DIVISION DE EDUCACION CONTINUA
CURSOS ABIERTOS
CURSO INTERNACIONAL DE DISEÑO DE DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

Del 14 al 18 de Marzo de 1994.

FECHA	HORARIO	TEMA	PROFESORES
Lunes 14	9;00 a 10;00 h.	Bienvenida	Organismos Coordinadores
	10;00 a 11;00	Situación Mundial	Dr. Luis F. Díaz
		Latinoámerica	Ing. Francisco Zepeda Porras
	11;00 a 12;00	Fundamentos del Relleno Sanitario	Mr. N.C. Vasuki
	12;30 a 14;00	Legislación	Dr. W. Forester Ing. Francisco Zepeda Porras Ing. Gustavo Solórzano Ochoa
	14;00 a 14;30	Mesa Redonda	
	17;00 a 19;00	Cáracterísticas de los Residuos Sólidos y procedimientos para su aceptación	Dr. León Van Arendonk
	19;00 a 20;00	Selección de Sitios, Aspectos Geologícos y no Geologícos	Dr. Isabelle A. Paris
	20;00 a 20;30	Mesa Redonda	
Martes 15	9;00 a 10;00 h.	Metodología para el emplazamiento de rellnos sanitarios	Ing. Jorge Sánchez Gómez
	10;00 a 11;00	Factores sociales y ecologícos	Lic. Rpsalba Cruz Jiménez
	11;00 a 12;00	Estudios previos	Ing. Ricardo Estrada Núñez
	12;30 a 14;00	Interpretación de las características del sitio en el diseño de un relleno sanitario	Dr. Robert K. Ham
	14;00 a 14;30	Mesa Redonda	
	17;00 a 19;00	Procesos de degradación y emisiones de un relleno sanitario	Dr. Rafaello Cossu Dr. Rainer Stegmann
	19;00 a 20;00	Implementación del diseño y construcción.	Mr. N.C. Vasuki
	20;00 a 20;30	Mesa Redonda	
Miércoles 16	9;00 a 10;00 h.	Water balance and leachate quiantity	Dr. Peter Lechner
	10;00 a 11;00	Control de biogas	Dr. Rainer Stegmann
	11;00 a 12;00	Manéjo y control de lixiviados	Dr. Rafaello Cossu
	12;30 a 14;00	Protección del agua subtérranea	Dr. Dik Beker
	14;00 a 14;30	Mesa Redonda	
	17;00 a 18;00	Operación del relleno sanitario, equipo y personal	Mr. Henrik Ornebjerg

	18;00 a 19;00	Sistemas de control en la operación del Relleno Sanitario	Ing. Arturo Dávila Villarreal
	19;00 a 20;00	Clausura del rellano sanitario y su cuidado a largo plazo	Dr. Luis F. Díaz
	20;00 a 20;30	Mesa Redonda	
Jueves 17	9;00 a 11;00 h.	Determinación de parámetros de diseño para latinoámerica	Ing. Jorge Sánchez Gómez
	11;00 a 12;00	Diseño del relleno sanitario y obras complementarias para latinoámerica Parte I	Ing. Felipe López Sánchez
	12;30 a 14;00	Diseño del telleno sanitario y obras complementarias para latinoámerica Parte II	
	14;00 a 14;30	Mesa Redonda	
	17;00 a 18;00	Modelos de predicción de movimiento de contaminantes	Dr. Adrián Ortega
	18;00 a 19;00	Análisis de costos	Ing. Fco. Zepeda Porras
	19;00 a 20;00	Implicaciones sobre la salud pública	
	20;00 a 20;30	Mesa Redonda	
Viernes 18	9;00 a 10;00 h.	Desarrollo Institucional	Lic. Jesús Barrera Lozano
	10;00 a 11;00	Mitos y realiudades sobre los residuos sólidos.	Ing. Arturo Dávila V.
	11;00 a 12;00	Muestreo, análisis e interpretación de los resultados de pruebas de laboratorio	Ing. Domingo Cobo Pérez
	12;30 a 14;00	Impacto y monitoreo ambiental	
	14;00 a 14;30	Mesa Redonda	
	17;00 20;30	Mesa Redonda, La participación de la iniciativa privado en los sistemas de aseo urbano.	

EVALUACION DEL PERSONAL DOCENTE

CURSO: Internacional de Diseño de Disposición Final de Residuos Sólidos (Rellenos Sanitarios)

FECHA: Del 14 al 18 de Marzo de 1994.

	CONFERENCISTA	DOMINIO DEL TEMA	EFICIENCIA EN EL USO DE AYUDAS AUDIOVISUALES	MANTENIMIENTO DEL INTERES (COMUNICACION CON LOS ASISTENTES, AMENIDAD, FACILIDAD DE EXPRESION).	PUNTUALIDAD	
1	Dr. Luis F. Díaz					
2	Dr. Robert K, Ham					
3	Dr. Peter Lechner					
4	Dr. Dik Beker					
5	Dr. Raffaello Cossu					
6	Mr. Henrik Ornebjerg					
7	Dr. Isabelle A. Paris					
8	Dr. William S. Forester					
9	Dr. Rainer Stegmann					
	ESCALA DE EVALUACION : 1 a 10					

EVALUACION DEL PERSONAL DOCENTE

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10	Dr. León Van Arendonk					
11	Mr. N.C. Vasuki					
12	Ing. Jorge Sánchez Gómez					
13	Ing. Arturo Dávila Villarreal					
14	Ing. Felipe de Jesús Barrera Lozano					
15	Ing. Eugenio Domingo Cobo Pérez					
16	Ing. Ricardo Estrada Núñez					
17	Lic. Rosalba Cruz Jiménez					
18	Ing. Felipe López Sánchez					
	ESCALA DE EVALUACION: 1 a 10					

EVALUACION DEL PERSONAL DOCENTE

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19	Ing. Gustavo Solorzano Ochoa					
20	Dr. Adrián Ortega					
21	Ing. Francisco Zepeda Porras					
	ESCALA DE EVALUACION: 1 a 10					

EVALUACION DEL CURSO

	C O N C E P T O	
1.	APLICACION INMEDIATA DE LOS CONCEPTOS EXPUESTOS	
2.	CLARIDAD CON QUE SE EXPUSIERON LOS TEMAS	
3.	GRADO DE ACTUALIZACION LOGRADO EN EL CURSO	
4.	CUMPLIMIENTO DE LOS OBJETIVOS DEL CURSO	
5.	CONTINUIDAD EN LOS TEMAS DEL CURSO	
6.	CALIDAD DE LAS NOTAS DEL CUSO	
7.	GRADO DE MOTIVACION LOGRADO EN EL CURSO	
	EVALUACION TOTAL	

ESCALA DE EVALUACION: 1 a 10

1.- ¿Qué le pareció el ambiente en la División de Eduación Continua?

MUY AGRADABLE ☐ AGRADABLE ☐ DESAGRADABLE ☐

2.- Medio de comunicación por el que se enteró del curso:

PERIODICO EXCELSIOR ANUNCIO TITULADO DIVISION DE EDUCACION CONTINUA ☐

PERIODICO NOVEDADES ANUNCIO TITULADO DIVISION DE EDUCACION CONTINUA ☐

FOLLETO DEL CURSO ☐

CARTEL MENSUAL ☐

RADIO UNIVERSIDAD ☐

COMUNICACION CARTA, TELEFONO, VERBAL, ETC. ☐

REVISTAS TECNICAS ☐

FOLLETO ANUAL ☐

CARTELERA UNAM "LOS UNIVERSITARIOS HOY" ☐

GACETA UNAM ☐

3.- Medio de transporte utilizado para venir al Palacio de Minería

AUTOMOVIL PARTICULAR ☐ ☐ OTRO MEDIO ☐

4.- ¿Qué cambios haría en el programa para tratar de perfeccionar el curso?

____

____

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5.- ¿Recomendaría el curso a otras personas? ☐ SI ☐ NO

6.- ¿Qué periódico lee con mayor frecuencia?

____

____

7.- ¿Qué cursos le gustaría que ofreciera la División de Educación Continua?

____

____

____

8.- La coordinación académica fué:

EXCELENTE [ ] BUENA [ ] REGULAR [ ] MALA [ ]

9.- Si está interesado en tomar algún curso INTENSIVO ¿Cuál es el horario más conveniente para usted?

LUNES A VIERNES DE 9 a 13 H. Y DE 14 a 18 H. (CON COMIDA)	LUNES A VIERNES DE 17 a 21 H.	LUNES A MIERCOLES Y VIERNES DE 18 a 21 H.	MARTES Y JUEVES DE 18 A 21 H.
[ ]	[ ]	[ ]	[ ]

VIERNES DE 17 a 21 H. SABADOS DE 9 a 14 H.	VIERNES DE 17 A 21 H. SABADOS DE 9 a 13 H. DE 14 a 18 H.	OTRO
[ ]	[ ]	[ ]

10.- ¿Qué servicios adicionales desearía que tuviere la División de Educación Continua, para los asistentes?

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11.- Otras sugerencias:

____

____

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* C O M E N T A R I O S *

DIVISION DE EDUCACION CONTINUA

CURSOS ABIERTOS

CURSO INTERNACIONAL DE DISEÑO DE DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

Del 14 al 18 de Marzo de 1994.

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G.I.E. Orion/Creed
Paris, France

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- Mr. N.C. Vasuki
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MANUAL FOR THE DESIGN OF SANITARY LANDFILLS

IN DEVELOPING COUNTRIES

DRAFT

This manual is selected as the overall text
for the Training Seminar conducted
by the ISWA Working Group on Sanitary Landfills,
Mexico City, Mexico, March 14-16, 1994. It was prepared
by CalRecovery, Incorporated, 725C Hercules, CA 94547
for The World Bank, Washington, DC 204433, and currently
is under review for later publication
by the UNDP-World Bank Program.

ISWA Working Group on Sanitary Landfills
1100 Wayne Avenue, Suite 700
P. O. Box 7010
Silver Spring, MD 20907-7010

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The cells are designed based on the quantity of wastes requiring disposal. The basic elements of a cell are:

- height
- length
- width of working face
- slope of side walls
- width of daily cover
- height of finished fill

The height of a cell is a function of the quantity of waste, thickness of daily cover, stability of slopes, and degree of compaction. As the height decreases, the need for cover material for the entire fill increases. Typical heights vary between 2 and 4 m.

The minimum width of the cell or minimum working face depends upon the type of vehicle used. It is generally recommended that the minimum width be about 2 to 2.5 times the width of the blade used for building the cell. Recommended cell widths as a function of quantity of waste are given in Table 5-1.

The width of the cell or working face also is impacted by the maximum number of vehicles arriving at the peak hour. The width of the working face (in meters) can be calculated by multiplying the maximum number of vehicles arriving at the peak hour by 4.

The slope of the cell is the inclined plane upon which the wastes are distributed. The maximum recommended slope is 1:3.

The trench method only has one working face. On the other hand, the area and combined methods may have two working faces.

Table 5-1. Recommended Cell Widths as a Function of Quantity of Wastes

Quantity of Wastes (TPD)	Traxcavator (HP)	Bulldozer (HP)	Front-End Loader (HP)	Blade Width (m)	Minimum Wic of Cell (m)
20-50	<70	<50	<100	up to 4.0	8
25-130	70-100	80-110	100-120	up to 5.5	10
130-250	100-130	110-150	120-150	up to 6.5	12
250-500	130-190	150-180	150-190	up to 7.5	15

5.1.2.1. Trench

As the name implies, the trench method involves the excavation of a trench into which the waste is disposed, i.e., spread and compacted (Figure 5-4). The waste is deposited on the slope of the trench (slope 1:3). The excavated material (spoils) serves as cover material. Spoils not used for the daily cover is stockpiled for later use in a subsequent area fill that might be constructed on top of the completed trench fill.

Sidewall stability is a critical factor in trench designs. Sidewall stability is a function of the characteristic strength of the soil, depth of the trench, distance between trenches, and slope of the sidewall. Maximum depth and steepness of sidewall slope are compatible with clays, glacial till, or other fine-grained, well-graded, consolidated soils. Weaker soils require gentler sidewall slopes. Other factors that may affect soil stability and permissible steepness of sidewall slope are the weather and the length of time the trench is to remain open.

Because a suitable distance should be maintained between the bottom of the fill and the groundwater table, compatibility with groundwater safety places another constraint on trench depth.

Since the amount of required cover material is a function of width of trench, theoretically the trench should be as narrow as is possible. However, because width must be adequate to permit dumping and accommodate the compaction equipment, feasibility (practicality) demands that the trench be sufficiently wide to accommodate the number and types of vehicles that use the fill. Generally, the indicated width is twice that of the largest piece of equipment that will work in the trench.

Depending upon the projected size of the fill, excavation may either be done continuously at a rate adjusted to landfilling requirements, or periodically on a contract basis.

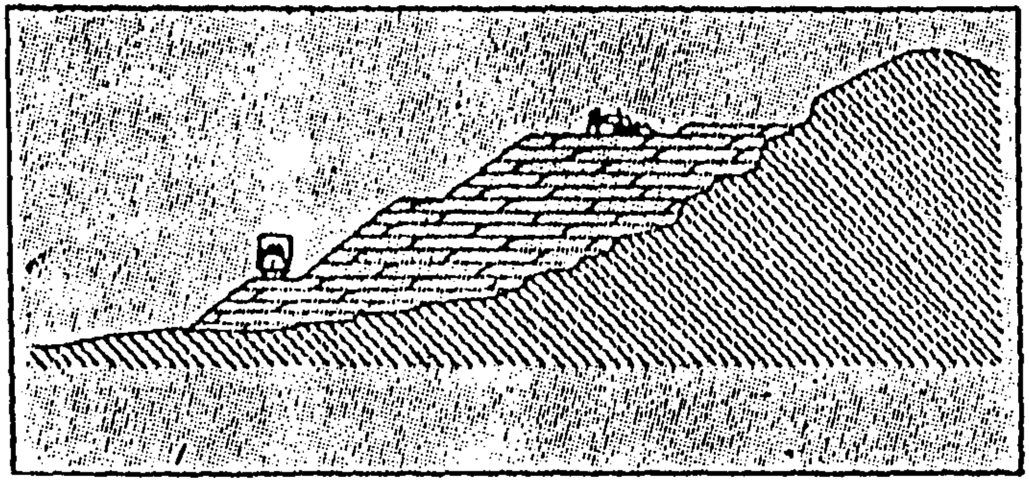

Figure 5-4. Canyon Fill

Alignment of the trenches relative to the prevailing wind exerts a significant influence on amount of blowing litter. The alignment most effective in terms of reduction of amount of blowing is one that is perpendicular to the prevailing wind.

To ensure drainage, the bottom of the trench should be sloped away from the active fill. Water that may collect at the bottom of the trench should be pumped out of the trench, because refuse should not be deposited on standing water. Surface water can be diverted from the trench by constructing temporary berms on the sides of the excavation.

5.1.2.2. Area

Unlike the trench method, the area method involves no excavating (Figure 5-3). Instead, a layer of waste is spread and compacted on the surface of the ground (on the inclined slope). Cover material is then spread and compacted over the layer of waste. The area method is used on flat and gently sloping land. It can be adapted to quarries, strip mines, ravines, valleys, canyons (Figure 5-4), other land depressions, and excavations made for the landfill.

5.1.2.3 Ramp

The ramp or progressive slope method consists of spreading and compacting the solid waste on a slope, as is illustrated in Figure 5-5. Cover material obtained directly in front of the slope is spread and compacted over the compacted waste. Because it does not involve the importation of cover, the ramp method promotes greater efficiency of site usage only when a single lift is constructed.

5.1.2.4. Combination

Both the area method and the trench method might be used if the site has varying thickness of topsoil and receives a large amount of wastes. The trench method would be used where the topsoil layer is thickest. Spoil not used for cover on the trench fill would be reserved

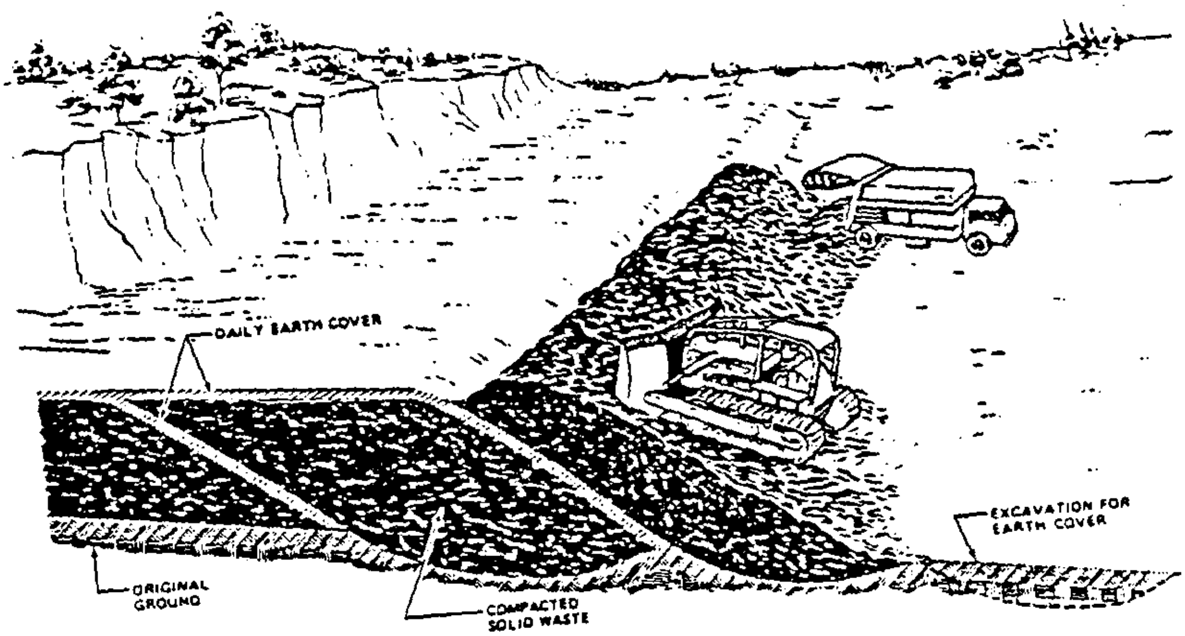

Figure 5-5. Sanitary Landfill - Ramp Method

for the area fill. Through the use of the area method and stockpiled cover material, additional lifts (layers) can be constructed upon a completed lift.

5.1.3. Covers

The main aspects of the design of a cover are its individual layers. The schematic in Figure 5-6 shows eight different layers that can be considered.

The most basic design of a final cover contains two layers: 1) the surface layer, and 2) the hydraulic layer.

In a developing country, it is advisable to use a thickness of 60 cm for the surface layer and 20 cm for the hydraulic barrier. This design would be acceptable in areas with high evaporation and low rainfall, (i.e., warm and dry) and it is depicted in Figure 5-7.

In other climates and where situations demand additional protection such as with a humid climate, it may be necessary to include other layers.

In order to prevent the downward flow of water, the cover must be designed such that the major fraction of rainfall and melting snow become run-off. This can be accomplished by building a cover having a slope between 1% and 2%. This inclination promotes flow off the cover and at the same time reduces erosion. Erosion also is reduced by establishing vegetation. Vegetation, in turn, promotes evapotranspiration (moisture form the soil is released to the atmosphere through uptake and evaporation. Thus, slope and vegetation play an important role in the performance of the cover.

In a basic design, the hydraulic barrier is below the vegetative support. The hydraulic barrier essentially is the first component of the cover specifically designed to prevent the passage of liquids into the waste.

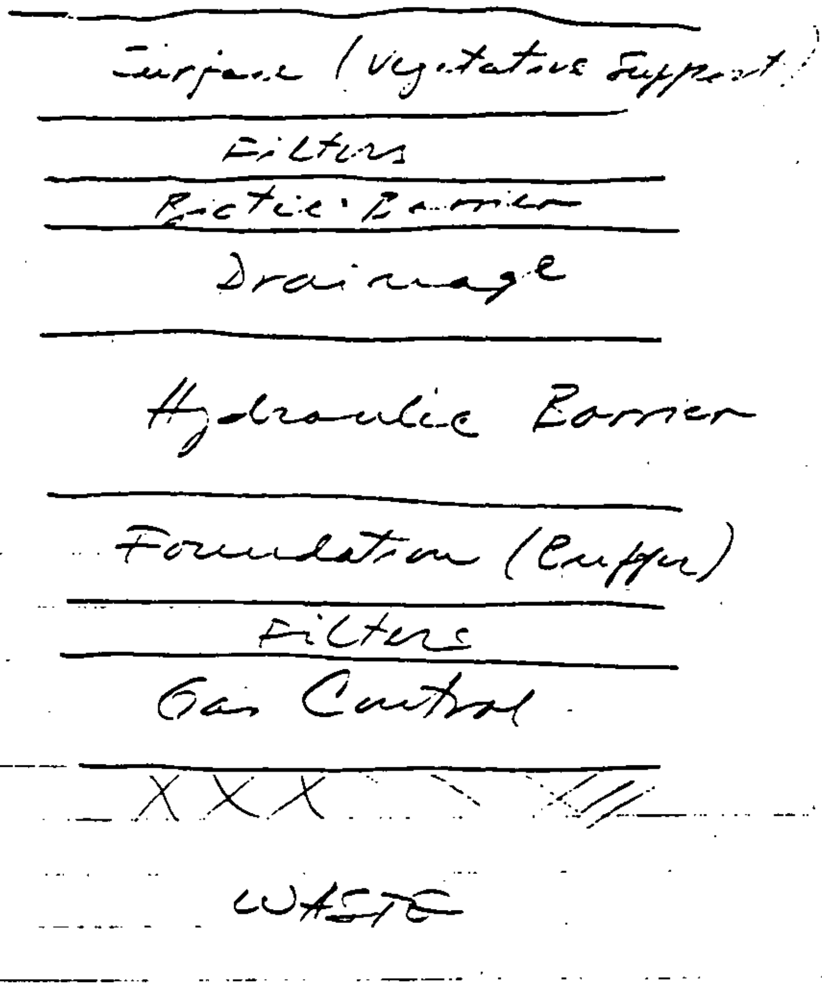

Figure 5-6. Components of a Final Cover

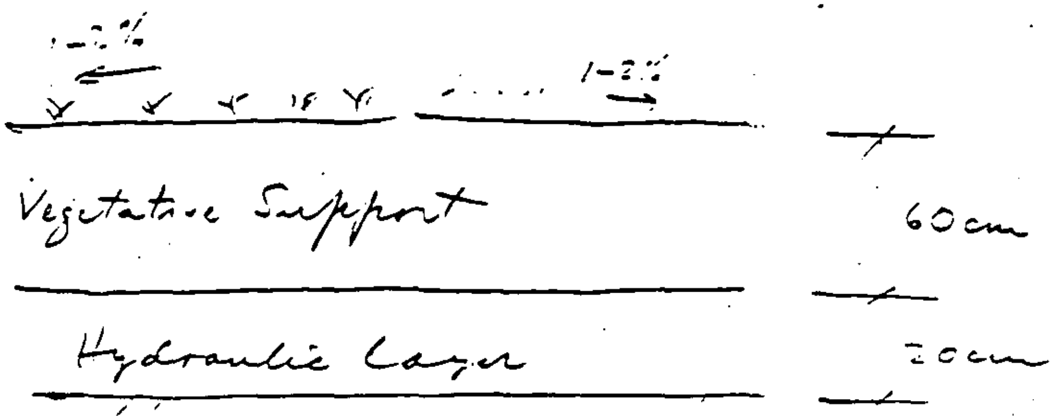

Figure 5-7. Basic Design of Final Cover

In the event that the layer of top soil (vegetative support) does not have a sufficiently low permeability to prevent percolation, then the waste will be subject to infiltration and thus the potential generation of leachate. Infiltration can be substantially reduced by the incorporation of a lateral drainage layer above the hydraulic layer as shown in Figure 5-6. The introduction of the drainage layer into the design brings about additional degrees of safety, complexity, and cost. All of which may not be acceptable to a less developed country. This is because the drainage must be accompanied by a filter zone. The filter zone consists of a layer of carefully selected cohesionless soil. This layer, as its name implies, serves the purpose of preventing downward motion (filtering) of small soil particles from the vegetative layer into the drainage layer. These particles would eventually clog the drainage layer.

Finally, if brush and tree growth is promoted and burrowing animals are present, it would be necessary to include a biotic barrier. This barrier generally is located between the filter and drainage layers. The biotic layer is designed to prevent damage to the hydraulic barrier due to tree roots or animals.

Surface (Vegetative) Layer: This layer is needed to protect the cover from erosion due to wind and water flow. This layer should be made up of nutritive and dense top soil in order to support plant growth. This material can be mixed with composted yard debris, sludge, or animal manures.

Filter Layer: Any time fine soils are placed above coarse soils there is potential for the migration (piping) of the fine soils into the voids of the layer of coarse grains. This phenomenon results in the plugging of the coarse layer. Filter layers are used to remove fine particles from infiltration and to allow upward flow of landfill gases. Soil or non-soil particulate filters can be used. In the event they are not available, geotextiles may be used.

Biotic Barrier: The integrity of the hydraulic barrier must be maintained in the design of the final cover. Plants and animals can perforate the hydraulic barrier and thus ruin the design.

One method of controlling this potential problem is through frequent mowing and pruning the plants and through the use of rodenticides. Another method of control is through the installation of a biotic barrier. A biotic barrier consists of a layer of construction debris of crushed rock of such size to prevent the movement of plants and animals.

Drainage Layer: The design of final covers should, in most cases, incorporate the design of a drainage layer. The few exceptions would be in very dry areas where precipitation is very low. The only purpose of this layer is to intercept the downward flow of infiltration and to remove it before it can penetrate the hydraulic barrier.

A schematic of a drainage layer is shown in Figure 5-8. As shown in the figure, the layer must slope in the direction of collection points on the perimeter of the landfill. The layer should be made up of porous material.

Hydraulic Barrier: This is the most important layer of a final cover. The main function of the hydraulic barrier is to prevent infiltration of precipitation into the solid waste.

In industrialized countries, these barriers are made up of fine-grained soil carefully compacted. The soil can be mixed with other materials such as bentonite clay and fly-ash in order to attain the desired permeability. The success of the final cover depends upon the maintenance of the hydraulic barrier's integrity.

The integrity of the hydraulic barrier can be impacted through three mechanisms: chemical, mechanical, and environmental. Chemical impacts are the least troublesome and relate to vapors and gases. Mechanical impacts involve, primarily, damage due to construction such as excessive overburden, high compaction, and coarse materials punctures. Environmental impacts are those related to drying, wetting, and root penetration.

Synthetic membranes can be used in place of soil as hydraulic barriers. These materials can be prohibitively expensive for these applications in some less developed

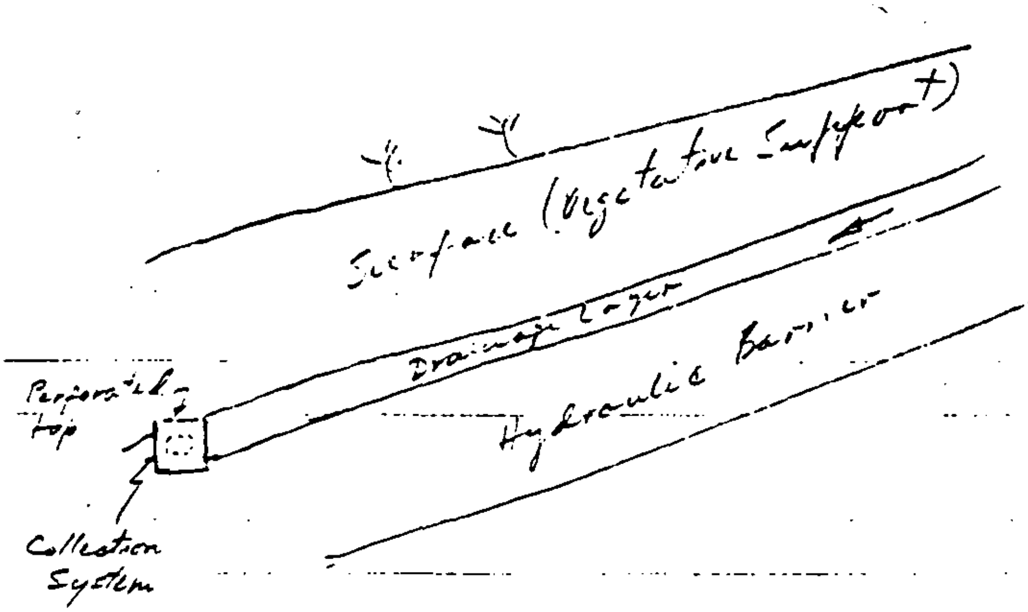

Figure 5-8. Schematic of a Drainage Layer

countries. If synthetic membranes are used, they must be properly protected from mechanical damage (both during construction and maintenance) by installing adequate underlayment and a protective layer such as sand on top.

Foundation Layer (Buffer): The foundation layer is designed to serve as a buffer between the final cover and the wastes as well as to support the load from the cover. This layer is made up of compacted coarse-grained soil placed on top of the uppermost waste lift.

One of the main concerns in the design of a final cover is subsidence or settlement due to decomposition of the wastes. Thus, one of the most effective means of protecting the foundation layer and therefore the final cover is by ensuring that the wastes are thoroughly compacted.

Gas Control: Landfill gas (biogas) is a product of decomposition of organic matter in the landfill. The gas is primarily composed of methane and carbon dioxide. The quantity and composition of the gas depends upon a number of variables including: nature of wastes, climate, and moisture content.

Gas control mechanisms typically utilize a porous layer placed as close to the waste as possible. The layer may be part of a static or dynamic gas collection system (See Section 6.3).

5.1.4. Customized Methods

If the intention is to use sanitary landfilling for some specific purpose in addition to waste disposal, it may be advisable to adapt ("customize") the landfill design to fit both the waste disposal and the desired use. Examples are topographical contouring, land reclamation for agricultural use, strip mine reclamation, and gas (methane) recovery. Other uses are discussed in Section 9.3.

5.1.4.1. Topographical Contouring

An example of topographical contouring is the construction of a fill that becomes a hill in a land area unrelieved by variation in elevation prior to completion of the fill. An advantage of such an approach is more efficient usage of land area, i.e., more waste can be disposed within a given area.

Basically, the completed fill would be a vertical series of more or less circular lifts tapered to achieve the contour of a hill. The area method would be used in the construction of the lifts. Permissible steepness of the slope is determined by the angle of repose of the soil cover, the climbing capacity of the equipment, and the angle of slip (slide) and tip (roll over) of the equipment when operating at normal loading. The design specifications should be low enough to provide a comfortable margin of safety with regard to these items. In summary, the maximum grade of the slope must be one at which several requirements (e.g., spreading, compaction, covering) for a satisfactory fill can be met without endangering the safety of the workers, and at which the eventual landscaping of the hill can be done.

It should be emphasized that constructing such a hill is difficult. Among the many factors and items that intensify the difficulty are the following:

- It is inherently easier to operate equipment on level ground than on a slope; and certainly, equipment "wear-and-tear" is less.
- Even though the slope may be within the angle of repose, some slippage takes place during normal operation. The slippage intensifies the difficulty of achieving the degree of compaction required for the refuse and cover material.
- Blowing of litter is accentuated.
- Abrasion of soil cover by wind and erosion by downflowing surface water during rainfall easily reaches problem levels.
- To the usual problems encountered in establishing a vegetative cover on a completed fill (Section 9.3.) must be added those of planting and maintaining vegetation on a hillside.

5.1.4.2. Land Reclamation for Agriculture

Sanitary landfilling designed to accomplish land reclamation for agriculture combines satisfactory waste disposal with very practical land reclamation. The approach is applicable to a wide variety of situations. Examples are abandoned quarries, problem canyons, strip mined areas, agricultural lands no longer workable because of excessive soil erosion, and other land areas severely damaged through exploitation.

Despite the considerable diversity suggested by the preceding list of examples, the method of sanitary landfill followed in all cases is essentially the area method adapted to fit a particular situation. For nonworkable agricultural land, a single lift may be sufficient; whereas several lifts would be required for abandoned quarries, canyons, and exhausted strip mines. In all cases, the depth of the final cover (i.e., of the topmost lift) should be such that plant roots do not enter the buried waste mass before the wastes have been sufficiently stabilized. Required depth and type of soil will vary with type of crop to be grown on the fill.

Measures must be taken to prevent or minimize unfavorable impacts upon the environment which otherwise would be exerted by the landfill. Precautions against groundwater pollution by leachate intrusion are the same as those applicable to all sanitary landfills in general. Design concepts addressed to minimize or prevent adverse environmental impacts from leachate generated are described in Sections 4.2 and 6.2.

Because of the safety hazards (fire and explosions) associated with accumulations of biogas, steps must be taken to prevent or dissipate accumulations. In addition to the safety hazard, accumulated biogas is likely to inhibit root development. An approach other than simply dissipating the gas to the atmosphere, consists in recovering the gas and using it as a fuel. Gas management is treated in Section 6.3.

5.1.4.3. Reclamation of Aquatic Environment

Refuse is often dumped into rivers on the pretext that it is land reclamation. Solid waste should not be disposed near potential sources of water supply. In some cases it may be acceptable to reclaim marshes and areas with pockets of water with higher salinity. In these situations, the water should be removed or allowed to evaporate and the appropriate evaluations carried out (geological, hydrological, etc). Consideration should be given to the ecological conditions of the site.

5.2. PROVISION FOR MATERIAL RECOVERY

5.2.1. Introduction

Since sanitary landfilling is the subject of this manual, the present section deals only with material recycling (scavenging) done at the landfill site. This does not include scavenging at the point of waste generation, during collection, or during transport. Presently, the sequence most commonly followed for scavenging at the disposal site is as follows:

1. Incoming refuse is dumped as usual at or near the working face, i.e., immediately behind or at the foot of the working face.
2. Scavengers sort through the dumped load.
3. Machinery spreads and compacts the residues from the scavenging activity.
4. The rest of the procedure is conventional landfilling.
5. The scavengers sort their materials into organized lots.

Although the coverage of scavenging in this section of the manual is restricted to that which takes place at the disposal site, it does not affect fundamental arguments for and against the practice as a whole. Typical materials recycled this way include unbroken bottles, any type of metal, plastics, cardboard, paper products, textiles, and glass.

5.2.2. Associated Problems

The case for the necessity of scavenging must be strong enough to counterbalance the many objections that can be raised against scavenging at the site. These objections stem from the safety hazards to the personnel of both the scavenging group and landfill employees and from the interference caused by the scavenging activity that prevents the efficient conduct of work at the fill. Scavenging activities have severe negative impacts on the productivity of the equipment and the efficiency of overall process. The hazards caused by the intermingling of the manual scavenging activity and the equipment-oriented sanitary-landfilling activity increase when heavy equipment is involved, as is the case with landfills on a municipal scale. Furthermore, scavenging results in delays and often interferes with compaction and application of the soil cover. Therefore, the problem is essentially one of developing a safe interface between scavenger and landfill equipment that allows for efficient operation of the landfill.

5.2.2.1. Designation of Scavenging Site

The problem of developing an interface between scavenging and efficient landfill operation can be lessened or even eliminated by treating the scavenging activity as a first step in a sequence of steps that make up the landfill activity. Such an approach makes feasible a spatial separation of the two activities. Unfortunately, such a spatial separation adds a step to the overall operation. The step has two parts: 1) discharge the incoming wastes at the scavenging portion of the disposal site, and 2) transfer the residue remaining after scavenging to the burial site.

If the scavenging site is kept relatively close to the burial site, the transfer from the one site to the other may be done quickly by means of a bulldozer. Such an arrangement would demand that the scavenging site be movable. Of course, the two sites must not be so close as to promote mutual interference between man and machinery. The scavenging area could also be located about 1 to 2 km away from the working face. In this case, the waste to be disposed could be transported by means of dump trucks.

A fixed scavenging site for the life span of the fill would be indicated when transfer by bulldozer is no longer feasible. A fixed scavenging site would be neither feasible nor advisable for a small disposal site. Dedication of a fixed portion of the disposal site to scavenging takes on many of the characteristics and advantages of a transfer station. For instance, scavenging done in a fixed area can be sheltered from the elements (wind, rain, etc.) and an undesired impact upon the environment can be avoided or minimized. The operation itself can be kept more orderly and closely controlled, and abuses can be discouraged. Furthermore, efficiency can be improved by including a certain amount of mechanization (e.g., conveyor belts and screens). Best of all, encounters between scavengers and landfill equipment could be more easily avoided. These several advantages combine to enhance efficiency. This alternative would also allow for the provision of much needed sanitary facilities and a better working environment for the scavengers.

Perhaps the strongest objection to designating a fixed site is the fact that the added step of pick up and transfer mentioned earlier becomes a necessity. This objection does not come into play until the distance between the scavenging and burial sites becomes great enough to render transfer by bulldozing no longer feasible. Of course, the capital expenditure associated with the erection of a building and introduction of added equipment would be another disadvantage. The scavenging area can be located about 1 to 2 km away from the working face. In this case, the waste to be disposed would be transported by means of a truck. From the preceding discussion it can be seen that the size of the disposal site is the decisive factor regarding advisability and necessity for dedicating a portion solely to scavenging. In general, a minimum life span of 10 years would justify the incorporation of a fixed scavenging area.

5.2.3. Management of Scavenging Activity

Important factors when managing scavenging activities are the relative priorities of the scavenging and the burial activities. Burial should have precedence over scavenging since the reason for the fill is the disposal of wastes. Therefore, scavenging must be managed in a way that does not unduly interfere with the main activity of the landfill site burial, or disposal, of waste. On the other hand, consideration must be given to the loss income to the scavengers as well as the loss of secondary materials to the local industry.

5.2.3.1. Traffic

Unless carefully managed, traffic to and from the disposal site can be one of the more disruptive of the interfaces between scavenging and burial (disposal). Among the more obvious causes of disruption are the increase in number of vehicles using the same road and the different moving speeds that result from the different types of vehicles involved. Scavengers' vehicles may be as small as a pushcart or as large as the vehicles used to transport the larger loads of scavenged material. On the other hand, waste collection and haul vehicles would surpass the scavenger vehicles in terms of size, weight and speed. In some instances, long delays are brought about by the discharge of recyclable materials from the waste collection vehicles. Waste hauling traffic will move at a much faster pace than would scavenger traffic, and would be materially slowed both by intermingling with scavenger traffic and by the increase in traffic density. Unfortunately, the best way to separate the traffic would be to provide separate access roads, and this probably would be the most expensive way. Hence, the decision as to separation of access would rest upon economic feasibility.

The amount of access by scavengers to the disposal site depends upon the degree of separation between scavenging traffic and disposal traffic. If separation is complete, the access could range from unlimited to somewhat limited. On the other hand, if the two traffics are not separated, unlimited access is immediately ruled out because of the excessive interference with disposal traffic. If access is to be restricted, the question becomes one of which individuals are to be excluded. In arriving at decisions, it should be remembered that political and social expediency would inevitably enter into any decision that would limit access.

5.2.3.2. Supervision

The scavenger activity should be under the direction of a supervisor whose principal function is to see to it that the activity proceeds efficiently and fairly and does so with a minimum of interference with the disposal operation. Accomplishing the latter implies working closely with the director of the disposal operation. The latter should have the final say in decisions that affect the disposal operation (landfilling). The supervisor of the scavenging activity may be assisted by subordinates, if efficiency of operation requires such a provision. Efficiency and safety demand that good housekeeping be rigorously enforced – the supervisor would see to it that this is done.

5.2.3.3. Guidelines

A relatively fixed set of guidelines should be established that ranges from general for all participants to specific for the individual parties involved in the scavenging activity. Among the subjects that could be regulated are:

1. Assignment of spaces, refuse loads, etc., to individual scavengers or groups of them.
2. Removal of scavenged material from the site – i.e., how soon, how often, and how it is done – everything from separation of scavenged material to loading it and hauling it away – cart, motorized vehicle.
3. Ideally, the municipality should be responsible for the sale of the recovered materials.

The laborers should be provided with uniforms and safety equipment, bathrooms, showers, eating facilities, and first aid equipment.

5.3. PROVISION FOR SPECIAL WASTES

5.3.1. Baled Wastes

Because of the technology involved and the high costs, baling municipal wastes generally would not be a practical disposal option for a developing country. However, it is a remote possibility that baling might be adopted. Therefore, this section briefly describes landfilling baled wastes.

Type and moisture content of the waste determines the cohesiveness and density of the bales. With respect to those two characteristics, the optimum moisture content is between 15% and 25%. With the present baling technology and suitable moisture content, densities of bales range from 950 kg/m^3 to 1130 kg/m^3. Bale dimensions range between 0.9 and 1.2 in the minimum dimensions and from 1.2 to 1.8 m in length. To keep recoil (expansion after pressure is released) at a minimum, baling pressure should be greater than $1.4 \times 10^7 N/m^2$. Even under optimum baling conditions, the volume of the bales eventually expands 10% to 15%.

The bales are tightly stacked in the fill. In the United States, efficiency apparently dictates that each lift be no higher than three layers of bales. Maximum stability is attained by arranging the layers in a manner similar to bricklaying in which each layer is offset so that abutting ends of bales in one layer are directly under those in another. Each lift should consist of three layers of bales and is covered with a thin layer of soil to accommodate truck and equipment traffic. The contours of the floor of the site should reflect the contours desired for the completed site. A photograph showing a bale fill is presented in Figure 5-9.

Proponents of balefilling (landfilling baled wastes) claim that the following advantages can justifiably be attributed to the use of baling in MSW disposal:

1. Baling ensures a higher effective density, thereby reducing the land requirement. For example, the wet density of refuse in a conventional landfill was approximately 133% greater than it had been originally. In a high-density landfill, the density was about 143% that of the original; and in a balefill, about 192% denser.

2. Apparently, use of on-site equipment and personnel is less intensive in a balefill.

3. Damage to the environment is diminished. Judging from United States experience, balefills do not have environmental problems to the extent characteristic of conventional fills. The experience thus far is that leachates from balefills have fewer contaminants than do those from conventional fills. The reason advanced for the fewer contaminants is the tendency for infiltrating water to be diverted to the spaces between the bales because of the low permeabilities of the spaces.

Figure 5-9. View of Refuse Bales. (Photograph courtesy of Caterpillar)

4. Problems related to vectors, dust, blowing litter, traffic, and moisture are considerably reduced in number and severity. Of course, all of these advantages are contingent upon the balefill being operated in an environmentally safe manner.

5.3.2. Co-disposal

As the term implies, "co-disposal" involves the mixing of one type of waste with another and the subsequent disposal of the mixture. Although the co-disposal described in this section applies to most types of non-industrial sludges, the section is directed primarily to sludges associated with the storage, treatment, and disposal of human body-wastes (primarily, the fecal wastes). Examples of the latter sludges are those produced by a conventional wastewater (sewage) treatment facility, septic tank pumpings, sludge from the storage pits of unsewered public toilets, and nightsoil in general.

Despite the many hazards to public health and nuisances attributed to the practice, untreated nightsoil frequently is co-disposed with municipal solid wastes in developing countries. These hazards and nuisances are amplified by the prevalence of the open dump method of disposal. Although perhaps not as pronounced, the same hazards attend the open dump co-disposal of primary (i.e., raw) sewage sludge from a sewage treatment facility. The hazards can be substantially reduced by resorting to sanitary landfilling.

In an operation involving co-disposal by sanitary landfilling, an approach is to deposit the sludge (20% to 30% solids) on top of the refuse at the working face of the landfill. The sludge and refuse are thoroughly mixed. The mixture is then spread, compacted, and covered in the manner usual to the sanitary landfilling of refuse. Liquid in the sludge is absorbed by the refuse. In the United States, municipal refuse has a considerable moisture absorption capacity – as much as 60 to 180 kg of moisture per 100 kg of refuse. With such refuse, the weight of water in the sludge should not exceed about 50% of the weight of the refuse to which it is applied. Because the moisture and organic contents of refuse generated in developing countries are much higher than those in United States refuse, the absorption capacity of developing country refuse would be correspondingly lower. Hence, the maximum weight of the water in the sludge should be much lower than 50% of the weight of the refuse.

Sludges having a low solids content (2% to 4% solids) may be spray-applied from a tank truck to a layer of refuse at the working face. The refuse serves as a bulking agent. For example, with United States refuse, the bulking ratio for a 3% solids sludge would be at least 7 Mg of refuse to 1 Mg of sludge. If the solids content of the sludge were 20% or more, the bulking ratio of refuse to sludge could be as low as 4 to 1. In a developing country, the ratio of refuse to sludge would have to be much higher. In practice, application of sludges having a solids content approaching 3% should be avoided because of the likely development of operational and environmental problems. In this particular option (co-disposal), scavengers should not be permitted to come in contact with the wastes.

A different approach involves the use of sludge/soil mixture as an interim or final cover over completed areas of the refuse landfill. The approach has some advantages:

1. Sludge is removed, or reduced, from the working face of the fill.
2. Because of the nitrogen and phosphorus contents of the sludge, the mixture promotes the growth of vegetation over the completed fill area, thereby reducing fertilizer requirements.
3. The development of sanitation and erosion problems might also be mitigated.

A major disadvantage is the limitation of the approach to well-stabilized sludge (i.e., digested). The limitation arises from the incomplete burial of the sludge and its resulting exposure to the hazards and nuisances associated with pockets of incompletely stabilized sludges.

5.3.3. Hazardous Wastes (Secure Landfill)

5.3.3.1. Introduction

Hazardous wastes are equally dangerous and toxic in developed and developing countries. Locale of origin or occurrence has no bearing on the degree of hazard inherent in a particular hazardous waste. At the most, there is the possibility that a given hazardous waste might pose a greater danger in a developing country, since "legal" definitions, standards, and safeguards tend to be more relaxed in developing countries. The result is that: 1) measures required in the disposal of hazardous wastes in developing countries should not differ materially from those imposed in developed countries; and 2) the "secure landfill" approach described in this section applies equally in developed and developing settings. The only differences would be those arising from conditions peculiar to the individual settings.

5.3.3.2. Definition and Specifications

A "secure landfill" is a sophisticated engineered earthen excavation especially designed to contain hazardous wastes such that they cannot escape into the environment. Therefore, a genuinely secure landfill must have the following features:

1. Waste disposed in it is completely enclosed by a layer or liner of impervious material.
2. The distance between the bottom of the liner and the groundwater is sufficient to prevent contact between the two.
3. Leachate and all other liquids are not allowed to accumulate inside or outside the containment layers.
4. Groundwater is monitored such that leakage from the fill can be detected.
5. The fill is located such that it is isolated from surface and subsurface water supplies; is free from flooding, earthquake, or other disruptions; and its site is not needed for other uses after the facility is closed [1].

5.3.3.3. Design

As with all sanitary landfills, design is largely dependent upon the hydrogeological characteristics of the site. Thus, if the distance to the water table is substantial and the soils are very impermeable, compaction of the soils at the site coupled with the placement of single liner either of natural or of synthetic material would be sufficient. In such a case, soil or bentonite could serve as a natural material and polyvinyl chloride, high density polyethylene, or chlorinated polyethylene could serve as a synthetic material. If conditions are not ideal, but do meet minimum standards, it would be necessary to excavate the soil presently at the landfill site and replace it with a sand/gravel layer followed by a compacted clay liner, a synthetic liner, and a final layer of compacted clay. In all cases, provision should be made for preventing the various wastes from mixing together and thereby triggering a chemical reaction (e.g., highly caustic waste with a strong acid waste). This is done by separating different areas from one another by forming subcells using earthen dikes.

Arrangements must be made for collecting and withdrawing leachate as it accumulates in the basin. This is done through a network of piping installed in the fill. Quality of the groundwater should be monitored by means of monitor wells placed along the perimeter of the fill. Monitoring of groundwater should be begun prior to the initiation of the deposition of wastes and be continued thereafter until chances of pollution become non-existent.

The design, operation, and monitoring of a secure fill is a highly sophisticated process which requires the participation of skilled professionals.

The various elements of a secure fill are diagrammatically indicated in Figures 5-10 and 5-11.

5.3.3.4. Closure of the Fill

Obviously, the operation of the fill is terminated when it s capacity has been exhausted. The closure operation must be designed such that total and complete decontamination of the facility is assured, and that the completed fill does not pose a threat to the public safety and the environment. This objective is attained by adhering to the following procedure:

1. At termination, cover the upper surface of the completed fill with impermeable soils.
2. Cover this layer with a synthetic liner (if available) to effectively seal this layer and underlying wastes from rainfall.

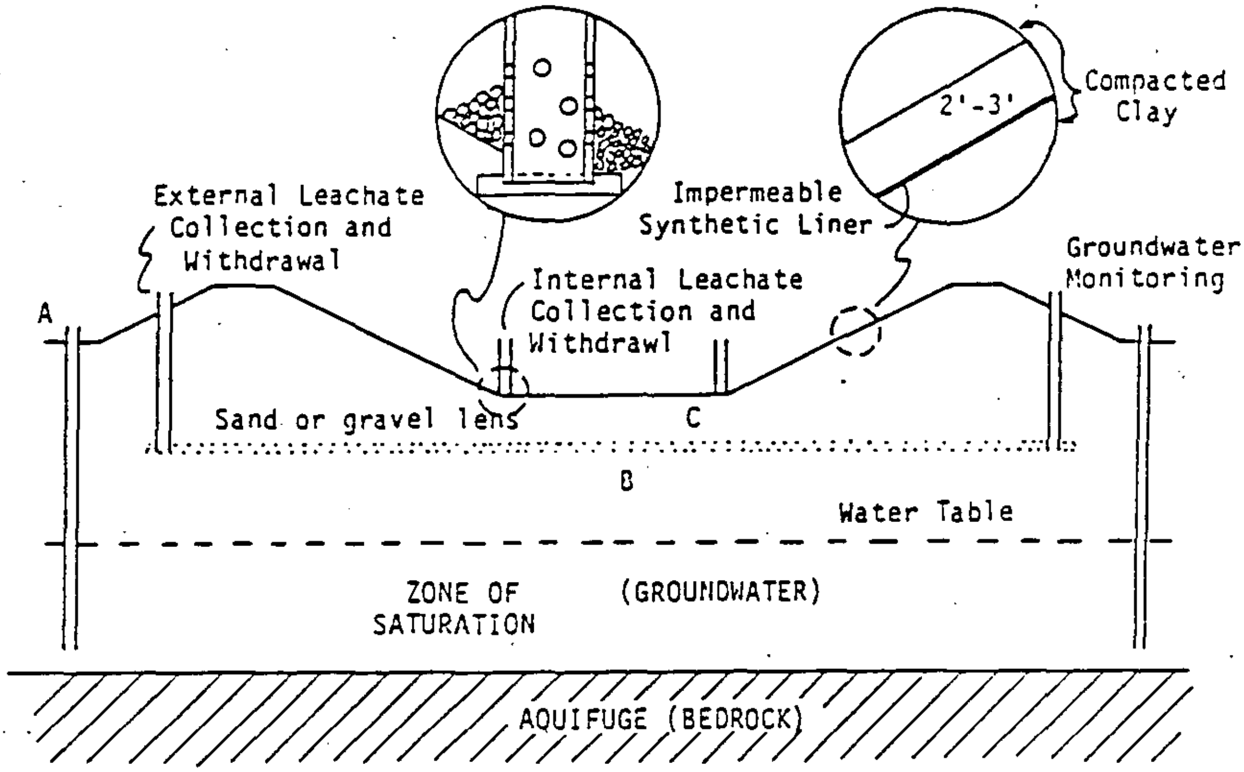

Figure 5-10. Components of a Secure Landfill

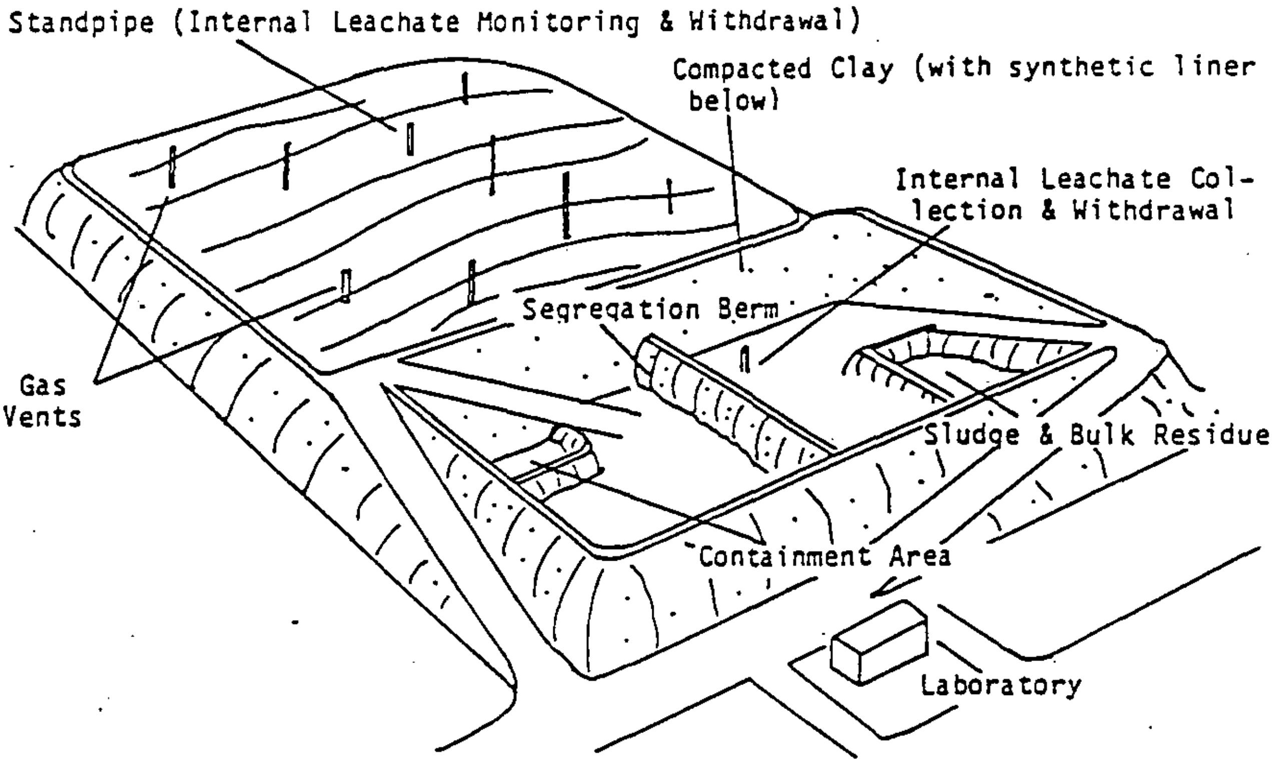

Figure 5-11. Typical Lay-out of a Secure Landfill

3. Cover the synthetic liner with topsoil and seed the topsoil to produce vegetation to complete the closure operation. Leachate and gas collection pipes should protrude through the final cover.

Finally, it is extremely important that the completed fill not be excavated in any way since most buried hazardous wastes continue to be dangerous long after their burial. The consequences could be disastrous, as has been amply demonstrated in the past.

REFERENCE

1. Northeim, C.M., et al, Handbook for the Design, Construction, and Operation of Sanitary Landfills, draft cop. Prepared for the U.S.E.P.A. by the Research Triangle Institute, Feb. 1987.

2. Bruner, D.R., and D.S. Keller, Sanitary Landfill Design and Operation, U.S.E.P.A., Report No. SW-65TS, 1972.

Section 6

FACILITY DEVELOPMENT

6.1. SITE DEVELOPMENT

This section deals with the wide variety of steps involved in preparing a site for an orderly and sanitary operation. Steps of major interest are:

- terrain upgrading (clearing, grubbing, etc.)
- construction of access and on-site roads
- provision of scales
- installation of facilities
- erection of necessary structures
- erection of fences

6.1.1. Terrain Upgrading

First, remove objects that may impede the free operation and movement of vehicles and equipment. Thus, trees, shrubbery, and other interfering vegetation should either be cleared from the site, or be restricted to its periphery. Due to chronic shortages of household fuel, in most developing countries the site might be without combustible vegetation long before being considered a landfill site. Therefore, this step may be irrelevant for some sites.

Second, grade the site so as to eliminate interfering surface (contour) irregularities. The surface of the site should be contoured such that a controlled runoff is promoted and ponding is prevented. Measures for minimizing erosion, the generation of dust, and sedimentation problems should be taken. To avoid danger of erosion and scarring of the land and allow closer supervision, large sites should be cleared in increments.

6.1.2. Roads

All-weather (permanent) access roads from the public road system to the site should be provided. With large sites, these access roads would be extended from the site's entrance to the vicinity of the working area. The roads should be designed to support the anticipated volume of pedestrian and vehicular traffic. Adequate drainage should be provided to prevent the roads from flooding during wet seasons. Ideally, the roadway should consist of two lanes (minimum total width, 7.3 m) for two-way traffic. Grades should not exceed motorized equipment limitations (uphill grades, less than 7%; downhill grades, less than 10%) [1]. Although the initial cost of on-site permanent roads may be higher than that of temporary roads, the difference is more than compensated by savings in equipment repair, maintenance, and time.

Because the location of the working face is constantly changing, roads for the delivery of wastes from the permanent road system to the working face usually are temporary in terms of nature and construction. Temporary roads may be constructed by compacting the natural soil already present and by digging drainage ditches. The roads may be topped with a layer of tractive material, such as gravel, crushed stone, cinders, broken concrete, mortar, or bricks. Lime, cement, or asphalt binders would increase the serviceability of the temporary roads.

If the expected truck traffic is only 25 to 50 trips per day, a graded and compacted soil usually would suffice. Traffic consisting of more than 50 trips per day probably would justify the use of calcium chloride as a dust inhibitor, or of binder materials such as soil cement or asphalt. Traffic consisting of more than 100 to 150 round trips per would necessitate a base course plus a binder.

The preceding specifications would have to be modified to fit the condition peculiar to the level of local development, and more specifically to those of the community being served. As stated earlier, it can be expected that construction of a facility in a developing country would be mostly confined to relatively large communities, metropolitan areas, and capital cities -- at least for the near future. Therefore, it can be expected that sanitary road systems would have to accommodate conventional garbage collection trucks. Moreover, since all urban centers, even the most advanced, have sizeable economically depressed areas, it also is likely that traffic to, from, and on the landfill will include a range of transport vehicles that extends from the very primitive to the relatively modern. This wide variation would add to the complexity of road planning and designing and regulation of traffic. The special provisions needed to accommodate additional traffic brought on by the inclusion of a scavenging operation at the disposal site, are discussed in Section 5.2.3.1.

6.1.3. Measurement of Weight (Scales)

An accurate knowledge of the gravimetric and volumetric amounts of wastes delivered to the disposal site is an essential element in the development and implementation of solid waste collection and landfilling strategies, as well as in the regulation and control of the landfill operation. Therefore, to the extent feasible, all incoming wastes should be weighed. Weighing the emptied vehicle (i.e., determining tare weight) would not be necessary if its weight were already known – as would be true if standard conventional vehicles were used. Manufacturer's specifications for such vehicles include vehicle weight. However, such standardization may not exist.

Types of scales range from highly automated electronic scales down to simple, portable beam versions. The platform, or scale-deck, may be constructed of wood, steel, or concrete. The scale should be able to weigh the largest vehicle that will come to the landfill on a routine basis. Thirty to sixty tons probably would be adequate. Ideally, the platform should be long enough to weigh all axles simultaneously, although separate axle-loading scales (portable versions) would suffice. A schematic diagram of a truck scale is presented in Figure 6-1.

The accuracy of the scale should be checked periodically. This can be done using one of the following ways:

- Check for a change in indicated weight as a heavy load is moved from the front to the back of the scale.
- Look for irregularities in the action (motion) of the dial during weighing.
- Use test weights.

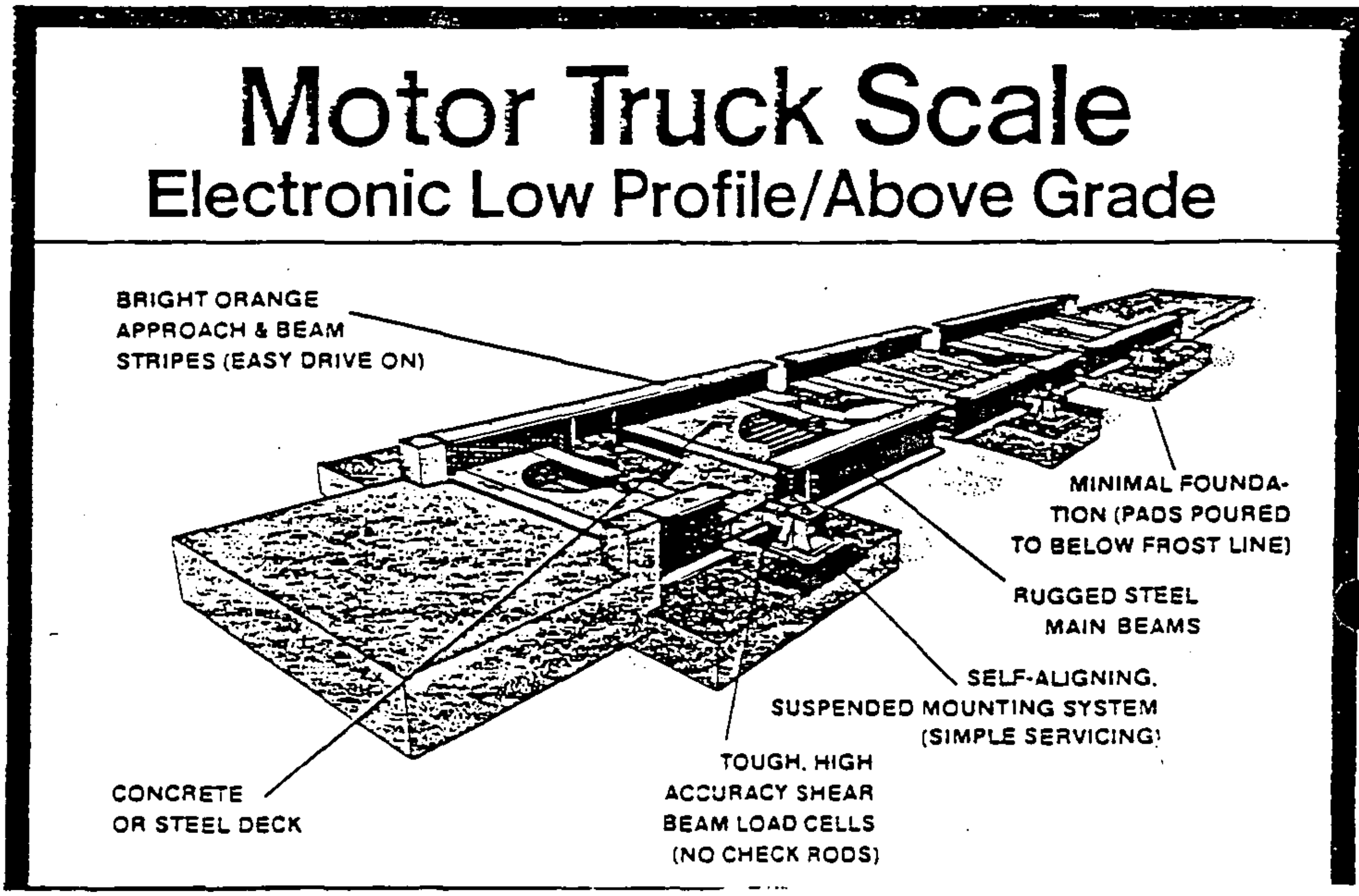

Figure 6-1. Schematic Diagram of a Truck Scale

6.1.4. Utilities (Electricity, Water, Etc.)

Ideally, electrical, water, and sanitation services should be provided. However, the likelihood of all three being available at a disposal site in a developing country is unlikely. Electricity can be used for illumination and power. These two uses are almost essential if equipment maintenance and repair are to be done at the site. Electricity can be generated at the site by means of a portable generator. Water should be available for drinking, fire fighting, dust control, and employee sanitation. In the absence of access to a sewer, ventilated latrines should be built.

6.1.5. Structures

If technical and economic feasibility permit, a structure or structures should be erected to provide office space; to house employee facilities; to provide a sheltered area for equipment storage, maintenance, and repair; and to serve as a scale house. The office space is needed for record keeping and required clerical activities. Employee morale, well-being, and efficiency would be immensely benefited by providing a structure that includes a health clinic; provisions for workers' washing, changing, and toilet facilities; and a canteen. The equipment structure serves as garage and repair shop. Buildings that will be used for less than ten years should be temporary types and preferably be movable. The design and construction of all buildings should take into consideration landfill gas movement and differential settlement of the fill. If these facilities are not provided, operation of the landfill will be impeded.

6.1.6. Fencing

Access to the landfill operation can be controlled by erecting a fence around the site. The fence does the following:

- keeps out children, as well as dogs and large animals
- screens the landfill
- delineates property lines

Type and height of the fencing are determined by the available resources and conditions prevailing at the site.

Litter fences may be erected in the immediate vicinity of the working face to control blowing paper and other litter. A low (about 1 m) fence usually suffices at a trench operation; whereas a 2 to 3 m height may be necessary at a windy, area-type operation. Litter fences should be movable. A diagram of a screen as well as a typical installation are presented in Figures 6-2 and 6-3.

6.2. WATER MANAGEMENT (WATER RESOURCE PROTECTION)

The two principal types of water resources to be protected are the surface waters and the groundwater. Surface waters may be polluted by runoff from the landfill; whereas groundwater may be contaminated by leachate from the fill. These relations are indicated in Figure 6-4. The aim is to directly and indirectly prevent the landfill from adversely influencing inputs to the water resource. This is best accomplished by excluding from the water resources inputs that originate in the landfill.

6.2.1. Surface Water

The first step is to minimize surface waters entering the sanitary landfill. Upland drainage can be accomplished by means of pipes through fills that are located in gullies, ravines, and canyons. Runoff from areas surrounding the fill can be excluded by excavating a series of channels or shallow ditches to divert it (i.e., the runoff).

All runoff from the disposal site and the fill itself must be excluded from all unaffected water resources. This is done by channeling the runoff to a collection and storage site where it can be treated. Ultimately, however, the best recourse is to exercise careful control over the amount of water retained on the fill site and the length of time the runoff is retained there. The longer the retention time, the greater the opportunity for the water to be contaminated before it leaves the fill site. Since runoff from the fill itself occurs only when the upper surface of the fill is as high or higher than the level of the surrounding land, an effective means of minimizing the extent of degradation of the runoff is to shorten the time it is retained at or on the fill. This is done by grading the landfill cover to promote runoff of rainfall. The grade of the cover should

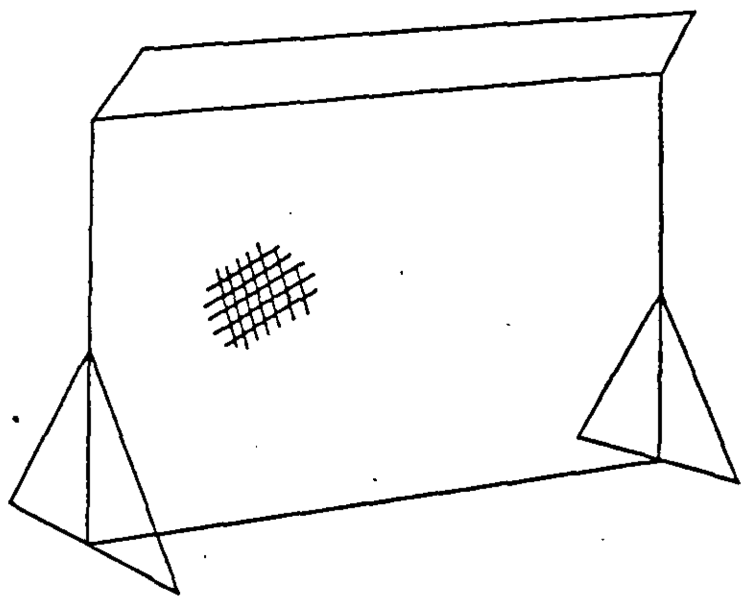

Figure 6-2. Portable Litter Fence (2 m high, 3 m wide)

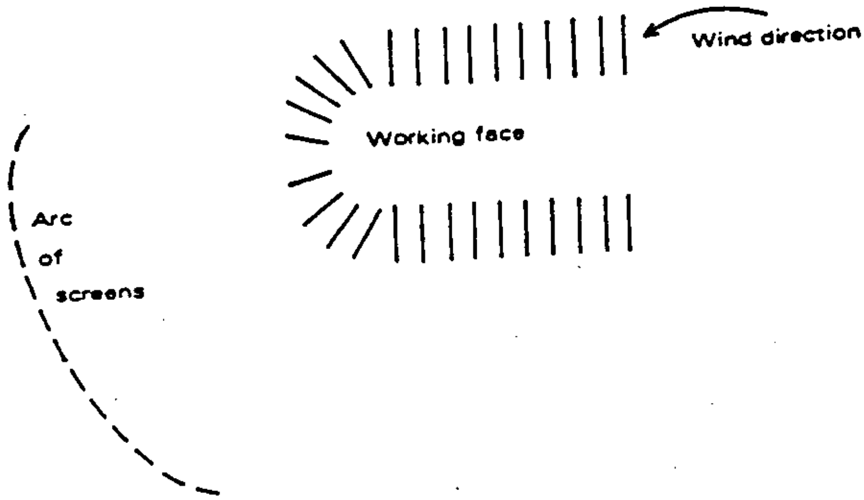

Figure 6-3. Installation of Portable Screens in Accordance with Wind Direction

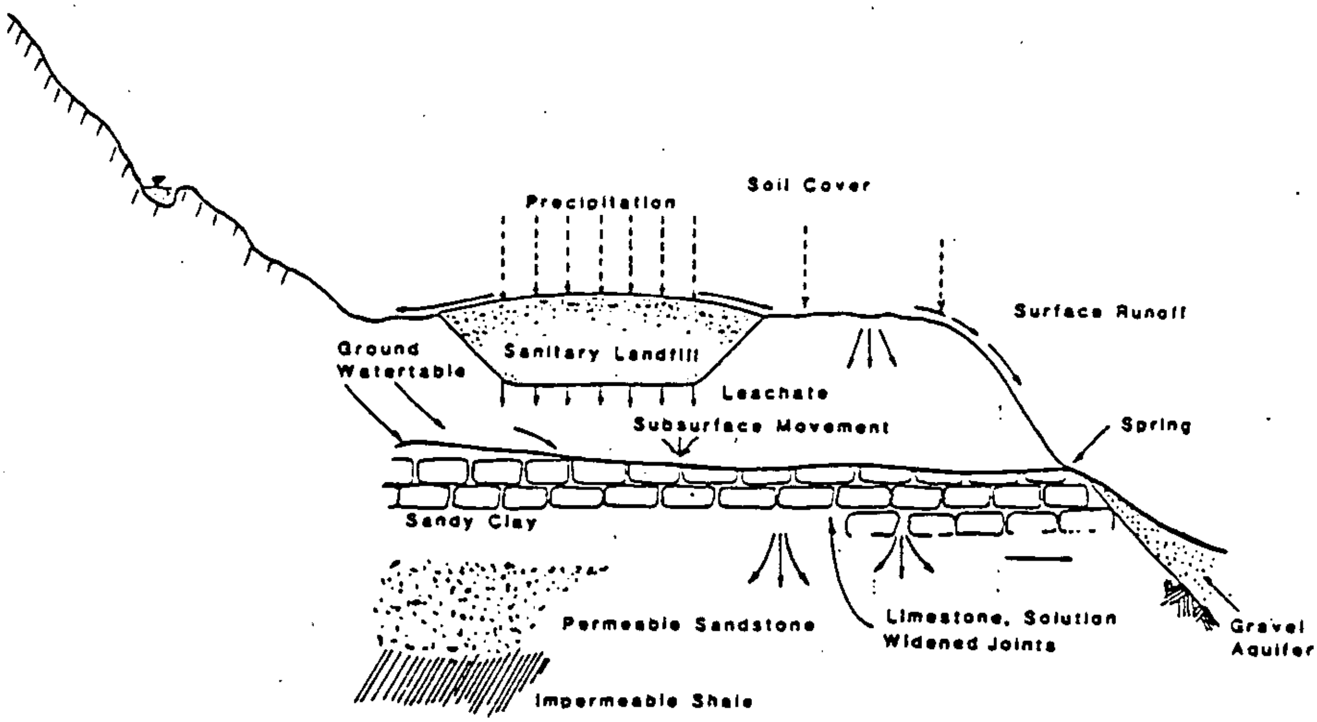

Figure 6-4. Interrelation between Climatic (precipitation), Topographic, Hydrologic, and Geologic Factors in Terms of Leachate Travel and Groundwater Contamination

be determined on the basis of the planned use of the completed site and of the ability of the cover material to resist erosion.

Surface water that runs off stockpiled cover material should not be allowed to enter watercourses without having been previously intercepted and ponded to remove settleable solids. A complete surface water plan must be developed with other site preparatory planning.

6.2.2. Groundwater

The basic premise of protection of groundwater quality is that landfilled solid wastes and any leachate from the wastes not be allowed to contaminate groundwater. Leachate and leachate formation are described in Section 3. Leachate is generated by the passage of water through the solid waste in a fill. If it is moisture already present in the fill, it is termed "primary leachate." If the moisture comes from rainfall infiltrating into and percolating through the fill, the leachate is termed "secondary leachate." In both cases, the eventual composition of leachate is dependent upon the type of solid wastes deposited in the fill, age of the fill, and several other factors.

The degree of required separation of fill from groundwater is determined by the potential of the leachate for contaminating the groundwater. The potential for contamination is greatest when the leachate contains toxic and hazardous compounds and/or when underlying material is highly permeable. The degree of separation necessary to protect groundwater increases with the potential for contamination. One should not plan on the leachate being diluted in the groundwater because the usually laminar pattern of groundwater flow allows very little mixing to occur in an aquifer.

An earlier step in protecting groundwater quality is to ensure that a suitably thick layer of soil is between the bottom of the fill and the groundwater. The interposition of the layer permits the attenuation of leachate that percolates through the layer (i.e., providing a soil column). Required thickness of the layer depends upon the nature of the soil and other factors. These factors, as well as the phenomenon of attenuation itself, and the other factors that also have a bearing on groundwater protective measures are all discussed in Sections 4.2.4. through 4.2.5.7.

In the early days of sanitary landfilling (1930 to 1939), attenuation by way of the underlying soil layer was the principal measure being advocated (Figure 6-4). However, in recent years, the fund of knowledge and the depth of the understanding of leachate and its contamination characteristics became sufficiently great to reveal the limitations of natural attenuation that takes place in the soil layer. This inadequacy has become more pronounced as MSW began to contain increasing concentrations of toxic or hazardous substances. Consequently, it became evident that more effective means would have to be developed for accomplishing the needed protection. Probably the best approach to controlling the movement of fluids into and out of landfilled solid wastes and establishing leachate collection systems in a fill is to enclose the fill with an impermeable liner or liners. The enclosure may or may not include the fill cover.

6.2.2.1. Soil and Clay Liners

Soil liners are used in single liner systems and in composite liner systems. In situations that require secure containment, such as hazardous waste containment, double and composite liners should be used. A single liner system may be the choice in a developing country.

A soil liner may either be the sole liner (single liner system) or the lower component of a composite liner system. Used as a single liner, a soil liner reduces or may even prevent leachate from migrating from the fill into the subsurface environment. As the lower component of a composite liner, a soil liner constitutes a protective bedding for the overlying flexible membrane liner (FML) and it serves as a back-up for breaches in the FML. A useful function of all soil liners is to serve as a long-term structurally stable base for overlying facility components.

6.2.2.1.1. Materials: To adequately serve as a liner, a soil must have a low permeability (less than 1×10^{-7}) when compacted under field conditions. After compaction, the liner should be able to support itself and the overlying facility components. The liner material should yield to handling by construction equipment. Finally, a liner constructed of the material (i.e., the soil) should suffer no significant loss in permeability or strength when exposed to waste or leachate from the waste. A soil that is deficient in a particular characteristic may be rendered suitable by blending it with another soil or with a soil additive. An example is the addition of bentonite cement to decrease permeability. Ideally, the compaction and permeability characteristics of the selected soil liner material should be determined by laboratory tests, so as to provide necessary information regarding the interrelationship between moisture content, density, compactive effort, and permeability.

Of the available materials, well-compacted clay soil is one of the most commonly used. A clay liner usually is constructed as a membrane 0.3 to 1 m thick. To function as a liner, the clay membrane must be kept moist. If sufficient clay is not available locally, natural clay additives (e.g., montmorillonite) may be disked into it to form an effective liner. The use of additives requires evaluation to determine optimum types and amounts.

If it meets the necessary specifications, the native soil at the facility site would best satisfy cost and convenience considerations. Otherwise, a suitable soil must be imported. Obviously, cost becomes an important consideration when off-site material is used. In developing countries, the distance would depend upon local conditions. In most cases, a haul of any distance would be impractical. The liner material, whether excavated locally or imported, usually is stored as a borrow pile established at the site.

<u>6.2.2.1.2. Design and Installation</u>: Standard geotechnical practices adjusted to the geology and landfill operational requirements are followed in the design of the individual landfill liner. The soil liner must underlie the entire landfill. The liner should be permeable enough to impede leachate flow and thick enough to provide a structurally stable base for overlying components. With allowances for leachate collection pipes and sump, the liner should be uniformly thick. However, the toes of sidewall slopes should be somewhat thicker to prevent seepage and to adequately join the bottom and sidewall liners (see Figure 6-5).

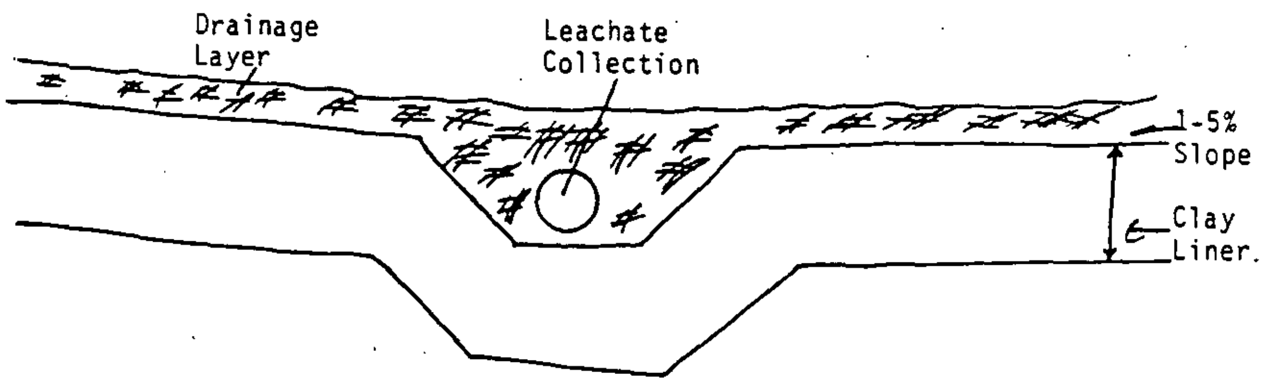

Figure 6-5. Schematic of Liner Design

In general, soil liners are constructed of compacted soils installed in a series of layers of specified thickness. Although the use of thinner increments (and consequently, more layers) facilitates compaction, it adds to construction costs because the number of layers per unit of liner thickness is increased. Generally, thickness of liner layers prior to compaction is on the order of 15 to 22 cm.

Liner Installation (Construction): The liner is installed (constructed) by placing the liner material (soil) with the use of scraper pans or trucks. The soil is spread evenly over the site and then is broken up and homogenized through the use of disk harrows, rotary tillers, or manually manipulated implements to facilitate compaction. If soil additives are used, they are applied evenly over the site and then are thoroughly mixed into the soil.

The liner may be constructed in sections or in one piece. With a small facility, the liner may be constructed in one piece over the entire facility. Sectional (segmented) installation probably would be more suitable with large facilities or in continuous operation facilities. In the latter operations, the wastes are placed as portions of the liner are built. It is important that the sections (segments) be installed such that no break occurs between them. This can be done by bevelling or step-cutting the edge of a section as soon as it is installed so that the succeeding section can be tied in with the previously installed section (Figure 6-6).

Because the necessary degree of compaction is dependent upon a proper moisture content, any required addition of moisture should be made prior to placement of the liner material. Care should be taken to distribute the moisture uniformly throughout the soil. This is done by allowing adequate equilibration time after the moisture addition. The time may require days or even weeks if the soil is very dry or certain additives are used.

Practices followed and equipment used in earthwork construction are suitable for compacting a liner. The success of the compaction effort depends upon the individual liner layers being properly tied together. Tying together the layers can be accomplished by scarifying the

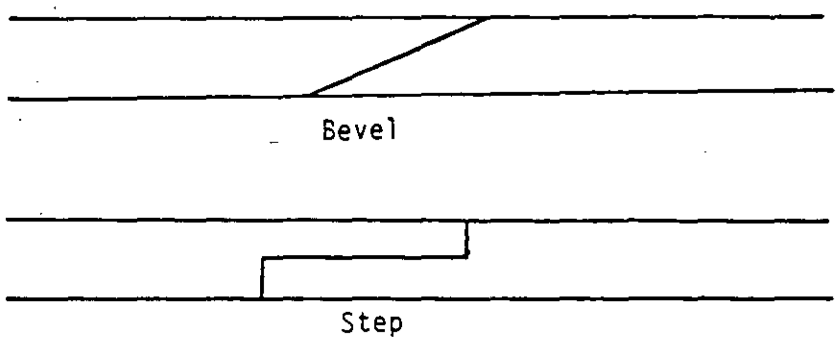

Figure 6-6. Detail of Binding Segments of Liner

surface of the last installed layer prior to adding the next one and ensuring that the moisture contents of adjacent layers are similar. If sidewall slopes are not very steep, they can be compacted in layers continuous with the bottom liner layers. Steeply sloped sidewalls may have to be compacted in horizontal layers because compaction equipment cannot operate on steep slopes. Tying together is especially important for steep sidewalls, because separation between layers can serve as pathways for the migration of leachate through the liner.

Because climatic conditions strongly influence activities related to soil liner construction, steps must be taken to minimize climate-related problems. For example, precipitation may interfere with construction operations by eroding or flooding the site or by over-moistening the liner material. A preventive step would be to seal-roll the compacted layer so that water will drain and not puddle or pond on the liner surface. Conversely, desiccation can cause cracks to develop and thereby seriously increase the liner permeability. Desiccation cracks can be remedied only by disking, adjusting the moisture content, and recompacting the affected portion of the liner. Liners must not be constructed of frozen soils, and constructed liners must be protected from below-freezing temperatures.

6.2.2.2. Flexible Membrane Liners

The constituent material of a flexible membrane liner (FML) is prefabricated polymeric sheeting. A flexible liner may be used in many ways. For example it may be used as a single liner installed directly over the foundation soil. On the other hand, it may be part of a composite liner placed upon a soil liner. Finally, it may be placed above or below a leak detection system in a double-lined landfill.

FMLs either may not be available in developing countries. However, should they be available attention must be given to cost as well as installation.

Major steps to be taken in the use of a flexible membrane liner are selection of the FML material, designing of the subgrade, and planning the installation. The last step includes the design of subcomponents, such as sealing and anchoring systems and vents. Among the types of membranes commonly used for lining sanitary landfills are high-density polyethylene, chlorinated polyethylene, chlorosulfonated polyethylene, and polyvinyl chloride [2,3]. Important criteria to follow for selecting a FML include:

- chemical compatibility with the leachate to be contained
- possession of appropriate physical properties such as thickness, flexibility, strength, and degree of elongation
- resistance to weathering and biological attack
- availability and cost

In the absence of testing facilities, judgments as to compatibility will have to be made on the basis of specifications listed by the manufacturer. Regarding mechanical properties, FMLs having high strength and low elongation are best suited where high stresses are expected (e.g. sidewalls steeper than 2.5:1). Lower strength and higher elongation FMLs (e.g., polyvinyl chloride, chlorosulfonated polyethylene, rubbers) are best used for applications likely to involve large deformations such as differential settlement and local subsidence. Other mechanical properties to be considered are:

- stiffness or flexibility at various temperatures, resistance to puncture
- thermal expansion
- seaming characteristics
- resistance to weathering
- resistance to biological attack
- instability of material on the service impoundment

Weathering may take the form of deterioration by ultraviolet light, ozone reactions, and plasticizer migration. Agents of biological attack include bacteria and fungi and rodents. Here again, reliance is on data provided by the manufacturer. Although some published literature is available, such information may be difficult to obtain in a developing nation.

The subgrade upon which a FML rests is a key factor in the maintenance of its integrity. It does this by serving as a supporting structure and by preventing the accumulation of gas and liquid beneath the liner. The gas could be produced by microbes in the underlying soil. It may be either the air entrapped during liner installation or that which is being forced through the soil by a rising groundwater table. Regardless of its origin, the gas can lift up the membrane, thus imposing a stress on it (i.e., the membrane). Liquid may accumulate as a consequence of leaks in the liner and of infiltration of groundwater from surrounding soils. Consequences of the accumulation can be uplift stress and reduction of the strength of underlying soils. Leachate that escapes from the fill through breaks in the membrane can contaminate surrounding soils. In addition to those resulting from gas and liquid accumulation, mechanical stresses may be caused by subsidence beneath the liner. Other mechanical stresses may take the form of tangential stresses due to differential movements of the subgrade, of concentrated stresses that lead to punctures and tears, and of repeated stresses that fatigue or abrade the liner. All of these failure mechanisms can be prevented or minimized by:

- taking general foundation design measures to prevent settlement, subsidence, slope failure, and other undesirable occurrences
- determining foundation configuration
- appropriately designing protective bedding layers
- specifying proper surface preparation measures.

Among the foundation design measures are configuration of the subgrade to be free of abrupt changes in grade and as plane and regular as is possible. Sidewall slopes should be such that tangential stresses do not exceed the tensile strength of the liner. Important design features of protective bedding layers are the provision of drainage to prevent the accumulation of gas or liquid and the protection of the liner from being punctured. The drainage layer may consist of sand, gravel, or other comparable granular material. Alternatively, it may take the form of a geotextile (a fabric designed to provide tensile strength and serve as a filter).

