66.9	90.1	99.8	96.5	39.4	0.0	0.0	**526.8**
1976		17.3	5.0	28.9	54.9	30.1	112.5	256.4	104.7	124.4	3.1	36.1	**773.4**
1977	3.1	3.6	0.0	11.3	46.8	70.7	143.5	48.3	140.4	53.8	1.8	1.5	**524.8**
1978	3.9	12.6	47.2	1.6	50.6	205.0	78.2	27.0	60.4	152.6	18.3	14.6	**672.0**
1979		19.1	3.0	21.8		77.0	130.0	149.3	122.8	2.0		14.7	**539.7**
1980	34.2	5.5	4.7	39.8	59.6	47.7	69.7	162.8	118.9	45.2	12.9	0.0	**601.0**
1981	19.9	20.3	10.2	40.1	23.9	177.6	148.4	67.5	50.7	35.3	1.6	1.3	**596.8**
1982	0.0	9.1	16.9	28.0	66.4	108.9	178.2	57.1	21.7	64.0	1.9	3.3	**555.5**
1983	13.5	0.7	3.9		35.2	66.4	109.2	102.8	82.0	50.7	10.1	15.6	**490.1**
1984	5.3	6.7	0.4		52.5	65.5	179.4	119.6	169.0	36.6	0.2	1.3	**636.5**
1985	9.4	2.1	14.4	91.3	44.6	159.6	79.4	60.8	65.6	15.1	0.7	0.0	**543.0**
1986	0.0		0.0	10.4	57.4	193.8	69.3	70.6	50.8	28.1	5.2	0.0	**485.6**
1987	0.0	1.7	2.6	12.7	36.3	97.3	135.2	94.4	125.0	0.0	18.9	0.0	**524.1**
1988	0.5	13.6	37.8	11.1	56.2	144.0	106.0	135.6	89.4	4.7	7.9	0.0	**606.8**
1989		0.5	9.7	8.5	41.2								**59.9**
Average	**7.7**	**6.8**	**9.9**	**24.9**	**49.0**	**108.9**	**122.5**	**102.3**	**89.2**	**45.9**	**7.7**	**5.3**	

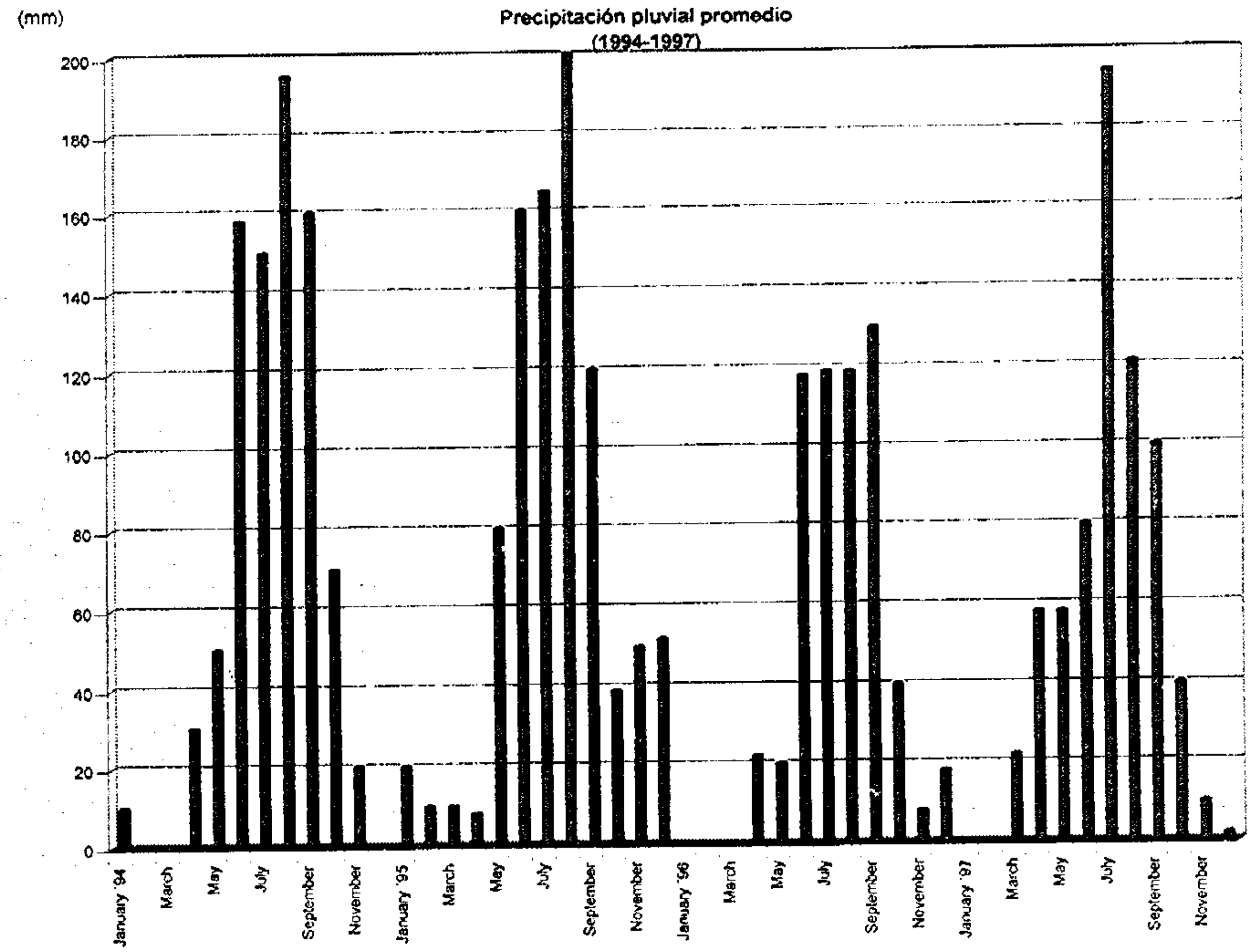

Figure 2-4: Average Rainfall (1994-1997)

Maximum rainfall in 24 hours

The graphic behavior is similar to that of total precipitation, except that the values are variable: from June to September there is a maximum rainfall level of 23 mm, whereas from November to March the values are less than 6 mm.

Table 2-5 shows the data on the maximum rainfall in 24 hours, recorded at the International Airport and at the Nezahualcoyotl station.

Evaporation

Potential evaporation in the Texcoco lake area ranges between 1700-1950 mm, which is a greater value than rainfall. March, April, May and June commonly have the greater evaporation values.

Regarding the evaporation, the area of study has a greater evaporation level during the summer season, with the lowest values being recorded during winter.

With respect to the division into zones of the evaporation in the area, it should be indicated that it is more remarkable at the ex-Lake Texcoco than in the rest of Mexico City. In this regard, Table 2-6 shows the variations in evaporation of the zone concerned.

Frequency of Elements and Special Phenomena

Table 2-7 and Table 2-8 show the elements and special phenomena that took place in the last 10 years at the meteorological stations of Mexico City's International Airport and at Nezahualcoyotl, respectively.

Dominant Winds

It is observed that during a long period of time the wind direction varied considerably, with several directions from the four cardinal points; however, as of 1985, a trend that lasted until the last year of recording was observed, and it indicates that the dominant winds have a speed of no more than 4m/sec throughout the year and with a northern direction (Table 2-9).

Likewise, Table 2-10 shows the daily average direction and velocity of dominant winds during July and August 1998 of the Bordo Poniente's meteorological station, where the same trend of previous years is observed.

Maximum wind speed

For the 1970-1989 period, the maximum wind speed ranges between 12 and 22m/sec with a northern direction (Table 2-11).

The height of the mixed layer for the zone is normally between an altitude of 0 and 200m and the predominant atmospheric stability according to Pasquill is type D.

Table 2-5: Maximum Rainfall in 24 Hours

Station: Mexico City Airport

unit: mm

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970	1.3	1.0	3.3	3.5	5.0	16.1	33.5	28.3	20.2	15.9	0.1	0.0
1971	0.5	1.1	8.6	2.2	7.9	39.8	27.4	29.7	32.6	24.0	6.1	3.5
1972	0.3	0.7	2.6	19.6	35.9	31.0	18.2	25.6	16.6	34.6	4.8	1.0
1973	0.0	4.5		33.8	14.0	14.0	23.4	31.1	16.9	12.5	26.6	
1974	2.0						26.1	14.1	30.7	10.9		0.0
1975	14.1	2.4	0.0	15.0	11.3	12.2	14.9	28.3	31.4	11.9	0.0	0.0
1976		9.1	3.4	10.3	8.8	11.6	19.8	55.0	23.7	35.6	2.2	18.3
1977	2.3	3.4	0.0	3.9	18.6	21.7	32.3	10.4	32.5	12.9	1.3	1.4
1978	3.9	7.4	20.8	1.6	12.0	28.1	15.3	10.3	13.9	38.4	7.3	9.3
1979		9.1	2.3	10.5		16.1	24.8	20.6	49.9	1.3		11.9
1980	10.3	3.2	4.7	9.8	13.9	12.5	20.0	36.7	23.9	12.7	4.8	0.0
1981	11.1	14.2	5.4	12.2	5.9	49.8	24.8	24.1	15.4	16.0	1.6	0.7
1982	0.0	5.1	8.8	9.5	10.2	36.0	51.7	10.1	12.3	30.9	1.8	2.0
1983	9.0	0.9	3.5		12.2	18.9	20.9	22.8	12.7	15.5	5.5	14.0
1984	3.3	3.4	0.4		15.4	12.4	24.8	20.7	56.2	10.7	0.2	0.7
1985	9.2	1.3	8.0	28.9	13.7	41.2	21.1	14.0	12.4	8.0	0.7	0.0
1986	0.0		0.0	5.8	21.5	46.3	19.2	10.9	14.6	11.0	1.9	0.0
1987	0.0	0.9	1.0	5.6	10.3	18.5	30.6	23.8	44.0	0.0	10.1	0.0
1988	0.5	10.7	32.4	5.6	14.1	28.0	16.2	38.7	29.3	3.0	7.3	0.0
1989		0.5	4.8	6.5	15.4							
Average	**4.0**	**4.4**	**6.2**	**11.1**	**13.6**	**25.2**	**24.5**	**24.0**	**25.7**	**16.1**	**4.8**	**3.5**

Table 2-6: Total Evaporation (mm)