Among the problems associated with granular drainage layers are the following:

- difficult to install on slopes
- not stable on steep slopes
- vulnerable to disturbance by workers during construction
- can be eroded by wind or water during construction
- possibility of the liner being punctured by damaged or displaced pipes

These problems are avoided by resorting to geotextiles. Moreover, geotextiles protect the liner from mechanical stresses.

Surface preparation should include removal of rocks (larger than 25 mm), roots, and other debris from the surface. Organic material should be removed so as to minimize settlement and gas production under the liner. Soils that expand or shrink excessively should be avoided because of the repeated stresses imposed on the liner by the shrinking and swelling. Finally, the substrate soil surface should be compacted to provide a firm and unyielding base for the liner.

Because the actual installation of a flexible membrane liner is a complex and critical task, it should be done by a qualified and competent company under the supervision of the manufacturer or one designated by the manufacturer.

6.3. GAS MANAGEMENT

6.3.1. Origin, Composition, and Volume of Gases

Gases (biogas) constitute one of the more important groups of products generated in consequence of the biological degradation (biodegradation) of the organic fraction of the wastes disposed in the landfill. For a brief period after burial and covering, sufficient oxygen is contained in the air entrapped in and with the buried wastes to permit the initial biological degradation to be largely aerobic. The predominant gases synthesized during this stage are carbon dioxide (CO_2) and water vapor.

Compaction of the wastes and of the landfill cover should effectively block the entry of air into the fill. As a result, the oxygen in the entrapped air is gradually depleted, and eventually biodegradation becomes anaerobic. The shift to anaerobiosis is marked by the production of methane (CH_4) and CO_2, as well as an assortment of trace amounts of reduced carbon and sulfur compounds. The ratio of CH_4 to CO_2 varies, generally, the composition of the gas will be on the order of 40 to 50% CH_4, 30 to 40% CO_2, 10 to 20% nitrogen (N_2), 1% oxygen (O_2), and traces of sulfides and volatilized organic acids. Typical composition of the gas is presented in Table 6-1. The gas may also contain volatile organic compounds that may have been disposed with the refuse. A sample of the type of organic compounds found in a landfill is California, United States, is given in Table 6-2.

The transition from aerobic to anaerobic decomposition and the latter's attendant methane production proceeds as a series of phases. The first phase is the aerobic phase. Its duration is the time required to use up the entrapped O_2. This may be days or weeks. The second phase begins as conditions shift from aerobic to anaerobic, obligate aerobes die off and facultative aerobes shift to their anaerobic mode, and CO_2, and to a lesser extent, hydrogen (H_2), are the principal gases produced. The third phase is marked by the gradual appearance of CH_4. Within the range of the ratio named in the preceding paragraph (40 to 60% CH_4:60 to 40% CO_2), methane production becomes constant in the fourth phase.

Rate and volume of gas production are functions of wastes disposed and of the particular conditions prevailing in the landfill. Other factors that affect gas production in a landfill include temperature, pH, moisture content, and size of the wastes as well as age of the landfill. Because wastes and conditions vary markedly from one region to another, it follows that reported rates and volumes encompass a wide range of values [5,7,8]. Thus, reported gas pro

Table 6-1. Typical Composition of Landfill Gas [5]

Component	Component Percentage (dry volume basis)
Methane	47.5
Carbon dioxide	47.0
Nitrogen	3.7
Oxygen	0.8
Paraffin hydrocarbons	0.1
Aromatic and cyclic hydrocarbons	0.2
Hydrogen	0.1
Hydrogen sulphide	0.01
Carbon monoxide	0.1
Trace compounds[a]	0.5

[a] Trace compounds include sulfur dioxide, benzene, toluene, methylene chloride, perchloroethylene, and carbonyl sulphide in concentrations up to 50 ppm.

Table 6-2. Trace Organic Compounds in Raw Landfill Gas, Mountain View Landfill, 1980 [6]

Compound	Concentration (mg/m^3)
1,2-Dichloroethylene	5.2
Trichloroethylene	10.4
Methyl isobutyl ketone	5.1
Chlorobenzene	0.4
Toluene	4.0
Tetrachloroethylene	4.5
Ethylbenzene	4.0
Xylene	2.3

duction in landfills in developed countries ranges from 0.064 to 0.44 m^3/kg of refuse disposed (1 to 7 scf gas/lb). Reported rates range from 1.19 to 6.8 m^3 gas/Mg/yr of waste disposed (42 to 240 scf/ton/yr). Most of the production occurs during the 20 years following landfill closure, although production is most active during the first 5 years or so. Gas production, in gradually dwindling amounts, may continue as long as 50 years.

Several models have been developed to predict the production rates of gas from landfills. Most of the models, however, require actual measurements of gas production in order to determine the values of constants for the models.

A relatively rigorous stoichiometric approach (i.e. relative to other approaches) for estimating landfill gas production is described in Recovery, Processing, and Utilization of Gas from Sanitary Landfills [4]. This approach takes into consideration the two major classes of material that decompose to produce landfill gas. The first class consists of the easily biodegradable fraction (e.g., food waste or garbage, garden debris). The second class includes the less easily biodegradable fraction (e.g., paper, textiles, etc.).

The variables mentioned in the preceding paragraph, as well as others, have an effect on the accuracy of models developed for predicting rates of landfill gas generation, especially rates of methane production. Among the variables for rates of methane production are volume of gas that escapes the fill, percentage of carbon that passes through the methane fermentation route, and percentage of carbon that becomes a part of microbial protoplasm. Consequently, such models should be regarded only as being approximate indicators of expected gas production trends.

Although most municipal wastes in LDCs have a high concentration of organic matter, the wastes usually are not adequately covered and thus the gases readily escape.

6.3.2. Disposition of Gas

Gases generated in the fill may be allowed to disperse and migrate beyond the confines of the fill without any effort being made to control, or they may be collected. Collected gases may be put to some use, may be flared, or may simply be vented into the environment. However, the collection and use of these gases entails significant capital and operating costs that must be compared to other energy sources.

Accumulated gases and uncontrolled dispersal and migration can lead to the development of hazardous situations due to flammability, asphyxiating properties, and trace organic composition of the gases. The slightly positive pressure usually existing within a landfill permits gases to flow uncontrolled from the fill to areas of lower gas pressure by convective gas transport. Furthermore, gases with higher concentrations of CO_2 and CH_4 can diffuse into gases with lower concentrations of the two gases. Finally, accumulated biogas (i.e., in the fill) is likely to be inhibitory to roots of plants grown on the cover.

In the absence of adequate gas control, landfill gases migrate to the atmosphere through the landfill cover; or, they can migrate laterally through the soil around the fill until they reach areas from which they cannot escape and as a result, accumulate. As long as the concentrations are relatively small, the gases only pose a nuisance; but when the concentration (accumulation) reaches a critical point, explosive levels of methane may be reached. (The explosive concentration level of methane is between 5 and 15% by volume. At higher concentrations, methane simply burns.) Because of the possibility of gas accumulation, buildings on or near landfills should not have underground structures. If such structures are present, they should be thoroughly and continuously ventilated.

Accumulation of gases in the fill can be avoided through the use of a porous final cover. Migration from the fill and the attendant hazards can be averted by providing an area of high permeability vented to the atmosphere. Gases flow to the surface of the vented areas where they are diluted in the atmosphere to harmless levels (Figure 6-7). The areas take the form of

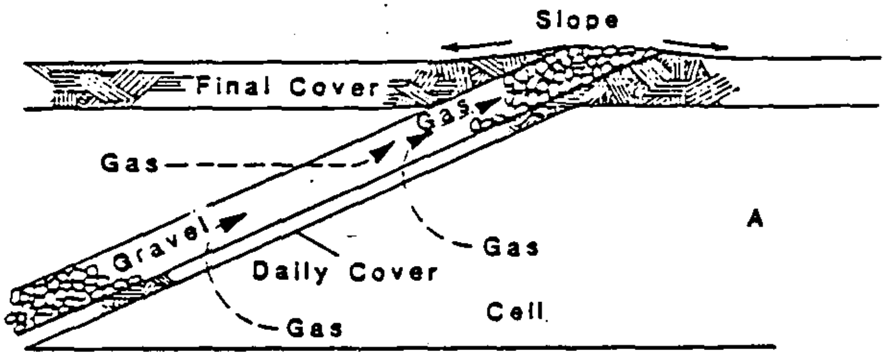

Figure 6-7. Dissipation of Biogas by Providing a Porous Area

boreholes, of gas wells, or of interceptor trenches installed around the borders of the fill (Figure 6-8). A more useful measure is to recover (collect) the gas and use it for fuel.

6.3.3. Collection, Upgrading, Utilization of Landfill Gas

6.3.3.1. Collection

If methane recovery is planned for a new facility, certain features should be incorporated into the design of the fill. Some of the features are characteristic of modern landfill design regardless of whether or not the methane is to be recovered. For methane recovery, the fill must be effectively sealed off from the land and water environments. The steps involved in providing such sealing are the same as those described in Section 6.2. Old or existing fills should be sealed to the extent economically and practically feasible.

Gas recovery involves designing the fill such that the migrating gas can be controlled and collected. Collected gas either can be used directly as a low-heat fuel, or can be processed (purified) to form a high-heat fuel. Collection is made possible by providing a combination of strategically spaced wells and areas of high permeability through which gases are channeled to collection points. This is done by installing underground venting pipes and a gravel layer between a liner and the waste, or gravel filled trenches. The gas is removed (i.e. extracted) from the landfill by way of a piping or header system to transport the gas, and a suction pump to pull the gas from the fill through the headers [3,4,5] as shown in Figure 6-9.

Proper functioning of the gas collection system is ensured through the use of blowers. The blowers are operated such that a partial vacuum is created in the headers and collection system and the gas is pulled from the landfill. Although some gas will flow unassisted into the collection wells because of the slightly elevated internal pressure of the landfill, the flow rate is too low to ensure proper collection performance. Blowers both increase the flow of gas from the landfill and broaden the effective landfill area serviced by each gas well. The blowers can be adjusted either: 1) to pull gas from the fill and discharge it at atmospheric pressure for dis

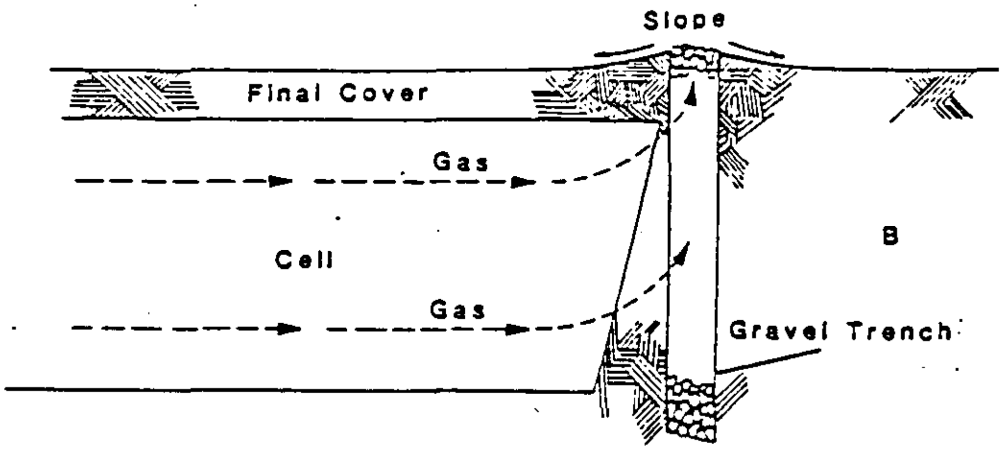

Figure 6-8. Dissipation of Biogas by Providing an Interceptor

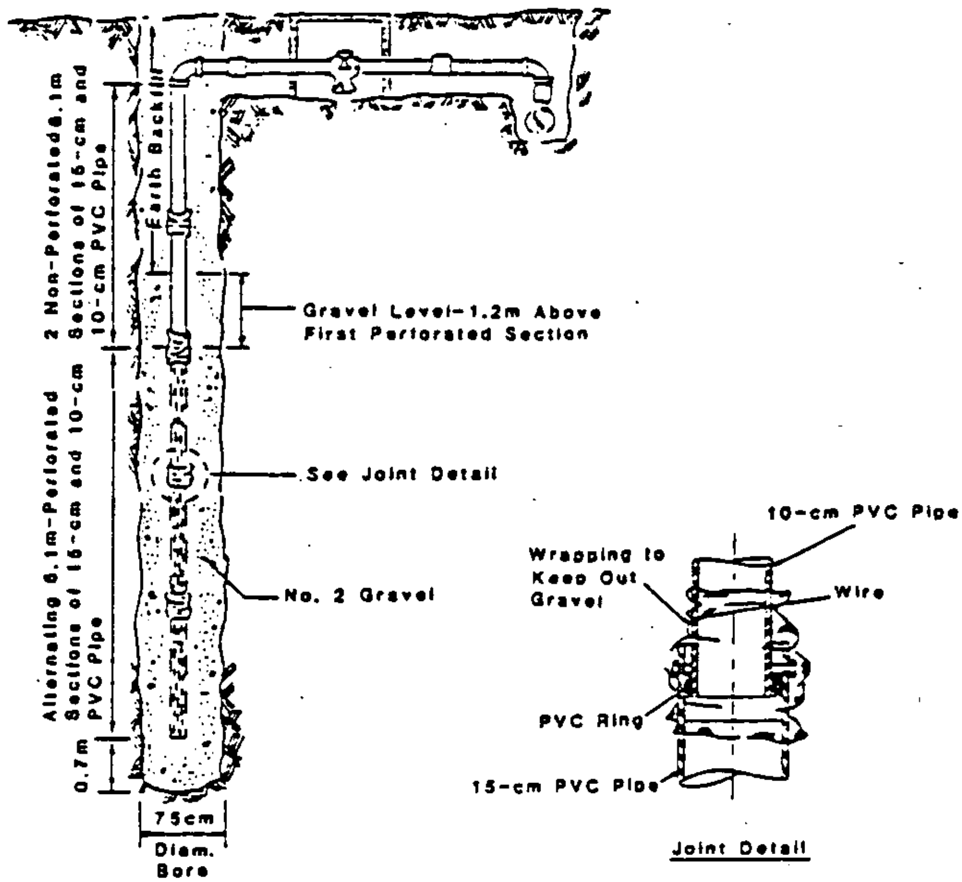

Figure 6-9. Gas Collection Well

persion, flaring, or combustion; or 2) to compress the gas to higher pressures for distribution or for further processing.

Gas can be recovered from a landfill not originally designed for that purpose by way of drilling a number of boreholes into the landfill at selected gas collection points, if the landfill has been properly operated during its lifetime. The boreholes should be 0.66 to 1 m in diameter. Their depth should be from 50 to 90% of the refuse depth. The boreholes are fitted in the same manner as collection wells used in fills designed for gas recovery. These collection wells are described in the following paragraph.

Collection wells are gravel-packed wells equipped with casings that extend the full depth of the fill. The casings are perforated in the section exposed to the contents of the fill. The casings must have telescopic connections between pipe segments such that connections between segments are maintained despite the significant and nonuniform subsidence characteristic of landfills.

The wells are built by progressively backfilling gravel around the gas collection pipe. The backfilled gravel (or a coarse substitute) serves as a highly permeable collection zone through which the gas flows into the collection pipe for removal from the well. The gravel area is covered with a gas-tight seal topped by backfilled soil to form a barrier against intrusion of external air into the well. Air intruding into a well (or into any part of the fill) would dilute the collected gas and thereby lower its heating value and complicate purification. Moreover, intruding air can lead to the development of serious problems. With respect to dilution, the concentration of nitrogen in the collected gas would be increased and the quality of the gas would be lowered correspondingly. A second, and perhaps more serious problem would come from the presence of oxygen in the air thus introduced. The oxygen would inhibit the activity of the methane-forming microorganisms. More importantly, it may raise the CH_4 and O_2 to explosive levels.

The arrangement of the collection wells is determined by their respective capacities as well as by the characteristics of the soil cover and provisions for directing gas movement in the fill. The dimensions of the fill area affected by a well is a function of the rate of pumping. For example, in a 12 m California fill having a gas well which was 6 m deep and was being pumped at 2.83 m^3/min the negative pressure ranged from -5.1 cm of water at the well to less than -0.8 cm at a distance of 30.5 m from the well. Advancing the pumping rate to 8.5 m^3/min brought the respective negative pressures to -17.8 and -2.54 cm [9].

It is important that the gas not be withdrawn at a rate great enough to pull air through the cover and into the fill, especially if the cover material is relatively porous. Air thus introduced into the fill leads to the problems described earlier.

6.3.3.2. Upgrading and Utilization

Unless the gas is to be used for simple space heating and household cooking, it should be upgraded before being put to use. Upgrading is especially essential if the gas is to be used as a fuel for an internal combustion engine, or is to be injected into existing transmission lines.

Quality and content of landfill gas does not compare favorably with those of natural gas. Moreover, its composition and other characteristics are more variable. With regard to the latter, the heat and moisture contents and oxygen concentration of landfill gas may vary as much as 50% from day to day and season to season. The heat content of landfill gases ranges from 7,450 to 22,350 kJ/m^3; whereas the lowest heat content of natural gas is 37,260 kJ/m^3. Moisture content is another problem. In landfill gas, it may be as low as 5% and as high as saturation. Oxygen content varies from trace levels to levels that are potentially explosive. However, the latter levels are reached very infrequently. Finally, the usually sizeable CO_2 and N_2 contents of landfill gas materially lower its heat content, and hence, the quality of the gas.

The utility of landfill gas can be increased significantly by upgrading it (the gas). Among the uses for upgraded gas are on-site generation of electricity and/or injection into a public utility transmission line. With respect to on-site generation of electricity, the gas can be used to fuel an internal combustion engine or to drive a gas turbine. If the gas is to be used in an internal combustion engine, it is compressed to about 5 psig. For a gas turbine, the pressure is increased to 150 psig.

Procedures are available for removing H_2O (dehydration), CO_2, and N_2 from landfill gas, and thereby considerably raising its heating value. For example, dehydration brings about an 10% increase in heating value. Dehydration accompanied by CO_2 and hydrogen sulfide (H_2S) removal results in a heating value of 22,360 to 26,000 kJ/m^3. Among the dehydration procedures are in-line gravity outflow; filtering; use of special solvents (e.g., glycol, polyethylene); passage through molecular sieves or permaselective membranes; and subjection to heating, air cooling, and refrigerant cooling. Of these procedures, passage through a molecular sieve combines a relatively low cost with high efficiency.

The triethylene glycol system (TEG system) is widely used for gas dehydration. Reasons for its extensive use are the high degree of hygroscopicity of glycols, their excellent thermal and chemical stability, low vapor pressures, and moderate cost. Briefly, the system operates as follows:

- Gas entering the system is compressed and bulk contaminants are removed in a "knockout" drum.
- After compression and cooling to remove the greater part of the water, the gas is passed through a triethylene glycol absorber/separator tower.
- Free liquids in the gas are removed as it (gas) passes through lower part of the tower (separator section) and begins to ascend to the upper or absorber section of the tower.
- In the upper section, the gas stream comes into contact with lean triethylene glycol on bubble-cap trays.
- Water, CO_2, and H_2S can be removed in a single operation by coupling the Triethylene Glycol system with a hot potassium carbonate scrubbing system.

A diagram of a dehydration process is shown in Figure 6-10.

Certain uses (e.g. space heating, household cooking) only require that H_2S be removed. Hydrogen sulfide can be removed by passing the gas through a dry-gas scrubber that contains a mixture of ferric oxide and wood shavings ("iron sponge"). The removal capacity of the mixture is 105 kg of sulfur/m^3 mixture. The mixture can be regenerated by exposing it to air. Doing so converts the ferric sulfide formed in the scrubbing operation to ferric oxide and elemental sulfur. A schematic diagram of an iron oxide process is given in Figure 6-11.

6.3.3.3. Economic Feasibility Factors

In terms of economic feasibility, several factors have a decisive part in determining the advisability of recovering gas from a landfill and putting it to use. Among the more important factors are size and location of the fill, permeability of cover material and surrounding soil layer, climatic conditions, and proposed use of the gas. With regard to permeability of surrounding soil layer, it is far more feasible to provide for an impermeable barrier between the landfill contents and the surrounding soil while the fill is as yet in the design stage than to install one after the fill has been completed. If the latest sanitary landfill design criteria are followed, permeability of cover and surrounding soil layer should not be a problem. Nothing much can be done about the size and location of a completed fill or of one presently in use. The same can be said of climatic conditions. Regarding utilization, if it involves a top quality gas, cost of upgrading may be prohibitively high and technological infrastructure may be inadequate – as well they could be in a developing country.

The mass of waste in the fill should be sufficiently great to ensure an eventual total gas output that would have a monetary and energy value in excess of that expended on necessary departures from conventional fill practice. The size of the fill must be great enough to ensure gas production over a period sufficiently long to warrant the installation of equipment needed for collecting, upgrading, and using the gas.

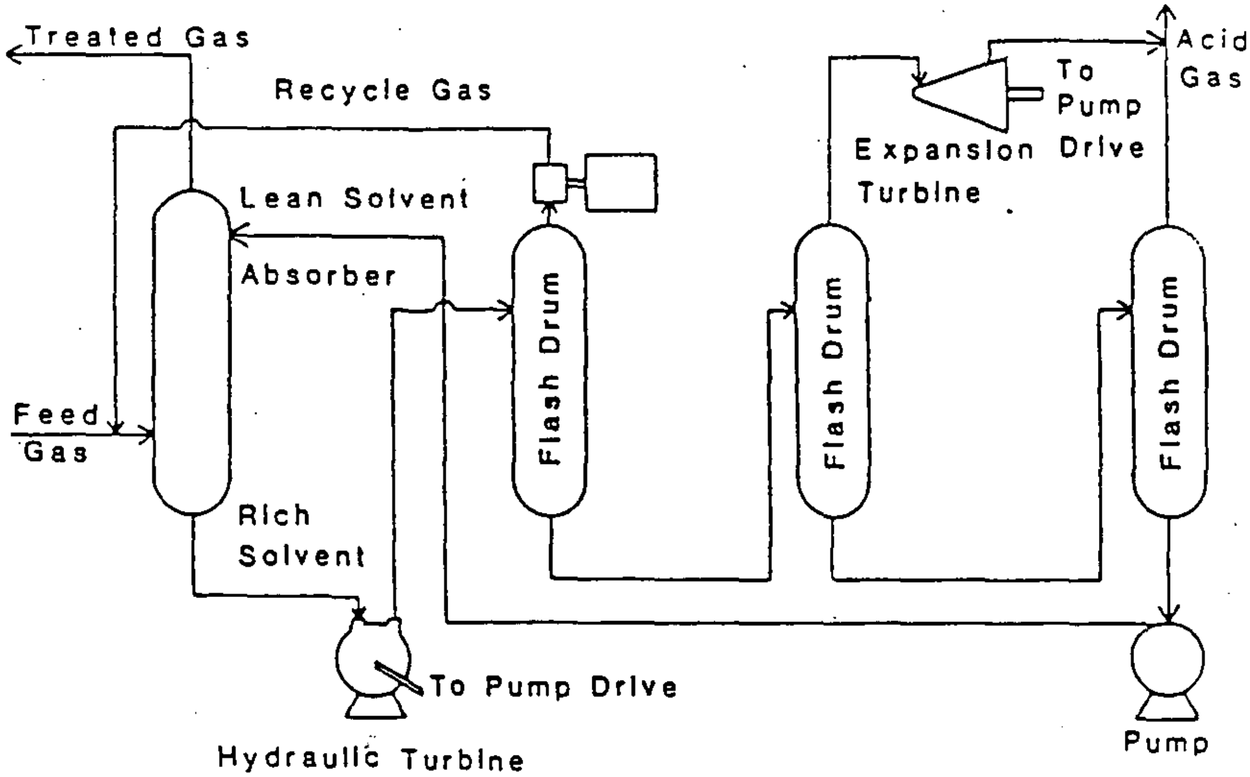

Figure 6-10. Diagram of a Glycol Dehydration Process

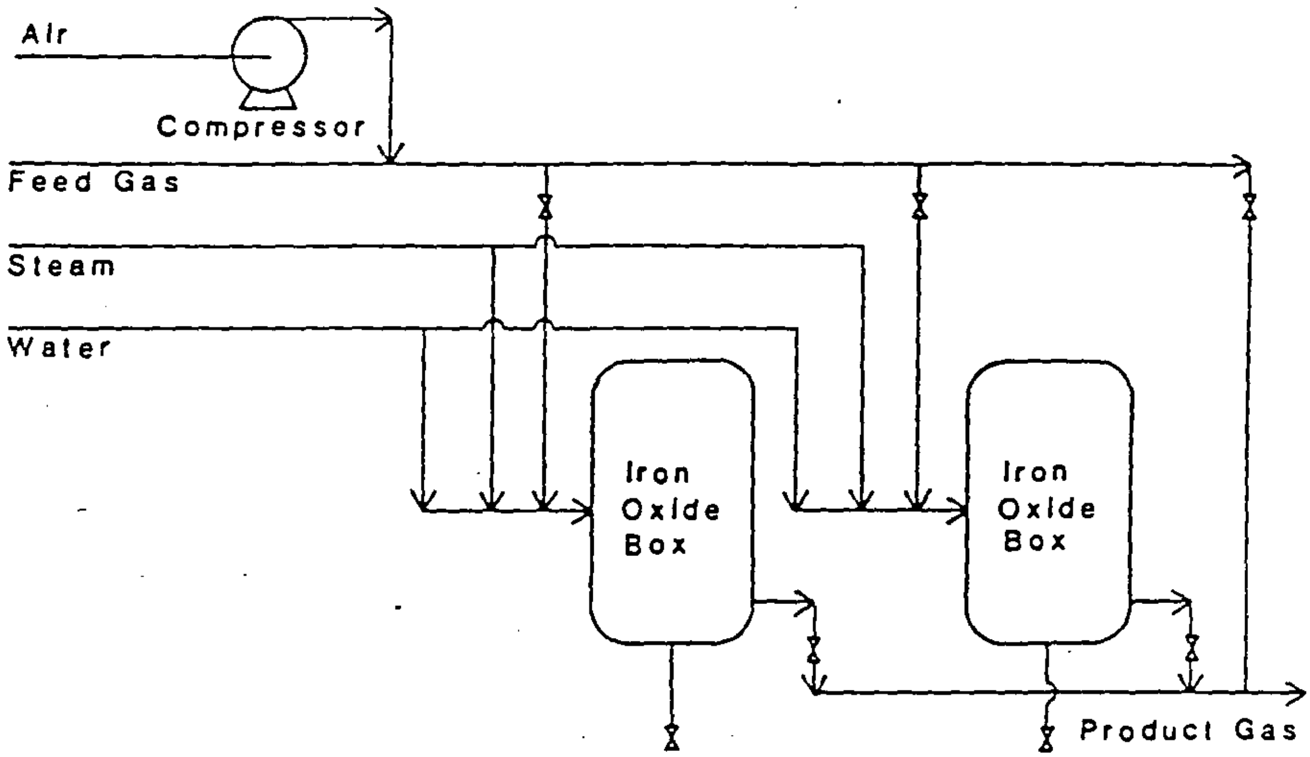

Figure 6-11. Schematic of an Iron Oxide Process

It would not be advisable to utilize a fill that is less than 13 m deep. The completed fill should contain at least about two million Mg of municipal solid waste at least [3]. In the same reference it is stated that at the peak rate of generation, raw gas production from such a fill would be from 23 to 34 m^3/min or 759 mmkJ/day.

It is readily apparent that the proposed use of the gas exercises a decisive influence on economics and energetics. In a developing country, a safe use might be as a fuel in steam generation or for an internal combustion engine after a minimum of cleaning. Because of the relatively high moisture content and presence of corrosive elements in raw landfill gas, on-site usage of the gas is to be recommended.

6.4. PEST CONTROL

A carefully planned and conscientiously applied pest control program is a key characteristic of an acceptable sanitary landfill operation Pests not only are nuisances, they also are potential hazards to public health. They are hazardous to human health because as a group, pests function as vectors for several serious and not-so-serious diseases. Because of this function, they often are referred to as "vectors." Vectors likely to be encountered at landfills include several types of flies, mosquitoes, and rodents (e.g., rats, mongeese). The unfavorable impact of the vectors is not limited by the boundaries of the landfill operation, it can extend over an appreciable distance beyond the fill. For example, an improperly managed landfill could support a rat population within a radius of 5 miles (8 km) beyond the confines of the fill.

Since the working face is the only area in which uncovered waste can be found with a well-managed landfill, it (working face) also is the area most attractive to and supportive of all types of vectors. Consequently, every effort should be made to reduce the size of this area. To prevent fly emergence, the thickness (depth) of a daily cover consisting of adequately compacted soil should be about 15 cm. In addition, it is essential that the landfill be subjected to a regular inspection and a fly control program. The program should take local and regional regulations into consideration.

Mosquito abatement is best accomplished by eliminating all standing water due to the fact that the larval stage of mosquitoes takes place in stagnant water. Consequently, a program of grading should be maintained for eliminating low spots on the cover of the fill. Waste materials that hold water should be covered immediately so as to keep them from serving as breeding sites for mosquitoes. Common examples of such materials are food and beverage containers and discarded automobile tire casings.

6.4.1. Birds

Although they may not be classified as "vectors" in the strict sense of the term, birds are discussed in this section because certain types become pests when taken in the context of a landfill operation. Birds attracted to landfills for food can become a hazard to aircraft and create a nuisance for operating personnel and neighbors. On rare occasion, certain species (for example, seagulls) can serve as vectors for certain diseases by way of their droppings or by serving as hosts to insectivorous vectors. As is true with problems arising from other pests, the bird problem is best met by rapidly and completely covering all wastes. Although a number of physical and chemical measures have been employed for controlling birds at a landfill, none as yet have been found to be consistently successful.

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Section 7

EQUIPMENT SELECTION

7.1. INTRODUCTION

7.1.1. Basic Concepts

The construction of a sanitary landfill requires proper equipment, suited to the work to be done, and typically involves a large capital investment. Equipment acquisition accounts for a large fraction of this investment. Furthermore, equipment operation and maintenance usually accounts for a large portion of the operating costs. Equipment selection must be in accordance with the landfilling method, and with the amount and efficiency of the machinery to be used in order to ensure successful operational and least cost procedures. The requirements must take into account the handling, compaction, and covering of the solid waste, as well as the construction of cells and the completion of general earth work. These activities must be in accordance with the sequential scheme of the work scheduled. The following basic items will be considered: a) spare equipment, b) multi-purpose equipment, and c) maintenance and repair.

a) Spare equipment: The recommended rate of backup equipment capacity is about 30%. This percentage is applicable to the total amount of work hours resulting from the design of the landfill operation, considering a maximum of 20 hours per day for the performance of heavy machinery. For instance, if the design specifies two machines operating a total of 36 hours per day, it is recommended to increase the number of machines to three. Although the purchase of spare equipment will strain the capital costs, it will also assure the continuity of service and extend the useful life of the machines. The backup capacity suggested is related to the type and frequency of the maintenance and repair operations.

b) Multi-purpose equipment: One way of balancing the cost of spare equipment is through the use of multi-purpose equipment that is able to perform more than one task. An example is a landfill compactor that can be utilized for either compaction or covering of solid waste, and to build haul roads. Another example would be a track-type loader with a multi-purpose bucket, which can be used for earth-moving and/or to push and compact solid waste. This strategy demands that the time requirement for each particular task and equipment be carefully recorded, supplementing the requirement for the spare equipment until the maximum useful hours for each piece of equipment is completed according to each specific task. The careful description of the methodology and schedule to be used will ultimately determine the equipment requirements. The next step would be the selection of the different pieces of equipment, considering first all the possible multi-purpose ones.

c) Maintenance and repair: This item requires detailed planning in order to satisfy the need for continuous service. It is recommended that these tasks be performed in the field in order to avoid the inconvenience of hauling the equipment to the workshop. Proper washing of all the rolling stock assigned to the handling of solid waste is required on a daily basis. Washing will help increase the useful life of that equipment and decrease potential friction resulting from solid waste blockage of the different mechanical components of the equipment. Inspection, cleaning, and washing of the machines' radiators is another task that shall be systematized for all equipment that comes into direct contact with solid waste. This operation must be performed at least once a week. The rest of the normal maintenance operations, described in the corresponding equipment manuals and/or catalogs, must be programmed in advance and performed according to the manufacturer's specifications. The repair operations should include light mechanical jobs (that require no more than two days to be completed). For that purpose, it is very important that all the necessary tools and a complete set of minimal spare parts be readily available at the site. The latter might not be necessary if a reliable supplier is able to provide the required parts within a reasonable period of time.

7.1.2. Factors

In addition to the obvious factors of suitability of particular equipment to landfill construction and operation and the probable multiple use of that equipment, three important factors enter into equipment selection:

1) amount of waste to be landfilled and the type of materials to be handled

2) economic feasibility

3) availability of maintenance and repair facilities and skilled personnel.

Economic feasibility and maintenance and repair are especially important in developing countries. However, failure to take into account any one of the three factors makes it virtually impossible to operate a successful landfill.

The importance of maintaining a steady flow of waste into the fill for the success of the operation is fairly obvious. Maintenance and repair are important as well, with the exception of the smallest of operations, a landfill involves a relatively large amount of materials handling (soil and municipal waste). The handling begins with site preparation, continues through operation of the fill, and ends with the closing of the fill. Because practicality sharply limits the amount of wastes and soils that can be handled manually, most operations must rely on mechanization. Under certain conditions, it is possible to rely on manual labor and on suitably modified farming equipment (i.e., tractors). Under the rigorous conditions characteristic of landfill operation, even the most rugged equipment breaks down frequently unless it is conscientiously maintained.

The need for conscientious maintenance takes on added significance in developing countries because replacement parts often are difficult to obtain. The problem is increased due to scarcity of skilled personnel.

7.1.3. Functions Served by Equipment

Basic functions served by landfill equipment fall into the following three categories:

1) functions related to soil (excavation, handling, compaction)

2) functions related to wastes (handling, compaction)

3) support functions

Based on the size of the operation, the same piece of equipment can be used for more than one of the three categories. Versatility becomes an essential consideration in equipment selection for situations in which equipment is likely to be used for more than a single function.

7.1.3.1. Relative to Soil

The excavation, handling, and compaction of soils used as liner and cover material are considerations when determining the function of the landfill equipment. Procedures and equipment for accomplishing those tasks differ only slightly from those used in other earth-moving operations. Consequently, the degree of mechanization and sophistication of equipment suitable for sanitary landfilling in a given situation would not differ markedly from that which is characteristic of other earth-moving operations in that area. This limitation extends to the procedural and equipment variations to meet specific requirements due to local topographic and soil conditions. For example, wheeled equipment usually is satisfactory for excavating soils in which sand, gravel, clay loams, and silt loams are the predominant constituents. On the other hand, tracked equipment would be indicated for the less workable soils. Other variations may reflect seasonal changes in soil properties. If soil is to be moved over distances shorter than about 100 m, loaders, dozers, etc. used to move waste in the fill can serve the purpose. Other equipment must be used for distances longer than 100 m.

Spreading and compaction have been discussed in other sections. Types of equipment are discussed in Section 7.2.

7.1.3.2. Relative to Wastes

Functions served by equipment relative to wastes are distribution, spreading, and compaction. With small-scale operations, and those sharply constrained by inadequate economic resources, equipment used for earth-moving is adequate for the waste handling functions. Distribution can be accomplished by confining the unloading of collection vehicles to the immediate vicinity of the working face, and thereby combining distribution and spreading. This dual function can be done by means of the bulldozer used to move, spread soil, and for compaction.

The compaction function demands full attention because of its many short- and long-term effects on the operation of the landfill and rate and extent of settling, but mostly because it is an important determinant of landfill capacity (Figure 7-1). Heavy equipment specifically designed for compaction would be more effective and efficient for this function than would be a piece of lightweight equipment designed primarily for earth-moving. However, weight can be significantly compensated by increasing the number of passes of lighter equipment over the waste mass. Spreading the waste in thin layers in addition to increasing the number of times the machine passes over the layers compensates for weight, also. The number of passes required to attain sufficient compaction also depends upon the moisture content and composition of the waste.

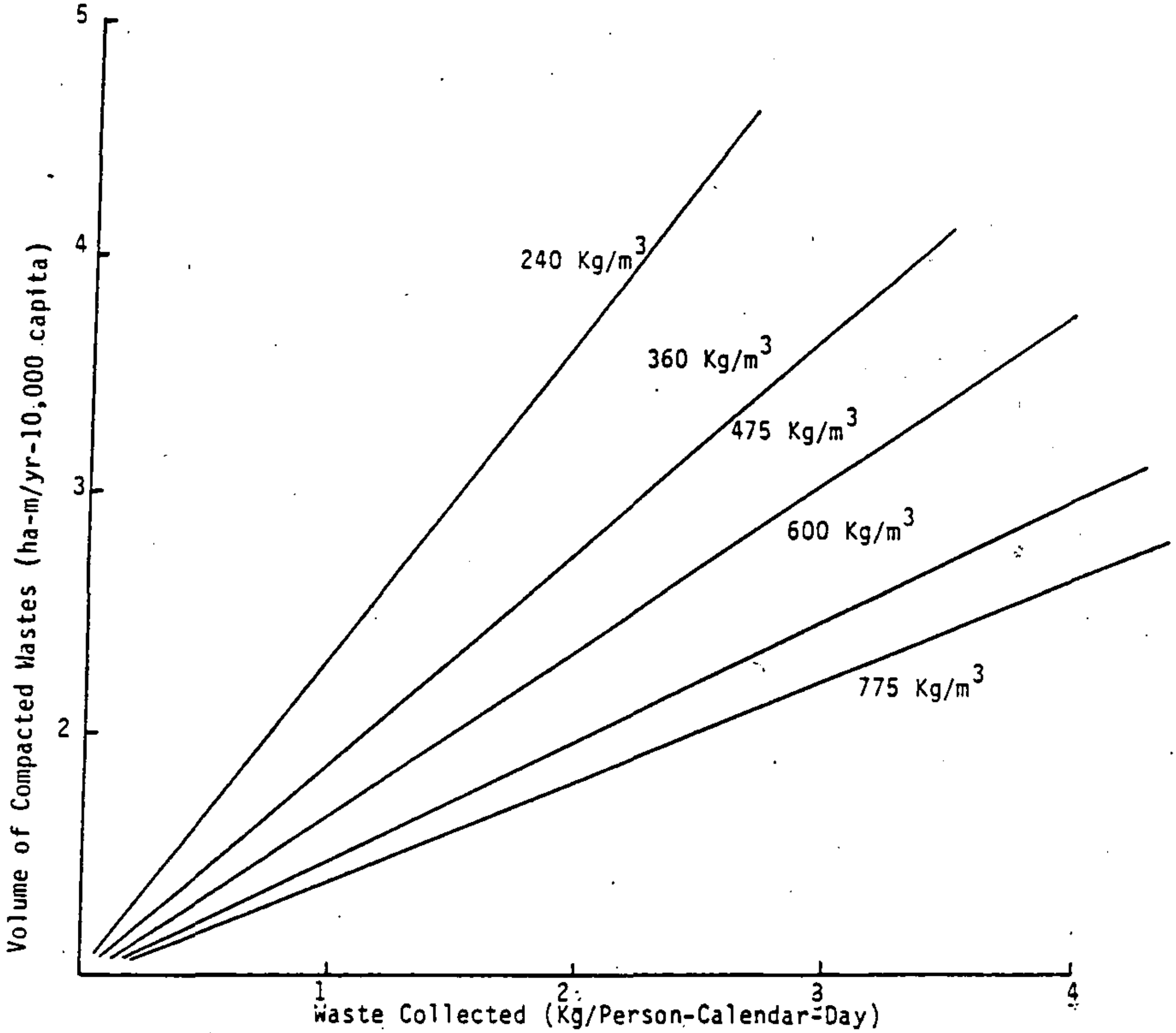

Figure 7-1. Relationship between Density and Volume per Hectare per Year

Landfill equipment must be rugged because operational conditions for equipment used at the fill are far from ideal. Radiators tend to become clogged and damaged, and the body and operating parts of the equipment can be damaged by protruding or dislodged wastes. Tires, even heavy-duty types, can be punctured or cut, which results in a short life span. This combination of unfavorable factors emphasizes the necessity of maintaining a parts inventory and an adequate repair and maintenance facility convenient to the fill.

7.1.3.3. Support Functions

With respect to the initial and subsequent construction phases of a landfill, support equipment would be needed for the installation of environmental control measures such as flexible membrane liners and covers, a leachate collection facility, and gas vents.

Support functions during the operational phase include extension and maintenance of roads to the working face of the fill, dust control, and fire protection. Unless the collection and transport vehicles are equipped with self-unloading features, support equipment might be needed to assist unloading. If labor is abundant, the unloading can be done manually. This would be the case with more primitive collection vehicles. Generally, some of the support functions (such as road extension and maintenance) during the operational phase can be supplied by the machine used for spreading and compaction.

7.2. EQUIPMENT TYPES: DESCRIPTIONS AND SPECIFICATIONS

7.2.1. Considerations

Factors which will be considered in this section are closely related to types and characteristics of earth-moving machines themselves. One characteristic that should receive careful consideration in equipment selection is the ability of earth-moving machines to perform multiple functions. More importantly, the selection should be based upon the primary function of each piece of equipment and its ability to handle those functions under the conditions peculiar to the site. Considerations related to primary function include those imposed by the soil, topographical, and climatic characteristics of the site; by waste characteristics, quantity, and delivery rates; and by budgetary constraints. Possible off-site use is another consideration.

7.2.2. Types of Equipment

The following paragraphs will deal with the main functions and characteristics of the different types of equipment used at sanitary landfills.

7.2.2.1. Track-Type Tractors with Push-Blades (Bulldozers)

Function: To distribute and compact solid waste, as well as to perform site preparation, provide daily and final cover, and general earth work. A photograph showing a bulldozer is presented in Figure 7-2.

Characteristics

Bulldozers are equipped with metal tracks having variable standard widths, such as 457 mm (18 in.), 508 mm (20 in.), 559 mm (22 in.) and 610 mm (24 in.). The tracks must be high enough to allow for better size reduction of the solid waste and to avoid possible sliding. The pressure exerted on the solid waste is achieved by distributing the weight of the machine over the contact surface. The following table presents some typical values for these machines.

Power (HP)	Weight (Kg)	Area of Contact with Refuse (m^2)	Pressure (Kg/cm^2)
140	11,750	2.16	0.54
200	16,100	2.76	0.58
300	24,770	3.19	0.78

The degree of compaction of the solid waste depends on the pressure exerted. As mentioned before, the thinner the layer of refuse, the more effective the pressure. Tracked machines are not very efficient at compacting solid wastes due to their low ground pressure.

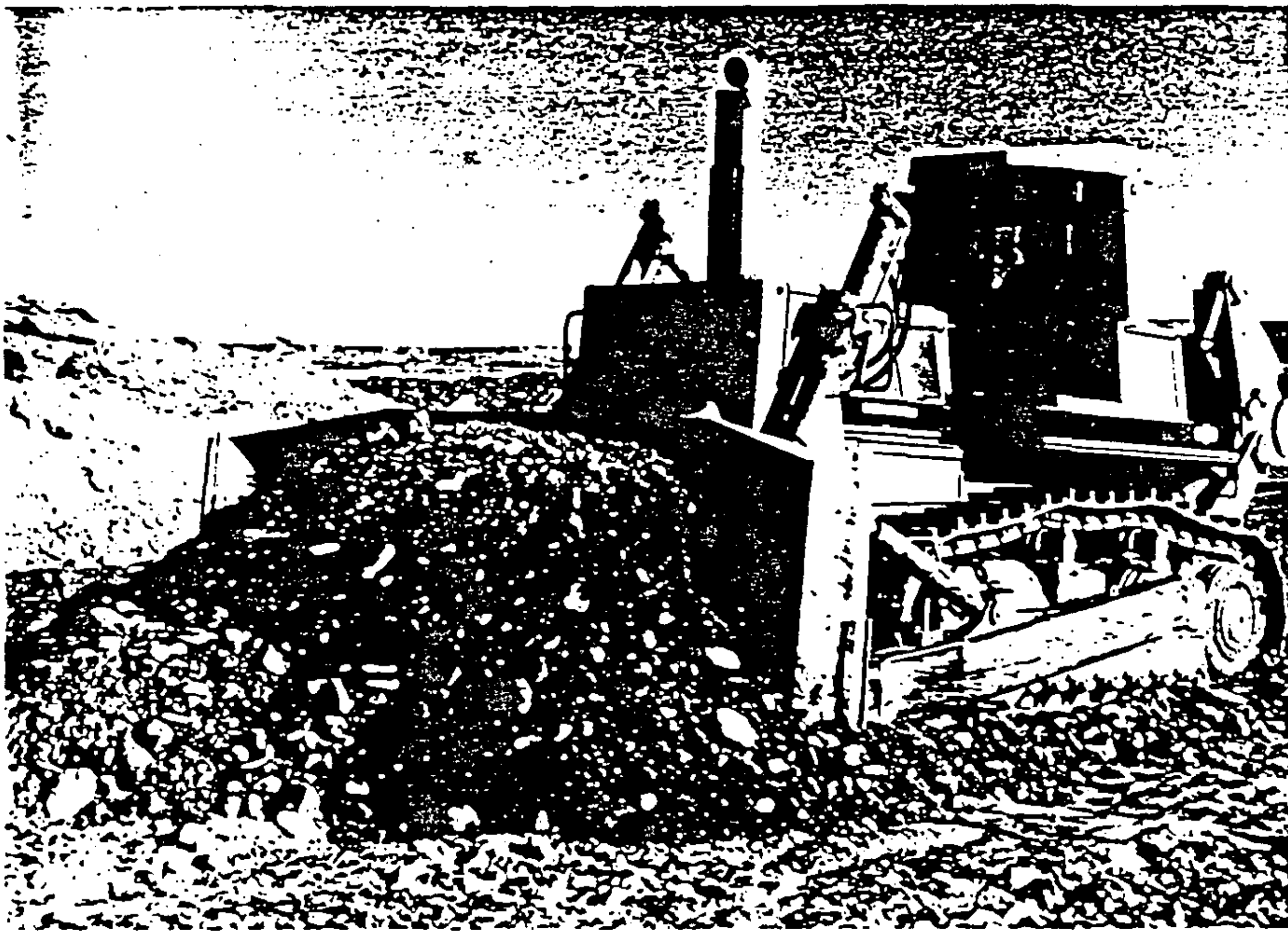

Figure 7-2. Bulldozer (Courtesy of Komatsu)

In order to obtain maximum efficiency from a track-type machine, it is very important that it be equipped with an adequate blade to push the material. The density of solid waste is about 3 times less than that of soil; therefore, it is possible to increase the capacity of the blade. The capacity of a blade can be increased by increasing its height. A steel screen can be used to increase the height of the blade. A screen avoids interfering with the operator's visibility. The dimensions of the blades vary with each model. For example, a typical 140 HP machine would have a blade with the following dimensions:

- Width (straight): 3.2 m.
- Height (without screen): 1.13 m.
- Height (with screen): 1.80 m.

The push-blade is controlled through a hydraulic mechanism. The estimated productivity for a typical 140 HP model, on flat surfaces, is on the order of 50 tonnes of solid waste per productive work-hour. On sloped surfaces the production will obviously decrease; thus, for a recommended maximum slope of 30°, production will be reduced to 30 tonnes per hour for the same 140 HP model.

7.2.2.2. Steel-Wheeled Compactors

Function: Spreading and compacting the incoming solid waste. A photograph of a steel-wheeled compactor is presented in Figure 7-3.

Characteristics

Compactors are typically equipped with a either a standard or turbo diesel engine. The metal wheels usually have alternated inverted V-shaped teeth that allow them to concentrate the weight on a smaller contact surface (than that for a track-type machine) and to exert a greater pressure on the solid waste. The following table indicates the average pressure for two types of machines.

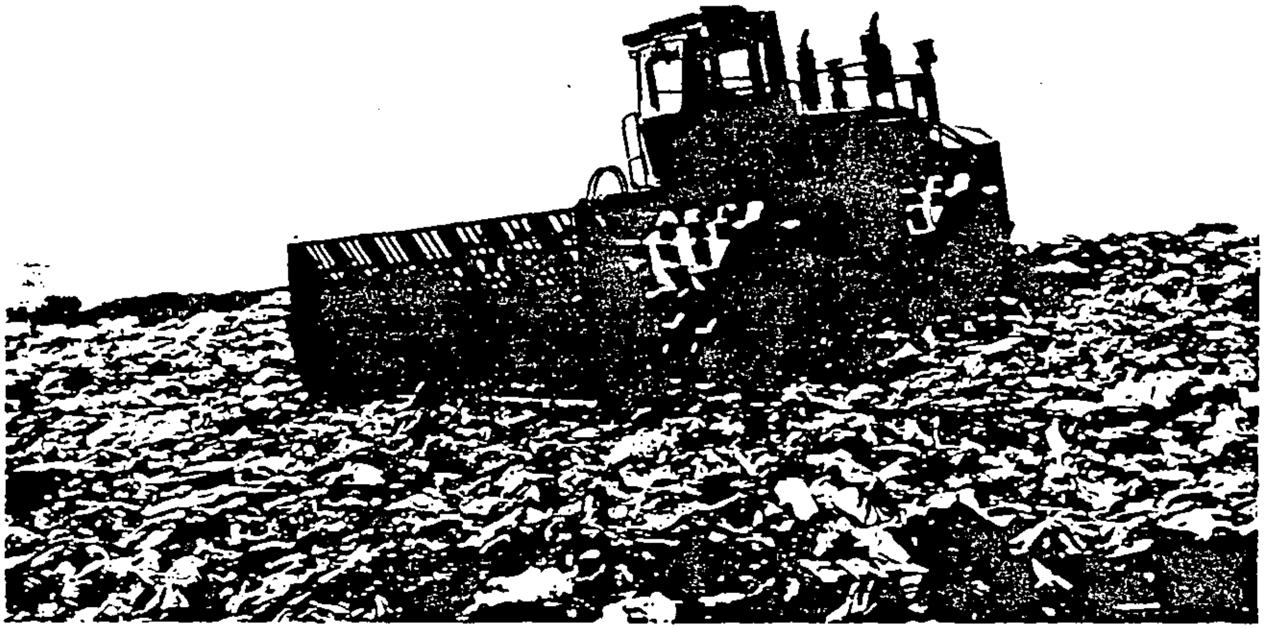

Figure 7-3. Steel-Wheeled Compactor (Courtesy of Ingersoll-Rand)

Power (HP)	Weight (Kg)	Average Pressure (Kg/cm^2)
150	16,000	75
175	26,000	120

Compactors are more versatile and faster than bulldozers. A typical 150 HP model will have a productivity of approximately 75 tonnes per hour on flat surfaces. The productivity decreases to about 50 tonnes per hour for a 30° slope.

Steel-wheeled compactors are equipped with a hydraulically controlled blade. The blade has an additional metal screen to increase its capacity. The common dimensions of the blade are as follows:

- Width: 3.04 m.
- Height (with screen): 1.88 m.

7.2.2.3. Wheel Loaders

Function: To excavate soft ground (i.e., ground offering little resistance), load the excavated material onto trucks, and pick up or transport that material to distances not greater than 50 m to 60 m (for optimum efficiency). A photograph of a wheel loader is presented in Figure 7-4.

Characteristics

Wheel loaders generally are equipped with a diesel engine and four-wheel drive. The front axis is fixed and the rear axis can oscillate. Models vary in power, ranging from 65 HP to 375 HP. The capacity of the bucket varies from 0.8 m^3 to 6 m^3. The most commonly used models are those falling in the range of 100 HP to 150 HP.

Some characteristics of these models are presented in the following table:

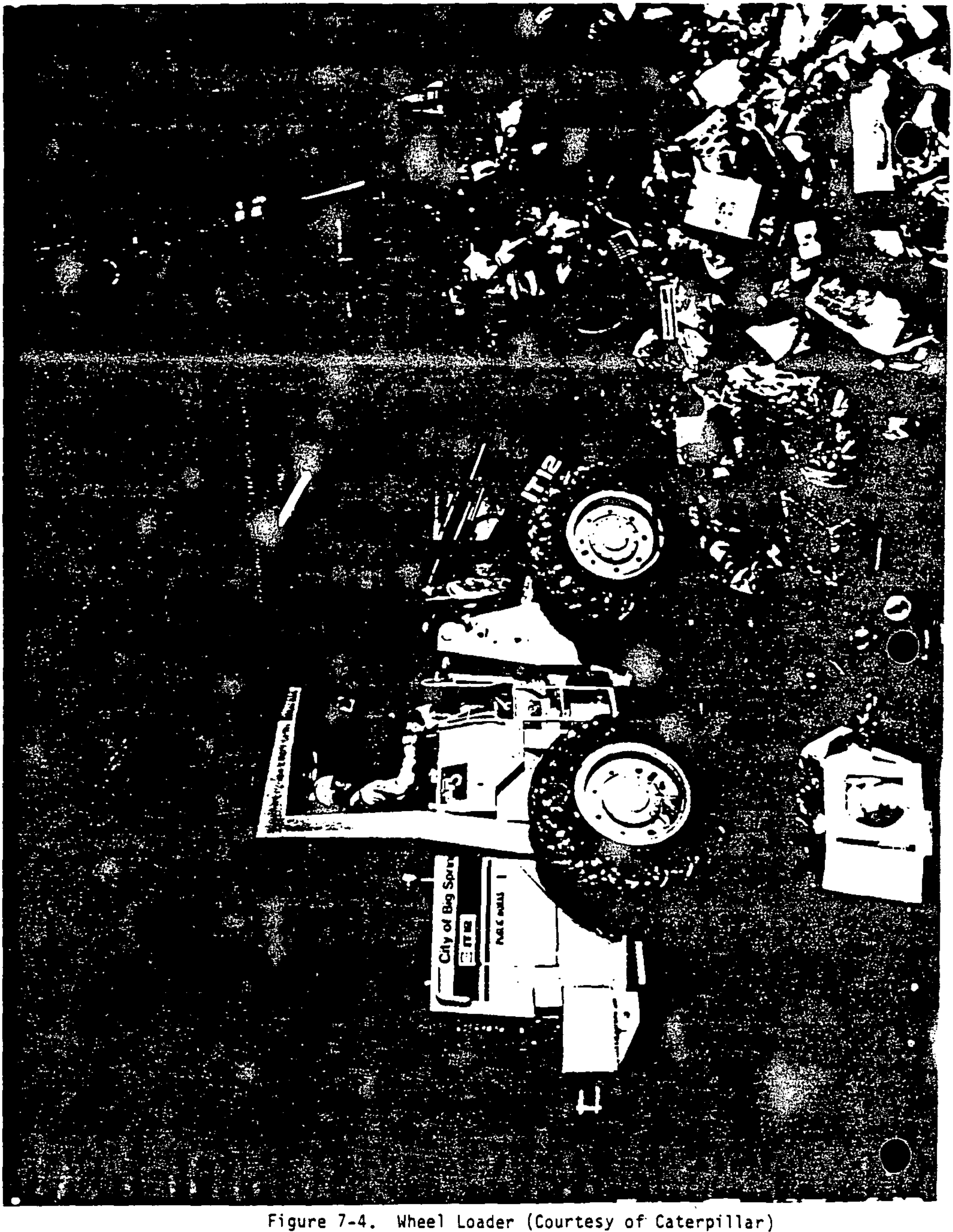

Figure 7-4. Wheel Loader (Courtesy of Caterpillar)

Power (HP)	Weight (Kg)	Bucket Capacity (m^3)
100	9,280	1.34 - 1.72
130	11,550	1.72 - 2.68

On soft ground, a 130 HP machine with a bucket capacity of 1.91 m^3 would be able to excavate and load a dump truck at a rate of about 160 m^3/work-hour. On tougher ground, the production would decrease, and this machine would probably need to be replaced with a more suitable piece of equipment to perform the excavation work.

Wheel loaders are also able to perform efficient earth work with clay-like soil, such as cell covering operations and preparation of sites to be landfilled.

7.2.2.4. Track-Type Loaders

Function: These machines can perform similar functions as the wheel loaders. Track-type loaders are also able to excavate tougher ground. Their optimum material transport distance does not exceed 30 m.

In emergency cases, track-type loaders can be used to handle (i.e, to spread and compact) solid waste. They can also be utilized to contour and level the cover material.

Characteristics

Tracked loaders are equipped with a diesel engine having power ranging from 65 HP to 275 HP. The following table presents some typical values for this type of equipment.

Power (HP)	Weight (Kg)	Area of Contact with Refuse (m^2)	Bucket Capacity (m^3)
95	12,340	1.54	1.34
130	13,700	1.79	1.34 - 1.74
190	21,300	2.48	1.90 - 2.48

The bucket in track-type loaders is easily and quickly operated through a hydraulic mechanism. Better efficiency and flexibility can be achieved with this equipment when it is equipped with multi-purpose bucket. This type of bucket performs four different operations according to the position in which the bucket is operated.

The bucket has a stationary section and a moving section. Movement can be controlled by the operator with the same lever control. The bucket can act as a:

a) Loader: opening the grapple will allow the material within the bucket to be totally discharged.

b) Dozer: lifting the moving section will allow pushing and levelling of the material.

c) Scraper: in soft and/or clay-like soils the cutting action can be controlled with the grapple opening.

d) Clamp bucket: can be used to lift materials like trunks and branches of trees. This can be accomplished by holding the material between the grapple and the edge of the bottom part of the bucket.

The versatility of this equipment is necessary in sanitary landfills; especially when the availability of equipment is limited.

7.2.2.5. Track-Type Excavators

Function: To excavate soil and load trucks, and to apply the daily or primary cover of solid waste (for the trench method). This equipment can also be used for certain tasks in earth work operations.

Characteristics

The excavator is equipped with a diesel engine and a hydraulic system to control the movement of the loading arms and that of the bucket.

The excavation cycle is composed of four phases:

a) Loading of the bucket.

b) Oscillation when loaded.

c) Discharge of the bucket.

d) Oscillation when unloaded.

The length of time (in seconds) of the excavation cycle depends on the size of the equipment and on the site conditions. Thus, when the excavation is more difficult or the trench is deep, the excavation procedure will be slower. The commercial literature of the different manufacturers available on the market indicate the calculation and/or estimate of the cycle time, according to the equipment model and each particular site condition (e.g., type of soil, excavation depth). The excavation depth (measured from the ground level) depends on the reach of the loading arms. The following table provides some typical values for this type of equipment:

Power (HP)	Weight (Kg)	Length of Loading Arm (m)	Bucket Capacity (m^3)	Maximum Depth of Excavation (m)
135	22,680	2.44	0.75	6.4
195	34,020	2.90	1.18	7.3
325	56,200	3.20	1.94	8.5

7.2.2.6. Front-Shovel Excavators

Function: To excavate trenches for the placement of solid waste, and to perform the daily or primary cover of these cells (without compaction nor levelling of the solid waste).

Characteristics

Front-shovel excavators are mounted on tracks and equipped with a diesel engine having power ranging from 140 HP to 169 HP. The tracks are formed by shoes having a width ranging between 666 mm (26 in.) or 762 mm (30 in.).

These machines are equipped with a boom that is operated mechanically. The length of the boom can vary from 10 m to 15 m. The operational turning radius varies according to the equipment from 6.1 m to 13.7 m. Depths of excavation of up to 7.5 m can be reached, depending on the type of soil and on the size and use of the bucket. The buckets generally have a capacity of either 0.57 m^3 or 0.76 m^3.

The weight of a 140 HP equipment in operational conditions is about 20,500 Kg.

7.2.2.7. Motor Grader

Function: The construction and maintenance of hauling roads, embankments, drainage ditches and the profiling and levelling of cover material.

Characteristics

Graders are equipped with a diesel engine, rubber wheels and power steering.

Typical weight and power for this type of equipment are presented in the following table:

Power (HP)	Weight (Kg)
125	12,000
220	18,280

The standard blade for these machines has the following dimensions:

- Length: 3.962 m.
- Height: 0.71 m.
- Thickness: 25 mm.

The blade can reach a maximum slope of 90°, and is able to adopt different positions.

These machines can carry a scraper as an additional equipment. The scraper is used to rip the ground or to mix soils. It has 11 teeth shaped as hooks, with replaceable ends.

The scraping depth varies according to the model from 0.15 m to 0.22 m.

The approximate earth moving capacities for loaders and scrapers are presented in Table 7-1.

7.2.2.8. Sheeps Foot Compactors

Function: Compaction of soils and embankments.

Characteristics

Sheeps foot compactors can be either self-propelled or pulled by tractors (165 HP).

Basically, they are formed by two cylindrical drums with "feet" that convey pressure to the soil to be compacted. The drums can be ballasted with water. The average pressure depends on the type of "foot" used. There are several designs. Thus, for the case of two cylindrical drums having the following dimensions:

- Diameter: 1.53 m
- Rolling width (2): 3.4 m
- Number of "feet" per drum: 120
- Weight of drum with water ballast: 12,600 Kg

The pressures exerted on the ground, according to the type of "foot" would range from about 27 to 82 kg/cm^2.

Since these machines have a mechanism that allows oscillation of the drums, uniform compaction can be achieved even on irregular layers of soil.

Table 7-1. Approximate Earth Moving Capacities for Average Soils

Capacity of Units (Cubic Yards)	One Way Haul Distance - Ft. 0	100	200	300	400	500	600	800	1000
	Cubic Yards/Hour								
Tracked Loader									
1 1/4	40	30	25	20	15	-			
1 1/2	50	35	30	25	20	15			
2	80	60	45	40	35	30			
Pulled Scrapers									
14					190	170	150	125	100
12					165	145	125	100	75
7					90	80	75	60	55
Self-Propelled Scrapers									
20						400	380	340	300
14						250	240	210	180
11						170	160	140	120

7.2.2.9. Pneumatic Tire Compactors

Function: Adapted to the compaction of topsoils and sub-layers, especially when loamy material is present. High and uniform densities can be obtained throughout the thickness of the layers.

Characteristics

These machines can be either self-propelled or hauled by tractors. The load is transmitted to the ground through the contact surface of the tires, which form the rolling unit. Typically, these compactors have seven tires.

The ballasting of the equipment is done with wet sand (density = 2,000 Kg/m^3) which can reach weights ranging from 13,000 Kg to 35,000 Kg. The operation is as follows:

- Initially, low tire pressures are used in order to have greater contact areas and less compaction resistance.
- During the compaction process, the tire pressures are increased, reducing the contact area and, therefore, the compaction pressure.

These machines have a device that allows proper control of the pressure of the tires.

7.2.2.10. Self-Propelled Vibratory Drum Compactors

Function: Adapted to effectively compact soils, cover material formed by normal soils, granulated or clay-like.

Characteristics

Vibratory drum compactors have a metal drum on the front. The approximate dimensions of the drum are: width, 2.15 m; diameter, 1.5 m. The compactors have pneumatic tires on the back.

The vibration system is operated by a hydrostatic engine directly connected to the vibrator, allowing variations in amplitude and frequency, independent from the speed of the propelling engine. The vibration frequency can be regulated to reach a maximum of up to 2,000 vibrations per minute.

The weight of the equipment varies according to the model (9,000 Kg to 12,000 Kg).

7.2.2.11. Drainage of Ditches

There are two types of equipment that can be used to perform this task:

a) Centrifugal pumps driven by internal combustion engines: Power of the engines varies between 8 HP and 15 HP. It is possible to obtain flows from 6 m^3/h up to 30 m^3/h, depending on the efficiency of the system.

b) Submersible pumps with electric motors: These pumps are recommended for the handling of leachate. The range of flows for these pumps varies between 8 m^3/h and 15 m^3/h.

7.2.2.12. Rubble Shredders

The purpose of these machines is to shred large soil particles in order to obtain adequate size distribution of the cover material.

These machines usually have power of 6 HP and a production rate of 2 m^3/h. Shredders usually are operated by an internal combustion engine or an electric motor.

7.3. INSPECTION AND MAINTENANCE

As previously indicated, the costs associated with operation and maintenance of the equipment used in landfills account for a major portion of total operation costs. Disregard to both frequent inspection and a systematic maintenance program can lead to severe problems. The problems can take the form of machinery breakdowns, inadequate compaction or insufficient cover material. Breakdowns can be costly. Poor compaction and lack of cover material can cause negative environmental impacts.

Consequently, it is extremely important to institute a program for inspecting the equipment used on the landfill. Some of the equipment may require daily inspection and others may only need weekly inspection. In addition, continuous operation and low frequency of breakdowns can only be achieved through the implementation of preventive maintenance program. The maintenance program should be based on guidelines provided by the equipment manufacturers.

Facilities must be provided for carrying out the various maintenance procedures. Facilities include garages, tools, testing equipment, and a stock of replacement parts. Equipment manufacturers should provide a list of basic replacement parts and the name and location of a source for additional parts. Ideally, the source should be located within the country.

A summary of typical equipment needs as a function of waste generated per day is presented in Table 7-2.

REFERENCE

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Table 7-2. Equipment Needs as a Function of Waste Generated

Daily Tonnage	Equipment			
	Quantity	Type	Weight (lb)	hp
0-20	1	CD	<15,000	<08
		CL	<20,000	<70
		RTL	<20,000	<100
		SWC	N/A	N/A
20-50	1	CD	15,000-20,000	80-110
		CL	20,000-25,000	70-100
		RTL	20,000-22,000	100-120
		SWC	Smallest Available	
50-130	1	CD	20,000-25,000	110-130
		CL	25,000-32,000	100-130
		RTL	22,500-27,500	120-150
		SWC	As Available	150
130-250	1	CD	30,000-35,000	150-180
		CL	32,500-45,000	150-190
		RTL	27,500-35,000	150-190
		SWC	30,000-42,000	150-190
250-500	1-2	CD	47,500-52,000	250-280
		CL	Combination	
		RTL	Combination	
		SWC	Combination	
		S		
		DL		
		WT		

CD: Crawler dozer
SWC: Steel wheeled compactor
WT: Water truck
CL: Crawler loader
S: Scraper
RG: Road grader
RTL: Rubber tired loader
DL: Dragline

Section 8

OPERATION

8.1. INTRODUCTION

This section presents an approach for the efficient operation of a solid waste landfill. A detailed outline of all daily activities is the basis of an effective operating plan. The plan must be sufficiently flexible to encourage managerial ingenuity in reaching the objectives, and rigid enough to support proper operations. An efficient operating plan implies equipment that is compatible with the characteristics of the solid waste, the site conditions and the landfilling method.

In this section, site operation is divided into two parts: 1) operational procedures that do not depend on the method of landfill used; and 2) operational procedures that are specific to the method of landfilling.

8.2. GENERAL OPERATING PROCEDURES

Operations factors that must be considered for all types of landfilling include:

- Operating hours
- Site preparation and maintenance
- Inclement climate
- Environmental control

8.2.1. Operating Hours

Operating hours typically are set by the collection schedules. It is possible, however, to modify collection practices to accommodate site operations. Generally, sites in the U.S. are open from about 6:00 a.m. to approximately 6:00 p.m. The hours of operation should take into consideration local traffic conditions.

Operating hours may be modified based upon the quantity of waste produced during a certain time of the year. If the site is not open 24 hours per day, the gates should be closed sufficiently early to allow for waste covering and cleanup. Containers (dumpsters) may be placed outside the gate to allow for the disposal of small quantities of wastes after operating hours.

Personnel should arrive at the facility early enough to prepare the equipment and the site prior to the arrival of collection vehicles. Some of the tasks that are carried out before the arrival of the collection vehicles include: snow plowing (where appropriate), relocation of wind fencing, maintenance of equipment, fueling, preparation of unloading areas, and cleaning of roads.

8.2.2. Site Physical Maintenance

8.2.2.1. Site Preparation

As the working area gets filled and additional areas are required for filling, those new areas should be cleared, excavated, and lined. Similarly, as the working areas are filled, a final cover should be applied on them as soon as possible.

The sites must be prepared and constructed according to design specifications. Site preparation and construction include:

- clearing and grubbing
- installation of liners and leachate collection systems
- erection of building structures
- installation of utilities
- constructions of roadways
- soil stockpiling

8.2.2.2. Road Maintenance

Maintenance of access roads at landfill sites is a continuous process. Road maintenance can be, and often is, an expensive operation. Regardless of the type of surface (soil, gravel, or pavement), the roads must be inspected and repaired frequently. Typical repairs include cleaning, adding or grading soil and gravel, filling holes, and cleaning drainage ditches. Since road maintenance can be a costly operation, it often is neglected. Lack of proper road maintenance leads to equipment damage, unnecessary delays, and safety problems. A few sections of well-marked rough areas can be left on some roads in order to control excessive speed.

8.2.2.3. General Maintenance

All waste treatment and disposal sites require continuous maintenance. The site manager should prepare a detailed maintenance schedule. Specific dates should be scheduled for the performance of tasks. The types of tasks that are required include:

- the removal of litter
- maintenance of gate, fence and building
- maintenance of drainage system and final cover
- the preparation and upkeep of final site maps

As areas of the site are finished, a series of maps indicating phased filling should be maintained and updated. The maps should identify areas used for special wastes, the fill depth of the various areas, as well as other site specific features. An example is given in Figure 8-1.

8.2.3. Inclement Climate

The weather plays an important role in the successful operation of a landfill site. Long periods of excessive rainfall, freezing temperatures, or extreme heat can disrupt routine operation of a landfill. The relative amount of rainfall during site preparation has a direct impact on the moisture content of the soil as well as on groundwater saturation levels. Both of these pa

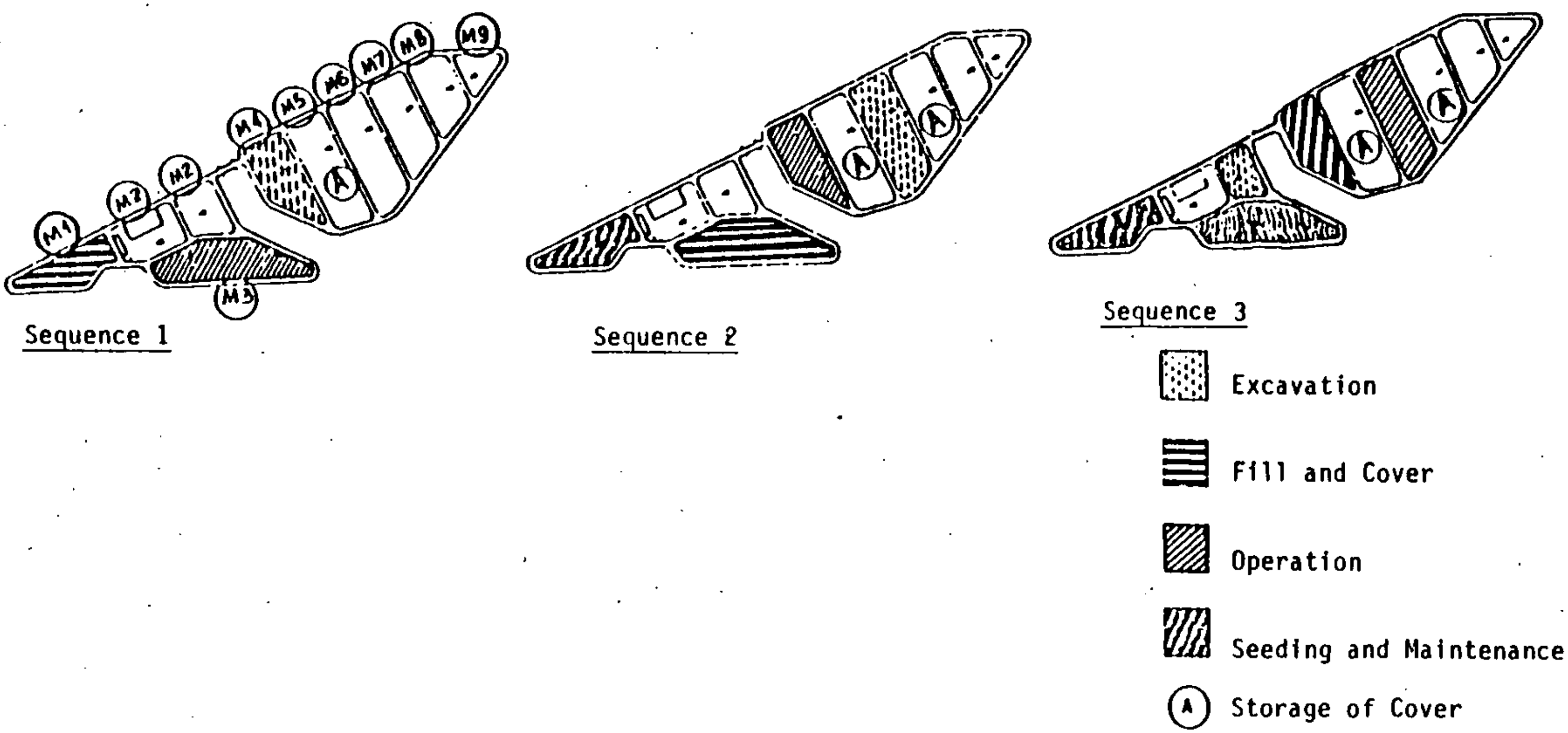

Figure 8-1. Sequence of Operation

rameters are important in the control of soil strength and permeability during construction of a clay liner or other compacted soil components. Extremely low temperatures (i.e., freezing conditions during construction of the landfill site) also impact soil workability and permeability. Temperature levels also affect the installation of flexible membrane liners (FML) in particular seaming requirements.

Climate can also have an impact on the performance and operation of the facility. This is particularly true in less developed countries where heavy rainfall often results in extremely muddy access roads and unloading areas thus leading to long delays. Extremely high precipitation also has an impact on the water table. An excessively high water table may increase the groundwater pressure on the sidewalls of a trench operation resulting in unstable conditions. One of the most effective means of dealing with high rainfall is to construct and maintain drainage canals on the periphery of the site to divert water away from the wastes. In the event that the site is relatively flat, leachate collection systems help to reduce some of the problems associated with increased precipitation. However, if the collection system does not have the capacity to deal with the extreme conditions, liquid pressure in the facility will increase. High liquid pressure may result in migration from the site. Decreased soil density, which may cause liner instability, may also result from heavy precipitation.

On the other hand, very dry conditions may make the soil hard to excavate or compact. In addition, in the absence of moisture, organic matter does not readily breakdown. In arid areas, evaporation from the ground is greater than rainfall. Consequently, very little or no leachate is formed from the MSW after disposal. Landfills in arid and semi-arid regions may be operated without liners and leachate collection systems. In fact, it has been indicated that the best sites for landfills are in arid regions [10]. Dry soil may also lead to the formation of cracks and increase the permeability of the soil. Freezing temperatures may cause stockpiles soil to freeze and become unusable. In extreme cases, very low temperatures may affect the proper operation of site equipment as well as main components of the leachate collection system that are located above the frost line. Efficient operations require that operational problems of this nature be anticipated and contingency plans be developed in order to address the problems satisfactorily. In Table 8-1 are listed problems due to inclement weather and their potential solutions.

8.2.4. Waste Receipt and Vehicle Routing

Every landfill site should maintain a controlled gate. A gate would enable operators to: 1) keep records of weights or volumes of incoming loads, 2) direct incoming vehicles, and 3) reject materials that can not be disposed on the site. A sign which clearly indicates site regulations, operating hours, user (tipping) fees, emergency telephone numbers, permit information, and other relevant data should be placed on the gate.

Monitoring the weights, or volumes, of residues received at the site allows operators to assess the efficiency of the operation in terms of land use and compaction. These records would also allow the operator to predict, with a certain degree of accuracy, remaining site life. Remaining site life can be calculated in conjunction with aerial surveys. Aerial surveys maybe unnecessary and too costly for certain locations. In addition, user fees can be properly and accurately assessed by monitoring the quantity of waste received. There are various methods to monitor the quantities of waste received. Most large, modern landfills utilize a truck scale. Although it is preferable to monitor weights, small sites may opt to record volumes. In the absence of a scale, weights may be recorded over a short term using a scale located away from the site. The results of the survey can be used to develop user fees and evaluate waste receipt over a year. This method does not take into consideration any changes in the waste stream.

8.2.5. Environmental Control

In most situations, regulations are established which require the inclusion of environmental controls to protect the environment from the potential negative impacts of landfills. The most commonly used types of environmental controls include impermeable barriers (liners), leachate collection systems, and cover systems. The proper design and construction of these

Table 8-1. Inclement Weather Practices

Problem	Solution
	Wet Weather
Access roads (muddy)	• Add cinders, crushed stone, or demolition debris • Maintain a special working area that has permanent roads
Unloading area (muddy)	• Stockpile well-drained soils and apple as necessary • Keep compactive equipment off area by unloading and moving refuse perpendicular to area • Grade unloading area slightly to permit runoff
Soil is wet/unworkable	• Maintain compacted, sloped stockpiles and/or cover with tarpaulin
Soil permeability/density varies from design	• Do not compact soils in overly wet weather • Cover soil
Leachate collection system clogging from runoff	• Add barriers for fines • Periodic cleaning of pipe network
	Dry Weather
Dry soils – unable to excavate and increased permeability	• Cover soil to prevent drying • Wet soil
	Cold Weather
Soil (freezes)	• Insulate stockpiles with leaves, snow, or straw • Salt soil • Continually strip and cut soil • Maintain well drained soil/sand • Use hydraulic rippers on frozen soil

controls were discussed in Section 5. Environmental controls are necessary to protect the environment during landfill operation and during closure. These practices are described in the following sections and are outlined in Table 8-2.

8.2.5.1. Leachate

Leachate is a liquid that results when rainfall or other type of liquid enters a waste disposal facility and percolates through the wastes. Leachate typically contains high concentrations of suspended and soluble chemicals that were originally part of the waste. The characteristics of leachate vary from site to site and depend on several factors, such as the type of waste, moisture content, quality of the cover, climatic conditions, and others. The characteristics of leachate from municipal solid wastes are presented in Table 8-3.

The production and control of leachate is an important aspect of landfill operations because the liquid may migrate from the boundaries of the facility and contaminate both ground and surface waters [1]. The rate of leachate production can be substantially reduced by covering the solid waste during facility operation with a material having a low-permeability. Leachate production can be controlled after closure by installing a final cover system that minimizes the amount of liquid that penetrates the waste. Low-permeability liners (i.e., compacted soil, flexible membranes) serve two main purposes in the control of the quantity of leachate. A discussion on permeability and covers is presented in Section 5.

1) Liners prevent groundwater from entering the facility and contributing to the leachate volume.
2) Liners prevent the leachate from migrating outside of the disposal area.

In most cases, leachate will be produced in municipal solid waste disposal facilities. Therefore, these facilities generally are required to be equipped with leachate collection systems to prevent the accumulation of leachate pressure on the liner. Leachate production, collection, and treatment system operation are discussed in references 2, 3, and 4.

Table 8-2. Environmental Controls

Environmental Problems	Safety Program	Maintain Washrooms for Personnel	Training of New Personnel	Maintain Road Markings and Trench Barriers	Maintain Fencing	Apply Insecticides	Maintain Buffer Areas and Grass	Proper Equipment Maintenance	Spray Water/Oil/Liquid Asphalt	Truck Wash Pad (to clean trucks)	Maintain Grass Waterways, Diversion Ditches, Rip-Rap	Final Grading of Disturbed Areas	Chemical Masking Agent	Workers Supplied with Aerators	Cover Solid Waste Daily	Water Diverted Away from Site	Construct Low-Permeability Liners and Leachate Collection Systems	Construct Low-permeability Final Cover System	Extermination Program
Leachate			●					●				●			●	●	●	●	
Spillage		●	●	●			●												
Siltation and Erosion			●	●		●	●			●	●	●				●			
Mud		●	●	●		●	●	●	●	●		●				●			
Dust		●	●			●	●	●	●	●		●		●					
Vectors		●	●		●		●								●			●	●
Odors		●	●			●	●		●				●	●	●			●	
Noise			●		●	●	●	●											
Aesthetics		●	●	●	●	●	●			●	●	●			●				
Safety	●	●	●	●	●		●	●				●		●	●				
Birds			●												●				●
Litter			●		●				●						●				
Fires			●					●	●						●				

Table 8-3. Summary of Leachate Characteristics from Municipal Solid Wastes [9]

Components	Range of all values (mg/L)
Alkalinity ($CaCo_3$)	0 - 20850
BOD (5 day)	9 - 54610
Calcium	5 - 4080
COD	0 - 89520
Copper	0 - 9.9
Chloride (Cl^-)	34 - 2800
Hardness ($CaCo_3$)	0 - 22800
Iron - Total	0.2 - 5500
Lead	0 - 5.0
Magnesium	16.5 - 15600
Manganese	.06 - 1400
Nitrogen-NH_3	0 - 1106
Nitrogen-Kjeldahl	0 - 1416
Nitrogen-NO_3	0 - 1300
Potassium	2.8 - 3770
Sodium	0 - 7700
Sulfate ($SO_4^{=}$)	1 - 1826
TDS	0 - 42276
TSS	6 - 2685
Total Phosphate	0 - 154
Zinc	0 - 1000
pH	2.7 - 8.5[a]

[a]Excluding incinerator residue.

8.2.5.2. Siltation and Erosion

Improper grading generally leads to production of run-off containing high concentrations of silt. Grades with a slope of 2% to 5% should be maintained, if possible, where feasible to promote surface drainage and at the same time minimize flow velocities. Denuded areas should be kept to a minimum during site operation. Ongoing construction and maintenance of sediment control devices (e.g. grass waterways, diversion ditches, rip-rap, sediment basins) are critical for an environmentally sound operation. During final closure, proper final grading, seeding and maintenance of a final cover system help prevent long-term erosion and siltation problems.

8.2.5.3. Mud

Heavy rains and snow melt during the spring can result in the production of mud. In order to reduce the negative impact that mud can pose on daily operations, access roads should be paved or graveled. Another alternative is to mix soils of large particle size such as sand and gravel into clay soils in roadways where vehicle traffic is heavy. Mud can be tracked onto public roadways by landfill equipment or collection vehicles and can result in significantly poor public relations for sanitary disposal facilities [5]. Ideally, an area for washing should be installed near the gate to the facility in order to remove the mud from transport vehicles. In some cases, landfill sites have specific areas that are used only during poor weather conditions and when conditions in other areas of the facility are muddy and would make operation difficult. Wet weather operation areas should be located as close to the main gate as possible in order to reduce on-site travel.

8.2.5.4. Dust

Dust in a landfill site is generated by collection vehicles, and heavy equipment moving over dry dirt roads and by the wind. Dust can also be generated during, the discharge, placement, and compaction of dry waste materials or during the excavation and movement of dry soils. In order to reduce the amount of dust generation, access roads should be graveled or paved. As an alternative, water or other environmentally acceptable dust control chemicals can be applied to dirt roads on a continuous basis. The relatively common practice of applying waste oils to roads should be discontinued. Excavating or moving soils when they are damp will limit dust production. Similarly, dry waste materials should be slightly moistened prior to disposal. Another means of reducing the total amount of dust generated from a particular facility is to revegetate completed areas as soon as possible.

Landfills should be equipped with a water truck or trailer to moisten dirt roads and working areas for dust control.

8.2.5.5. Vectors

Flies, mosquitos and rodents may be present at landfill sites. Vectors can be controlled by frequently placing an adequate quantity of compacted soil over the wastes. It has been demonstrated that a daily cover consisting of 6 in. (15 cm) of compacted soil having a low clay content will prevent the emergence of flies. However, even under the best conditions, a landfill should have a regular inspection and fly control program. Mosquito control is best accomplished by preventing the accumulation of stagnant water anywhere on the site. The accumulation of stagnant water can be prevented by filling low spots and placing cover soil over waste materials.

Occasionally, rats and mice may be delivered to the site with the solid waste. If harborage is available in areas adjacent to or in some neglected portion of the site, extermination by the local health department will be necessary. Employees at the landfill should be trained to recognize burrows and other signs of the presence of rats and mice so that appropriate measures can be taken.

8.2.5.6. Odors

There are several potential sources of odor at a landfill. Odors may be generated in the following situations:

- when the waste is delivered
- from decomposing waste in place at the landfill
- from storage ponds and treatment systems

Odors generated by the refuse can usually be mitigated by rapidly covering the wastes and ensuring that the cover is maintained intact.

Occasionally, loads of particularly malodorous materials may be delivered to the landfill. Deliveries of these materials should be scheduled such that sufficient manpower and equipment are available to immediately cover the waste. If not possible, malodorous loads can be mixed or covered with other wastes in order to alleviate the problem. In extreme cases, lime and/or chemical masking agents can be used.

8.2.5.7. Noise

There are several sources of noise at landfills. These sources include operating equipment and collection vehicles. Typically, the noise is very similar to that generated by any heavy construction activity, and is limited to the site and to the streets used to transport the solid waste to the site. In order to reduce the total number of individuals exposed to the noise, every effort should be made to route traffic through the least populated areas. In additicn, the site can be isolated or surrounded by a buffer zone such that the noise cannot disturb anyone. The installation of noise barriers such as earthen berms, walls, and trees can be very effective.

8.2.5.8. Aesthetics

In order to reduce environmental impacts and make the landfill acceptable, the site should be designed to be as compatible with its surroundings as possible. During site preparation, it is important to leave as many trees as possible to form a visual barrier. Berms can also be used to form visual barriers. The use of architectural effects at the entrance, confining disposal to designated areas, and the use of attractive landscaping will assist in the development of a sound operation. Additionally, every attempt should be made to minimize the size of the working area.

8.2.5.9. Birds

Birds, especially in landfills located in coastal areas, are attracted to landfills for food. Birds can pose a serious hazard to aircraft and create a nuisance to operating personnel and neighbors. In the U.S., criteria for the classification of waste disposal facilities and practices indicate that if a solid waste facility is sited within 10,000 ft (3,000 m) of an airport serving turbojets or within a 5,000 ft (1,500 m) of any airport used by piston-type aircraft, the landfill shall be operated so as not to pose a hazard to air traffic [6]. The most effective control practice is rapid and complete covering of all refuse. Noise production, distress calls, or similar measures can provide some temporary control.