Airport of Mexico City

unit: mm

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1970	188.0	153.2	70.7	182.1	150.6	157.6	142.6	153.8	145.5	181.4	168.5	212.9	**1906.9**
1971	167.1	166.3	201.6	210.0	237.6	155.3	144.8	132.9	138.2	129.7	145.3	157.7	**1986.5**
1972	150.4	153.6	195.3	212.9	164.6	144.0	132.1	156.4	145.8	137.6	132.3	110.0	**1835.0**
1973	138.6	154.3	217.9	225.2	208.7	162.7	127.6	119.3	106.0	98.2	112.9	196.3	**1867.7**
1974	104.5						112.6	146.7	130.3	134.0	101.5	130.1	**859.7**
1975	99.0	144.2	193.0	225.2	153.2	110.9	129.6	115.4	107.0	136.4	130.5	135.1	**1679.5**
1976	131.0	138.1	154.1	152.4	140.7	159.5	185.7	115.1	114.3	97.7	11.7	70.9	**1471.2**
1977	97.5	107.4	178.8	155.2	161.0	116.3	116.7	140.5	135.8	120.7	89.7	82.9	**1502.5**
1978	111.0	117.7	177.6	199.6	193.3	117.4	119.0	126.7	99.8	79.2	90.8	85.9	**1518.0**
1979	106.5	109.8	179.0	160.4		148.9	151.1	112.1	100.1	142.6	99.4	89.2	**1399.1**
1980	93.3	147.0	197.1	160.0	145.7	153.9	141.1	121.0	105.1	118.0	88.3	87.1	**1557.6**
1981	86.9	105.3	158.2	163.7	160.4	39.1	130.1	119.5	88.4	97.3	99.0	92.2	**1340.1**
1982	86.5	114.8	119.0	104.0	140.1	174.2	135.1	146.4	139.1	112.7	76.3	87.3	**1435.5**
1983	110.6	104.9	107.8	173.3	196.6	173.1	128.1	128.6	97.0	120.2	91.4	88.8	**1520.4**
1984	94.0	121.5	175.3		158.5	130.9	117.1	111.6	86.7	125.7	103.6	79.3	**1304.2**
1985	91.7	124.7	164.4	125.9	154.3	118.3	116.5	119.8	142.7	113.0	99.1	81.4	**1451.8**
1986	96.5	142.3	195.5	160.7	143.8	109.6	129.3	108.3	121.5	102.3	91.4	96.6	**1497.8**
1987	118.0	149.2	183.8	171.6	179.8	130.8	108.3	144.6	154.8	154.4	108.3	108.0	**1711.6**
1988	109.0	134.6	153.8	172.7	178.1	141.5	123.0	128.3	122.2	114.3	110.0		**1487.5**
1989	76.9	94.8	183.3	152.4	159.5								**666.9**
Average	**112.9**	**130.7**	**168.7**	**172.6**	**168.1**	**135.8**	**131.1**	**128.8**	**120.0**	**121.9**	**102.6**	**110.7**	

Table 2-7: Monthly Frequencies of Elements and Special Phenomena (1)

Meteorology Station: Aeropuerto Internacional Benito Juarez; Gustavo A. Madero, D.F.

	Years	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
No. of days with perceivable rain	12	1.75	2.63	3.18	6.72	11.63	17	19.33	18.08	14.75	8.25	2.41	1.5	107.23
No. of days with non-perceivable rain	12	0.58	1	1.63	2.9	2.27	1.81	2.5	2.58	1	1.83	1.91	0.83	20.84
No. of clear days	11	15.25	12.63	10.9	10.81	4.45	2.36	3	2.5	3.33	6	9.63	12.81	93.67
No. of partly cloudy days	11	10.83	11	15.27	15.45	16.18	10.45	8.72	7.66	8	11.3	13.45	12.9	141.21
No. of cloudy days	11	4.91	4.63	4.81	3.72	7.63	17.18	19.27	20.83	18.66	13.7	6.9	5.18	127.42
No. of days with dew	2	0	0	0	0	0.18	0	0	0.08	0	0.66	0.58	0.08	1.58
No. of days with hail	12	0	0	0	0.27	0.18	0.18	0	0.25	0.08	0.08	0.08	0	1.12
No. of days with frost	12	5.41	2.09	0.27	0.36	0	0	0.08	0	0	0.25	1.91	2.5	12.87
No. of days with electric storm	12	0.16	0.09	0	0	1.45	1.72	1.16	2.58	0.91	0.58	0	0	8.65
No. of days with mist	12	4.83	4.09	9.09	9.09	6.09	6.63	9.91	4.58	7.66	8.08	6.33	7.66	84.04
Days with snow	12	0	0.27	0	0	0	0	0	0	0	0	0	0	0.27

Table 2-8: Monthly Frequencies of Elements and Special Phenomena (2)

Meteorology Station: Nezahualcoyotl (Palacio Municipal) Mex.

	Years	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
No. of days with perceivable rain	10	1.18	2.18	2.81	5.45	9.8	12.72	17.9	16.9	14	7.6	2.9	1.8	95.24
No. of days with non-perceivable rain	10	1.36	1.27	3.09	3.18	5.5	4.27	2.9	2.8	1.7	2.5	2	0.9	31.47
No. of clear days	10	20.09	18	16.36	12.54	8.1	5.45	2.5	3.2	6.4	11.4	14.2	16.8	135.04
No. of partly cloudy days	10	8.18	8.09	12.9	14.1	16.6	16.27	19.5	20	15.5	14.4	12.7	11.8	170.04
No. of cloudy days	10	2.72	2.18	1.72	3.36	6.3	8.27	9	7.8	8.1	5.2	3.1	2.4	60.15
No. of days with dew	10	0	0	0	0	0	0	0	0	0	0	0	0	0
No. of days with hail	10	0	0	0	0.18	0.4	0.27	1.2	0.4	0.1	0.1	0.3	0.2	3.15
No. of days with frost	10	6	1.81	0.09	0	0	0	0	0	0	0.6	1.9	7.4	17.8
No. of days with electric storm	10	0	0	0	1.36	1.8	2	1.7	0.9	0.6	0.3	0.4	0.1	9.16
No. of days with mist	10	1.54	0.45	0.18	0.09	0	0	0.3	0	0.3	1.1	1.5	1.9	7.36
Days with snow	10	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2-9: Dominant Directions and Average Velocity of Winds

Airport of Mexico City

unit: m/s

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970	C	C	C	C	C	C	C	C	C	C	C	C
1971	C	C	C	C	C	N 2.4	N 1.6	NE 2.0	N 2.4	N 4.2	N 1.4	N 2.5
1972	SSE 2.8	N 2.5	N 2.3	N 1.1	S 2.6	N 1.4	N 3.0	N 1.8	N 1.7	N 1.8	N 1.6	N 1.8
1973	SE 2.3	SE 3.1	S 3.3	S 1.7	NE 3.6	NNE 2.6	N 2.3	NNE 2.2	N 1.3	N 1.9	N 1.7	N 1.4
1974	N 1.8						N 1.8	N 1.3	NNE 2.6	NNE 2.6	NNE 2.1	SSW 2.6
1975	NE 1.6	SE 2.8	SE 3.4	NNE 2.2	NNE 2.3	N 2.6	NE 2.6	NE 1.9	NNW 2	SE 2.3	NS 1.8	SE 1.5
1976	NE 2.2	E 1.9	SE 3.1	SE 2.6	SE 2.4	E 3.3	SW 2.21	SE 2.4	NE 1.6	E 2.0	N 1.7	ENE 1.5
1977	SSE 2.4	S 2.5	SSE 3.1	SE 2.2	NNE 2.0	NNE 2.4	NNE 2.3	NNE 2.7	NNE 2.0	N 1.6	ESE 2.1	
1978	ESE 2.3	N 1.8	SSE 4.2	SSE 2.6	NNE 2.1	NNE 1.8	NNE 1.4	N 1.9	NE 1.8	N 1.4	N 1.1	S 2.0
1979	S 1.7	N 2.0	SE 3.1	NNE 2.2		N 2.2	N 2.2	N 1.6	NNE 1.8	NNE 2.4	SE 3.4	NNE 1.7
1980	SSW 3.5	NNE 2.8	SSW 4.2	NNE 2.8	NNE 2	ENE 2.9	NNE 1.4	NW 1.9	N 1.8	NNE 1.4	NNE 1.5	NNE 1.2
1981	SSE 2.8	E 1.2	S 3.0	ENE 2.2	ENE 2.9	NE 2.9	NE 3.7	ENE 3.3	NNE 3.0	ENE 2.3	NE 2.9	SSE 3.6
1982	SSE 3.5	NE 2.1	ENE 3.1	ENE 2.2	ENE 2.0	ENE 2.8	ENE 2.6	NNE 2.7	NE 3.6	NWE 3.6	ENE 3.0	SSE 3.8
1983	SSE 3.9	SSE 3.6	SSW 5.6	SSW 5.3	SSW 5.0	NE 3.6	NNE 3.4	NNE 3.2	NNE 3.2	NNE 4.4	NE 2.7	SE 2.7
1984	ESE 1.6	ESE 2.0	ESE 4.0	SE 4.3	SSW 4.5	NE 3.2	NE 3.2	NE 3.2	NE 3.6	ESE 2.3	N 3.2	ESE 1.4
1985	SE 2.4	N 3.3	N 3.3	N 3.2	N 3.3	N 3.3	N 3.4	N 3.2	N 3.2	N 3.2	N 2.8	N 2.9
1986	N 2.8	N 3.8	N 3.0	N 3	N 2.7	N 2.3	N 3.5	N 3.2	N 3.3	N 3.3	N 3.6	SE 3.2
1987	S 3.6	N 3.4	N 2.9	N 2.9	N 3.6	N 3.9	N 3.8	N 3.9	N 4.0	N 3.9	N 3.0	N 2.5
1988	N 2.3	N 3.2	N 3.4	N 3.7	N 3.7	N 3.8	N 3.0	N 3.8	N 3.6	N 3.4	N 3.0	N 2.9
1989	N 3	N 4.1	N 4.0	N 3.4	N 4.2							

Table 2-10: Daily Average Dominant Direction and Velocity of Winds in July and August