8.2.5.10. Litter

One of the most frequent complaints from residents living near landfills concerns blowing litter. Blowing litter can be substantially reduced by:

- Discharging the waste at the toe of the working face
- Frequent and thorough cover of the face and completed portions of the cell
- Application of water or damp waste to loads containing a high concentration of paper
- Installation of portable or stationary fencing around the working face.

Generally, despite the operators best efforts and control measures, the accumulation of some litter is inevitable at a landfill site. The installation of a fence around the site will help to contain litter and keep it from reaching adjacent property. Daily cleanups, particularly at the end of the working day can limit the quantity of litter that can reach other property.

8.2.5.11. Fires

Ignition of combustible materials (open burning) should not be permitted at landfills. However, there are several potential sources of fires at landfills. Some of these sources include receipt of hot wastes, sparks from vehicles, equipment fire, vandalism, and purposeful incineration for salvaging (i.e., removal of insulation from copper wire). A good security program combined with alert spotters can mitigate most of the problem. Hot and highly flammable wastes should be directed to specific areas in the landfill and wetted down or smothered with soil or water prior to disposal. All landfill vehicles should be equipped with fire extinguishers to limit damage resulting from equipment fires.

In the event that pumped water is not available, a water truck or trailer equipped with a gas-powered pump should be on-hand. There are several techniques available for dealing with fires. Fires near the surface of the fill can be excavated and extinguished with soil and/or water. Deep fires can sometimes be smothered by placing damp soil on the surface of the fill. More commonly, however, deep fires will have to be thoroughly excavated and smothered at the surface. Particularly large fires may have to be dealt with by experienced personnel.

8.2.6. Self Haul

Most disposal sites allow the transportation and discharge of wastes by private individuals. Typically, small vehicles comprise a considerable portion of the traffic. These users (either small haulers or private individuals), usually unfamiliar with practices at the site, can damage their vehicles, can cause delays at the working face, and may cause accidents.

There some options for dealing with self-haul vehicles. Self-haul vehicles can be directed to specific areas in the working face away from large collection vehicles. Alternatively, transfer systems can be used. Transfer systems commonly used are large self-dumping trailers (which are periodically towed to the working face), dump trucks, and roll-off containers. Normally, a platform is constructed to unload small volumes of waste into the large containers.

The transfer point should be located inside the gate and adjacent to a good road. This area should be located at a point where it can be watched by site personnel. If utilization is high, an employee may need to supervise and operate the facility. A resource recovery operation can also be added if supervision is available. These areas have a certain amount of problems, especially from abuse by the users. Litter is a common problem and fires may take place in the container. Nevertheless, the value of some type of transfer system usually is justified in reduced roadway costs, simpler and safer operations at the working face, and improved public relations.

8.2.7. Salvage/Scavenging

Scavenging or uncontrolled sorting through raw wastes to recover materials that may be reusable is a common practice in most less developed countries. This practice is strictly prohibited at the working face of a landfill in developed countries because there is a high risk of injury and a potential health hazard to the scavenger. Where regulations allow controlled salvaging, it can be conducted away from the working area by individuals under direct supervision of the operator. Salvaging operations and storage must be confined to a specific area or facility so that they will not interfere with the landfill operation. Strict controls must also be established on the types of materials, storage, and removal frequencies so that nuisance conditions do not develop. It is highly recommended that the individuals working in the salvaging area be provided with uniforms, hard hats, masks, boots, and basic sanitation services. Additional information is provided in Section 5.

8.3. LANDFILL SPECIFIC OPERATIONAL PROCEDURES

There are three basic operational procedures that depend on the method of landfilling. They are:

1) site preparation
2) traffic flow and unloading

3) waste compaction and covering

These procedures are presented as a function of the two basic methods of landfilling-- area or trench.

The sequence and method of operating a sanitary landfill is dictated by several factors that are specific to a site. Some of the most important factors include physical site characteristics, types of waste, and the rate of refuse receipt. However, there is not an "optimum" method that is applicable for a given disposal site.

As has been previously indicated, the two basic operational techniques are the trench and area methods. The primary difference between the two is that the trench operation employs a prepared excavation and as such, confines the working face between the two side walls. The area method, on the other hand, does not use extensive surface preparation. The width of the working face is, in theory at least, unlimited. A common approach of landfills is to use both methods at different locations or times. For example, initial disposal operations may employ a trench design and subsequently the area method may be used on top of the trench. There are some variations to the two basic methods. Some of these variations include progressive slope, progressive trench, and the cut and cover approach.

8.3.1. Area Method

The area method typically is used in natural depressions, in prepared areas, or on top of filled trenches. The subgrade may consist of either natural soil, a prepared surface using liners or compacted soil or soil supplements. The use of either of these materials depends upon local regulations and design preferences. A typical area fill operations shown in Figure 3-4. Area fills usually utilize the land more efficiently than trench operations. Area fills, on the other hand, require imported soil for liners and covers.

8.3.1.1. Site Preparation

The primary objective in preparing a site for an area fill is to utilize most of the available soil that meets the design requirements. At the same time, site preparation should keep to a minimum disturbance of natural soil and vegetation. In order to accomplish these objectives, it is necessary to conduct a comprehensive inventory of the amount and type of soil available.

Excavations should follow a particular sequence such that the soil that is removed can be used elsewhere on-site without stockpiling. This procedure eliminates double handling and increased costs. A model has been developed to provide assistance in the planning of soil movement [7]. However, it is frequently necessary to stockpile a certain amount of soil in order to take full advantage of the various types. For instance, topsoil should be stockpiled for use on roads, as daily cover, or for the construction of leachate collection systems or surface drainage systems. Clay may be selectively excavated and used as liner material, dikes, interim and final cover or, if necessary, used to supplement subgrades.

Soil that is stockpiled should be placed in appropriate areas, compacted, and appropriately sloped to keep it as dry as possible. Soil should be stockpiled as close to the location where it will be used as practical. Stockpiles should never be placed in areas where they will interfere with traffic, cover soil that might be needed for other functions, or impede the function of drainage control systems.

8.3.1.2. Traffic Flow and Unloading

The general procedure for managing the receipt of solid waste at the gate is discussed elsewhere. This procedure is applicable to both methods.

The spreading, compacting, and covering of waste can be facilitated by controlling the position of the collection vehicles while unloading. If the collection vehicles are directed over previously filled areas, the areas should be well compacted. When possible, demolition debris and other dense rubble should be placed to take advantage of the drainage plan. Roads should be designed and built such that they do not interfere with stockpiling or soil handling.

The working face should be as narrow as possible without interfering with normal operations. To facilitate this, an operator (spotter) should be at the face of the fill during operating hours using a whistle, a bullhorn, or flags to direct incoming vehicles to the appropriate section of the working face. Barricades and markers may be used to delineate the area that is used a given day.

It is preferable to keep the unloading area at the toe of the working face. This is because spreading and compaction are easier and generally more effective when performed from the bottom (see Figure 8-2). If the unloading is carried out from the top, care must be taken to prevent the refuse from being pushed over a steep working face and little or no compaction is applied until the end of the day. Unloading at the toe generally reduces blowing litter. The unloading area should be kept clean and level to prevent vehicles from being damaged or tipped. In small sites it may be necessary to provide an unloading area that is wider than the working face. At large sites, or at sites that process large quantities of wastes in relatively short time spans, a portion of the unloading area should be set aside for unloading trucks manually. If the face of the fill is not sufficiently wide to allow for this process, manually operated vehicles may be routed to the top of the lift.

8.3.1.3. Compacting and Covering Solid Waste

Spreading and compaction operations should be aimed at maintaining proper cell density, height, slope, and width throughout the day.

The compacted density of the solid waste depends upon two main variables. Compaction is a function of the thickness of the layers and of the number of passes made by equipment. Usually four to six passes with wheeled or tracked equipment will provide sufficient degree of compaction. Although additional passes do result in higher compaction, the return for the effort diminishes beyond six passes. An experienced operator should be able to know when additional passes will result in greater compaction. In order to prevent soft spots in the

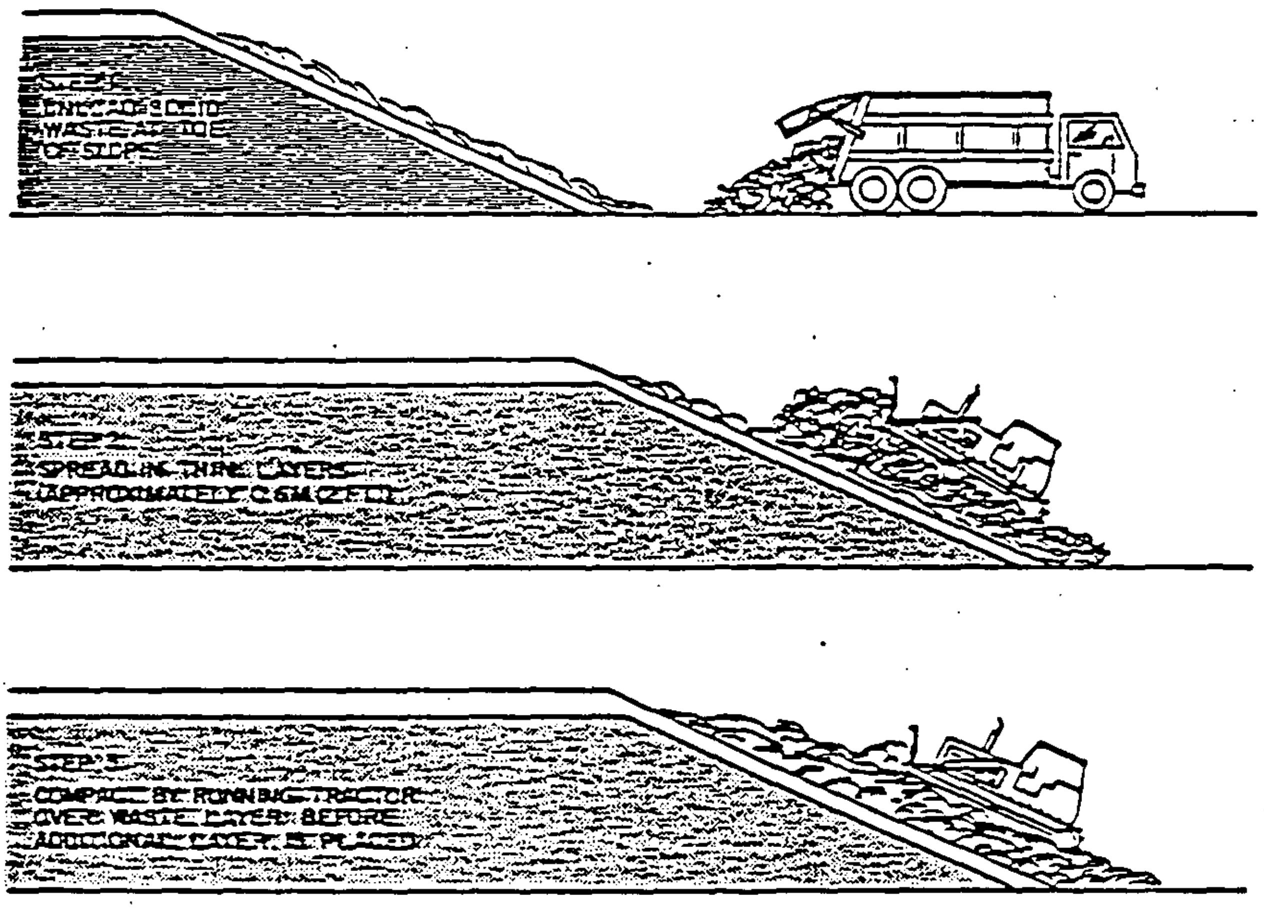

Figure 8-2. Unloading and Compacting Processes

fill area, excessively wet loads should be separated and mixed with dry materials before and during spreading. The compaction sequence is demonstrated in Figure 8-2.

The final height of lifts usually is determined by the grade plan for the facility, soil usage, and operational limitations. In extremely deep fills with a large number of lifts, the height of the lift may be limited by the equipment. For instance, a lift may be limited to the maximum height at which a scraper can provide complete coverage with one pass. Typical heights for lifts range between 8 and 16 ft (2.4 to 4.5 m).

The relationships between density and the number of passes as well as the thickness layer are presented in Figures 8-3 and 8-4.

The slope of a cell should not exceed 20° or about 3:1 (horizontal:vertical). The slope should be established with initial loads and maintained constant throughout the day. Some sites may operate effectively by using horizontal cells. However, sloped cells require less soil for cover, reduce the area of exposed wastes, facilitate spreading, and encourage proper compaction of wastes.

There are three types of soil cover: 1) daily, 2) intermediate, and 3) final. Each type depends upon the thickness of the cover and the duration of exposure to the elements. Suggested thickness for a range of exposures are presented in Table 8-4.

The stockpiling of soil and the method of application of the soil should be carried out such that the cover will not be littered with refuse. This situation can be prevented by depositing the soil at the top of the cell or adjacent to the face. At the time that the cover is applied, the soil spreading equipment should only travel over the soil. The spreading equipment should not travel through refuse onto fresh soil because this tends to draw waste on top of the cover material. The tires for the various types of equipment should be cleaned before applying or compacting soil.

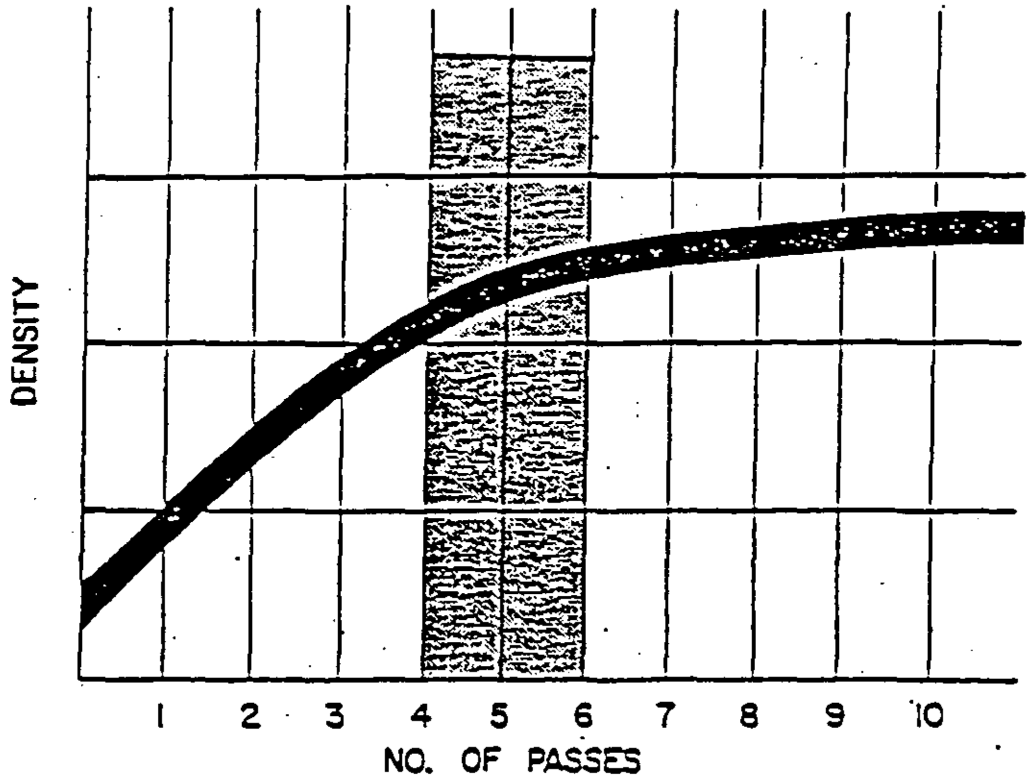

Figure 8-3. Number of Passes and Landfill Density

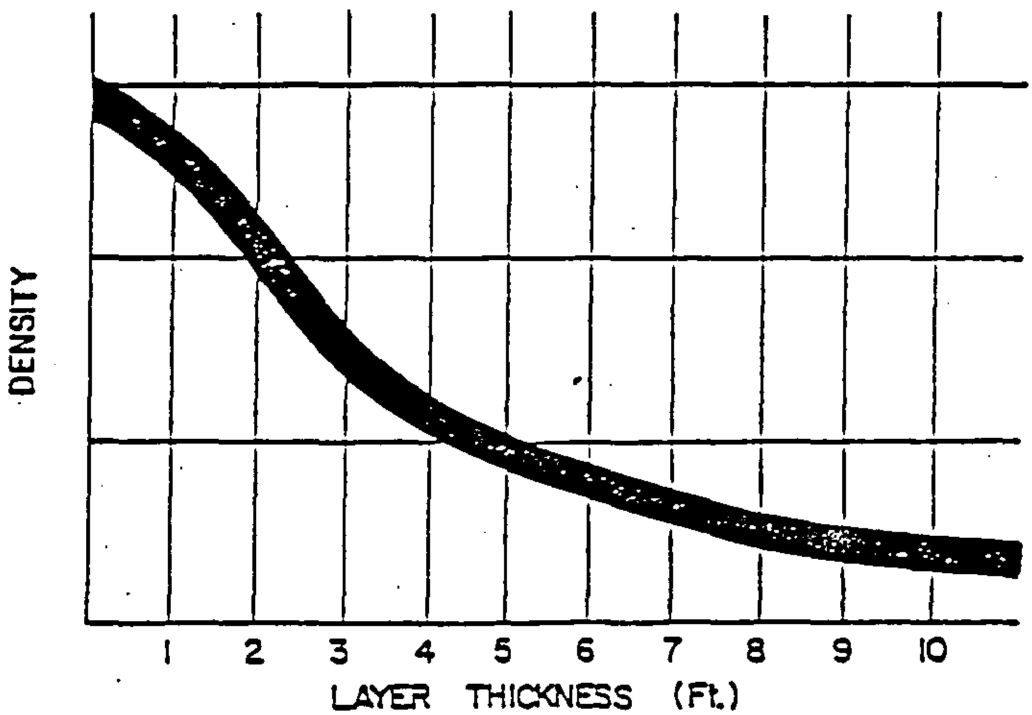

Figure 8-4. Layer Thickness and Landfill Density

Table 8-4. Thickness of Cover Soil and Exposure Time

Cover Material	Minimum Thickness (in.)	(cm)	Exposure Time[a)]
Daily	6	15.2	0 - 30 days
Intermediate	12	30.4	30 - 365 days
Final	24	60.8	>365 days

a) Length of time cover material will be exposed to wind and rain.

Scrapers and draglines are the most frequently used types of equipment for the application of cover material. Scrapers reduce the amount of double handling. Unfortunately, the tires may be damaged by the waste materials. Draglines can also be used for the application of cover material. The use of draglines, however, requires additional grading and compacting of soil. Regardless of the placement method, the cover should be compacted and smoothed. Typically, two passes using appropriate equipment will provide sufficient compaction for daily cover soil.

The main purposes for applying daily cover are to control vectors, litter, odor, water infiltration, and, to some extent, fire. The solid waste should be compacted immediately prior to placing the daily cover. Compaction of the waste will level the site and facilitate both covering and subsequent operations by providing a smooth surface. Typically, a minimum compacted thickness of 6 in. (15 cm) of daily cover soil is sufficient to accomplish the objectives. The thickness may exceed 6 in. (15 cm) if a greater depth is required to cover all of the waste. Cover should be applied to the top and side slopes as cell construction progresses. This procedure prevents the litter and only the working face would need to be covered at the end of the working day [9].

Intermediate soil cover has the same general function as daily cover. The intermediate cover, however, remains exposed to the elements for a longer period of time. The intermediate cover may also serve as a temporary surface for traffic movement. The minimum compacted depth for an intermediate cover is 1 ft (0.3 m). This cover should be placed as soon as possible on the lift surface, but kept a sufficient distance away from daily activity to prevent littering from equipment moving over it.

Completed areas should be covered with a final layer of soil as soon as possible. It is generally recommended that the final cover have a minimum thickness of 2 ft (0.6 m). The depth and type of soil to be used and the compaction requirements must be specified in the facility design and operation plan. All but the upper few inches should be compacted in order to reduce the soil permeability. Topsoil can be added to the surface of the final cover. Seeding, mulching, fertilizing, and pH adjustment should immediately follow final covering. A recent EPA publication provides useful information on standard procedures for planting vegetation on final covers [8]. A discussion on covers is presented in Section 5. Soil used as final cover should not be applied when it is too wet or frozen. A certain amount of soil should be saved after site completion to facilitate any grading that may be required to maintain an even surface. Completion should be phased such that once the final cover is applied, no additional traffic will be permitted to go over the completed area.

8.3.2. Trench Method

The trench method is most applicable on flat or gently rolling ground with deep soils. The widths and depths of the trenches can vary substantially from site to site. A typical trench operation is illustrated in Figure 3-3. Trench operations usually result in surplus soil and provide lateral confinement at the operating face. Trench operations may require more land and equipment than area operations. In addition, trench operations may need extensive soil stockpiling and handling.

8.3.2.1. Site Preparation

Generally the depth and width of the trench are specified in the design and operation plans. The excavation of the first trench and even portions of later trenches may require stockpiling of large quantities of soil. The stockpiling must be conducted such that it will allow the soil to be available for use as liner and/or cover material and to avoid interfering with operations.

As previously indicated, the size of unexcavated areas between trenches depend upon the depth of the trench and the characteristics of the soil. In general, the more cohesive the soil the less area that will be required between the trenches. On the other hand, as the depth of the trench increases, the more area between the trenches will be required.

The amount of soil handling and stockpiling can be reduced by following either of two approaches. The first approach is called the phased fill and covering. This approach uses soil from a trench being excavated to provide cover for an adjacent trench that is in the process of being filled. Soil from the first trench must be stockpiled. The second approach is known as the progressive trench. The progressive trench method uses soil excavated from one end of the trench as cover material for waste deposited at the other end of the same trench.

8.3.2.2. Traffic Flow and Unloading

The working face in trench operations usually is more sharply defined than in area operations. In the trench method, waste may be discharged from the side or from within the trench. Operational procedures must be developed according to the landfill method. Stability of the sidewall is extremely important if the unloading is going to take place from the side of the trench. In addition, allowances must be made to prevent the vehicles from entering the trenches. Typically, logs or poles are placed near the edge of the trench. A spotter should be present during unloading operations. It is preferable to unload the waste from within the trench. In this particular case, a ramp leading to the base of the trench should be built and maintained at a grade appropriate for vehicle traffic. Contingency plans should be provided during wet weather or when other situations make the ramp hazardous or difficult to use. The same considerations dealing with traffic control for unloading in the area method also apply to trench operations.

Waste handling practices presented for the area method also are common to trench procedures. The walls in the trench help control the width of the face width and size of the cell. On the other hand, the walls of the trench can interfere with compaction if the side slope is too steep for the wheels or tracks to reach the side and still maintain blade clearance.

Narrow trenches may have a rapid build up of refuse during peak periods. In this particular case, adequate compaction cannot be obtained if the refuse is discharged on the face.

In order to prevent this situation, it is best to at least loosely compact the refuse in the bottom of the trench, and spread and compact it thoroughly when time permits.

8.3.2.3. Covering and Compacting Solid Waste

Soil cover should be placed at the same times and depths as specified for the area method. When an area fill is placed on top of a trench fill, the operation should be phased such that the area fill is completed as soon as possible after trench fill. This procedure will help in preventing soil loss and achieve the desired ratio of soil to refuse. Sufficient soil for cover should be available so that area lifts on top of trenches will have adequate cover.

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LANDFILL PROCESSES

9.1. CHARACTERISTICS

Characteristics of a completed fill can be grouped according to three general headings:

- type and nature of wastes in the fill
- phenomena associated with physical, chemical, and biological processes that occur in the buried wastes
- fill design and conduct of the fill operation

The three characteristics are closely interrelated with respect to their effects on the completed fill. For example, type and nature of the wastes determine the quantities and characteristics of products associated with physical, chemical, and biological processes which are influenced by fill design and conduct of the fill operation. Moreover, they also determine the extent and the course of the processes. Because of this interrelationship, all three are discussed under the single heading, "Processes".

Section 9.1 is closed with a discussion of characteristics that exert a major influence not only on the impact of the completed fill on the public welfare and quality of the environment, but also on the use intended for the completed fill and the attention that must be accorded. Characteristics of concern may be grouped under the headings, "density", "settlement", "landfill emissions", and "corrosion".

9.1.1. Processes

Physical, chemical, and biological processes are discussed in this section. Of the three types, the biological processes probably are the most significant. However, the biological processes are strongly influenced by the physical and chemical processes.

9.1.1.1 Physical

In general, significant physical reactions in the fill are in one of three very broad forms: compression (compaction), dissolution, and sorption. Because settlement is an invariable accompaniment of compression, the two usually are discussed under the hyphenated heading, "compression-settlement." Similarly, dissolution and transport are closely associated phenomena, but, not to the same degree as compression-settlement. All components of the buried fill are subjected to the three reactions.

Compaction is an on-going phenomenon that begins with compression by machinery operating in the daily fill activities and continues after the wastes are in place. The continuing compression is due to the weight of the wastes and that of the soil cover. Sifting of soil and other fines is responsible for some consolidation. Settling of the completed fill is an end result of compression. This settling is in addition to the settlement brought about by other reactions (e.g., loss of mass due to chemical and biological decomposition).

The amount of water that enters a fill has an important bearing on physical reactions. Water acts as a medium for the solution of soluble substances and for the transport of unreacted materials. The unreacted materials consist of animate (living) and inanimate particulates. Particulate sizes range from colloidal to several millimeters in cross section.

In a typical fill, the broad variety of components and particle sizes of the wastes provide conditions that lead to an extensive amount of adsorption. Of the physical phenomena, adsorption is one of the more important because it brings about the immobilization of living and nonliving substances that could pose a problem if allowed to reach the external environment. Adsorption is the adhesion of molecules to a surface. Adsorption could play an important part in the containment of viruses and pathogens and of some chemical compounds. Adsorption does have its limits, one of which is its questionable permanency. One or several factors can alter permanency. For example, it can be altered by the effect of biological and chemical decomposition on adsorption sites.

Absorption is another of the physical phenomena that takes place in a fill. It is significant in large part because it immobilizes dissolved pollutants by immobilizing the water that could transport them and suspended pollutant particulates out of the confines of the fill. Absorption is the process whereby substances are taken in by capillarity. The absorption potential of a fill is a function of its fiber content. In developed countries, most of the absorption potential of landfilled municipal waste is attributable to its paper content; whereas that due to the presence of other fibers (cotton and wool) is relatively insignificant. In developing countries, absorption due to fibers in general would be minor in extent. However, certain crop residues may provide some absorption potential. Of course, chances are that those fibers would be reclaimed before they reached the waste stream. Finally, it should be recognized that eventually all absorbent material in a fill becomes saturated. Consequently, absorption may be regarded as being only a delaying action as far as pollutant release is concerned.

9.1.1.2. Chemical

Oxidation is one of the two major forms of chemical reactions in a fill. The other form includes the reactions that are due to the presence of organic acids and carbon dioxide (CO_2) synthesized in the biological processes and dissolved in water (H_2O). Obviously, the extent of the oxidation reactions is rather limited, inasmuch as the reactions depend upon the presence of oxygen trapped in the fill when the fill was made. Ferrous metals are the components likely to be most affected.

Reactions involving organic acids and dissolved CO_2 are typical acid-metal reactions. Products of these reactions are largely the metallic ions and salts in the liquid contents of the fill. The acids lead to the solubilization and hence mobilization of materials that otherwise would not be sources of pollution. The dissolution of CO_2 in water deteriorates the quality of the water, especially in the presence of calcium and magnesium.

9.1.1.3. Biological

The importance of biological reactions in a fill is due to the following two results of the reactions:

- The organic fraction is rendered biologically stable, and as such, no longer constitutes a potential source of nuisances.
- The conversion of a sizeable portion of the carbonaceous and proteinaceous materials into gas substantially reduces the volume of the organic fraction.

At this point, it should be remembered that a fraction of the nutrient elements in the waste is transformed into microbial protoplasm. Eventually, this protoplasm will be subject to decomposition, and hence it makes up a reservoir for breakdown in the future.

The wide variety of fill components that can be broken down biologically (biodegraded) constitute the organic fraction of MSW. This fraction includes the garbage fraction, paper and paper products, and "natural fibers" (fibrous material of plant or animal origin). Although the organic fraction is the primary substrate for the biological reactions, certain inorganic components may be indirectly affected.

Biological decomposition may take place either aerobically or anaerobically. Both modes come into play sequentially in a typical fill, in that the aerobic mode precedes the anaerobic mode. Although both modes are important, anaerobic decomposition exerts the greater and longer lasting influence in terms of associated fill characteristics.

Aerobic: The greater part of decomposition directly after the wastes are buried is aerobic. It continues to be aerobic until all of the oxygen (O_2) in the interstitial air has been removed. The duration of the aerobic phase is quite brief and depends upon the degree of compaction of the wastes and the moisture content (moisture displaces air from the interstices). Microbes active during this phase include obligate as well as some facultative aerobes. During this phase, temperatures as high as 45 to 55°C may be reached in the interior of the fill.

Because the ultimate end-products of biological aerobic decomposition are "ash," CO_2, and H_2O, adverse environmental impact during the aerobic phase is minimal. Although intermediate breakdown products may be released, their amounts and pollution contribution usually are small.

Anaerobic: Because the oxygen supply soon is depleted, most of the organic matter in a landfill eventually is subjected to anaerobic breakdown. This anaerobic decomposition is biologically much the same as that in the anaerobic digestion of sewage sludge. Microbial organisms responsible for anaerobic decomposition include both facultative and obligate anaerobes. A noticeable difference between the aerobic phase and the anaerobic phase is the absence of a discernible rise in temperature in the latter phase. Because of this absence, temperature in the buried (landfilled) mass gradually drops to that of the ambient.

Unfortunately, the breakdown products of anaerobic decomposition can exert a highly unfavorable impact on the environment unless they are carefully managed. The products can be classified into two main groups: volatile organic acids and gases. Most of the acids are malodorous and of the short-chain fatty-acid type. Examples are formic, acetic, propionic, and isovaleric acids. In addition to chemical reactions with other components, the acids serve as substrates for methane-producing microbes.

Finally, the two principal gases formed are methane (CH_4) and CO_2. Gases in trace amounts are hydrogen sulfide (H_2S), hydrogen (H_2), and nitrogen (N_2). The adverse effects of CO_2 are discussed in Section 9.1.1.2. Methane production, management, and recovery are discussed in considerable detail in Section 6.3.

Environmental Factors: The nature, rate, and extent of biological decomposition in a fill are greatly influenced by the environmental factors that affect all biological activities. The nature of biological decomposition determines the nature of the decomposition products. Among other things, rate determines the length of time during which the completed fill must be monitored and which must pass before the "reclaimed" area (i.e., completed fill) can be put to use – whether it be for recreation, agriculture, construction, or other purposes.

One of the ways in which decomposition affects use of the completed fill is through its effect on rate and amount of settlement (reduction in elevation), in that settlement is a major constraint on the use of the completed fill. Settling continues until biological decomposition has run its course. Therefore, the obvious conclusion is that the higher the rate of decomposition, the sooner can the site be put to use.

The principal factors that influence biological decomposition in a conventional fill are moisture, temperature, and the microbial nutrient content and degree of resistance of the waste to microbial attack. An ideal moisture content in terms of decomposition is one that approaches saturation. Moisture is a limiting factor in a fill at moisture content levels of 55% to 60% or lower, because microbial activity is increasingly inhibited as the moisture drops below the 55% level sludge can be added to increase moisture. For practical purposes it ceases at 12%. Therefore, decomposition can be expected to proceed very slowly in fills in arid regions.

The activity of most microbes increases with rise in temperature until a level of about 40°C is reached. For some types of microbes, the upper temperature is on the order of 55 to 65°C. The former are termed "mesophiles," and the latter known as "thermophiles". Some mesophiles are high temperature tolerant (facultative thermophiles), and some thermophiles are tolerant of temperatures in the mesophilic range (facultative mesophiles). Because temperatures in tropical regions are more favorable, decomposition proceeds very rapidly and to a greater extent in those regions.

With respect to nutrients, wastes characterized by a high percentage of readily putrescible organic matter approach the ideal in terms of decomposition. Among the wastes that fall in such a category are green crop debris, food preparation waste, marketplace produce waste, and animal and human manures. An interesting point is that one is likely to find such a combination of ideal decomposition factors in developing countries in humid tropical regions of the world.

9.1.2. In-Place Density, Compaction, Settlement – The Interrelation

9.1.2.1. Density

Representative densities of raw wastes are discussed in Section 5. Among the factors that determine or influence in-place density (i.e., density after the wastes have been deposited in the fill) are:

- composition of the wastes
- operational procedure
- end-products of decomposition
- compaction applied by machine during fill construction
- weight of cover material
- progressive settlement of the entire mass, resulting from the further increase in density brought about by consolidation of landfill components, by the weight of the upper strata of wastes and the cover material, and by the decomposition of the wastes

Because of the effect of settlement, increase in density becomes a continuing phenomenon. The in-place density of a properly conducted, relatively deep fill can be on the order of 900 kg/m^3; whereas that of a poorly compacted fill would only be about 300 kg/m^3. In the U.S.A., the usual range of density directly after compaction is on the order of 475 to 712 kg/m^3 [1].

9.1.2.2. Settlement

Settlement is manifested by a decrease in volume of the affected mass and subsequent reduction in elevation. For several reasons, the drop in elevation is not uniform throughout the fill. The lack of uniformity may be a serious constraint on the use of the completed fill. Undoubtedly, the larger the organic fraction and the deeper the fill, the greater will be the extent of settling. Rate of settling depends in large part upon that of the decomposition of the wastes, and hence upon the factors that affect decomposition.

Because of the variations in the above factors and wide differences between operational procedures encountered in sanitary landfill practice, it is not surprising that a similarly wide variation exists between reported rates and the extent of settlement. Of the total settling, usually about 90% takes place during the first year [1]. Another report mentions settlement of a 20-ft landfill was greatest during the first month, and uniformly very small after the third month. As for extent, a report on a fill in a region of moderate rainfall (>11 cm/yr) and average temperature, a 6-m fill settled 1.2 m in year-1. On the other hand, a fill in a region of modest rainfall (<6 cm/yr) but somewhat warmer average temperature, a 23-m fill had settled only 0.7 m by year-3, and a 14-m fill, only 0.4 m [1]. In "Settlement of Landfill," A. C. Cheney [2] states that whereas no physical settlement will occur if the initial density exceeds 1,060 kg/m^3, nevertheless a theoretical settlement of 40% due to waste decomposition processes is possible. However, he points out that with wastes 650 to 1,200 kg/m^3 placement density, annual rates of 0.55 to 4.7% have been measured in practice.

9.2. MONITORING

Ultimately, the rationale for monitoring is to detect adverse impacts of the landfill on the adjacent air, water, and soil environments so as to be able to take the remedial measures needed to counteract the impacts. This is done by: 1) establishing baseline environmental data and characterizing the nature, extent, and magnitude of the impact; and 2) developing a remedial course of action. Impacts are indicated and identified by differences between the pre-landfill and post-landfill qualitative and quantitative characteristics of the three environments, or by the existence of gradations in quality and quantity with respect to proximity to the fill. Programs and methods for monitoring can range from minimal to quite extensive in terms of extent, complexity, type, and costs. The minimal category would be sufficient for situations in which the need for monitoring does not warrant an extensive program. The only exception might be situations in which technical and financial resources are seriously limited, such as may be true in many developing regions.

9.2.1. Groundwater

According to the general principles mentioned in the preceding paragraph, impact on groundwater quality can be evaluated on the basis of difference between groundwater quality (e.g., pH, dissolved solids concentration, chemical composition, presence, identity, and concentration of microorganisms before and after construction and completion of the fill). Impact of an existing fill on groundwater flowing under and around the fill can also be evaluated on the basis of difference between the quality of the groundwater before it reaches the vicinity of the fill and after it has moved beyond the fill. Estimates depending upon groundwater flow presuppose a knowledge of the direction and velocity of the groundwater flow. Groundwater flow is discussed in Section 4.2.6.

Potential impact on groundwater quality can be estimated on the basis of the composition and quantity of leachate generated in the fill. Knowledge of leachate composition and rate of production would also be of use in the identification of contaminants attributable to the landfill and in predicting the intensity of the contamination. To obtain such knowledge, it is necessary that the fill be provided with a leachate collection and sampling system. The problem is that even in developed nations, such installations are few and far between. If a leachate collection system is available, then monitoring would consist in measuring rate of leachate production and analyzing the leachate for items of interest. Examples of such items are physical characteristics, the identity and concentration of toxic chemicals and chemical constituents adverse to water quality, and of pathogenic organisms.

9.2.1.1. Monitoring Wells

Because sampling (collection and analysis) is a key element in a groundwater monitoring program, method of sampling must be carefully considered. In this connection, networks of monitoring wells have an important part. A diagrammatic sketch of a monitoring well is presented in Figure 9-1. The extent and sophistication of this network are determined in part by the purpose of the program and by the economic and technological resources of the region that is to be served by the network. With regard to purpose, a monitoring well network for gross groundwater quality indicators differs drastically from wells intended for detecting toxic organic compounds or heavy metals. The wells must be installed at proper horizontal and vertical positions near the landfill.

Appropriate methods for installing the wells are determined on the basis of anticipated nature of subsurface aquifer materials, site accessibility, availability of drilling water, desired diameter and depth of the well, the nature of subsurface contaminants, and economic and time constraints. (A list and evaluation of the many methods may be found in "Guidelines for the Land Disposal of Solid Wastes" [3].)

Of the various applicable criteria, all wells should at least meet these two criteria: 1) water must flow freely into the well; and 2) downward migration of surface water or upward migration of undesired groundwater to the well-intake zone must be prevented. Basic elements in the design of monitoring wells are the casing, filter pack, seal, annulus backfill, and grouting. The elements are indicated in Figure 9-1. Installation is completed by well-development. Well-development accomplishes two tasks: 1) the well is cleared of foreign materials introduced during drilling, and 2) the natural formation adjacent to the well screen is restored. Develop

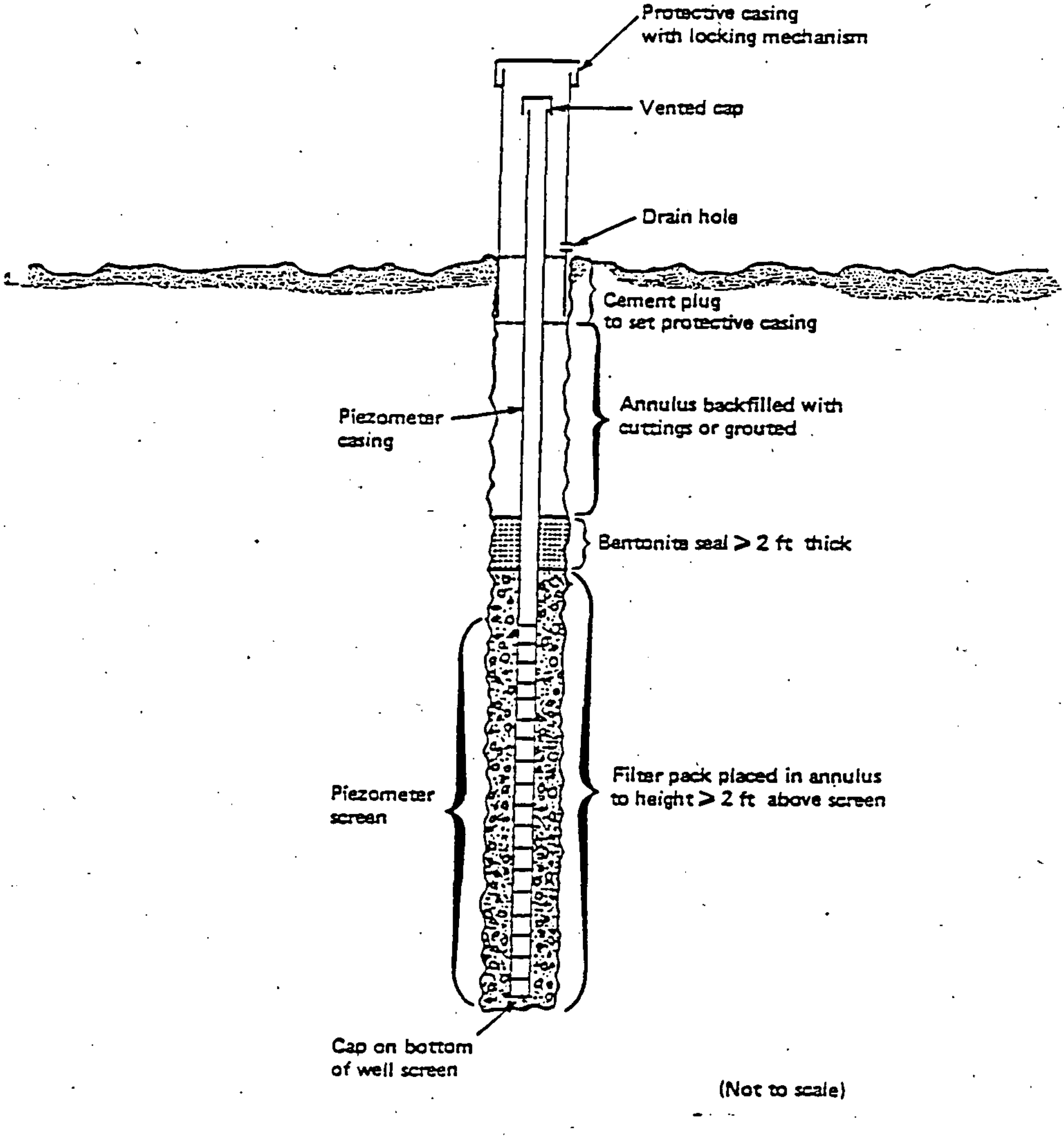

Figure 9-1. Example of a Monitoring Well

ment may be accomplished by way of bailing, pump surging, air lifting, and combined air lifting and bailing.

Among the several methods for drilling a monitoring well are hand-augered boring, auger drilling, mud-rotary drilling, air-rotary drilling, and cable-tool percussion drilling [4]. Of these methods, hand-augered boring is the least expensive. However, it is best suited for shallow borings (less than 4 m deep) that are only 5 to 15 cm in diameter. Auger drilling is suitable for depths of about 45 to 50 meters.

9.2.1.2. Collection and Analytical Methods

With the use of the installed and developed wells, it is possible to obtain samples that are chemically representative of the water taken in by the well. Consequently, attention must be directed to:

- The physical extraction of the water from the well
- The preservation of the chemical integrity of the sample in transit to the place of sample analysis
- The attainment of analytical results that are accurate and have a high degree of precision

Among the several means of collecting samples from the wells are:

- Down-hole collection devices
- Suction-lift, positive displacement, the gas-lift, and the gas-drive methods
- Gas squeeze or bladder pumps
- Jet or venturi pumps [1].

Among the pertinent sample parameters for analytical determination are:

- pH
- Specific conductance
- Total dissolved solids
- Total dissolved iron
- Nitrate

- Chloride
- Total organic carbon
- Total organic halogens
- Heavy metals
- Hardness

The pH level and specific conductance should be determined in the field.

Most of these tests can be carried out by laboratories at universities or those that typically analyze potable water.

9.2.2. Surface Water

The necessity or advisability of monitoring surface water quality depends upon: 1) the proximity of the landfill to surface water; and 2) the drainage patterns between the fill and the surface water. The approach followed in the selection of sampling stations, equipment, and procedures should be similar to the approach used in the selection process for groundwater monitoring. The stations should be located in areas that have the greatest potential for contamination. These areas include the pathways through which leachate can enter a surface body of water. Flow patterns and seasonal variations should also be taken into consideration. Equipment used for sampling surface water and the methods used to analyze the samples should be consistent with procedures selected for testing groundwater samples.

9.2.3. Landfill Gas and Migration

As stated in Section 6.3, landfill gas can escape by vertical and lateral migration. Obviously, if the landfill cover is sufficiently permeable, gas can exit vertically, i.e., through the cover. If the cover is impermeable (e.g., rain-saturated cover soil, pavement, or a clay or synthetic membrane cap) this escape route is blocked. Because of this blockage, lateral migration becomes the only avenue of escape. The distances involved in lateral migration can be significant, especially if the fill is adjacent to permeable soil strata.

Sampling devices should be located near the property boundary and offsite on the landfill side of structures in pathways most susceptible to gas migration. Simple gas probes can serve as gas sampling devices. The technique used in the collection of the samples is determined by the type of sampling probe. Methane usually is monitored by means of a portable meter. Methane gas concentration in facility structures, -- and in structures not on the facility -- should not exceed 25% of the lower explosive limit. (The lower explosive limit is 5% methane.)

9.3. USES

Use of the completed fill as a "green area," for recreational purposes, and for agriculture was discussed in Sections 5.1.4. This section, therefore, deals only with use for construction and urban development.

9.3.1. Construction and Urban Redevelopment

Because of the many and often severe constraints associated with the construction and utilization of structures erected on a completed fill, the use of completed landfills as sites for construction and particularly for urban development generally should be discouraged in developed countries [5]. However, a growing land shortage is prompting a more favorable reconsideration of the potential of such sites. The situation is different in developing countries, especially in those in which the migration of populations from rural to urban is extremely great. Because of the migrations, all unoccupied land has become attractive. Such being the case, the only recourse is to apply to the fullest possible extent, precautionary measures designed to lessen associated hazards. Examples of proposed use of completed fills are described in two World Bank Reports. They are: Swamp Reclamation in Tropical Monsoon Regions by Appropriate Refuse Landfilling: Case Study Evaluations in Thailand [6] and Study of Landfill and Resource Recovery in Metropolitan Colombo, (Draft Final Report), prepared for the World Bank by Environmental Resources Limited, June 1987 [7].

Constraints mainly take the form of problems associated with use of the site. Consequently, a sizeable share of these problems are geotechnical in origin and nature. Of equal importance is a group categorized as "potential hazards".

9.3.1.1. Geotechnical Problems

Settlement, a major geotechnical problem characteristic of all waste landfills, is addressed in Section 9.1.2. Not discussed, however, is the problem posed by the relatively low bearing capacity of a completed fill. Despite the high degree of uncertainty characteristics of determinations of the bearing capacity of completed fills, the fact remains that reported values do indicate the prevalence of very low bearing capacities. Reported values range from 2443 to 2906 kg/m^2. These rather low values apparently would restrict the construction of buildings on the completed fills to light-weight, single-story structures.

Solutions: The best course of action is to suspend the floor slab on sulfate-resistant cement piles. (The cement is of Class 4 or 5 (BRE 1981)). If the piles are made of materials other than concrete, they should be protected by corrosion-resistant material so as to cope with corrosive decomposition products in the fill.

A light one-story building designed to accommodate settling may not require piling. However, its foundations should be reinforced to bridge gaps formed by differential settling. Continuous floor slabs reinforced as mats also can be used

Roads, parking areas, and walkways should be constructed of flexible and easily repaired material.

9.3.1.2. Potential Hazards

An important feature of the hazard potential of landfills is the fact that the potential persists as long as decomposition processes continue. This persistence is due to the decomposition processes that take place in a fill. Unfortunately, the decomposition processes continue long after the site has been closed.

The three broad categories of potential hazards are landfill gas production, chemical contamination, and corrosion. In addition to the attention given in this section, gas production receives considerable attention in Sections 5.1.3.3, 6.3 (Gas Management), and 9.1.1.3. Chemical contamination also is addressed in Sections 3.2.1.1, 6.2, and 9.1.1.

Landfill Gas Production: As stated earlier, the rapid depletion of O_2 entrapped within the mass of buried wastes results in a rapid shift in the composition of the landfill gas from a preponderance of CO_2 to one of CH_4. The significance of this shift stems from the combustible and under some conditions, explosive nature of CH_4. The gas becomes explosive if its concentration is from 5 to 15% CH_4 in air at the time of ignition. Because the rate of methane generation is extremely slow, methane production, *per se*, does not constitute a hazard. Consequently, methane becomes a combustible or explosive hazard only when the gas accumulates in a confined space within the fill itself or within a structure erected either on the fill or close to it. In some cases, pressure exerted by the buildup of landfill gases has been high enough to force the gas through permeable strata in soil adjacent to an unlined fill.

Although not necessarily hazardous, the malodorous nature of some trace constituents of landfill gas can be sufficiently intense as to constitute a problem. Examples of malodorous constituents are esters and organosulfurs. However, high dilution factors and low generation rates combine to keep malodorous gases from posing a problem in the use of the completed fill.

Corrosion: The hazard posed by corrosion is to building materials, utilities (pipes), and other items related to construction. The corrosion potential is in the many highly chemically active breakdown products found in decomposing municipal wastes. For instance, the mechanisms of attack on concrete include leaching of soluble materials, degradation of the binding capacities of cement by chemical change, disruption caused by expansion of reaction products, and crystallization of salts within the concrete pores. With respect to utilities, metals are subject to attack by the acids generated within the fill as products of anaerobic decomposition. (Of course, steel reinforcement rods are subject to the same acid corrosion.)

Solutions: Procedures for preventing gas production from becoming a hazard at the fill and its environs are described in Section 6.3. Measures described in this section are specific to the use of the fill for construction and urban redevelopment. With regard to construction on a fill, the following measures should be taken:

- Install the floor slab carefully so as to prevent cracking and to keep the concrete from becoming porous.
- Do not allow cavities to develop under the slab.
- Install an impermeable plastic membrane within or beneath the floor slab.
- Lay the slab on a layer of gravel or crushed stone. The layer may be actively or passively ventilated.
- Build the structure above the surface of the landfill and incorporate a well-ventilated subfloor area. Active ventilation involves the use of a pump capable of ensuring several air changes per hour. Passive ventilation (i.e., "naturally occurring") is sufficient in situations in which the rate of gas evolution is low.
- Do not install utilities by penetrating the floor slab. Therefore, piping, conduits, etc. enter the structure above floor-level.
- Strategically located methane alarms should be installed in the structure.

9.3.1.3. Recommendations for Construction on Completed Fills

The following recommendations are based on criteria listed by Stearns and Petroyan [8]:

- Construction and urban redevelopment should not be allowed on a newly completed deep fill that has a large concentration either of industrial wastes or of freshly deposited highly organic wastes.
- The fill should have been completed ten years prior to redevelopment.
- The completed fill should not be deeper than 10 m.
- The fill site should have a stable, low water table.
- The fill itself should contain no toxic or hazardous wastes, particularly liquid wastes.
- The development should be in keeping with the site conditions.
- Expenditures on the development should be in keeping with the intended use of the development.

Redevelopment need not be approached solely on a cost-effective basis. The approach also must be equally satisfactory on an environmental basis. Thus, adequate safety measures must be taken into consideration in the design of structures.

9.3.3. Summary of Potential Uses

As stated in the other sections, all uses of completed landfills are subject to certain constraints that remain in force until the biodegradable fraction of the buried wastes has been almost completely decomposed, and chemical and physical processes going on in the fill have reached a relatively high degree of stability, i.e., are approaching equilibrium. Among the more important of the constraints are those that arise from:

- The low-bearing capacity of the fill cover
- Extensive settling (especially the uneven settling)
- Presence of combustible and explosive gases
- The corrosive character of decomposition products and the internal landfill environment in general

These processes and their associated constraints continue long after the fill has been completed. The duration of this period is a function of climate (rainfall, temperature), nature of the buried wastes, and design and operational features of the landfill. For example, it may be as brief as two or three years in a developing country located in a humid, tropical setting and longer than ten years in an arid environment.

The uses may be divided into the three general categories: open space, agricultural, and urban developmental.

9.3.3.1. Open Space and Recreation

Although "recreation" and "open space" can be treated as separate entities, they can also be regarded as mutually inclusive. Many reasons can be given for regarding recreation as being the most beneficial of the potential uses of a completed fill. In some cases, the completed fill probably provides the only site that will be available for recreation within the foreseeable future. The list of potential recreational uses is extensive. The types of uses largely reflects culture (e.g., cricket vs baseball), although open space would appeal to the widest spectrum. It is important to note that all constraints attending the construction and use of structures apply to structures erected for recreational purposes. A photograph of a completed fill is shown in Figure 9-2.

9.3.3.2. Agriculture

The completed fill can be used as pasture or cropland when reservations concerning this use are taken into consideration. Among the agricultural uses are grazing, crop production, tree farms, orchards, nurseries, etc. In all cases, the cover should be deep enough to ensure that roots do not come into contact with the buried wastes. Not only would such penetration be inhibitory to the crop plant(s), whether it be grass or trees, it may also serve as an avenue for introducing harmful substances into the food chain and the environment. The precaution becomes especially important when food crops are concerned. (Examples of depth are: grasses - 0.7 m., shrubs, corn, alfalfa - 1.3 m, trees with laterally branching root systems - 1.3 - 2 m, trees with tap root systems – >4 m)

9.3.3.3. Construction and Urban Redevelopment

Even though construction and urban development are low priority uses, it is highly likely to occur in developing countries, especially in regions undergoing rapid or accelerated urbanization. For example, in Cairo, apartment buildings for the poor are built on landfills. In these regions, vacant space for residential and commercial construction is becoming increasingly scarce. Every effort should be made to observe necessary constraints associated with this use.

Figure 9-2. Completed Fill

(Repeat Figure 2-2)

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5. Emberton, J.R., A. Parker, "The Problems Associated with Building on Landfill Sites", Waste Management and Research, 5(4):473-482 (Dec. 1987).

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7. Study of Landfill and Resource Recovery in Metropolitan Colombo, Draft Final Report prepared for the World Bank by Environmental Resources Limited, June 1987.

8. Stearns, R.P., G.S. Petroyan, "Identifying and Controlling Landfill Fires", Waste Management and Research, 2:75-83 (1984).

MANAGEMENT AND RECORD KEEPING

10.1. MANAGEMENT RESPONSIBILITIES

Quality management is one of the more important factors that determine whether or not a landfill operation will be a successful undertaking. Regardless of size of the landfill operation and its technological level, the responsibilities of management are quite diverse and the specialties required are correspondingly numerous. The responsibilities cover three areas: operational, social, and fiscal. The operational responsibilities include:

- Maintenance of conformity with design and regulations
- Conduct of routine and other daily operations
- Provision of security
- Supply of maintenance
- Replacement of equipment

Social responsibilities include:

- Public relations
- Assurance of safety
- Hiring and training of personnel

The fiscal responsibilities include:

- Equipment and personnel record keeping
- Operational record keeping
- Environmental reporting
- Development and observation of budgets
- Financing

Generally, the size of the operation is the deciding factor regarding the advisability of investing these responsibilities in a single individual or of entrusting them to a management team headed by a single leader or authority. It is essential that functioning either as the sole manager or as the head of a team, the leader should be adept and forceful in the management functions, and especially be above reproach ethically.

For a large-scale sanitary landfilling undertaking at the technological level of developed regions, personnel and equipment are the two major management items of concern in terms of importance and expense. Conversely, with small- and large-scale landfill undertakings at a technological level befitting the resources of a developing nation, personnel becomes the key item. The reason is that, in developing regions, labor usually is abundant and equipment is scarce and expensive.

10.1.1. Personnel

Number and types of personnel (jobs and positions) required for a sanitary landfill operation are function of size and level of technology employed. The smaller the size of the operation, the fewer the number and types of personnel required. The number of personnel increases almost proportionally to the size of the fill. But the types of personnel are not only dependent upon size of operation but upon technology also. Therefore, as the size of the operation and the level of technology increases, the need for trained operators and position types for those operators (mechanics, bulldozer operators) increases. As a result, both the number and types of personnel increase. But, if the level of technology is low, less equipment is used, hence fewer trained operators are needed, thus reducing the number of types of operators.

10.1.1.1. Types

In moderately and in fully industrialized settings, types of personnel positions are for the most part a function of the size of the facility. Thus, for a facility handling less than 50 to 70 Mg per day, a single full-time operator probably could carry out the necessary operation of equipment, recording of waste input, and performance of administrative and maintenance functions.

At the opposite end of the size spectrum, a facility accommodating inputs in the hundreds of Mg/day would require one or more supervisors, equipment operators, mechanics, laborers, and check station attendants. However, in a developing-region setting, equipment operator and mechanic could be combined to constitute a single position, and the number of positions involved correspondingly becomes but a fraction of that in a developed setting. The number of laborers required obviously would increase in proportion to size.

Supervisor: Responsibilities of a supervisor extend to all aspects of landfill operation, particularly those pertaining to its management. Time not spent on supervisory duties can be directed to other positions. The supervisor should have had experience in landfill operations and should be fully conversant with all that sanitary landfilling involves, such as aims and goals and relevant governmental regulations and guidelines. The supervisor should be familiar with the use, servicing, and maintenance of all heavy equipment that may be used. In non-developed regions, the ideal would be that the supervisor be acquainted with basic engineering principles of landfilling design and construction, and be conversant with environmental protection principles, especially those regarding sampling and analytical procedures.

Equipment Operator: An equipment operator not only should be experienced with the uses and capacities of the types of equipment used in the operation, but also should be able to operate a variety of equipment. Familiarity with methods and techniques used in solid waste landfill operations would be a distinct advantage – if not a requisite. Such an operator may be difficult to find in a developing country, although the chances are improved by the fact that operations involving even moderately advanced technology would be limited to metropolitan settings.

Check Station Attendant: Although the position, check station attendant, is a common feature of landfill operations in developed settings it is much less common in developing settings. Nevertheless, a check station attendant could be an important functionary - perhaps a minor bureaucrat - in a developing country. The reason is that in practice, such a functionary not only may collect fees and keep a record of traffic and material entering and leaving the site, but also can enforce regulations concerning ingress and egress of individuals, vehicles, and materials.

Skilled and Unskilled Labor: The category, "labor," applies to the male and female members of the work force (employees) engaged in the physical and manual aspects of the routine operation of the fill. Among the many functions of labor are collection of litter, installation of drainage lines, performance of landscaping tasks, routine maintenance on buildings and other facilities, and serving as "spotter" at the working face.

Mechanics: Even in a developed country, the full-time services of a mechanic generally are not required at small fills. However, one should be available for providing needed equipment maintenance without undue delay. The latter is particularly important in a developing country. In such a setting, the uninterrupted operation of a fill may depend upon the functioning of a piece of equipment for which no replacement is available. Mechanics should be well versed with maintenance and operation of heavy equipment.

Number: Employee requirements are site specific. Thus, number of employees required for the satisfactory operation of a landfill is mostly a function of the size and technological level of the operation. The lower the technological level, the more direct is the proportion between labor-need and size of the operation. In other words, a low-level operation is more labor intensive than is a high technology one. For a developed country setting, it has been estimated that one employee is needed for every 65 Mg of solid waste received each day [1]. With respect to type of landfill, trench operations generally are more labor intensive than are area fills. Other factors are size of the operation, type of wastes received, site characteristics, and operating hours.

10.1.2. Equipment

The selection of equipment is discussed in Section 7. In this section, we deal with cost categories relative to purchase, and with operation, maintenance, and record keeping.

10.1.2.1. Costs and Cost Recovery

Items of cost pertinent to equipment are those of owning and operating the equipment and down-time cost. Resale value is the major determinant in the recovery of equipment costs. Owning costs include the price of the equipment, related interest charges, taxes, and insurance premiums. Due to mark-ups, shipping costs, import and export duties (fees), commissions, etc., owning costs in developing countries generally are substantially higher than those in developed countries. Although the financial burden may seemingly be lightened in a developing country through the purchase of obsolete or of used equipment, scarcity of replacement parts and increased maintenance and down-time costs render the savings illusory. Scarcity of parts and increase in maintenance and down-time also considerably diminish the benefits of being the recipient of donated pieces of equipment.

A range of costs for landfill equipment is presented in Table 10-1.

Operating costs include those for fuel (powering the machine), for preventive maintenance, for repairs, and for associated labor. The item "fuel costs" includes the price for the fuel itself (i.e., diesel, gasoline) and that of lubricants.

Because the landfill operation must be continuous (uninterrupted), functions not being filled by a malfunctioning piece of equipment must be performed by standby equipment. This is true because, by its nature, landfilling depends upon equipment. Even where it is plentiful, manual labor cannot entirely compensate for basic equipment. Unfortunately, standby equipment is an unaffordable luxury in most developing countries. Therefore, the entire operation deteriorates during equipment downtime.

Table 10-1. Capital Cost per Landfill Equipment

Type	Power (hp)	Weight (kg)	Approximate Cost (U.S. $)
Compactor	<200	<18,000	140,000
	200 - 300	23,000 - 27,000	220,000
Track Dozer	<100	8,000	70,000
	100 - 200	14,000 - 20,000	138,000 - 199,000
	210 - 300	20,000 - 28,000	200,000 - 260,000
Wheel Loader	<100	9,000	66,000
	100 - 200	10,000 - 15,000	106,000 - 140,000
	<200	20,000	153,000
Track Loader	<100	9,000	78,000
	110 - 130	14,000 - 16,000	102,000 - 115,000
	140 - 200	20,000 - 23,000	172,000 - 185,000
Wheel Tractor	300 - 400	11,000 - 27,000	130,000 - 218,000

Resale is probably the major avenue of cost recovery. Resale value is the rate of depreciation and potential market value of a piece of equipment.

10.1.2.2. Operation and Maintenance

The full potential of a piece of equipment cannot be realized without a competent and well-qualified operator. Inasmuch as landfill operation is heavily dependent upon equipment, an efficiently functioning and environmentally sound operation depends on the realization of that potential. Ultimately, the competency and qualification of the equipment operator is a major factor in a well-run landfill. Ideally, the operator should have extensive experience in equipment operation. New operators should undergo an adequate training program. In addition, all operators should have access to operation manuals for the equipment.

The cost for maintaining heavy landfill equipment is on the order of 15% of the original capital cost per year.

The cost of equipment maintenance is an expensive item that can be substantially lowered by the institution of a program of daily preventive maintenance. Equipment maintenance is a critical aspect of landfill operations. Unfortunately, maintenance is a task that often is overlooked, and in some cases ignored, in many LDCs. The life span of equipment can be increased by performing periodic and thorough maintenance procedures. Daily routine maintenance involves such activities as checking water and oil levels, lubricating moving parts, keeping bulldozer tracks and radiator clean, etc. This maintenance can be done by the equipment operator, except in a very large operation. For a large operation, a full-time or part-time mechanic may be assigned this duty.

A comprehensive, daily report should be completed for each piece of equipment and be readily accessible. The report can take the form of the one shown in Figure 10-1. Such daily record keeping is an assurance of better maintenance and consequent lower maintenance costs.

Manufacturers generally supply the equipment with a list of maintenance procedures and their frequency as well as a suggested list of replacement parts. Very small jurisdictions can rely on private enterprises for the maintenance and repair of the equipment. On the other hand, medium to large (larger than 300 to 500 tons/day) sites should consider having a full-time mechanic on staff for performing routine maintenance and minor repairs. Furthermore, it is strongly recommended that the landfill include a garage and repair shop equipped with, at the very least, basic tools and some spare parts.

REFERENCE

1. Flintoff, F., Management of Solid Wastes in Developing Countries, WHO Regional Publications, South-East Asia Series No. 1, New Delhi, 1976.

Site: ______________________

Machine: ______________________

Date: ______________________

Completed By: ______________________

Hour Meter Reading: ______________________

REMARKS

BEFORE STARTING CHECK

- WATER ☐ ______________________
- ENG. OIL ☐ ______________________
- TRANS. ☐ ______________________
- FUEL ☐ ______________________

WATER ADDED FRONT	☐	________	WATER ADDED REAR	☐	________
ENG. OIL ADDED FRONT	☐	________	ENG. OIL ADDED REAR	☐	________
TRANS. OIL ADDED FRONT	☐	________	TRANS. OIL ADDED REAR	☐	________
HYDRAULIC OIL ADDED FRONT	☐	________	FINAL DRIVE OIL	☐	________

AFTER STARTING LEVEL MACHINE AND CHECK

- ENGINE OIL ☐ ______________________
- TRANS. ☐ ______________________
- HYDRAULIC OIL ☐ ______________________
- ANY LEAKS ☐ ______________________
- BRAKES ☐ ______________________
- STEERING ☐ ______________________
- TRANSMISSION ☐ ______________________
  - PRESSURE ☐ ______________________
  - GAUGES ☐ ______________________
  - SHIFTING ☐ ______________________
- ENGINE ☐ ______________________
  - TEMP. ☐ ______________________
  - OIL PRESSURE ☐ ______________________
  - WATER TEMP. ☐ ______________________
- UNDERCARRIAGE ☐ ______________________
  - TRACK ADJUST. ☐ ______________________
  - ROLLER WEAR ☐ ______________________
  - TIRES ☐ ______________________
- BLADE ☐ ______________________
  - CUTTING EDGES ☐ ______________________
- HYDRAULICS ☐ ______________________
  - PUMP ☐ ______________________
  - JACKS ☐ ______________________
- OTHER ☐ ______________________
  - AIR CLEANERS ☐ ______________________
  - RAD. CLEAN ☐ ______________________
  - TRACK CLEAN ☐ ______________________
  - TIRES FREE OF MUD ☐ ______________________

Figure 10-1. Equipment Inspection Form

ECONOMIC CONSIDERATIONS

11.1. BACKGROUND

The economic costs of individual disposal operations vary substantially from country to country and within each country. The variations are impacted by local conditions, regulations, as well as other factors not related to landfilling (i.e., assessments for funding recycling, groundwater protection, etc.). Therefore, the coverage discussed in this section is limited to the costs of the general components of landfill costs. An example of the extent of the variation as a function of time in the U.S.A. is shown by the data in Table 11-1.

The data in Table 11-1 show how the costs for landfilling have varied over time. In the 1970s, the major fraction of the costs for landfilling was that associated with site operation. Since a large number of LDCs do not have regulations which require closure and post-closure care, these costs would be similar to those currently experienced in LDCs. As regulations and other conditions changed, in 1986 construction costs increased and operation costs decreased. In addition, post-closure care was added to the overall cost. More recently (in 1990), the costs due to construction and operation have been kept relatively constant. On the other hand, a new item unanticipated) has begun to make an impact on the cost of landfilling.

Cost of landfilling depends in part upon the type of waste disposed, size of the operation, availability of fill and cover material, and whether or not construction was phased. Phased landfill construction is cheaper than construction of the landfill all at once. Varying site conditions and regulatory requirements for landfill construction are important factors in the variability in landfill construction costs.

As for accurately determining the landfill costs in a particular area, the best approach is to examine past and current landfill operations in that area. In each area, cost of landfill

Table 11-1. Changes in Landfill Development Costs[a)]

Item	Typical Cost (%)		
	1975[b)]	1986[c)]	1990[d)]
Predevelopment	5.9	5 -10	7.0
Construction	12.3	25 - 35	35.0
Operation	75.7	40 - 50	36.0
Closure	6.1	1 - 5	3.0
Post Closure Care	0	10 - 15	11.0
Unanticipated	0	0	8.0
	100	100	100

a) Profit is not included, 16-ha site, 1 million tons, 15-year site life.
b) Includes 117 cm soil liner and leachate collection system.
c) Includes 150 cm clay liner (available on site) and 30-year post-closure.
d) Includes 150 cm clay liner (available on site), 30- mil synthetic liner, leachate collection system, increased monitoring, $1.50 U.S./ton fee.

Adapted from Reference 2.

disposal depends upon the cost of the land upon which the facility is sited, the design of the landfill, cost of labor, and governmental regulations that must be met.

Not only do landfill costs directly affect the total cost of waste management, they also have a bearing on the extent and nature of the processing to which the wastes might be subjected prior to ultimate disposal. In other words, the way that wastes are managed by communities generating the wastes is determined to a considerable extent by the cost of disposing of those wastes. Regardless of the developmental level of a nation, landfill construction and operation costs are only a relatively small fraction of the total disposal cost when and where land suitable for landfilling is available at a low cost. Obviously, under such a circumstance, landfilling the wastes without pretreatment usually would be the least expensive, although not necessarily the best disposal option. On the other hand, some form of waste processing to reduce amounts and volumes of wastes destined to be landfilled most likely would be economically justified in areas where land is expensive or unsuitable for landfilling.

In most communities in developed countries, the cost of operating the landfill is recovered by means of a user fee. The fee typically is known as "tipping fee." Tipping fees generally vary as a function of weight, type of waste, and availability of landfill space.

11.1.1. Landfill Costs vs Total Cost of Solid Waste Disposal

The total cost of waste disposal is the sum of the costs for each component of the waste disposal operation. The disposal operation begins with the collection of waste from residential and industrial generators and ends with final management of the landfill site after closing (i.e., closure and post-closure). The total cost of each component of the waste disposal operation is the sum of its capital and operating costs.

An outline showing the positions of the major operations that precede the landfill operation is presented in Figure 11-1. The three leading operations are collection, hauling, and processing. Processing is optional. Collection involves the pickup of discarded materials from

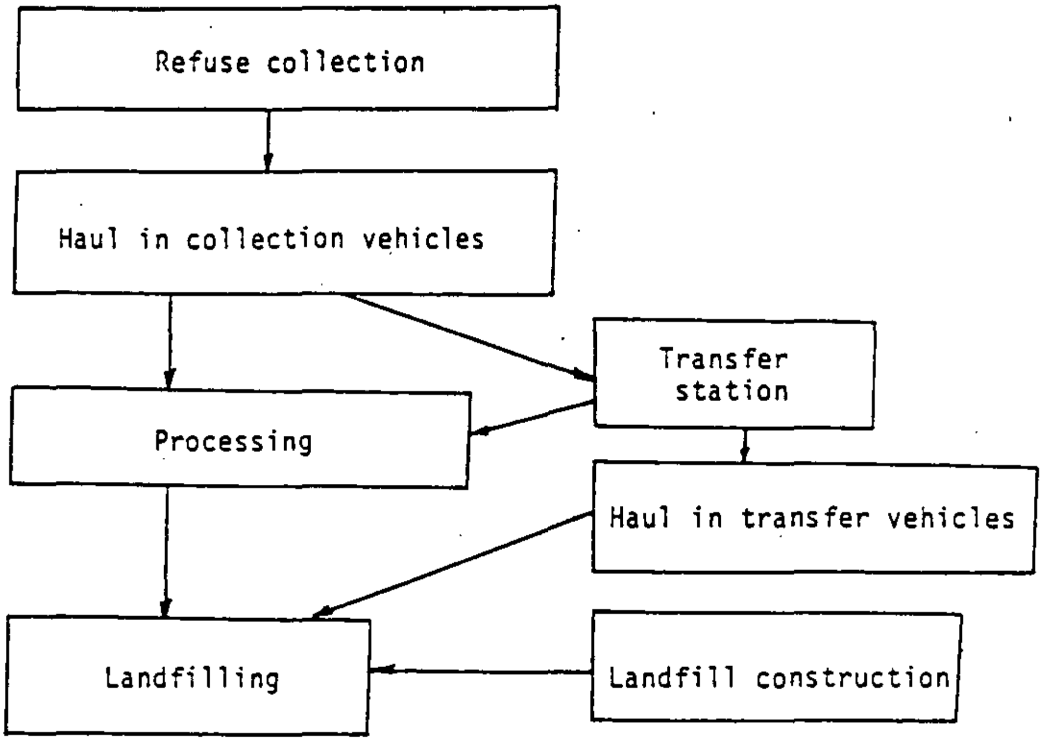

Figure 11-1. Waste Management Components

residential and industrial areas. Hauling is the transportation of the collected wastes either to the landfill or to central collection or to processing locations. The actual burial of the wastes at a landfill constitutes landfill disposal. In developing nations, collection represents the major fraction of the costs for waste management.

11.1.1.1. Effect of Processing on Cost of Waste Disposal

Shredding and baling are two of the more common examples of processing. Either process increases the density of the collected waste, thereby reducing the volume of the waste. This expands the total capacity of the fill. Additionally, less cover soil is required. Expanding landfill capacity and easing cover-soil requirements obviously lower landfill costs.

Removal of recyclable materials (e.g., scavenging, composting) is a form of waste processing that equals shredding and baling in terms of reduction of amount of waste destined to be landfilled. The scavenging may take place before, during, or after collection.

One way processing can reduce costs other than by volume reduction, is by upgrading of the quality of the waste to a level at which exceptional landfilling measures are not required. Examples of exceptional measures are those prescribed for "secure" landfill (see Section 5.3.3., Hazardous Wastes). Among the approaches to upgrading are detoxification of toxic wastes, encapsulation or solidification of hazardous or toxic substances, and removal of particularly objectionable characteristics of putrescible wastes.

The most typical unit processes used in LDCs include shredding and screening. Size reduction and screening usually are associated with preparation of the waste for composting. Size reduction is an energy- and maintenance-intensive process. The process should be carefully designed and operated so that it does not become a burden to the overall process. Waste processing, in order to recycle and reduce the quantity of waste landfilled, may be justifiable in areas where landfill capacity is low and alternate sites are far away (i.e., more than 50 km away).

11.2. CAPITAL AND OPERATING COSTS

Among the principal capital costs are those of land, buildings and construction, and vehicles. These capital costs usually are fixed costs in that as a rule, they are set, or fixed, during the course of the landfill operation. Labor required for maintenance, fuel costs, and cost of cover material emplaced during the operation of the landfill are all classified as operational costs. Operational costs are variable in that they generally increase with increase in the rate and magnitude of waste disposal.

11.2.1. Landfill Cost Models

The relative costs associated with development, operation, and closure of a sanitary landfill in the U.S. are presented in Table 11-2.

A major difficulty in developing a landfill cost model that reflects conditions and costs in a developing country is the small amount of available data, and the few data to be found have a questionable reliability. Such being the case, the logical approach is to develop and accumulate reliable data on costs. This task can be considerably facilitated by following a suitable model for calculating the costs involved in sanitary landfilling. Such a guide or model is proposed by L.E. Joyce [1]. The model is presented in the form of a worksheet for calculating the real cost of waste disposal. A worksheet is presented in Table 11-3.

Although the model and worksheet are based on U.S.A. conditions, it can be adapted for use in developing countries. It can be adapted because it is based on generic rather than specific principles. Costs as listed in the table can be interpreted as being "indicators" of relative costs.

The worksheet in Table 11-3 covers the development, operational, and closure costs under specific headings:

- "Pre-Development Costs"
- "Initial Construction costs"
- "Annual Operational Costs"

Table 11-2. Individual Component Cost Relative to Total Landfill Cost[a)]

Component	Percent of Total Cost
Predevelopment	3.6
Construction Costs	35.5
Operation Costs	46.0
Closure	0.9
Long-term Care	11.5
Other	2.5

a) Adapted from References 2, 3, and 4.

Table 11-3. Worksheet for Estimating Landfill Costs (620 ha, 200 ton/day facility)

Pre-Development Costs

Siting the facility (engineering, legal fees & preliminary geotechnical investigations)	$ 75,000
Site mapping (topographic/boundary surveys) & final geotechnical investigation	75,000
Engineering design & regulatory permit application	100,000
Legal & public hearings	50,000
Land purchase (620 ha)	250,000
Regulatory permitting fees	5,000
Administrative support services	25,000
Contingency	50,000
[a]Total Pre-Development Cost	$630,000

Initial Construction Costs

Entrance & access roads	$ 100,000
General site excavation & land clearing	750,000
Erosion & sediment control facilities	50,000
Liners & liner cushion system	550,000
Leachate collection & landfill gas venting system	50,000
Leachate treatment system	100,000
Site landscaping	50,000
Scale system	50,000
Scalehouse & office building	20,000
Equipment maintenance facility	75,000
Public convenience area	30,000
Miscellaneous site paving	30,000
Miscellaneous (lighting, gates, signs, etc.)	50,000
Construction engineering & quality control testing	50,000
Subtotal	1,955,000
Contingency	45,000
[b]Total Initial Construction Cost	$2,000,000

Annual Operational Costs

Site personnel & management	$200,000
Facility overhead (including building & grounds, site maintenance, electricity, etc.)	50,000
Equipment operations & maintenance	50,000
Equipment rental	150,000
Road maintenance	25,000
Routine environmental monitoring (ground water, surface water & landfill gas)	25,000
Engineering services	30,000
Site & equipment insurance/closure bonding	50,000
On-going development & construction costs	250,000
Leachate treatment at a municipal sewer system	10,000
Pre-treatment of leachate prior to disposal into municipal sewer system	50,000
Unanticipated costs	50,000
[c]Total Operational Costs	$940,000

Closure and Post Closure Costs

This assumes the final cap on the landfill is part of the cost while the landfill is operating. The annual amount should be set aside during the operational years of the landfill.

Costs include the following:

Engineering fees for preparation of a closure plan
Regulatory approvals of the closure plan
Final site grading & re-vegetation
Maintenance of erosion & sediment control facilities
Maintenance of landfill gas system
Operation & maintenance of leachate collection and treatment system
Leachate treatment at offsite treatment plant

[d]Annual Closure/Post-Closure Costs	$50,000

Annual Cost

[e]Capital costs (a + b)	$2,630,000
[f]Amortization of capital costs – straight line depreciation over 20 years at 9%	285,000
[g]Annual operating cost (c)	940,000
[h]Annualized closure & post-closure costs (d)	50,000
[i]Total annual cost (f + g + h)	1,275,000
[j]Annual tons per year (200 tons/day x 6 days/week x 52 weeks/year)	62,400 tons
[k]Cost per ton (i + j)	20/ton
[l]Host community fee for capital improvements	–
[m]State or local fee	–
[n]Total Tipping Fee (k + l + m)	$20/ton

Cost per Household per Month

[o]Annual cost (i)	$1,275,000
[p]Population	100,000 people
[q]Cost per person (o + p)	$12.75/year/person $1.06/month/person
[r]Persons per household	4.0
[s]Cost per household (q x r)	$4.25/month/household

Adapted from Reference 1.

- "Closure and Post-Closure Costs"
- "Cost Per Household Per Month"

The costs listed in the worksheet assume a 200-ton/day facility designed to serve populations of 80,000 to 100,000 people, operating in the U.S.A. The facility is situated on a ~~101~~ ha site, of which 61 ha will be used for disturbed and non-disturbed buffer, 18 ha of which will be designated as "non-disposal areas" (roads, etc.) The average excavation depth is about 3.1 m. The costs also include a double lining system and a leachate collection and detection system. The facility operates 6 days per week, 52 weeks per year.

Although costs estimated by way of a model in which survey data are used may be inaccurate, they do indicate potential magnitudes of construction and other landfill costs. As such, they are useful in making design decisions and comparisons between various disposal options.

Additional costs for landfilling are provided in Table 11-4. The data in the table are presented for landfill sites having 100, 200, 300, and 400 ha in total area. The items included in Predevelopment are given in Table 11-5. Similarly, the items included in Closure and Post-Closure Care are presented in Table 11-6. These items are described in Tables 11-5 and 11-6 so that users of this document can get an indication of the requirements of each phase.

11.3. LANDFILL EQUIPMENT COSTS

Capital costs of heavy equipment used for landfilling refuse constitute a major cost component for the development of landfills. An indication of the magnitude of this component may be gained from the data presented in Table 11-7. Because of the costs associated with sanitary landfilling, the acquisition of a sufficient number of the appropriate equipment for the efficient operation of a fill often times is not carried out in developing countries.

Table 11-4. Summary of Landfill Development and Annual Operating Costs in 1990
(U.S. Dollars)

Item	ACTIVE LANDFILL AREA 100 ha	200 ha	300 ha	400 ha
Predevelopment	340,000	410,000	480,000	550,000
Site Preparation				
Clay (on-site)	6,840,000	14,300,000	23,100,000	33,100,000
Clay (16 km haul)	8,300,000	17,100,000	27,100,000	38,600,000
Membrane/Clay (on-site)	9,300,000	19,100,000	30,200,000	42,600,000
Membrane/Clay (16 km haul)	10,100,000	20,700,000	32,700,000	45,900,000
Operations	175,000/yr	300,000/yr	415,000/yr	455,000/yr
Closure	1,100,000	2,200,000	3,300,000	4,500,000
	1,800,000	3,600,000	5,500,000	7,300,000
Post-Closure	133,000/yr	241,000/yr	350,000	457,000

Table 11-5. Items Included in Predevelopment Costs[a)]

- Environmental Impact Statement
- Feasibility Report
- Design and Plan of Operation
- Administration

a) Land costs have been purposely omitted.

Table 11-6. Items Included in Closure and Post-Closure

Closure

- Earthwork
- Seeding
- Gas Collection

Post-Closure

- Monitoring (groundwater, gas, leachate)
- Leachate Treatment
- Site Maintenance
- Liability Insurance

Table 11-7. Equipment Capital Costs

Machine Type	Flywheel (kW)	Weight (Mg)	Approx. Weight[a)] (Mg)	Approx. Cost[b)] (U.S. $)	Comments
Crawler Dozer	<60	<6.8	8.6	25,000	Landfill blade
	82 - 97	9.0 - 11.3	14.4	45,400	Landfill blade
	186 - 209	21.4 - 23.4	30.2	83,600	Landfill blade
Crawler Loader	<52	<9.0	9.5	25,000	GPB[c)]: 0.8 m^3
	75 - 97	11.3 - 19.6	14.0	35,800	GPB: 1.5 m^3
	75 - 97	11.3 - 14.6	14.4	38,200	MPB[d)]: 1.3 m^3
	119 - 142	14.6 - 20.1	20.3	54,900	GPB: 2.3 m^3
	119 - 142	14.6 - 20.1	21.2	58,600	MPB: 1.9 m^3
Rubber-tired Loader	<75	9.0	7.7	25,000	GPB: 1.3 m^3
	<75	9.0	8.1	25,000	MPG: 1.1 m^3
	89 - 119	10.1 - 12.04	9.5	39,500	GPB: 3.0 m^3
	89 - 119	10.1 - 12.4	11.7	43,000	MPB: 1.7 m^3

a) Basic machine plus engine sidescreens, radiator guards, reversible fan, roll bar, and either a landfill blade, general-purpose bucket, or multiple-purpose bucket as noted.
b) December 1990.
c) General-purpose bucket.
d) Multiple-purpose bucket.

Source: Reference 7.

As was mentioned in Section 7 "Equipment Selection", the two principal uses for landfill equipment are to move and compact wastes and to move and compact soil. Waste movement and compaction are accomplished by spreading the wastes in layers on the working face of the landfill and in doing so, compacting them to the desired density. The same piece of equipment is employed for both tasks. Soil must be excavated and transported to the working face of the landfill for daily cover. Immediately upon dumping the soil onto the working face, it must be spread and compacted into a relatively uniform layer.

Under U.S.A. conditions, the life span of mobile landfill equipment is generally estimated to be about 5 years.(i.e., about 10,000 hours of operation) [7].

In an industrialized nation, annual cost of maintaining heavy landfill equipment (lubrication, tire repair, parts, etc.) is estimated as being 16% to 18% of the original capital cost of the equipment. The actual cost in a developing country would depend very strongly upon the age of equipment, type of equipment, maintenance procedures, as well as on the various factors peculiar to a developing country. However, the maintenance cost to capital cost ratios in the two settings probably would be similar.

As with maintenance costs, fuel costs vary with type and condition of the equipment. Obviously, they also depend upon the prices locally charged for various components of maintenance costs (e.g., fuel, parts). Nevertheless, an indication of fuel consumption may be had from the data reported in Reference 6. According to those data, total fuel consumption averages about 3.5 liters fuel/Mg waste disposed. At that rate of consumption, the fuel consumption per piece of equipment probably would be on the order of 100 liters per day.

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by way of radio broadcasts, and public (official) announcements, and to some extent, by way of the printed media and "public education" programs.

Loss of Living Space – Because of dense urban sprawl brought about by mass migration from rural to urban areas, vacant land in the urban areas has become extremely scarce. Preferable areas have been taken over by business and the economically advantaged segments of the population to the extent that either no space is left for the poor, or the space is undesirable for some reason. Inasmuch as the landfill must be sited not too far from the waste generators, it often happens to compete with landfill. Regardless of the unsuitability of such low-grade land areas, they are the last recourse for living areas for a significant fraction of the poor. Nevertheless, it may well happen that these unfortunates have to compete with a landfill undertaking for those sites. It is not surprising that a strong antipathy against any proposed landfill is aroused in those individuals.

Dispelling such a source of antipathy will be a difficult task. An obvious way is to find other land for the dispossessed individuals, but this task is not always carried out, for various reasons. A more realistic way to cope with the problem is to design and operate the landfill such that when completed, the site can provide living or recreational space, even though its promised remedy is postponed to a somewhat distant future (Section 9.3.1.3). "Selling" that remedy to the affected individuals undoubtedly would be an almost insuperable task, despite reliance upon the conventional means of making such an attempt. About the only course remaining is to keep the number of those potentially affected at a minimum. Motivations in the form of sacrifices for the common good, preservation of the public health, patriotism, etc. have little weight among a group for the members of which mere survival is a pressing problem.

12.1.2.2. "Middle Class"

A middle class, as the term is defined in a developed country, either may be non-existent or may be very small in a developing country. As used in this section, the term is one of convenience and is intended to encompass a wide segment that neither fits within the category "poor", nor is financially endowed sufficiently to be categorized "wealthy". Thus, it includes individuals and professionals who are at the management and/or decision-making levels of the organizations for which they work. Examples of the organizations are businesses and all branches of government. Also included are members of the educational system, of the health care professions, informed concerned citizens groups, etc.

Causes of the antipathy, and hence opposition of the middle class are not as basic as those of poor nor as widespread. They are not as basic in that they do not concern survival. However, some are not far removed from that extreme, in that they relate to loss of living space – space which already is extremely scarce. They are less widespread in that they are mostly confined to individuals living or involved (e.g., own property) in the immediate neighborhood of the proposed landfill. The opposition lessens in proportion to distance from the fill. Most of the causes are in the form of perceived threats to :

- Health through contamination of resources, primarily water, and fostering the generation of insect and animal vectors (e.g., flies, rats)
- Aesthetically and visually lowering the quality of life
- Adversely affecting property values in general

The opposition arising from concerns about health and quality of life could be considerable if not entirely eliminated by showing that a properly designed and operated sanitary landfill would not be a threat. However, the fears regarding reduction of living space and lowering of property values would not be as easily allayed. The matter of the reduction of living space could be taken care of to some extent by way of the same measures prescribed for the poor. Adverse effects on value of surrounding property would be much more difficult. Of course, the difficulty would be considerably lessened if the proposed fill were to replace an open dump operation.

The best course of action is to publicize the advantages of a sanitary landfill. Because the greater percentage of the middle class is literate, "spreading the word" would be much easier than it would be among the poor class. The printed media as well as the radio and television could also be put to use.

12.1.2.3. Wealthy

Antipathy on the part of the wealthy probably would neither be as deep-seated nor as strong as among the other two classes. Moreover, chances of members of this class having any immediate contact with a fill usually would be remote. Any antipathy would arise from a concern about deterioration of the quality of water resources in the area, endangerment of the health of the public at large (i.e., beyond the vicinity of the fill), or of any nearby property members may chance to own. Members of this class would dwell in the developed areas of the community in which the quality of the environment would approach that in a developed country. Because the cultural (social and attitudinal) characteristics would be comparable to those generally encountered in developed nations, measures taken to attract and engage their participation in a present or proposed sanitary landfill undertaking would also be comparable.

Objectives: Although some of these objectives may be difficult to attain in many LDCs, they are included here to guide the more advanced developing countries and to serve as a model for those less developed. Among the objectives of a public participation program for this group and to some extent, for the middle or intermediate group, would be the following:

1. Making certain that the public has the opportunity to understand official programs and proposed actions, and that the government gives due consideration to the public's concerns

2. Assuring official decisions on significant activities are not made without consulting interested and affected segments of the public

3. Making certain that government action is as responsive as possible to public concerns

4. Informing the public about significant issues and proposed project or program changes as they arise

5. Providing opportunities for public participation and stimulate and support participation.

These objectives can be accomplished through the maintenance of communication between the landfill planners, designers, operators, and the public.

Advantages Associated with Public Participation: In addition to the advantages mentioned earlier, are these:

- It increases likelihood of public agreement with the final plans
- It is an effective method of providing useful information to decision makers, especially where values or factors that are not easily quantified are concerned
- It constitutes assurance that all issues are fully and carefully considered
- It ensures accountability by decision makers
- It is an effective mechanism to force decision makers to take into consideration issues beyond the project, but which nevertheless have an influence on it, albeit indirectly

As would be expected, public participation is not without it disadvantages. Among them are:

- A potential is created for confusion of the issues because many new perspectives may be introduced
- Some uninformed participants may disseminate erroneous information
- Public involvement will add cost to the project
- Delays in the project because of public opposition and involvement of additional parties
- There is a strong possibility that the program might not involve the appropriate people or that citizens will not develop an interest in the project until it is too late for changes to be initiated

None of this list of disadvantages is great enough to outweigh the many benefits associated with an effective public participation program. The benefits are such that they facilitate the formation of an effective decision making process essential to publicly accepted landfill.

Participants: Among the potentially more useful participants would be groups and individuals likely to be directly affected by the landfill. They would be strongly motivated because they would have a personal stake in the success of the project. Other useful participants would be those who have demonstrated a serious interest in environmental affairs. In fact, their participation should be encouraged in the process.

Among the organizations and individuals that could have a part of the program are the following:

- Any interested members of the public
- Representatives of consumer, environmental, and minority associations
- Representatives of trade, industrial, agricultural, and labor organizations
- Civic associations
- Public officials
- Governmental and educational associations

Identifying and contracting these groups is only a first step. Although some of these groups are traditionally perceived as intransigent, gaining the support of these groups is not easily accomplished at the planning stage of the landfill, before it becomes and emotional issue. Moreover, gaining support early in the process can benefit subsequent program activities.

Extent of Public Input in Relation to Stage of Project Development: Although useful at all stages in the development of a sanitary landfill undertaking, public input can be critical at certain stages.. For example, the first stage, the planning process, is a critical stage. It is critical because it is the stage in which public input has the greatest potential for shaping the final plan. For that reason it also is the time when involvement should be greatest. In addition, it is the time for determining the limits to public and political acceptability. As a result of this early input, the public plays a constructive rather than a reactive role in decision making. Appropriate mechanisms for shaping and applying this input are public hearings, public meetings, and workshops.

The site selection and design stage is the succeeding critical stage [2]. Although the number of participants probably will be less than that in the planning stage, it nevertheless is a very active stage. This stage is marked by tours and field trips in which special interest groups can make their concerns known. Additional approaches in this stage are audio-visual presentations, establishments of task forces for recommending design procedures in areas of particular public concern. The forces could be part of an advisory committee consisting of residents near the site. One or more formal public hearings is essential at this time.

A third critical stage is the construction and operation stage. Although utilizable public input is perforce limited in this stage, the input nevertheless is critical, in that it is a means of monitoring the quality of construction and operation.

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CLOSING AND/OR PHASING AN OPEN DUMP INTO A SANITARY LANDFILL

I.1. BACKGROUND

One of the most common aspects of solid waste management in developing countries, particularly in small municipalities, is the open dump. Most of these jurisdictions lack both the technical and financial resources to develop a sanitary landfill as it is known in the developed nations. A possible solution to the severe negative impacts generated by an open dump is the closure or conversion of the dump into a sanitary landfill.

The financial and technological resources of the country and area where the open dump is located, determine the extent to which the procedure followed in closing it, or in phasing it into a sanitary landfill operation, can or will conform with the "ideal". If resources are minimal, the extent of the conformity also is minimal. The rationale is that minimum conformity is better than no conformity.

Rarely would closure be a two-step operation in which upgrading the dump to the sanitary landfill level would have to precede closure. The unfavorable conditions (hydrogeological, topographical, proximity to densely populated area, etc.) that could necessitate conversion into a sanitary landfill before closure, perhaps also would render it more desirable to transfer the wastes to another site for final disposal. However, both courses (i.e., two-step closure, transfer to another site) might be beyond the resources of the area. Nevertheless, if resources do permit, conformity should be at the ideal level, inasmuch as benefits to be reached from closing the dump are commensurate with the degree of conformity with the "ideal". Obviously, there is a range between the two extremes, i.e. both with respect to degree of conformity and to magnitude of the two resources. Reflecting the two extremes of conformity and resources, Appendix I is presented under the two headings, "Minimal" and "Ideal".

Closing an open dump can be either the final step of an open dump operation; or, it can or will be the first step in the upgrading of an on-going disposal operation to the status of a sanitary landfill. In both cases, the basic steps are identical. However, upgrading an on-going operation involves a step or two beyond the basic steps. For convenience, the first case is termed "terminal closure" and the second case is termed "transition closure".

I.2. TERMINAL CLOSURE

I.2.1. Minimum Conformity

Minimum conformity involves three main steps. Depending upon the topography, a fourth step may also be added. The steps are:

1) consolidation
2) compaction
3) covering the wastes
4) construction of systems to divert and intercept run-off waters (when required by reason of topography)(An example of the bearing had by topography is a dump on the top or on the side of a hill).

I.2.1.1. Consolidation

Consolidation involves collecting scattered wastes and concentrating and confining them with all the other wastes that had been dumped during the active "life" of the open dump as a single mass in a defined area. This activity is done such that the site is tidied and thereby rendered less objectionable. A tracked bulldozer or loader can be used for this activity.

I.2.1.2. Compaction

The reasons that give compaction its importance in sanitary landfilling also apply here (see Section 2.2). The consolidated wastes are compacted with the use of equipment much like that utilized in sanitary landfilling. If that type of equipment is not available, repeatedly running a bulldozer equipped with tracks or any other piece of equipment similarly equipped with tracks should suffice. Aside from being much less effective, the problem with using equipment not equipped with tracks would be a tendency to sink and stall in the waste mass, especially if the thickness of the mass exceeds 75 cm (30 in.). This tendency would seriously lessen the maneuverability of non-tracked equipment.

I.2.1.3. Cover

Of the steps listed earlier, the cover is first in terms of importance. Its importance centers on its isolation of the wastes from the environment. The isolation serves to protect the quality of the environment from being degraded by contract with the wastes. The cover is a key element in the isolation of the wastes from the environment. As stated previously, the cover lessens or removes the attractiveness of the wastes to vectors, rodents, and wildlife in general. It not only removes the attraction, it also impedes or at least discourages their access to the wastes. By doing so, it serves to protect public health. Finally, it effectively removes the aesthetic affront that would be imposed by the wastes if they were not covered.

Cover materials, specifications, and methods for applying them are the same as those described in Section 5.

I.2.1.4. Diversion and Interception Systems

The purpose of the diversion system is to prevent surface water from reaching the closed fill. The purpose of the interception system is to prevent leachate and water that has been contaminated by contact with the disposed wastes from reaching a water resource. The water in this case is that which flows off the surface of the fill. Leachate may reach the surface because of the topography of the site, in that it might drain from its lower perimeter.

Diversion and interception can be accomplished with the use of ditches. Arrangement of the ditches is illustrated by the sketch in Figure I-1. Diverted water can be discharged without having been treated. Intercepted water may have been sufficiently contaminated to require collection and some treatment prior to discharge. Leachate would require treatment. Treatment can be accomplished by way of a holding pond.

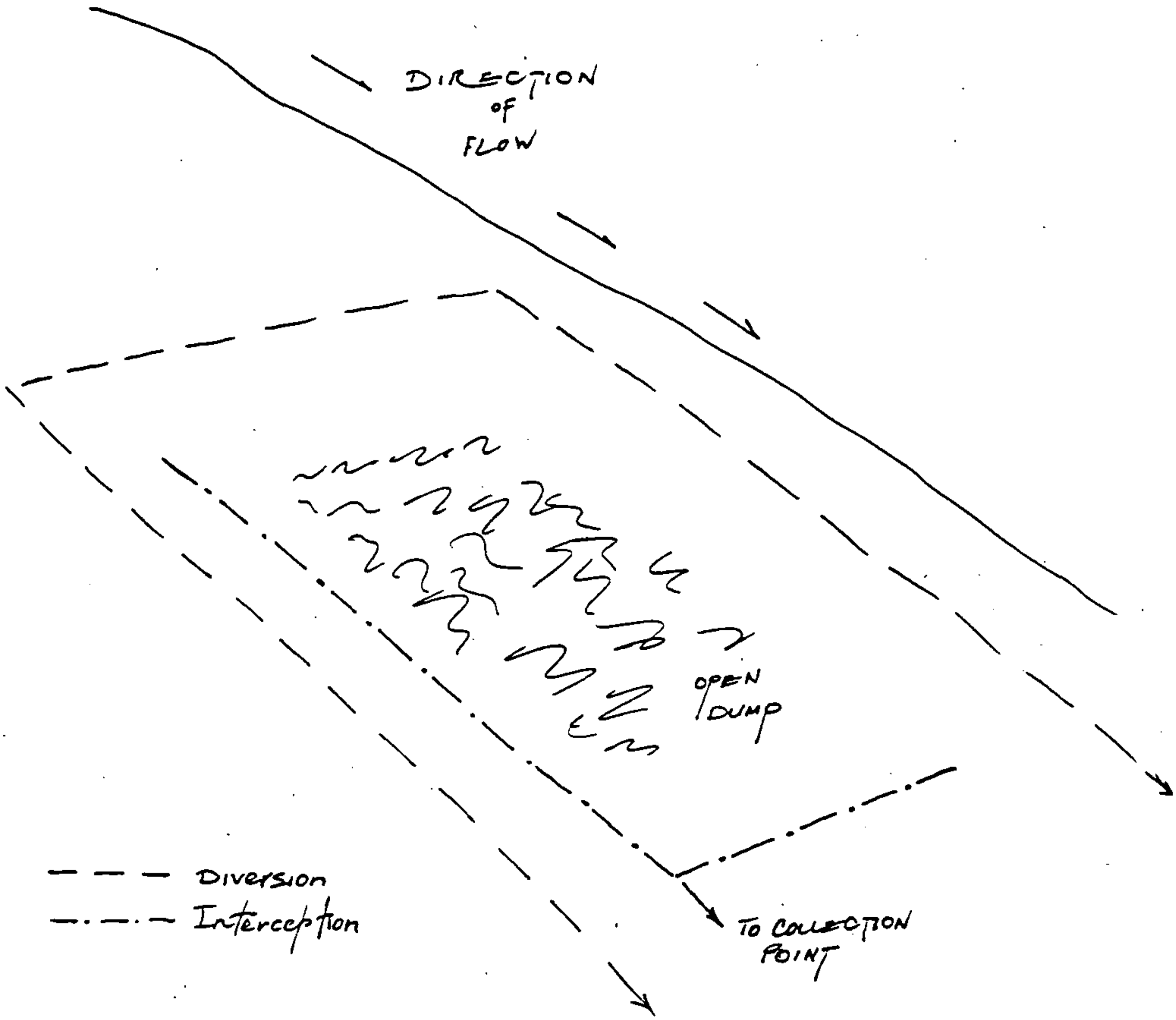

Figure I-1. Arrangement of Diversion and Interception Ditches

I.2.2. Ideal Conformity

For ideal conformity, the contents of the open dump are "re-disposed" according to conventional sanitary landfill procedure. This involves moving the wastes to a site prepared in the same manner as for a sanitary landfill. The site preferably would be adjacent to the open dump. Doing so would reduce the transfer process to a minimum. The wastes could simply be pushed by means of a bulldozer to the adjoining site. Of course, the adjoining site would have to meet all necessary conditions (hydrogeologic, etc.). The site would be prepared and lined as for a new sanitary landfill (Section 5). Of course, if the adjacent site is hopelessly unsuitable, another site would have to be found.

If the trench method is to be followed, the excavation is done immediately adjacent to the open dump, such that the contents of the dump can simply be pushed into the trench. Unless the area and amounts involved are too large, a full layer of wastes can be deposited at one time. Otherwise, each layer can be deposited in segments. Following standard sanitary landfill procedure, each layer is duly compacted and properly covered. At the completion of the transfer, the new fill is closed and completed in the manner described in Section 9.

Except for the excavation of a trench, the procedure is much the same with the area and ramp methods and modifications thereof. In all cases, the procedure described for sanitary landfilling in the preceding sections of this manual are also followed here.

I.3. CLOSURE AS A TRANSITION TO A CONTINUING OPERATION

Either the minimum or the ideal conformity closure can serve as a transition to a continuing sanitary landfill operation. The ideal type of closure would be preferable to the minimum conformity closure. In either case, the closed dump (ideal and minimum) is not an integral part of the continuing operation. In other words, the continuing operation is treated as a new operation independently of the closed operation. Acceptable sanitary landfill practice is followed in the continuing operation.

I.4. LANDFILL MINING

Closing an open dump either with or without upgrading it to sanitary landfill status presents an opportunity to interject landfill "mining".

I.4.1. Principles

The landfill "mining" concept involves the excavating of completed and closed landfill sties followed by processing the excavated material to produce a soil conditioner and recycle other useful materials (e.g., ferrous metal). The rationale is that through the biological decomposition that takes place in a fill, organic wastes eventually are transformed such that they can serve as a soil amendment somewhat analogous to compost. This material can be separated by way of screening and further processed for use as a soil conditioner. If there is a market for them, ferrous metals can be mechanically separated from the excavated material for recycling. Thus a combination of a screen (preferably a trommel) with a magnetic belt would serve the purpose. Residue that can not be put to use is returned to the fill. Since the volume of this residue is only a small fraction of that of the excavated material, a significant part of the original volumetric capacity of the mined fill has been restored. Moreover, useful resources have been recovered.

I.4.2. Historical Survey

Landfill mining made its first documented appearance on a practical scale in the 1950's [1]. The process took place at a facility operated to dispose of wastes generated in Tel Aviv, Israel. The plant consisted of a series of conveyors and a trommel screen. The screen was about 5.3 m (21 ft) long and 1.8 m (6 ft) in diameter. The screen had 2.5 cm (1 in.) openings and had internal vanes. The trommel was rotated at about 13 rpm. The presence of glass shards in the recovered amendment limited the use of the amendment to citrus orchards.

Although adoption of the "mining" option seemed to have been confined to the Tel Aviv operation, interest in the option was briefly revived in the 1960's as a result of the efforts of a solid waste management expert in the U.S.A. In 1982-1983, an adapted version of the concept was proposed for application to the processing of waste disposed at the Metro Manila Commission's Balut disposal site in the Philippines [2].

Recently (i.e., 1985), the concept has again begun to receive serious attention with the result that several full-scale adaptations have been proposed, adopted, and are now being implemented in the U.S.A [3]. The primary incentive for the resurgence of interest is the potential of "mining" as a means of "recycling" completed landfills – i.e., restoring their capacity, at least in part.

I.4.3. Application to Landfill Closure and to Upgrading an Open Dump Operation

The technology would be very similar to that described for the Tel Aviv operation, namely transfer of the excavated material via conveyor belt into a rotating trommel. Material retained in the screen ("overs") would be moved to a salvaging area for removal of recyclable materials. If economic resources permit, ferrous material would be removed by way of a magnet. Otherwise, it, along with other salvageables, would be separated by hand. Material that passed through the screen opening (soil amendment) would be further processed by way of vibrating, flat-bed screens to remove glass shards. All rejects (residues) would be returned to the fill.

I.4.3.1. Places for Mining in Closure or Upgrading

Simple (minimal) Closure of Open Dump: The point at which the mining process could best be incorporated into a closure operation depends upon: a) whether or not the closure is terminal or is a transitional step in an upgrading to sanitary landfill status; and b) the extent to which the procedure followed in the closure conforms to the ideal. With a terminal-minimum conformity closure, mining would take place at the beginning of the consolidation step. If the closure is terminal but ideal in conformity, mining would be the first phase of the transfer step. If closure is the first step in the upgrading of an on-going operation to the sanitary landfill status, mining would be a apart of the transfer step, as is the case with terminal, ideal closure.

Landfill mining is particularly attractive in old disposal sites which have received residential residues. These residues typically contain a high concentration of organic matter.

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Appendix II

SMALL (MANUAL) SANITARY LANDFILLS

II.1. INTRODUCTION

With small operations (up to 20 tons/day), reasonable modifications can be made in the application of the basic principles of landfilling. Reasonable modifications are those that can be made without significantly adverse environmental consequences and detrimental effect on the public health and safety. The ideal should be to adhere as closely as possible to the elements that distinguish sanitary landfilling from open dumping, namely:

1) spread and compact incoming wastes
2) cover the wastes with a 15-20-cm layer of soil at the end each day
3) top completed areas with a final layer of soil to a depth of about one meter
4) site and operate the fill such as not to endanger the public health and quality of air and water resources

The manual sanitary landfill is a technically and financially viable alternative for small localities. A manual landfill only requires the use of heavy equipment for site preparation, the construction of internal roads, and excavation of cover material. All other required tasks can be carried out manually. This would allow small communities to share or rent heavy equipment.

II.1.1. Permissible Modifications

II.1.1.1. Site Selection

Available sites may be limited because of the probable need to select land that is unusable or minimally usable for essential purposes such as housing, farming (food production), and community facilities. At the minimum, the site should be such that water resources are not endangered in terms of deterioration of water quality. The site should be accessible to collection and transport vehicles of all types -- from pushcarts to trucks. Limitations on distance between point of waste generation and site of disposal should reflect this wide latitude of vehicles. In general, site selection should follow the basic principles indicated in Section 4.

In the absence of a natural depression on the site, some excavation will be involved. The dimensions of the excavation should be such as to accommodate the waste output from the community. The amount of soil needed for covering the waste should be extracted through manual or mechanical excavation. Otherwise, the soil should be acquired in sufficient quantities to guarantee continuous operation.

II.1.1.2. Other Modifications

Other modifications, particularly operational modifications, involve equipment and equipment selection.

Equipment: Even in a developed country, the costs involved in owning and operating a small bulldozer may be too high for a community that disposes of only 20 tons or less per day. The same would be especially true for a community in a developing country. However, if excavation and stockpiling of cover soil are necessary for preparing a site, a piece of heavy equipment may be needed until the excavation and stockpiling are completed. Equipment can be rented from another municipality or from a construction company. Daily operation of the fill, i.e., spreading and compacting solid waste, can be done manually on with the use of a farm tractor equipped with a blade or bucket. Unfortunately, the degree of compaction will not be much, even if the wastes are spread in a thin layer before being compacted. Poorer compaction means a larger fill area requirement.

Equipment Selection: The machine used in a one-machine operation must not only be rugged and able to spread and compact the incoming waste and cover soil, it may also have to be used to excavate trenches and cover material. The preferred type of machine would be a track loader. However, if the machine will be used elsewhere part of the time, a wheeled loader would be more suitable because of its mobility.

Dependability of the machine is a key requirement in a one-machine operation. The reasons are obvious. Dependability is especially essential, if a replacement machine is not immediately available in case of a breakdown, as would be the case in a developing country. For further details regarding requirements, see Section 7.

The operation of a manual landfill requires the equipment shown in Figures II-1 to II-3. Typical use of the equipment is shown in Figure II-4. At the end of the working day, all tools and equipment should be cleaned and repaired. Equipment that cannot be repaired should be substituted immediately.

II.1.2. Methods

The topography of the site determines the selection of either the area, trench, or combination method. If the trench method is selected, it is advisable that a sufficiently large trench be excavated each time such that it can hold the wastes produced during a 30 day period.

II.1.3. Access Roads

The sanitary landfill should be accessible by means of a good public, all-weather road. This road should be connected to the working face by means of a simple, well packed road with suitable drainage channels. The internal roads should be carefully planned since they are continually moved and periods of wet weather can cause serious problems. Rainy weather can lead to poor circulation of collection vehicles especially over completed cells since manual compaction cannot achieve high densities. A method that has been used to alleviate this problem is the construction of artificial roads. These roads can be built using boards or trunks to form a plank of about 3 m by 3 m as shown in Figure II-5. The trunks should be tied with wire of about 2 to 3 mm in diameter. The planks are then covered with material that would improve traction. The road is built as the fill advances. This allows for re-use of the planks as the location of the road changes.

Drainage of Surface Water: Guidelines for building drainage ditches should follow those presented in Section 6. The ditches can be built manually and should be sized to meet local conditions.

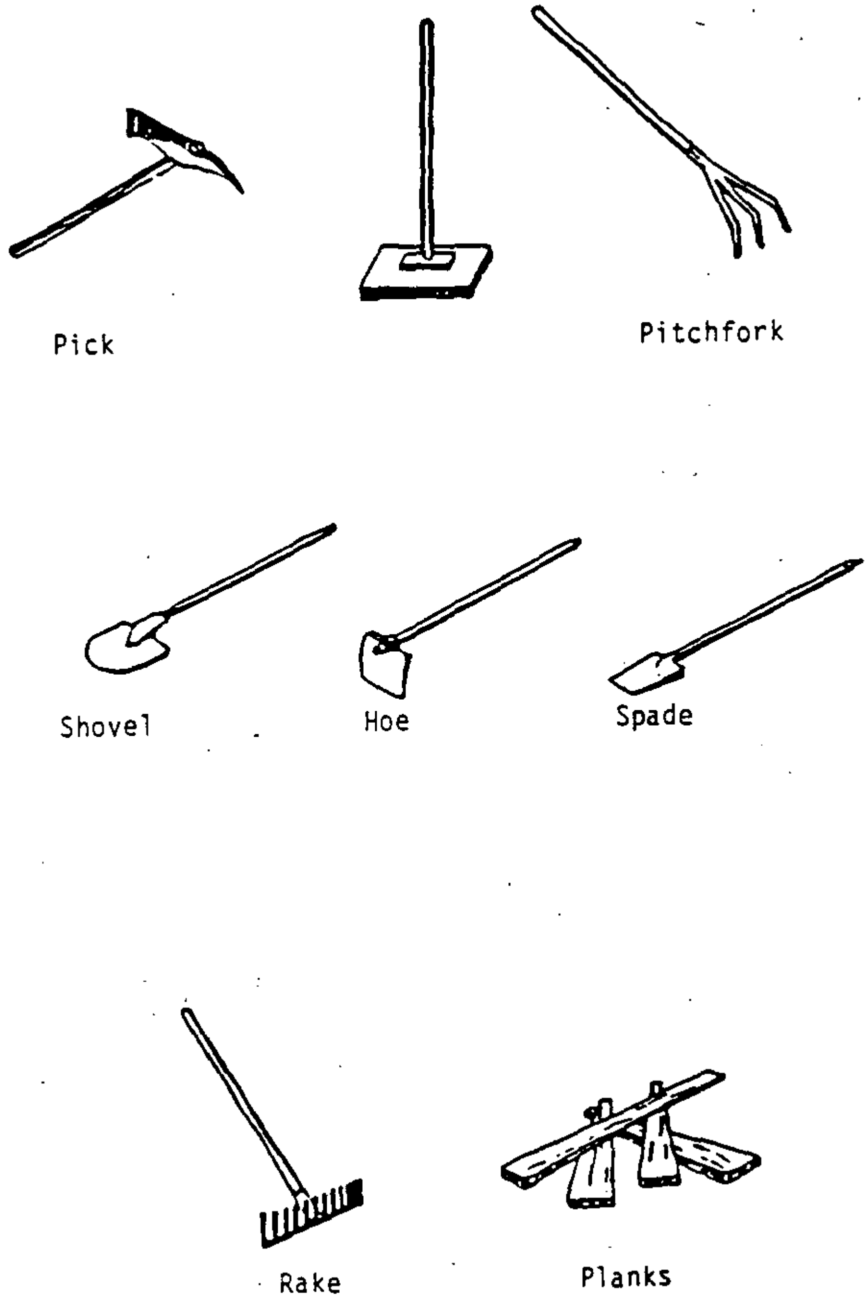

Figure II-1

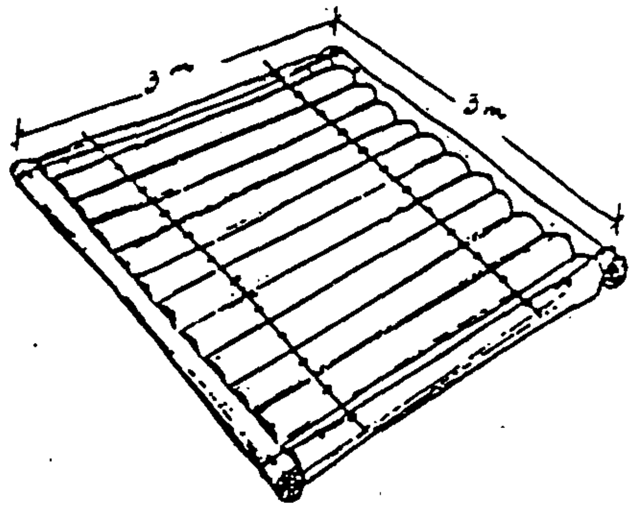

Figure II-5. Typical Plank

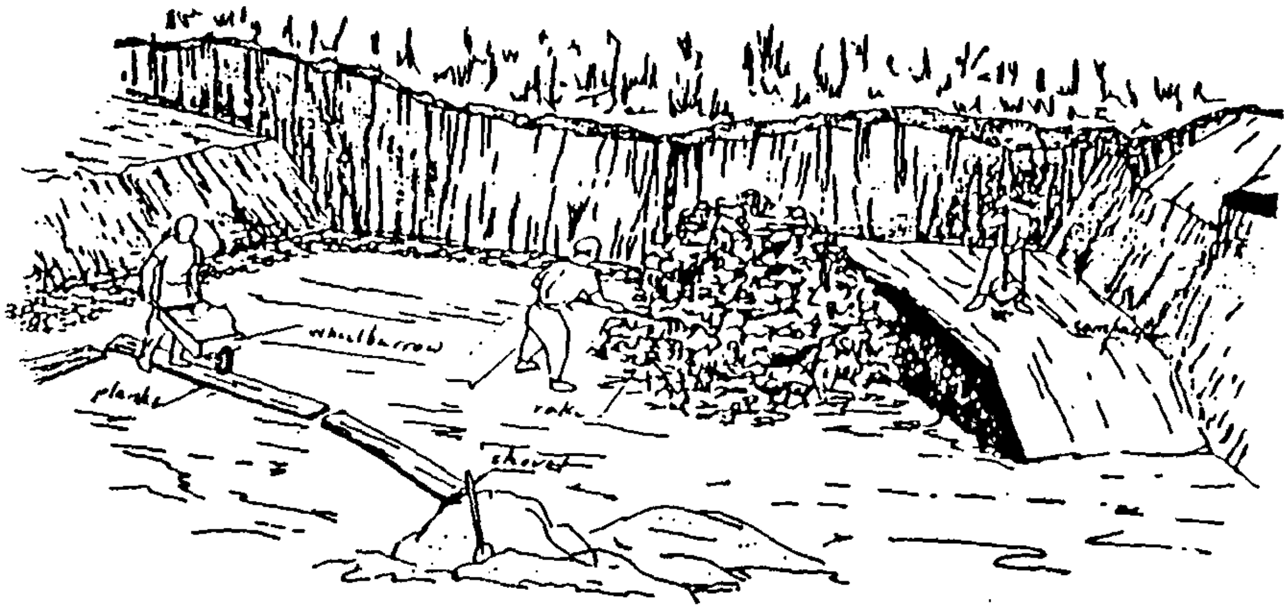

Figure II-4. Typical Use of Equipment

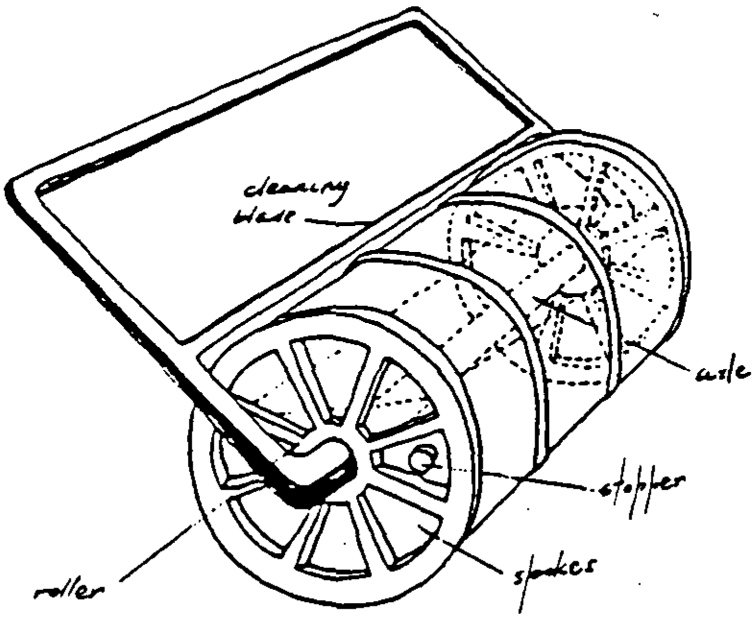

Figure II-2. Reconditioned 55-gallon drum filled with oil for use as compactor

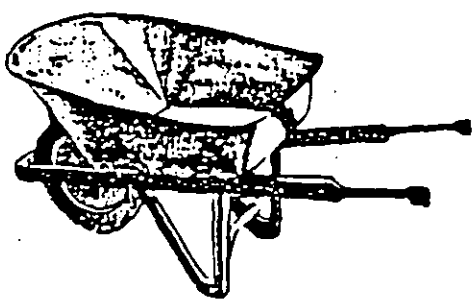

Figure II-3. Wheelbarrow

II.1.4. Construction Method

The construction method to be used for a small landfill depends upon the same factors as those indicated in Section 5 of this report. Some of these factors include: topography of the site, characteristics of the soil, and the depth of the groundwater table. The procedures for building a fill using the area method are shown in Figures II-6 through II-13 and those for the trench methods re shown in Figures II-14 through II-17. In either case, the solid waste is discharged from the collection vehicle and distributed over the base of the landfill or over a completed cell. The distribution in carried out using rakes or pitchforks into successive layers 20 to 50 cm deep. The surface and sides of the layers should be carefully leveled and the wastes kept against the slope of the site or the finished cell. The wastes are then compacted by means of a hand compactor until the cell is relatively uniform and reaches a height of about 80 cm.

Distribution and compaction of the wastes should be conducted in horizontal layers. the layers should be placed with a slope of 1 to 3. Once finished, the cell is covered with a layer of soil on the order of 15 to 20 cm. The soil can be distributed with wheelbarrows or a small tractor and then compacted as shown in Figures II-11 and II-17.

Typically, one individual can deal with 10 tons of refuse per day. Thus a municipality that generates 20 tons per day would require two laborers at the landfill. Since these individuals would be in close proximity to the wastes, they should be provided with boots, gloves, and clean clothing (if at all possible). In addition, they should have access to sanitary facilities.

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2. Flintoff, F., Management of Solid Wastes in Developing Countries, World Health Organization, 1976.

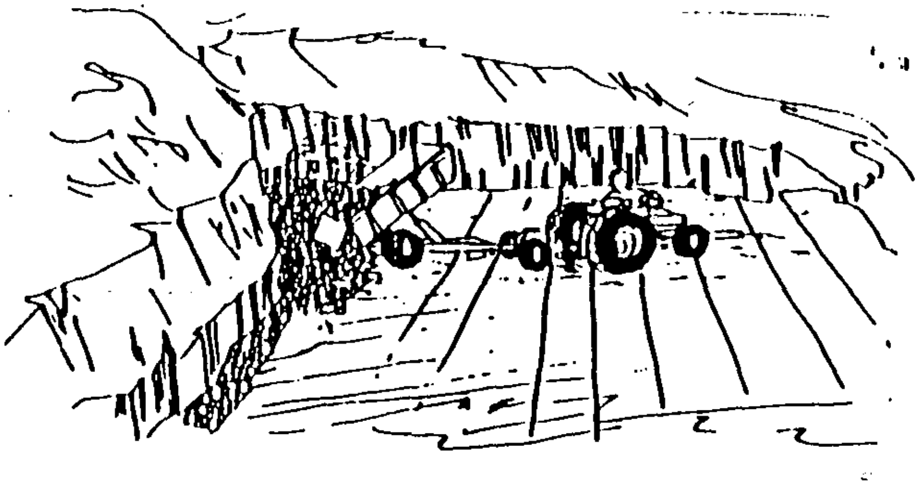


Figure II-6. Discharge of Wastes
(Area Method)

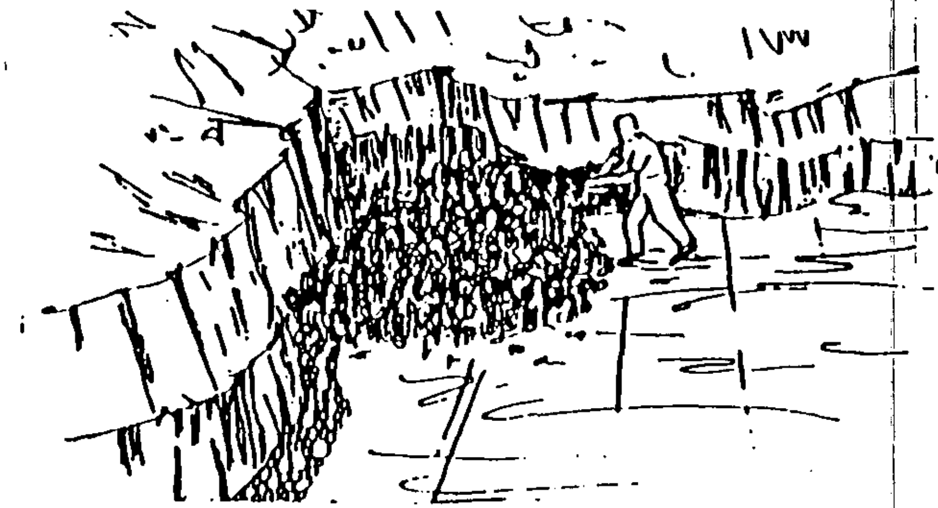


Figure II-7. Distribution of Wastes

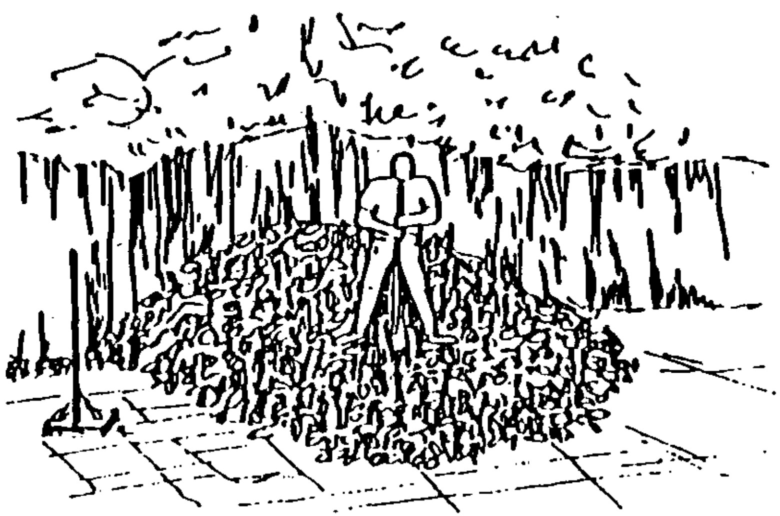


Figure II-8. Compaction

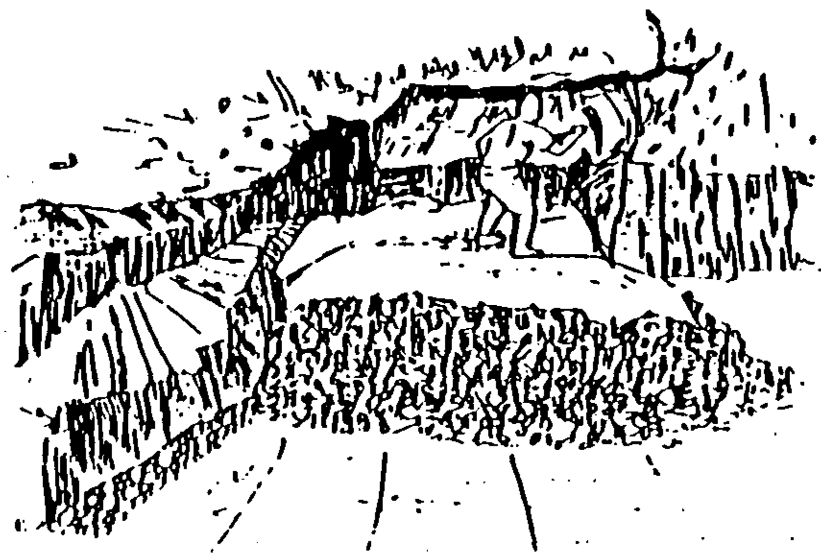


Figure II-9. Extraction of Soil for Cover

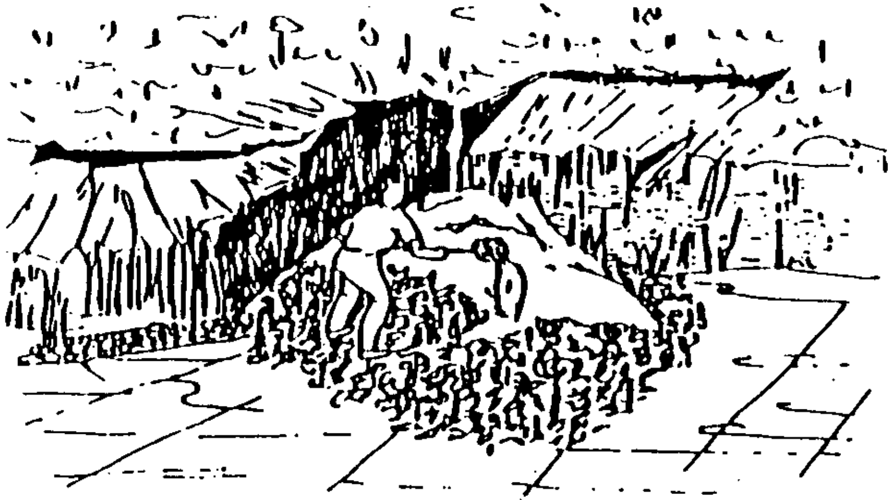


Figure II-10. Application of Cover

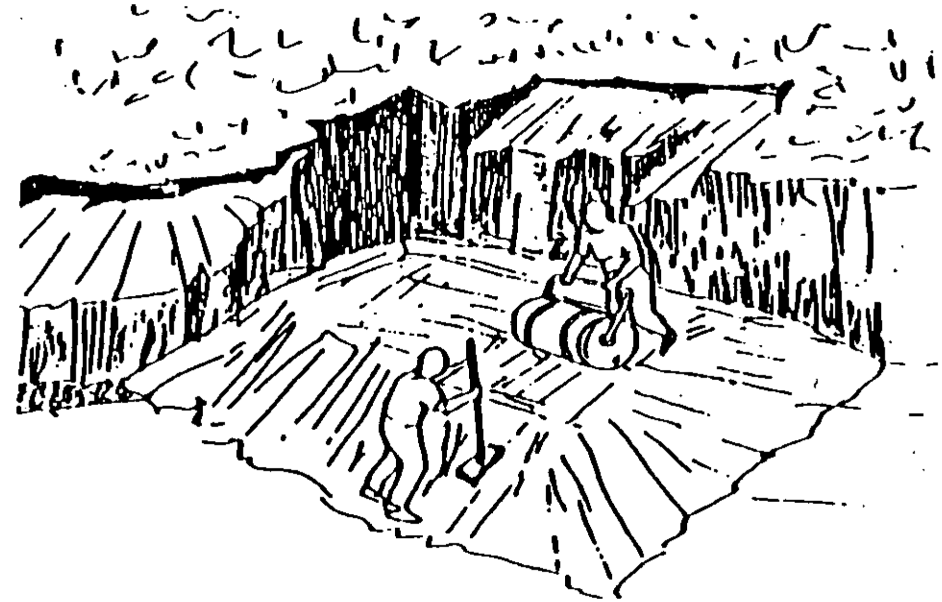
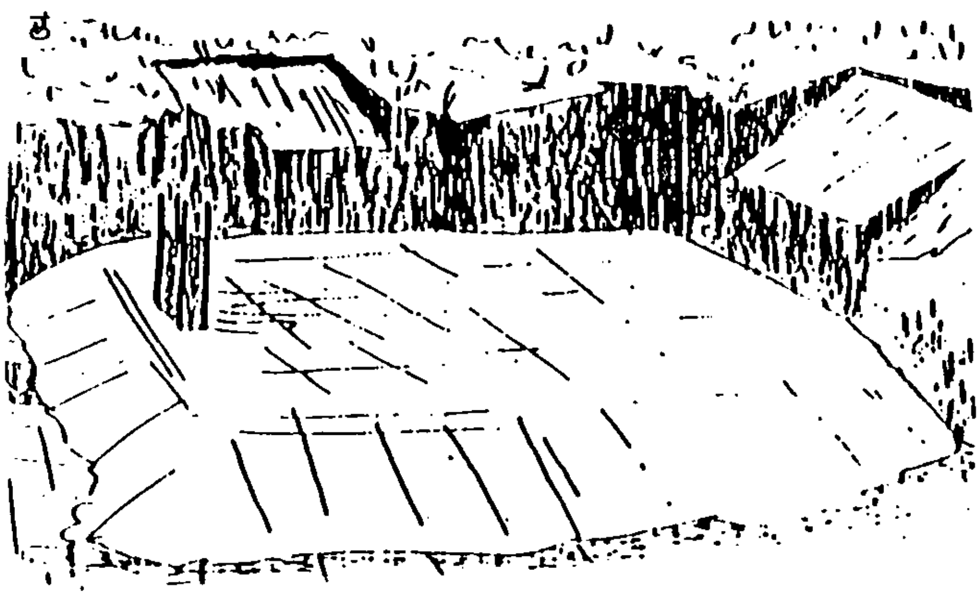


Figure II-11. Compaction of Completed Cell



F' re II-12. Construction of New Cell

Figure II-13. Construction of Gas Vent

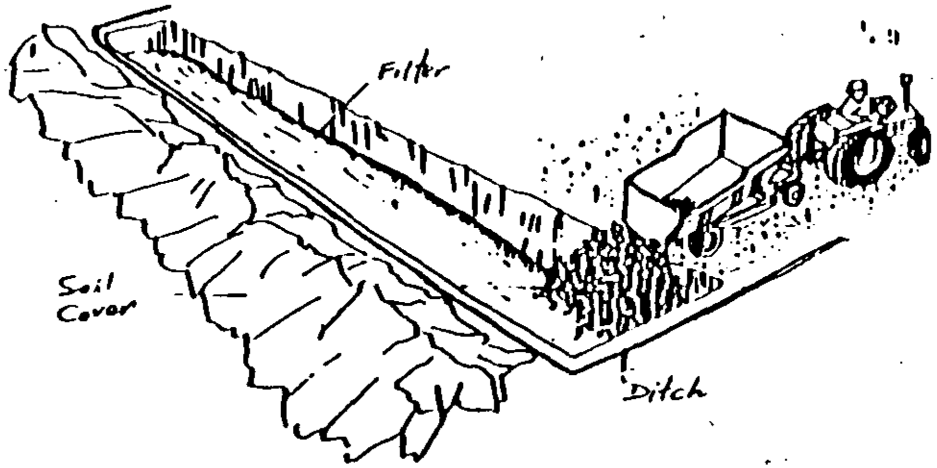


Figure II-14. Waste Discharge (Trench Method)

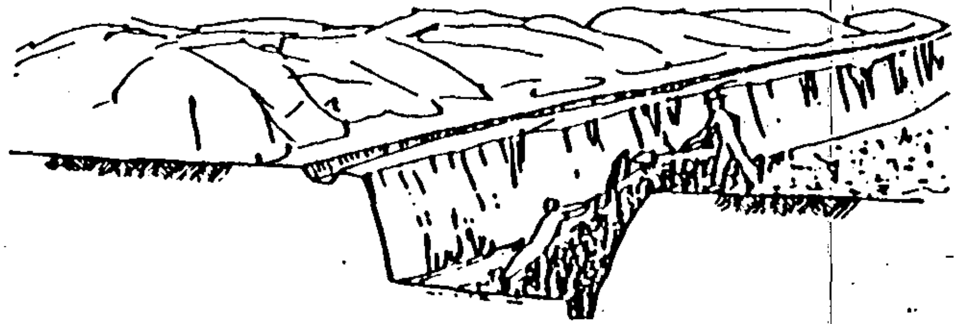


Figure II-15. Layering of Wastes

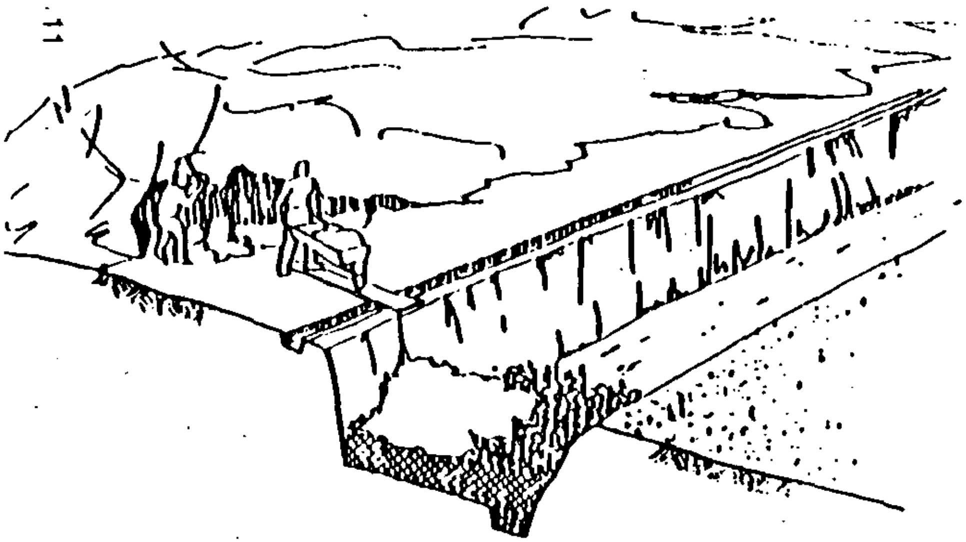


Figure II-16. Development of Cell and Application of Cover

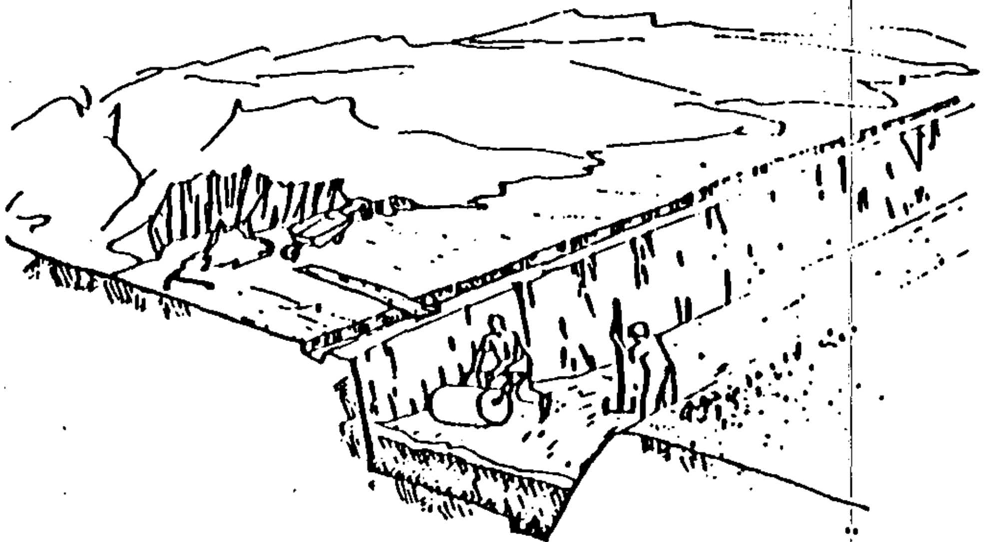


Figure II-17. Compaction

CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

ESTUDIOS PREVIOS

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PALACIO DE MINERIA, MEXICO D.F.   14-19 de Marzo de 1994

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1.7.2 Procedimiento de impacto ambiental

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Una vez aplicada la metodología para el emplazamiento de relleno sanitario y definido el sitio propuesto se iniciaran como en toda obra, una serie de estudios específicos, los cuales se realizaran en el sitio seleccionado para la ubicación del relleno sanitario. El objetivo principal de los estudios previos es verificar a detalle la factibilidad del predio para alojar sin riesgo al ambiente esta obra de ingeniería, así como recabar la información necesaria para la realización del proyecto. Con los resultados obtenidos se definirá y señalarán las características que deben contemplarse en los proyectos ejecutivos de la obra.

Con la finalidad de evitar problemas a los habitantes de las zonas circundantes al sitio propuesto, por esta razón las autoridades locales programarán los trabajos de campo informando a las comunidades los objetivos de los estudios que se realizarán en la zona.

Un factor que garantizá el buen desarrollo de los proyectos ejecutivos, es el mantener una estrecha comunicación de los profesionales que realizaron los estudios básicos con los encargados del proyecto ejecutivo del sitio durante la realización de este.

Es importante que se contemple de manera clara y precisa en los términos de referencia los alcances que se persiguen en cada estudio que se realice, y se cumplan la totalidad de los estudios comentados.

Es conveniente se cumplan la totalidad de los estudios preliminares que se detallan en el presente documento, ya que si no se cuenta con los resultados de los estudios, no se estará en posibilidad de diseñar un relleno sanitario confiable.

Una de las situaciones que se deben establecer, es la constante comunicación que se tendría entre las autoridades locales y las compañías consultoras.

1.1 Definición de zona influencia del Relleno Sanitario

Las "zonas favorables" para la ubicación de rellenos sanitarios, se subdividen en: zonas con altas posibilidades en terrenos duros y en zonas con altas posibilidades en terrenos blandos; esta clasificación tiene por objetivo, dar una idea previa de las facilidades o no que el terreno brindará a la construcción del relleno. En estas zonas es muy conveniente llevar a cabo estudios de detalle que concluyan si puede existir algún riesgo al implementar en ellos los rellenos sanitarios y que definan el tipo de estructuras que permitan profundizar en el conocimiento del sistema natural, o en la evolución química o biológica que pueden seguir los lixiviados en el subsuelo, si es que éstos llegan a penetrarlo; un ejemplo de estas estructuras son los pozos, con los cuales se tendrá un conocimiento directo y real de la posición que tiene el nivel del agua subterránea, qué tipo de terrenos están por encima del material que almacena el agua, qué grado de permeabilidad tienen, la comunicación que puede existir entre relleno sanitario y acuífero, etc.; a partir de estas obras (pozos), se deberán realizar monitoreos periódicos de la calidad físico-química y bacteriológica de las aguas subterráneas, tanto en la zona saturada como en la zona no saturada, a fin de conocer cuál es su situación inicial antes de la implantación del relleno sanitario y evaluar si estas condiciones iniciales van variando con el tiempo, estas prácticas permitirán evaluar también la capacidad autodepuradora del terreno, todo lo anterior en el supuesto de que éste permita el paso de los lixiviados. Estas y otra serie de investigaciones que permitan conocer mejor la estructura del subsuelo, como los métodos geofísicos, permitirán definir mejor la bondad de un sitio para ubicar en él, rellenos sanitarios.

Una vez llevado a cabo el análisis donde se establecen los criterios para la definición de las zonas favorables, (fig. 1.1.1) que como ejemplo fueron elejidos Tlalnepantla y La Paz, se define la zona de influencia del sitio propuesto.

Como no todas las áreas contenidas en una localidad presentan las características antes señaladas es importante tener como objetivo establecer una esquema de servicio con un enfoque regional que redunde en la optimización y eficiencia del mismo sistema. En la figura 1.1.2 se pueden apreciar, además de las zonas favorables elejidas, la zona de influencia de uno

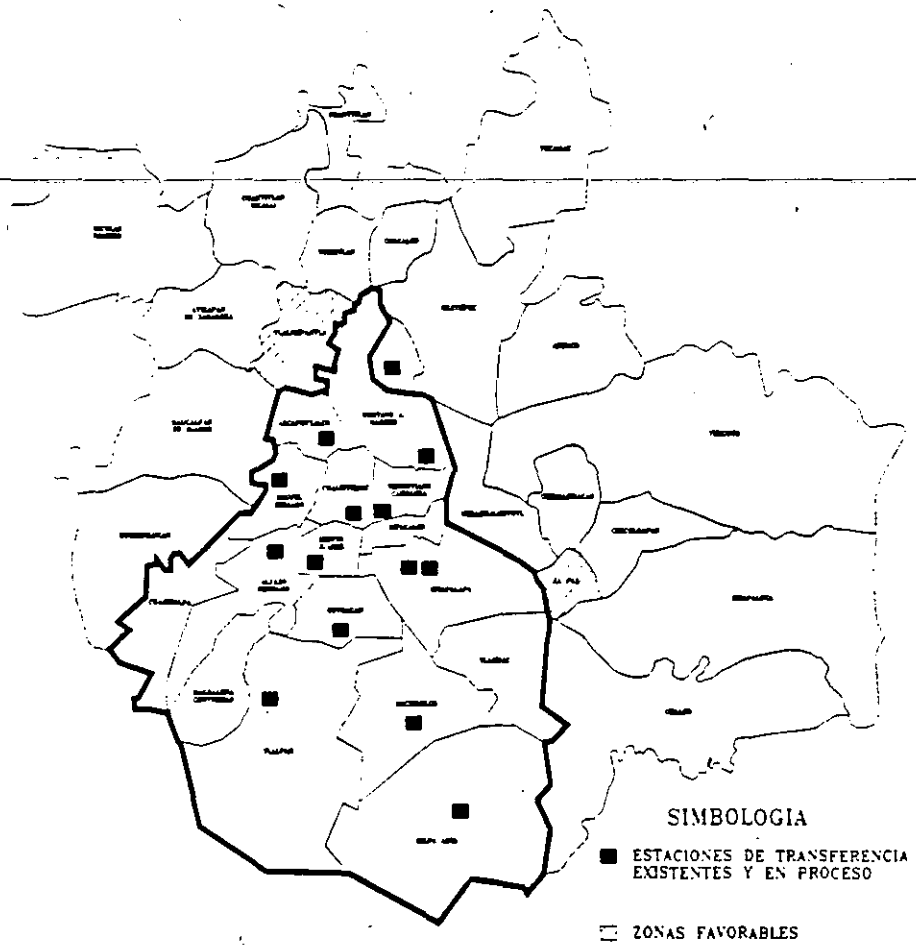


FIG. 1.1.1

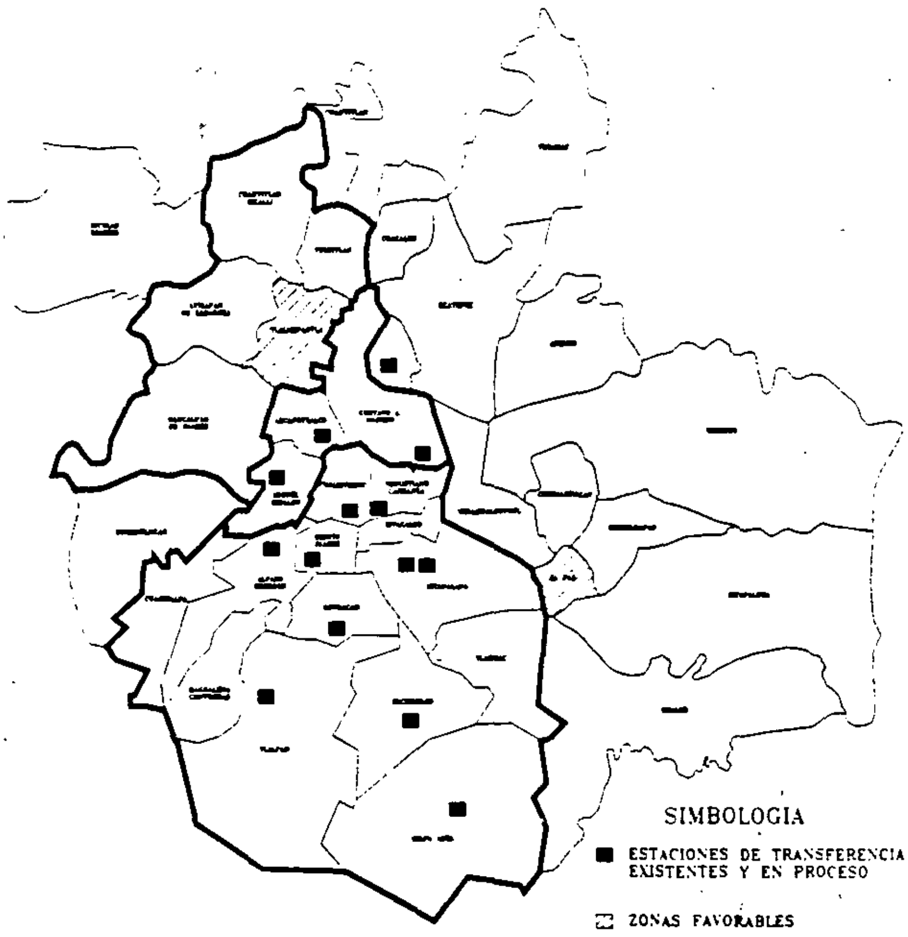


FIG. 1.1.2

de los sitios.

1.2 Caracterización Físico-Química de los Residuos que se Depositarán en el Sitio.

Durante el diseño de un relleno sanitario, es parte importante establecer y conocer las características físico-químicas de los residuos sólidos que serán depositados, así como de los productos que se forman por la degradación de éstos y que pueden migrar fuera de la vecindad de dicho sitio, como es el caso de los lixiviados y del biogás. El contar con estos indicadores permitirá establecer las bases para el diseño de las obras complementarias que garanticen el control y tratamiento que se aplicará en el sitio de disposición final.

1.2.1 Cuantificación de los Residuos Sólidos.

Antes de entrar de lleno en la caracterización intrínseca de los residuos, resulta importante destacar que dentro de la conceptualización de un relleno sanitario deben considerarse y analizarse ciertos indicadores básicos de los residuos sólidos para su adecuada disposición como son el tipo, la cantidad y el volumen de los subproductos que componen la basura generada en las diversas fuentes municipales.

Con el fin de conocer las características cuantitativas de estos indicadores se lleva a cabo una serie de análisis en campo de los residuos sólidos, relacionados con la cuantificación de subproductos, el peso volumétrico y la determinación de la generación total y per-cápita. La metodología empleada para la determinación de estos parámetros se apega a la establecida en las normas oficiales mexicanas vigentes.

- NOM-AA-61-1985
- NOM-AA-22-1985
- NOM-AA-19-1985

La composición de los residuos ha variado en los últimos años y esto se ha debido principalmente a los cambios en los patrones de producción y a los hábitos de consumo de la población. Actualmente la cantidad de subproductos inertes y de lenta degradación, que componen la basura y que se depositarán en los sitios de disposición final, se ha visto incrementada considerablemente, pero aun así en la ciudad México como en otras ciudades en paises en vías de desarrollo, el porcentaje de subproductos orgánicos de fácil degradación, como son los residuos alimenticios, alcanza más de un 40% del total de los residuos sólidos que se genera actualmente.

Referente al peso volumétrico de los residuos, se considera uno de los principales parámetros a identificar, pues la importancia de conocer el volumen de los residuos que se dispondrán en relleno sanitario es esencial para saber o estimar la vida útil de estos sitios.

Retomando el punto de los materiales que son resistentes a la degradación biológicas y ambiental, esto nos lleva a pensar en el volumen ocupado por este tipo de residuos en el relleno sanitario y que se mantendrán de esta forma por mucho tiempo.

Por ello la importancia de la recuperación de materiales para la reducción del volumen que se dispone en relleno sanitario y alargar la vida útil de estos.

1.2.2 Proyección de Generación.

Tomando en cuenta todo lo antes mencionado, en relación a la información arrojada por este tipo de estudios se puede establecer una tasa de incremento anual de los residuos que serán depositados en el relleno sanitario en los próximos años, es importante que con anterioridad se hubiera realizado la proyección de población con la cual se podrá estar en posibilidad de realizar la proyección de generación.

El objeto de las proyecciones de generación, permitirá determinar el volumen y la cantidad de residuos sólidos que serán depositados en los sitios de disposición final y poder estimar de esta manera la vida útil de un relleno sanitario, la proyección se recomienda se realice en un periodo de 15 años.

1.2.3 Caracterización Físico-Química.

Considerando la variación de las características que presentan los residuos según sea la fuente que los genera, es importante el establecimiento y conocimiento de las características físico-químicas de los residuos a disponer.

Este análisis se lleva a cabo en un laboratorio especializado y es complemento de los estudios mencionados en el inciso anterior. Los principales parámetros que se determinan por norma son los siguientes:

- Humedad
- Cenizas
- Poder calorífico
- Carbono total
- Nitrógeno total
- Materia orgánica
- Hidrógeno
- Oxígeno

Posteriormente, durante la operación del relleno sanitario, se toman muestras de los residuos enterrados a diferentes profundidades, así como de los lixiviados y del biogás, productos que se forman durante la estabilización y transformación de los residuos, y que son impactantes de alto riesgo para el ambiente, por lo cual la importancia de conocer la composición y cuantificar la magnitud de estos productos y de otros que se generan durante el proceso de degradación.

Inicialmente el proceso es de tipo anaerobio, de corta duración y en el cual hay una elevación de la temperatura y se genera bióxido de carbono, agua, nitratos y nitritos. A medida que el oxigeno disponibles se va agotando, organismos facultativos y anaerobios empiezan a predominar, volviéndose más lenta la degradación y generándose como elementos típicos de esta fase anaerobia: ácidos orgánicos, nitrógeno, bióxido de carbono, metano y en menor proporción ácido sulfhídrico.

Ahora bien, cabe señalar que uno de los impactantes más importantes es el biogás, formado durante la fase anaerobia y cuyos componentes más significativos son el metano y el bióxido de carbono, el cual puede emigrar fuera del sitio y provocar que se presenten incendios y/o explosiones, además de que en combinación con el agua puede haber producción de ácido carbónico, el cual es altamente corrosivo.

Otro de los impactantes de importancia, son los lixiviados, la producción de estos líquidos percolados se debe principalmente al paso del agua de lluvia a través de los estratos de los residuos sólidos que se hayan en la fase de descomposición anaerobia arrastrando componentes disueltos, en suspensión, fijos y/o volátiles. Estos elementos les dan las características contaminantes por las elevadas cargas orgánicas y catiónicas, así como de metales pesados presentes y que son peligrosos pese a la disolución que tienen al penetrar al acuífero.

Los principales parámetros que se analizan en el laboratorio se muestran en la siguiente tabla.

PRODUCTO	PARAMETRO
BIOGAS	CH_4, CO_2, O_2, N_2, EXPLOSIVIDAD, TOXICIDAD, TEMPERATURA, FLUJO
LIXIVIADOS	METALES PESADOS, COMPUESTO ORGANICOS, OXIGENO DISUELTO, pH, CONDUCTIVIDAD, MICROORGANISMOS

1.3 Estudios de Exploración de Suelos

Los estudios geológico, geohidrológico, hidrológico y geofísico, se engloban en un sólo apartado dado que la exploración del suelo para determinar las características del mismo se realizan paralelamente.

Este tipo de estudios se realizan por medio de sondeos para la toma de muestras o análisis realizados con los datos obtenidos del sondeo. Hay sondeos de distinto tipo y para propósitos diferentes, los que a continuación enlistamos:

Métodos Exploratorios de Carácter Preliminar

a) Pozos a cielo abierto, con muestreo alterado e inalterado
b) Perforaciones con posteadora, barrenos helicoidales o métodos similares
c) Métodos de lavado
d) Métodos de penetración standard
e) Método de penetración cónica
f) Perforaciones en boleos y gravas (con barretones, etc.)

Métodos de Sondeo Definitivo

a) Pozos a cielo abierto, con muestreo alterado e inalterado
b) Métodos con tubo de pared delgada
c) Métodos rotatorios para roca

Métodos Geofísicos

a) Sísmico
b) De resistencia eléctrica
c) Magnético y gravimétrico

Los estudios geológicos y geofísicos de detalle se apoyan en el marco geológico regional además de la geologia local y geologia superficial, la geofísica permite conocer las caracteíristicas físicas y la homogeneidad de las unidades, conformando los datos de la geologia local. La principal ventaja que representa utilizán métodos geofísicos es el costo en relación a los sondeos, el cual, en los estudios geohidrológicos aportan el conocimiento del modelo de flujo del agua a través de las formaciones geológicas superficiales y del subsuelo tomando en consideración el aprovechamiento hidráulico.

Las unidades hidrológicas correlacionan las rocas que afloran regionalmente, apoyándose en los estudios geológicos y geofísicos, calculando el tiempo de infiltración al nivel de saturación determiando la profundidad el nivel estático/flujo de agua subterránea. En la figura 1.3.1.1 se oberva un mapa hidrológico del aguas superficiales de la precipitación media anual realizado a partir de la precipitación en la zona de estudio.

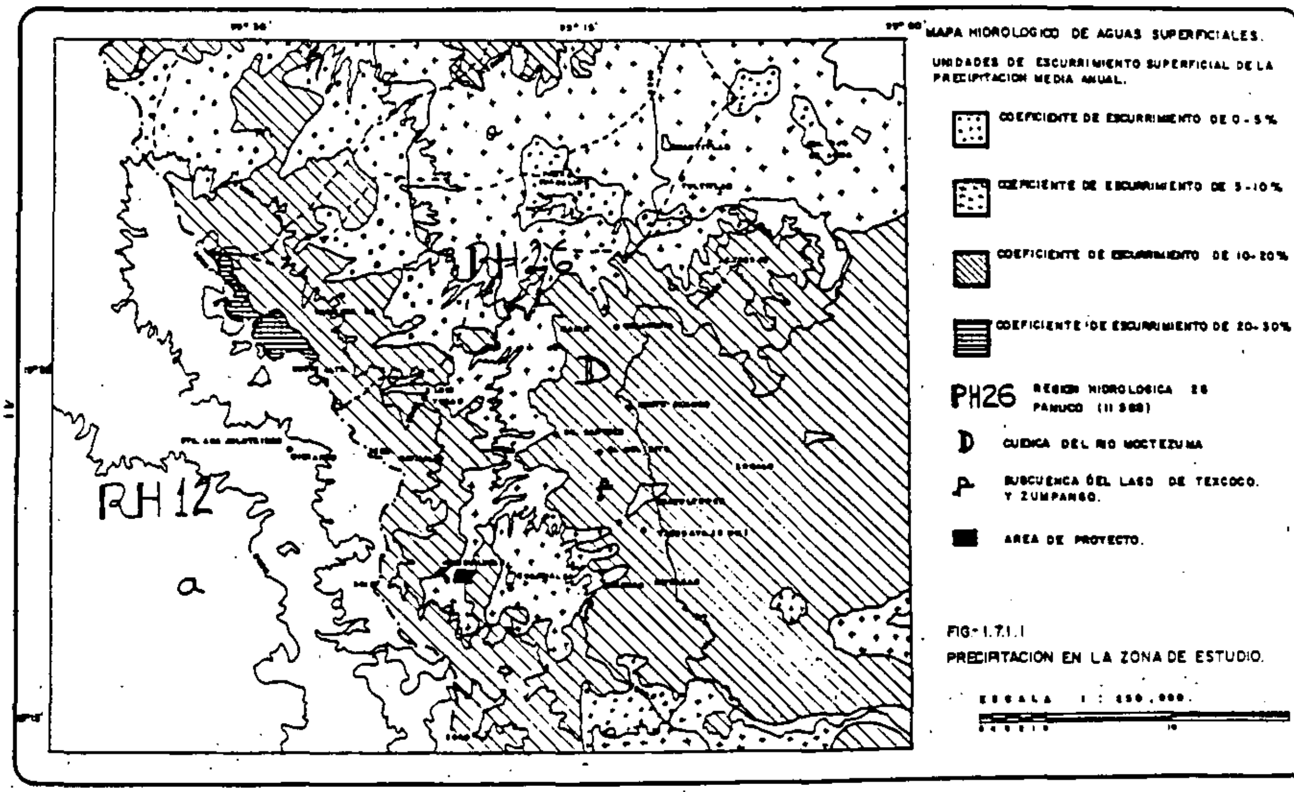


Figura 1.3.1.1

La figura 1.3.1.2 presenta una sección transversal del flujo de agua subterránea en la región. Información básica que se obtendrá para la realización del proyecto ejecutivo.

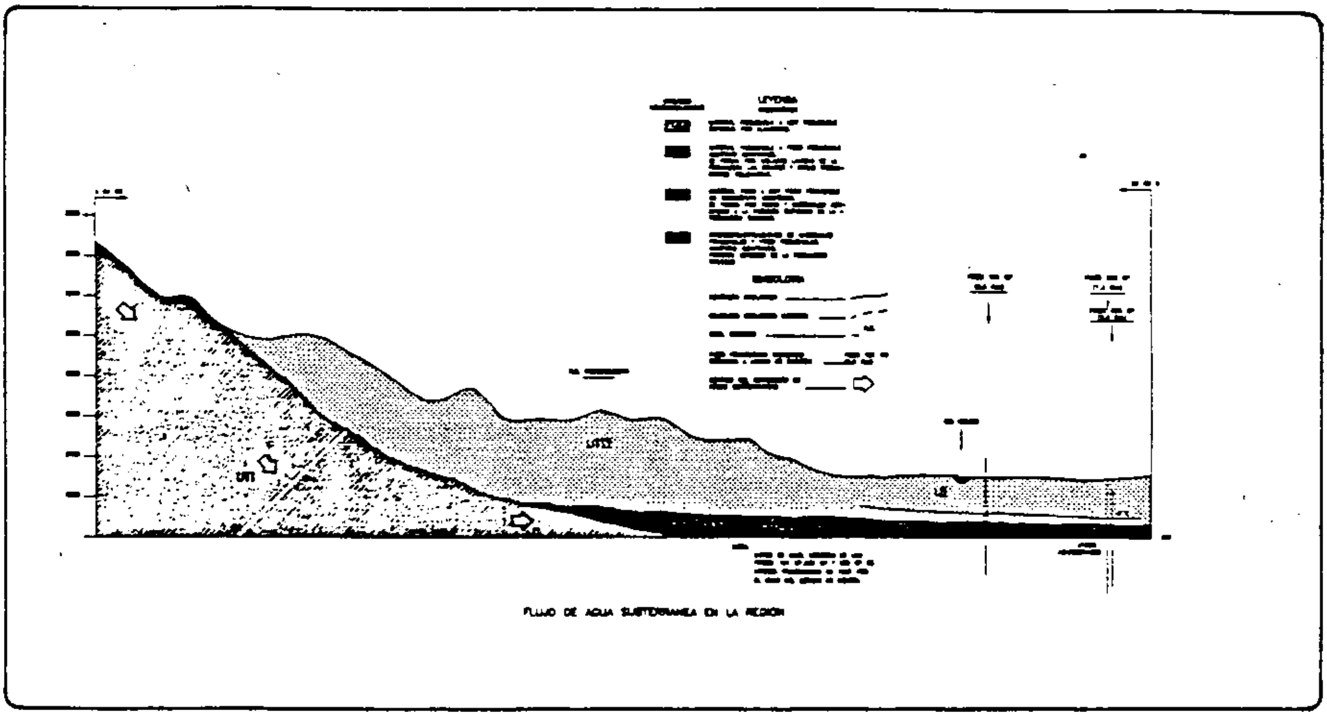


Figura 1.3.1.2

1.3.2 Mecánica de Suelos

Los trabajo se inicarán con la visita al sitio por parte de un ingeniero especialista con el objeto de definir el número de sondeos de penetración, la excavación de los pozos, las calas exploratorias. Así mismo, se programarán los ensayos de laboratorio para determinar las propiedades, índices y parámetros representativos del comportamiento del subsuelo.

Los pozos a cielo abierto serán en dimensiones suficientes para que un individuo pueda acceder a él para extraer las muestras; ésto es, entre 1.5 y 2.0 mts de lado, con profundidades hasta de 6 m o al nivel de una capa impermeable, si las condiciones lo permiten; ya que estos apoyarán los estudios geológicos.

El número de pozos recomendados serán como mínimo los siguientes:

Hasta 5Ha	3
De 5 a 20Ha	5 - 6
De 20 a 40Ha	8 - 9
Más de 40Ha	11 - 15

En estos pozos se pueden formar muestras alteradas o inalteradas de los diferentes estratos que se hayan encontrado, anotando los datos necesarios para su identificación; banco, fecha, pozo y profundidad. Las muestras alteradas se tomarán de cada uno de los pozos y las inalteradas se tomaran uno como minimo, de cada uno de los estratos encontrados en el sitio.

Las muestras alteradas son porciones de suelo que se protegerán contra perdidas de humedad introduciéndolas en botes o bolsas emparafinadas. Para las muestras inalteradas deberán tomarse mayores precauciones, generalmente labrando la muestra en una oquedad que se practique al efecto en la pared del pozo, la muestra debe protegerse contra perdidas de humedad, envolviéndola en una o más capas de manta debidamente impermeabilizada con brea y parafina.

Derivado del sondeo y la toma de muestra se determinarán los parámetros que a continuación se enlistan:

Clasificación visual y al tacto.
Contenido orgánico total
Granulometría
Capacidad de intercambio catiónico
Límites de consistencia
pH
Clasificación de suelo
Porosidad
Humedad

Permeabilidad

Capacidad de carga

Capacidad de compactación

Compresión triaxial

Profundidad de los mantos fréaticos

Estratigrafía.

Estabilidad de taludes

Peso volumétrico

En la figura 1.3.1 se puede apreciar la ubicación de los puntos donde se ralizarán los sondeos, cubriendo el sitio con secciones transversales y longitudinales procurando que la ubicación de los sondeos cubrirán la configuración del sitio.

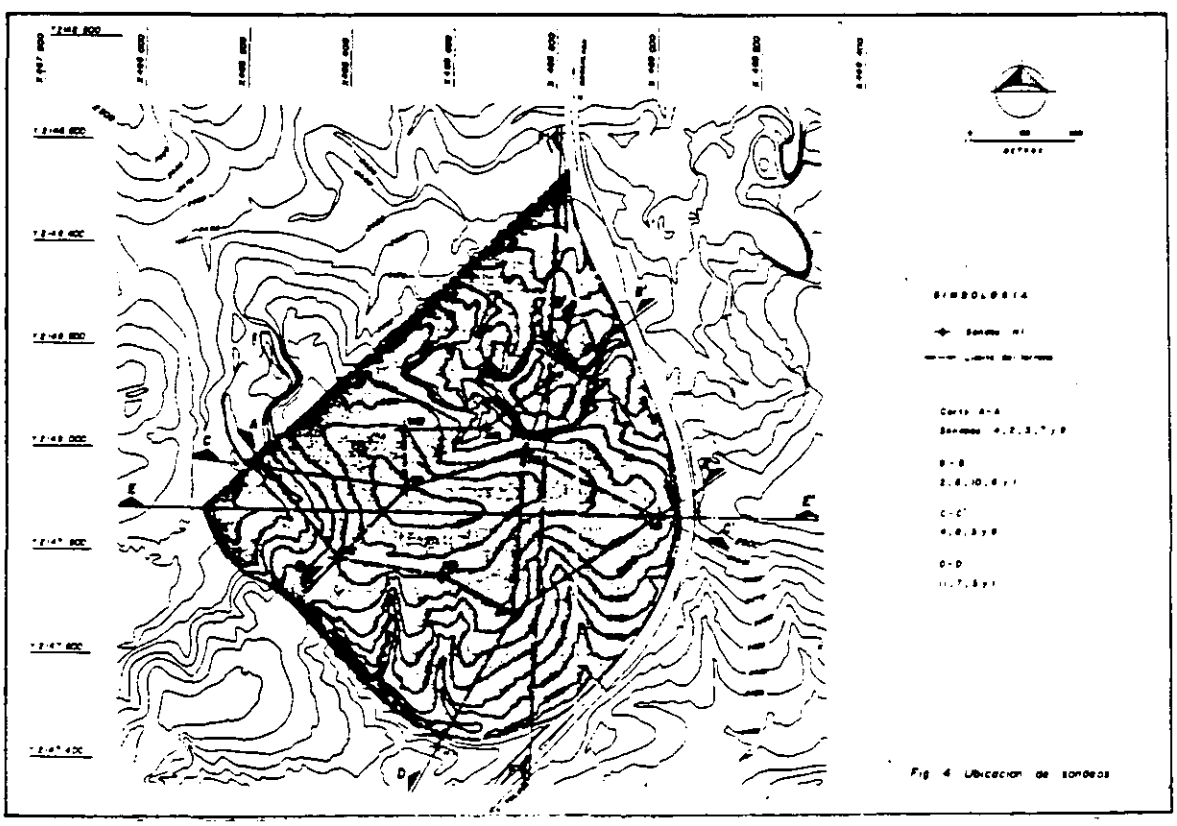


Figura 1.3.2.1

En la figura 1.3.2.2 se presentan algunas secciones transversales obtenidas a través de los estudios de mecánicas de suelos.

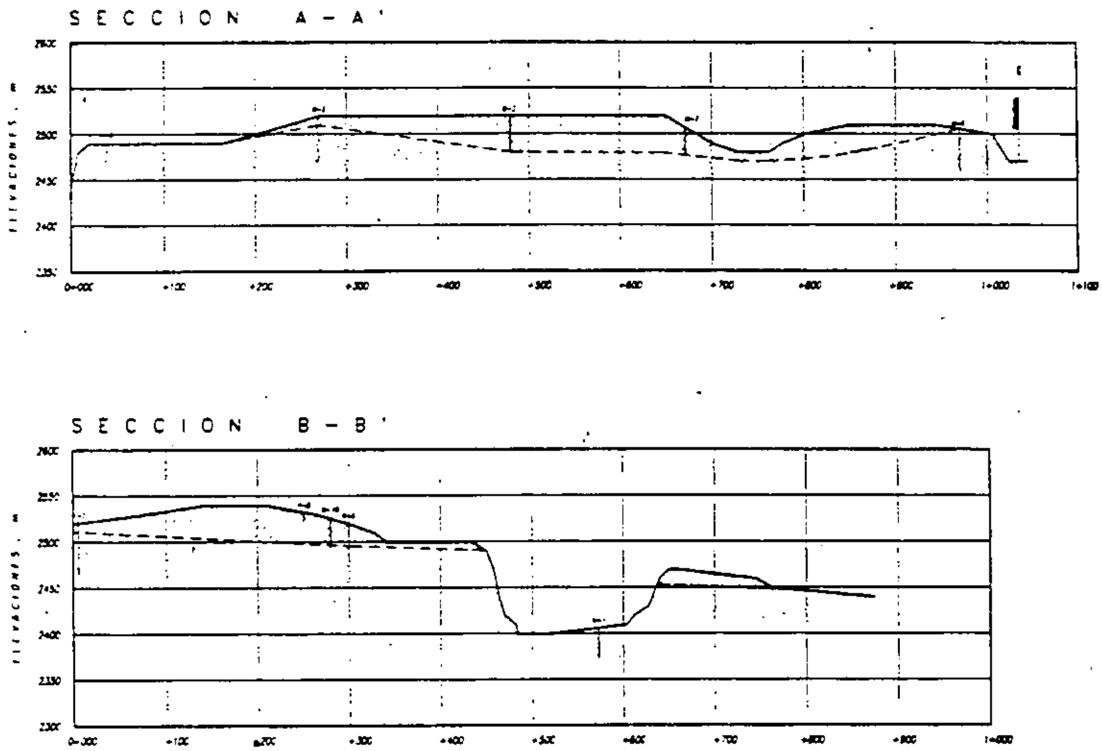


Figura 1.3.2.2

1.4 Información Meteorológica

Debido a la complejidad de los procesos naturales que intervienen en los fenómenos meteorológicos, es difícil examinarlos mediante un razonamiento deductivo riguroso. No siempre es aplicable una ley física fundamental para determinar el resultado meteorológico esperado. Más bien, lo que parece razonable es partir de una serie de datos observados, analizarlos estadísticamente y después tratar de establecer la norma que gobierna dichos sucesos.

Lo anterior establece la necesidad de contar con registros de varios años de las diversas componentes que intervienen en los problemas meteorológicos.

En la República Mexicana las principales fuentes de información son la Comisión Nacional del Agua, la Comisión Federal de Electricidad y la Secretaría de Agricultura y Ganadería.

En general, cada análisis de una zona es único y las conclusiones cuantitativas de su análisis no pueden extrapolarse a otro problema. Esto ha ocasionado que muchas veces se juzgue un método de cálculo en forma equivocada, al no tenerse en cuenta sus limitaciones en cuanto a aplicabilidad. Conviene establecer primero la bondad del método, ya que, aunque el problema por analizar no tenga las mismas condiciones para las cuales fue deducido, puede proporcionar un resultado cualitativo de gran utilidad, siempre y cuando se sepa interpretar.

Meteorología es la ciencia que estudia los fenómenos que ocurren en la atmósfera, tales como viento, precipitación, temperatura, etc. El comportamiento de esos fenómenos en un determinado lugar y por un cierto tiempo se llama clima. La meteorología es una rama de la física, debido a que la atmósfera es una mezcla de gases, donde la interrelación entre temperatura, presión y volumen sigue las leyes de la dinámica y termodinámica. Además, está relacionada con la geografía, ya que la latitud, altitud, localización y topografía de áreas de tierra y agua, afectan las características y distribución de los elementos meteorológicos sobre la superficie terrestre.

1.4.1 Características fisiográficas de una cuenca

La cuenca de drenaje de una corriente es el área que contribuye al escurrimiento y que proporciona parte o todo el flujo de la corriente principal y sus tributarios. Esta definición es compatible con el hecho de que la frontera de una cuenca de drenaje y su correspondiente cuenca de agua subterránea no necesariamente tienen la misma proyección horizontal.

La cuenca de drenaje de una corriente está limitada por su parteaguas, que es una línea imaginaria que divide a las cuencas adyacentes y distribuye el escurrimiento, originado por la precipitación, que en cada sistema de corrientes fluye hacia el punto de salida de la cuenca. El parteaguas está formado por los puntos de mayor nivel topográfico y cruza las corrientes en los puntos de salida.

Muchas veces se requiere dividir las grandes cuencas para facilitar su estudio. Las subáreas o cuencas tributarias estarán a su vez delimitadas por parteaguas interiores. En general estas subdivisiones se hacen de acuerdo con las estaciones hidrométricas existentes en la zona.

No necesariamente se analiza con el mismo criterio una cuenca tributaria o pequeña que una cuenca grande. Para una cuenca pequeña, la forma y cantidad de escurrimiento están influidas principalmente por las condiciones físicas del suelo; por lo tanto, el estudio hidrológico debe enfocarse con más atención a la cuenca misma. Para una cuenca muy grande, el efecto de almacenaje del cauce es muy importante, por lo cual deberá dársele también atención a las características de este último.

Es difícil distinguir una cuenca grande de una pequeña, considerando solamente el tamaño. En hidrología, dos cuencas del mismo tamaño son diferentes. Una cuenca pequeña se define como aquella, cuyo escurrimiento es sensible a lluvias de alta intensidad y corta duración, y donde predominan las características físicas del suelo con respecto a las del cauce. Así, el tamaño de una cuenca pequeña puede variar desde unas pocas hectáreas hasta un límite que, para propósitos prácticos, Chow considera de 250 km^2.

El escurrimiento del agua en una cuenca depende de diversos factores, siendo uno de los más importantes las características fisiográficas de la cuenca. Entre estas se pueden mencionar principalmente su área, pendiente, características del cauce principal, como son longitud y pendiente, elevación de la cuenca y red de drenaje. A continuación se describirán las formas de calcular las características fisiográficas, según su uso.

En algunos casos, como por ejemplo al valuar la pendiente de la cuenca, se indican diversos criterios, no con el fin de resaltar el concepto, sino con la idea de obtener diversos resultados. Esto es de gran importancia, pues, como se verá posteriormente, muchas veces se requiere determinar una relación entre las características del escurrimiento y las caracteristicas fisiográficas de una cuenca y, conociendo varios valores, se escoge el que proporcione mayor aproximación a la relación. Lo anterior implica la inconveniencia de agrupar, por ejemplo, los métodos para valuar las pendientes, ya que cada uno proporciona un resultado diferente. Es necesario tomar cada criterio como un factor más de las características fisiográficas de una cuenca. A partir de la definición del sitio se realizará la restitución fotogramétrica con la cual se podrá realizar la configuración del sitio con respecto a la cuenca en la figura 1.4.1.1. En la cual se oberva un modelo de configuración del terreno por computadora.