Day	Direction	Velocity, m/sec	Day	Direction	Velocity, m/sec
01.07.98	NE	1.9	01.08.98	NE	2.7
02.07.98	NE	2.0	02.08.98	NE	2.9
03.07.98	SE	5.2	03.08.98	NE	1.7
04.07.98	NE	1.7	04.08.98	no. deter.	no. deter.
05.07.98	SE	2.5	05.08.98	NE	3.7
06.07.98	NE	2.4	06.08.98	NE	1.7
07.07.98	NW	3.0	07.08.98	SE	8.5
08.07.98	NW	3.8	08.08.98	NE	2.4
09.07.98	NE	5.7	09.08.98	NE	3.2
10.07.98	SE	2.7	10.08.98	NE	2.5
11.07.98	SE	3.0	11.08.98	NE	2.0
12.07.98	NE	2.0	12.08.98	NE	2.5
13.07.98	NE	2.2	13.08.98	NE	4.0
14.07.98	NE	3.2	14.08.98	SE	2.7
15.07.98	NE	3.0	15.08.98	SE	4.3
16.07.98	SE	2.3	16.08.98	SE	2.7
17.07.98	SE	2.9	17.08.98	SE	2.4
18.07.98	NE	3.0	18.08.98	NW	2.5
19.07.98	NE	2.2	19.08.98	NW	3.4
20.07.98	NE	3.1	20.08.98	NW	4.8
21.07.98	NW	2.8	21.08.98	NW	3.3
22.07.98	NE	2.8	22.08.98	NE	2.0
23.07.98	NE	3.4	23.08.98	NE	3.3
24.07.98	NE	3.2	24.08.98	NE	2.2
25.07.98	NE	3.9	25.08.98	NE	3.2
26.07.98	NE	4.2	26.08.98	NE	2.8
27.07.98	NE	4.0	27.08.98	NE	2.7
28.07.98	NE	3.0	28.09.98	MW	2.9
29.07.98	NE	2.1	29.08.98	NE	2.9
30.07.98	NE	1.6	30.08.98	NW	2.6
31.07.98	NW	2.6	31.08.98	NE	2.6

Monthly velocity average: 2.9 m/sec in July, 4.1 m/sec in August
Monthly direction average: Northeast 20 days in July and 19 days in August
Source: Bordo Poniente Meteorology Station

Table 2-11: Maximum Velocity and Direction of Winds

Airport of Mexico City

unit: m/s

Month / Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970	W 16.8	N 16.3	SE 21.0	N 22.8	NNW 18.2	N 18.8	N 15.9	SE 17.3	ENE 22.2	ESE 14.4	NNW 13.7	NNW 10.1
1971	NNE 18.3	SSE 15.9	SSE 20.2	N 20.1	E 20.2	N 17.8	NNE 17.3	NNE 13.8	NE 14.7	NNE 16.4	N 14.2	SSW 17.0
1972	N 15.0	SW 19.0	SE 16.2	E 19.0	NW 19.3	NE 22.9	SSE 15.3	NNE 15.0	N 18.5	NE 14.6	N 14.2	WSW 10.0
1973	S 16.3	S 14.6	SSE 20.0	SW 21.2	ESE 22.8	NNE 13.8	NNE 15.6	N 17.8	S 18.0	W 14.8	N 7.0	SSW 13.9
1974	SSE 14.0						SE 15.0	NNE 17.3	NNE 14.0	NNE 14.2	NNE 16.0	SSW 17.8
1975	S 16.4	SE 16.0	E 14.2	NW 16.0	SE 20.0	ENE 20.7	N 17.0	NW 5.0	SSE 13.9	E 14.8	S 16.8	NNW 14.0
1976	NNE 14.2	N 12.0	ESE 19.0	N 17.0	SSE 16.2	SW 17.2	SW 17.0	NW 15.0	SSE 13.9	E 14.8	S 16.8	WNW 12.5
1977	WSW 15.3	S 17.0	SW 17.0	NE 17.0	S 15.9	NNE 14.0	E 15.2	NNE 19.7	ESE 17.0	NE 14.1	WNW 12.4	
1978	SSE 13.8	SSE 24.0	S 16.0	SSE 16.8	NNE 20.2	S 17.8	NE 13.0	NNE 15.9	NE 12.0	E 14.7	SE 8.0	SE 12.0
1979	SSW 12.1	SE 19.0	SW 15.0	SE 20.0		NNE 18.9	NNE 17.0	ENE 20.0	NE 16.3	NNE 14.0	SE 12.2	SSE 11.9
1980	NNE 10.0	SSW 24.5	ENE 18.0	S 22.5	SE 14.0	E 19.0	NE 10.0	NNW 15.9	ENE 14.0	NNE 11.4	SW 13.0	ESE 12.0
1981	WSW 17.3	NNW 20.0	S 17.0	S 18.0	SSW 16.7	SE 16.7	NE 16.7	ENE 13.6	SE 15.3	SSE 16.1	NE 10.0	NE 12.8
1982	SW 13.5	S 16.0	SE 17.4	NNE 16.5	ESE 18.9	E 16.1	ESE 17.4	ESE 14.7	WNW 21.0	SSE 17.0	SSW 14.2	SSE 14.7
1983	WSW 15.4	SSE 19.2	SW 17.5	WSW 17.4	ESE 18.9	SSW 14.4	SE 18.8	E 16.8	NE 15.3	ENE 16.4	NE 14.7	SSW 13.3
1984	WNW 15.0	SSE 13.6	NW 17.2	N 16.7	NE 19.2	ESE 16.7	SE 18.3	E 19.6	SSW 13.3	SE 14.9	NE 14.1	SE 13.5
1985	SSW 15.6	SSW 14.4	SSE 18.2	ENE 16.8	SSW 15.8	ENE 15.0	NNE 17.2	E 12.8	NNE 16.3	N 15.3	N 16.8	NNE 11.8
1986	N 11.5	S 18.9	SW 16.7	SSE 16.8	N 15.0	ESE 15.9	SSE 17.2	ENE 16.6	N 15.0	S 14.1	N 12.0	SSW 15.4
1987	SSW 12.9	W 17.0	SW 17.0	SW 13.7	N 16.8	NNW 16.9	NE 14.7	N 12.2	N 18.2	ESE 19.2	N 13.0	
1988	S 16.2	NNW 12.7	NNW 12.7	SSW 22.8	NE 16.8	SSW 20.2	E 20.8	N 16.8	NNE 17.9	N 12.7	N 12.3	
1989	SSW 12.4	N 13.6	N 13.6	N 18.5	WNW 17.8	WNW 18.0						

2.1.4 Air

Thermal Inversion

One of the factors that aggravate the pollution problem in Mexico City is the frequency of thermal inversions, specially during the winter, when the high pressure systems and other meteorological phenomena retain the pollutants longer time than during the summer season. From November to March, the time for breaking up such inversion is at 9:00 AM, since the insolation at this time of the year is lower if compared with that of the summer. In this regard, Figure 2-5 illustrates the frequency of thermal inversions that took place in Mexico City, from 1994 to 1997, according to the data of the Environment Department of the GDF.

Air Pollution

Suspended particles are one of the important pollutants of the city's atmosphere, particularly in the project area, as dust storms are generated during the dry season.

Desiccation of the lake has induced the formation of an extensive area without vegetation, which has been exposed to the effects of the erosion by the dominant winds of this region. Said winds cause dust storms that carry particles towards Mexico City's metropolitan zone, and an significant portion of them remain in the air and their size is less than 10 micron.

This condition turns this region into an important emitter of particles, which are recorded mostly by the atmospheric monitoring network station at the Nezahualcoyotl municipality.

The maximum PM10 values of the Air Quality Metropolitan Index (IMECA) recorded at Nezahualcoyotl station between January 1996 and September 1998 show that the limit of the norm (100 IMECA points for the admissible breathable particles) is surpassed during the first three months of the year; however, in 1998 this situation continued critically until June, with a maximum average value in this month of 210 IMECA points.

During the analyzed period, the Nezahualcoyotl station recorded 17 months in which the limit was surpassed; i.e., 50% of monthly records indicated that the air quality was between the range of Non Satisfactory and Bad.

Due to the aforementioned, the Metropolitan Environmental Commission had to elaborate the Program to Strengthen Air Quality Improvement Actions in Mexico Valley. It states that the National Water Commission (CNA) is to strengthen the restoration activities of the ex-Lake Texcoco.

Likewise, the Government of the State of Mexico, by means of the Urban Development, Public Works, Farming Development and Ecology Departments and in coordination with the CNA, elaborated a program to mitigate the emission of suspended particles in the Mexico Valley. Such program establishes immediate actions for the ex-Lake Texcoco federal zone.

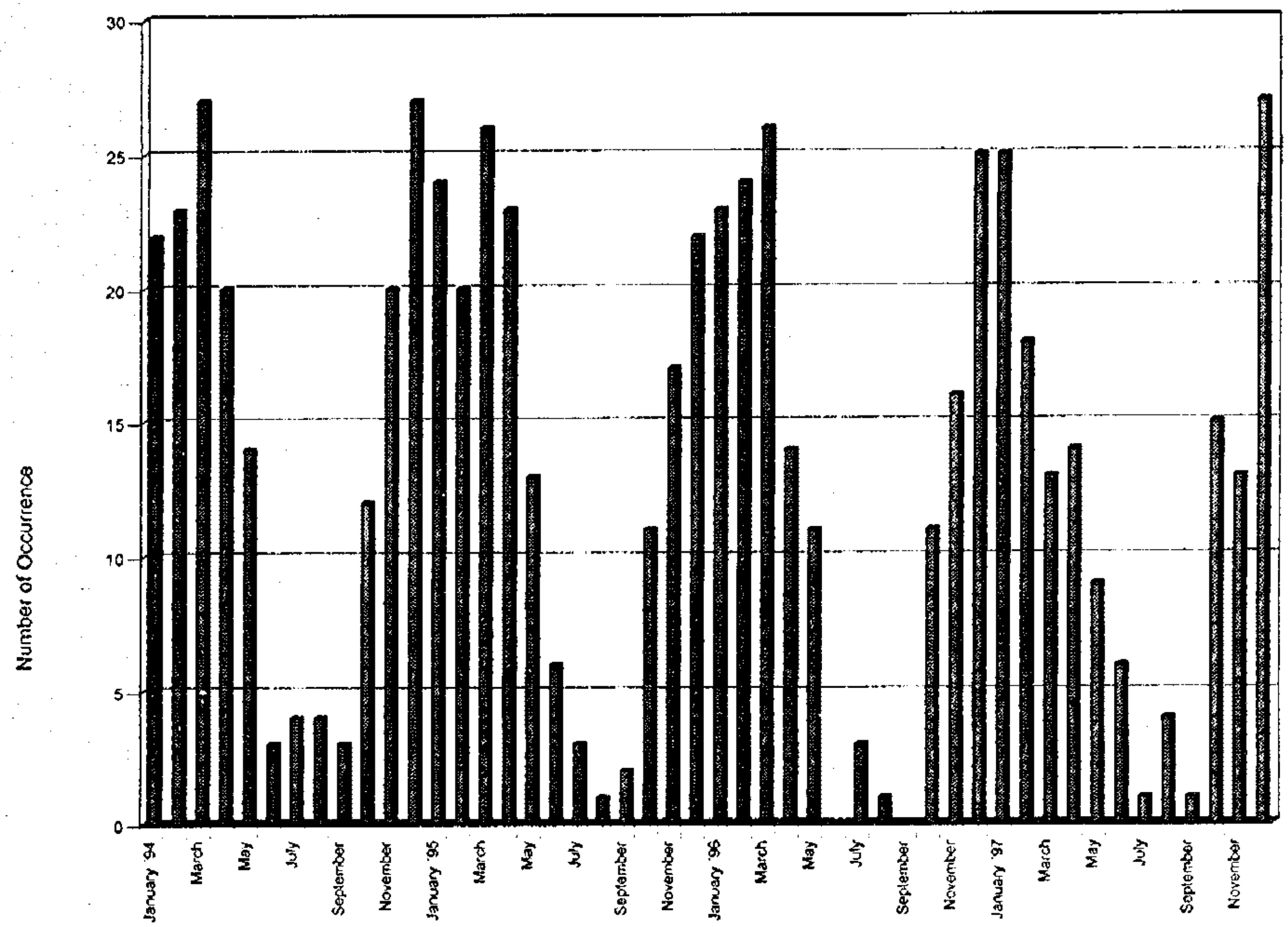

Figure 2-5: Number of Event of Thermal Inversion

Fourteen projects are highlighted from this program:

- Trees and grass seeding
- Forest lines
- Forest buffer zones
- Recovery and protection of soil at the eastern basin (sub-basin of San Juan Teotihuacan river)
- Recovery and protection of soil at the eastern basin (sub-basin of San Francisco river)
- Construction and operation of an irrigation system to control dust storms in "El Caracol" structure
- Drainage of the area flooded with wastewaters and construction of sport zones
- Rehabilitation and recovery of Churubusco regulation pond
- Wastewater treatment for irrigation
- Construction of treated water storage lake, Churubusco
- Construction of Lago Texcoco Norte treatment facility
- Pressurized irrigation, including operation and maintenance
- Drainage through the channeling of wastewater discharges

2.1.5 Geological and Geomorphologic Traits

The zone in which the sanitary landfills currently operated by the GDF are located, and in which the composting plant is proposed to be constructed, belongs to the ex-Lake Texcoco federal zone. It is at an elevation of 2,230 m above the sea level, located in the northeast of Mexico City.

Apart from being a receiver of the wastes coming from Mexico City, this zone also involves regulation ponds of superficial runoffs; likewise, Lago Nabor Carrillo and Lago de Regulación horaria were constructed here.

Among the activities developed within this zone there are the cultivation of halophyte species, which resistant to salinity, and diverse experiments on hydraulic, sanitary and farming works. Also, wastewater treatment facilities and an experimental module for the artificial recharge of aquifers with treated waters have been constructed there.

2.1.5.1 Regional Geology

The geographic site known as Mexico Valley Basin is located at the southern limit of the Mexican highland plain, between the 20° 15' and 19° 01', northern latitude, and 99° 31' and 98° 15' of western longitude.

In geological terms, said basin is located in the center of the volcanic strip that crosses from east to west the Mexican Republic. It has been subject to intense tectonic stress, as well as volcanic eruptions since the beginning of the Tertiary Period and up to recent times. The formations of the Middle Tertiary period include the remains of stratified volcanoes, tuffs, breccia and lava spillage and deposits. The type of rocks of this stage has a wide range: andesites, basaltic andesites, basalts, *dasitas*, and so on. These formations crop out at the lower part of the sierra bounding the basin. The strata belonging to the Tertiary Superior period show big lava deposits to the eastern and western zones of the basin.

Mexico basin was formed by the volcanic and tectonic processes that have been developing -sometimes slowly, sometimes abruptly. In the last 50 million years, as of the Eocene Superior period, such processes were particularly in a big scale and have affected the Trans-Mexican volcanic strip, and in general terms all the southern zone of the Mexican Republic from the Pacific coasts.

Before the Eocene period, the space in which the basin is currently located was flooded with shallow tropical seas. At the beginning of the Tertiary period, these waters withdrew when the limestone sediment folded and the continent gradually lifted. In this manner, the regression of the seas began in the Tertiary period and the volcanism stage began, which produced thickness of 2 km and more of lava, tuffs and breccia.

From a physiographic point of view, the basin is divided into three sections:

- Southern zone. It is bounded to the east by Sierra Nevada and Sierra de Rio Frio; to the west by Sierra de las Cruces; to the south by Sierra Chichinautzin and Ajusco; and to the north -though not completely- by the elevations of Sierra de Guadalupe, Cerro de Chiconautla and Sierra Patlachique. This zone is interrupted by a series of recent volcanoes, such as Cerro del Pino and Sierra de Santa Catarina; these volcanoes originate two sub-zones: the southern one that reaches Sierra de Santa Catarina and the range of mountains of the Ajusco, at the Xochimilco-Chalco sub-zone. The other sub-zone -Mexico-Texcoco- spreads from the Sierra de Santa Catarina to the south up to the northern boundary of the southern zone.

- Northern zone. This part of the basin is bonded to the southern zone through a bottleneck known as San Cristobal Strait, located between Cerro de Chiconautla and Sierra de Guadalupe. This partially represents the continuation of the Southern Level Ground and reaches the north towards the spurs of Sierra de Pachuca. Towards the east and west, several elevations such as Sierra de Monte Alto and Sierra de Tepotzotlan and other minor ridges form an irregular divide. Towards the east is the Tezontlalpan area, which is an old and faulted block settled to the south. It is also known as Zumpango-Xaltocan zone.

- Northeastern zone. Known also as Apan plain, it has a smaller surface than the other ones. It is a complex area with several minor volcanic elevations placed randomly in the landscape. It spreads as a thick strip towards the east, occupying a level and extensive space between Sierra de Pachuca and Sierra de Rio Frio.

During the Quaternary period a final volcanism cycle took place, and its outcome still exists, such as Cerro Gordo, Chimalhuacan and Chiconautla volcanoes, in which the Texcoco sub-basin is physically located.

From a geological point of view, the specific site under study is a structure formed by a powerful stratigraphy of lacustrian and alluvial materials, with remarkably soft, highly compressible clayey strata saturated with water, and with small layers of silt, sands and volcanic glass, which show hard consistency.

Within the study area, there are slopes that range from almost 0% at the ex-Lake Texcoco federal zone to more than 60% at Sierra Nevada. The slopes within the ex-Lake Texcoco federal zone are less than 2%. The level ground spreads to the south toward Cerro de Chimalhuacan, where the slope has values greater than 20%; to the north, it reaches Chiconautla, with slopes of 20%; finally, to the east, the plain areas slightly reach the eastern part of the former lake, where a zone with small hills begin, which represents the transition between the level ground and the sierra (Figure 2-6).

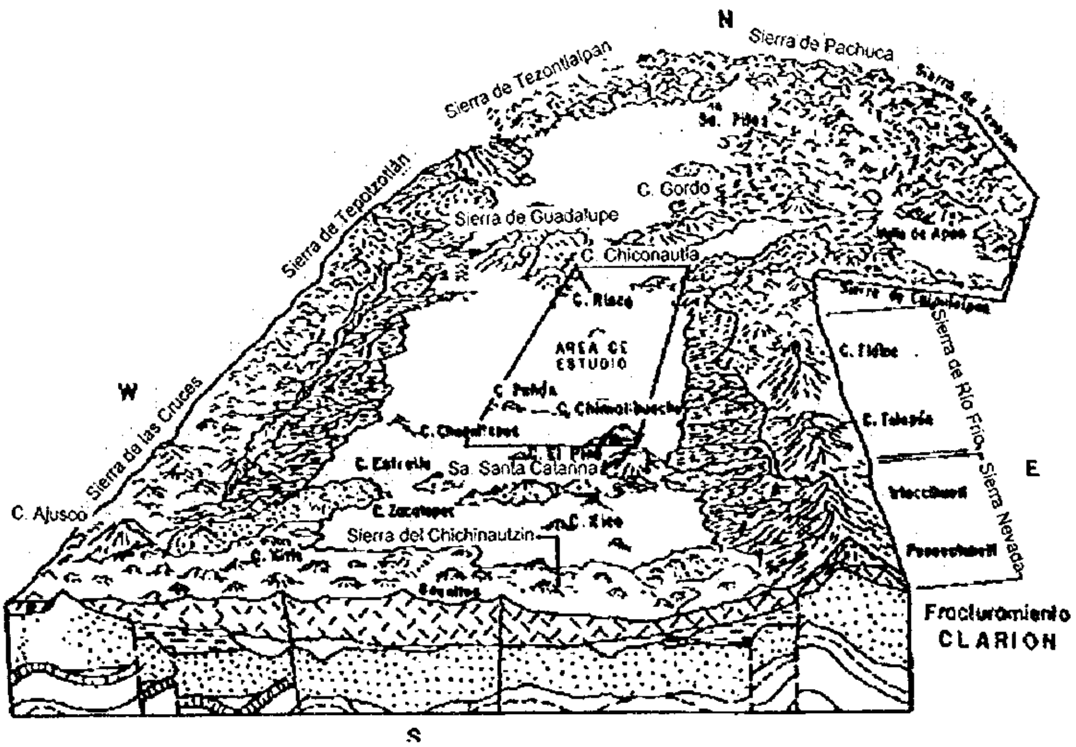

Figure 2-6: General View of Mexico Valley Basin

2.1.5.2 Evolution of Lakes in the Mexico Valley Basin

The Mexico Valley Basin is located in the central portion of the Trans-Mexican Volcanic Strip, whose origin is linked with the movement of the tectonic plates.

These processes led an intense igneous activity, as well as complex fault systems and associated fractures, some of which are still active; thus, the Mexico Valley Basin is a high-risk seismic zone.

Aguayo *et al.* (1989) carried out an structural stratigraphic study in the Mexico Valley to analyze the fracture and fault systems of the city, and the conclusion was that they are controlled by a regional S-NE and SE-NW fault. Besides, he also identified 16 main local distensible faults that have an effect on the inner part of Mexico Valley Basin.

Some of these faults gave origin to some of the depressions where the main lakes of the basin are located; an example of this is Lake Zumpango, which is found between two distensible faults: one is located close to the Presa de Guadalupe dam to the southeast, which goes on towards the northeast up to Tizayuca and Pachuquilla, Hidalgo; the other one goes from southwest to northeast, close to the following towns: Tepozotlan, San Andres Jaltengo, Zumpango, Zapotlan de Juarez and Mineral de Reforma, fault No. 13. Both faults form a tectonic pit that allows the formation of the lake.