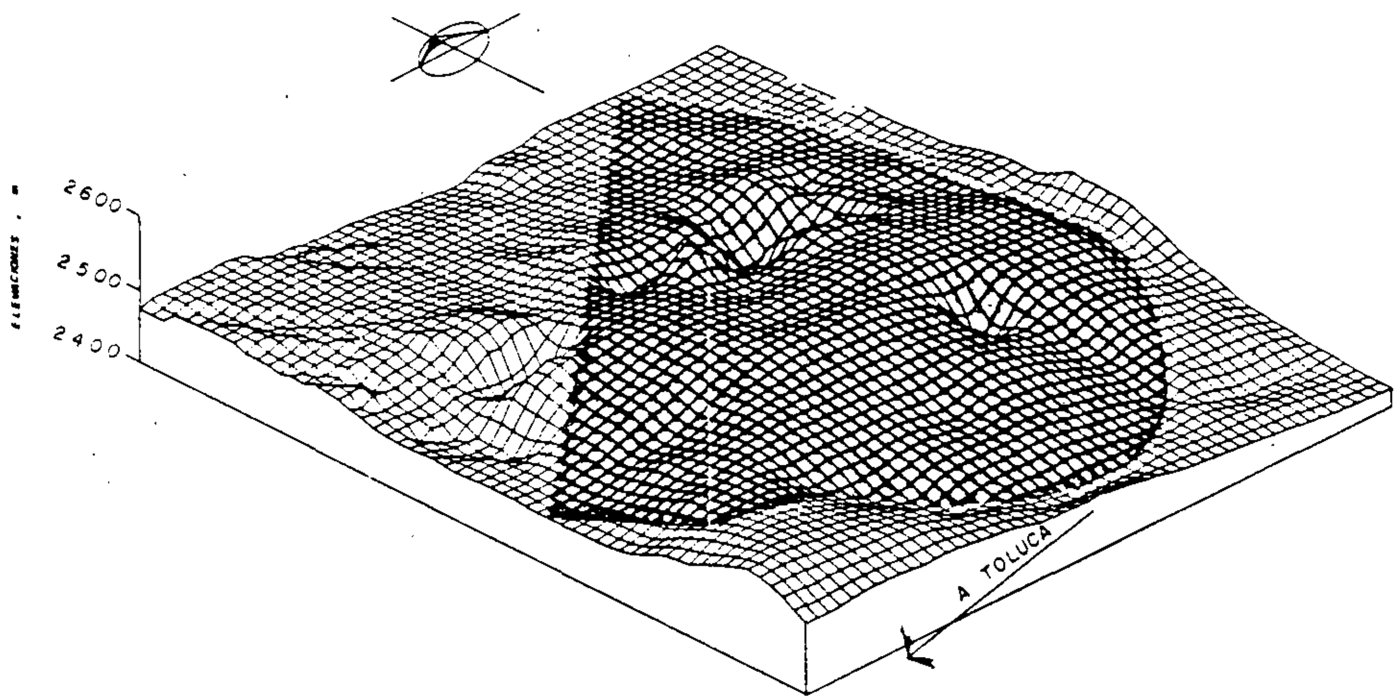


Figura 1.4.1.1

<u>Area de una cuenca</u>

El área drenada de una cuenca es el área en proyección horizontal encerrada por el parteaguas. Generalmente esta área se determina con un planimetro y se expresa en kilómetros cuadrados.

Pendiente de una cuenca

Existen diversos criterios para valuar la pendiente de una cuenca, dependiendo del uso posterior que se le vaya a dar al resultado o bien al criterio que lo requiere.

Criterio de Alvord

Para obtener la ecuación que proporciona la pendiente de la cuenca por este criterio, se analiza primero la pendiente existente entre curvas de nivel. Analizando la faja definida por las líneas medias que pasan entre las curvas de nivel, se tiene que para una de ellas la pendiente de su área tributaria es:

$$S_c = \frac{D\,L}{A}$$

donde:

A: área de la cuenca, en km^2

D: desnivel constante entre curvas de nivel, en km

L: longitud total de las curvas de nivel dentro de la cuenca, en km

S_c: pendiente de la cuenca

Criterio de Horton

En este criterio se traza una malla de cuadrados sobre el plano del área de la cuenca en estudio, la cual conviene orientar en el sentido de la corriente principal. Si la cuenca es de 250 km^2 o menor, se requiere por lo menos una malla de cuatro cuadros por lado; si la cuenca es mayor de 250 km^2, deberá incrementarse el número de cuadros de la malla, ya que la aproximación del cálculo depende del tamaño de esta.

Una vez hecho lo anterior, se mide la longitud de cada línea de la malla comprendida dentro de la cuenca y se cuentan las intersecciones y tangencias de cada línea con las curvas de nivel. La pendiente de la cuenca en cada dirección de la malla se valúa como:

$$S_x = \frac{N_x D}{L_x} \qquad y \qquad S_y = \frac{N_y D}{L_y}$$

donde

D: desnivel constante entre curvas de nivel

L_x: longitud total de las líneas de la malla en la dirección x, comprendidas dentro de la cuenca

L_y: longitud total de las líneas de la malla en la dirección y, comprendidas dentro de la cuenca

N_x: número total de intersecciones y tangencias de las líneas de la malla en la dirección x, con las curvas de nivel

N_y: número total de intersecciones y tangencias de las líneas de la malla en la dirección y, con las curvas de nivel

S_x: pendiente de la cuenca en la dirección x

S_y: pendiente de la cuenca en la dirección y

Finalmente, Horton considera que la pendiente media de la cuenca puede determinarse como:

$$S_c = \frac{N\, D \sec \theta}{L}$$

donde

L: $L_x + L_y$

N: $N_x + N_y$

θ: ángulo entre las líneas de la malla y las curvas de nivel

Como resulta demasiado laborioso determinar la sec θ de cada intersección, Horton sugiere usar un valor promedio de 1.57. En la práctica, y para propósitos de comparación, es igualmente eficaz ignorar el término sec θ, o bien considerar el promedio aritmético o geométrico de las pendientes S_x y S_y como pendiente de la cuenca.

Criterio de Nash

Análogamente al criterio de Horton, se requiere trazar una malla de cuadros sobre el plano topográfico de la cuenca, de manera que se obtengan aproximadamente 100 intersecciones.

En cada intersección se mide la distancia mínima entre las curvas de nivel y la pendiente en ese punto se considera como la relación entre el desnivel de las curvas de nivel y la mínima distancia medida. Así, se calcula la pendiente de cada intersección y su media se considera la pendiente de la cuenca.

Cuando una intersección ocurre en un punto entre dos curvas de nivel del mismo valor, la pendiente se considera nula y ese punto no se toma en cuenta para el cálculo de la media.

Al emplear este criterio, es posible construir una gráfica de distribución de frecuencias de las pendientes medidas en cada punto, mostrándose así la distribución total de la pendiente en la cuenca. Conviene hacer esta distribución sobre papel semilogarítmico, donde en el eje logarítmico se tiene la pendiente de la superficie, y en el otro, el porcentaje de área con pendiente igual o mayor que el valor indicado.

Elevación de una cuenca

La variación en elevación de una cuenca, asi como su elevación media, puede obtenerse fácilmente con el método de las intersecciones. El mapa topográfico de la cuenca se divide en cuadros de igual tamaño, considerando que por lo menos 100 intersecciones estén comprendidas dentro de la cuenca. La elevación media de la cuenca se calcula como el promedio de las elevaciones de todas las intersecciones.

Red de Drenaje

Otras características importantes de cualquier cuenca son las trayectorias o el arreglo de los cauces de las corrientes naturales dentro de ella. La razón de su importancia se manifiesta en la eficiencia del sistema de drenaje en el escurrimiento resultante. Por otra parte, la forma de drenaje proporciona indicios de las condiciones del suelo y de la superficie de la cuenca.

Las características de una red de drenaje pueden describirse principalmente de acuerdo con el orden de las corrientes, longitud de tributarios, densidad de corriente y densidad de drenaje.

Orden de las Corrientes

Antes de hablar del orden de las corrientes, conviene ver su clasificación. Todas las corrientes pueden dividirse en tres clases generales, dependiendo del tipo de escurrimiento, el cual está relacionado con las características físicas y condiciones climáticas de la cuenca.

Así, una corriente puede ser efímera, intermitente o perenne.

Una corriente efímera es aquella que sólo lleva agua cuando llueve e inmediatamente después. Una corriente intermitente lleva agua la mayor parte del tiempo, pero principalmente en época de lluvias; su aporte cesa cuando el nivel freático desciende por debajo del fondo del cauce. La corriente perenne contiene agua todo el tiempo, ya que aún en época de sequía es abastecida continuamente, pues el nivel freático siempre permanece por arriba del fondo del cauce.

Densidad de Drenaje

Esta característica proporciona una información más real que la anterior, ya que se expresa como la longitud de las corrientes por unidad de área, o sea que:

$$D_d = \frac{L}{A}$$

donde

A: área total de la cuenca, en km^2

L: longitud total de las corrientes perennes e intermitentes en la cuenca, en km

D_d: densidad de drenaje por km

Pendiente del Cauce

El perfil de un cauce se puede representar llevando en una gráfica los valores de sus distancias horizontales, medidas sobre el cauce contra sus cambios de elevaciones respectivas. En general, la pendiente de un tramo se considera como el desnivel entre los extremos del tramo dividido, por la longitud horizontal de dicho tramo.

$$S = \frac{H}{L}$$

donde

H: desnivel entre los extremos del tramo del cauce, en m

L: longitud horizontal del tramo del cauce en m

S: pendiente del tramo de cauce

1.4.2 Precipitación

La precipitación es una componente fundamental del ciclo hidrológico y se ha tomado como el inicio del análisis de dichas componentes. En este inciso se explican las nociones de meteorologia, con el fin de mostrar la diversidad de elementos que influyen en la precipitación, lo que, en la mayoria de los casos, no permite generalizar métodos de análisis.

para zonas ajenas a las que los originan. Además, se examinan diferentes métodos de procesamiento de los datos de precipitación para lograr su utilidad práctica.

Tipos de precipitación

Precipitación es el agua que recibe la superficie terrestre en cualquier estado físico, proveniente de la atmósfera. Para que se origine la precipitación es necesario que una parte de la atmósfera se enfríe hasta que el aire se sature con el vapor de agua, originándose la condensación de vapor atmosférico. El enfriamiento de la atmósfera se logra por la elevación del aire. De acuerdo con la condición que provoca dicha elevación, la precipitación puede ser por convección, orográfica y ciclónica.

Aparatos de medición

La precipitación se mide en términos de la altura de la lámina de agua y se expresa comúnmente en milímetros. Los aparatos de medición se basan en la exposición a la intemperie de un recipiente cilíndrico abierto en su parte superior, en el cual se recoge el agua producto de la lluvia u otro tipo de precipitación, registrando su altura. Los aparatos de medición se clasifican de acuerdo con el registro de las precipitaciones en pluviómetros y pluviógrafos.

Los registros de pluviógrafos se pueden transformar y obtener el hietograma de las diversas tomermentas medidas. El hietograma es una gráfica que indica la variación de la altura de lluvia o de su intensidad con respecto a un intervalo de tiempo, el cual se escoge arbitrariamente, siguiendo ciertas convenciones.

Actualmente se emplean pluviógrafos de registro directo en cinta magnética, pudiendo combinarse la recopilación de datos con el uso de las máquinas electrónicas. Aun más, se están empleando aparatos que trasmiten directamente sus registros a una estación central, sin que se registren en los aparatos. También se han desarrollado técnicas para usar el radar con el objeto de determinar el área de la distribución de la intensidad de precipitación, combinado con estaciones pluviométricas o pluviográficas.

Para conocer la distribución y la precipitación media de una tormenta en una determinada zona, se requiere de varias estaciones pluviométricas o pluviográficas, localizadas convenientemente.

Precipitación media sobre una zona

En este caso se requieren conocer la altura de precipitación media en una zona, ya sea durante una tormenta, una época del año o un periódo determinado de tiempo. Para hacerlo se tienen tres criterios.

a) Promedio aritmético. Para calcular la altura de precipitación media en una zona empleando el promedio aritmético, se suma la altura de lluvia registrada en un cierto tiempo en cada una de las estaciones localizadas dentro de la zona y se divide entre el número total de estaciones.

   La precisión de este criterio depende de la cantidad de estaciones disponibles, de la forma cmo están localizadas y de la distribución de la lluvia estudiada. Es el criterio más impreciso, pero es el único que no requiere del conocimiento de la localización de las estaciones en la zona en estudio.

b) Método de Thiessen. En este criterio, es necesario conocer la localización de las estaciones en la zona bajo estudio, ya que para su aplicación se requiere delimitar la zona de influencia de cada estación dentro del conjunto. Para determinarla, primero se trazan triángulos que ligan las estaciones más próximas entre sí. A continuación se trazan líneas bisectoras perpendiculares a los lados de los triángulos, las cuales forman una serie de poligonos; cada uno de ellos contiene una estación.

   Cada poligono es el área triburaria de cada estación. Entonces, la altura de precipitación media es

$$hp = \frac{\sum_{i=1}^{n} hp_i A_i}{A} = \sum_{i=1}^{n} hp_i \frac{A_i}{A}$$

donde

A:	área de la zona, en km^2
Ai:	área triburaria de la estación i, en km^2
hpi:	altura de precipitación registrada en la estación i, en mm
hpm:	altura de precipitación media en la zona en estudio, en mm
n:	número de estaciones localizadas dentro de la zona

c) Método de isoyetas. Para emplear este criterio se necesita un plano de isoyetas de la precipitación registrada en las diversas estaciones de la zona en estudio. Las isoyetas son curvas que unen puntos de igual precipitación. Este método es el más exacto pero requiere de un cierto criterio para trazar el plano de isoyetas. Se puede decir que si la precipitación es de tipo orográfico, las isoyetas tenderán a seguir una configuración parecida a las curvas de nivel. Por supuesto, entre mayor sea el número de estaciones dentro de la zona en estudio, mayor será la aproximación con la cual se trace el plano de isoyetas.

Para calcular la altura de precipitación media en una determinada zona, se usa la ecuación anterior, pero en este caso Ai corresponde al área entre isoyetas, hpi es la altura de precipitación media entre dos isoyetas, n el número de tramos entre isoyetas.

Deducción de datos faltantes.

Muchas veces se requieren los registros de una determinada estación, los cuales están incompletos por uno o varios dias, o inclusive por años.

Si se necesita completar un registro al que le falta uno o varios días, se puede emplear uno de los dos criterios que se basan en registros simultáneos de tres estaciones que se encuentran distribuidas lo más uniformemente posible y curcundando a la estación en estudio. a) Si la precipitación anual normal en cada una de las estaciones auxiliares difiere en menos de 10 por ciento de la registrada en la estación en estudio, para estimar el valor o los valores faltantes se hace un promedio aritmético con los valores registrados en esa fecha en las estaciones auxiliares. b) Si la precipitación anual normal de cualquiera de las tres estaciones auxiliares difiere en más del 10 por ciento de la registrada en la estación en estudio, para valuar un dato faltante se usa la ecuación

$$hpx = \frac{1}{3}\left[\frac{px}{pA}hpA + \frac{px}{pB}hpB + \frac{px}{pC}hpC\right]$$

hpA, hpB, hpC: altura de precipitación registrada en las estaciones auxiliares

hpx: altura de precipitación faltante en la estación en estudio

pA, pB, pC: precipitación anual media en las estaciones auxiliares

px: precipitación anual media en la estación en estudio

Ajuste de registros de precipitación

Cuando se desee saber si el registro de una determinada estación ha sufrido modificaciones que pueden ocurrir por una alteración en la localización de la estación, en sus condiciones adyacentes, o bien al cambiar de operador, se puede usar el método de la curva masa doble. Este método permite ajustar los registros de precipitación de tal manera que se puede considerar que la estación medidora no ha sufrido cambio alguno desde el inicio de su operación.

El método de la curva masa doble compara la precipitación anual acumulada en la estación por analizar con la precipitación media anual acumulada en un grupo de estaciones cercanas, de preferencia del orden de diez. En un plano coordenado, en el eje de las abscisas se lleva el valor acumulado de la precipitación anual de la estación en estudio, y en el eje de las ordenadas el valor acumulado de la precipitación media anual de las estaciones circunvecinas.

La acumulación puede hacerse del último año de registro hacia adelante. Uniendo los puntos se obtiene la gráfica llamada curva masa doble. Sie el registro no ha sufrido ninguna alteración, se obtendrá una línea recta; un cambio de pendiente indicará que se debe ajustar el registro, siendo dicho ajuste proporcional al cambio de pendientes.

Aunque el método se basa en precipitaciones anuales, en zonas donde exista una marcada variación durante las diferentes estaciones del año, conviene hacer el análisis para las mismas.

1.4.3 Evaporación

El agua regresa a la atmósfera a través de las acciones combinadas de evaporación sublimación y transpiración. Estas acciones son esencialmente modificaciones de un solo proceso. La evaporación es el proceso por el cual las moléculas del agua, en la superficie de un recipiente o en la tierra húmeda, adquieren suficiente energía cinética debido a la radiación solar, y pasan del estado líquido al gaseoso.

Un aumento en la temperatura del agua origina una mayor evaporación, ya que se incrementa la velocidad de las moléculas del agua y disminuye la tensión superficial.

La sublimación difiere de la evaporación solo en que las moléculas del agua pasan directamente del estado sólido al gaseoso. La transpiración es el proceso por el cual el agua absorbida por las plantas regresa a la atmósfera en forma de vapor.

Durante la evaporación, el movimiento de las moléculas de la superficie del agua produce una presión, denominada presión de vapor. Esta es una presión parcial del vapor de agua en la atmósfera, ya que en una mezcla de gases, cada gas ejerce una presión parcial, la cual es indispensable de la de otros gases.

Si en un espacio cerrado se considera a p como la presión total del aire húmedo contenido en ese espacio, y a p' como la presión debida al aire seco, la diferencia $e = p - p'$ será la presión de vapor ejercida por el vapor de agua.

Para propósitos prácticos, la máxima cantidad de vapor de agua que puede existir en cualquier espacio dado es una función de la temperatura, y es independiente de la coexistencia de otros gases. Cuando un espacio dado contiene la máxima cantidad de vapor de agua, para una temperatura dada, se dice que el espacio está saturado, y la presión ejercida por el vapor de agua en ese medio se denomina presión de saturación. La temperatura a la cual se satura un espacio donde se conoce con el nombre de punto de rocio. Cualquier disminución de esa temperatura origina la condensación.

Tratando de ver el proceso en conjunto, puede considerarse que parte del vapor de agua liberado por evaporación de la superficie del agua, puede retornar a esta, una vez que se condensa. Cuando el número de moléculas que escapan de la superficie libre del agua es igual al número de moléculas que retorna a esta, el espacio se satura y se alcanza un equilibrio entre la presión ejercida por las moléculas que escapan y la presión atmosférica. Esto implica que la evaporación es mayor que la condensación si el aire sobre la superficie del agua no está saturado.

Factores que afectan a la evaporación

De acuerdo con lo anterior, se puede decir que la evaporación está relacionada con la diferencia entre la presión de vapor de la masa de agua y la existente en el aire sobre la superficie de la misma, temperaturas del aire y agua, velocidad del viento, presión atmosférica, y calidad del aire.

Diferencias en la presión de vapor

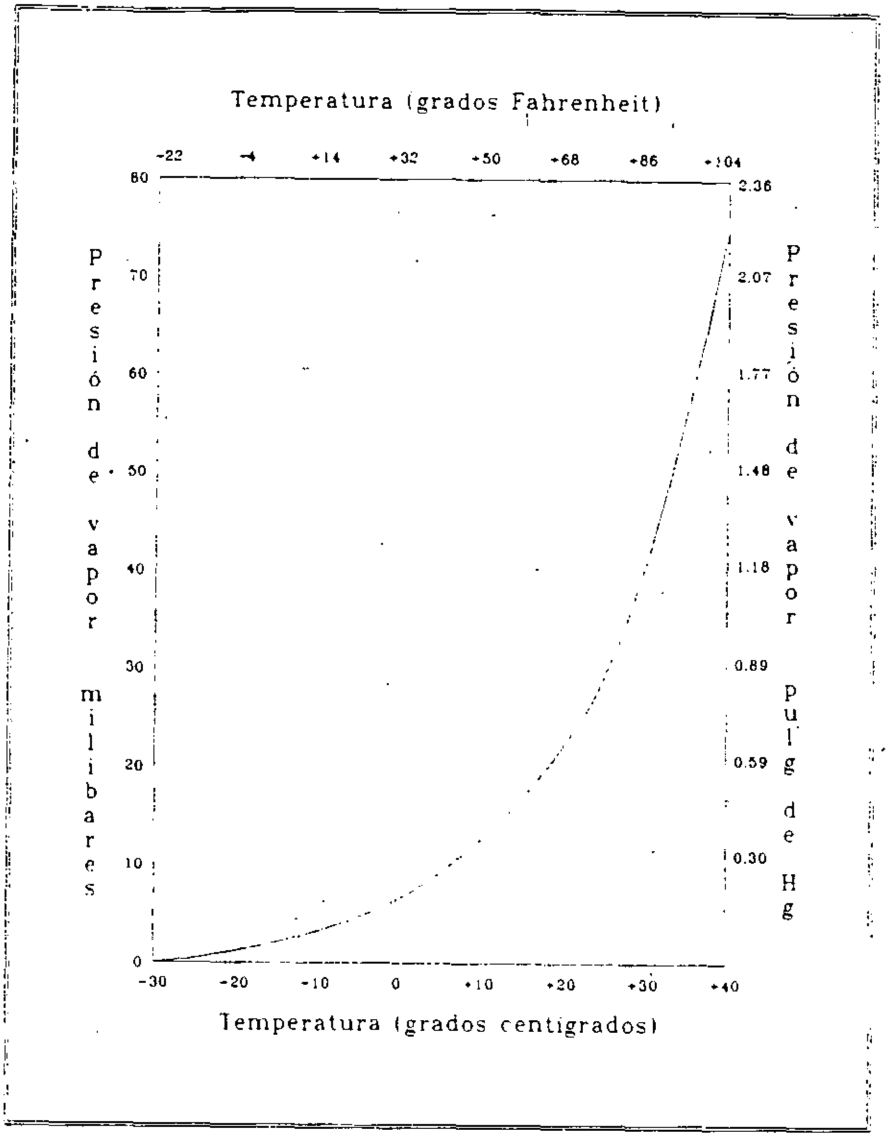
Si se considera que e_w es la presión de vapor del agua, y e_a la presión de vapor del aire sobre la superficie del agua, se puede decir que la evaporación es proporcional a $e_w - e_a$.

Cuando el aire es más caliente que el agua, su presión de saturación e_s es mayor que la de la superficie del agua ($e_s > e_w$), y la evaporación continúa hasta que $e_a = e_w$, lo cual ocurrirá antes de que el aire llegue a saturarse. Sin embargo, si el aire es más frío que el agua, se tendrá que $e_s < e_w$ y la evaporación continuará hasta que $e_a = e_w$, lo cual ocurrirá antes de que el aire llegue a saturarse. Además, se el aire es más frío que el agua, se tendrá que $e_a = e_w$, existirá un estado de sobresaturación ($e_a > e_s$), o la condensación ocurrirá en el aire.

Temperatura

Este aspecto y el anterior están íntimamente relacionados ya que la presión de vapor depende de la temperatura. La cantidad de emisión de moléculas de la masa de agua está en función de su temperatura, ya que a mayor temperatura, mayor será la energía molecular liberada. La evaporación no depende de la temperatura de la superficie del agua, sino del resultado directo del incremento en la presión del vapor con la temperatura.

En la siguente figura se muestra la variación entre la temperatura del aire y la presión de saturación.



Viento

El viento es un elemento efectivo para remover las moléculas que se desprenden de la superficie del agua debido a la evaporación, lo que origina variaciones en las caracteristicas de la masa de aire que se envcuentra sobre esta. Puede, así, traer masas de aire caliente, lo cual origina un aumento de evaporación; si la masa de aire es frio, puede disminuir la evaporación e, inclusive, favorecer la condensación.

El efecto del viento sobre la evaporación es mayor en grandes masas de agua que en pequeñas. Esto se debe a que una vez que el viento desplaza el vapor de agua que se encuentra en el aire sobre la superficie del agua y se altera la evaporación, se requieren variaciones muy grandes de velocidad para que se altere apreciablemente la evaporación existente. En el caso de pequeños recipientes, un incremento pequeño en el viento puede ser suficiente para remover el vapor de agua que se está generando. En extensas áreas de agua, pueden requerirse velocidades grandes y movimientos turbulentos de aire para que se incremente la evaporación.

Presión atmosférica

La presión atmosférica están tan íntimamente relacionada con los otros factores que afectan la evaporación, que es prácticamente imposible estudiar los efectos de sus variaciones bajo condiciones naturales.

La evaporación puede disminuir con el incremento de altitud. El número de moléculas de aire por unidad de volumen aumenta con la presión. Consecuentemente, ante presiones altas hay más oportunidad de las moléculas que escapan de la superficie libre del agua choque con las del aire y retornen al líquido.

Calidad del agua

La cantidad de evapòración, menor en agua salada, disminuye conforme se incrementa el peso específico.

<u>Medición de la evaporación</u>

Como la evaporación es de gran importancia dentro del ciclo hidrológico, se han hecho grandes esfuerzos tendientes a establecer un método que permita medirla en forma directa. Obviamente, lo primero que se ocurre para determinar la evaporación en lagos y recipientes es usar la ecuación de equilibrio, y medir el gasto que entra y sale, la lluvia y el agua que se infiltra. Sin embargo, el agua que se infiltra no se puede valuar, y los errores al medir los otros factores pueden exceder a la evaporación. Por lo tanto, este procedimiento no se puede aplicar para valuar la evaporación.

La medición del grado de evaporación de una región se puede hacer en forma directa usando un evaporímetro. El evaporímetro más usual consiste en un recipiente circular de lámina abierto en su parte superior, de aproximadamente 1.20 m. de diámetro y 0.26 m. de alto.

El recipiente se llena de agua hasta un nivel arbitrario y se mide la variación del nivel después de un cierto tiempo, usualmente un día. Para medir el nivel del agua se introduce dentro del recipiente un cilindro de reposo que contiene un tornillo con vernier. La diferencia de niveles proporciona un índice de evaporación en la región.

Como la evaporación está relacionada con los cambios atmosféricos, además del evaporímetro se acostumbra instalar otros aparatos que permitan registrar distintos datos meteorológicos. Los elementos meteorológicos más importantes son el movimiento del aire, su temperatura y la de la superficie del agua, humedad atmosférica y precipitación.

El problema que plantean las mediciones de evaporación efectuadas con el avaporimetro es su explotación a la zona donde se quiere conocer esta componente. En el caso del almacenaje en una presa o un lago, el principal problema es la variación de la masa de agua almacenada con respecto a la contenida por el avaporímetro. Puede decirse que la evaporación registrada por un evaporímetro es mayor que la evaporación que puede sufrir una masa adyacente de agua. La relación de evaporaciones se conoce con el nombre de coeficiente del evaporímetro. Este coeficiente es variable y, usualmente, más alto en invierno que en verano; además, los coeficientes de evaporación mensual varían más que los de evaporación anual, pudiéndose considerar que lo coeficientes medios oscilan entre 0.70 y 0.80.

Formulas de evaporación

Exite una gran diversidad de ecuaciones para valuar la evaporación, las cuales se pueden agrupar en:

a) Ecuaciones empiricas obtenidas a partir de relaciones entre datos de evaporímetros y elementos climáticos.
b) Ecuaciones basadas en consideraciones teóricas de cambios de energia.

Las ecuaciones del primer grupo se basan en la ley de Dalton, modificándola de acuerdo con los factores que afectan a la evaporación.

Las del segundo involucran hipótesis basadas en evidencias experimentales o coeficientes, los cuales se deben valuar empíricamente.

Ecuaciones empíricas

Como se vió al principio, la evaporación es proporcional a la diferencia entre la presión de vapor de agua, e_w, y la presión de vapor del aire, e_a, que se encuentra sobre la superficie del agua. Esto se puede expresar, según la fórmula de Dalton, como:

$$E = k(e_w - e_a)$$

donde k es un coeficiente de proporcionalidad. Esta ecuación es válida, cuando el agua y el aire están a la misma temperatura.

Esta ecuación se ha usado como base de una gran variedad de expresiones. Así, para evaporaciones mensuales se puede usar la fórmula de Meyer, la cual se expresa en la forma:

$$E = c(e_s - e_a) \; 1 + \frac{V_w}{16.09}$$

donde

- c: Constante empirica que tiene un valor aproximado de 38 para evaporimetros y pequeños depósitos, y de 28 para grandes depósitos
- E: Evaporación mensual, en cm.
- e_a: Presión de vapor del aire basada en la temperatura media mensual del aire y en la humedad relativa en la cercanía de los depósitos pequeños. Para depósitos grandes, los datos se deben recabar a 10 m sobre la superficie libre del agua. La presión de vapor se expresa en pulgadas de Hg.
- e_s: Presión de saturación del vapor correspondiente a la temperatura media mensual del aire si se trata de depósitos pequeños, y a la temperatura media mensual del agua, para depósitos grandes. Se expresa en pulgadas de Hg.
- V_w: Velocidad media mensual del viento registrada a 10 m sobre la superficie, en Km/h.

Para evaporaciones diarias, Horton propone la ecuación

$$E = 1.016\,(\Psi e_s - e_a)$$

donde

$$\Psi = 2 - e^{-0.0128 V_w}$$

Las variables tienen el mismo significado que en la fórmula de Meyer, sólo que ahora se usan valores diarios en lugar de mensuales.

Esta ecuación sólo sirve para pequeños depósitos. Para grandes depósitos, el valor encontrado de E se multiplica por

$$(1 - P) + P\,\frac{\Psi - 1}{\Psi - h}$$

donde:

h: Humedad relativa

P: Fracción del tiempo durante el cual el viento es turbulento

Ψ: Factor de viento, ec. 6.4

Basándose en un correlación gráfica coaxial, Linsley encontró, para valuar la evaporación en función de parámetros meteorológicos, una relación general de la forma:

$$E = c\,(e_s - e_a)(baV^n_w)$$

donde a, b, c y n son constantes a determinar basándose en los valores conocidos de los parámetros meteorológicos, que en este caso son e_a, e_s y V_w, y el valor de la evaporación E.

Ecuaciones basadas en cambios de energía

Siendo el movimiento vorticoso el principal mecanismo por el cual el vapor de agua es removido de la vecindad de la superficie sujeta a evaporación, existen numerosas expresiones para determinarla basándose en consideraciones de transporte de masa por cambios turbulentos. De estas expresiones, la ecuación de Thornthwaite-Holzman ha dado resultados satisfactorios. Suponiendo una condición atmosférica adiabática y una distribución logarítmica en la vertical de la velocidad del viento y de la humedad, esta ecuación puede expresarse como

$$E = \frac{210.43(e_1 - e_2)(V_{w2} - V_{w1})}{(T - 459.4)\ \ln\,(h_2/h_1)^2}$$

donde

E: Evaporación, en cm/h

e_1, e_2: Presión de vapor, en altura inferior h_1 y en la superior h_2, respectivamente, sobre la superficie del agua, en pulgadas de Hg.

T: Temperatura media del aire entre h_1 y h_2, en °F

V_{w1}, V_{w2}: Velocidad del viento para h_1 y h_2, respectivamente, en Km/h.

Otro enfoque para calcular la evaporación se conoce con el nombre del método del balance del calor, y aunque existen diversas expresiones, estas son difíciles de aplicar por los problemas que se presentan al tratar de valuar algunos de los parámetros que intervienen.

1.4.4 Infiltración

Infiltración es el proceso por el cual el agua penetra en los estratos de la superficie del suelo y se mueve hacia el manto freático. El agua primero satisface la deficiencia de humedad del suelo y, después, cualquier exceso pasa a formar parte del agua subterránea.

La cantidad máxima de agua que puede absorber un suelo en determinadas condiciones se llama capacidad de infiltración. Durante una tormenta sólo se satisface la capacidad de infiltración mientras ocurre la lluvia en exceso. Antes o después de la lluvia en exceso, la capacidad de infiltración está ligada a la intensidad de lluvia.

Factores que afectan a la capacidad de infiltración

La infiltración puede considerarse como una secuencia de tres pasos: entrada en la superficie, trasmisión a través del suelo, y agotamiento de la capacidad de almacenaje del suelo. Además de estos factores, se deben tener en cuenta el medio permeable y el flujo.

Entrada en la superficie

La superficie del suelo puede obstruirse por el lavado de finos y el impacto de gotas de agua, lo cual evita o retarda la entrada del agua dentro del suelo; por este hecho, un suelo con una buena red de drenaje puede tener baja capacidad de infiltración. La vegetación tiene una influencia importante en este aspecto.

Trasmisión a través del suelo

La rapidez con que el agua penetra en un suelo depende de su capacidad de trasmisión, la cual varia para los diferentes horizontes del perfil del suelo; una vez que este se ha saturado, la capacidad de infiltración está limitada por la menor trasmisión del agua infiltrada que tenga el suelo.

Si la entrada del agua en la superficie del suelo es menor que la trasmisión más baja de cualquier horizonte del suelo, la infiltración quedará supeditada.

Agotamiento de la capacidad de almacenaje del suelo

El almacenaje disponible en cualquier horizonte depende de su porosidad, espesor y contenido de humedad. La naturaleza y magnitud de la porosidad del horizonte del suelo depende de su textura, estructura, contenido de materia orgánica, penetración de las raices y muchos otros factores.

La infiltración que ocurre en el inicio de la tormenta está controlada por el volumen, tamaño y continuidad de los poros no capilares, ya que proporcionan fáciles trayectorias para el movimiento del agua. La capacidad de almacenaje afecta directamente a la cantidad de infiltración durante la tormenta. Cuando esta última cantidad está controlada por su trasmisión a través de los estratos del suelo, esta irá disminuyendo conforme se agote el almacenaje de los estratos superiores al estrato que tiene la menor trasmisión.

Características del medio permeable

Para el suelo, la capacidad de infiltración está relacionada con el tamaño del poro y su distribución. En las arenas, los poros son relativamente estables, aunque durante una tormenta se puede formar una mezcla más densa; sin embargo, este cambio en las arenas es relativamente lento comparado con las arcillas y los limos.

En suelos en estado seco con cantidades apreciables de limo o arcilla, es posible tener poros relativamente largos que pueden desintegrarse durante una tormenta. Dichos suelos normalmente contienen material coloidal, el cual se hincha cuando está húmedo; así, un cambio en la permeabilidad de la masa es más frecuente que en las arenas. Por otra parte, el impacto de las gotas de agua compactan el suelo y ocasionan que partículas muy pequeñas de limo y arcilla penetren en los poros del material, sellandolos y reduciendo la infiltración.

Las modificaciones del tamaño del poro y su distribución son comunes en el campo, dependen principalmente del contenido de materia orgánica del suelo.

Características del flujo

Otros grupos de factores que afectan a la infiltración, aunque en grado menor, son aquellos que modifican las características físicas del agua. Uno de los cambios más importantes en el agua infiltrada es su contaminación, que, en la mayoría de los suelos, ocurre en menor o mayor escala, debido a las arcillas finas y los coloides. Esto afecta en forma directa a la infiltración,.ya que el material en suspensión que lleva el agua infiltrada bloquea los poros del suelo por los cuales pasa.

La temperatura y viscosidad del fluido también afectan a la cantidad de agua que se mueve a través del suelo.

Medición de la infiltración

Para medir la infiltración de un suelo se usan los infiltrómetros, que sirven para determinar la capacidad de infiltración en pequeñas áreas cerradas, aplicando artificialmente agua al suelo.

Los infiltrómetros se unen con frecuencia en pequeñas cuencas o en áreas pequeñas o experimentales dentro de cuencas grandes.

Cuando en un área se presenta gran variación en el suelo y vegetación, esta se subdivide en subáreas relativamente uniforme, de las cuales, haciendo una serie de pruebas, se puede obtener información aceptable.

Siendo la infiltración un proceso completo, a partir de los infiltrómetros es posible inferir la capacidad de infiltración de cualquier cuenca en forma cualitativa y no cuantitativa. La aplicación más favorable de este equipo se obtiene en zonas experimentales, donde se puede valuar la infiltración para determinar tipos de suelos y contenido de humedad.

Infiltrómetros de carga constante

Estos infiltrómetros permiten conocer la cantidad de agua que penetra en el suelo en un área cerrada, a partir del agua que debe agregarse a dicha área para mantener un tirante constante, que generalmente es de medio centimetro.

Los infiltrómetros de carga constante más comunes consisten en dos arcos concéntricos, o bien en un solo tubo. En el primer tubo, se usan dos arcos concéntricos de 23 y 92 cm de diámetro, respectivamente, los cuales se hinchan en el suelo varios centímetros.

El agua se introduce en ambos compartimientos, los cuales deben conservar el mismo tirante. El objeto del aro exterior es evitar que el agua dentro del aro interior se expanda en una zona de penetración mayor que el área correspondiente. La capacidad de infiltración del suelo se determina a partir de la cantidad de agua que hay que agregar al aro interior para mantener su tirante constante. El segundo tipo consiste en un tubo que se hinca en el suelo hasta una profundidad igual a la que penetra el agua durante la medición, lo que evita que el agua se expanda. En este caso se mide el agua que se le agrega para mantener el nivel constante.

Aunque estos aparatos proporcionan un método simple y directo para determinar la cantidad de agua que absorbe el suelo con estas condiciones, sólo considera la infiltración del uso del suelo, vegetación y algunas variables físicas. Esta forma de medir la infiltración puede cambiar con respecto a la real, porque no toma en cuenta el efecto que producen las gotas de lluvia sobre el suelo, como son la compactación y el lavado de finos. Por otra parte, tampoco considera el efecto del aire entrampado, el cual se escapa lentamente. Además, es imposible hincar los arcos o el tubo sin alterar las condiciones del suelo cerca de su frontera; el área afectada puede ser un porcentaje apreciable del área de prueba, ya que esta es muy pequeña.

Métodos para Calcular la Infiltración

Todos los métodos disponibles para determinar la capacidad de infiltración en una cuenca están basados en el criterio de la relación entre lo que llueve y lo que escurre. En la práctica, resulta complicado analizar detalladamente el fénomeno y sólo es posible, con ciertas limitaciones, para cuencas pequeñas donde ocurren tormentas sucesivas.

Los métodos que permiten obtener la infilrtación de una cuenca, para una cierta tormenta, requieren del histograma de la precipitación media y de su correspondiente hidrograma. Esto implica, que en la cuenca donde se require valuar la infiltración, se necesita, si desean hacer análisis horarios, por lo menos un pluviógrafo y una estación de aforos en su salida. En caso de contar únicamete con estaciones pluviométricas, sólo se podrán hacer análisis diarios.

Los criterios que se analizan en este inciso permiten conocer la infiltración producida por una tormenta, una vez que ha terminado el escurrimiento. Debido a esto, se considera que

$$P = Q + F$$

donde

F: volumen de infiltración
P: volumen de precipitación
Q: volumen de escurrimiento directo

En esta ecuación se considera que en F también están involucrados la intercepción y el almacenaje por depresiones ya que no es fáctible medirlos; además, en esta forma se valúa todo el escurrimiento directo, que es de interés fundamental, ya que permite determinar la cantidad de agua que escurre con respecto a la de lluvia.

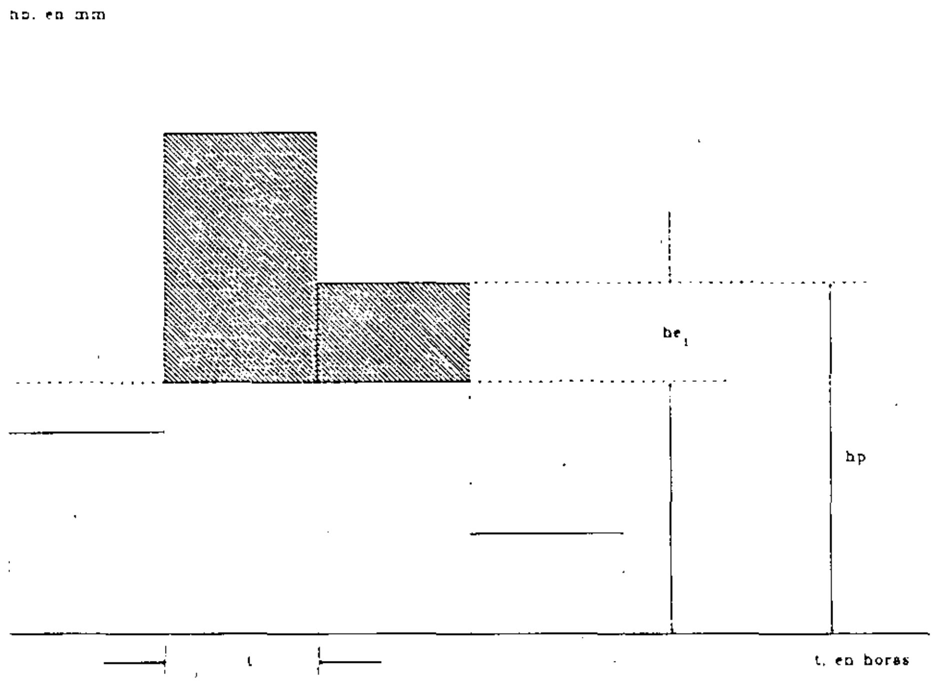
El primer criterio que se verá está relacionado con los coeficientes de infiltración. El uso de tales índices no constituye una aplicación racional de la teoría de la infiltración, pero los resultados, que son de tipo empírico, son de gran utilidad práctica; aunque existen diversos índices, aquí sólo se verá el índice ϕ, el cual puede considerarse como de inlfiltración media.

A continuación se presenta un criterio debido a Horner y Lloyd que permite obtener la curva de la capacidad de infiltración media en cuencas pequeñas cuando se dispone de una serie de tormentas sucesivas. Finalmente, se analizará el criterio de Horton para obtener la capacidad de infiltración media en cuencas grandes.

Indice de Infiltración Media

Este índice está basado en la hipótesis de que, para una tormenta con determinadas condiciones iniciales, la cantidad de recarga en la cuenca permanece constante a través de toda la duración de la tormenta. Así, se conoce el histograma de la tormenta, el índice de la infiltración media, ϕ, es la intensidad de lluvia media sobre la cual el volumen de lluvia es igual al del escurrimiento directo observado.

Para obtener el índice ϕ se procede por tanteos, suponiéndose valores de ϕ y deduciendo la lluvia en exceso del histograma de la tormenta. Cuando esta lluvia en exceso sea igual que la registrada por el hidrograma, se conocerá el valor de ϕ.



Determinación del índice

Según la figura, el valor correcto de ϕ se tendrá cuando

$$\sum \Delta h_{ei} = h_e$$

donde

h_{ei}: lluvia en exceso, deducida de volumen de escurrimiento directo, V_e , dividido entre el área de la cuenca, A.

Δh_{ei}: lluvia en exceso en el intervalo de tiempo Δt_i, deducido del histograma de la tormenta

Debe señalarse que, como la lluvia varia con respecto al tiempo y el índice ϕ es constante, cuando la variación de la lluvia Δh_{pi} en un cierto intervalo de tiempo Δt_i sea menor que ϕ, se acepta que todo lo llovido se infiltro. El problema se presenta cuando se desea valuar el volumen de infiltración, ya que si se valua a partir del índice ϕ, se obtendrá por este hecho un volumen mayor que el real. Para calcular el volumen de infiltración real, se aplica la ecuación siguiente

$$F = (h_p - h_e) A$$

donde

A: área de la cuenca

h_e: altura de lluvia en exceso

h_p: altura de lluvia a la tormenta, la cual es la suma de los Δh_{pi}

Obtención de la curva de capacidad de infiltración media.

En una cuenca pequeña, si se tiene una serie de tormentas sucesivas y se dispone del hietrográma e hidrográma correspondientes, es posible obtener la curva de la capacidad e infiltración aplicando el criterio de Horner y Lloyd.

Para cada tormenta se obtiene, de su hietrográma, la altura de lluvia, h_p, y, según el hidrográma, la lluvia en exceso, h_e, a que dio lugar. A continuación se calcula el volumen de infiltración, F, expresado en lámina de agua, que, de acuerdo con la ecuación

$$F = (hp - he) A$$

lo mismo que en la ecuación anterior sólo que todos los volúmenes están expresados en altura de lámina de agua, tenemos que

$$hf = \frac{F}{A} = h_p - h_e$$

En la formula h_f es una infiltración media. Para obtener la capacidad de infiltración media para cada tormenta, f, el valor de cada h_f deberá dividirse entre el tiempo promedio en que ocurre la infiltración en toda la cuenca.

En este criterio se acepta que la infiltración media se inicia cuando empieza la lluvia en exceso y continúa durante el lapso después de que esta termina. En ese momento, si la tormenta cubre toda el área, la infiltración continúa en forma de capacidad e irá disminuyendo conforme al área de detención del escurrimiento disminuye. Horton considera que el periodo equivalente durante el cual el mismo volumen de infiltración residual ocurre sobre toda la cuenca es igual a un tercio del periodo de tiempo que sucede desde que la lluvia en exceso finaliza hasta que cesa el flujo sobre tierra, el cual se puede detectar al analizar el hidrográma correspondiente.

Según lo anterior, el tiempo promedio en el cual ocurre la capacidad de infiltración se expresa como:

$$t = d_e + \frac{\Delta t}{3}$$

donde

d_e: duración de la lluvia en exceso, en h

t: duración de la infiltración, en h

Δt: periodo de tiempo desde que termina la lluvia en exceso hasta que cesa el flujo sobre tierra, en h

Por lo tanto, la capacidad de infiltración media será:

$$f = h_f/t$$

donde

h_f: altura de infiltración media, en mm

t: duración de la infiltración, en h

Una vez conocido el valor de f para cada tormenta, se lleva a una gráfica en el punto medio de cada periodo t. Al unir resultantes se obtiene la curva de capacidad de infiltración media.

Capacidad de infiltración en cuencas grandes

Para cuencas donde no se acepta que la intensidad de lluvia es uniforme en toda el área, Horton propone un criterio para calcular la capacidad de infiltración media, f_a, que se tiene para una tormenta cualquiera.

Este criterio supone la disponibilidad de registros de lluvia suficiente para representar su distribución satisfactoriamente, y que al menos uno de los registros se obtuvo a partir de un pluviógrafo. Esto implica estimar que la distribución de lluvia registrada en el pluviógrafo sea representativa de la distribución en toda la cuenca. Por otra parte, considera que el escurrimiento superficial es igual a la diferencia entre la precipitación y la infiltración que ocurre durante el periodo de la lluvia en exceso; o sea que se desprecia la infiltración antes y después de la lluvia en exceso. Entonces, el valor de f_a que se encuentra es tal que multiplicado por la duración de la lluvia en exceso y restado de la lluvia total para el mismo periodo, proporciona el escurrimiento superficial total.

La estación pluviográfica recibe el nombre de estación base y las pluviométricas se llaman subestaciones. Con el fin de tener un criterio de cálculo general para la cuenca en estudio, conviene transformar a porcentajes la curva masa de la estación base. Una vez hecho esto, se suponen alturas de lluvia y, a partir de la curva masa en porcentaje, se obtiene la variación respecto al tiempo. A continuación, se inventan capacidades de infiltración media y se deduce para cada altura de lluvia supuesta su correspondiente lluvia en exceso.

Lo anterior permite obtener gráficas de alturas de lluvias totales contra alturas de lluvia en exceso, para diferentes capacidades de infiltración media. Así, conocida la altura de precipitación media en la cuenca para la tormenta en estudio, y su correspondiente altura de lluvia en exceso a partir del hidrográma del escurrimiento directo, es posible obtener su capacidad de infiltración media.

Si se observa, este criterio es similar al del índice de infiltración media, solo que ahora los tanteos se llevan a gráficas, que en el caso de tener una tormenta con una duración grande es muy conveniente, ya que se disminuye el tiempo de cálculo. Por otra parte, permite disponer de una gráfica que relaciona para cualquier tormenta su lluvia en exceso, su lluvia total y su correspondiente capacidad de infiltración media.

1.5 Estudios topográficos

Una vez delimitado el lindero del terreno que ocupara el relleno sanitario se procederá a realizar el levantamiento topográfico para obtener una conceptualización adecuada de la configuración del lugar.

Los trabajos de topografía son determinantes para la elaboración del proyecto ya que con ellos se determina la capacidad del sitio, así como su vida útil, además de todos los elementos necesarios para el diseño y la operación del relleno sanitario.

En los trabajos de topografía se deberán de considerar las siguientes actividades:

- Localización: Se determinará con una poligonal abierta desde el eje de la via que se tenga de acceso, uniéndola con el área del terreno. Señalando las vias principales de acceso desde la población, y su ubicación con relación a la misma.

- Planimetría: La poligonal cerrada que limite el sitio, se unirá a la abierta que se trazó desde el acceso, dando a las dos orientación astronómica.

- Altimetría: Para realizar esta fase del trabajo, se determinará un punto que sirva como banco de nivel, y que se pueda localizar fácilmente,
  Se colocaran mojoneras en cada uno de los vértices de la poligonal para que sirvan de bancos auxiliares de nivel.
  Establecidos los bancos de nivel, se procederá a correr una nivelación,

con puntos nivelados a cada 20 m como máximo y menor en caso de encontrar algún accidente topográfico.

- Secciones: Las secciones se deberán realizar perpendicularmente a las nivelaciones y abarcando 20 m a cada lado.
  Para mayor claridad la representación gráfica de los planos, estará en escalas verticales mayores que las horizontales.

- Curvas de nivel: Las curvas de nivel se harán a cada 0.5 m para terrenos planos a cada 1 m para sitios sinuosos, hondanadas profundas y valles escarpados a cada 5 mts.

- Volumetría Con base en las secciones se calculará la volumetría del terreno, lo que dará por resultado la vida útil real del terreno elegido. El procedimiento del cálculo puede ser con cualquier método reconocido, de preferencia con tablas calculadas en computadoras.

La escala que más frecuentemente se utiliza varía de 1.100 a 1:500 la definición de la escala variará de acuerdo al tamaño del previo una vez realizada la topografía se estará en posibilidad de realizar la ubicación de las principales características del sitio como se muestra en la figura 1.5.1.

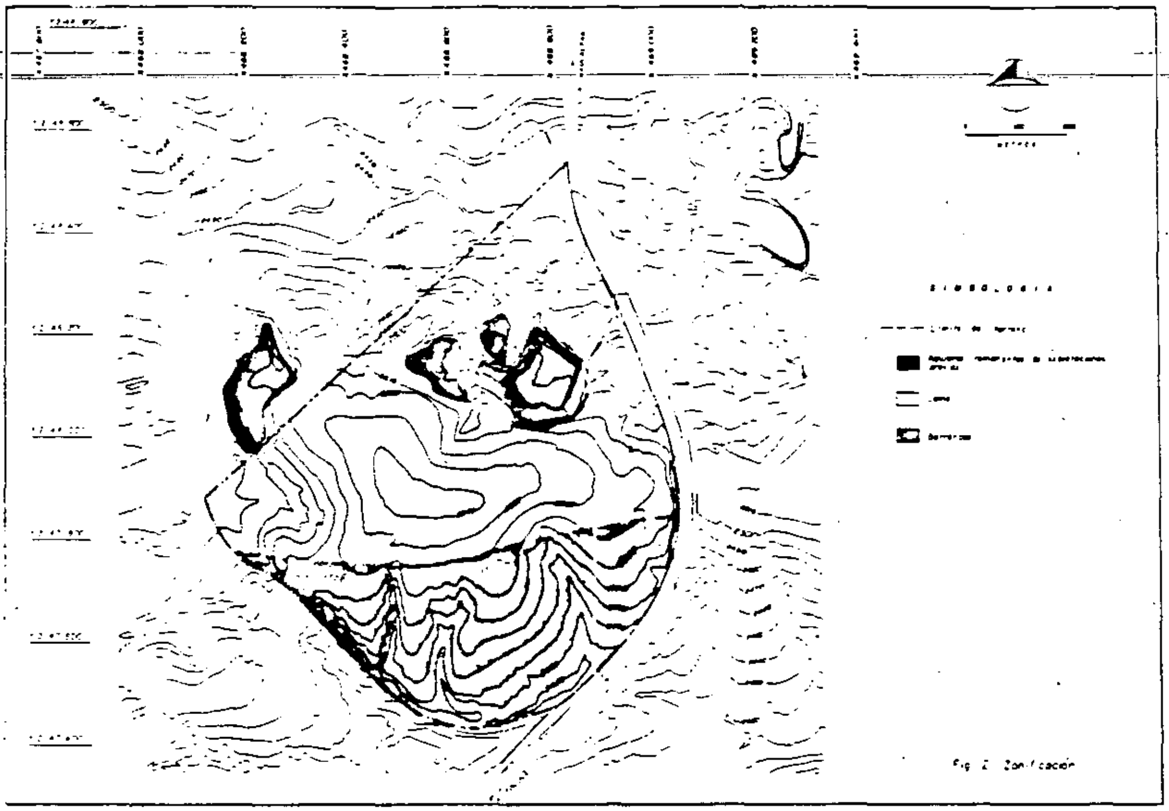


Figura 1.5.1

1.6 Impacto vial

Mitigar el impacto vial que pueda ocacionarce al implementar una serie de obras como las que requiere un relleno sanitario, es un requerimiento indispensable para el optimo funcionamiento de dicha obra, para ello es necesario tomar en cuenta las siguientes recomendaciones:

1.- Utilizar en forma adecuada y congruente de la infraestructura vial existente.
2.- Elegir la o las rutas principales que deban utilizar las unidades de transferencia hasta el sitio de disposición final.
3.- Evitar que el proceso de transportación de los desechos solidos cause el menor impacto negativo, tanto en la infraestructura vial existente como en la imagen urbana y social.
4.- Elegir rutas opcionales así como horarios y tipos de transporte, en función de

contingencias que puedan presentarse fuera de rutina, como son: eventos cívicos, políticos, deportivos, sociales y de desastre, incluso.

5.- Minimizar el impacto vial realizando obras complementarias como son la adecuaciones geométricas, semaforización, señalización, etc.

Para solucionar esta problemática, es necesario realizar estudios y mediciones vehiculares, para tener un conocimiento detallado de la infraestuctura existente en la zona, con el fin de formular las propuestas de solución más adecuadas.

1.6.1 Determinacion de rutas

La minimización de impacto vial tiene consideraciónes de muchas categorias, como lineas de tráfico, topografía, consideraciones para la población y para el ambiente.

La ruta debe estar de acuerdo con la linea que seguiria la parte principal del tráfico como si tuviera una opción libre, que no es necesariamente la distancia más corta entre los puntos. Puede preferirse, para transitar, una ruta larga que de un buen servicio de tráfico a estaciones de transferencia o finales de ruta de recolección a lo largo de la ruta y en la que puedan circular vehiculos de transferencia.

Con objeto de llegar a la solución precisa y suficiente es conveniente señalar las rutas de accesibilidad al sitio, a partir de las estaciones de transferencia o los fines de ruta, anotando a la vez, un inveterio general de sus secciones, número de carriles, capacidad, y cruceros conflictivos suceptibles de modificación y adecuación, permitiendo a la vez, establecer el horizonte de vida útil en cada uno de los casos en particular.

Esta es una consideración importante para determinar el estado actual de la zona, en donde aparece la información relativa a los arroyos y banquetas; así como accidentes topográficos y/o físicos, existentes, complementandose con la ubicación de postes, señales, árboles y retornos.

Posteriormente es indispensable la definición de la o las rutas principales a seguir a partir de los centroides de referencia o de las estaciones de transferencia, ademas del diseño o adecuación de aquellas que sean seleccionadas, ya sea que se encuentren obsoletas o en deterioro, tanto en su sección transversal como en sus cruceros conflictivos y hasta su estructura de pavimentos. Por lo anterior se debe considerar, en algunos casos, la necesidad de aumentar la capacidad del camino, repavimentar, modificar geométricamente, tanto en su alineamiento vertical como horizontal, verificar y adecuar la señalización y semaforización, así como reforzar el equipamiento urbano existente.

De esta forma se logrará la optimización en todos los rubros que se mencionan anteriormente. Para tal efecto es conveniente la implementación del plan en varias etapas y en diversos frentes para obtener el funcionamiento integral que se pretende.

1.6.2 Estudios de ingeniería de tránsito.

Para determinar las condiciones de funcionamiento de las alternativas de recorrido propuesto, se efectúan aforos vehiculares en las principales intersecciones. Los aforos nos indican el comportamiento de los movimientos vehiculares y direccionales, en las horas pico.

Estos aforos vehiculares se determinan considerando 16 horas de observación, determinándose la hora máxima de demanda vehicular durante el día, con la clasificación de acuerdo al tipo de automóviles, autobuses y camiones que circulan. Realizando las gráficas de variación horaria y determinación de el volumen vehicular a cada 15 minutos durante las 16 horas.

El resultado de los estudios referidos, es la elaboración del proyecto de vialidad integral, en el que se decriben los por menores de las rutas, así como las gráficas de volúmenes de transito y aforos direccionales que representan la cantidad de vehiculos que transitan en las principales avenidas, su tipo y dirección durante un periodo de tiempo de 1 hora. Como se presenta en figura 1.6.1 y 1.6.2 a este comportamiento se le tendria que agregar los vehículos de limpia que tendrán que circular por estas vías con lo que se determinará el impacto por tránsito que ocasionará el sitio de disposición final.

AFORO VEHICULAR

'\`TERSECCION: AV. ALTA TENSION - AV. RIO BECERRA

FECHA: 2 DE ABRIL DE 1991 HORA: 12:30 - 13:30 AFORO: J.C.M.

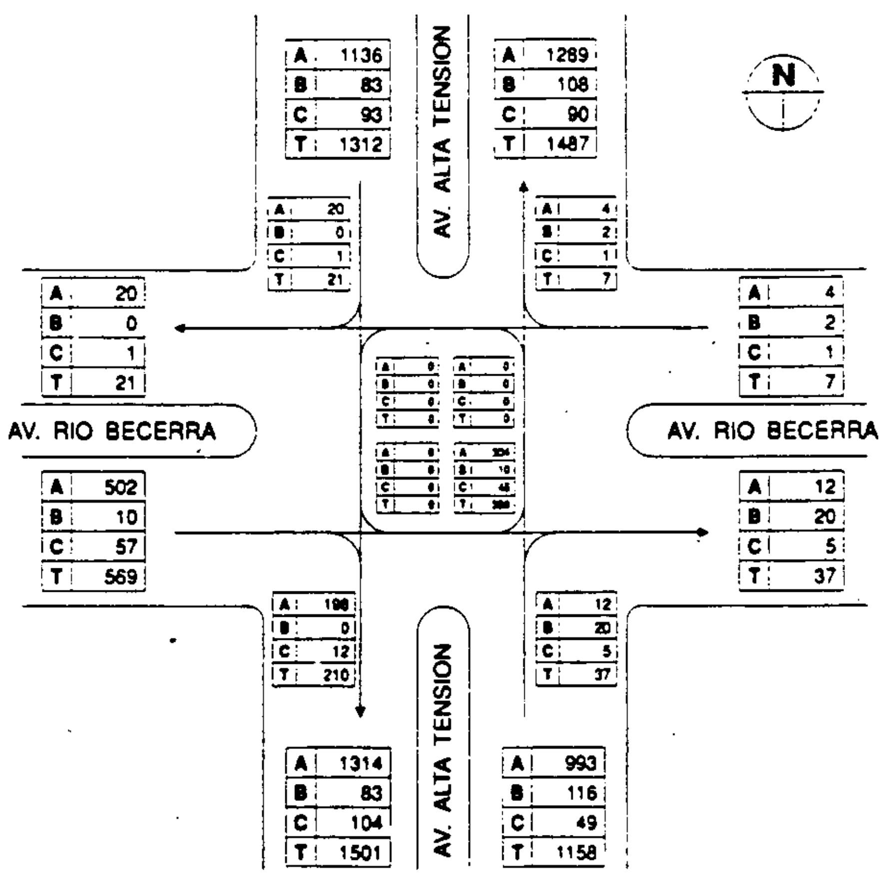
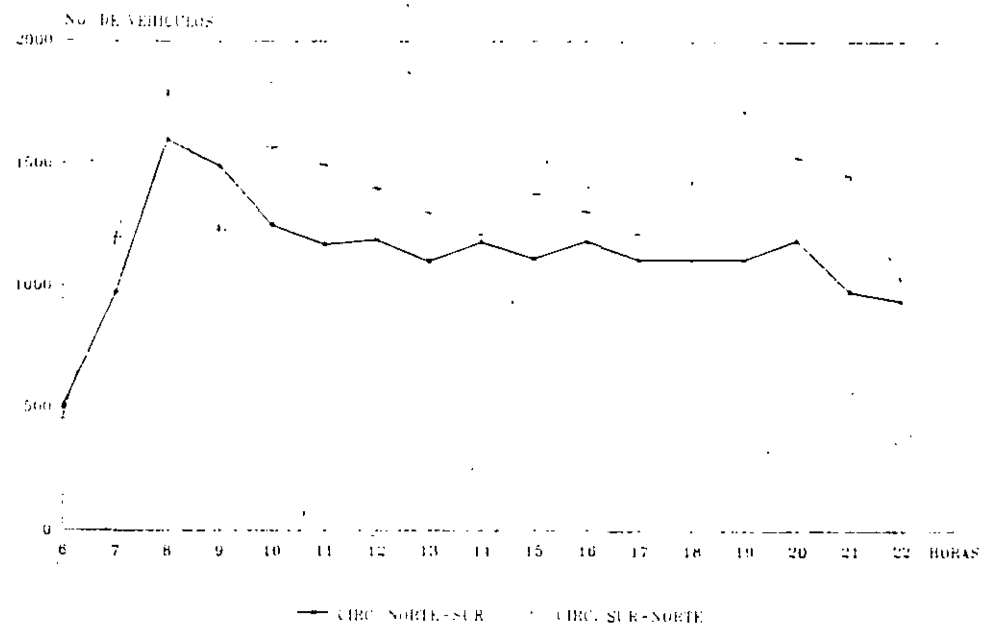


Figura 1.6.1

VARIACION DE VOLUMENES DE TRANSITO
INTERSECCION CALLE 1 Y CALLE 2



CEDULA PARA EL ANALISIS DE CAPACIDAD Y PROGRAMACION DE SEMAFOROS

INTERSECCION ______________________

DELEGACION ______________________

DATOS ______________________

UBICACION ______________________

LONGITUD DEL CICLO ______________________

FACTOR DE HORA MAXIMA ______________________

TASA DE CRECIMIENTO DEL TRANSITO ______________________

TIPO DE CRECIMIENTO ______________________

POBLACION ______________________

EXISTENTE			
FASE A	FASE B	FASE C	FASE D

FASE	ESTACIONAMIENTO	ANCHO DE ACCESO m	% C	%	E	PARADA AUTOBUS	B/AHORA	G/C %	VOL. HOR. MAXIMO	VOLUMEN DE SERVICIO					
										C		D		E	
										No. VEH	AÑO	No. VEH	AÑO	No. VEH	AÑO
A															
B															
C															

FASE	PROGRAMACION							
	VERDE		AMBAR		ROJO		TOTAL	
	%	SEG	%	SEG	%	SEG	%	SEG
A								
B								
C								
D								
E								

OBSERVACIONES : ______________________

CALCULO ______________________ FECHA ______________________

INTERSECCION ______________________________

DELEGACION ______________________ DIA DE LA SEMANA ______________________

COORDENADAS ______________________ FECHA ______________ HORA DE INICIO ______________

CONDICIONES ATMOSFERICAS ______________________ Y DEL PAVIMENTO ______________________

CIRCULACION NORTE-SUR
VUELTA DERECHA

TIEMPO DE OBSERV.		TRANSITO EN EL ACCESO					
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T O T A L							

CIRCULACION SUR-PONIENTE
VUELTA DERECHA

TIEMPO DE OBSERV.		TRANSITO EN EL ACCESO					
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.30	.45						
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T O T A L							
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T O T A L							

OBSERVADOR ______________________________

1.7 Impacto Ambiental

El procedimiento de impacto ambiental es el camino a seguir para llevar a la consecución de un estudio o manifestación de impacto ambiental que permita soportar la toma de decisiones respecto a la autorización o no del proyecto en cuestión.

Manifestación de Impacto Ambiental (MIA)

Se elabora previamente a la ejecución del proyecto y se define como el documento mediante el cual se da a conocer, con base en estudios, el impacto ambiental, significativo y potencial que generaría una obra o actividad, así como la forma de evitarlo o atenuarlo en caso de que sea negativo.

1.7.1 Ambito legal

El procedimiento de impacto ambiental como figura jurídica, es incluido en la Ley General de Equilibrio Ecológico y la Protección al Ambiente (LGEEPA) el 28 de Enero de 1988. La cual hace mención sobre la reglamentación de las disposiciones de la Constitución Política de los Estados Unidos Mexicanos que se refieren a la Preservación y Restauración del Equilibrio Ecológico, así como a la Protección al Ambiente, en el Territorio Nacional y las zonas sobre las que la Nación ejerce su Soberania y Jurisdicción.

1.7.2 Procedimiento de impacto ambiental

Definamos ¿qué es el procedimiento de impacto ambiental?. Es una serie ordenada de pasos que habrán de seguir tanto las autoridades de gobierno como los responsables de la ejecución de una obra o actividad y consultores privados (que contratan estos últimos), la cual se describe en el siguiente cuadro.

Las Manifestaciones de Impacto Ambiental, pueden ser de 4 diferentes grados de profundidad.

- Informe Preventivo
- Modalidad General
- Modalidad Intermedia
- Modalidad Especifica

Estos niveles de profundidad dependen de:

1.- Las caracteristicas de apoyo, su magnitud, extensión, volúmenes de obra y de operación, procesos, materias primas, en insumos a utilizar, riesgo de procesos, etc.

2.- Ubicación del proyecto (caracteristicas del Medio Físico, Biótico, Socioeconómico).

Los estudios de Impacto Ambiental se componen básicamente de:

a) La descripción del proyecto, describiendo:

1.- La Etapa de Planeación
2.- La Etapa de Construcción
3.- La Etapa de Operación
4.- La Etapa de Mantenimiento
5.- Los Proyectos Futuros y Complementarios
6.- La Etapa de abandono.

b) La descripción del Medio

1.- Físico
2 - Biótico
3 - Socioeconómico
4 - Otros factores (Culturales, Políticos, Económicos).

c) Las regulaciones de uso de suelo y la compatibilidad del proyecto con su entorno.

d) La identificación y cuantificación de Impactos Adversos y Benéficos

e) Las medidas de:

- Mitigación
- Compensación

f) Los efectos

- Inevitables
- Irreversibles
- Acumulados
- Indirectos
- Residuales

g) El escenario ambiental modificado.

h) Las conclusiones y recomendaciones.

1.7.3 Metodología de identificación y evaluación del impacto ambiental

Las metodologías de evaluación de impacto ambiental son herramientas que ayudan a la identificación, medida, interpretación, y/o comunicación de los diferentes impactos ambientales que se asocian a un proyecto a actividad que se vaya a realizar en un cierto espacio-tiempo. Su implementación tiene cono finalidad principal la previsión de las posibles afectaciones negativas que puedan surgir en las diferentes fases de un proyecto y la evaluación de las diferentes alternativas del mismo.

Entre las metodologías que más comúnmente se utilizan en esta fase del proceso en esta fase del proceso de E.I.A. se pueden señalar las listas de chequeo, matrices y redes; estas metodologías deben considerar cuatro aspectos básicos:

- Que incluyan todos los aspectos "clave" del ambiente y del proyecto o actividad en cuestión.

- Que sirvan como guías para la búsqueda-generación de información básica del ambiente y del proyecto.

- Que puedan servir para la evaluación de alternativas sobre una base común.

- Que se puedan utilizar en la evaluación de las medidas de mitigación en términos de costo-efectividad, de los diferentes impactos negativos detectados.

Listas de chequeo.- Se pueden utilizar listados de los factores ambientales locales que puedan ser afectados por el proyecto, los cuales por medio de un signo convencional se pueden resaltar, otro tipo de lista puede incluir un cuestionario el cual se llena con las respuestas de la población adyacente, y una variante más de factores ambientales con información relativa a la evaluación medida y predicción de los impactos.

Matrices de Interacción.- Este tipo de matrices muestran generalmente en un eje horizontal, las actividades-acciones del proyecto y en un eje vertical los factores ambientales implicados en la evaluación. La matriz utiliza para identificar impactos al observarse de manera sistemática, las interacciones entre las actividades del proyecto - elementos del medio; si se infiere que componente(s) del medio enlistado, se coloca una marca en el respectivo cuadro de intersección con la cual se va a identificar al impacto.

Después de la identificación del impacto (se puede usar una linea diagonal en el cuadro correspondiente), se puede describir la interacción en términos de magnitud e importancia, entendiéndose la primera en un sentido de extensión o escala y la segunda en términos del efecto (ecológico) en los elementos del medio.

Impactos en las diversas fases del proyecto (preparación del sitio, construcción, operación, etc.). La matriz producida finalmente puede contener a manera de resumen a los diferentes impactos identificados, y a algunas de sus características-categorías nominales tales como impactos: benéficos o adversos; reversibles o irreversibles; reparables o irreparables de corto, mediano o largo plazo; temporales o continuos; locales, regionales o globales; directos o indirectos; sumatorios, sinergísticos o antagónicos, etc. Estos juicios de valor o características se deben establecer con el trabajo de un equipo multidisciplinario en interdisciplina.

Redes.- Se consideran como variantes de las matrices de interacción anteriormente señaladas, mediante estas se intenta integrar las causas y consecuencias de los impactos al identificar y manejar interrelaciones entre acciones causales y factores del ambiente alterados.

Los análisis por medio de redes en la E.I.A., son particularmente útiles para identificar impactos secundarios, terciarios y de orden superior que pueden surgir a partir de un impacto inicial.

Para intentar hacer una evaluación lo más objetiva posible es necesario considerar:

1.- El estudio detallado de las características del medio y su equilibrio dinámico antes de la presión ejercida por el proyecto (estadio cero).

2.- El estudio de la evolución de las características ambientales con la supuesta implementación del proyecto.

3.- El estudio del "eventual" equilibrio tras la operación del proyecto.

Matriz de impacto ambiental

La elaboración de matrices de impacto ambiental es una técnica desarrollada por Leopold y cuya función es identificar los impactos que podría ocasionar la implementación de una obra o actividad.

Las técnicas de análisis son varias y ésta se presenta como ejemplo a ser utilizado por el proponente: su ejecución no es obligatoria ya que, como se ha mencionado para la identificación de impactos en la cual se deja abierta la posibilidad de utilizar la metodología que más se apegue a las características del proyecto.

El primer paso para la elaboración de la matriz consiste en identificar las interacciones existentes, para lo cual se deberán tomar en cuenta todas las acciones necesarias para el desarrollo del proyecto, así como los factores ambientales que puedan resultar afectados para cada una de las acciones previstas.

Su formación se lleva a cabo colocando en columnas (forma vertical) las actividades previstas en las diferentes áreas que puedan sufrir efectos ambientales. Esto puede hacerse sobre un papel cuadriculado de manera que se facilite la intersección de las actividades con las áreas, e identificar en el cuadro respectivo el posible impacto ambiental.

Las alteraciones sobre el medio ambiental pueden ser positiva o negativa y varían en cuanto a la magnitud del mismo. Por lo tanto, en la elaboración de la matriz es importante evaluar qué impacto es más importante que otro; la evaluación de este tipo se lleva a cabo usando técnicas numéricas en donde se aplica una escala de 1 a 10, representando este último la magnitud mayor y el 1 la menor; así como criterios ponderativos en donde se asignan categorías como: significativo, poco significativo, considerable, etc. e incluso el desconocimiento del efecto.

Con el fin de que el proponente elabore la matriz de impacto ambiental a continuación se enlistan una serie de acciones y áreas que podrían verse afectadas, sin que ello implique que se deberán aplicar a todas las acciones mencionadas. Es importante que se elabore la misma, considerando las características propias de cada proyecto, ya que incluso puede darse el caso que el presente listado no incluya efectos peculiares inherentes al proyecto en cuestión.

ETAPA DE SELECCION DEL SITIO

- Prueba de suelo
- Pruebas geológicas
- Pruebas geofisicas
- Pruebas topográficas

ETAPA DE PREPARACION DEL SITIO

- Deslindes
- Limpieza
- Excavaciones/dragado
- Demolición
- Despiedre
- Colocación de escolleras y diques
- Campamentos provisionales
- Maquinaria y equipo
- Almacenamiento
- Emisiones de humos y polvo
- Residuos liquidos
- Recursos humanos
- Desmontes
- Quema
- Nivelaciones/relleno
- Desecación
- Uso de explosivos
- Obras sobre corrientes
- Caminos de acceso
- Servicios
- Puentes provisionales
- Residuos sólidos
- Ruidos
- Otros

ETAPA DE CONSTRUCCION

- Infraestructura
- Bancos de material
- Lineas de transmisión
- Canales, revestimientos de
- Escolleras y diques
- Servicios
- Emplazamientos industriales y de edificios
- Barreras incluyendo vallados
- Modificaciones al drenaje
- Cruce de corrientes

- Estruturas en altamar
- Estruturas industriales
- Recursos humanos
- Requerimiento de energia
- Residuos sólidos
- Ruidos
- Destino final de infraestructura

- Estruturas en altamar
- Túneles y estructuras subterráneas
- Bodega de almacenamiento
- Operación de maquinaria y equipo
- Requerimiento de agua
- Residuos liquidos
- Emisiones de humos y polvos
- Rehabilitación

ETAPA DE OPERACION

- Dragado de mantenimiento
- Requerimiento de energia
- Utilización de recursos naturales del área
- Equipo de transportación
- Desplazamientos del personal
- Servicios
- Manejo y disposición final de residuos líquidos
- Emisiones a la atmósfera
- Fugas y derrames
- Creación de zonas verdes

- Mantenimiento de estructura y equipo
- Requerimiento de agua
- Operación de maquinaria y equipo
- Recursos humanos
- Infraestructura
- Almacenamiento
- Manejo y disposición final de residuos sólidos
- Fallas de operación
- Explosiones accidentales

ACTIVIDADES CONSECUENTES AL PROYECTO

- Comunicaciones y transportes
- Urbanización
- Desarrollo tecnológico
- Reforestación

- Infraestructura
- Desarrollo industrial
- Empleos y recursos humanos

MEDIO NATURAL

AGUA

SUPERFICIAL

- Alteración del lecho
- Flujo
- Características gravimétricas
- Calidad del agua

SUBTERRANEA

- Flujo
- Calidad del agua
- Interacción con la superficie

MARINAS

- Variaciones superficiales
- Calidad del agua
- Variaciones en la batimetria

SUELO

- Características geológicas
- Características topográficas
- Calidad del suelo
- Uso potencial
- Características geomorfológicas
- Asentamientos y compactación
- Uso actual
- Area inundable

ATMOSFERA

- Microclima
- Calidad del aire

PAISAJE

- Cualidades estéticas
- Valor ecológico
- Valor cultural
- Atractivo turístico
- Valor histórico

FLORA TERRESTRE

- Estrato herbáceo
- Estrato arbóreo
- Especies de interés ecológico
- Estrato arbustivo
- Asociaciones vegetales
- Especies de interés comercial

FAUNA TERRESTRE

- Invertebrados
- Aves
- Especies de interés ecológico
- Reptiles
- Mamíferos
- Especies de interés comercial

FAUNA ACUATICA

- Zooplancton
- Peces
- Reptiles
- Mamíferos
- Especies de interés comercial
- Invertebrados
- Anfibios
- Aves
- Especies de interés ecológico

FACTORES SOCIOECONOMICOS

- Tenencia de la tierra
- Empleo y recursos humanos
- Salud pública
- Economia regional
- Infraestructura y servicios públicos
- Educación

- Costumbres y calidad de vida
- Areas de interés científico, cultural o patrimonial
- Pérdida de valores culturales.
- Centros recreativos
- Migración poblacional
- Reubicación poblacional

Monitoreo ambiental y de salud

A. INTRODUCCION

Un tema de creciente importancia dentro de la evaluación de impacto ambiental y salud (EIA) incluye la conducción de estudios de monitoreo ambiental tanto previos como posteriores. El monitoreo ambiental se refiere al grupo de actividades que proporcionan información ambiental química, física, geológica, biológica y otras requeridas por los especialistas en este ramo.

Debido a que se ha adquirido mayor conciencia de la importancia del monitoreo ambiental a lo largo del tiempo de vida de un proyecto, se ha enfatizado la planeación e implantación de programas de monitoreo.

Los componentes incluidos en la amplia definición del monitoreo ambiental abarcan: planeación de recolección de información ambiental que cumpla con los objetivos específicos y con las necesidades de información ambiental; el diseño de sistemas y estudios de monitoreo; la selección de sitios de muestreo; recolección y manejo de muestras; análisis de laboratorio; el almacenamiento y reporte de los datos; el asegurarse de la calidad de los datos; así como el análisis, interpretación y el poner la información al alcance de aquellos que toman las decisiones.

B. DEFINICIONES

Existen varias definiciones de monitoreo. Una de las más ampliamente aceptadas corresponde a la reunión intergubernamental de 1971, preparatorio de la conferencia de Estocolmo de

1972. En esa reunión se definió el monitoreo como "un sistema continuo de información, de mediciones y de evaluaciones para propósitos definidos". El hecho más importante a notar bajo esta definición, es que el monitoreo debe llevarse a cabo para "propósitos definidos". Estos propósitos deben ser vistos dentro del contexto de la administración ambiental.
Existe con frecuencia cierta confusión en cuanto a la diferencia entre monitoreo y vigilancia. En ciertos casos, la vigilancia se toma como el monitoreo llevado a cabo para observar tendencias, más que como apoyo de objetivo administrativo específico. sin embargo, en estudios epidemiológicos, la vigilancia ambiental o de salud, tiene un significado mucho más específico.

Harvey (1981) llevó a cabo una análisis extenso de la terminología usada en relación a monitoreo. Ha demostrado que los términos monitoreo y vigilancia pueden significar cosas bastante distintas para diferentes usuarios. El uso más común aparenta se amplio, abarcando tanto el monitoreo descriptivo, orientado a problemas, como el monitoreo reglamentario.

C. OBJETIVOS DEL MONITOREO

Los principales objetivos que persigue un sistema de monitoreo ambiental, posterior a la implementación del proyecto, incluyen (Marcus, 1979):

1. Proporcionar información para la documentación de los impactos que resultan de una acción propuesta. Con esta información es posible hacer una predicción más confiable de los impactos con otras acciones similares.

2. Advertir a las agencias involucradas y/o al grupo tomados de decisiones, de impactos adversos no anticipados en el estudio de la EIA o de cambios bruscos en las tendencias de los impactos previamente evaluados.

3. Proporcionar un sistema de información inmediato, cuando un indicador de impactos, previamente seleccionado, se acerca a su nivel critico.

4. Proporcionar información para determinar la localización, nivel y tiempo en que se presentan los impactos de un proyecto. Las medidas de control involucran una planificación inicial y, a la posible instrumentación de reglamentos y medidas, para asegurar su cumplimiento.

5. Proporcionar información que pueda usarse para evaluar la efectividad de las medidas de mitigación instrumentadas y para verificar los impactos predichos y, por lo tanto validar, modificar y/o ajustar las técnicas de predicción utilizadas.

D. NIVELES DE MONITOREO

Se pueden cubrir extensiones geográficas diferentes dependiendo de la naturaleza del problema en cuestión y de la jurisdicción, estos niveles pueden ser los siguientes:

- Locales: Se extienden entre 0 y 100 Kilómetros como la contaminación del aire.
- Regionales: Se extiende entre 100 y 1,000 Kilómetros, como la contaminación de ríos.
- Continentales: Se extiende entre 1,000 a 10,000 Kilómetros como la contaminación del mar.
- Globales: Se extienden más de 10,000 Kilómetros como el calentamiento de la atmósfera por la acumulación de monóxido de carbono y otros gases.

E. PERIODOS DE MONITOREO

Una característica del ambiente es una variabilidad en espacio y tiempo y esto con frecuencia dificulta separar, los diferentes procesos que pueden estar funcionando, cada uno con sus propia escala de tiempo y variación. Probablemente el ejemplo menos comprendido y el más complejo sea el de la evaluación de los cambios climáticos. Existe un número de ciclos en operación: estacional, anual, manchas solares, cambios en el campo magnético, etc.

Tomando en cuanta algunos de los aspectos mencionados y las etapas de desarrollo de un proyecto podemos diferenciar los siguientes periodos de monitoreo dentro de una EIA.

- Previo a la construcción del proyecto
- Durante la etapa de construcción y montaje de equipo
- Mientras se opera y mantiene la obra
- Posterior a la vida útil del proyecto

F. CLASES DE MONITOREO

Varias clases de monitoreo ambiental y de la salud se han estado poniendo en práctica entre ellas se mencionan las siguientes:

- Monitoreo de identificación
- Monitoreo de asociación
- Monitoreo de trayectoria
- Monitoreo de exposición
  * de alimentos
  * al agua potable
  * a la contaminación del aire
  * de la piel
  * de objetivos (órgano blanco).

G. TIPOS DE MONITOREO

Dentro de los tipos de monitoreo se incluyen los vínculos a las fuentes de contaminación del ambiente físico y del natural.

- Monitoreo de fuentes de contaminación
  * Monitoreo de emisión
  * Monitoreo de proceso

- Monitoreo biológico
- Monitoreo Organismos bioaculadores

H. PLANIFICACION DEL MONITOREO EN UNA EIA

El monitoreo descriptivo que apoya la identificación y estimación, de riesgos o impactos, se encuentra en una etapa relativamente temprana de su desarrollo y se requieren esfuerzos de importancia para asegurar el progreso en esta área.

Para planificar el monitoreo dentro de la EIA, se recomienda tomar en cuenta las siguientes situaciones y acciones:

- Recopilación de diversidad de datos provenientes del monitoreo ambiental, recolectados en forma rutinaria por parte de agencia gubernamentales y por el sector privado. Estos datos necesitan ser identificados, compilados e interpretados.

- Como los programas de monitoreo ambiental son costosos, debe hacerse el esfuerzo por utilizar programas de monitoreo existentes y modificarlos apropiadamente.

- Debido a la superposición de responsabilidades en muchas agencias gubernamentales, en cuanto al manejo y monitoreo ambientales, resulta necesario coordinar la planificación del monitoreo ambiental.

- Una necesidad básica en programas de monitoreo ambiental, es la interpretación científica de la información recolectada. Frecuentemente la información se compila pero nunca se interpreta en relación a la calidad del ambiente sujeto a monitoreo.

- Nunca se podrá recopilar la suficiente información para responder a todas las preguntas que puedan presentarse en un programa de monitoreo ambiental. Es necesario extender, por lo tanto, los datos del monitoreo por medio del juicio profesional.

- También debe definirse con anticipación quienes serán los responsables en llevar a cabo el programa de monitoreo elaborado.

PREDICCION DE BASURAS Y ESPACIO PARA RELLENO SANITARIO PARA EL MUNICIPIO DE "EJEMPLO"

ANO	HABIT.	K/H/D	COBERT	T/D	M3/ANO	M3 ACUM.
1993	650,000	0.90	0.60	351	136,013	136,013
1994	666,250	0.91	0.65	394	152,541	288,553
1995	682,906	0.92	0.70	439	170,065	458,619
1996	699,979	0.93	0.75	487	188,636	647,255
1997	717,478	0.94	0.80	538	208,304	855,559
1998	735,415	0.95	0.85	591	229,125	1,084,684
1999	753,801	0.96	0.90	648	251,155	1,335,839
2000	772,646	0.96	0.90	671	260,008	1,595,847
2001	791,962	0.97	0.90	695	269,173	1,865,020
2002	811,761	0.98	0.90	719	278,662	2,143,682
2003	832,055	0.99	0.90	744	288,484	2,432,167
2004	852,856	1.00	0.90	771	298,654	2,730,820
2005	874,178	1.01	0.90	798	309,181	3,040,001
2006	896,032	1.02	0.90	826	320,080	3,360,081
2007	918,433	1.03	0.90	855	331,363	3,691,444
					3,691,444	

NOTAS:
1. SE SUPONE UNA POBLACION METROPOLITANA DE 650.000 HAB EN 1993.
2. SE SUPONE UNA GENERACION PER CAPITA PROMEDIO DE 0,9 K/D, CRECIENTE EN 1% ANUAL.
3. SE SUPONE UNA COBERTURA PROMEDIO DE 60%, CRECIENTE EN UN 5% ANUAL HASTA ALCANZAR UN 90%.
4. SE SUPONE QUE LA DENSIDAD DE LA BASURA EN EL RELLENO ALCANZA 0,8 T/M3.

Section 12

PUBLIC PARTICIPATION

12.1. INTRODUCTION

Recent developments and trends have made the public realize that its well-being is intimately tied to the quality of the environment, and that attaining and maintaining a quality compatible with its well-being requires the elimination of all offenses to the environment. One of the serious offenses is the indiscriminate disposal of society's wastes. Because the environment has such an important bearing on the public's well-being, and indiscriminate waste disposal is detrimental to environmental quality, it is beginning to demand a more active role in waste management. As a consequence, the public has significantly expanded its formerly negligible role in decision-making regarding landfills, as well as other waste management facilities. Consequently, attention is being given to the exploration, adaptation, and adoption of public involvement mechanisms and activities. Ideally, therefore, a public participation program should be established to actively involve citizens in all phases of developing publicly owned or operated landfills, including site selection, design, operation, completion, and use after closure.

Some social and political structures may not allow or be accustomed to the active participation of the public in the decision making process. Institutionally, many LDCs are not organized for active public involvement. Nevertheless, it is recommended that the public take part in the landfill development process or at the very least by kept well-informed of the plans. Uninformed groups can disrupt the development of waste management facilities (i.e., transfer stations and landfills) which can have severe negative impacts on the overall waste management system.