The faults that form the Texcoco lake are the following: fault No. 8, that goes from the southwest in Contreras delegation and continues to the central zone of Mexico City (Napoles, Del Valle, Narvarte, Roma, Doctores, Juarez, Cuauhtemoc and other adjacent *colonias*), heading to the northeast where "El Caracol" in the ex-Lake Texcoc is located, and runs up to Otumba, Tlanalapan and Cuautepec de Hinojosa.

The other fault is No. 9: it begins at the southwest in the town known as El Zarco, heading towards the northeast, parallel to Constituyentes-Reforma avenue, crosses through the northern portion of El Caracol in the ex-Lake Texcoco and continues to San Martin de las Piramides, up to Singuilucan to the northeast. These geological structures cross a distensible zone with a NW-SE direction, forming the depression in which Lake Texcoco is found.

On the other hand, in 1978, Mooser utilized a division criterion for the lakes that takes into account the composition of salty water and fresh water lakes; the former ones were formed in the lower parts and constituted evaporation ponds, such as Xaltocan and Texcoco lakes; fresh water lakes were formed near Sierra Chichinautzin and were fed by springs, such as Xochimilco and Chalco lakes.

2.1.5.3 Local Geology

The area of study encompasses Sierra de Guadalupe, ex-Lake Texcoco and Cerro Chimalhuache. This zone is constituted mainly of volcanic and volcanoclastic units with acid and base composition, as well as alluvial and lacustrian materials.

A description of the features of the units located in the area is shown next, beginning with the oldest one.

Tm. (A) Tertiary Miocene, Andesites

This unit is constituted of Miocene-aged rocks, with a variable composition and within an intermediate range -from basic andesites to *dasitas*. Mooser (1962) considers these rocks to belong to the Xochitepec formation and to the Santa Isabel-Peñon series, which form the eastern base of Sierra de Guadalupe and Cerro del Peñon de los Baños; however, Schlaepfer (1968) rather calls them "volcanic rocks from the Middle Tertiary Period".

Andesites have a porphyritic texture, with plagioclase and ferro-magnesian crystals, as well as vesicles and fractures in flagstones. They are gray colored in recent samples and turn into ocher tonalities when exposed in the open air. They are covered with *clastic* and pyroclastic units. These rocks have a high degree of intemperance and their permeability is considered to be middle-ranged.

Type (T) Tertiary Pliocene, Tuffs

This unit crops out at Sierra de Guadalupe and at the skirts of Cerro Peñon de los Baños (the latter being encompassed in Tm. (A)). It constitutes a series of clastic and pyroclastic materials, such as sandy tuffs, ashes, pumice stones, old tuff and lacustrian soils, hybrid and flagstone tuffs, along with sandy conglomerating lenses and benthic layers.

This unit has been called a part of Tartago Formation (Secretaria de Programacion y Presupuesto; Hernandez H.M. 1983). Mooses (1973) calls them Nochistongo and Requena series. Due to the great variety of materials found, this unit is considered to have a permeability that ranges from middle to low.

Q (bbc) Quaternary, Basic Volcanic Breccia

This unit widely spreads to Cerro de Chimalihuache and its greatest concentration is at the southern part of it; it is pseudo-stratified with alternations of sandy material (*lapilli*), basalt and scoria (*tezontle*). As a whole, they have a dark gray color.

The breccia material is formed by basaltic rock fragments as well as scoria, with sizes ranging from 5 to 10 cm, with red-colored angular shapes and porous, with a sand matrix with the size of *lapilli*; besides, there are isolated tuffs (*tepetate*) with silt granulometry and yellow colored. Likewise, there are dark gray colored basalt filterings, with an aphanite texture and a vesicular structure, and middle to moderate fractures.

The unit of volcanic breccias is considered to have a great permeability due to the low compression and cohesion of the components, as well as the open fractures of basalts.

Q (tb) Quaternary, tuff

This unit is distributed at the northwestern portion of Cerro Chimalihuache; it is formed by a series of materials placed as semi-horizontal layers, which have a thickness of 20 m as a whole. They are constituted of pyroclastic volcanic materials with the size of clay and sand, with *lapilli* lentils not totally compacted in the base, as well as 5-10 cm basalt fragments.

Materials in general only change from package to package, due to the difference in granulometry and colors, and the thickest ones are at the base. The consistency of the unit varies from low to moderate, with easily disintegrating layers; no fractures or cracks are observed.

The unit formed by a series of volcanic and rhythmical emissions, and in each one of these, the materials are projected into the air.

Q (la) Quaternary, lacustrian

Mexico valley and the ex-Lake Texcoco are level grounds formed by a series of clayey stratums intercalated with sand, silt and volcanic glass layers. They are commonly referred to as a whole as lacustrian material, forming a package that sometimes may reach more than 180 m.

These deposits also mix with volcanic material and alluvial sediments. Since the materials are mostly clays, they are considered to have a low permeability. This is a dominant unit in and around the project site.

Q (al) Quaternary, alluvium

These are alluvial deposits without being compacted, which are derived from extrusive igneous rocks and composed by clastic materials of different sizes, ranging from sub-angular to rounded shapes. The grains are thick at the zones close to Chimalihuache volcano.

These materials are widely distributed at level grounds and as a filling of the valleys. The boundary of this unit with lacustrian deposits is transitional, since both sediments overlap each other.

Due to its granulometric features and to its reduced degree of compression, it is considered to have a high permeability.

2.1.5.4 Subsoil Geology

Due to the fact that the project will be located at the ex-Lake Texcoco lacustrian zone, a description of the sediments that form this area will be made next.

The ex-Lake Texcoco basin forms a plain of lacustrian deposits, which is the result of the erosion of rocks that form the mountain ranges surrounding the former lake, as well as pyroclastic products that volcanoes emitted during their creation.

Most of the deposits are clayey with silt-sandy layers. The depth and origin of the sediments are similar to those underneath Mexico City (Marsal and Mazari, 1959). This is the reason why the subsoil has been subject to several studies to analyze its mechanical properties, and the accurate determination of its stratigraphy becomes a secondary issue.

In view of the fact that the materials that filled the Mexico Valley Basin were carried and deposited in several ways, their distribution is therefore variable, as well as their texture; thus, the stratigraphic sequence is quite complicated.

The aforementioned is confirmed in the deposits that were studied, since the sedimentation process is controlled by different parameters. As a consequence, the deposit is not uniform in time or space; there are several fragments of other materials that developed -sometimes gradually, sometimes abruptly-, as well as sand and silt lenses, mainly. These features have been detected in most of the cross sections of wells; therefore, it is not easy to make a detailed lithology list.

In general terms, the clays of the ex-Lake Texcoco are complicated mixtures with clayey materials (*montmorillonite* and *illite* to a minor extent), with a great amount of glass, volcanic ashes, microorganisms, dissolved salts and animal fats (Morales, 1991). To explain this formation, it is necessary to take into account the drastic climatic changes undergone during the Quaternary period.

For instance, Sanchez Diaz (1989) provides an hypothesis to explain the origin of clayey materials within the ex-Lake Texcoco, stating that the winds carried aeolian soil to the lake, whose origin was volcanic dust (loess) and when deposited in the lake, they became hydrated; thus, this fact originated the clays of Mexico City.

On the other hand, Nieto (1973) explains the accumulation of clayey material as follows: during heavy rainfall seasons, the lake level increased, and clays were deposited in tranquil waters and far away from stream mouths. Since these materials were very fine, they were also carried by the wind at long distances.

During the drought seasons, evaporation decreased the lake level, and marshy vegetation outcropped (root spaces can be found at different depths in the wells bored by Compañia Sosa Texcoco, S.A.).

Volcanic water was deposited in this shallow water, which was the result of the great volcanic activity during the Quaternary period, and during the drought season it was hardened and dried, forming what is known as "hard layers", which will be described later.

Regardless of the lithological complexity of the subsoil in the ex-Lake Texcoco, the sequence of lacustrian sediments and the underlying rocks is being established; to achieve this, the drilling of deep well (numbered as PP1) was carried out, which was programmed down to 2065 m. This is the only one of its kind in the area and has been used to establish the stratigraphy in general of the Mexico Valley Basin.

However, no samples were collected in the first 180 m, therefore the drilling of deep level strata (BNP-1, BNP-2 and BNP-3) was carried out. These drillings had geotechnical purposes, but they were useful as well to set the stratigraphy of the first 180 m, since they were bored down to 200 m.

Marsal and Mazari (1959) established an informal terminology for Mexico City's subsoil from a viewpoint of soil, which is still being used nowadays. This terminology was also applied to Lake Texcoco, since similar features were found in it.

The units defined by such authors have been modified as time has passed by; nonetheless, most of these concepts match the definitions, which are described next.

Top layer or Superficial Stratum (CS[1])

It is formed by dried clays, clayey silts and silty sands. Its approximate thickness is 1.5 m, which increases towards Sierra de Guadalupe; these materials are furrowed with cracks filled with air-born components, specially at the zones close to Bordo de

[1] CS: Capa Superior

Socias, at the intersection of Bordo Poniente and Peñon-Texcoco road and at the airport zone. This stratum lies on the top clayey formation.

Top Clayey Formation (FAS[2])

It is formed by highly plastic soft clays with diverse thickness levels according to the place: 18 m at El Caracol zone, 40 m at Bordo de Socias, 6 m at the surroundings of Sierra de Guadalupe, 25 m at the center zone of Mexico City, from 39 to 17 m in a section at a distance of 3 to 13km from the Peñon-Texcoco road.

The clays that form this unit have a volcanic lacustrian origin, with sand, silt and volcanic glass intercalations and layers. It is above the hard layer.

Hard Layer (CD[3])

It is composed by sandy-silty materials, cemented by calcium carbonate and with desiccation traces; it has a variable thickness from 2.0 to 3.5 m; at the eastern zone, next to the surroundings of the Nezahualcoyotl municipality, it fades away.

This layer was formed during the Sangamon interglacial stage (Mooser, 1992), which is characterized for being a very dry period, and the soil became hardened and dried. This layer has clay intercalations that correspond to the wet cycles of this period.

Lower Clayey Formation (FAI[4])

Also known as sandy-clayey layer. It is a series of clay stratums with a high plasticity degree, sandy-silt and volcanic glass lenses and strata; it differs from the top clayey formation because it has less water. Its middle thickness at the center of the lake is 20 m, and gradually reducing towards the east and north. This formation fades away towards Sierra de Guadalupe.

Deep Deposits (DP[5])

They are constituted of compacted silts, gravel and clays with less plasticity than that of the top clayey formation. These materials are interstratified between fine sand layers and volcanic and alluvial material lenses. Thickness cannot be defined, since this formation goes deep into subsoil.

Some authors like Murillo (1978) and Torres G. (1992) use this terminology and simultaneously call these deep deposits "the second hard later". The former authors and Morales (1991) define a third clayey formation within deep deposits, with a thickness of more than 6 m and at a depth of 52 m in the center of the former lake and 64 m in Bordo Poniente.

Likewise, they call them the internal deep deposits or fourth clayey formation to the group of sandy, silty and sandy-silty strata found at a depth between 145-160 m; sometimes these layers have clay and gravel.

Soil mechanics studies, probing and lab tests were carried out within the Bordo Poniente zone (Murillo y Laboratorios Tlalli, 1993) to know about the stratigraphy of

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[2] FAS: Formación Arcillosa Superior
[3] DF: Capa Dura
[4] FAI: Formación Arcillosa Inferior
[5] DP: Depósitos Profundos

the site's subsoil. Such studies showed the existence of a massive package of clays (FAS) with sand and volcanic ash intercalations, that were found at a depth of 9, 14, 20, 34 and 36 m.

A highly compacted sandy-silt material package was found at a depth of 38-42 m with greater compression, with an approximate thickness of 1.50 m and considered as the first hard layer.

After studies conducted by TGC in 1992, the depths to which the former sediments are located were determined: FAS between 1-36 m deep; CD between 36-38 m; FAI between 38-53 m and DP beyond 53 m.

On the other hand, from lithological cross sections of wells No. 536-19 and 35, a clayey package with a thickness between 80-90 m was observed. Within this package there are 1m-thick fine sand layers from a depth of 9 m.

2.1.5.5 Stratigraphy

The stratigraphy of deep materials in the Mexico Valley Basin is based on the drilling of deep well No. 1 (PP-1). Alvarez Jr. proposed a stratigraphic table without taking into consideration the first 180 m, from which no sample was obtained.

Nonetheless, he later considered Bryan's (1948) and Arellano's (1953) works, who recognized three lithological units from the Quaternary period in Mexico's basin; said units have not been displayed in cartographic drawings and they are known as Tacubaya, Caliche Morales and Becerra formations.

Other authors such as Mooser (1962) call these formations "Pluvial and Alluvial Clastic Series from the Quaternary period", whereas Schlaepfer (1968) names them "Alluviums, soils and lacustrian layers from the Quaternary period". On the other hand, Oviedo de Leon (1986) classifies the conglomerate known as Balsas formation by Alvarez Jr. as Texcoco conglomerate, and he calls the clayey limestone layers on top of it as Texcoco Anhydrite (Calcium sulfate), aged from the Oligocene period.

A modified stratigraphic column was defined while considering the aforementioned.

The units drilled by PP-1 are briefly described.

Balsas Formation

It is a calcareous conglomerate found at a depth of 2065 m with fauna from Cretaceous Superior period; its age is calculated to be from the Eocene Superior-Middle Oligocene period, according to Schlaepfer (1968) and Alvarez Jr. (1968). Oviedo de Leon (1967) classifies it as Texcoco conglomerate, with different phases to those of Balsas and the Morro conglomerates.

Texcoco Conglomerate

The matrix is formed by spathic calcite and lithic quartz fragments, whereas Balsas conglomerate only has spathic calcite matrix, and its lower limit is unknown. It is underneath a thick anhydrite layer.

Texcoco Anhydrite

It is found above the Texcoco conglomerate. It is found as intercalated stratum with thin limestone layers. It is calculated to be from Oligocene period.

Xochitepec Formation

It is a sequence of tuffs, breccias and trachyte-andesite lava (Schlaepfer, 1968). It is calculated to be from the Late Oligocene-Middle Miocene period and at a depth of 1125-1437 m from PP-1.

Tepoztlan Formation

It is found within a range of 1030-1125 m, corresponding to andesite, epiclastic volcanic rocks deposited by water and mud streams that formed layers with a depth of less than 10 m. It is calculated to be from the Late Oligocene-Early Miocene period.

Huatepec Trachy-Andesites

It is found within a range of 814-1030 m. It is a sequence constituted by andesite lava, clayey tuffs, agglomerates and sands. Alvarez Jr. calls them Huatepec rocks, and based on radiometric analysis, they were calculated to be from Miocene period.

Tlalyecac Formation

It is found within a range of 505-814 m. It is material carried by mud streams, not classified and inter-stratified with volcanic rocks. They have been defined as hybrid tuffs, and they also have rhyodacthic, lathitic and andesite lava spills. It is believed to be from the Pliocene-Pleistocene period (Alvarez Jr., 1968).

Tarango Formation

Found between 189 and 505 m deep. It is formed by marls, lacustrian limestones, tuffs, ashes, pumice stone, gravel, sand and clays, fluvial volcanic gravel, thin layers of pumice stones and alluvial deposits formed at the skirts of Sierra Nevada, due to the erosion undergone by volcanoes.

Most of the authors set this Tarango formation at a depth of 33 m, which would include the hard layer, the lower clayey formation and deep deposits, according to Marsal and Mazari.

Other units that are not described in PP-1 but reported by different researchers in other studies are described next.

Tacubaya Formation

It is constituted by alluviums, tuffs, breccias, pumice stones and volcanic ashes in its marginal surface (Cecear, 1952). The lacustrian surface is formed by montmorillontic clay with ash and pumice stone intercalations, diatoms and *ostracodos*; Schlaepfer (1968) defines it as semi-consolidated silty tuffs from a volcanic origin, deposited in a lacustrian means. Sediments that extend at a depth of 3-30 m in PP-1 correspond to this type and to the top clayey formation.

Caliche Morales Formation

Benthic clay, cracked and with an abundance of calcium carbonate in its lacustrian surface. Its fluvial surface has sediments known as *caliche* (lime crusts or flakes). It crops out at Lomas de Chapultepec zone.

Becerra Formation

Its marginal faces have alluviums, aeolic deposits, pyroclastic material and an abundant fauna of vertebrates. Bryan establishes three other units based on a edaphologic criterion and in accordance with Arellano and De Terra works; he calls them Noche Buena formation, which is constituted of sand, alluvium, aeolic materials, humus and soils, with several traces of roots left by aquatic plants.

Totoltzingo Formation

It is constituted of clay with a great amount of humus. It defines a post-glacial cold weather. Schlaepfer includes in this unit the Noche Buena deposits (alluvium soils) and *Caliche* Barrilaco, which represents a period with warm weather and constituted by plastic clays and *caliche*.

2.1.5.6 Geophysics

In order to complement the knowledge available on the subsoil stratigraphy, the geophysics works carried out in the ex-Lake Texcoco have been analyzed.

These geophysical studies date from 1952-1953, when gravimetry, refraction seismography and geoelectrical research were conducted.

The regional gravimetry survey was carried out at the flat section of the valley and it was only a qualitative interpretation of the subsoil, since the underground stratigraphy and the density of the rocks were unknown. Four underground sub-basins were determined from this survey: Texcoco, Teotihuacan, Mexico City and Chalco.

A gravimetric shoal was detected at the first sub-basin, close to Cerro Chimalhuacan; this zone was later used as a reference for additional seismic studies.

In 1966, a seismic survey was programmed (Proyecto Texcoco, SHCP), consisting of a series of lines. The first one is the base line and runs from Chimalhuacan to Cerro Gordo; this line matches the gravimetric shoal previously mentioned. The second line (line 2) goes from Cerro Peñon de los Baños to Chapingo, at the intersection of the base lines and where the drilling of deep well 1 (PP 1) was programmed (Figure 2-7).

The results of the seismic studies (profiles) detected two refractory contacts denominated "A" and "B". These have a semi-horizontal behavior at the base line, and before reaching PP-1 they start going down and heading southeast; i.e. towards Cerro Chimalhuacan, and when they are 3 km away northwest of PP-1, "A" is found at a depth of 770 m, whereas "B" is found 1850 m down. The spills from Chimalhuacan volcano apparently were deposited on refractor "A" (Figure 2-8).