12.1.1. Definition and Principles of Public Participation

Public participation can be best explained, and perhaps even be defined by describing the relation between public attitude and public manifestation of its attitude. The relationship is diagrammed in Figure 12-1. In part A of the figure, the gradation of attitude from one extreme to another (i.e., from antipathy through neutrality to favorable (desirable)), is separated by the horizontal line from the corresponding gradation of manifestation (i.e., from opposition through indifference to promotion). The close interrelation between the gradations is indicated by connecting (broken line) arrows. The relation between attitude and manifestation is further illustrated in parts B and C of the figure. As illustrated in part B, there is a direct relationship between opposition and antipathy. In part C, promotion is also shown to be directly related to favorable.

From the relationships diagrammed in the three parts of the figure, it appears that an effective way of securing public participation in a landfill project is to prevent the development of antipathy to the project. Any existing antipathy should be dissipated. On the other hand, only removing antipathy is not enough, inasmuch as it would merely be replaced by the intermediate stage, indifference or disinterest. Although with regard to a landfill project, indifference or disinterest would mean no opposition, it would also mean no positive input for bringing the project to fruition. It is at this point that motivation and incentive come into play. They constitute the moving force needed for advancing public attitude to the favorable level. If its attitude towards the landfill project is favorable, the public is willing to provide the input necessary for the success of the project.

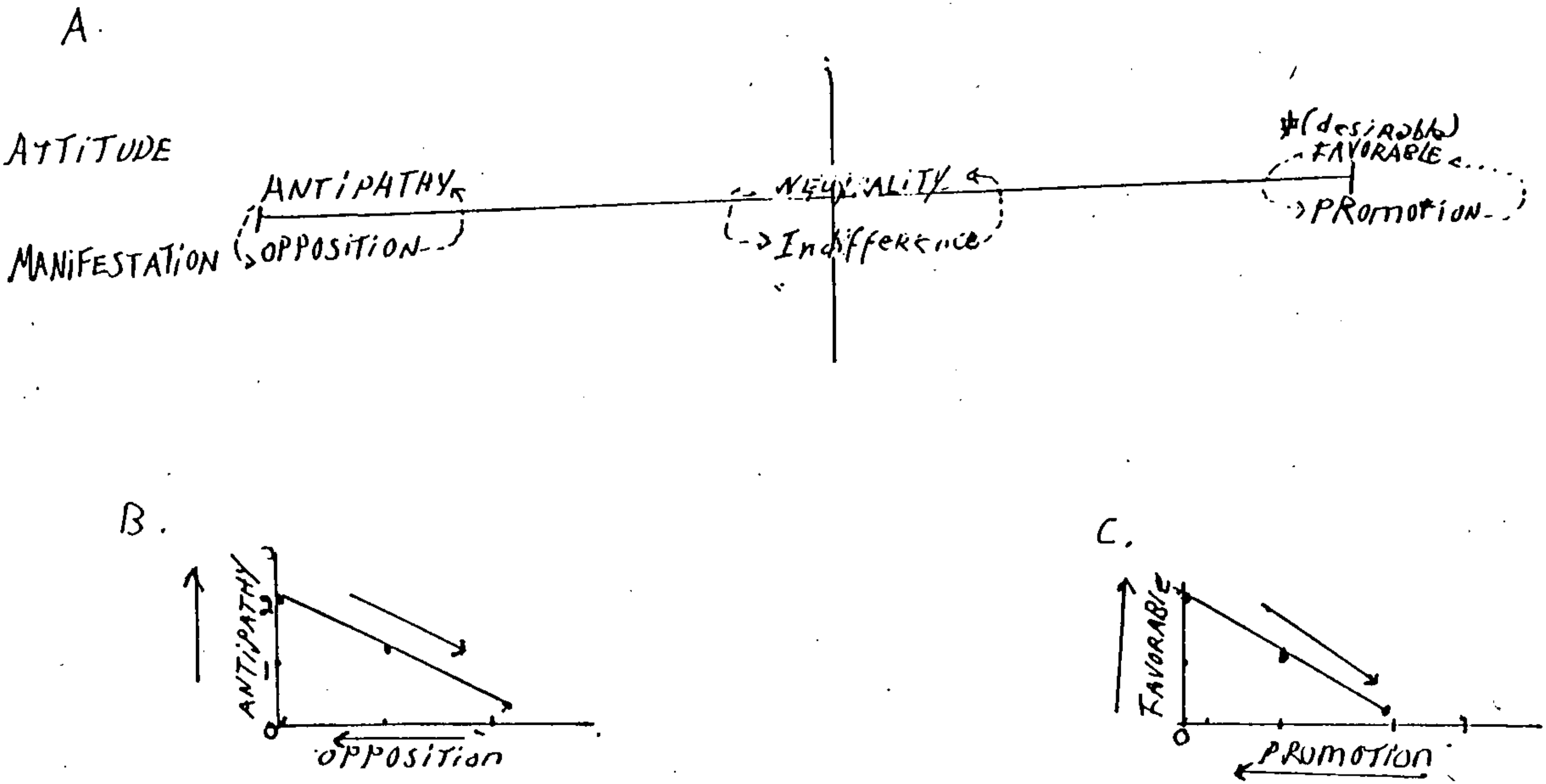
Although the presentation that follows is geared to developing countries, much of it is also applicable to developed countries.

12.1.2. Dissipation of Antipathy

In this section, the "public" is divided into three groups entirely on the basis of position in the economic hierarchy and relative influence on decision-making regarding public undertakings – specifically those concerned with solid waste disposal. The three groups are:

- Financially Distressed (the Poor or Impoverished)
- Middle (Intermediate)

Fig. 12.1 Relation between Public ~~Participation~~ attitude & manifestation



- Financially Secure (Moneyed, Wealthy)

We emphasize that our division has no implication regarding importance to or in the social fabric. For convenience of presentation in the discussion that follows we refer to the first class as "The Poor", the second class as "Middle", and the third class alternatively as the "Wealthy" and the "Moneyed".

12.1.2.1. Financially Distressed

Of necessity, survival is the major concern of the poor. Consequently, any perceived threat to survival arouses antipathy to the source of that threat. The threat may be in the form of an increase in danger to life and limb, a serious hazard to health, and/or a loss or diminution of livelihood and essential living space. Thus any undertaking, existing or proposed, can arouse antipathy if it is perceived as constituting one or more of these threats.

The threat perceived in a landfill operation is not so much against life and limb, as it is against means of livelihood, essential living space, and possibly, health.

Loss of Livelihood – For individuals whose principal means of livelihood is scavenging, another landfill is a threat, and hence cause of antipathy, if it eliminates or even curtails scavenging in any way other than to regulate it. The obvious way to remove that cause is twofold:

- Do not prohibit scavenging at the site other than to confine it to a designated area and impose regulations needed to ensure accident prevention and prevent interference with the efficient operation of the fill (Section 5.2).
- Assure the scavengers that aside from the regulation needed to protect the safety of the workers and the public-at-large and to efficiently operate the fill, no steps will be taken to eliminate scavenging.

It may be difficult to dispel the suspicion almost universally held by the general public regarding governmental regulations. Suspicion can be dispelled by showing the scavengers the plans and designs, and/or requesting input from their leaders. Word of that assurance can be spread by word-of mouth, by way of scavenger associations, contractors, and others in the industry,

CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

DETERMINACION DE PARAMETROS DE DISEÑO PARA LATINOAMERICA

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PALACIO DE MINERIA, MEXICO D.F. 14-19 Marzo de 1994

1. GENERALIDADES

No obstante la importancia que en todo el mundo han cobrado los asuntos ecológico-ambientales; y a pesar de la mayor utilización que en la última década, el relleno sanitario ha tenido en América Latina como método de disposición final de residuos sólidos; el "tiradero a cielo abierto", sigue siendo la forma más común de disponer los residuos sólidos, como informa la Oficina Panamericana Sanitaria dependiente de la Organización Mundial de la Salud (OPS/OMS), la cual reporta que únicamente el 30% de la basura generada en América Latina, se dispone sanitariamente (alrededor de 75,000 Ton./día) (1). Así mismo, con base en un estudio realizado en 17 ciudades de esta región con más de un millón de habitantes, señala que tan sólo el 35% de la basura generada, se dispone en rellenos sanitarios de buena calidad, el resto se dispone en sitios controlados y en tiraderos a cielo abierto (1). Sin embargo, a pesar de cifras tan poco alentadoras, se debe mencionar que para la misma región de Latinoamérica, dicho organismo reporta para la década 1980-1990 un avance sustancial en la utilización del relleno sanitario (2), aún cuando se haya dado mayormente en las grandes concentraciones urbanas.

Por otro lado, en países con mayores recursos, problemáticas ambientales diferentes y con niveles tecnológicos mucho más desarrollados; el relleno sanitario, sigue siendo un elemento fundamental en sus sistemas de control de residuos sólidos, como lo demuestran las cifras de la Tabla No. 1, donde se observan las tendencias de utilización que en países con alto desarrollo en el manejo de los residuos sólidos, tienen las diferentes alternativas de tratamiento para el aprovechamiento de estos residuos, en relación con el uso del relleno sanitario.

TABLA No. 1

TENDENCIAS DE UTILIZACION DEL RELLENO SANITARIO Y DE LAS TECNICAS MAS COMUNES PARA EL APROVECHAMIENTO DE RESIDUOS SOLIDOS, EN PAISES CON ALTO DESARROLLO EN MATERIA ABIENTAL

PAIS	RELLENO SANITARIO	OPCIONES DE APROVECAMIENTO DE LOS RESIDUOS SOLIDOS				COMENTARIOS
		INCINERACION	COMPOSTEO	RECICLAJE	OTRO	
E.U.A.	73 %	14 %	1 %	12 %	——	ALTA DEMANDA DEL RELLENO SANITARIO.
JAPON	27 %	25 %	2 %	46 %	——	GRAN PARTE % DEL RECICLO SE UTILIZA PARA INCINERACION. SE INCLUYE EN RECICLAJE ESCOMBROS Y OTROS MATERIALES.
ALEMANIA	52 %	30 %	3 %	15 %	——	UTILIZACION IMPORTANTE DEL RELLENO SANITARIO Y ELEVADO % DE RECICLO
FRANCIA	48 %	40 %	10 %	<3 %	——	IMPORTANTE UTILIZACION DE COMPOSTA E INCINERACION
SUECIA	40 %	52 %	5 %	<4 %	——	INTENSIVA UTILIZACION DE LA INCINERACION

REF.: (2), (3) y (4)

Con base en las cifras de la Tabla No. 1, se pueden establecer los siguientes comentarios:

a) El relleno sanitario es todavía utilizado en Francia, el cual tal vez sea el único país donde el composteo ha encontrado su mejor y más importante utilización; y en donde la incineración es una práctica importante para el tratamiento de los residuos.

b) En Japón y Suecia, países líderes en el empleo de la incineración de residuos sólidos para generación de energía eléctrica, el relleno sanitario es todavía utilizado.

c) En países considerados "Campeones del Reciclaje", como son Alemania y E.U.A., es curiosamente donde el relleno sanitario tiene un altísimo porcentaje de utilización.

Considerando los comentarios antes señalados, queda claro que un relleno sanitario, es obra de ingeniería no exclusiva de países altamente tecnificados, ni dependientes de economías bien desarrolladas; por otro lado, es posible conjugarlo sin ningún problema con las diferentes alternativas de tratamiento que existen en la actualidad. Por consiguiente, es posible concluir que lejos de que la utilización del relleno sanitario haya entrado en decadencia, o que esté siendo sustituido por las distintas alternativas de tratamiento empleadas en la actualidad; se debe considerar como una infraestructura que puede ser compatible con cualquier esquema de control de residuos sólidos, propia de países en vías de desarrollo, o con alto nivel de tecnificación y desarrollo.

Ahora bien, considerando la variación de las características que presentan los residuos sólidos según sea la fuente que los genera; a partir de su composición, se definirá la vocación o el tipo de aprovechamiento que deben dárseles. Es decir, sería muy costoso y poco racional incinerar la basura de mercados, mientras que los residuos generados en tiendas de autoservicio donde abunda el plástico, el papel y el cartón, no son los más adecuados para la fabricación de composta. Lo anterior invita a establecer un sistema integral para el adecuado control de los residuos sólidos, donde se conjuguen las alternativas de tratamiento más adecuadas para los tipos de basura que se generen, puesto que es racionalmente imposible, que una sola opción de tratamiento se aplique por igual a los diferentes tipos de residuos sólidos. Partiendo de este concepto, se puede afirmar que el relleno sanitario viene a ser la columna vertebral de cualquier sistema, ya que por cuestiones de diversa índole, no siempre es viable la implementación de todas las alternativas de tratamiento que se requieren, por lo que se deberá contar con un sitio que reciba aquellos excedentes de residuos que no sea posible darles algún tratamiento para su aprovechamiento, amén de que las propias opciones de tratamiento que se apliquen, siempre generarán un cierto rechazo que también deberá ser dispuesto; de manera tal que el contar con un relleno sanitario, permitirá ordenar paulatinamente los sistemas de control de residuos, hasta el nivel de organización que se pretenda alcanzar, ya que siempre se tendrá un sitio para recibir todo aquel residuo que no pueda ser manejado de otra manera.

Tomando en cuenta todo lo antes comentado, en el futuro, el relleno sanitario será vital para el ordenamiento de los sistemas de control de residuos sólidos; por lo que para su aceptación plena por la población en general y las agrupaciones civiles, quienes normalmente son sus principales detractores, debe contemplarse no como un sitio que genere problemas de contaminación ambiental, sino como una instalación controlada que confine tanto al biogás como a los lixiviados, para que no puedan migrar más allá de su vecindad, buscando siempre mejorar su funcionalidad operativa y aprovechar el combustible que genera acelerando su estabilización. Es por todo esto, que cualquier relleno sanitario deberá contar con los sistemas operacionales y con los mecanismos y dispositivos de control que le permitan operar en forma segura y adecuada, evitando alterar su entorno, contaminar el ambiente o dañar la salud pública en general; amén de crear entre la población, una percepción favorable y por ende una buena opinión de la función que cumple un relleno sanitario.

2. CRITERIOS RECTORES PARA UN DISEÑO ADECUADO Y UNA RACIONAL FUNCIONALIDAD DEL RELLENO SANITARIO

La buena o mala operación de un relleno sanitario, depende de las medidas de control que se estén aplicando, amén de ser en muchos casos indicador del nivel de afectación ambiental con el que se esté deteriorando la vecindad del sitio. Por tanto, para evitar o disminuir la alteración que los impactantes generados en un relleno sanitario puedan tener sobre su entorno, es imprescindible aplicar en las diferentes etapas que demanda el emplazamiento de este tipo de obras, una serie de criterios rectores cuyo objetivo fundamental sea prevenir la contaminación por residuos sólidos. Estos criterios, deben establecer el sendero por donde debe dirigirse el diseño, la funcionalidad conceptual y los programas de control y monitoreo que necesita un relleno sanitario para operar adecuadamente.

Para el diseño, los criterios rectores que deben cumplirse son los siguientes:

- Definición de las secciones más adecuadas para la preparación del sitio, que aseguren una mínima estabilidad en las zonas más críticas.
- Considerar en el diseño, el tipo de impermeabilización más adecuado para la base y las paredes del sitio.
- Determinación de la capacidad de campo de los residuos sólidos por disponer.
- Cálculo de la producción de lixiviados (potencial y real).
- Cálculo de las necesidades de agua para la estabilización vía anaerobia de los residuos.
- Estimación de la producción de biogás.
- Determinación de los gastos de diseño de los escurrimientos pluviales, para el dimensionamiento de la infraestructura hidráulica necesaria para su manejo.

Tomando en cuenta que la aplicación de los "CRITERIOS RECTORES" antes señalados, son el camino más viable para propiciar una urgente mejoría en la tecnología aplicada actualmente para el diseño y operación de rellenos sanitarios; se debe iniciar la implementación de tales criterios, justamente a partir de la fase de planeación y diseño, para que tengan continuidad en la operación y también durante el monitoreo ambiental.

Ahora bien, considerando que los impactantes de mayor riesgo que puede generar un relleno sanitario, son el "biogás" y los "lixiviados", cobran mayor importancia los Criterios Rectores que dentro del diseño se refieren al control de tales impactantes. Por esta razón a continuación se describen los Lineamientos Técnicos más significativos que deben ser tomados en cuenta en el diseño del relleno sanitario. Estos Lineamientos se presentan en dos vertientes, una que se refiere a la Estimación de parámetros para la medición de estos impactantes; y la otra que establece las recomendaciones de más importancia para el diseño de los sistemas de impermeabilización necesarios para mantener confinados dichos impactantes, dentro del relleno sanitario.

A) DETERMINACION DE PARAMETROS BASICOS DE DISEÑO.

a) Cálculo de la Capacidad de Campo de los Residuos Sólidos.

La capacidad de campo se define como la cantidad de agua que pueden retener o absorber los residuos sólidos antes de lixiviarla. Para la determinación de la capacidad de campo experimentalmente, los residuos sólidos por disponer en el relleno deberán empacarse dentro de un lisímetro, compactándolos en capas hasta alcanzar el peso volumétrico deseado. A continuación se agrega agua al lisímetro hasta alcanzar el nivel superior de los residuos ya compactados, con el fin de saturar su capacidad de absorción. Después se realiza un drenado del lisímetro, hasta que se alcance un escurrimiento mínimo, lo cual ocurre normalmente hasta después de 48 horas de drenado.

La capacidad de campo de los residuos sólidos, se determinará entonces mediante el empleo de la siguiente expresión:

$$C = \left[\frac{(H/100 * V_1 * PV_1) + (Si - Di) * d}{V_1 * PV_1 * (1 - (H/100))} \right] * F \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{ec. (1)}$$

Donde:

C: Capacidad de campo de los residuos sólidos, (% de humedad/base seca).

H: Humedad de los residuos sólidos antes de realizar la determinación de la capacidad de campo, (% en peso).

PV_1: Peso volumétrico de los residuos empacados al inicio de la experimentación, (Kg/l).

Si: Volumen de agua de saturación del lisímetro, (litros).

Di: Volumen de agua drenada del lisímetro, (litros).

V_1: Volumen ocupado por los residuos sólidos compactados dentro del lisímetro, (litros).

d: Densidad del agua, (Kg/l).

F: Factor de ajuste de la capacidad de campo, debido a la disminución que en algunos casos puede sufrir este parámetro, por efecto de la compactación de la basura en el relleno sanitario. En ocasiones este factor puede despreciarse cuando la humedad y contenido de materia orgánica no son representativos. Aunque hay experiencias en Latinoamérica donde se ha observado que la capacidad de campo disminuyó por efecto de la compactación en el relleno sanitario hasta en un 30%, debido a que la basura generada en esta gran región, presenta un contenido importante de materia orgánica y un alto % de humedad.

b) Cálculo de las Necesidades de Agua para la Estabilización Vía Anaerobia de los Residuos.

No se consideró en este análisis, la humedad generada por la descomposición anaerobia que se da al inicio de la biodegradación, debido a que el porcentaje de materia orgánica que se llega a estabilizar es menor al 1%.

Para el cálculo de la humedad requerida para llevar a cabo la descomposición anaerobia de los residuos sólidos, es necesario considerar la reacción estequiométrica siguiente:

$$CaHbOcNd+(4a-b-2c+3c)/4H_2O \longrightarrow (4a+b-2c-3d)/8CH_4+$$
$$+(4a-b+2c+3d)/8CO_2+dNH_3 \quad \ldots \quad ec.\ (2)$$

Para balancear esta ecuación, se considerarán los coeficientes incluidos en la Ref. No. 1, los cuales se listan a continuación:

C = 43.02 %
H = 5.96 %
O = 49.09 %
N = 1.93 %

Tomando al carbono como base, se obtienen los siguientes coeficientes relativos:

C = 1
H = 1.66
O = 0.86
N = 0.038

Afectando la ecuación No. 2 por los coeficientes anteriores, se tiene:

$$CH(1.66)O(0.86)N(0.04)+(0.19)H_2O \longrightarrow (0.52)CO_2+$$
$$+(0.48)CH_4+(0.04)NH_3 \quad \ldots \quad ec.\ (3)$$

De esta ecuación No. 3, se obtuvo la siguiente relación entre el "CHON" y las necesidades de agua para el proceso anaerobio:

$$Ro = \frac{(0.19)H_2O}{CH(1.66)+O(0.86)+N(0.04)} = \frac{3.42}{27.98}$$

$Ro = 0.122$

$Ro_1 = Ro/k$

Donde:

k: % de materia organica en base seca contenida en los residuos.

Por otro lado, la fracción de materia orgánica en base seca, contenida en la basura está dada por la siguiente expresión:

$$MO = \left[(M/100*PV*V)-(PV*V*H*0.8/100))*(1-(z/100))\right] \quad \text{ec. (4)}$$

Ro: Requerimientos de agua para la degradación de los residuos sólidos.

Ro_1: Requerimientos de agua para la degradación de la materia orgánica en base seca contenida en los residuos sólidos.

Donde:

M: Fracción orgánica presente en la basura, (% en peso).

PV: Peso volumétrico de los residuos sólidos en el relleno sanitario, ($Ton./m^3$).

V: Volumen unitario de relleno sanitario, ($1\ m^3$).

H: Humedad propia de los residuos sólidos, (% en peso).

Z: Fracción de cenizas contenida en la Mat. orgánica en Base seca, (% en peso).

MO: Materia orgánica en base seca, contenida en $1\ m^3$ de basura.

Considerando la relación "Ro_1", así como la ecuación No. 4, la cantidad de humedad necesaria para la digestión anaerobia, se describe a continuación:

$$H_i = [MO] * [Ro_i] \quad \text{.......... ec (5)}$$

[Ton. M. orgánica en base seca contenida en 1 m³ de basura] [Ton. de H_2O requerida para degradar 1 Ton. de M. orgánica en base seca.]

$$H' = H_i / d \quad \text{.......... ec (6)}$$

Donde:

H_i: Toneladas de H_2O, para degradar la materia orgánica en base seca contenida en 1 m^3 de basura.

H': m^3 de H_2O, para degradar la materia orgánica en base seca presenta 1 m^3 de basura.

d: Densidad del agua, (Ton./m^3).

c) Cálculo de la Humedad Lixiviable Proveniente de la Precipitación Pluvial.

Este parámetro, podrá obtenerse mediante la aplicación del Método de Balance de Agua desarrollado por C.W. Thornthwaite, según se describe a continuación:

c.1) Determinación de las Evapotranspiraciones Potenciales Corregidas.

Se determinarán mensualmente, a partir de las temperaturas mensuales promedio, empleando para ello la siguiente formulación:

$$EPj = 1.6\ (10\ Tj/I)^{a} \quad \text{.......... ec. (7)}$$

$$ij = (Tj/5)^{1.514} \quad \text{.......... ec. (8)}$$

$$I = \sum_{j=i} ij \qquad \text{ec. (9)}$$

$$\alpha = 0.49239 + 1{,}792 * 10E - 05\ (I) - 771 * 10E - 07\ (I^2) + 675 * 10E - 09\ (I^3) \qquad \text{ec. (10)}$$

Donde:

EPj: Evapotranspiración potencial mensual sin corregir, (mm).

Tj: Temperatura media mensual, (°C).

I: Sumatoria de los índices mensuales de calor, (adimensional).

ij: Indice mensual de calor (adimensional).

α: Coeficiente que está en función de la sumatoria de los índices mensuales de calor (adimensional).

j: No. del mes considerado.

Los valores de "EPj" calculados para cada mes, se corrigen por medio de un coeficiente mensual "K", que toma en cuenta el número de días y el número real de horas entre la salida y la puesta del sol.

c.2) Cálculo de la Humedad Potencial de Infiltración.

También se hará mensualmente, realizando el siguiente balance, para cada uno de los meses del año:

$$IPj = Pj - (CEj * Pj) - EPj \qquad \text{ec. (11)}$$

Donde:

IPj: Humedad potencial de infiltración mensual, (mm).

Pj : Precipitación media mensual, (mm).

CEj: Coeficiente de escurrimiento mensual (Adimensional).

c.3) Establecimiento del Balance de Agua.

Se realizará a lo largo de los meses del año, para la cubierta diaria del relleno sanitario, a partir de las siguientes consideraciones:

- Cuando la precipitación mensual es igual o superior a la evapotranspiración potencial mensual, se producirá un exceso en el aporte de agua a la cubierta de suelo, exceso que al ser absorbido, alimentará la reserva de agua almacenada por el mismo suelo.

- Si la altura de precipitación mensual es inferior a la evapotranspiración potencial mensual, sucederá que la evapotranspiración real, consumirá totalmente la precipitación, generándose por tanto, un cierto déficit el cual es cubierto con las reservas de agua del suelo hasta su agotamiento. Si la reserva del suelo es suficiente para satisfacer dicho déficit, la evapotranspiración real será igual a la evapotranspiración potencial, por lo que se cae dentro de la consideración anterior; mientras que si por el contrario, la reserva de suelo resulta ser insuficiente, entonces la evapotranspiración real queda ligada a las precipitaciones mensuales, agotándose las reservas de suelo y estableciéndose por tanto, un déficit en el almacenamiento de agua en el suelo.

El parámetro resultante de este análisis, se expresa en los siguientes términos:

$$W = \left[\text{mm } H_2O \text{ / año} \right] \qquad \text{ec. (12)}$$

d) Cálculo de la Producción de Lixiviados.

Este cálculo se realiza básicamente a partir de la tasa de humedad lixiviable proveniente de la precipitación pluvial, la cual se obtendrá a partir del balance descrito en el inciso anterior.

De acuerdo con lo anterior, se tendrá:

$$L = [\ SU * W * 10\ ] \quad \text{ec. (13)}$$

Donde:

SU: Superficie del relleno sanitario expuesta a la lluvia, (Has.).

W: Humedad lixiviable proveniente de la precipitación pluvial, (mm/año).

L: Producción anual total de lixiviados (m^3 H_2O/año).

La expresión anterior No. 13, se aplicará cuando la basura haya sido totalmente degradada y cuado la capacidad de campo de la masa de residuos haya sido agotada, por lo que cualquier cantidad de agua que penetre a la masa de basura, se infiltrará sin que sea retenida por esta última, hasta aparecer en el fondo del relleno sanitario. Cuando no se de la condición de estabilización total de los residuos sólidos, la expresión No. 13, tomará la forma siguiente:

$$L' = L - \left\{ \sum_{i=1}^{n} \sum_{j=1}^{m} \left\{ Pij * ((M/100)-(H*0.8/100))* * (1-(z/100)) * Ro/d * Fij \right\}\right\} \quad \text{ec. (14)}$$

Donde:

$P_{ij} = [PV * (S_i * 1000 * E_j)]$: Factor para identificar las secciones constructivas del relleno sanitario.

S_i: Superficie de la Etapa "i" del relleno sanitario, expuesta a la lluvia, (Has.).

E_j: Espesor de la capa "j" del relleno sanitario, (m.).

F_{ij}: Porcentaje que engloba el remanente de materia orgánica por estabilizar, que se halla en la fracción "i,j" del relleno sanitario. (Decimales).

L': Producción anual total de lixiviados, (m^3 H_2O/año), para cuando el relleno sanitario no está totalmente estabilizado.

e) Determinación del tiempo en que aparecerá el lixiviado.

Para este cálculo, se hará un balance de los siguientes parámetros: capacidad de campo de los residuos, humedad propia de los residuos, humedad para la degradación anaerobia y humedad lixiviable debida a la precipitación pluvial.

$$\text{TIEMPO EN QUE APARECERA LIXIVIADO (T)} = \frac{\left[\begin{array}{c}\text{CAPACIDAD DE CAMPO DE LA BASURA (CC)}\end{array} - \begin{array}{c}\text{HUMEDAD PROPIA DE LA BASURA (HB)}\end{array} + \begin{array}{c}\text{HUMEDAD PARA DEGRADACION ANAEROBIA (HD)}\end{array}\right]}{\left[\text{HUMEDAD LIXIVIABLE (HL)}\right]}$$

Desarrollando cada uno de los términos indicados, se tendrá:

$$\text{CAPACIDAD DE CAMPO DE LA BASURA (CC)} = \left[PV*A*(1-(H/100))*C \right] \text{; en (Ton. } H_2O/\text{ m. basura)}$$

$$\text{HUMEDAD PROPIA DE LA BASURA (HB)} = \left[PV*A*H/100 \right] \text{; en (Ton. } H_2O/\text{m. basura)}$$

HUMEDAD PARA DEGRADACION ANAEROBIA (HD) = [PV*A*((M/100)-(H*0.8/100))*(1-(Z/100))*Ro], en (Ton H_2O/m. basura)

HUMEDAD LIXIVIABLE (HL) = [W/1000*A]; en (m^3 H_2O/año)

Donde:

A: Superficie unitaria de relleno sanitario, (1 m^2)

Agrupando los términos se llega a la siguiente expresión:

$$T = [(CC - HB + HD) / HL] \quad \text{ec. (15)}$$

Por tanto, [T] estará dado en (años/m. Basura), ya que nos indicará el tiempo que le tomará al lixiviado recorrer un espesor de 1m. de basura.

f) Estimación de la Producción de Biogás.

Para determinar la cantidad de biogás que se genera por la descomposición anaerobia de los residuos sólidos, se debe utilizar la reacción estequiométrica ya balanceada identificada como ecuación No. 3, la cual describe dicho proceso de descomposición. De dicha ecuación, se obtienen las siguientes relaciones entre el "CHON" y los principales subproductos generados a partir de la reacción.

- Relación para el metano.

$$R_1 = \frac{(0.48)\ CH_4}{CH(1.66)+O(0.86)+N(0.04)} = \frac{7.68}{27.98} = 0.275$$

- Relación para el bióxido de carbono

$$R_2 = \frac{(0.52)\ CO_2}{27.98} = \frac{22.88}{27.98} = 0.818$$

Con base en estas relaciones, la expresión para el cálculo de los volúmenes de metano (CH_4) y bióxido de carbono (CO_2) contenidos en el biogás, se desarrolla a continuación:

B_{CH_4} = [MO] * [R_1] . . . . ec. (16)

{Ton. Mat. orgánica en Base Seca que contiene 1 m^3 de Basura} {Ton. CH_4 producido por 1 Ton. de Mat. Orgánica en Base seca}

B_{CH_2} = [MO] * [R_1] . . . . ec. (17)

{Ton. Mat. orgánica en Base Seca que contiene 1 m^3 de Basura} {Ton. CH_4 producido por 1 Ton. de Mat. Orgánica en Base seca}

B) ESFUERZOS DE TRABAJO A CONSIDERAR EN EL DISEÑO DE SISTEMAS DE IMPERMEABILIZACION.

Los esfuerzos de trabajo más comunes, que se presentan en los sistemas de impermeabilización con membranas artificiales que a últimas fechas se consideran como parte fundamental de un relleno sanitario, se ilustran en la Fig. No. 2 y se describen a continuación:

a) Esfuerzo de Tensión por el Peso Propio de la Membrana.

A partir del Detalle No. 1 del Diagrama de Definiciones de la Fig. No. 2, se establece el siguiente sistemas de fuerzas:

$E_1 = F_1 - R_2 = 0$ ec. (18)

Desarrolando los términos de esta expresión, se tiene:

$R_2 = R \text{ sen } \alpha$ ec. (19)

$F_1 = R_1 \tan \varphi_s = (R \cos \alpha) \tan \varphi_s$ ec. (20)

$R = \gamma_m * (H * \text{sen } \alpha) * e$ ec. (21)

Donde:

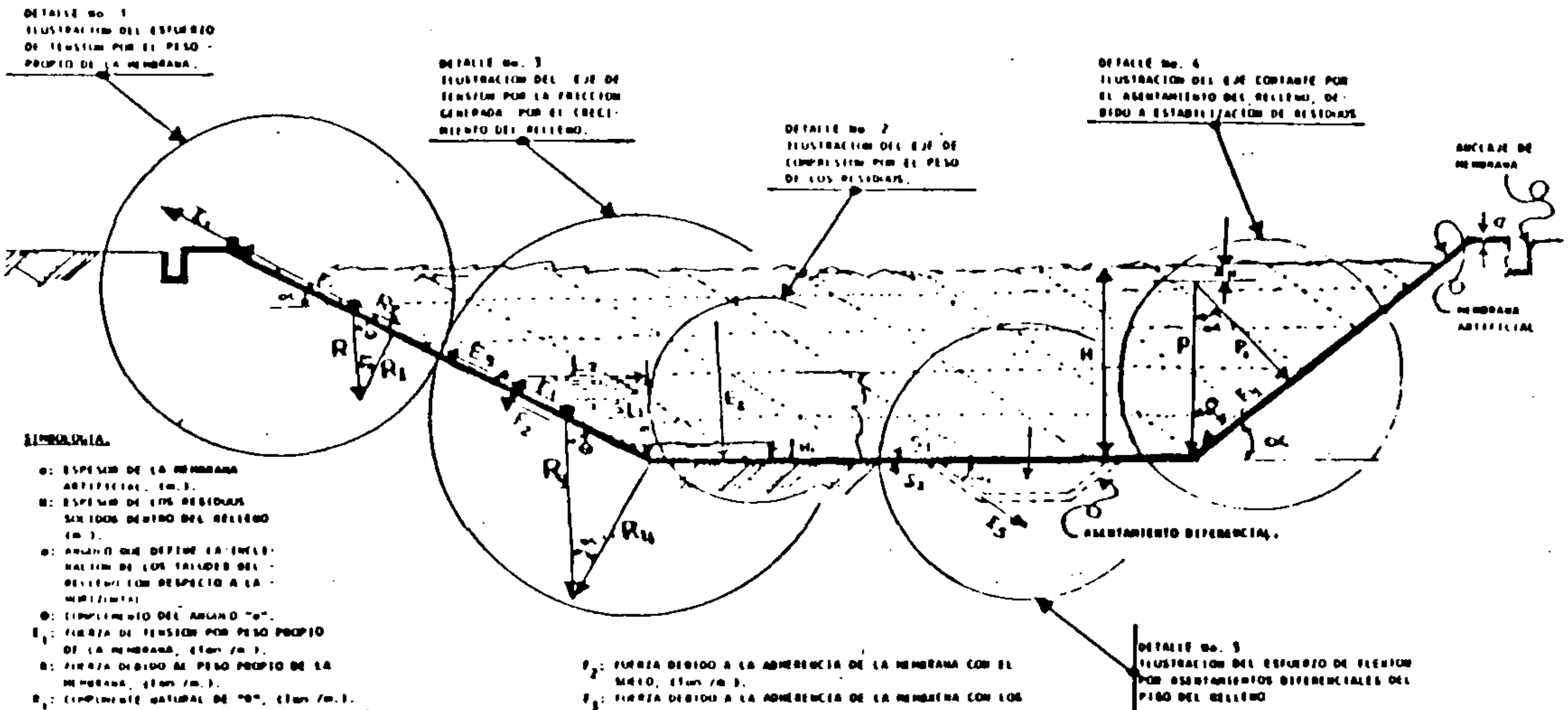
e: Espesor de la membrana artificial, (m.).

γ_m: Peso específico de la membrana artificial, (Ton./m_3)

φ_s: Angulo de fricción interna del suelo que sustentará la membrana artificial.

Fig. No. 2

DIAGRAMA DE DEFINICIONES PARA ANALISIS DE ESFUERZOS DE TRABAJO DEL SISTEMA DE IMPERMEABILIZACION



SIMBOLOGIA.

- e: ESPESOR DE LA MEMBRANA ARTIFICIAL, (m.).
- H: ESPESOR DE LOS RESIDUOS SOLIDOS DENTRO DEL RELLENO (m.).
- α: ANGULO QUE DEFINE LA INCLINACION DE LOS TALUDES DEL RELLENO CON RESPECTO A LA HORIZONTAL
- θ: COMPLEMENTO DEL ANGULO "α".
- T_1: FUERZA DE TENSION POR PESO PROPIO DE LA MEMBRANA, (Ton./m.).
- R: FUERZA DEBIDO AL PESO PROPIO DE LA MEMBRANA, (Ton./m.).
- R_1: COMPONENTE NATURAL DE "R", (Ton./m.).
- R_2: COMPONENTE TANGENCIAL DE "R", (Ton./m.).
- F_1: FUERZA DE ADHERENCIA DE LA MEMBRANA CON EL SUELO, (Ton./m.).
- E_2: SUMA DE ESFUERZOS DE COMPRESION POR EL PESO DE LOS RESIDUOS SOBRE LA MEMBRANA, (Ton./m.).
- H_1: ESPESOR DE RESIDUOS, SATURADOS CON LIXIVIADOS, (m.).
- E_3: FUERZA DE TENSION LA FRICCION GENERADA POR EL CRECIMIENTO VERTICAL DEL RELLENO, (Ton./m.).
- L_1: ESPESOR DE LOS RESIDUOS DENTRO DEL RELLENO, ANTES DE INICIAR UNA NUEVA CAPA, (m.).
- L_2: PROYECCION HORIZONTAL DE "L_1", SOBRE EL TALUD INCLINADO, (m.).
- R_3: FUERZA DEBIDO AL PESO DE LOS RESIDUOS SOLIDOS SOBRE EL TALUD INCLINADO, (Ton./m.).
- R_4: COMPONENTE NORMAL DE "R_3", (Ton./m.).
- F_2: FUERZA DEBIDO A LA ADHERENCIA DE LA MEMBRANA CON EL SUELO, (Ton./m.).
- F_3: FUERZA DEBIDO A LA ADHERENCIA DE LA MEMBRANA CON LOS RESIDUOS, (Ton./m.)
- E_4: FUERZA CORTANTE DEBIDO AL ASENTAMIENTO EN EL RELLENO, (Ton./m.).
- h: ESPESOR DEL ASENTAMIENTO DEL RELLENO, (m.).
- P: FUERZA DEBIDO AL ASENTAMIENTO DEL RELLENO, (Ton./m.)
- P_1: COMPONENTE NORMAL DE "P", (Ton./m.).
- E_5: FUERZA DE FLEXION POR ASENTAMIENTOS DIFERENCIALES EN EL PISO DEL RELLENO, (Ton./m.)
- S_1: REACCION DE LA MEMBRANA DEBIDO AL ESFUERZO DE LA FLEXION, (Ton./m.).
- S_2: FUERZA DEBIDO A LA ADHERENCIA DE LA MEMBRANA CON EL SUELO, (Ton./m.).

El esfuerzo de tensión estará dado por la siguiente expresión:

$$\sigma t_1 = \frac{E_1}{e} \quad \dots\dots\dots\dots\dots\dots \quad \text{ec. (22)}$$

Donde:

σt_1: en Ton./m_2

E_1: en Ton./m

e: en m.

Cabe aclarar que este tipo de esfuerzos de tensión, presenta su mayor solicitación, justo después de haber concluido la instalación de membrana y antes de iniciar con la disposición de los residuos.

b) Esfuerzos de Compresión Debido al Peso de los Residuos sobre la Membrana.

Considerando el Detalle No. 2 del Diagrama de Definiciones de la Fig. No. 2, el esfuerzo de compresión quedará definido por la siguiente expresión:

$$\sigma_c = E_2 \quad \dots\dots\dots\dots\dots\dots \quad \text{ec. (23)}$$

Donde:

$$E_2 = [\ \gamma_R*(H-H_1)\ ] + [\ \gamma_L*H_1\ ] + [\ \gamma_s*(1-(h/100))*H_1\ ] \quad \dots\dots\dots\dots \quad \text{ec. (24)}$$

γ_R: Peso volumétrico de los residuos sólidos dentro del relleno sanitario, (Ton./m^3).

γ_L: Peso volumétrico de los lixiviados, (Ton./m^3).

γ_S: Peso volumétrico seco de los residuos sólidos, (Ton./m^3).

h: Humedad propia de los resiudos sólidos, antes de su disposición dentro del relleno sanitario, (% en peso).

Este tipo de esfuerzos alcanzarán su condición de trabajo más crítica, justo al término de la vida útil del relleno sanitario, que es cuando se trendrá una mayor carga de residuos sobre la membrana.

c) Esfuerzo de Tensión Generado por la Fricción Debida al Crecimiento Vertical del Relleno Sanitario.

Con base al Detalle No. 3 del Diagrama de Definiciones que se presenta en la Fig. No. 2, se puede formular el sistema de fuerzas siguiente:

$E_3 = F_3 - F_2$ . . . . ec. (25)

Desglozando los términos de esta expresión, se tiene:

$F_3 = R_4 \tan \rho_R = (R_3 \cos \alpha) \tan \rho_R$ . . . . ec. (26)

$F_2 = R_4 \tan \rho_S = (R_3 \cos \alpha) \tan \rho_S$ . . . . ec. (27)

$R_3 = \gamma_R * (½*L_1*L_2)$ . . . . ec. (28)

Donde:

ρ_R: Angulo de fricción interna de los residuos sólidos.

El esfuerzo de la tensión quedará definido por la siguiente ecuación:

$$\sigma t_2 = \frac{E_3}{e} \quad \text{ec. (29)}$$

Donde:

σt_2: en Ton./m_2

E_3: en Ton./m

e: en m.

Se debe mencionar que este tipo de esfuerzos, se presentarán casi permanentemente durante toda la operación del relleno sanitario, incrementando su magnitud y haciéndose más críticos conforme se incrementen los paquetes de basura.

d) Esfuerzo Cortante Debido al Asentamiento del Relleno por la Estabilización de los Residuos.

El Detalle No. 4 del Diagrama de Definiciones de la Fig. No. 2, muestra la fuerza que se deben considerar para el cálculo del esfuerzo cortante.

$$\sigma_{CR} = E_4 = P_1 \tan \varphi_R = (P \cos \alpha) \tan \varphi_R \quad \text{ec. (30)}$$

$$P = \gamma_R (H- H) \quad \text{ec. (31)}$$

Este tipo de esfuerzos, normalmente se presentan una vez que la vida útil del relleno sanitario ha concluido, pero sobre todo cuando dicho relleno se encuentre en plena fase de estabilización.

e) Esfuerzo de Flexión por Asentamientos Diferenciales que se Presentan en el Piso del Relleno.

Consultando el Detalle No. 5 del Diagrama de Definiciones de la Fig. No. 2, se puede establecer el siguiente sistema de fuerzas:

$$(E_5 * \cos \alpha_1) - (S_1 + S_2) = 0 \qquad \text{ec. (32)}$$

$$E_5 = \frac{S_1 + S_2}{\cos \alpha_1} \qquad \text{ec. (33)}$$

Desglosando los términos, tenemos:

$$S_1 = (\gamma_R * H) \tan \varphi_R \qquad \text{ec. (34)}$$

$$S_2 = (\gamma_S * H) \tan \varphi_S \qquad \text{ec. (35)}$$

El esfuerzo de flexión quedará expresado por la siguiente ecuación:

$$\sigma_f = E_5 * L \qquad \text{ec. (36)}$$

Donde:

σ_f: en Ton./m

E_5: en Ton./m^2

L: Longitud de la membrana que se ve afectada por la fuerza de flexión.

Estos esfuerzos, aunque pueden presentarse en cualquier momento, incluso al iniciar la operación del relleno sanitario, es más factible que se presenten al término de la vida útil de esta obra, debido a que la carga de los residuos sólidos sobre el suelo será mucho mayor. Estos asentamientos, normalmente son debidos a fallas en la compactación de los materiales que soportarán al relleno sanitario, aunque en ocasiones estos asentamientos tienen su origen en fallamientos de capas más profundas, sobre todo en zonas con suelos calcareos.

CURSO INTERNACIONAL DE RELLENOS SANITARIOS

MEXICO D.F. DEL 14 AL 18 DE MARZO DE 1994

MITOS Y REALIDADES SOBRE LOS RESIDUOS SOLIDOS

M. en C. ARTURO DAVILA VILLARREAL

Los vendedores de soluciones mágicas
al problema de los residuos sólidos
pararán en el basurero de la historia

I.- INTRODUCCION

Es importante aclarar desde este inicio el significado que estoy utilizando de la palabra mito, es la propuesta de una solución que esta basada en una serie de mentiras, con o sin conocimiento de ello, que ocasionan esperanza y que terminan en frustración o en resultados contrarios a los que se buscaban inicialmente.

La idea de elaborar este documento nace de la infinidad de comentarios que he escuchado acerca de la frustración de muchos colegas del área de los residuos sólidos y de mis experiencias de más de 20 años, en el sentido de que muchas "soluciones mágicas", sobre todo copiando patrones extranjeros de otras sociedades con otro tipo de problemas, son escuchadas por personas que tienen el poder de decisión y que al final de la jornada adquieren un mito regularmente a costos muy elevados, limitando los recursos para el avance en el control de los residuos sólidos y peligrosos.

En fin, este documento recopila una serie de mitos que revolotean en cada cambio de gobierno, con las nuevas autoridades y algunos mas persistentes que duran mas allá de uno o varios periodos gubernamentales.

Aquí se comprueba el porque se le ha otorgado el nombre de mito en el sentido ya aclarado en el primer párrafo, agradezco a un sinnúmero de colegas que me han dado la veta de la inspiración para la consecución de este documento.

Quisiera dedicarlo a todas aquellas personas que envueltos en un afán de participación ecologista verdadero y a las autoridades de buena fe que se ven sorprendidos por las argucias de los vendedores de "soluciones mágicas" al problema de los residuos sólidos y peligrosos, sin mas finalidad que la de proporcionar una voz de alerta para eliminar ilusiones, elefantes blancos y endeudamientos en el futuro.

Agradezco a todos aquellos amigos y enemigos que por el paso de la vida me han dado la oportunidad por sus consejos o criticas participar con aciertos y errores en esta ultrainteresante área de los residuos sólidos y peligrosos, para ellos este documento a manera de extremaunción.

El documento presenta los mitos mas conocidos que han hecho daño en paises en vías de desarrollo y la realidad que hay atrás de los mismos.

Con cariño y recuerdo para mis amores, amigos y maestros.

II.- ANTECEDENTES

Desde mi primer contacto y hasta la fecha me ha tocado vivir una serie de procesos y situaciones que se han desarrollado dentro del área de los residuos sólidos, mas en los de tipo municipal que en los peligrosos hasta ahora, estos procesos en su mayoría están encaminados a implantar soluciones de sociedades desarrolladas a nuestros paises, estos procesos solo han dejado frustraciones, endeudamientos y han impedido avanzar de forma rápida en la aplicación de soluciones acordes a nuestros recursos.

Así, me he topado con una serie de propuestas de "soluciones mágicas", algunas, que han sido llevadas a la práctica, han resultado en fracasos que en nada ayudan y como perjudican con el tiempo, desgraciadamente la memoria de los eventos negativos no perdura, en ocasiones dichos eventos se repiten y se alcanzan los mismós resultados desgraciadamente.

Por lo tanto no queda otra oportunidad que divulgar los errores, (horrores), cometidos y los resultados de esas "soluciones mágicas", que en este documento las presento como mitos, siempre con la esperanza de que en el futuro se evite la venta de estos mitos a costa de la tributación de todos.

III.- RAZON DE LA EXISTENCIA DE LOS MITOS

Son tres las razones principales para que se produzca o genere un mito en el área de los residuos sólidos, la primera el afán ecológico puro, sin analizar la factibilidad técnica o económica de la propuesta por parte de algunos grupos ecologistas; la segunda, la voracidad económica desmedida de compradores y vendedores; y la tercera, el desconocimiento de algunas variables que intervienen en la propuesta que acarrean consecuencias funestas.

IV.- PRINCIPALES MITOS Y SUS REALIDADES

Uno de los temas principales que encierra una serie de mitos que giran alrededor del área de los residuos sólidos en los últimos cinco años es sin duda el relacionado con el reciclaje, sobre todo cuando es enfocado de una manera simplista.

Desde ese tiempo se ha desatado un furor por el reciclo de los subproductos, algunos grupos ecologistas han apoyado la idea y la ven como una solución al problema, sin embargo desde uno de los puntos de vista que se enfoca, que "la basura es dinero" es una falsedad que se ha demostrado con el tiempo.

En las siguientes cuartillas tocaremos los principales mitos que a continuación enlisto:

1.- La basura es oro
2.- La separación domiciliaria como fuente de ingreso
3.- Toda la basura es reciclable
4.- Las plantas de reciclo composta
5.- El abuso de la información y otros mitos

4.1.- La basura es oro

Por mucho tiempo, se ha mencionado que la basura es oro, esta aseveración por lo regular se ha basado por la riqueza que algunas personas han amasado durante su vida en el manejo de los residuos sólidos.

Esta situación ha sido extrapolada sin razón a todo el ámbito de los residuos sólidos, sin embargo la realidad es que los residuos se convierten en oro cuando existe en su aprovechamiento la explotación del hombre por el hombre o esta incorporada la utilización de bienes gubernamentales para beneficio de terceros.

4.2.- La separación domiciliaria como fuente de ingreso

Esta punto es el que mas ha sido utilizado por los grupos ecologistas, si bien es cierto y estoy convencido que el aumento del reciclaje de los subproductos provenientes de los residuos sólidos ayuda en mucho a la preservación de los recursos naturales y trae otros beneficios, el enfoque que en ocasiones se le ha dado, que sería una fuente de ingresos para los habitantes de la casa habitación es un mito mas del ambiente.

A continuación presento un análisis de esta situación, consideremos los siguientes batos básicos, seis habitantes por casa, 650 gramos por persona por día de generación, que los reciclables representen un 30 porciento del total generado, cabe aclarar que estoy considerando todos los reciclables con demanda en el mercado o sin demanda, por lo tanto tendremos lo siguiente:

6 hab/casa X 650 Gr/hab-día X 7 d/sem. X 0.30 de reciclables

Generación semanal de reciclables = 8.190 Kilogramos

El precio ponderado para la venta de los subproductos en México es de 0.12 Nuevos centavos por kilogramo por lo que tendríamos un ingreso total por semana de 0.98 = 1.00 nuevo peso, que llevandolo al año tendríamos 52 nuevos pesos, este ingreso anual representa un ingreso de un 12 porciento de un salario mínimo mensual, lo anterior demuestra que los subproductos en forma unifamiliar no tiene ningún atractivo económico.

4.3.- Todos los residuos sólidos son reciclables

Desde hace tiempo algunos grupos ecologistas han propalado la versión de la "no generación de basura" en la casa habitación, esto por supuesto es un mito, primero porque no todos los residuos sólidos en la actualidad es reciclable, ya que eso que llamamos basura esta compuesta por mas de 70 elementos de muy variadas características, los promotores argumentan que todo lo no orgánico es reciclable y lo orgánico hacerlo composta.

Me pregunto en una ciudad de un millón de habitantes se generan solo por residuos sólidos domiciliarios 650 toneladas diarias, de estas un 55 porciento es orgánica, por lo que tendremos 357.50 toneladas diarias de composta una vez que se inicie la producción.

La experiencia recomienda un promedio de 10 metros de áreas verdes por habitante, por lo que necesitariamos 1000 hectáreas en una ciudad de este tamaño, si lo recomendable es colocar 10 toneladas de composta por hectárea en pastos dos veces por año, necesitaremos 20,000 toneladas por año, y si generamos por año 130,000 toneladas, ¿que vamos hacer con el resto?.

Por otro lado viendo desde el punto de vista optimista que todo lo demás es reciclable, tendríamos 292.5 toneladas diarias de subproductos, las que se convierten en 106,000 toneladas anuales, me pregunto, ¿está la industria con la capacidad de absorber para reciclar esta cantidad anual?.

Aquí vale la pena hacer varias reflexiones, hasta la fecha la separación de los subproductos por parte del generador, no tiene un atractivo económico, solo puede resultar cuando existe una gran participación de los habitantes de una comunidad completa, esto es muy difícil de alcanzar.

Por otra parte es muy común y por cierto muy atractivo el llamado de la conciencia ecológica del reciclo, sin embargo es necesario ver y analizar las posibilidades de mercado en la zona donde se realizará un prógrama de reciclo, ya que si el programa tiene éxito, será muy común que la oferta del subproducto en un tiempo corto rebase la demanda del mismo, derrumbando los precios de éstos por la sobreoferta.

No todos los subproductos en la actualidad tienen una demanda en el mercado donde existen las industrias recicladoras, los de mayor demanda son: el cartón, papel limpio, periódico, papel de archivo y computadora, vidrio, aluminio y otros no metálicos y fierro,.

Todos estos subproductos en los residuos sólidos generados en la casa habitación solo representa en el mejor de los casos un 15 porciento del total y no el treinta con los que efectué los análisis para estar en el lado mas optimista.

Cabe la pena de tomar ejemplos de algunos paises desarrollados, en los que se tiene que subvencionar el reciclaje, pagando mayores costos del programa que lo que perciben por la venta de los subproductos y en muchos casos éstos van a parar a un relleno sanitario.

Por lo tanto antes de iniciar un programa de reciclaje en una localidad es de suma importancia el elaborar un estudio que tome en consideración todos los factores involucrados, con la finalidad de establecer las dimensiones del mismo de forma correcta y no llegar a resultados que todavía nuestros pueblos se pueden dar el lujo.

Por supuesto que el reciclar tiene una serie de ventajas entre las que destacan, preservación de materias primas vírgenes renovables o no, ahorro de energía, ahorro en los costos de producción y creación de fuentes de trabajo, estas son algunas de las principales y comunmente son utilizadas por los vendedores de "soluciones mágicas".

Cabe mencionar que uno de los grandes beneficiarios en el proceso del reciclaje ha sido la industria, ya que con la incorporación de los subproductos como materia prima, disminuyen sus costos de producción, situación que no se refleja en la disminución de los costos al consumidor y ha mantenido un monopolio y un férreo control de precios de los mismos para su beneficio, no obstante algunas veces se visten de benefactores últimos del ambiente.

4.4.- Plantas de reciclo composta

Las plantas de reciclo composta fueron a principios de la década de los setentas la "panacea" en México, se instalaron tres con tecnología suiza y otra con tecnología italiana, en las Ciudades de Toluca, Monterrey, Distrito Federal y Guadalajara y a finales de la década de los ochentas, se instalaron otras cuatro, localizadas otra vez en Guadalajara, ya que la anterior fue cerrada, en Oaxaca, en Mérida y en Villahermosa, de todas ellas han cerrado, con excepción la de Guadalajara, la que trabaja con números rojos.

Los vendedores de estas plantas fueron muy hábiles en la presentación de las bondades de las plantas, sus análisis principales se basaron en una recuperación alta de subproductos, usando los resultados de los análisis físicos que proporcionan las cantidades de subproductos reciclables en los residuos sólidos y por supuesto a la venta total de la composta.

El gancho fue precisamente ese, sin embargo nunca se consideraron los factores reales de recuperación de los subproductos en bandas y que la demanda por el composta nunca se igualo a la oferta de producción del mismo.

Los resultados fueron similares en todos los casos, altos costos de operación y mantenimiento; altos porcentajes de rechazo, bajos factores de recuperación de subproductos y prácticamente nula demanda del composta, todo lo anterior convirtió en pozos sin fondo a las plantas ya que siempre trabajaron con números rojos.

4.5.- Abuso de la Información

Otra parte importante de los mitos es el abuso de la información sobre los residuos sólidos desde el punto de vista técnico como político social.

Uno de los problemas graves a que se enfrenta el área del control de los residuos sólidos es los miles de "expertos" que nos encontramos cada día, opinando con gran autoridad sobre el problema y sus soluciones, las cuales están basadas en una o varias vivencias que han tenido con una visita al extranjero u hojeando un libro regularmente editado en el extranjero.

De lo anterior salen muchos horrores que en ocasiones ponen en peligro un buen proyecto o echan a andar un mal proyecto, así podemos encontrar a los que opinan que en el mundo desarrollado no hay rellenos sanitarios, que la incineración es la mejor solución porque viajaron a Japón, que todos los materiales contenidos en los residuos sólidos son reciclables y últimamente que la generación de energía y la pirolisis es lo recomendable.

Por otro lado cada quien dice sus cifras sobre la generación de los residuos sólidos, así se puede uno encontrar generaciones desde 500 gramos por persona por día hasta los que mencionan 1500 gramos, en lo que respecta a los residuos peligrosos todavía es peor el asunto ya que te puedes encontrar variaciones en la generación del país de hasta el 100 porciento.

Otro problema del abuso de la información es en la información técnica ya que las opiniones fáciles que en ocasiones se proporcionan son derivadas de experiencias de oídas, así podemos encontrarnos que dan información sobre pesos volumétricos en los rellenos sanitarios de 650 kilogramos por metro cúbico, siendo que es fácil alcanzar pesos volumétricos de mas de 800 kilogramos por metro cúbico.

Otra información comunmente utilizada es que los vehículos recolectores de carga lateral rectangular o tubular llevan de cinco a seis toneladas por viaje, nunca en mi vida profesional los he visto de mas de cuatro y media toneladas.

De todo el punto anterior se puede desprender la realidad de la falta de información confiable y estadísticamente valida que permita acercarnos lo mas posible a la verdad con la finalidad de que los resultados de las acciones tomadas resuelvan el problema planteado.

A ultimas fechas esta muy de moda las plantas de tratamiento para la fabricación de pellets para posteriormente incinerarlos y generación de electricidad, el gancho principal es que el cliente compra la electricidad a precios mayores que lo que ofrece la gubernamental.

Finalmente una reflexión sobre este tema, no siempre todo es verdad o todo es mentira, se debe hacer una recopilación de la información, analizarla y evaluarla detalladamente y resolver en consecuencia.

CURSO INTERNACIONAL DE DISEÑO DE DISPOSICION
FINAL DE RESIDUOS SOLIDOS
(RELLENOS SANITARIOS)
1994

ASPECTOS SOCIALES DEL MANEJO DE LOS RESIDUOS SOLIDOS

LIC. ROSALBA CRUZ JIMENEZ

ASPECTOS SOCIALES DEL MANEJO DE LOS RESIDUOS SOLIDOS

Lic. Rosalba Cruz Jiménez

El manejo de los residuos sólidos es un conjunto de servicios de intrínseca naturaleza social. Esto es, pocos servicios públicos pese a su composición "pública" presentan y requieren tan altos niveles de participación social. El manejo de la basura conlleva un hecho social. Cada persona, cada familia, una colonia..una ciudad, participan directa o indirectamente en la génesis, desarrollo y posterior disposición de sus desechos.

La generación de residuos es un hecho individual que deriva en un proceso acumulativo que involucra a la sociedad en su conjunto. Todos los elementos de la sociedad tienen roles y funciones bien definidas de participación en torno al manejo de los residuos sólidos tanto individual como colectivamente. De los patrones de comportamiento personal se afectan las magnitudes, de las conductas de grupo se definen sus componentes y de todos depende su impacto en el ambiente.

Pese a esta cualidad social inherente, el manejo de los residuos sólidos no ha mostrado una orientada participación de la sociedad de manera generalizada. Diversas son las modalidades y manifestaciones de participación que se requieren. De manera individual, es necesario actuar para generar menos residuos

En la casos cuando se han dado manifestaciones importantes, éstas se refieren a aspectos particulares con características muy específicas, que convendría analizar como estudio de caso a fin de identificar modalidades que han dado resultado y bajo que condiciones éstas se han generado.

Por lo anterior se concluye que todo elemento de política de mejoramiento del manejo de los residuos sólidos debe tomar como uno de los elementos básicos la orientación de participación social.

Se pueden distinguir tres etapas en la participación ciudadana en relación al manejo de los residuos sólidos. La forma más avanzada de estas etapas es la participación individual, la actitud conciente de cada persona en favor de una racionalidad en la generación de residuos, buscando generar la menor basura posible o quizá orientándose hacia el ideal ecologista de no generar residuos. En esta etapa se encuentra ubicado también el proceso de selección o separación en la fuente.

Esta etapa en la actualidad tiene pocas posibilidades de éxito si se le considera como un hecho generalizado. En la mayoría de las ciudades en las que ya se puede hablar de esta etapa se manifiesta como hechos poco sistemáticos y más bien de carácter zonal, regional o local, sin poder extender todavía su alcance al entero de las localidades.

Una segunda etapa de transición, pero muy importante ejercicio cívico urbano, lo constituye la participación social de grupo, orientada a fortalecer y mejorar los vínculos de la ciudadanía como grupo con los servicios inherente al manejo de los residuos sólidos. En general esta etapa se orienta a superar el reto que representa la aceptación de la infraestructura del servicio en un entorno determinado. El fenómeno mundial relacionado con las siglas NIMBY, no en mi patio, ha sido uno de los factores que mayormente han condicionado la evolución del servicio o en su caso han incrementado su costo a límites que ciudades de economías en desarrollo difícilmente pueden sufragar.

Este nivel como paso intermedio en la actualidad constituye la forma de participación social más importante, en ciudades que como la nuestra que empiezan un proceso de desarrollo, en donde la infraestructura básica se convierte en la plataforma de despegue de toda política o de la instrumentación de acciones de mejoramiento.

Esta etapa representa un reto a las autoridades e implica transformaciones de fondo tanto en los conceptos como en la definición de sistemas y procedimientos.

Lo anterior significa un cambio en las prácticas administrativas y una revisión a las condiciones del manejo de los residuos sólidos.

El primer obstáculo que enfrenta la participación ciudadana es la asociación peyorativa de la basura en su manejo. Efectivamente, a lo largo de los años en nuestras ciudades el manejo se había mantenido en condiciones de rezago con respecto a otros servicios urbanos. Presupuestal, administrativa y operativamente no se consideraba como servicio prioritario, lo que institucionalmente condicionó su manejo y sus impactos en el entorno social y en el ambiente.

En el caso de la ciudad de México la memoria urbana registra hasta hace muy pocos años las grandes montañas de basura en los tiraderos, el desprendimiento de olores y gases, la proliferación de fauna nociva en su alrededor, las escenas de ventas de subproductos. Situaciones semejantes se grabaron en la población en torno a las antiguas estaciones de transferencia.

Ante este panorama toda acción de exhortación de cambio se enfrentaba a la resistencia natural de la ciudadanía, convirtiéndose la participación de grupo en un rechazo total a sus nuevas construcciones y a la operación de las ya existentes.

Por otra parte, existía una firme convicción de cambio. Los grandes requerimientos ambientales de la Ciudad de México, la dinámica urbana y la existencia de grandes déficits a nuevas formas de manejo y administración, en donde la conformación de infraestructura básica representaba el papel más importante. Y éste constituía paradojicamente el mayor concepto de oposición de la ciudadanía.

Derivado de lo anterior, fué necesario instrumentar políticas o acciones concretas para lograr el apoyo ciudadano para estas acciones que actualmente constituyen uno de los elementos variables más importantes en el manejo de los residuos sólidos de ésta capital.

Esta concepción implicó lo siguiente:

- Considerar el manejo de los residuos sólidos como prioritario, eliminando la asociación peyorativa de la basura a las prácticas institucionales, presupuestales, administrativas, etc.

- Conferirle al manejo de la basura características ambientales, sanitarias, de funcionalidad y de imagen urbana.

- Iniciar acciones para conformar casos ejemplos de operación controlada con las características antes señaladas para contar con efectos demostración efectivos.

- Establecer compromisos y responsabilidades específicas de las autoridades; y derechos y obligaciones de los habitantes.

- Establecer un mecanismo de trabajo social urbano para atender las demandas, dar respuesta a dudas y en general explicar el contenido y alcances de las acciones específicas a diferentes niveles, individual, familiar, grupal, regional, etc.

- Formar comites de vigilancia ciudadana para controlar los impactos al ambiente, los efectos en el entorne urbano, la funcionalidad vial y la imagen de las instalaciones.

Todas esta consideraciones se sustentaban en una efectiva convicción política de mejorar el manejo de los residuos sólidos asumiendo compromisos que definitivamente deberían instrumentarse, viéndose resultados en el corto plazo que paulatinamente lograrían la aceptación de la población a la infraestructura básica.

Grandes fueron los esfuerzos de concertación, múltiples demandas que atender y responder, pero finalmente, los habitantes de la ciudad de México y las autoridades han ido ejercitando nuevas formas de relación en el manejo de los residuos sólidos y con ello se ha venido conformando la infraestructura básica para alcanzar nuevos estadios de desarrollo y así contar con la plataforma para atender formas más avanzadas de participación social.

Finalmente, la tercera etapa de participación se refiere al nivel inicial de ubicación y concientización del problema, a la etapa de conocimiento básico a la aceptación y disposición para conocer el problema.

Esta es una fase que paralelamente se ha trabajado a nivel de unidad básica y de alguna forma de comunicación masiva.

Es por ello que a continuación se presenta una muestra de los mecanismos utilizados para estimular la participación de la población en el apoyo a la construcción y operación de estaciones de transferencia.

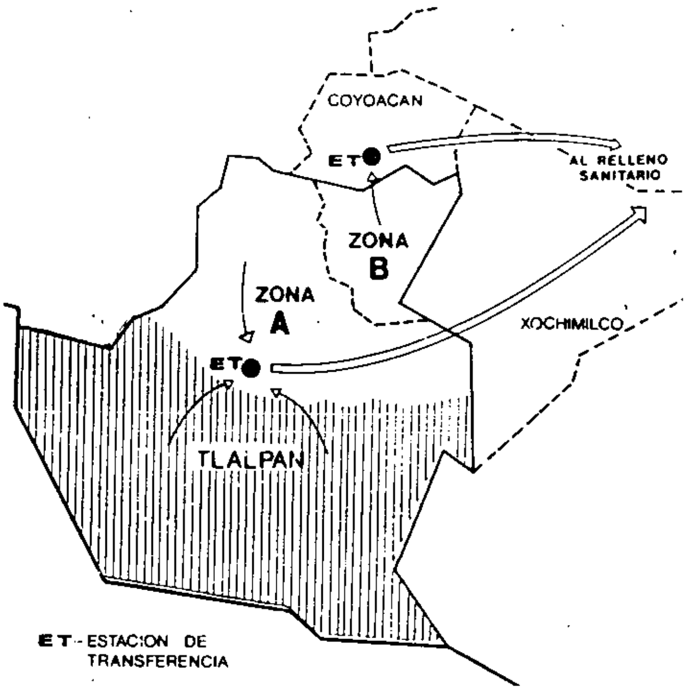
Un ejemplo de caso podría ilustrar este proceso, para lo cual mencionaremos la construcción de la Estación de Transferencia Tlalpan.

La Ciudad de México esta constituída por 16 delegaciones políticas que en conjunto suman una extensión de 1499 km2 con una población de 8'235,744 habitantes.

Al sur de la ciudad se localiza la delegación Tlalpan, la cual cuenta con una superficie de 312 km2, que la convierte en la Delegación más extensa, y representa 20.8 % del territorio del Distrito Federal. Limita al norte con las delegaciones Alvaro Obregón y Coyoacán, al este con Xochimilco y Milpa Alta, al sur con el estado de Morelos y al oeste con el estado de México y la delegación Magdalena Contreras. Los principales componentes climáticos como la temperatura y la humedad están condicionados por la presencia de sierras Ajusco y Xitle, sitios que por su riqueza forestal constituyen reservas de fauna y flora y actúan aunque cada vez menos, como equilibradores del clima dentro de la cuenca del valle de México. Estos sitios son parte de la reserva ecológica considerados como parques nacionales.

La delegación comprende 8 pueblos, 7 barrios, 143 colonias, que integran 104,292 viviendas. El 70% del territorio pertenece a comuneros, el 17% a particulares, el 10% al Gobierno Federal y el 3% a ejidatarios. Tiene una población de 484,866 habitantes que generan alrededor de 681 toneladas día de residuos sólidos.

En la década de los 80's esta delegación presentaba una problemática de gran envergadura al albergar un tiradero a cielo abierto en las inmediaciones del Ajusco, lo que condicionó por años el manejo de los residuos; además de contar con una recolección ineficiente motivada por los largos recorridos que realizaban los camiones recolectores - hasta 34 km de ida y vuelta -, ya que por carecer de una estación de transferencia, se veían obligados a depositar sus residuos en las estaciones de Xochimilco y Coyoacán.



En este sentido, las autoridades de Departamento del Distrito Federal iniciaron un análisis sobre la problemática existente en donde se determinó la necesidad de construir una estación de transferencia.

Es así como se realizan los estudios preliminares que permiten identificar que la ubicación más adecuada para la construcción de la estación, es en el kilómetro 5.5 de la carretera Picacho-Ajusco por las características topográficas que presenta este lugar, como son: un gran sistema de elevaciones de origen volcánico con un alto grado de fractura, acumulación de roca volcánica que forma depósitos de gran espesor y en general las texturas son del tipo francoarenoso, la consistencia suelta pulverulenta y friable cuando los suelos estan muy secos.

No obstante en sus inicios de edificación se empiezan a dar manifestaciones sociales en contra de su construcción, participando en estas desde asociaciones de colonos, padres de familia hasta grupos ecologistas que pertenecen a estratos socioeconómicos distintos y la existencia de una escuela privada que condicionaba su instalación.

Esta situación obligó a las autoridades a llevar a cabo un amplio programa de difusión y concertación con los distintos grupos sociales, que consistió desde pláticas personales, visitas a escuelas, programas de radio y juntas locales con apoyo de material didáctico: láminas, maquetas, trípticos, entre otros, explicándoles claramente en que consistía la instalación de este tipo de infraestructura. Asimismo, se les otorgó información respecto a los beneficios adicionales que obtendrían con obras complementarias como pavimentación de calles, incorporación de un tercer carril vial en la carretera Picacho-Ajusco, áreas arboladas, estacionamiento para el Colegio de México, etc; además de concientizarlos de que se requería mejorar los sistemas de manejo de los residuos que se estaban convirtiendo en un grave problema en la zona.

Derivado de lo anterior se creó un comité de vigilancia integrado principalmente por representantes de los distintos grupos involucrados, el cual tenía como finalidad llevar a cabo la supervisión y vigilancia de las emisiones al ambiente, el funcionamiento vial y los aspectos al entorno.

Bajo este contexto se definió la construcción de la Estación de Transferencia Tlalpan, con los criterios y especificaciones acorde a los requerimientos de operación y a las demandas ciudadanas.

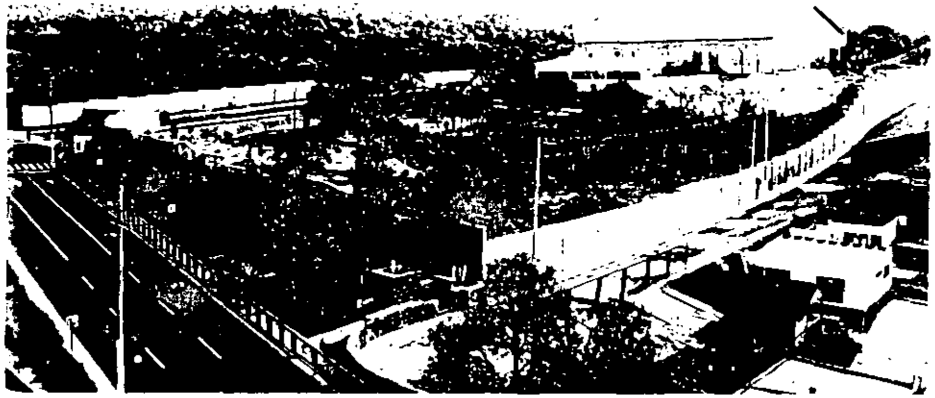
La Estación de Transferencia Tlalpan con una capacidad instalada de 700 toneladas día, comprende una superficie total de 25,000 m2 de los cuales 15,000 m2 se destinaron a áreas verdes y a la creación de un pequeño bosque que, junto con los árboles de la zona, demandaron la plantación de 1,000 árboles así como de cientos de plantas y flores.

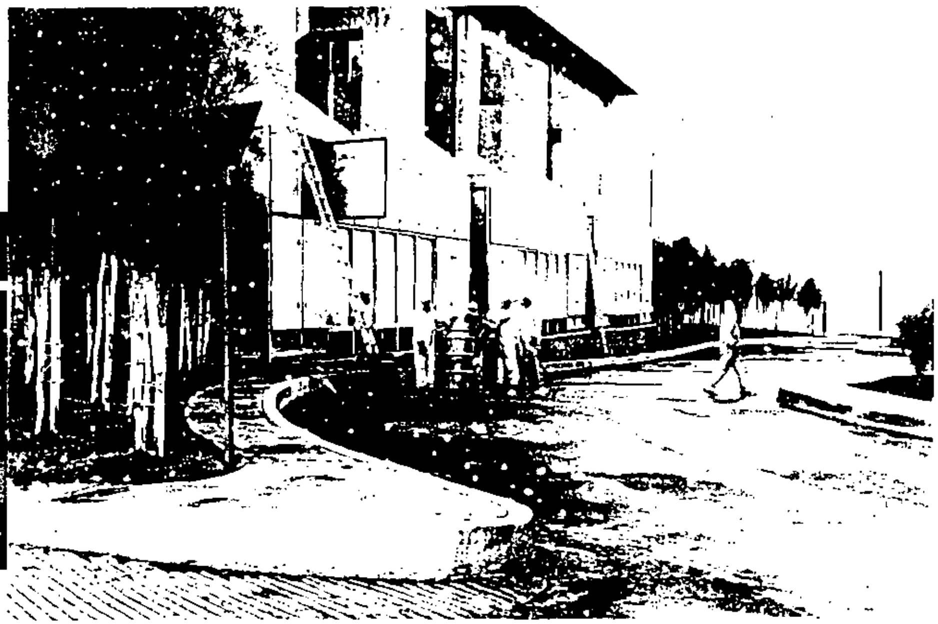
Para evitar posibles encolamientos de vehículos recolectores fuera de la estación así como para agilizar el tráfico vehicular, se construyeron 5,000 m2 de vialidad interna.

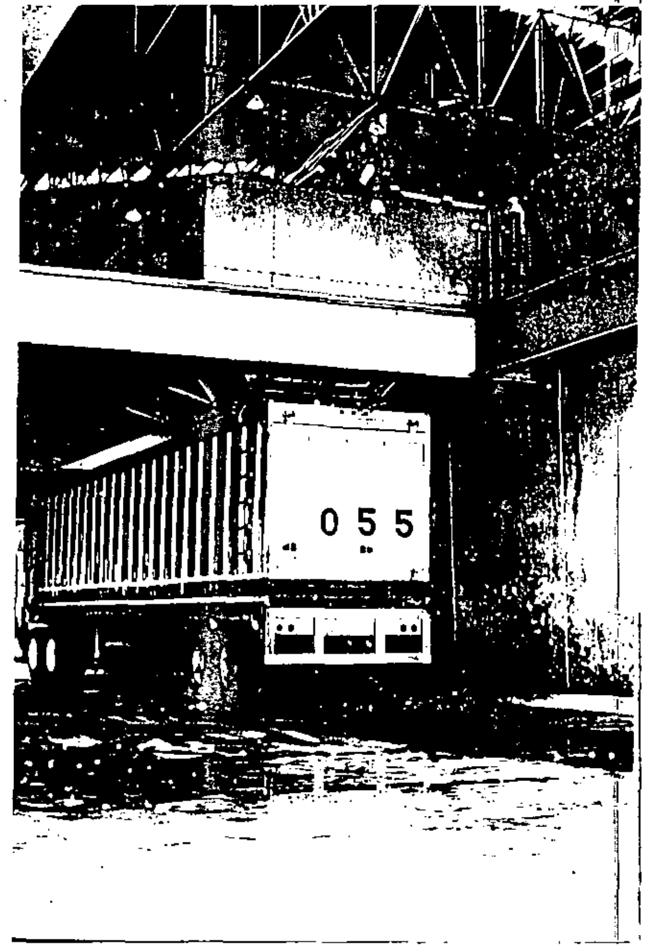
La estación cuenta con instalaciones totalmente cubiertas con lámina multipanel; muros de block para amortiguamiento de ruidos; tolvas para la descarga de residuos con dispositivos atomizadores para contrarrestar la emisión de polvos y olores; sistemas de depuración de aire; sistema hidroneumático para lavado y riego y cisternas de agua potable y de agua tratada para riego y lavado, elementos técnicos y ecológicos de avanzada que le dá una presencia urbanística más estética acorde a las características de la zona.

Además, cuenta con barda perimetral, rampas de entrada y salida de recolectores, taller de mantenimiento, área administrativa, estacionamiento y sanitarios.

Posterior a la Estación de Transferencia Tlalpan, y siguiendo los mismos criterios empleados, se construyeron las estaciones Alvaro Obregón y Central de Abasto II, así como la rehabilitación de las existentes en Coyoacán, Venustiano Carranza, Miguel Hidalgo y Central de Abasto I.



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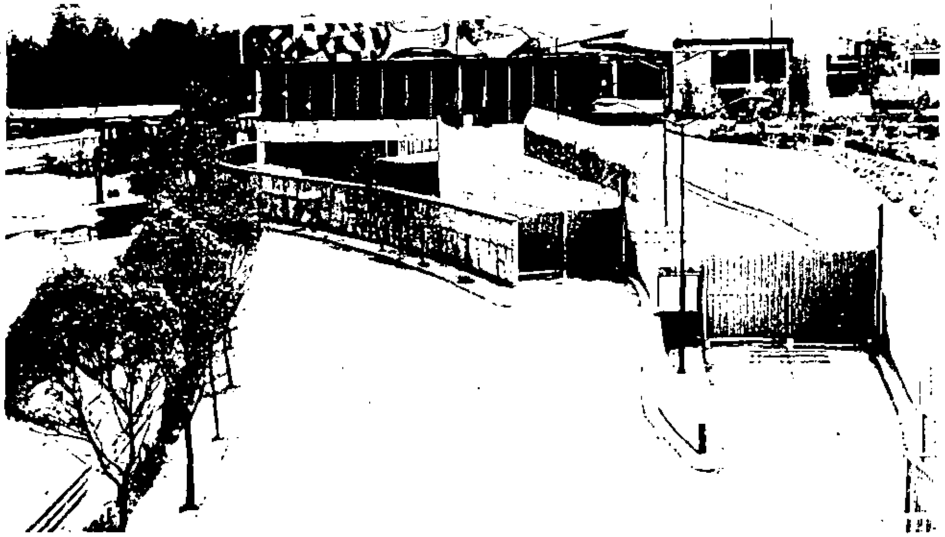
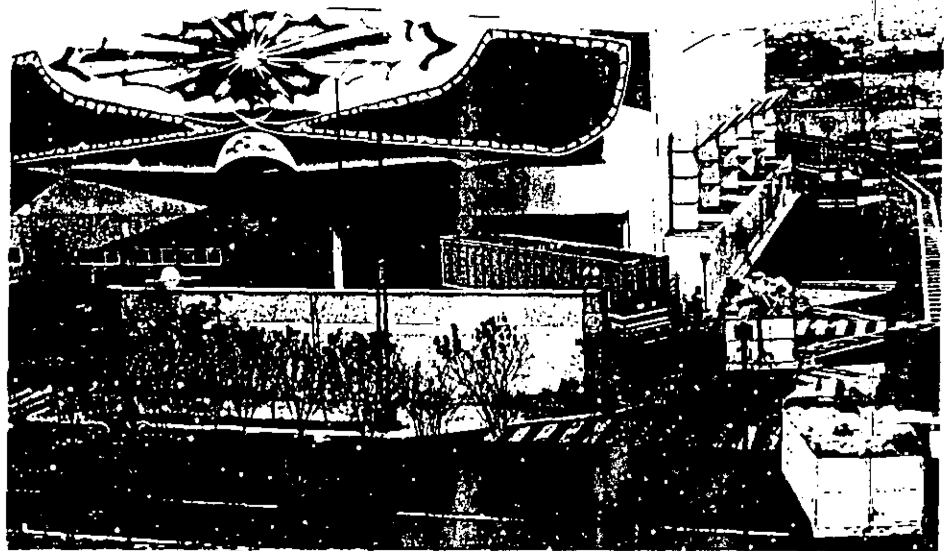
ESTACIONES DE TRANSFERENCIA

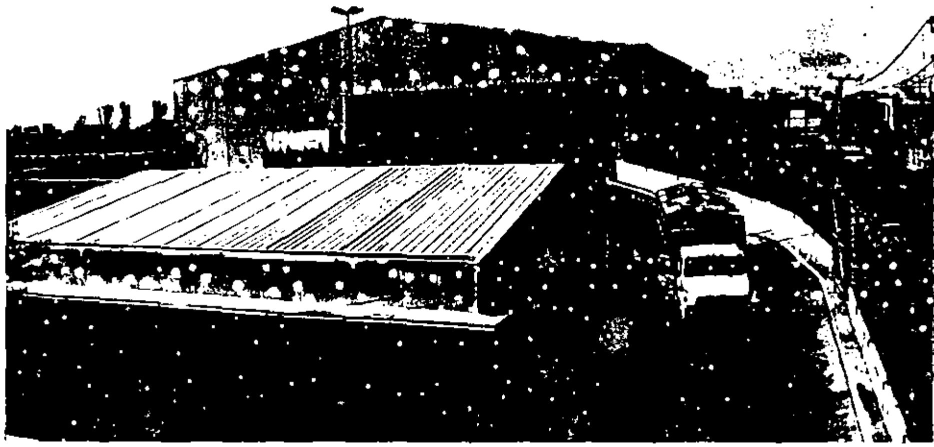


ALVARO OBREGON

IZTAPLAPA

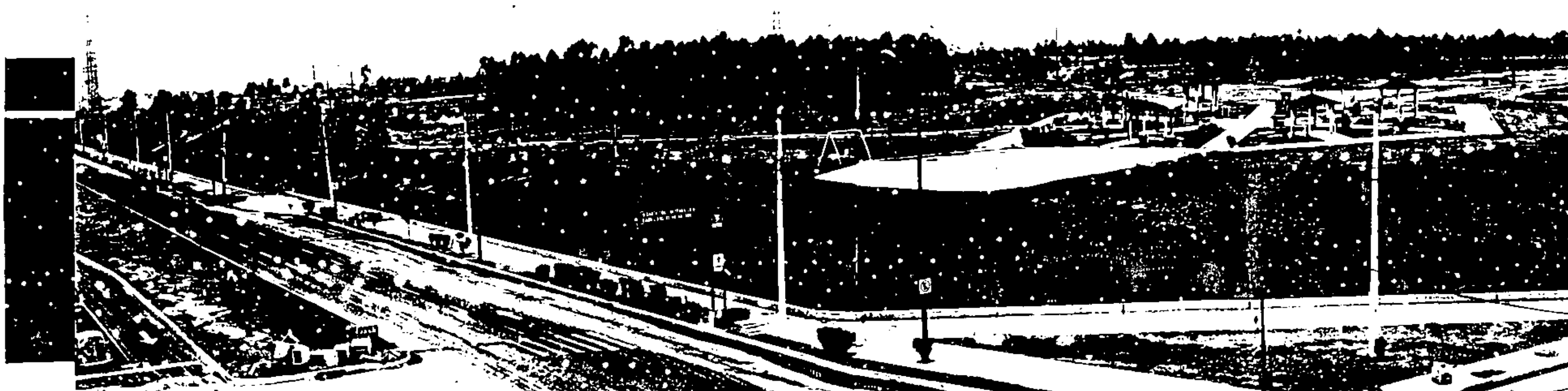


VENUSTIANO CARRANZA

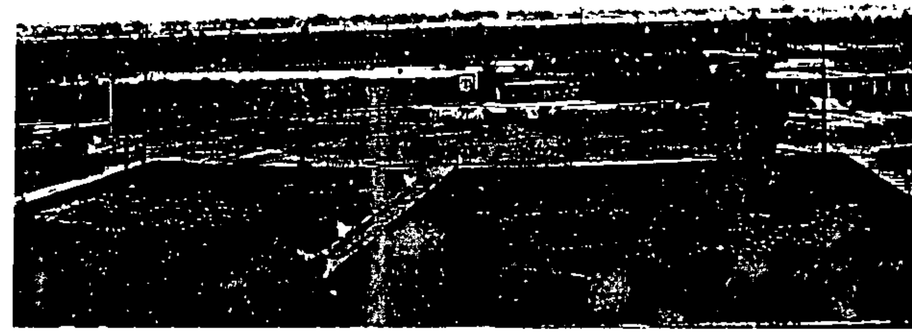


PARQUE CUITLAHUAC

ANTES Y DESPUES



ALAMEDA ORIENTE



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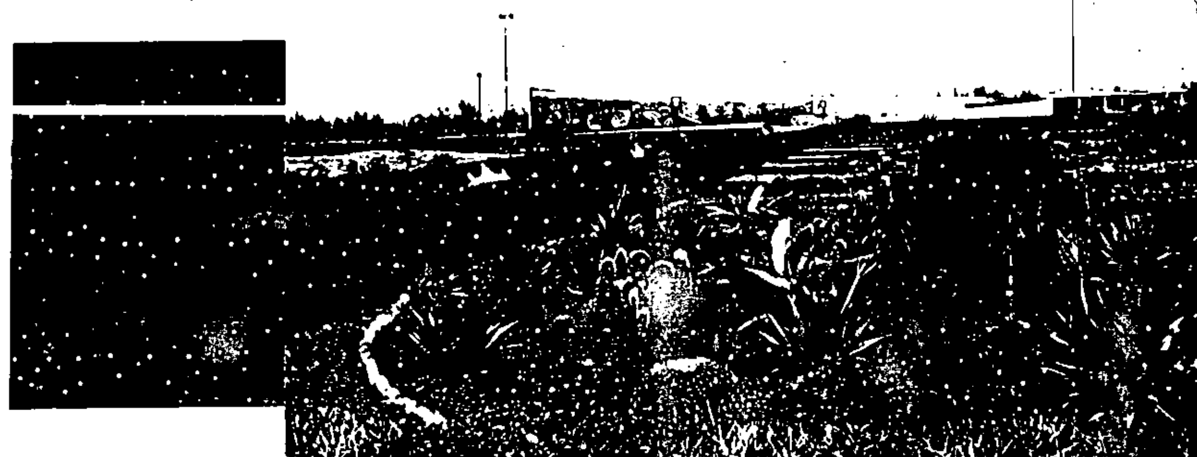

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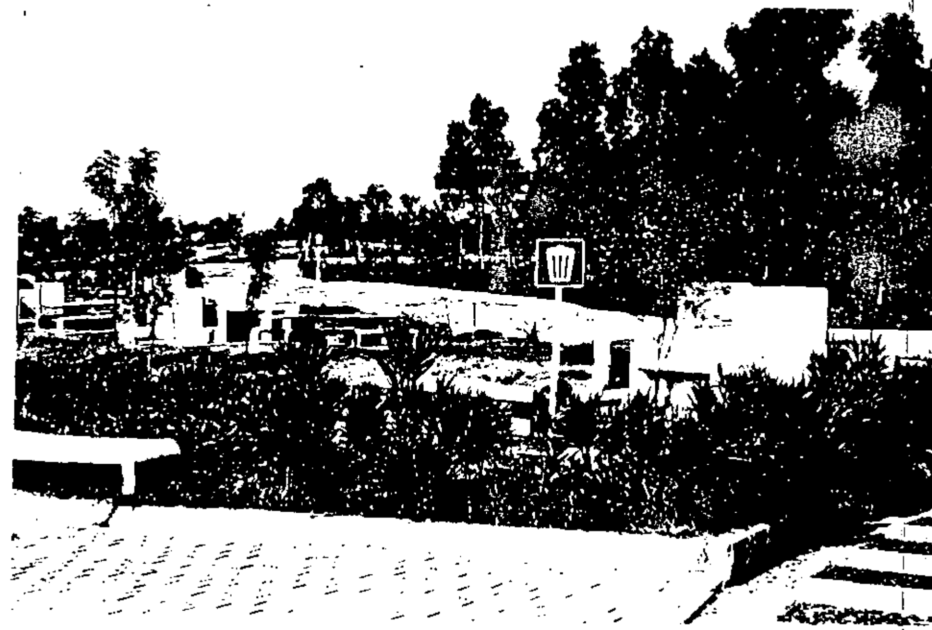
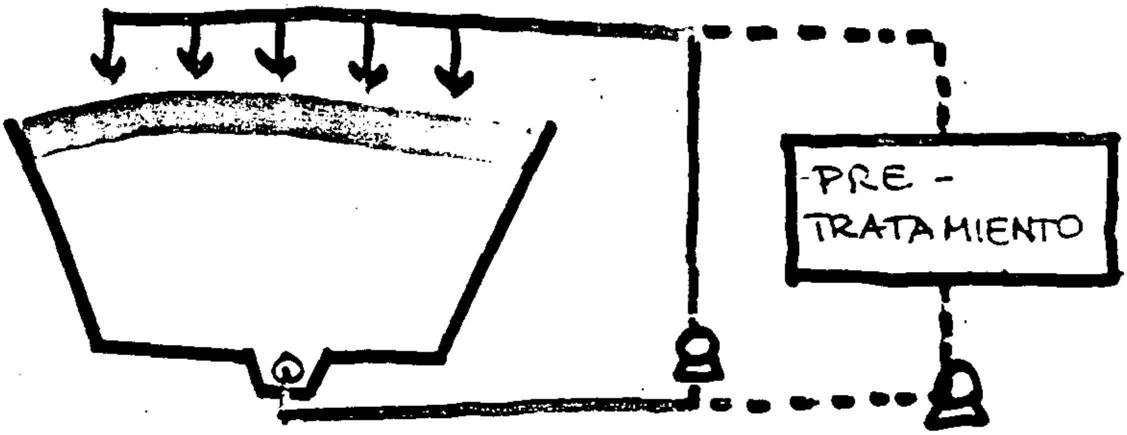
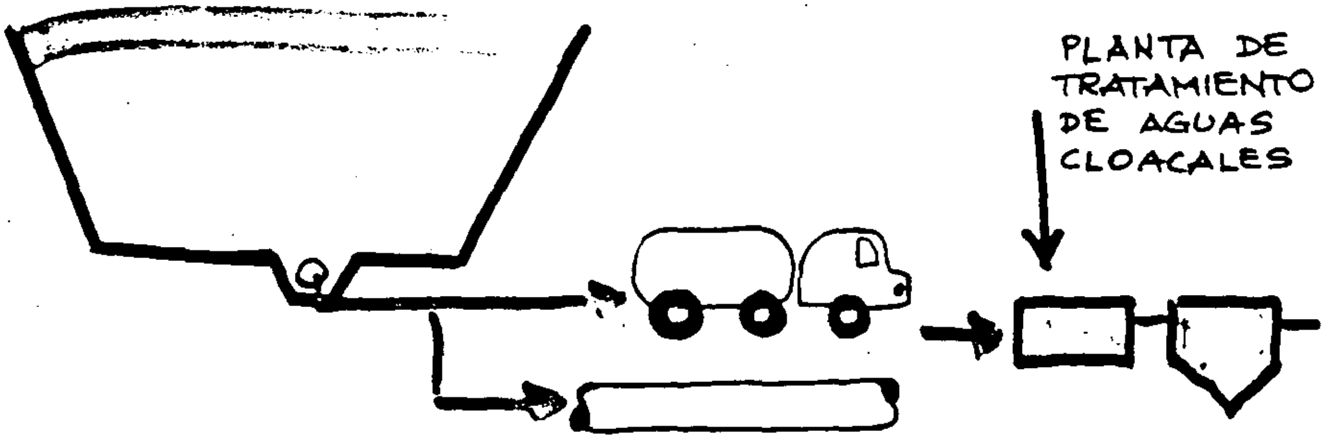
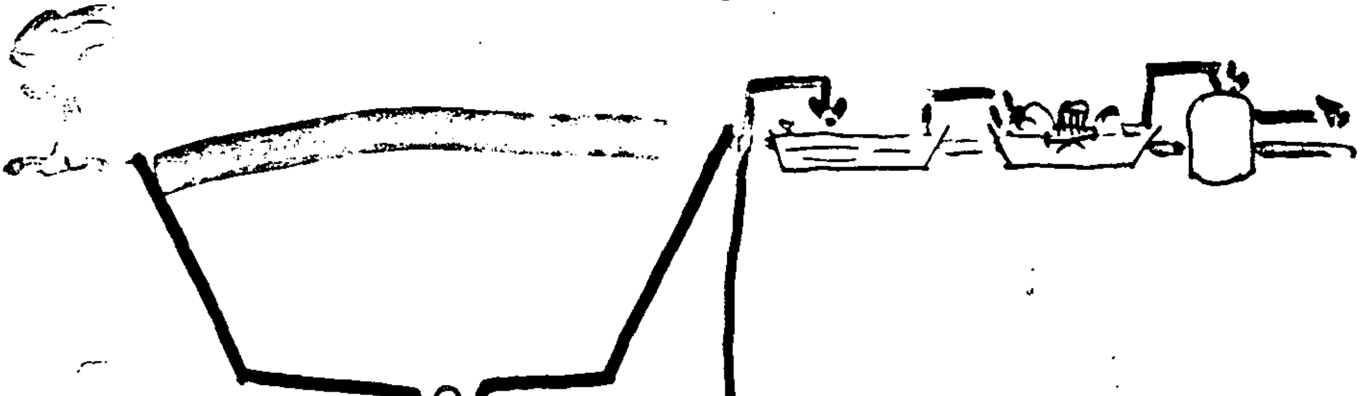


ANTES Y DESPUES

TRATAMIENTO DEL LIXIVIADO

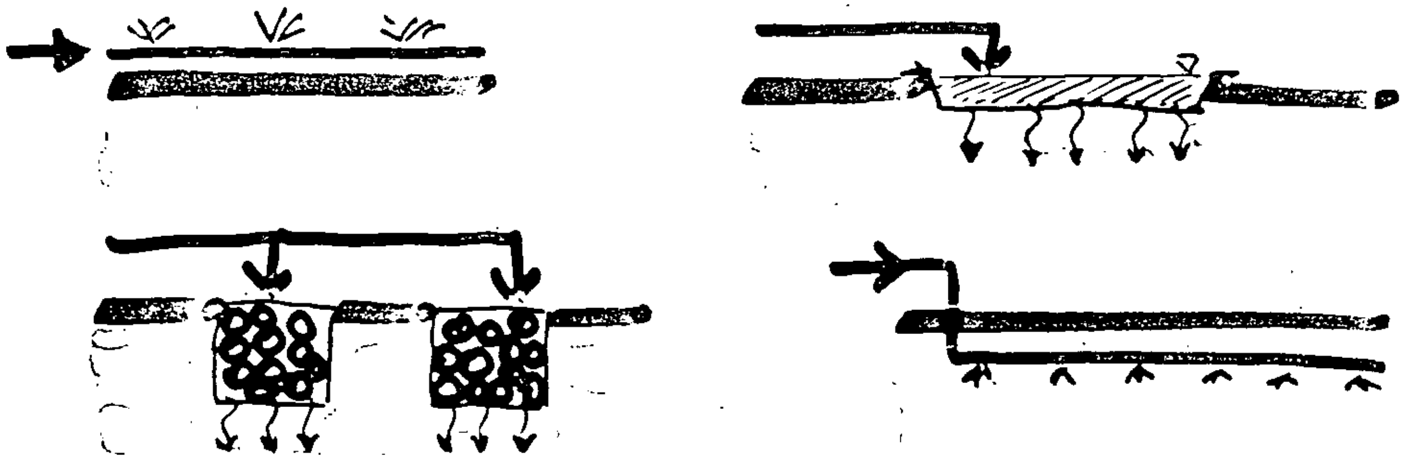






A RECIRCULO DEL LIXIVIADO SOBRE EL RELLENO

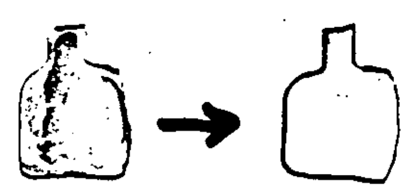
- Metodos



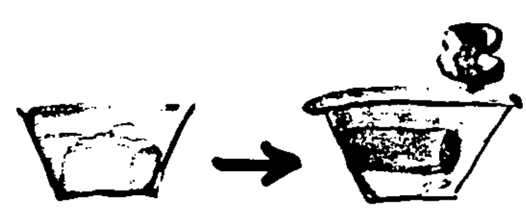
- Objetivos

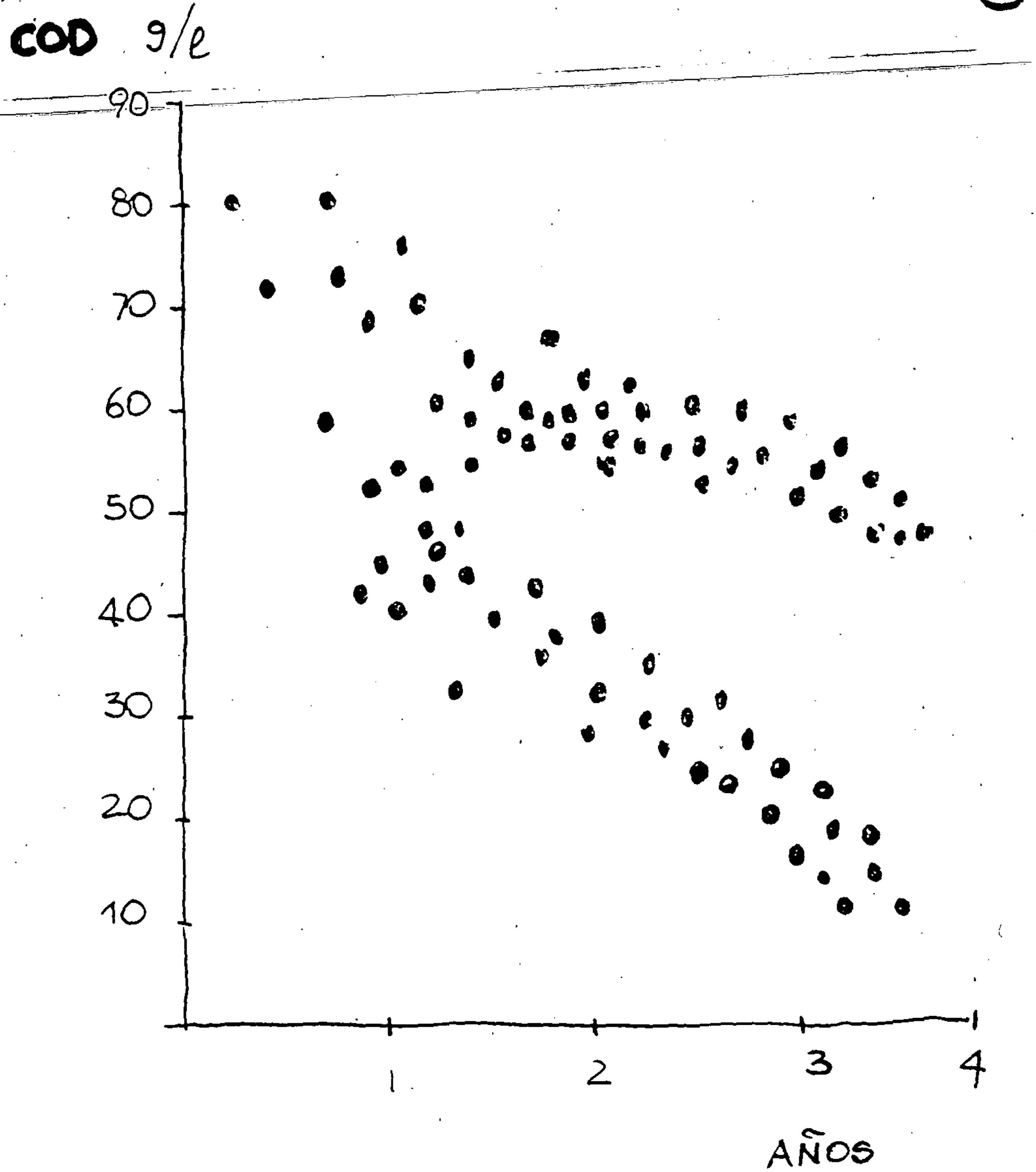
A. REDUCCIÓN DE LA CANTIDAD DE LIXIVIADO

B. MÁS BAJO CONTENIDO DE ORGANICOS EN EL LIXIVIADO



C. MÁS RAPIDA DEGRADACCION DEL RELLENO E MEJOR CONTROLO DE LA PRODUCCIÓN DE BIOGAS.





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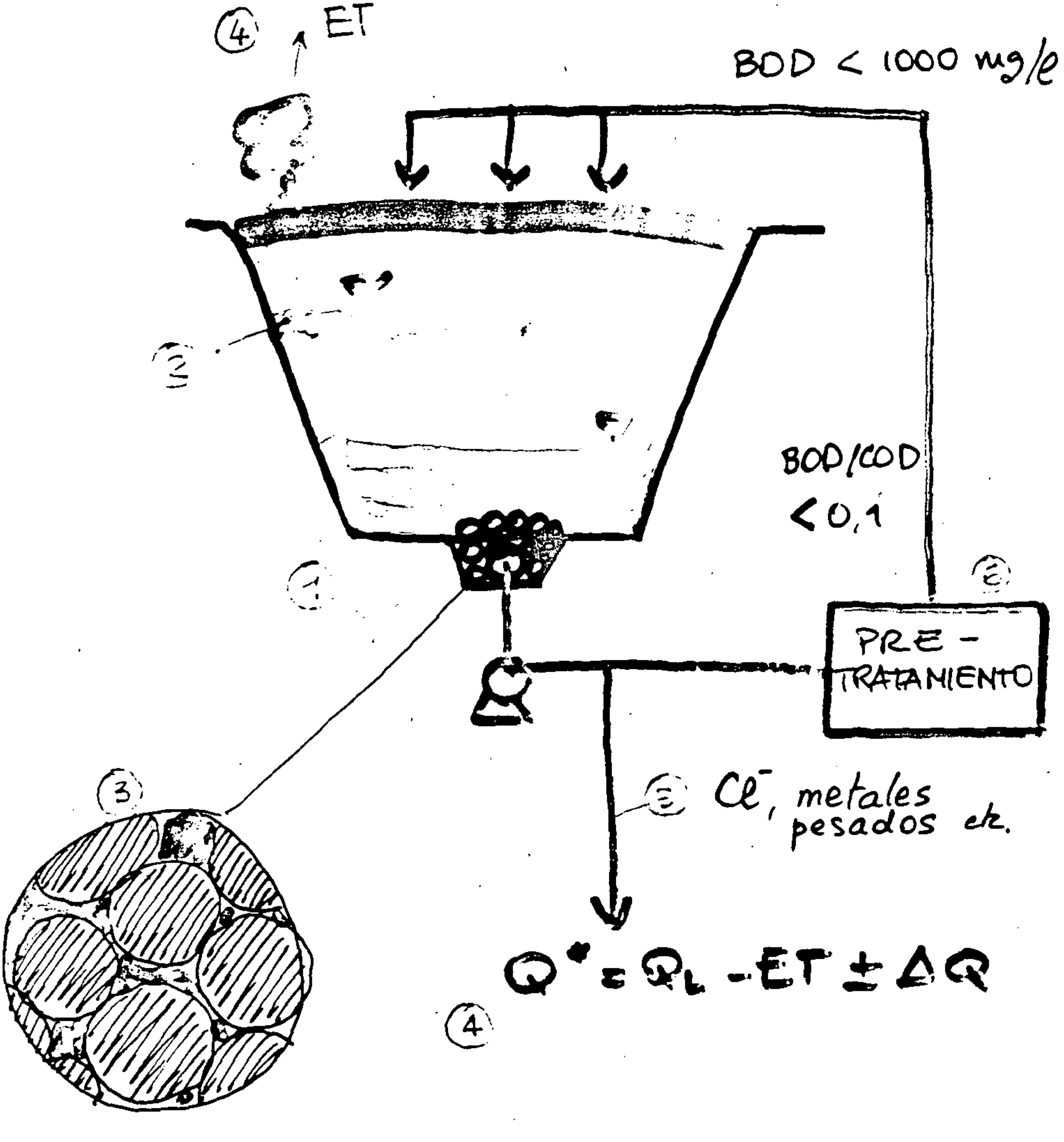
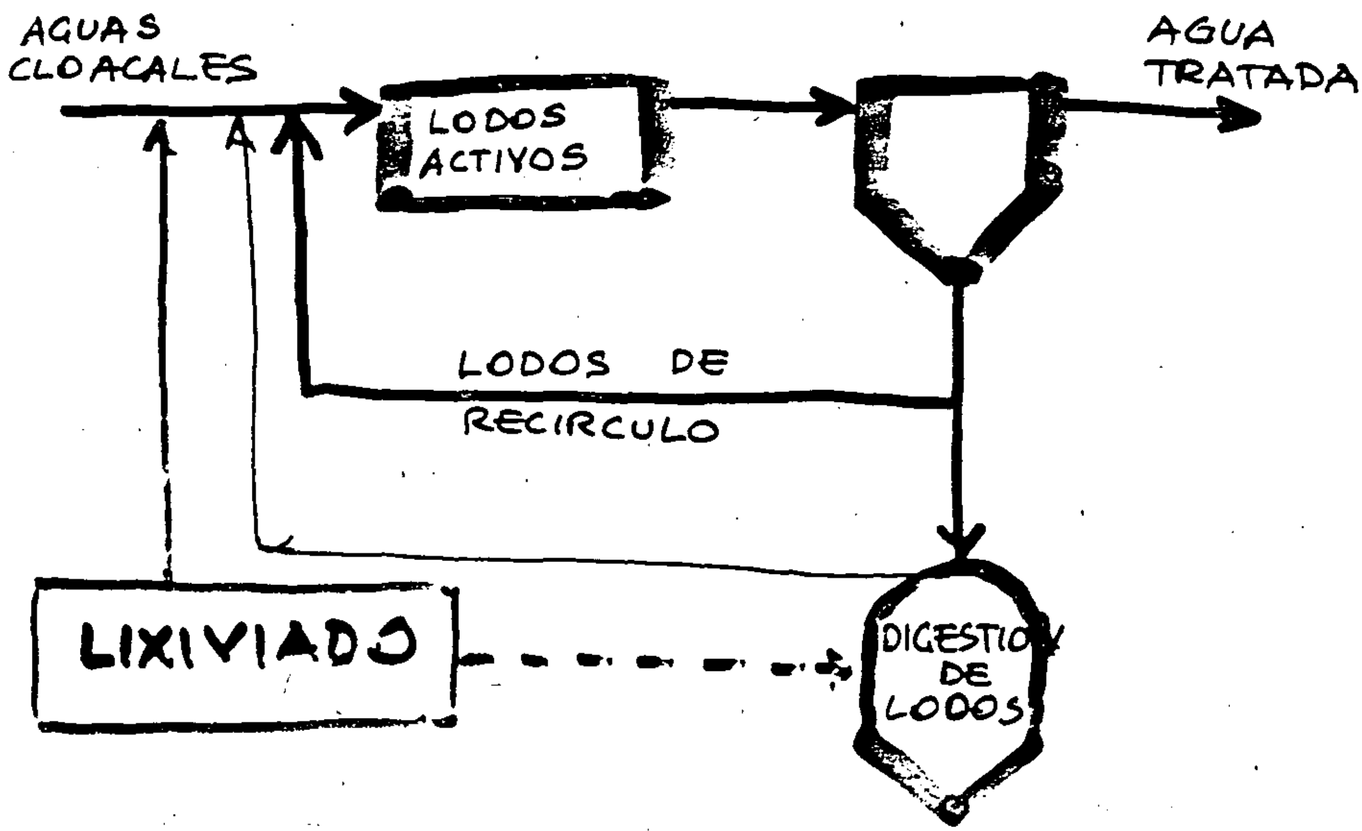
30
20
10
1
2
3
4
AÑOS

- Inconvenientes y problemas

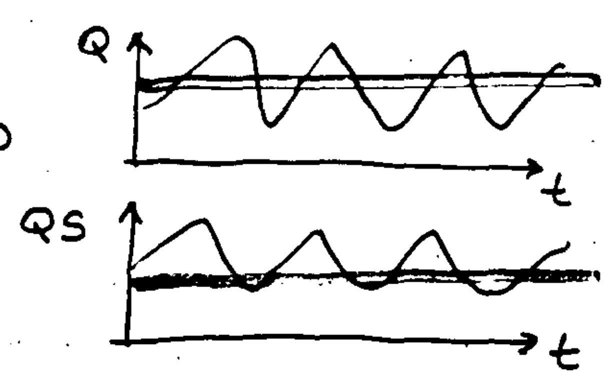


B TRATAMIENTO EXTERNO



PROBLEMAS

- CARGA ORGANICA
- CARGA INORGANICA (PRECIPITACCIÓN DE SAL DE HIERRO)
- DILUICCIÓN DE METALES E ALOGENOS ORGANICOS
- N & P
- PRE-TRATAMIENTO



COTRATAMIENTO IN SITU

PROCESSOS BIOLOGICOS

- ANAEROBICOS
- AEROBICOS

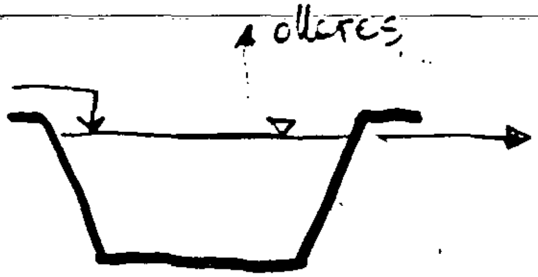
PROCESSES QUIMICO-FISICOS

- PRECIPITACCIÓN Y FLOCCULACCIÓN
- ADSORBIMIENTO SU CARBON ACTIVO
- OSMOSI REVERSA
- EVAPORACCIÓN

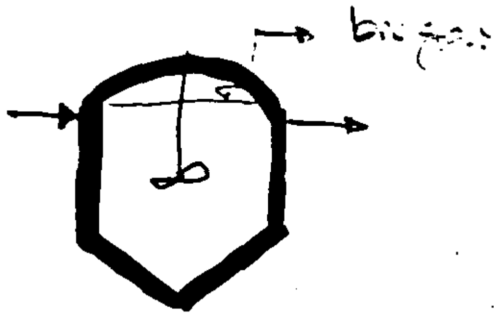
PROBLEMAS

- LIXIVIADO JOVEN O VIEJO
- EFICIENCIA Y LIMITES DE LEY
- COSTO
- COMBINACCION DE PROCESSES

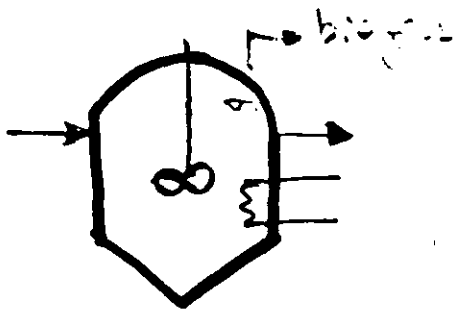
PROCESSES ANAEROBICOS



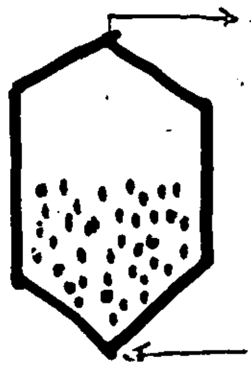
LAGUNAS



DICESTION FRIA



DICESTION CALIENTE



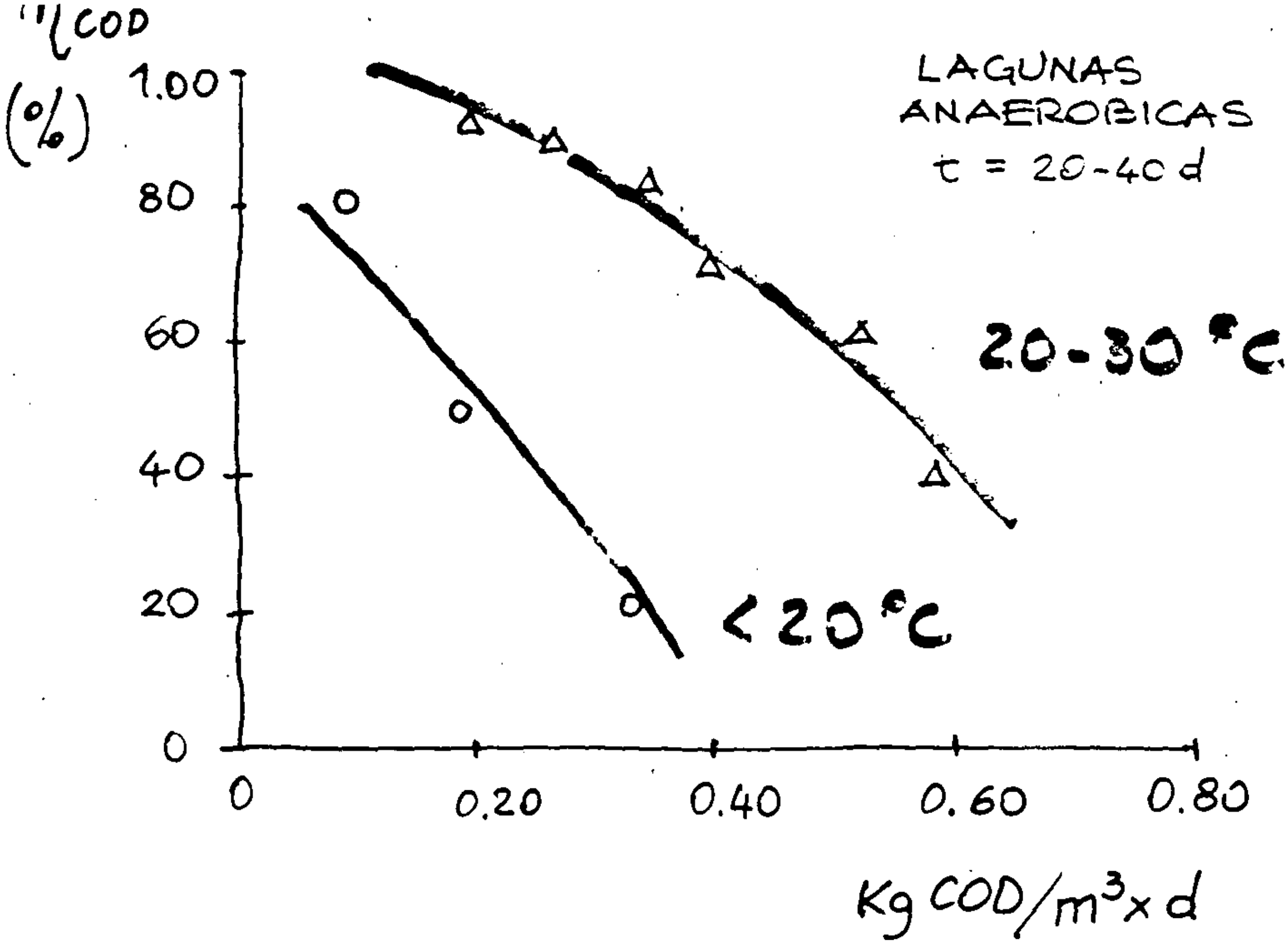
UASB
(LECHO DE LODOS SUSPESOS)

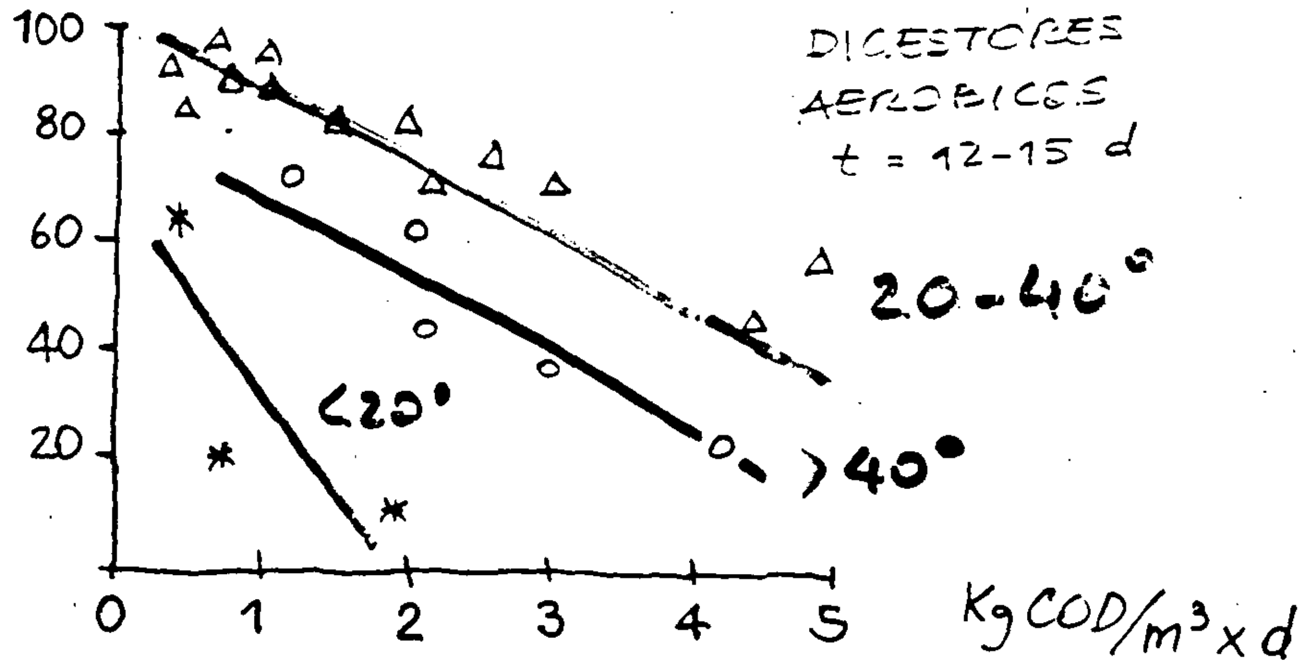
VENTAJAS

- REGOLACCIÓN DEL FLUJO
- BAJO CONSUMO DE ENERGIA
- BAJA PRODUCCIÓN DE LODOS
- PRODUCCIÓN DE METANO
- RIMOCCIÓN DE METALES (SULFURES)

DESVENTAJAS

- OLLORES PARA LAS LAGUNAS
- EFICIENCIAS PARA BOD, COD, NH_4^+.
- SENSIBILIDAD PARA INHIBITORES (pH, FENOLES, ECC.)





$\eta_{COD} \simeq 90\%$ per 10-30 Kg COD/m³ x d

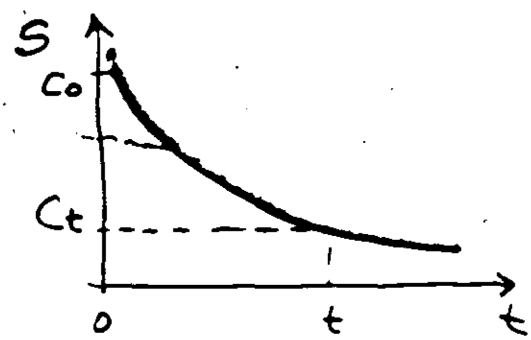
T = 25°C

UASB

DIMENSIONAMIENTO

$$V = \frac{Q\,S_0}{C_v}$$

Q: Flujo, m^3/d — S_0: COD, $Kg\,COD/m^3$ — C_v: $Kg\,COD/m^3 \cdot d$

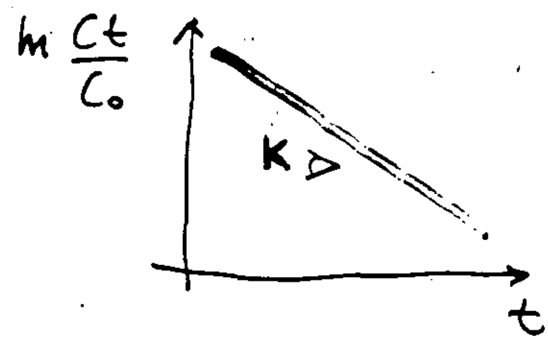


$$-\frac{dS}{dt} = kS$$

$$\int_0^t \frac{dS}{S} = \int_0^t -k\,dt$$

$$\ln \frac{C_t}{C_0} = -kt$$

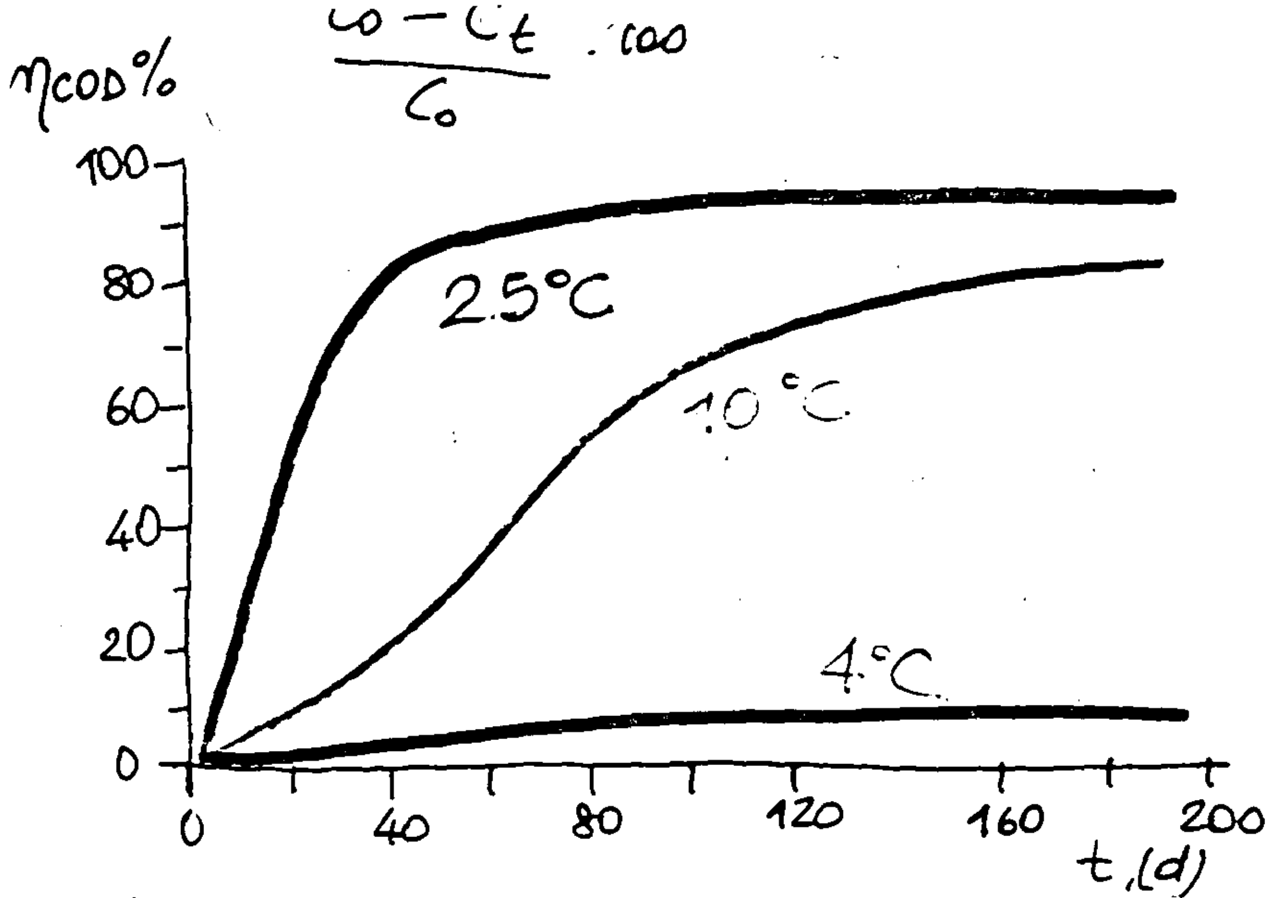
$$C_t = C_0\, e^{-kt}$$

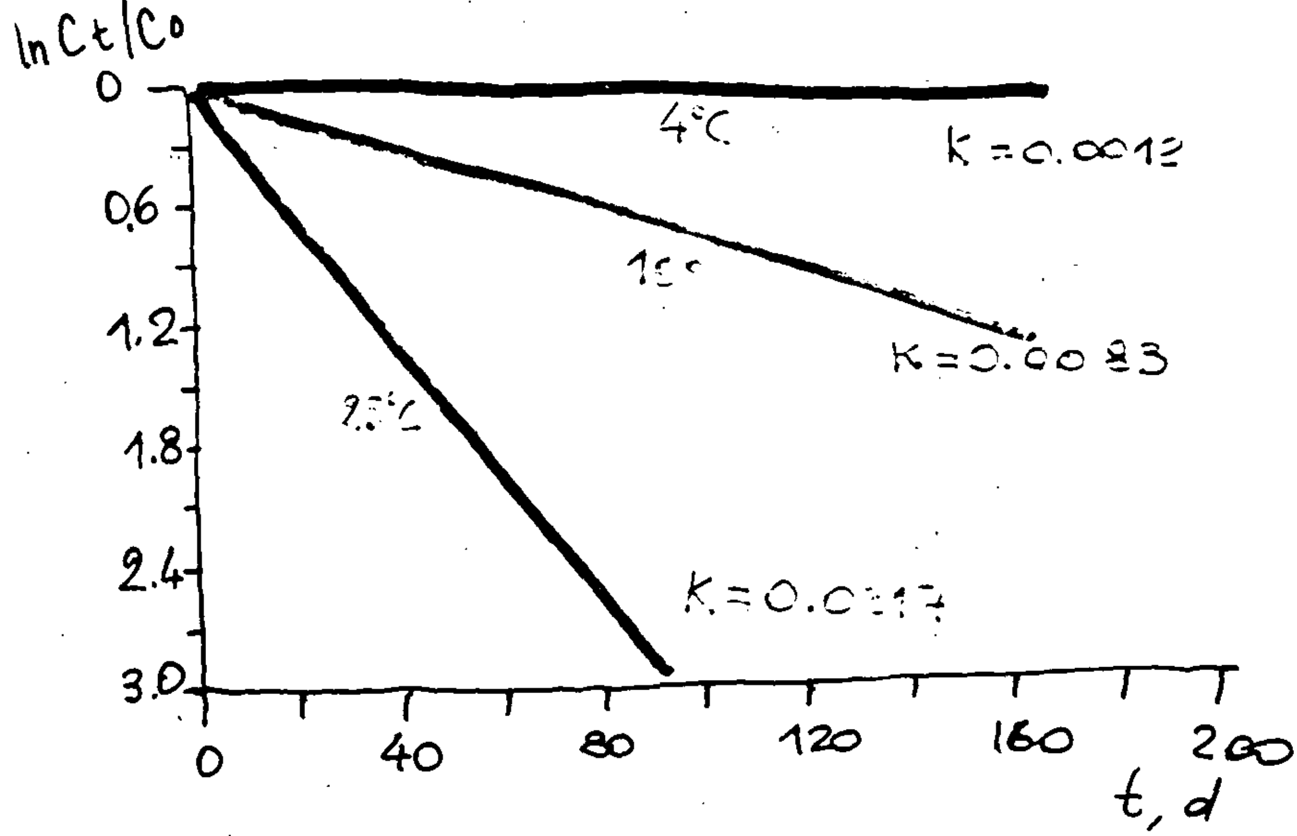


$$\eta_{COD} = \frac{COD_0 - COD_t}{COD_0} = 1 - \frac{COD_t}{COD_0}$$

$$= 1 - e^{-kt} = 1 - e^{-k\frac{V}{Q}}$$

$$V = -Q\left[\ln\left(1-\eta_{COD}\right)/K\right]$$



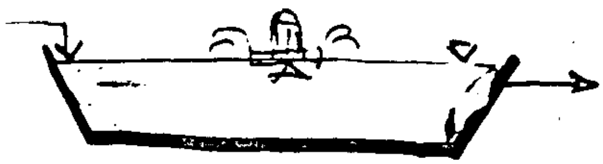


$$K_T = K_{25} \cdot \vartheta^{T-25}$$

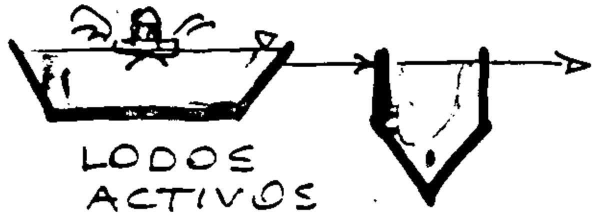
$$\underset{0,0317}{K_{25}} = \underset{0.0083}{K_{10}}\ \vartheta^{25-10}$$

(ϑ)

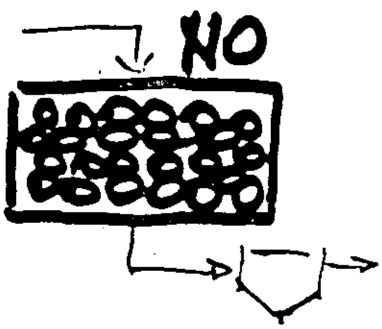
PROCESSOS AEROBICOS



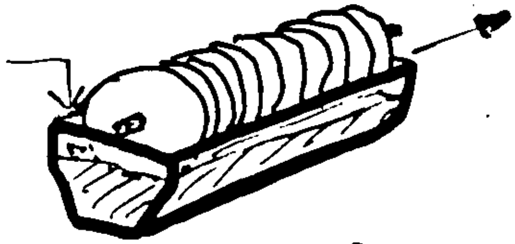
LAGUNAS AEROBICAS / AERATAS



LODOS ACTIVOS



LECHO PERCOLADORE



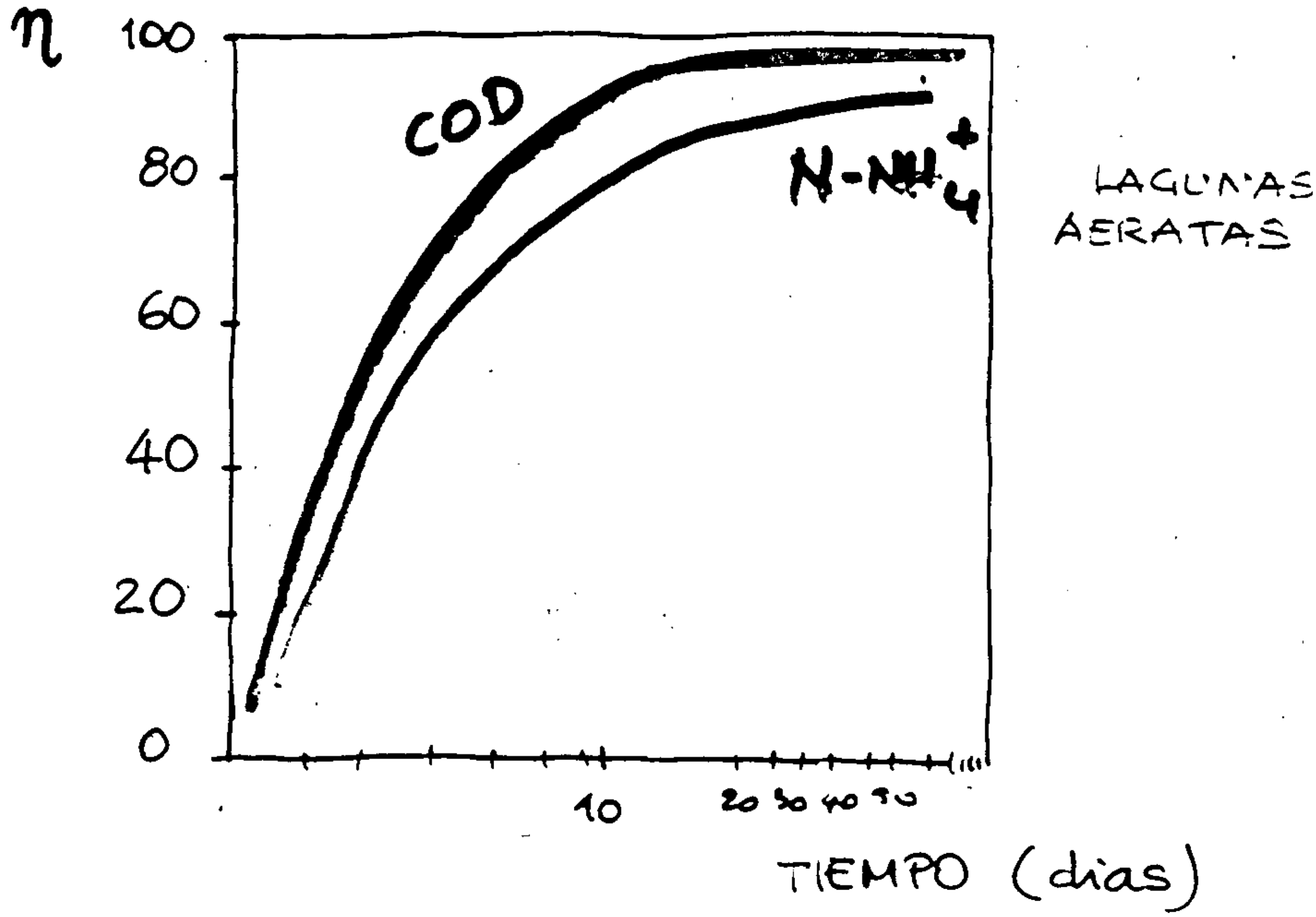
BIODISCOS (CONTACTORES ROTANTE)

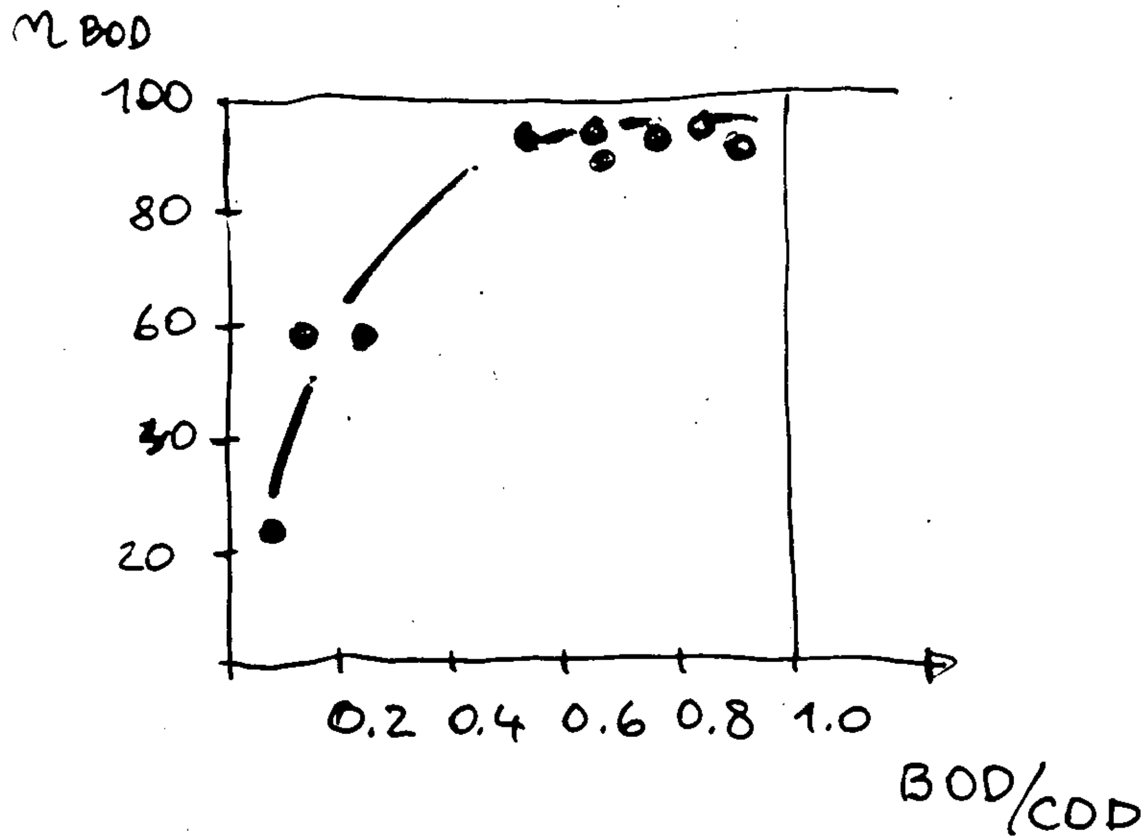
VENTAJAS

- EFICIENCIAS PARA COD, BOD $NH_4 \rightarrow NO_3$
- ALTA VELOCIDAD Y ALTA CARGA ORGANICA

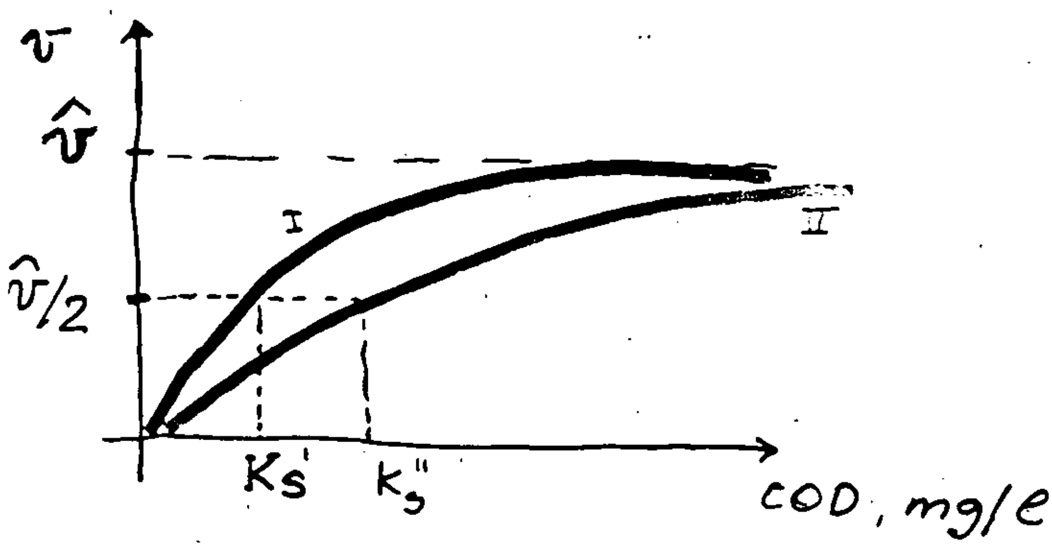
DESVENTAJAS

- SENSIBILIDAD A LA VARIACCIÓN DE FLUJO Y CARGA
- CONTROLO DE NUTRIENTES (FALTA FOSFORO)


η
100
80
60
40
20
0
COD
N-NH4+
LAGUNAS AERATAS
10
TIEMPO (dias)


η BOD
100
80
60
30
20
0.2 0.4 0.6 0.8 1.0
BOD/COD

Costante Kinetica		Lixiviado	Agua cloacale
$\hat{v}$	$\frac{Kg\ COD}{Kg\ TS \times d}$	1.8	5.6
K_s	mg COD/ℓ	182	22-100
K_d	d^{-1}	0.115	0.07
Y	kg TS/Kg COD	0.59	0.67



DIMENSIONAMIENTO

$H = 0.3-0.4\ m$

- LAGUNAS AEROBICAS $C_s = 35 \div 60\ g\ BOD/m^2 \cdot d$
- LAGUNAS AERATAS $\eta \simeq 70\%$

$BOD/COD > 0,4$ $\quad C_V = 0,025 \div 0,05\ \frac{Kg\ BOD}{m^3 \cdot d}$

$BOD/COD < 0,4$ $\quad C_V = 0.001 \div 0.01$ "

~~BOD/COD < 0.1~~ —

$$V = \frac{Q S_0}{C_V}$$

$H = 2-2,5\ m$

- LODOS ACTIVOS

$C_V = 0,2 \div 0,6\ Kg\ BOD/m^3 \cdot d$

C_F (F/M) $= 0.02 \div 0,05\ Kg\ BOD/Kg\ TS \cdot d$

$$V = \frac{Q S_0}{C_F \cdot X} \quad [m^3]$$

(X: Kg/m^3)

$$V = \frac{Q (S_0 - S)}{\hat{\nu} \cdot X}$$

TRATTAMENTI CHIMICO-FISICI

USATI SOPRATTUTTO PER:

- AOX - COMPOSTI ORGANICI ALOGENATI
- METALLI PESANTI
- COMPOSTI AMMONIACALI

QUINDI:

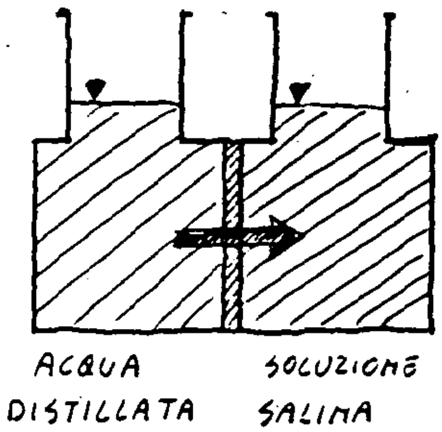
PERCOLATI VECCHI

↓

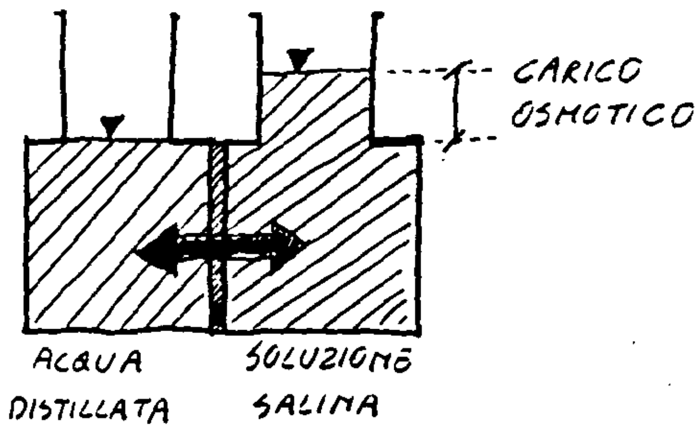
PERCOLATI GIOVANI SE LE NORME SONO MOLTO RESTRITTIVE

- PRECIPITAZIONE / FLOCCULAZIONE
- ASSORBIMENTO SU CARBONI ATTIVI
- OSMOSI INVERSA
- OSSIDAZIONE CHIMICA

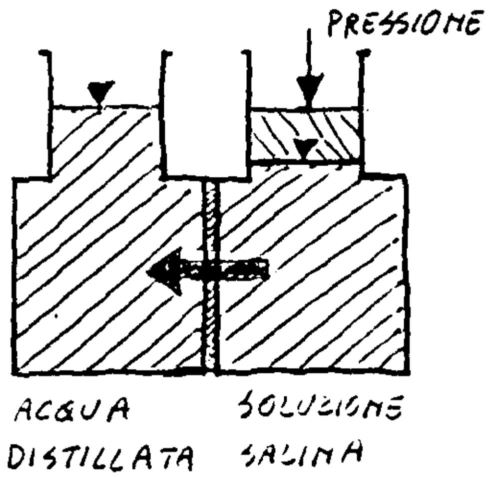
OSMOSI INVERSA



a) FLUSSO OSMOTICO



b) EQUILIBRIO OSMOTICO



c) OSMOSI INVERSA

IN CONDIZIONI NORMALI METTENDO A CONTATTO DUE SOLUZIONI A CONCENTRAZIONE DIFFERENTE SI HA LA OSMOSI NATURALE CIOE' UN FLUSSO DI SOLVENTE DALLA SOLUZIONE MENO CONCENTRATA A QUELLA PIU' CONCENTRATA. IL FLUSSO PROSEGUE FINO A QUANDO IL CARICO OSMOTICO NON EGUAGLIA LA PRESSIONE OSMOTICA. IN QUESTE CONDIZIONI SI HA L'EQUILIBRIO OSMOTICO. APPLICANDO UNA PRESSIONE ESTERNA SULLA SOLUZIONE PIU' CONCENTRATA IL FLUSSO DEL SOLVENTE PUO' ESSERE INVERTITO (MA NON IL FLUSSO DEL SOLUTO GRAZIE ALLA PRESENZA DELLA MEMBRANA SEMIPERMEABILE). DA QUESTA INVERSIONE DI FLUSSO IL TERMINE OSMOSI INVERSA.

$$\pi = \Delta C \cdot R \cdot T$$

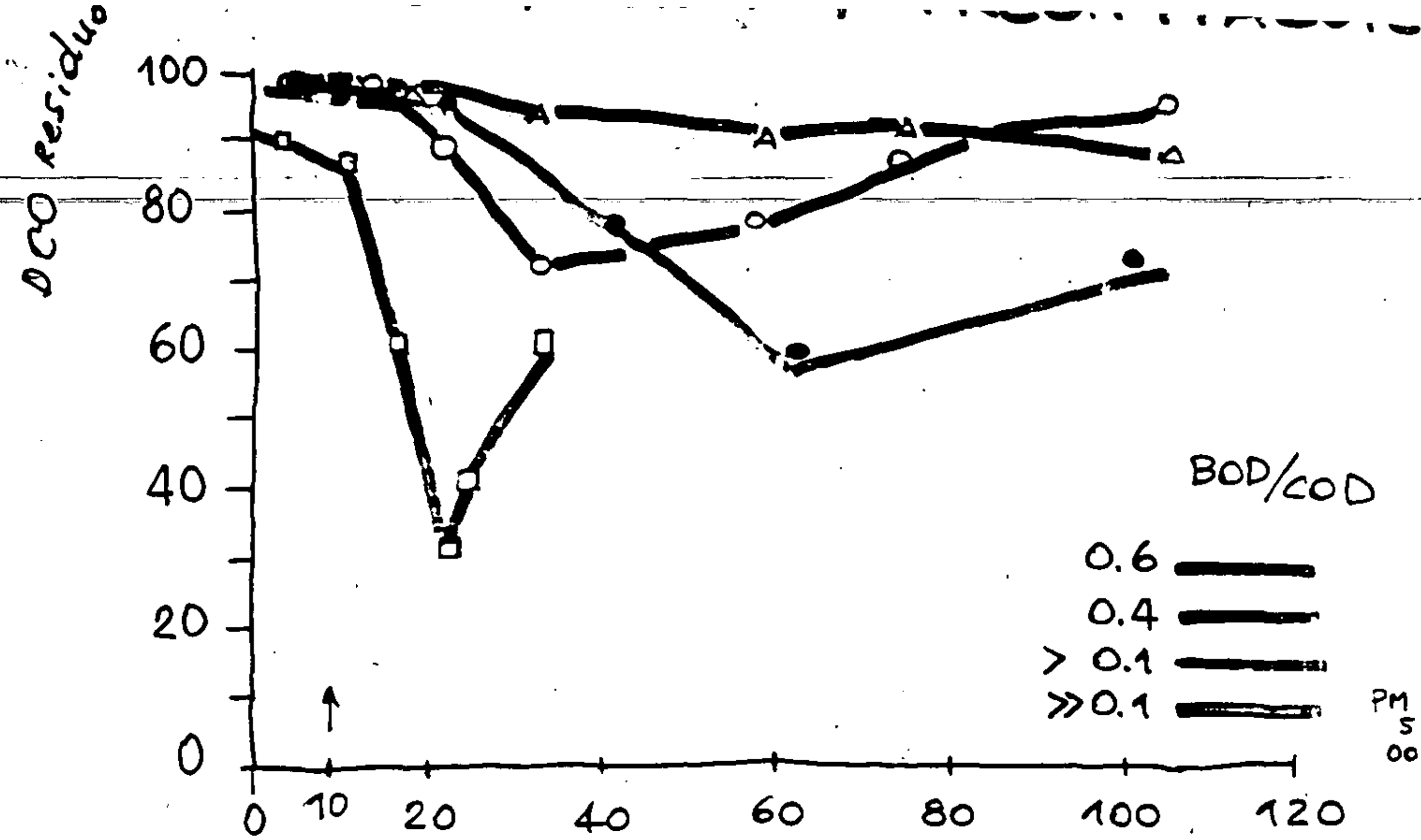
π = PRESSIONE OSMOTICA

ΔC = DIFFERENZA DI CONC. MOLALE FRA LE SOLUZIONI

R = COSTANTE

T = TEMPERATURA

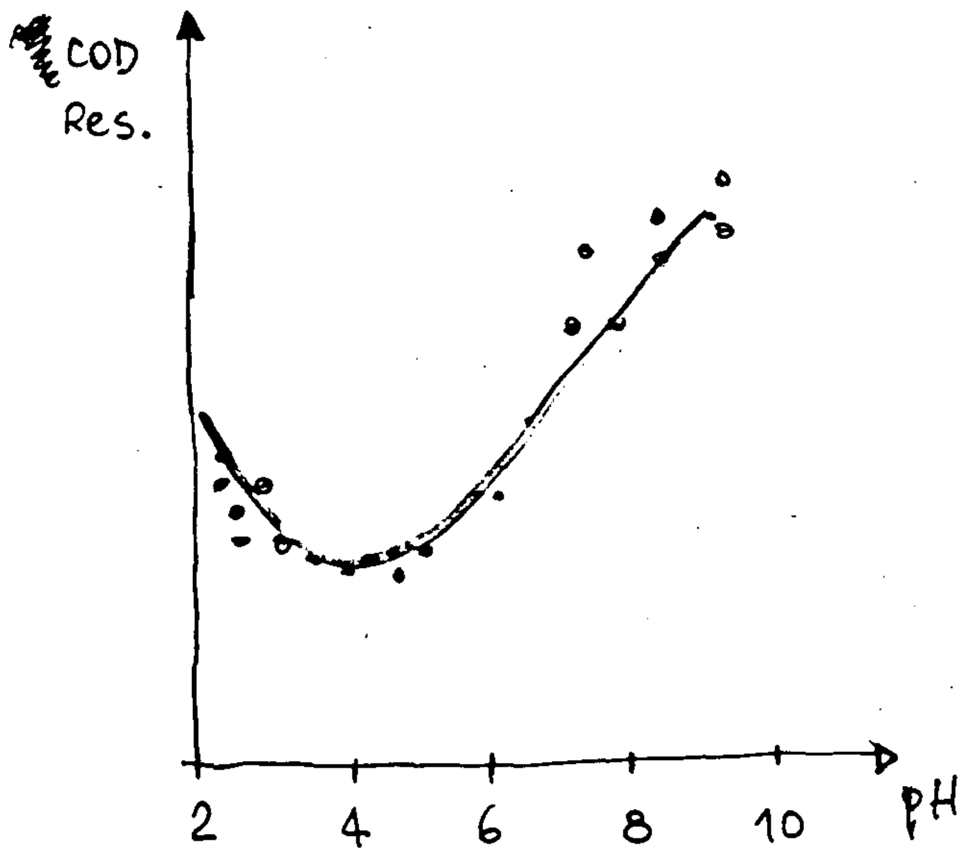
PER T = COST. LA π E' PROPORZIONALE A ΔC.



η COD = 80-90%
η AOX = 65%
η metales = 50-70%

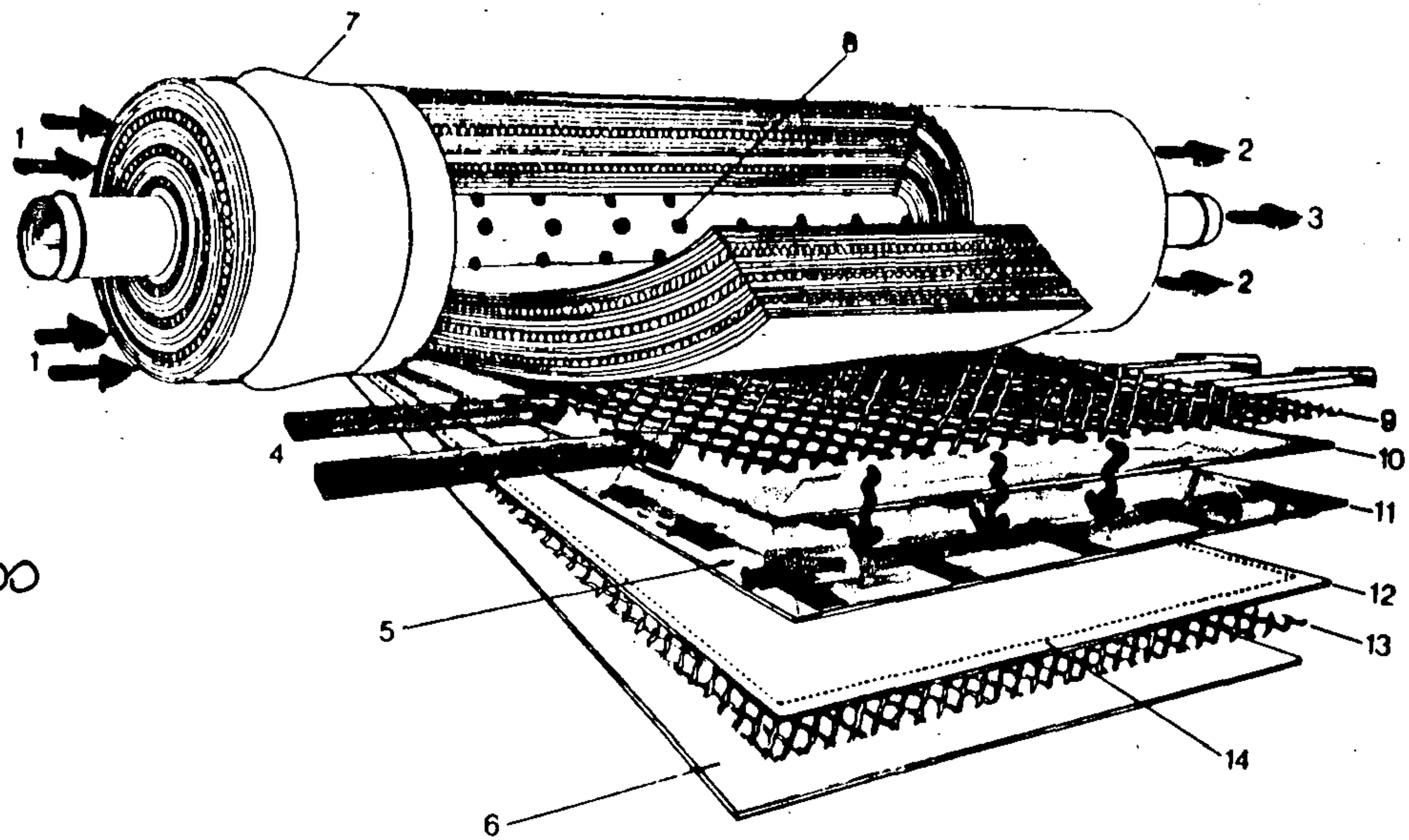
~~NH4~~

1 mole = 52 g



$FeCl_3$
$FeSO_4$
$FeClSO_4$

27 bis

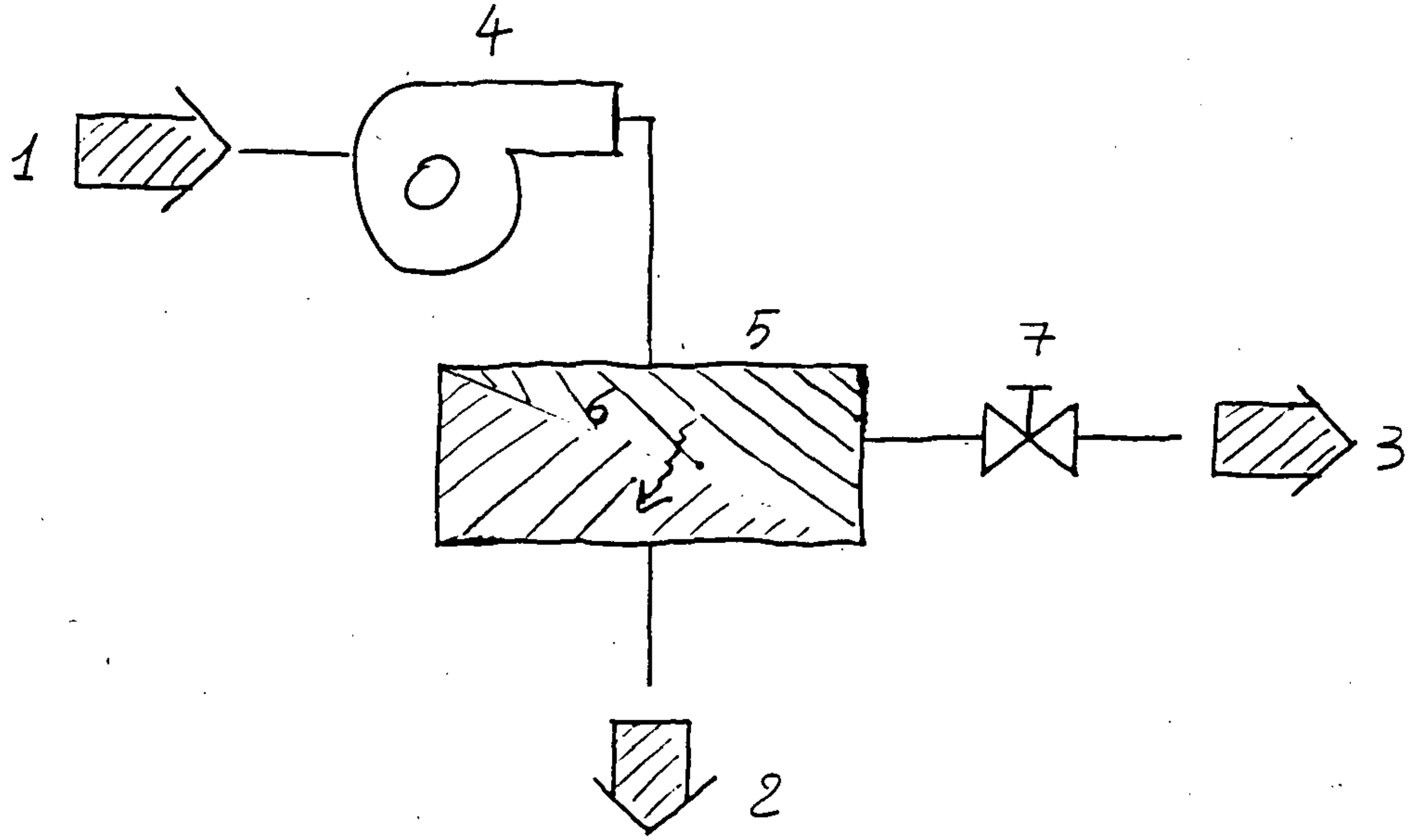


- ULTRAFILTRACCIÓN
  PM 10.000 ÷ 100.000
- OSMOSI REVERSA
  PM < 10.000

1. *Raw water*
2. *Reject*
3. *Permeate outlet*
4. *Direction of flow of raw water*
5. *Direction of flow of permeate*
6. *Protective coating*
7. *Seal between module and casing*
8. *Perforated tube for collecting permeate*
9. *Spacer*
11. *Membrane*
11. *Permeate collector*
12. *Membrane*
13. *Spacer*
14. *Line of seam connecting the two membranes*

Figure 7. Spiral-wound module scheme (Degrémont, 1979).

SCHEMA DI FLUSSO DEI PROCESSI A MEMBRANA



1 LIQUAME

2 LIQUAME DEPURATO

3 CONCENTRATO

4 POMPA AD ALTA PRESSIONE

5 MODULI DI DEPURAZIONE

6 MEMBRANA SEMI-PERMEABILE

7 VALVOLA DI SCARICO

- PRESSIONI OPERATIVE

28 bar POLIAMM. AROMATICA

30-42 bar ACETATO DI CELLULOSA

- EFFICIENZE

$\eta_{COD, BOD, AOX} = 80\%$	SINGOLO STADIO
$\eta_{COD, BOD, AOX} = 99\%$	DOPPIO STADIO
$\eta_{MET. PESANTI} = 70\%$	DOPPIO STADIO

SCARSE EFFICIENZE PER ACIDI VOLATILI E NH_4

↳ NECESSITA' PRETRATTAMENTI

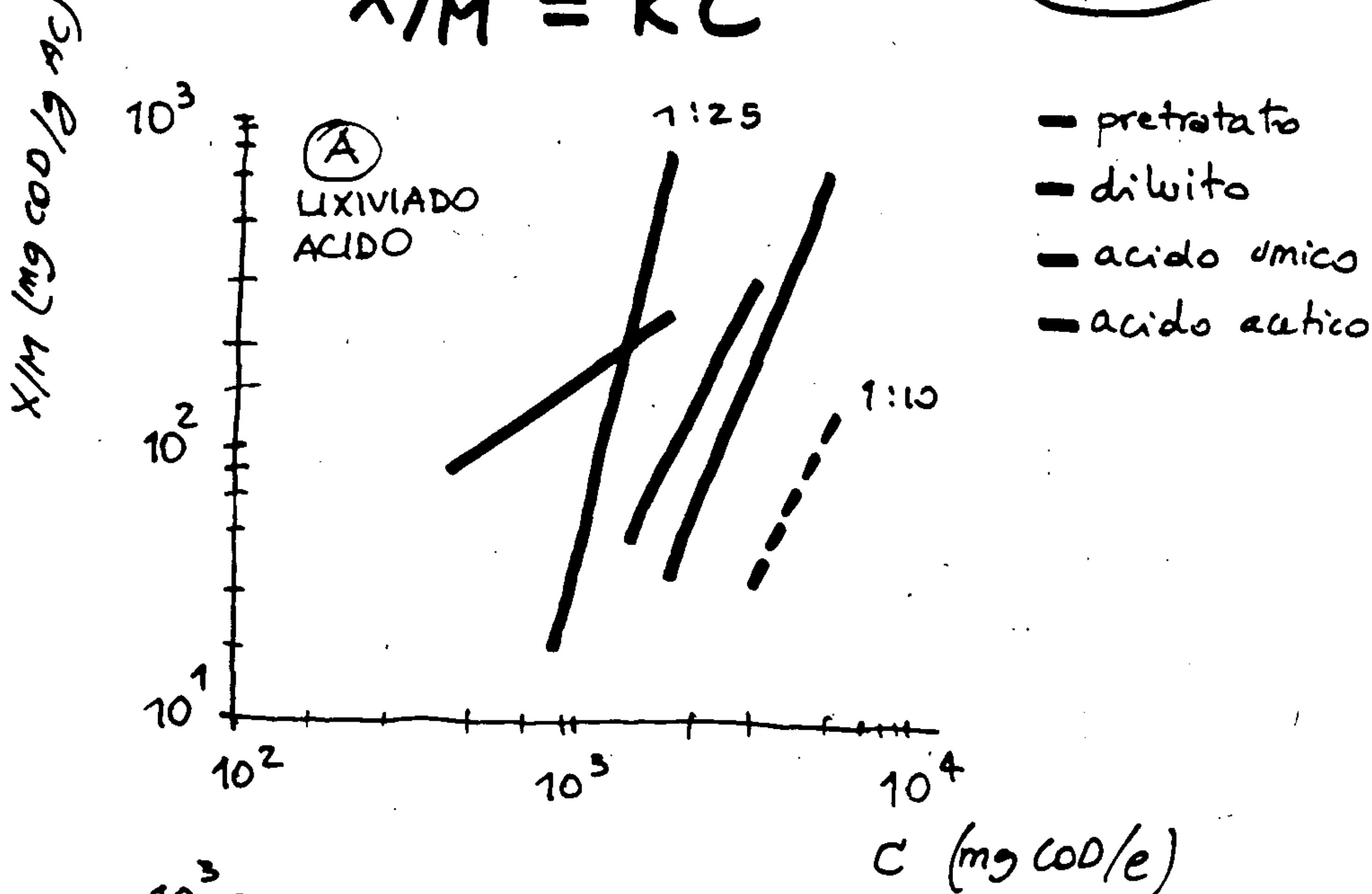
- PROBLEMI

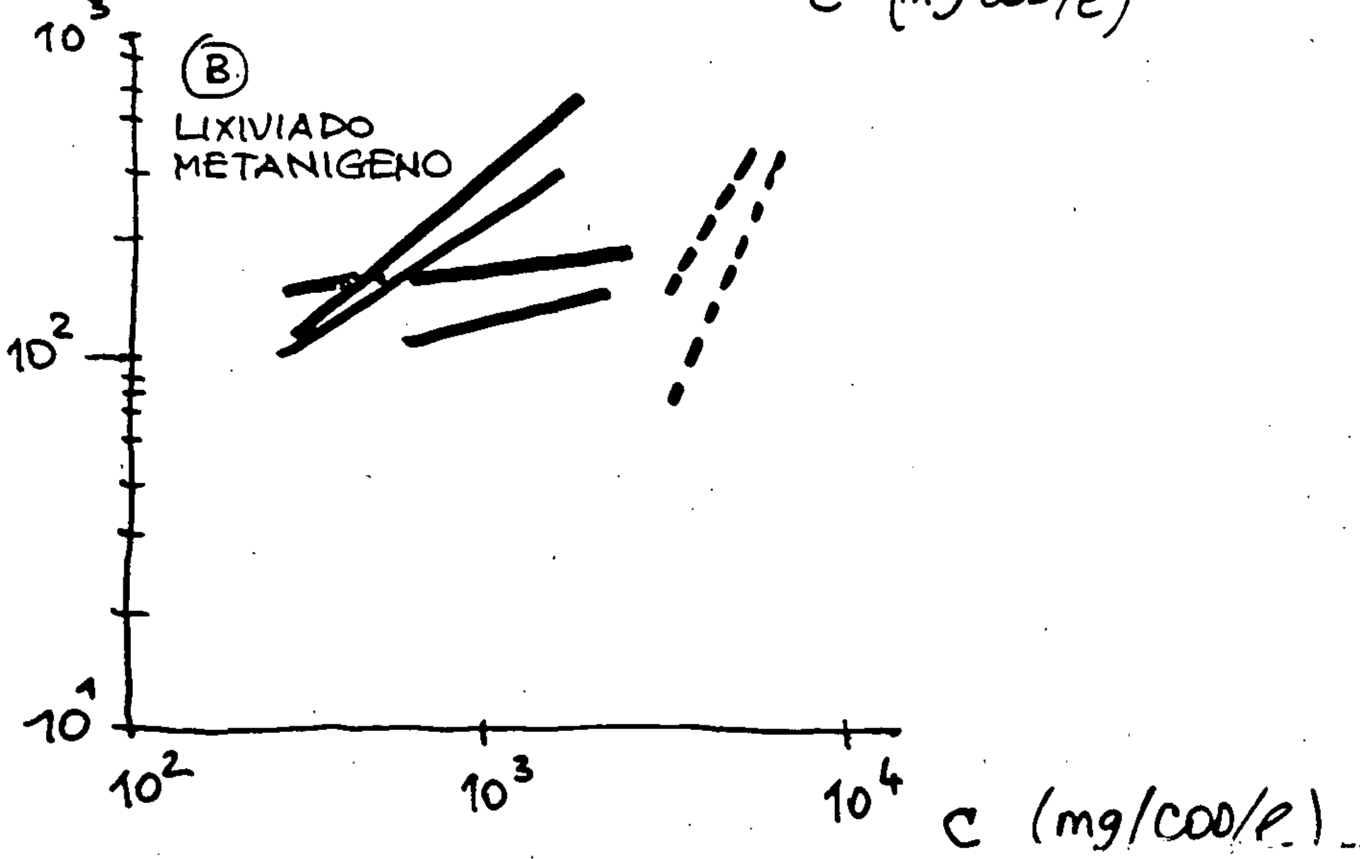
- CONCENTRATO ⟶ RIFIUTO TOSSICO E NOCIVO
- OCCLUSIONI
  - INCROSTAZIONI DA CARBONATI E SOLFATI
  - PRECIPITAZIONE METALLI
  - PARTICELLE GROSSOLANE NEL LIQUAME
  - CRESCITA BIOLOGICA
- PRESSIONI ELEVATE ⟹ COSTI ELEVATI

ADSORBIMENTO

$\eta_{COD,AOX} = 70-80\%$

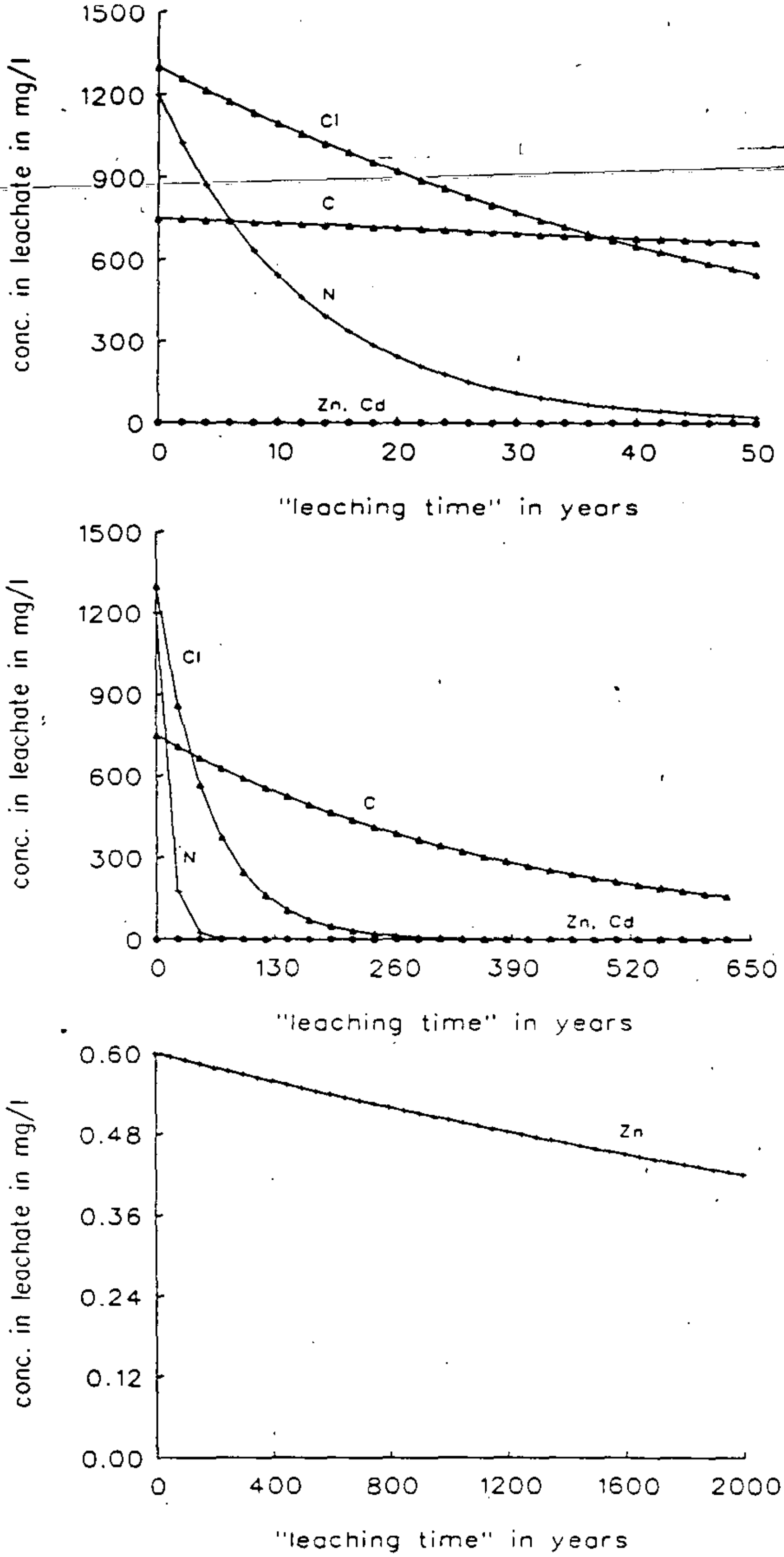
$$X/M = K C^{1/n}$$



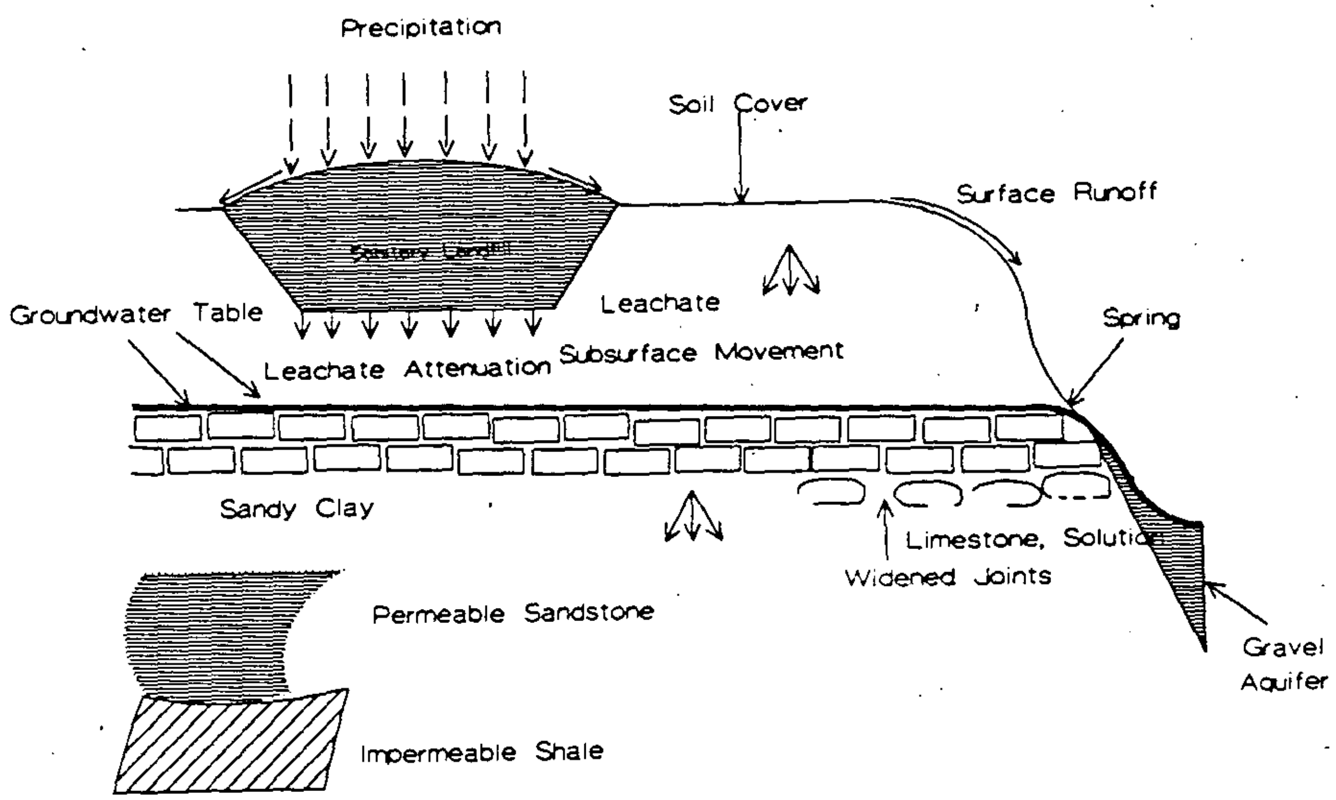


Average, minimum and maximum concentrations in leachate, the number of analyses, the number of landfills and the period of analyses.