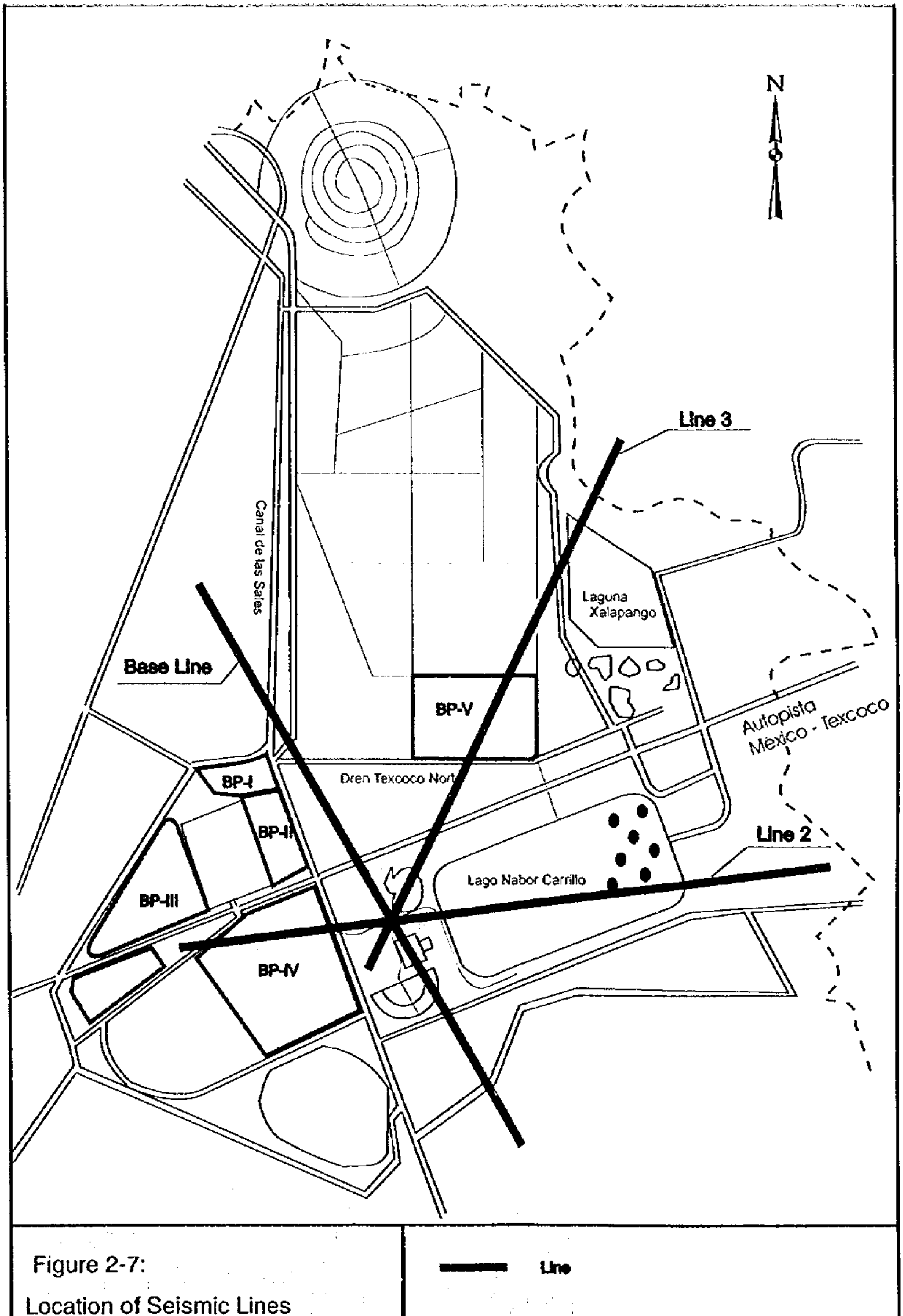

Figure 2-7:
Location of Seismic Lines

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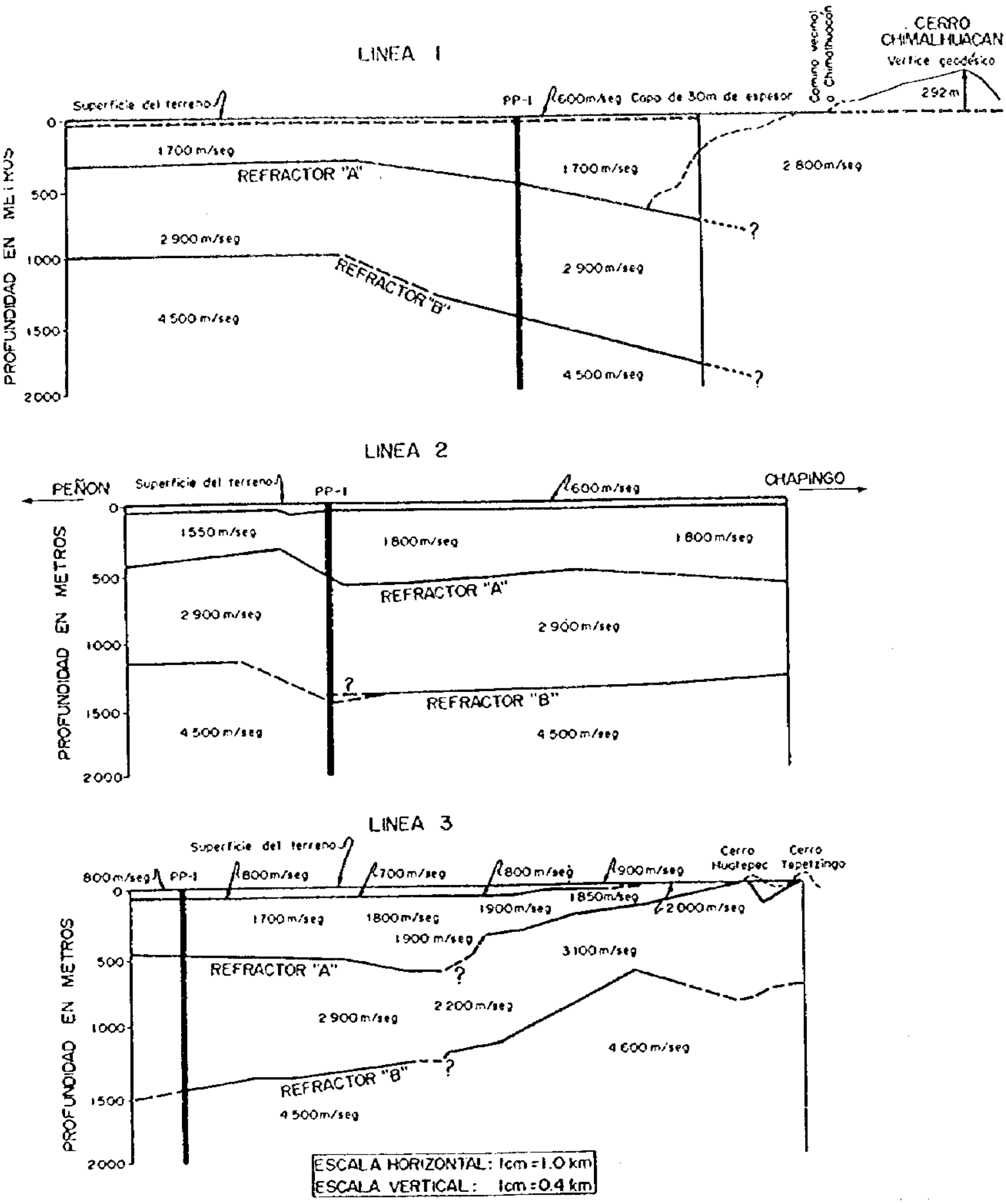

Figure 2-8: Profiles of the Seismic Exploration Lines of Refraction

With the previous note and with the gravimetric anomaly, it is concluded that close to Cerro Chimalhuacan there is a buried valley in a northeast-southwest direction, which probably represents a trace of the thickness of the sediments in the area.

The results of the refraction seismology determined four mantles, which are characterized by the different velocity of propagation of seismic waves and whose features are shown in the following table.

Table 2-12: Mantles and Refractors Determined at the Base Line

Mantle	Average velocity (m/sec)	Estimated depth (m)	Formation features
Top	600	0 to 30	Highly compressible clayey formation and saturated with water
First	1,700	30 to 520	Sandy-clayey formation, poorly compacted and saturated with water
Refractor "A"	--	520	--
Second	2,900	520 to 1,445	Compact tuffs with sandy horizon intercalations
Refractor "B"	--	1,445	--
Third	4,500	1,445 and beyond	Highly compacted rocks, probably igneous

The results obtained from the seismic refraction lines led to the conclusion that igneous rock spills and pyroclastic material at the ex-Lake Texcoco subsoil came from three volcanic systems:

- The first one from Huatepec volcano, whose deeper emissions reached to Cerro Chimalhuacan.

- The second one is formed by Cerro Gordo and Cerro Peñon de los Baños.

- The third one corresponds to Chimalhuacan volcano, whose emissions lay over the deep rocks of Huatepec volcano.

As a consequence of the 1985 earthquake, in 1987 the Geophysics Department of the Federal Electricity Commission (CFE) conducted subsoil studies in Mexico City to investigate on shallow deposits. Part of these studies encompassed the ex-Lake Texcoco area, which were taken into account for the geophysical survey.

Studies carried out included seismic refraction and vertical electric soundings (VES), with an approximate depth for the research of 500 m.

The seismic refraction studies conducted by the CFE also showed four mantles with the following features.

Table 2-13: Seismic Refraction Conducted by CFE in 1987

Mantle	Average velocity m/sec	Estimated depth m	Formation features
1	250 to 1,100	25	Superficial layer constituted by lacustrian clayey deposits (T3 laying)
2	850 to 1,500	70	Slightly compacted clayey deposits
3	1,700 – 2,000	300	Allumium deposits (T2- T1 laying)
4	2,000 – 3,000		Located only in laying T1 and T2

As it can be observed, the seismic studies carried out in 1966 and 1987 provided the features of four mantles:

The top stratum is the same in the two studies; its depth reaches 25-30 m and the velocity of seismic waves goes from 250 to 1,100 m/sec (and the velocity of 600 m/sec from the previous study included here).

In 1960 a velocity of around 1,700 m/sec and a thickness of 30-520 m was detected in the first mantle, up to the first refractor "A". In 1987, the CFE reports a speed of 850-1500 m/sec, yet at a depth of 70 m. In both cases this is related to sandy-clayey materials, but they are interpreted with a different granulometry.

The CFE detected another horizon at a depth from 70 to 300 m, which are regarded as regular-compaction alluvium deposits associated with lava spills; this layer is inside the first mantle of 1966 geophysics (Carrillo). Both stratums are made of the same material, but they were studied based on different granulometry techniques.

The last horizon detected by the CFE is found at a depth greater than 300 m, with velocities from 2,000 to 3,000 and even 4,000 m/sec, it is related to tuffs and lava spills and corresponds to the second mantle of the base line, with a different depth since the second layer is found beyond 520 m.

From the aforementioned, it can be concluded that the first layer is a slightly compacted clay with a thickness of 25 to 30 m. There is a second clayey sand stratum saturated with water at a depth of 70 m, which is lacustrian.

Below a depth of 70 m, the prevailing materials are sandy with a slight compression, which are probably associated with some lava spills and with water, with a depth of up to 300 m and 520 m in some sites (Chimalhuacan zone and up to Cerro Gordo area).

Compacted igneous rocks were found from these depths (300-500 m), which might be the foundation of granular alluvium-lacustrian materials that filled the ex-Lake Texcoco.

2.1.5.7 Electric Geophysics

Regarding the electric geophysics studies carried out by the CFE in 1987, only two geoelectrical lines penetrated in the ex-Lake Texcoco. Two big material packages were determined: one regarded as old (A), associated with volcanic rocks, and a recent one (R), related to filling materials of the lake.

In the section parallel to the Peñon Texcoco road four units were detected. Unit 1R is located between VES[6] 2581 to 1210; it has a depth of 225 m in its center (VES 1205) and merges towards its ends until it disappears. It is characterized for having a resistivity of 0.2 to 0.25 ohm-m in the first 20 m, and increasing to 1.2 in the rest of the unit. It has been related to lacustrian deposits with a predominance of fine elements (Figure 2-9). Locations of VES are shown in Figure 2-10.

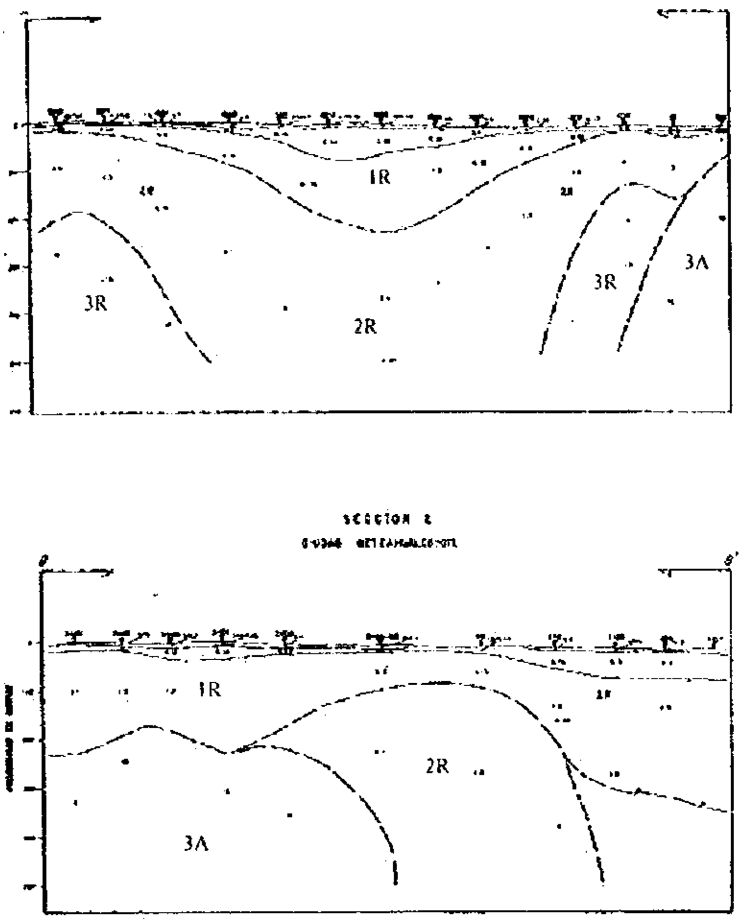

Figure 2-9: Electric Geophisics

[6] VES: Vertical Electrical Sounding

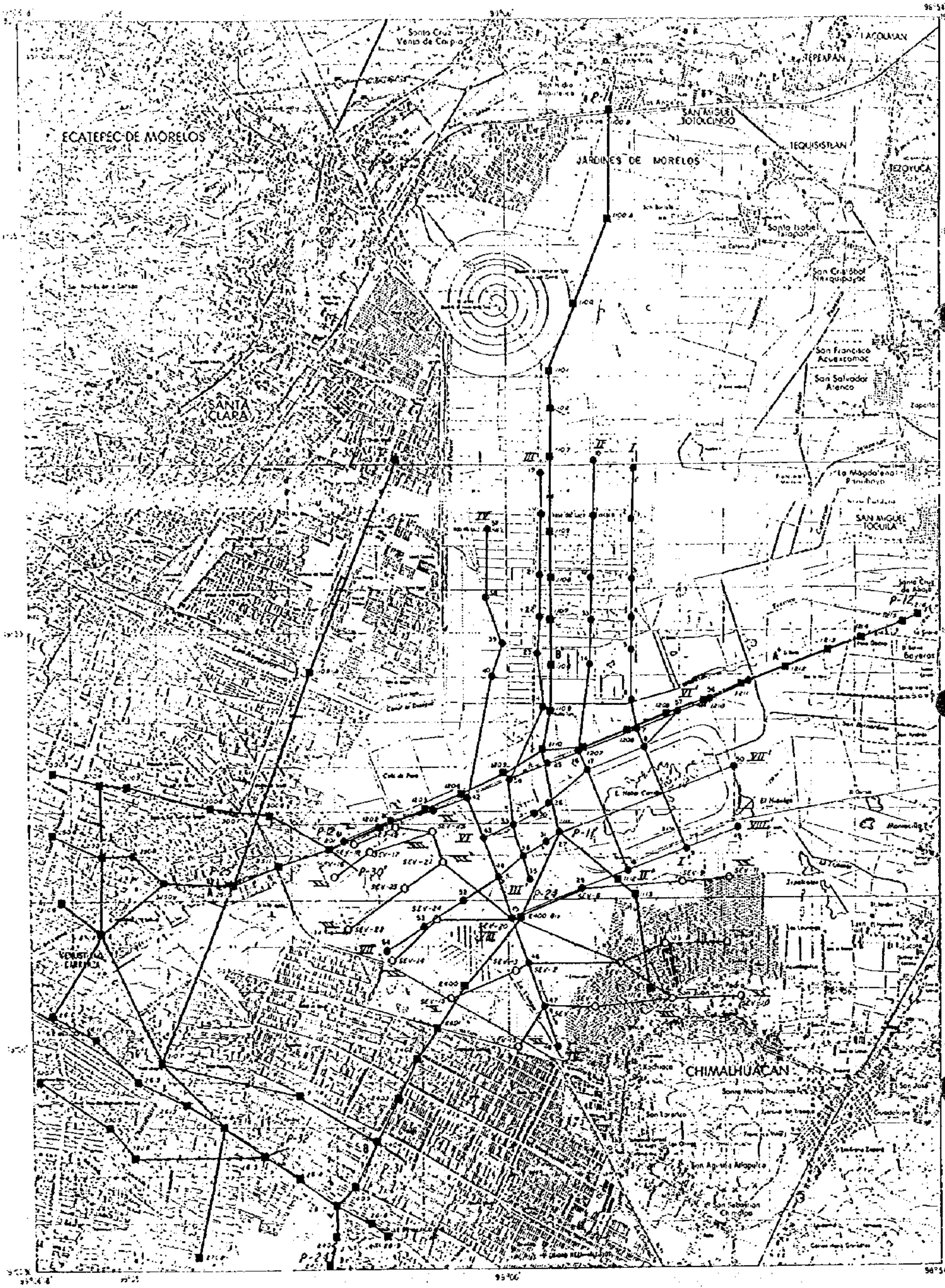

Figure 2-10: Location of Vertical Electric Soundings

ESCALA GRAFICA

Unit 2R underlies the 1R and deepens indefinitely into the center of the area (VES 1203-1205); thickness decreases towards the ends of the section until it reaches an average of 100 m. The resistivity recorded is 6.2 to 6.8 ohm-m, which was related to old lacustrian and alluvium deposits with a clayey sand consistency.

Geoelectrical unit 3R is located at both sides of the section. It begins at 200 m and deepens indefinitely towards the southwest, and it is only 200 m thick towards the northeast. The resistivity recorded is from 12-15 ohm-m and is related to a alluvium-type material.

Geoelectrical unit 3A is located at the northeastern end (VES 1201-1212). The resistivity of this unit is 6-15 ohm-m and is related to volcanic material, such as breccias and compacted tuffs, which are generally altered.

The section heading north-south only appears in units 1R, 2R and 3A; the first one has an oscillating contact, with a thickness of 300 m at its ends (VES 1110 and 2404 to 2400) and decreases to the center to 80 m (VES 1111).

Unit 2R was recorded only at the northern end (VES 2400-1110); it is found at a depth of 80 m and deepens indefinitely.

Unit 3A is found in a lateral contact with 2R and below 1R; it is located south of the section (VES 2404-2400). It is 300 m away from the surface and deepens indefinitely.

The following table shows the summarized features, including the longitudinal seismic velocity values.

Table 2-14: Integration of Geophysical Study Conducted by CFE (1987) and LESSER y Asociados, S.A. (1988)

Geo-electrical unit	Thickness (meters)	Resistivity Ohm-m	Longitudinal seismic velocity m/sec	Characteristics
1 R	20 - 335	0.2 and 1.5	Vp= 300 and 550	Lacustrian horizons predominance of fine elements
2 R	100 m in sec 1, undefined in sec 2	1.5 and 4	Vp= 450 and 900	Lacustrian horizons with alluvium deposits
3 R	200 m undefined	5 and 14	Vp=800 and 1300	Alluvium materials
3A	Undefined	6 – 15	Vp=1500-1800	Volcanic material

On the other hand, in 1988 Lesser y Asociados, S.A. carried out vertical electric soundings in the central and eastern part of the ex-Lake Texcoco, obtaining the following results.

Geoelectrical unit 1 was found all around the zone with a thickness of 1-10 m, a low resistivity of 0.044 to 25 ohm-m that corresponds to lacustrian clayey materials, which have water with a salinity greater than 10,000 ppm.

Geoelectrical unit 2 was also found all around the area with an average thickness of 60 m, which becomes thinner and even disappears towards the east (VES 57 and 58) in the surroundings of Lago Nabor Carrillo and Cerro Chimalhuacan. At the zone close to the airport, thickness increases. The resistivity recorded was 0.017 to 9.7

ohm-m that was related to clayey material, saturated with salty water -5,000 to 10,000 ppm- and regarded as an *aquitard.*

Geoelectrical unit 3 was also found all around the ex-Lake Texcoco with a variable thickness at the center of the ex-Lake Texcoco federal zone (VES 29-18,16) and close to the wastewater treatment facility. The reduction in thickness is towards the north (VES 37,201) and southeast, where it may be possible that it merges at Cerro Chimalhuacan. The resistivity recorded is 1.4 to 71 ohm-m, which is related to sandy-clayey deposits and saturated with water of 2,000 ppm salinity, and it is regarded as the main aquifer unit in the zone.

Geoelectrical unit 4 is underneath all the previous units; its thickness varies -beyond 500 m-, and no other lower unit is defined. Its resistivity is 12.8-255 ohm-m and is related to tuff and clayey material, and it is unknown if it contains water.

Table 2-15 summarizes the above features.

Table 2-15: Features of Geoelectrial Units

Geo-electrical unit	Thickness (m)	Resistivity Ohm-m	Salinity ppm	Characteristics
1	1 -10	0.044 – 25	10,000 (up to 54,000 in Sosa Texcoco)	Altered top layer, essentially clay
2	60	0.17 – 9.7	5,000 – 10,000	Saturated clayey material, which behaves as an *aquitard*
3	300 - 500	1.4 – 71	2,000	Sandy-clayey deposits, constituting the main aquifer of the zone
4	+ 500			

The following notes can be obtained from both geophysical studies:

From the vertical electrical soundings (VES) conducted over Peñon-Texcoco road, it was found that the CFE discovered a superficial layer (1R) that matches the geoelectrical units 1 and 2 of the second author. In both studies, the resistivity is similar -in the range of 0.2 to 1.6 ohm-m. Lesser y Asociados consider that layer 1 has a constant thickness of 15 m; unit 2 is semi-horizontal, with its lower limit being found at 80 or 100 m. The CFE regards the depth of unit 1R at the center of the section (VES 1205) down to 225 m. In both cases, it merges until it disappears towards the northeast, and it can also be considered that the materials are lacustrian clays for both instances.

CFE's geoelectrical unit 2R deepens into the subsoil, without reaching the foundation, in all the central zone (VES 1202-1110). This unit partially corresponds to Lesser's unit 3, since there is a boundary towards the southwestern part of the section 240 m deep, which increases up to 435 m to the northeast (VES 25).

According to the CFE, these are alluvium and lacustrian materials that also correspond to Lesser's alluvium materials, who regards them as the main aquifer; in both cases, the resistivity for the units is 1.5 to 5.8 ohm-m, and they are similar in this sense.

However, according to Lesser, there exists a semi-compact foundation located 240 m deep southwest and 435 m northeast, which is formed by tuffs and marl; in this case,