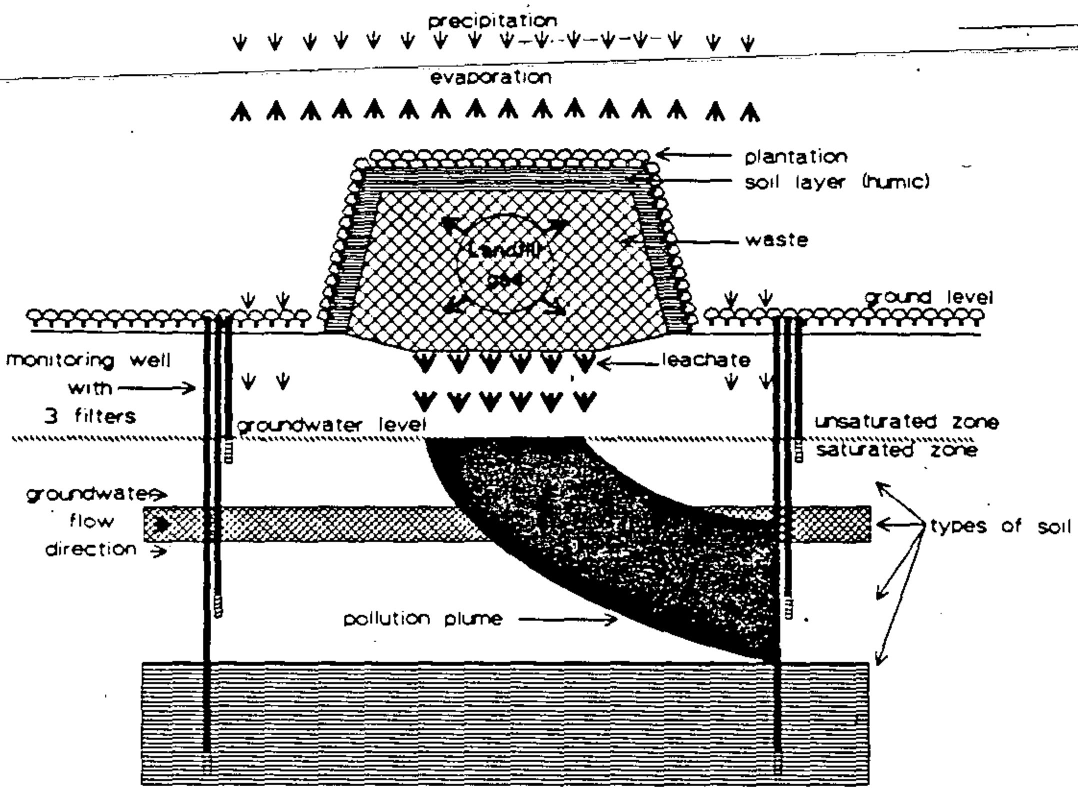
Component	unit	average	range	
~~CZV~~ COD	mg/l	5424	1	-68330
pH	-	6,8	4,7	- 8,4
Cl	mg/l	743	26	- 7122
NH_4-N	mg/l	237	6	- 1410
NO_3	mg/l	218	0	- 1740
Kjehldahl-N	mg/l	438	3	- 2250
SO_4	mg/l	842	36	- 5865
As	µg/l	51	0	- 499
Cd	µg/l	4	0	- 140
Cr	µg/l	67	0	- 1750
Cu	µg/l	30	0	- 830
Hg	µg/l	1	0	- 26
Ni	µg/l	92	0	- 1050
Pb	µg/l	394	0	-30300
Zn	µg/l	720	0	-30000
Ba	µg/l	556	0	- 7810
Fe	mg/l	417	1	- 2300
Ca	mg/l	787	33	- 3677
Mg	mg/l	177	20	- 729
Na	mg/l	2988	1640	- 4335
K	mg/l	1813	1450	- 2190
PAH	µg/l	2	0	- 10
EOCl	µg/l	29	0	- 450
~~Olie~~ OIL	mg/l	1386	0	-30200
Ar. solvents	µg/l	1042	7	- 2550



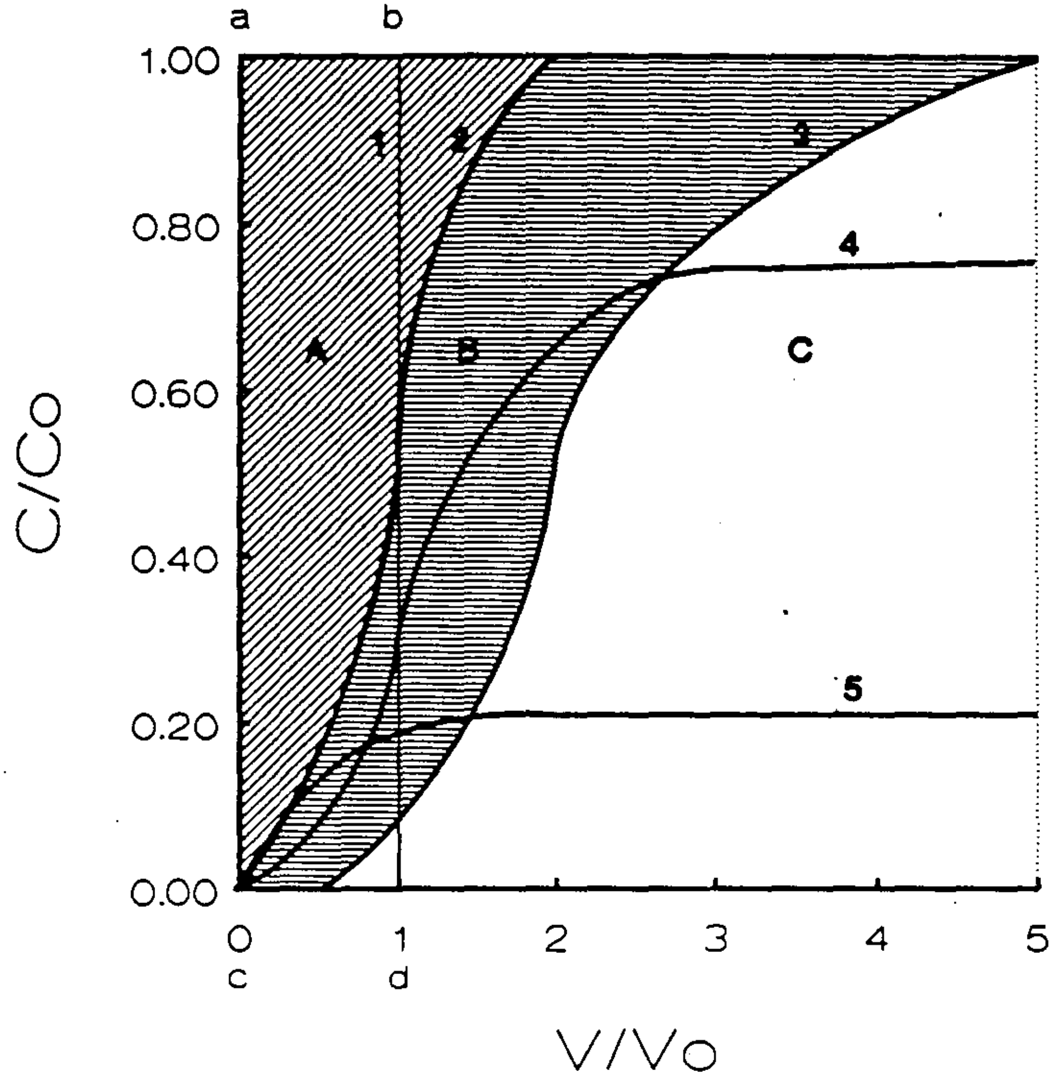
Concentration of some components in leachate versus time (calculated!).



Interrelation between climatic, topographic, hydrolic, and geologic factors in terms of leachate travel and groundwater contamination



Schematic diagram of key aspects of a completed landfill



Breakthrough curves:
1) convective flow;
2) convective flow + diffusion/dispersion (Cl⁻);
3) 2 + adsorption; 4) 3 + microbiological degradation;
5) 4 + precipitation.
C=effluent concentration; C_o=influentconcentration; V=total effluent volume: V_o=total watervolume in the column.

Distribution ratios of Cd, Fe and Ni in poor humic sand and rich humic sand

Metal	Humic-poor sand	Humic-rich sand
Cd	0.21	1.86
Fe	0.73	1.59
Ni	0.38	2.47

$$v^* = \frac{k * i}{\epsilon}$$

v^* = effective (pore)flow velocity of groundwater (m/yr)
i = hydraulic head gradient in the aquifer
k = hydraulic conductivity (m/d)

Next the transport of a pollutant along a streamline in the aquifer can be calculated. For the migration of a solute front the following equation is used:

$$v_i = v^* \left(\frac{1}{1 + R_i} \right)$$

v_i = migration velocity of solute front (m/yr)
R_i = distribution ratio, representing the distribution of solute i over solid phase (adsorption) and soil solution ($1 + R_i$ = retardation factor)

Average-, minimum- en maximum concentrations of some parameters in groundwater near landfill sites

Parameter	Unit	no.	Average	Minimum	Maximum
Cl	mg/l	3978	335.26	0.70	18200.00
COD	mg/l	3650	202.01	0.00	57756.00
EC	µS/cm	3378	1238.37	5.00	30400.00
N - kjeldahl	mg/l	3028	20.53	0.00	1250.00
pH	-	2986	7.60	2.90	711.00
Sulphate	mg/l	2544	109.51	0.00	4550.00
Nitrate	mg/l	2430	5.79	0.00	760.00
Total phosphate	mg/l	1863	2.50	0.00	325.00
NH_4-N	mg/l	1796	17.29	0.00	1170.00
Zn	µg/l	1693	183.60	0.01	34000.00
Ni	µg/l	1661	25.81	0.00	1300.00
Cr	µg/l	1592	38.81	0.00	34000.00
Cu	µg/l	1579	24.72	0.00	3500.00
Pb	µg/l	1550	19.43	0.00	700.00
Na	mg/l	1422	102.91	2.40	15000.00
K	mg/l	1418	23.70	0.00	1720.00
Cd	µg/l	1390	179.13	0.00	45300.00
As	µg/l	1338	26.92	0.00	2350.00
Hg	µg/l	1135	1.18	0.00	211.30
Bicarbonate (hardness)	mg/l	1131	415.46	0.00	18000.00
EOCl	µg/l	907	3.80	0.10	395.00
Total hardness	mg/l	828	559.94	0.00	3575.00
Ca	µg/l	685	24726.54	1.60	620000.00
Mg	mg/l	680	448.48	0.10	150000.00
Nitrite	mg/l	679	1.80	0.00	670.00
Fe	µg/l	610	10791.31	0.00	350000.00
Mn	µg/l	475	712.24	0.00	18000.00
Fluoride	mg/l	431	0.16	0.01	24.00
Benzene	µg/l	372	4.13	0.00	231.10
Toluene	µg/l	364	25.54	0.00	3500.00
Ethylbenzene	µg/l	359	6.08	0.00	231.30
Cyanide (total) CN	µg/l	352	14.05	0.00	1000.00
o-, *m*- *en p*-xylene	µg/l	348	15.16	0.00	800.00
Naphtalene	µg/l	286	4.99	0.01	270.00
BOD	mg/l	279	519.24	0.01	20300.00
Ammonia as N	mg/l	225	24.86	0.01	1250.00
Ba	µg/l	224	197.76	5.00	2750.00
Alpha-HCH	µg/l	217	1.08	0.00	30.00

Average-, minimum- en maximum concentrations of some parameters in groundwater near landfill sites					
Parameter	**Unit**	**no.**	**Average**	**Minimum**	**Maximum**
Fluoranthene	µg/l	217	2.78	0.00	220.70
Gamma-HCH	µg/l	215	1.82	0.00	60.00
HCB	µg/l	213	1.02	0.00	54.00
Benzo(b)fluoranthene	µg/l	212	1.49	0.00	221.10
Benzo(a)pyrene	µg/l	211	1.50	0.00	221.30
Benzo(g,h,i)perylene	µg/l	211	1.43	0.00	221.50
Benzo(k)fluoranthene	µg/l	208	1.43	0.00	221.20
Tetrachloroethene (per)	µg/l	207	4.62	0.00	232.70
Indeno(1,2,3-cd)pyrene	µg/l	199	1.55	0.00	221.60
Dibenzo(a,h)anthracene	µg/l	181	1.61	0.00	221.40
Total organic carbon	mg C/l	181	56.44	0.00	392.00
Benz(a)anthracene	µg/l	180	1.89	0.00	220.90
Chrysene	µg/l	179	1.72	0.00	221.00
Trichloroethene (tri)	µg/l	178	4.83	0.00	232.60
Pyrene	µg/l	175	1.72	0.00	220.80
Anthracene	µg/l	171	3.00	0.00	220.60
Phenantrene	µg/l	170	1.89	0.01	220.50
Nitrate + Nitrite	µg/l	163	0.16	0.00	4.30
Acenaphtene	µg/l	162	2.02	0.00	220.20
Fluorene	µg/l	162	1.98	0.01	220.40
Dichloromethane	µg/l	161	1.90	0.10	22.00
Mineral oil (total)	mg/l	152	373.47	0.01	16600.00
Trichloromethane (chlorooform)	µg/l	147	5.64	0.09	232.20
Tetrachlorocarbon (tetra)	µg/l	143	5.95	0.10	232.30
Acenaphtylene	µg/l	134	2.17	0.01	220.30
Beta-HCH	µg/l	132	0.43	0.00	2.00
D.D.D	µg/l	132	0.21	0.00	1.00
D.D.E	µg/l	132	0.24	0.00	3.80
D.D.T	µg/l	132	0.21	0.00	1.00
1,1,2-trichloroethane	µg/l	126	3.07	0.20	232.52
Endrin	µg/l	126	0.45	0.00	2.00
Propylbenzene	µg/l	122	4.61	0.00	231.40
1,1,1-trichloroethane	µg/l	117	5.20	0.20	232.51
Phenol	µg/l	108	3.65	0.20	67.00
Alpha-endosulfan	µg/l	105	1.33	0.00	5.00
Co	µg/l	105	36.18	1.00	700.00
P-number		105	0.16	0.00	2.20
Dieldrin	µg/l	104	0.54	0.00	2.00

Averages-, minimum- en maximum concentrations of some parameters in groundwater near landfill sites

Parameter	Unit	no.	Average	Minimum	Maximum
-Dichlorophenol (total)	µg/l	4	0.01	0.01	0.01
Phenitrothion	µg/l	4	2.00	2.00	2.00
C10-aromates	µg/l	3	13.33	5.00	30.00
Camphor	µg/l	3	26.00	1.00	47.00
Chlorophenols (total)	µg/l	3	0.50	0.50	0.50
Dichloroethene	µg/l	3	0.50	0.50	0.50
Organochloro-pesticides (total)	µg/l	3	0.50	0.50	0.50
o- *m*- and *p*-cresol	µg/l	3	0.50	0.50	0.50
PCB's (polychlorobiphenyles)	µg/l	3	0.40	0.40	0.40
Trimethyl bicyclo heptane	µg/l	3	101.00	47.00	200.00
Plasticizers (total)	µg/l	3	0.30	0.30	0.30
Acetone	µg/l	2	117.05	0.00	234.10
Cineole	µg/l	2	20.50	17.00	24.00
i-butanol	µg/l	2	177.31	120.00	234.61
Li	µg/l	2	0.10	0.10	0.10
Methylpropanol	µg/l	2	46.00	25.00	67.00
Trimethyl cyclohexanemethanol	µg/l	2	190.00	50.00	330.00
Trimethylcyclohexanol	µg/l	2	5.50	1.00	10.00
2 (3H) benzothiazolon	µg/l	1	60.00	60.00	60.00
Benzenepropanoicacid	µg/l	1	9000.00	9000.00	9000.00
Borium	µg/l	1	77.00	77.00	77.00
Butanone (total)	µg/l	1	1500.00	1500.00	1500.00
Dichloroethane (total)	µg/l	1	232.40	232.40	232.40
Dimethylpentanone	µg/l	1	15.00	15.00	15.00
Endosulfan (total)	µg/l	1	0.01	0.01	0.01
Formaldehyde	µg/l	1	0.07	0.07	0.07
Hexanol	µg/l	1	70.00	70.00	70.00
m- and *p*-ethyltoluene	µg/l	1	0.07	0.07	0.07
Methane, thiobis	µg/l	1	85.00	85.00	85.00
Methanamine, N,N-dimethyl	µg/l	1	34.00	34.00	34.00
Methylethylketone (= 2-butanone)	µg/l	1	500.00	500.00	500.00
p-isopropyltoluene	µg/l	1	0.12	0.12	0.12
Pentanone	µg/l	1	120.00	120.00	120.00
Pesticides and PCB's	µg/l	1	0.01	0.01	0.01
Sulphite	mg/l	1	99.00	99.00	99.00
Free carbon dioxide	mg/l	1	130.00	130.00	130.00

Average-, minimum- en maximum concentrations of some parameters in groundwater near landfill sites					
Parameter	**Unit**	**no.**	**Average**	**Minimum**	**Maximum**
Trichloroethane (total)	µg/l	13	18.81	1.00	232.50
Tetrachlorobenzenes	µg/l	12	0.03	0.01	0.10
2.3.4-trichlorophenol	µg/l	11	0.01	0.01	0.06
2.3.5-trichlorophenol	µg/l	11	0.01	0.01	0.06
2.3.5.6-tetrachlorophenol	µg/l	11	0.03	0.01	0.10
2.3.6-trichlorophenol	µg/l	11	0.05	0.01	0.40
2.5-dimethylphenol	µg/l	11	1.19	0.10	12.00
3-chlorophenol	µg/l	11	0.21	0.10	1.20
3.4-dimethylphenol	µg/l	11	0.59	0.10	5.00
3.4.5-trichlorophenol	µg/l	11	0.01	0.01	0.06
Sediment		11	3.20	0.20	19.00
m-cresol	µg/l	11	0.27	0.20	0.50
p-cresol	µg/l	11	0.18	0.10	0.50
2.3-dimethylphenol	µg/l	10	0.12	0.10	0.30
3.5-dimethylphenol	µg/l	10	0.10	0.10	0.10
Epsilon-HCH	µg/l	10	0.01	0.01	0.01
m-ethylphenol	µg/l	10	0.10	0.10	0.10
o-ethylphenol	µg/l	10	0.32	0.10	2.30
p-ethylphenol	µg/l	10	0.10	0.10	0.10
Suspended solids		10	142.74	2.90	590.00
Trihalomethanes	µg/l	9	1.63	1.00	3.80
2-chloroethylvinyl	µg/l	7	0.57	0.50	1.00
2.3-dichlorophenol	µg/l	7	0.04	0.01	0.10
2.5-dichlorophenol	µg/l	7	0.02	0.01	0.10
2.6-dichlorophenol	µg/l	7	0.02	0.01	0.10
3.4-dichlorophenol	µg/l	7	0.07	0.01	0.40
3.5-dichlorophenol	µg/l	7	0.14	0.01	0.90
Bromoform	µg/l	6	0.20	0.20	0.20
Bromodichloromethane	µg/l	6	0.20	0.20	0.20
Dibromochloromethane	µg/l	6	0.20	0.20	0.20
Tetrachloroethane	µg/l	6	0.20	0.20	0.20
Tetrahydrofurane	µg/l	6	133.92	2.40	450.00
Trichlorofluormethane	µg/l	6	0.20	0.20	0.20
Ag	µg/l	5	134.00	110.00	190.00
Be	µg/l	5	3825.94	5.70	11900.00
C9-aromates	µg/l	5	14.60	10.00	23.00
Phenthion	µg/l	5	0.05	0.05	0.05
Sn	µg/l	5	18.00	10.00	50.00

Average-, minimum- en maximum concentrations of some parameters in groundwater near landfill sites

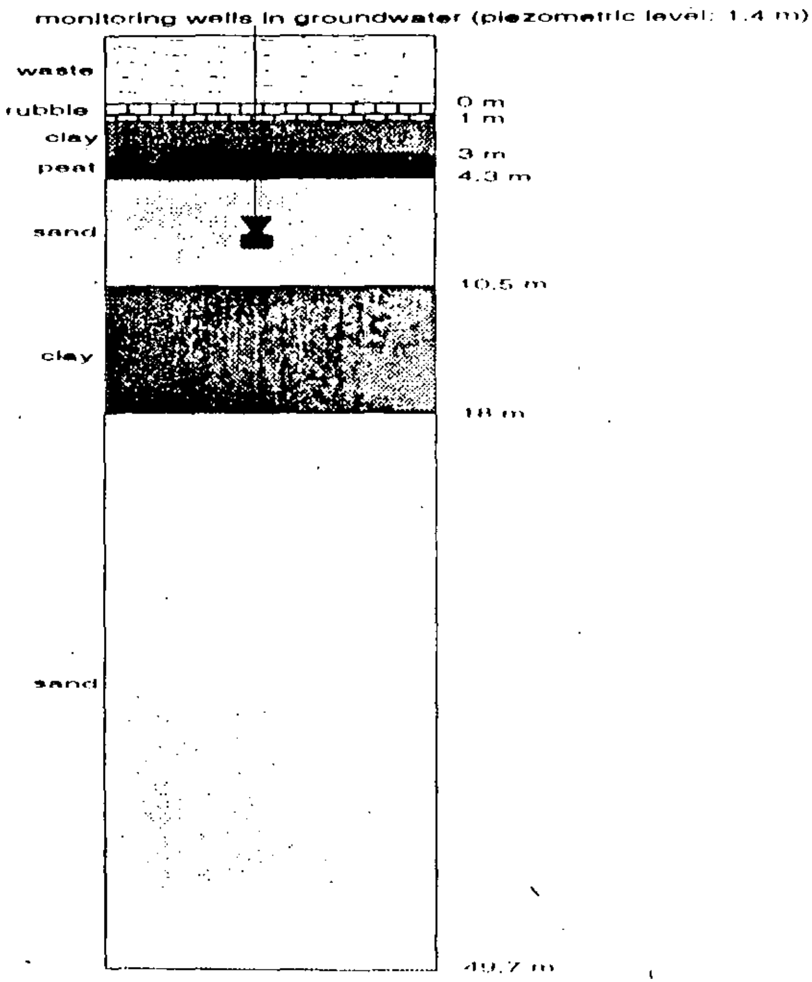
Parameter	Unit	no.	Average	Minimum	Maximum
Ortho-phosphate	mg/l	32	0.32	0.01	1.75
1.1-dichloroethene	µg/l	30	0.84	0.20	1.00
1.3-dichloropropene (trans)	µg/l	30	0.84	0.20	1.00
1.2-dichloroethene (trans)	µg/l	29	0.86	0.20	1.00
Mevinphos	µg/l	29	1.97	0.05	5.00
2-methyl-4.6-dinitrophenol	µg/l	28	10.00	10.00	10.00
4-nitrophenol	µg/l	28	10.00	10.00	10.00
Azinfos-ethyl	µg/l	28	10.00	10.00	10.00
Azinfos-methyl	µg/l	28	5.00	5.00	5.00
Enthion	µg/l	28	2.00	2.00	2.00
Methidathion	µg/l	28	2.00	2.00	2.00
Methylphenol (cresol)	µg/l	28	5.14	5.00	9.00
Sulfide	mg/l	28	1.20	0.00	8.95
4-chlorophenol	µg/l	27	26.32	0.10	220.00
Aromatic solvents (total)	µg/l	27	1.55	0.13	14.40
2.6 dimethylphenol	µg/l	26	6.19	0.10	78.00
Dimethylphenol (total)	µg/l	26	6.19	0.10	78.00
Disulfoton	µg/l	26	1.63	0.05	2.00
1.2-dichloroethene (cis)	µg/l	25	3.36	0.20	54.00
2.4-dinitrophenol	µg/l	25	20.00	20.00	20.00
Chloropyrifos	µg/l	25	4.01	0.05	5.00
1.2-dichloropropene	µg/l	24	1.00	1.00	1.00
1.2-dichloropropene (cis)	µg/l	24	1.00	1.00	1.00
1.2.3.4-tetrachlorobenzene	µg/l	24	0.50	0.50	0.50
1.2.3.5-tetrachlorobenzene	µg/l	24	0.50	0.50	0.50
1.2.4.5-tetrachlorobenzene	µg/l	24	0.50	0.50	0.50
Endosulfansulphate	µg/l	24	2.00	2.00	2.00
Endrin aldehyde	µg/l	24	5.00	5.00	5.00
Nitrophenol (total)	µg/l	24	1.32	0.50	5.00
Oily components	µg/l	24	100.00	100.00	100.00
Dimethylethyl benzoate	µg/l	20	16.67	2.00	100.00
Cholinesterase inhibitors	µg/l	19	0.10	0.02	0.90
Oxygen	mg O_2/l	18	6.91	0.30	12.50
Phenols (watervapour-volatiles)	µg/l	17	26.01	0.50	205.01
AOCl	µg/l	16	23.44	5.00	75.00
Cr -VI	µg/l	15	0.70	0.50	3.00
PAH, 6 of Borneff	µg/l	14	0.15	0.10	0.50
Organophosphor-pesticides (total)	µg/l	13	0.27	0.05	1.00

Average-, minimum- en maximum concentrations of some parameters in groundwater near landfill sites

Parameter	Unit	no.	Average	Minimum	Maximum
Delta-HCH	µg/l	39	1.44	0.01	2.00
PCB 28: 2.4-4' -trichlorobiphen.	µg/l	39	0.72	0.01	1.00
PCB 52: 2.5-2'5' -tetrachlorobiphen.	µg/l	39	0.72	0.01	1.00
PCB 101: 2.4.5-2'5' -pentachlorobiphen.	µg/l	39	0.72	0.01	1.00
PCB 118: 2.4-3'4'5' -pentachlorobiphen.	µg/l	39	0.72	0.01	1.00
PCB 138: 2.3.4-2'4'5' -hexachlorobiphen.	µg/l	39	0.72	0.01	1.00
PCB 153: 2.4.5-2'4'5' -hexachlorobiphen.	µg/l	39	0.72	0.01	1.00
PCB 180:2.3.4.5-2'4'5'-heptachlorobiphen.	µg/l	39	0.72	0.01	1.00
Pentachlorophenol	µg/l	39	3.59	0.01	5.00
1.2.3-trichlorobenzene	µg/l	38	0.43	0.05	1.00
1.2.4-trichlorobenzene	µg/l	38	0.43	0.05	1.00
1.3.5-trichlorobenzene	µg/l	38	0.43	0.05	1.00
Alpha-methyl-styrene	µg/l	38	0.64	0.50	2.00
Mesithylene	µg/l	38	0.83	0.50	5.00
Monochlorobenzene	µg/l	38	0.56	0.50	1.00
1.2.3-trichloropropane	µg/l	37	1.43	1.00	5.00
Dichlorovos	µg/l	37	2.06	0.05	5.00
m- and *p*-cresol	µg/l	37	10.50	0.25	160.00
2.4-dichlorophenol	µg/l	35	4.00	0.01	5.00
Phenols	µg/l	35	64.41	0.10	1000.00
Non-volatile hydrocarbon fraction	mg/l	35	0.20	0.10	2.30
1.2-dichloropropane	µg/l	34	0.86	0.20	1.00
Atrazine	µg/l	34	1.43	0.05	2.00
Propazine	µg/l	34	1.43	0.05	2.00
Simazine	µg/l	34	1.43	0.05	2.00
Terbutryn	µg/l	34	1.43	0.05	2.00
Volatile hydrocarbon fraction	mg/l	34	0.09	0.05	0.90
1.3-dichloropropane	µg/l	33	1.00	1.00	1.00
Bromophos (-ethyl)	µg/l	33	1.70	0.05	2.00
Bromophos (-methyl)	µg/l	33	1.70	0.05	2.00
Diazinon	µg/l	33	1.70	0.05	2.00
Dimethoate	µg/l	33	1.70	0.05	2.00
Malathion	µg/l	33	1.70	0.05	2.00
Parathion-ethyl	µg/l	33	1.70	0.05	2.00
Parathion-methyl	µg/l	33	1.70	0.05	2.00
Pentachlorobenzene	µg/l	33	0.37	0.01	0.50
PAH (10 "Leidraad lbs")	µg/l	33	0.36	0.03	3.77
Al	µg/l	32	1893.92	0.30	19700.00

Average-. minimum- en maximum concentrations of some parameters in groundwater near landfill sites					
Parameter	**Unit**	**no.**	**Average**	**Minimum**	**Maximum**
Heptachloroepoxide	µg/l	102	0.55	0.00	2.00
Heptachloro	µg/l	101	0.56	0.00	2.00
Anorganic carbon	mg C/l	99	169.08	53.00	476.00
Isopropylbenzene	µg/l	92	0.92	0.01	15.00
Styrene	µg/l	92	0.61	0.01	3.60
Sb	µg/l	89	9.85	0.02	212.20
PAH (total)	µg/l	81	5.11	0.04	220.00
V	µg/l	79	54.54	1.00	580.00
Se	µg/l	70	6.63	2.00	212.30
Chlorobenzenes (total)	µg/l	69	0.27	0.01	10.00
Beta-endosulfan	µg/l	68	2.06	0.00	5.00
Temperature	°C	68	12.63	7.00	18.50
1.2-dichlorobenzene	µg/l	61	0.49	0.01	6.90
1.3-dichlorobenzene	µg/l	61	0.45	0.01	4.00
1.4-dichlorobenzene	µg/l	61	0.44	0.01	3.40
isodrin	µg/l	58	0.00	0.00	0.01
1.2.4-trimethylbenzene	µg/l	56	3.74	0.08	51.00
EOX	µg/l	56	2.32	0.10	36.00
1.3 5.-trimethylbenzene	µg/l	55	1.06	0.02	12.00
Dichlorobenzenes	µg/l	55	0.39	0.05	7.50
1.2-dichloroethane	µg/l	49	10.53	0.20	232.42
Mo	µg/l	49	3.18	2.00	14.00
1.1-dichloroethane	µg/l	48	5.72	0.20	232.41
o-cresol	µg/l	48	0.91	0.25	3.90
2.6-dichloroobenzonitril(dichlobenil)	µg/l	47	0.00	0.00	0.00
Oil (with IR)	µg/l	46	277.24	50.00	7400.00
Telodrin	µg/l	46	0.00	0.00	0.01
Volatile halogens (VOX)	µg/l	46	26.01	0.00	265.00
2-nitrophenol	µg/l	44	6.45	0.25	10.00
ethylphenoles	µg/l	41	1.99	0.25	15.00
2.4-dimethylphenol	µg/l	40	5.29	0.10	20.00
2-chlorophenol	µg/l	39	3.63	0.10	5.00
2.3.4.5-tetrachlorophenol	µg/l	39	3.59	0.01	5.00
2.3.4.6-tetrachlorophenol	µg/l	39	3.59	0.01	5.00
2.4.5-trichlorophenol	µg/l	39	3.59	0.01	5.00
2.4.6-trichlorophenol	µg/l	39	3.59	0.01	5.00
4-chloro-3-methylphenol	µg/l	39	4.07	0.10	17.00
Aldrin	µg/l	39	1.44	0.01	2.00

Landfill site
Start: 1980
Yearly tonnage: 100.000 ton
Area filled with waste: 15 ha
Waste composition: 34 % MSW, 45 % Demolition waste, 17% Industrial waste, 4% Sludges
Distance between waste and groundwater: 70 centimeters



Reference values for groundwater in the Netherlands.

Parameter	Concentration in groundwater, A-level	Concentration in groundwater, B level	Concentration in groundwater C level
BOD, mg/l			
COD, mg/l			
Cl, mg/l	100.00		
pH			
NH_4-N, mg/l	2.00	1000.00	3000.00
Nitrate, mg/l	5.60		
N-Kjeldahl, mg/l			
P-total as PO_4^{3-}, mg/l	3.00	200.00	700.00
As, µg/l	10.00	30.00	100.00
Cd, µg/l	1.50	2.50	10.00
Cr, µg/l	1.00	50.00	200.00
Cu, µg/l	15.00	50.00	200.00
Fe, µg/l			
Hg, µg/l	0.05	0.50	2.00
Ni, µg/l	15.00	50.00	200.00
Pb, µg/l	15.00	50.00	200.00
Zn, µg/l	150.00	200.00	800.00
EOCl, µg/l	1.00	15.00	70.00

A-level: "Background concentration"
B level: Concentration which requires further investigation
C level: Concentration which requires an investigation for remedial action

Concentration of some parameters in leachate and groundwater near a landfill site (1980-1986).

Parameter	Concentration in groundwater, **upstream**	Concentration in groundwater, **downstream**	Concentration in **leachate**
BOD, mg/l	3.30	3.49	392.50
COD, mg/l	69.33	92.13	1111.25
Cl, mg/l	1641.50	2504.79	699.75
pH	6.88	6.84	7.43
NH_4-N, mg/l	21.33	22.86	100.00
Nitrate, mg/l	0.13	0.06	0.09
N-Kjeldahl, mg/l	21.50	23.88	113.50
P-total as PO_4^{3-} , mg/l	0.53	1.26	1.41
As, µg/l	6.15	11.57	46.60
Cd, µg/l	0.40	0.48	0.53
Cr, µg/l	9.20	12.00	16.63
Cu, µg/l	144.10	198.35	34.90
Fe, µg/l	55.40	68.58	5.95
Hg, µg/l	0.20	0.20	0.17
Ni, µg/l	15.17	20.27	65.07
Pb, µg/l	51.45	31.16	17.00
Zn, µg/l	49.30	158.62	709.33
EOCl, µg/l	0.50	0.38	82.55

MONITORING PRINCIPLES

1) SAMPLING WELLS, ANALYSIS

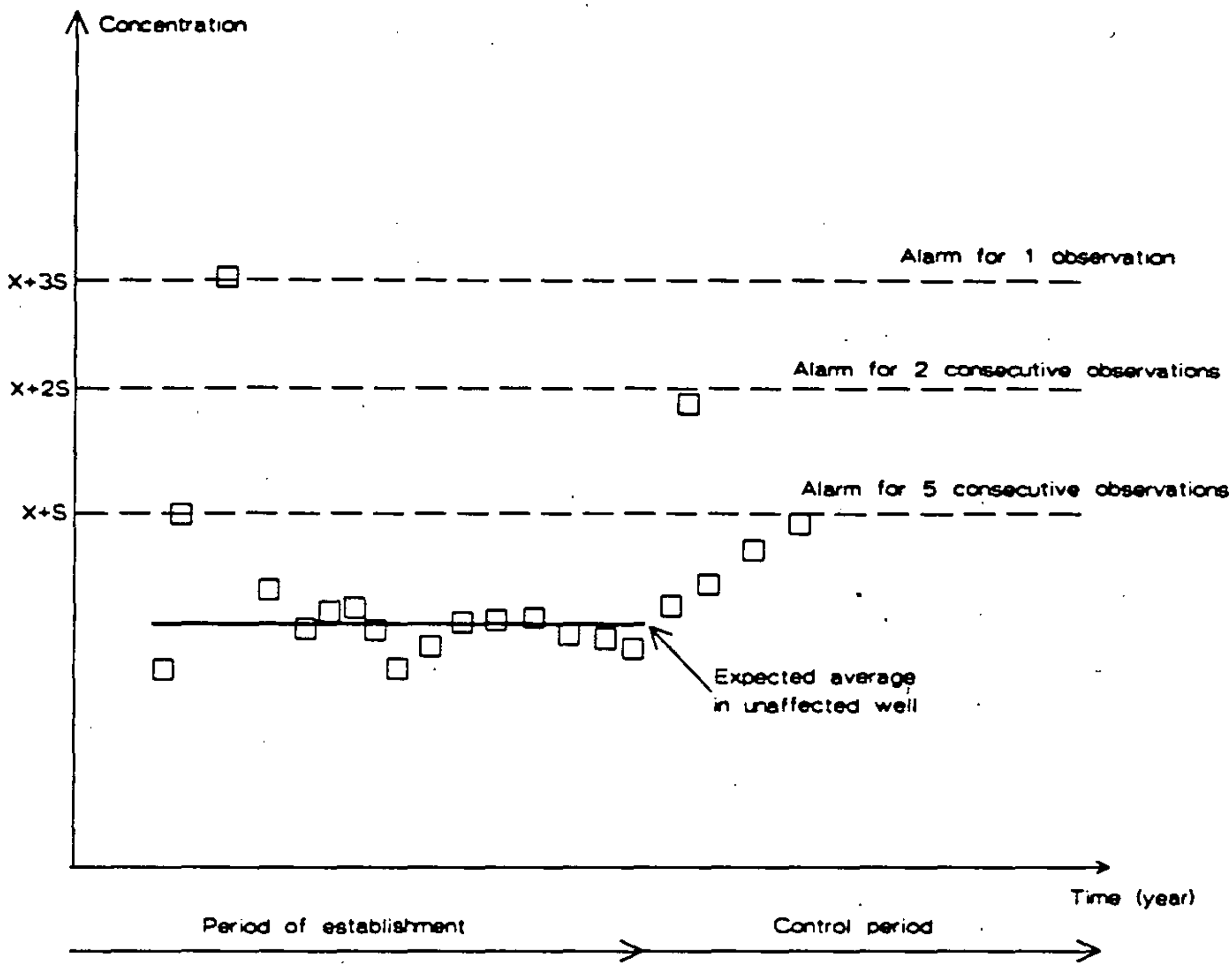
2) COMPARISON WITH UPSTREAM WELLS

* SIGNIFICANT DIFFERENCES (AVERAGE, STAND. DEV.) BETWEEN WELLS

  → COMPARISON WITH 1 UPSTREAM WELL

* VARIATION (AVERAGE, STAND. DEV.) WITH TIME OF AN INDIVIDUAL WELL

  → ENOUGH DATA COVERING A LONG PERIOD



An example of a control chart for a specific well and parameter; X=average background concentration; S=standard deviation.

With the use of these wells, it is possible to obtain samples that are chemically representative of the water taken in by the well. Consequently, attention must be directed to:

- physical extraction of the water from the well
- preservation of chemical integrity of the sample in transit to the place of sample analysis
- attainment of analytical results that are accurate and have a high degree of precision

Among the means of collecting samples from the wells are:

- down-hole collection devices
- suction-lift, positive displacement, gas lift, and gas-drive methods
- gas squeeze or bladder pumps
- jet or venturi pumps.[7]

Among the pertinent sample parameters for analytical determination are:

- pH
- specific conductance
- total dissolved solids
- total dissolved iron
- nitrate
- chloride
- total organic carbon
- total organic halogens
- heavy metals
- hardness

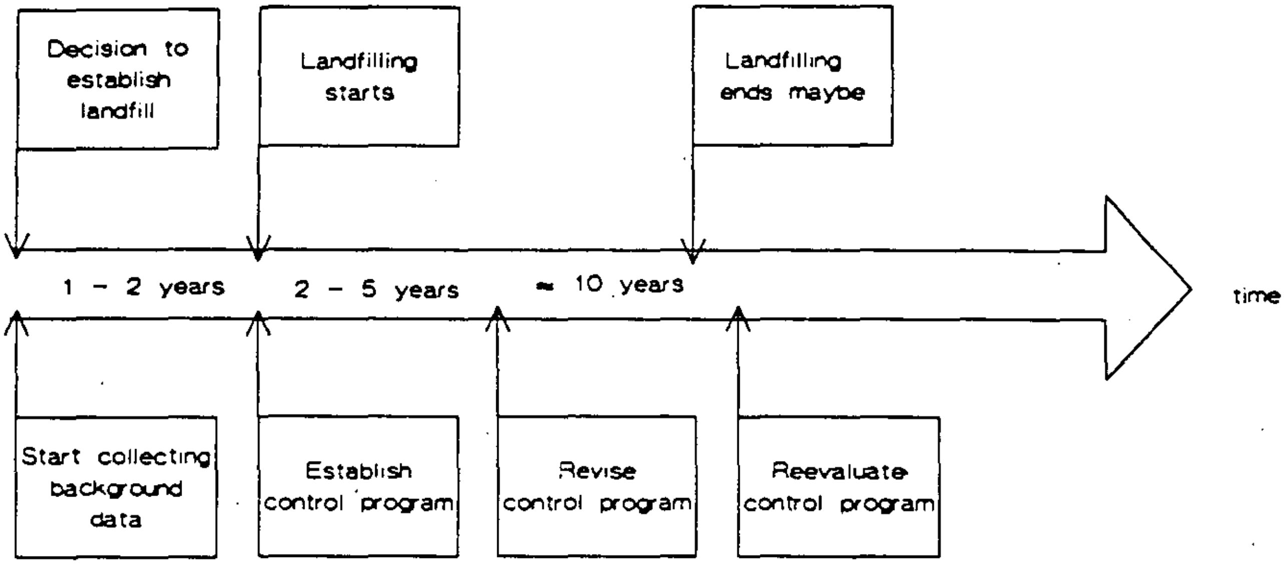


Illustration of the time phase of a groundwater control monitoring programm; the time estimates presented are given for illustration purposes only.

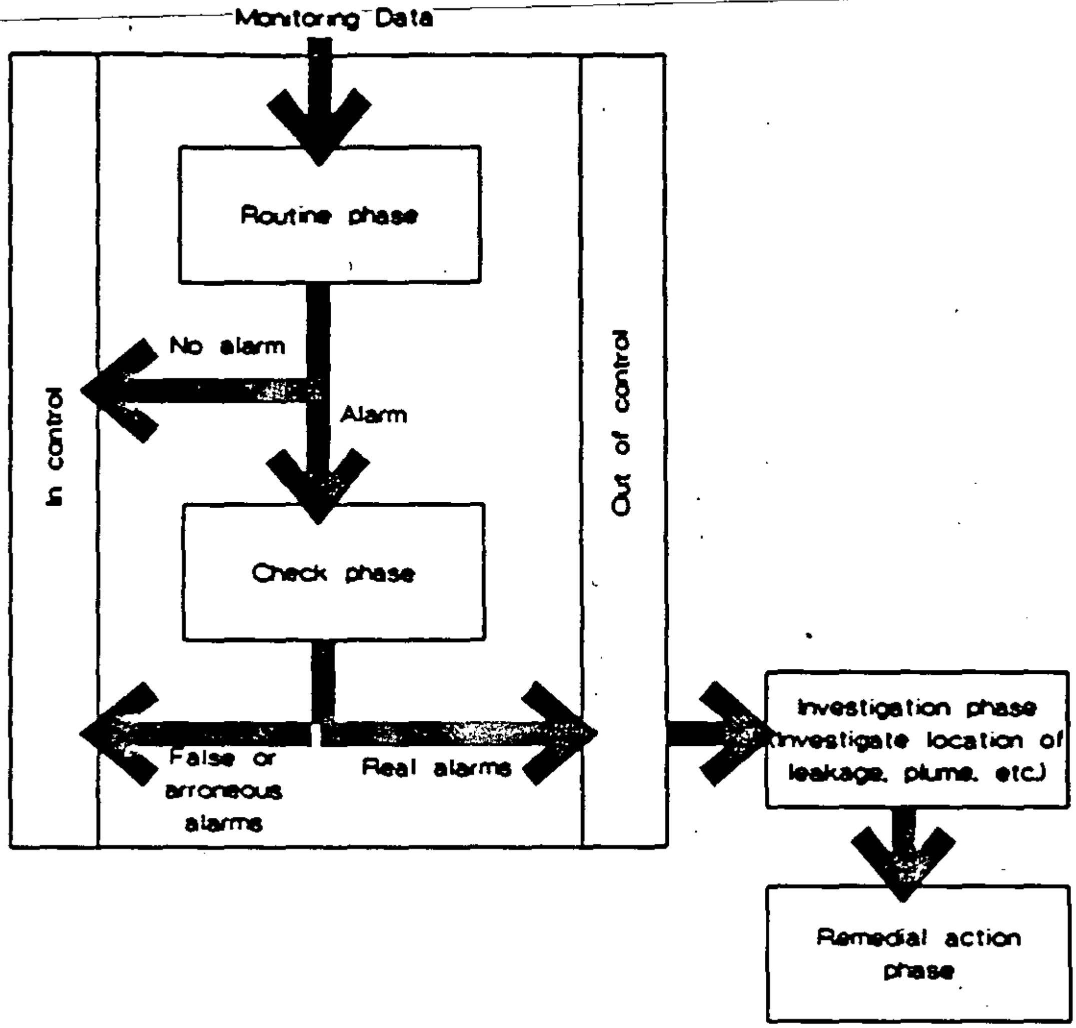
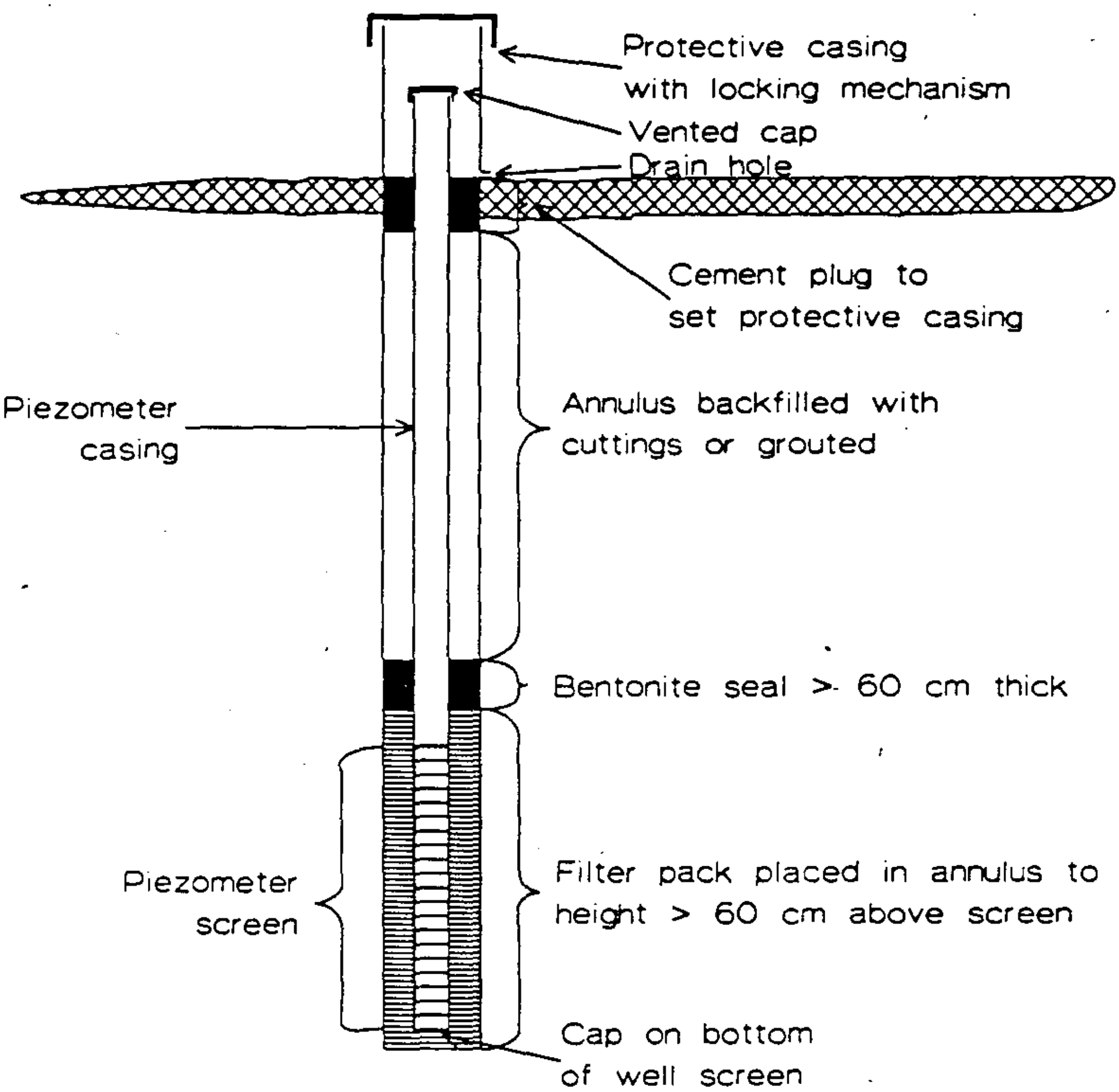
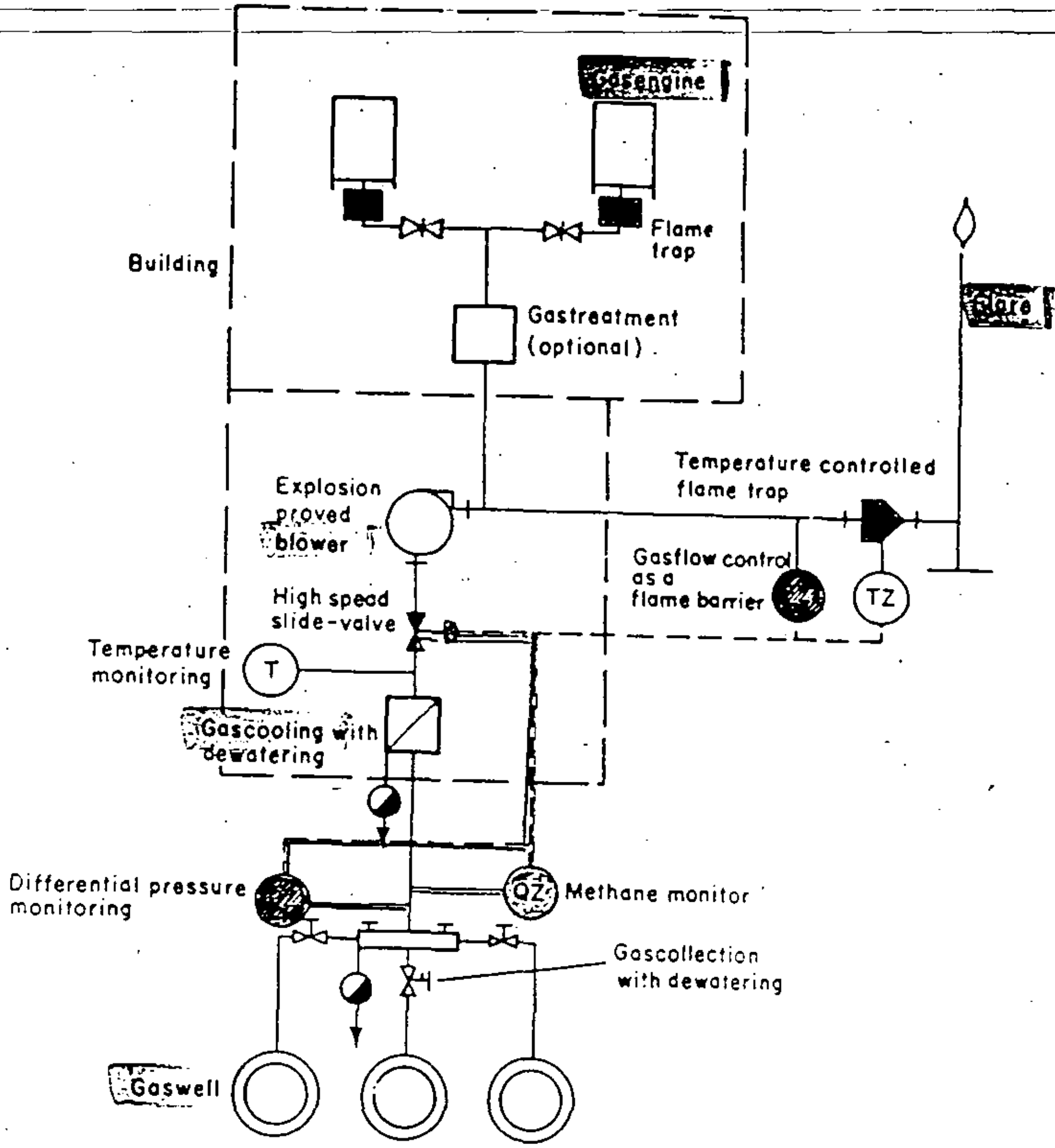


Illustration of the action phases related to a groundwater monitor programm.



Monitoring Well (not to scale)



igure 1. Example of a safety concept for a landfill gas utilization plant (Müller nd Rettenberger, 1986).

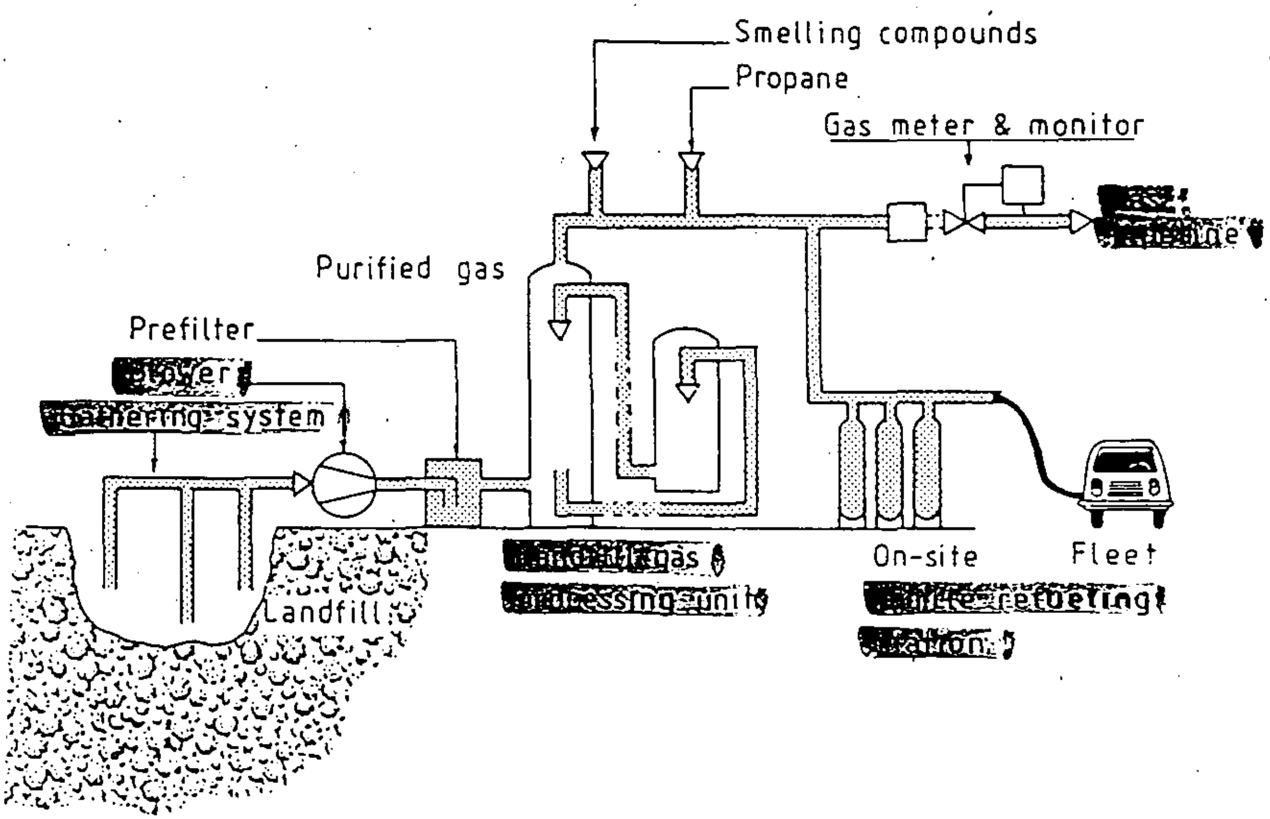


Figure II.47.
Upgrading of landfill gas to natural gas and end-use as vehicle fuel

Adapted from Henrich and Ross, 1983.

Table II.21
Major landfill gas end-uses, their limitations and the required landfill gas treatments

Landfill gas application	Required landfill gas treatment (1)	Limitations
Direct heat (burner)	[redacted]	[redacted]
	[redacted]	[redacted] (moderate distance)
Engine fuel	[redacted] (+ halocarbons)	[redacted] (moderate distance)
	Dehydration (thorough) Partial CO_2 removal (+ halocarbons)	Can be transported (moderate distance) and mixed with natural gas at low ratios
Turbine fuel	Dehydration (raw)	Can be transported via pipeline (moderate distance)
	Dehydration (raw) Partial CO_2 removal	Can be transported (moderate distance) and mixed with natural gas at low ratios
Chemicals Vehicle fuel Injection to the grid	[redacted]	[redacted]

(1) besides particle removal

Modified from Ham *et al.*, 1979.

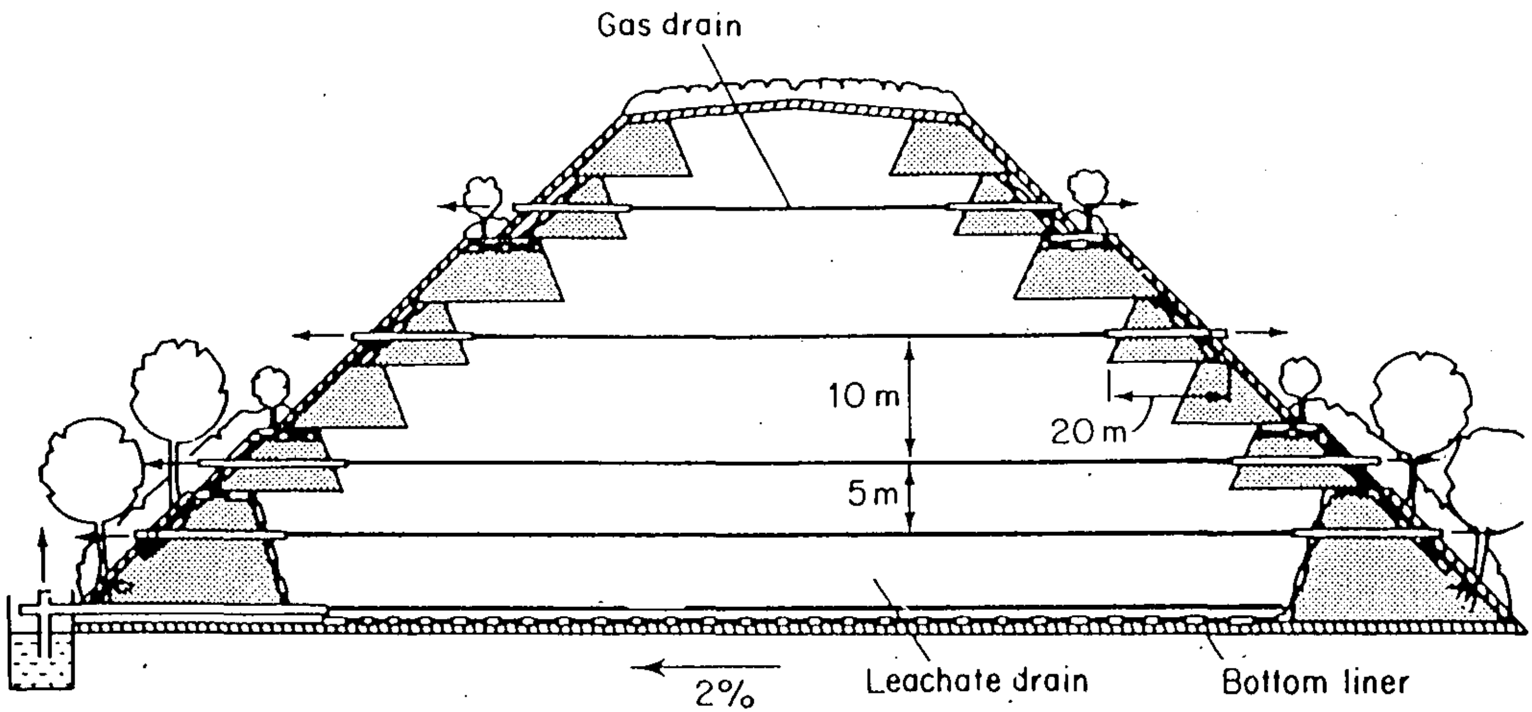


Figure 2. Possible design of a horizontal gas extraction system (Boll *et al.*, 1988).

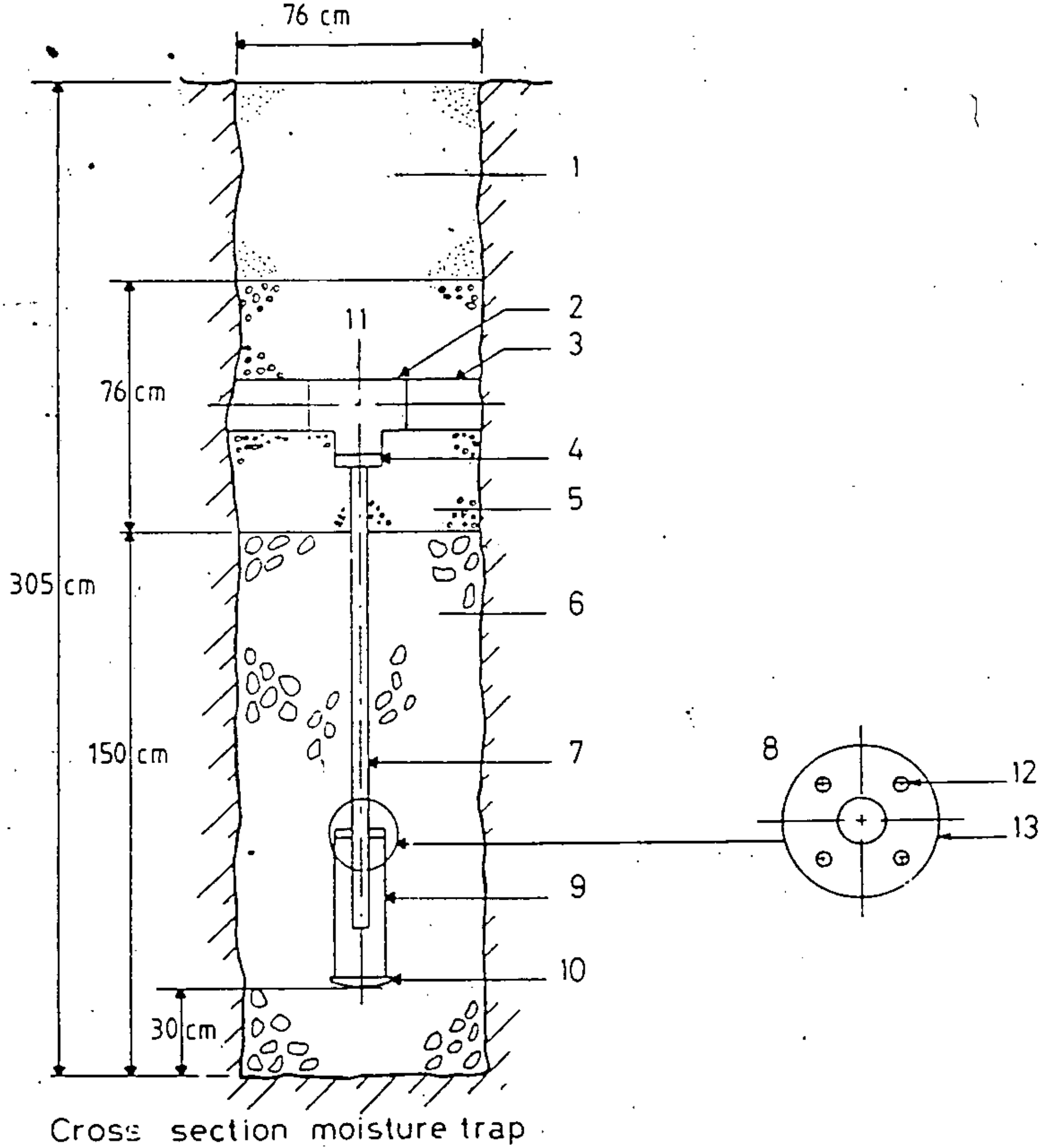


Figure II.40
Moisture trap construction to drain the condensate from a landfill gas collection pipe system

From Bard *et al.*, 1985, by courtesy of the authors.

2. SITING

Many of the above-described problems can be avoided if the landfill is located in an appropriate area. Of course adequate siting may be difficult in countries with a specific geological situation (e.g. high ground water tables, mountains). But it should be aimed at the following recommendations to be respected.

- No dumping of waste into lakes, rivers, ponds or into the sea. The water will be polluted due to dissolving of different components of the waste supported by biological processes. These may take place under aerobic and/or anaerobic conditions, where the anaerobic processes may stay for a certain period of time in the acid phase. The inorganic components may either be oxidized or reduced. Up to a certain degree, with the different stages of biological degradation the amount of soluble components increases. Also under optimum degradation conditions humic- and fulvic-like components are produced and solubilized. Organic nitrogen is converted into ammonia which may be oxidized into nitrate.

- Landfills should not be located in valleys where the slopes of the hills and the bottom of the valley are the borders of the landfill. As a consequence of such a location the surface water from the mountains or hills may flow into the landfill. Under this condition also water out of the mountain may penetrate into the landfill. Although a lot of technical measures can be taken to avoid these problems as drains on the slope and the channeling of the river/ditch by means of a pipe underneath a landfill, it has been shown in many cases that on a long term these measures do not work satisfactorily and remediation is very difficult to achieve if at all.

- Landfills should not be located on steep slopes where sliding of the landfill may occur.

- Landfills should not be located in areas where ground water is used for drinking water supply.

- Landfills should be sited in areas of low precipitation rates.

- Landfills should be located in areas with appropriate natural soil quality.

As a conclusion those areas should be favored where the subsoil is of low permeability, where no surface water can enter the landfill and where the ground water table is either very low and/or the quality of the water is too poor to use it for drinking water (e.g. high natural salt content). Landfills should preferably not be built in pits but as mounds so that a natural drain of the leachate out of the landfill can take place.

Of course often not all these aims can be met due to specific area situations. But it should be kept in mind that a landfill stays at its position forever and long-term problems will occur.

3. LANDFILL DESIGN

If the natural soil is not of low permeability it should be tried to build in a layer of clay or similar material or to upgrade the existing quality of the soil by mixing it with appropriate material (e.g. bentonite) to decrease the permeability. If there are significant fissures in the natural soil of low permeability, if possible, the surface layer (30-50 cm) should be removed and built in again under controlled conditions. In any way the low-permeable natural soil should be adequately sloped so that the water has the chance to drain off on the bottom of the landfill site by gravity (see Figure 1).

On top of the graded soil coarse inert material should be placed in order to function as a dewatering system. If this kind of material is not available and also pipes cannot be emplaced rigoles should be placed on the bottom of the landfill that transport the leachate outside the landfill. The distance between these rigoles should be as short as possible; at least they should exist every 30 m. The

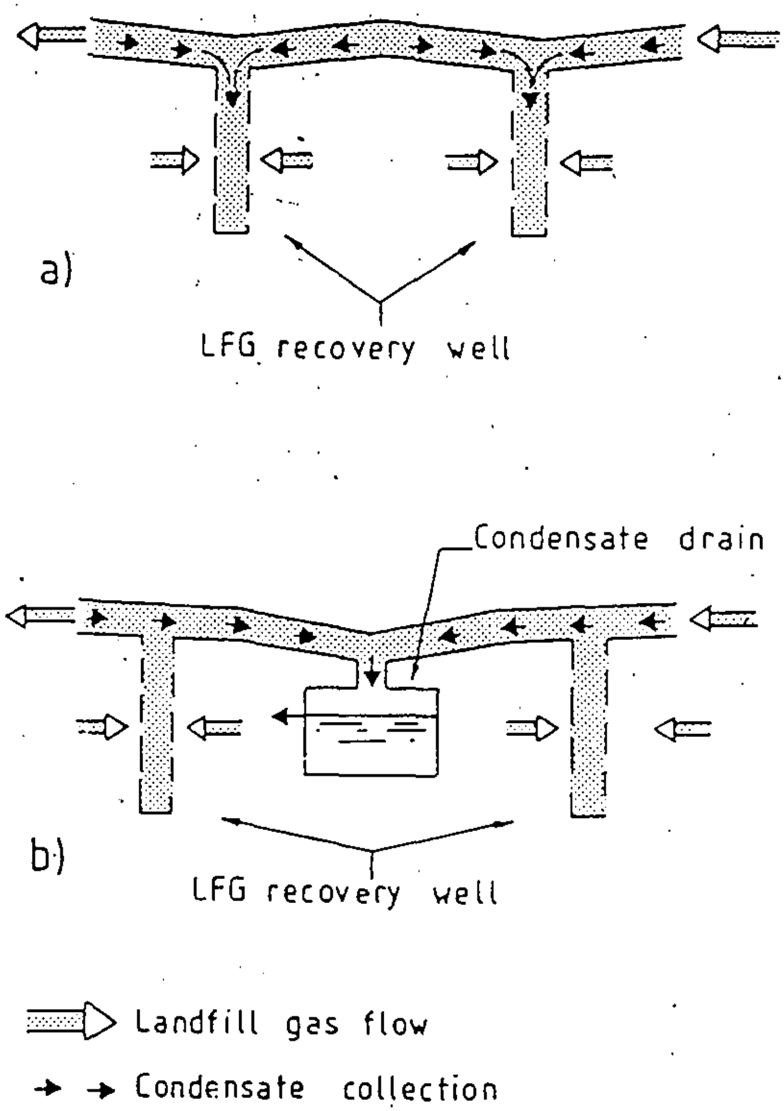


Figure II.39.a + b
Condensed water collection in a landfill gas recovery header

Adapted from Rovers et al., 1977.

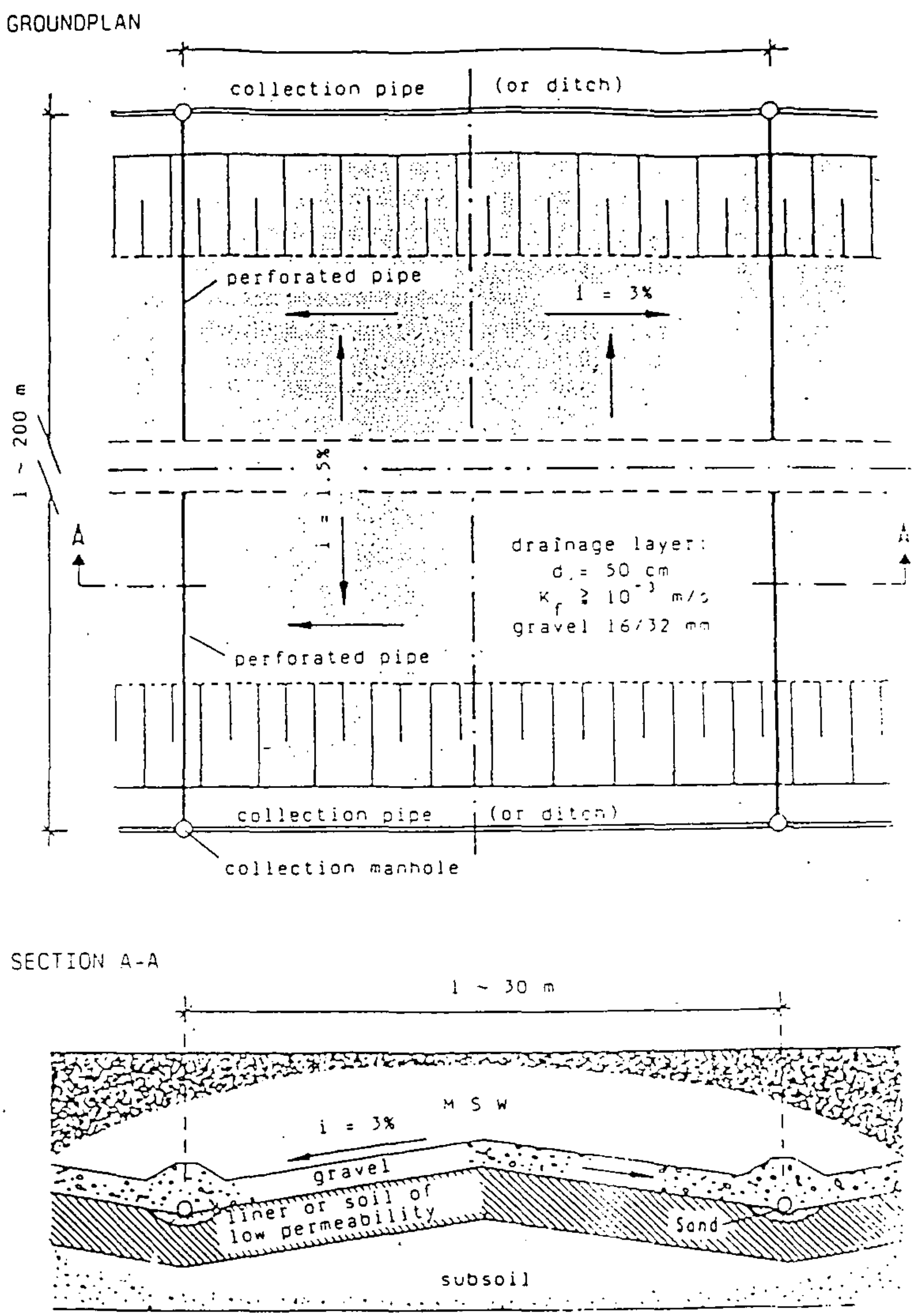
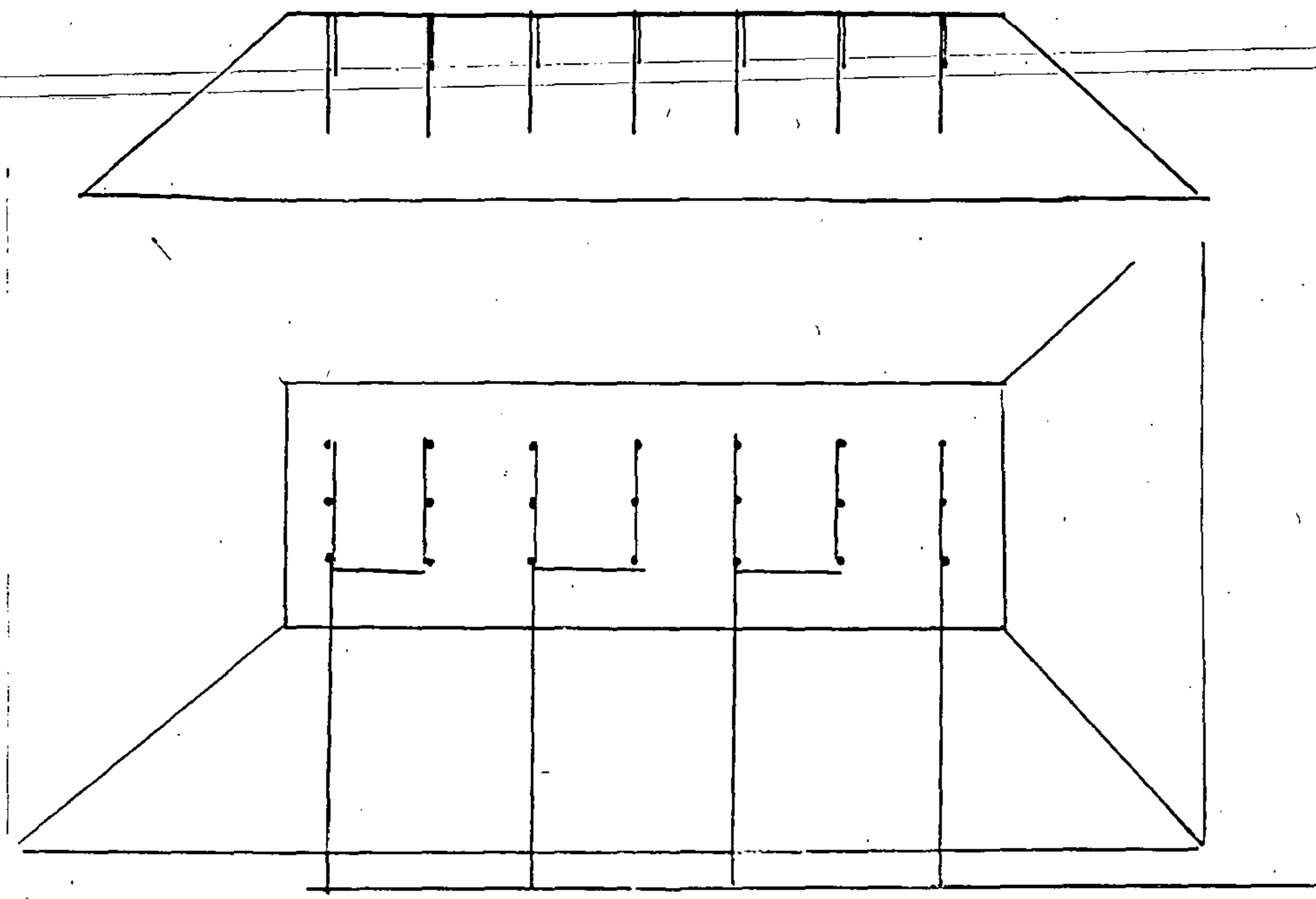
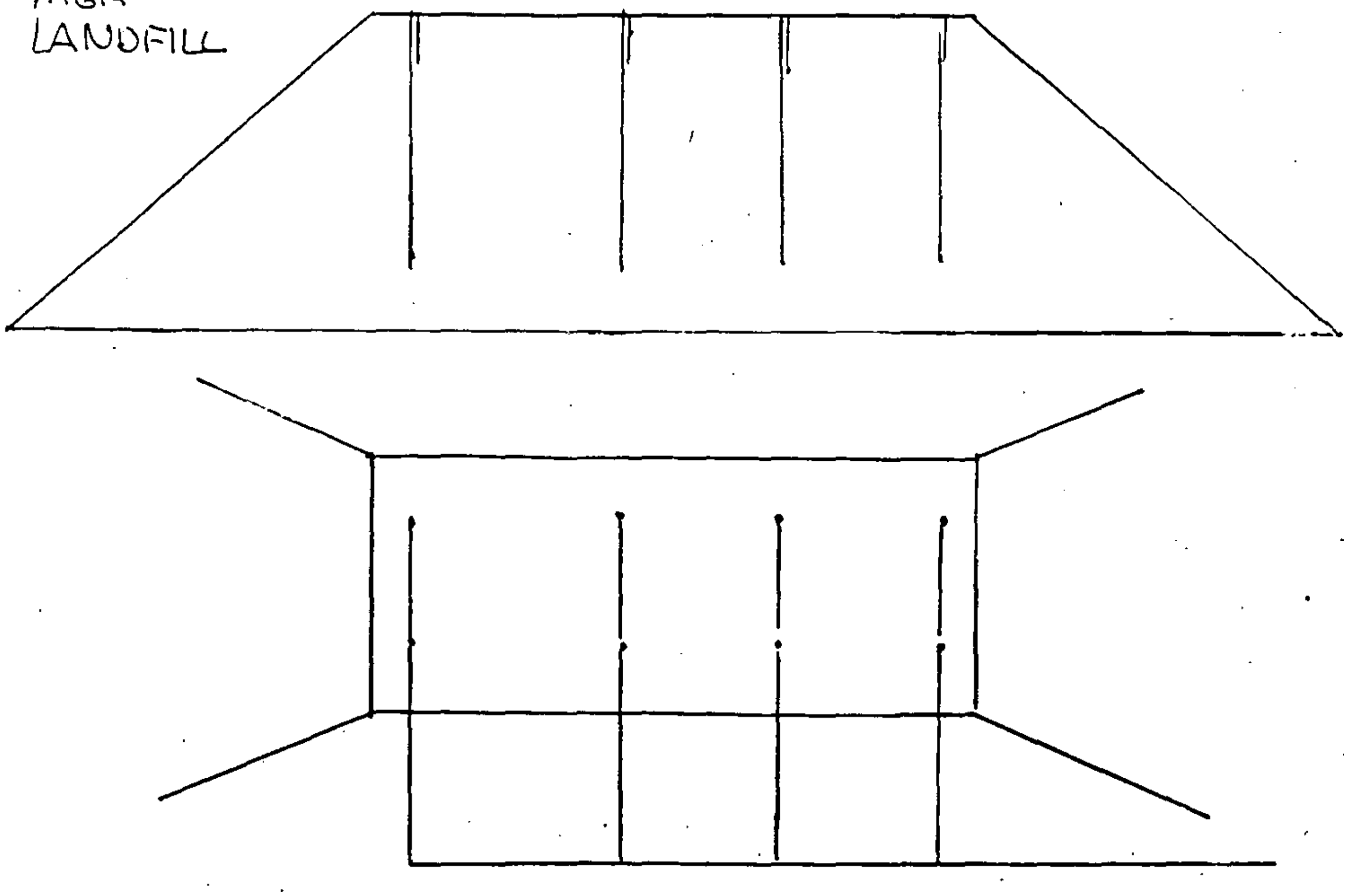


Figure 1. Example of a drainage system for leachate

SHALLOW LANDFILL



HIGH LANDFILL



leachate is collected either in manholes connected by pipes or - if this is not possible - in a ditch that surrounds the landfill. These measures can be realized much easier if the landfill is a mound.

Surface water should be captured by means of ditches in order to avoid its contact with the waste.

If virgin soil had been removed at the landfill base this soil should be stored aside the landfill. After the landfill is completed this material can be used as final cover.

The slopes of the landfill mound should not exceed 1:3 otherwise sliding or foundation failure may take place. In areas with high precipitation rates (during the year or day) possible erosion problems should be avoided by covering the surface with grass or other adequate plants; in addition ditches should be built in supported with gravel or stones to transport the surface water out of landfill; no mixing with the leachate should take place.

4. LANDFILL OPERATION

4.1 Emplacement of a layer of composted refuse as a first lift

Enhancement of anaerobic processes can be achieved if landfills are operated aerobicly for a certain period of time. This can - partly - be achieved if the refuse is not compacted or is placed in thin layers without cover (highly compacted). Enhancement is documented by the early decrease of organic concentrations in the leachate.

As a result of different investigations (Stegmann and Spendlin, 1989) the following concept for a full-scale landfill has been developed. The first layer of landfill should be prepared in such a way that the polluted leachate from the lifts above can be anaerobicly treated in this area. In order to achieve this the first layer of refuse (1.5-2 m height) must not be compacted, so that readily degradable organic waste components can decompose aerobicly. Leachate recirculation should be practiced in a controlled way. The rate of recirculation should be moderate in order to avoid anaerobic contitions. After 1 year of placement, the usual landfill operation can start. The disadvantage of this procedure is that a high leachate production rate will result during the first year; in addition, odors may occur and vermins may develop. For these reasons it is much more effective if already composted MSW is emplaced as a first lift of about 2 m. This is a normal procedure for new landfills in Germany today; if this has been done, the operation of landfill can proceed immediately after the layer of compost has been built in. On top of the compost from MSW, the refuse should be compacted in thin layers (±30 cm) so that the MSW is equally wetted and some aerobic processes may take place in the surface area.

As a consequence of this kind of operation, the following results can be expected:

- The concentration of the organics in the leachate is expected to be very low, so that energy requirements for the aerobic leachate treatment are reduced.
- Gas is produced due to the anaerobic degradation of the leachate inside the compost layer.
- Controlled leachate recirculation will result in equal wetting of the MSW and in an evaporation loss of leachate.
- If leachate of this quality leaves the landfill in an uncontrolled way the environmental damage is significantly lower.

4.2 Leachate recirculation

Recirculation of the leachate on top of the landfill with the aim to evaporate as much leachate as possible should be considered. In this case the proportion of the leachate that evaporates may only be partly treated (for odor control); if leachate originates from an old landfill, pretreatment may not be necessary. For this procedure the climatic situation is of great importance. If there is a large lagoon available (e.g. for biological leachate treatment) water can be stored and recirculation should only take place during times of high evaporation rate. During recirculation the distribution of the leachate should be done equally over the landfill surface. The amount of leachate being

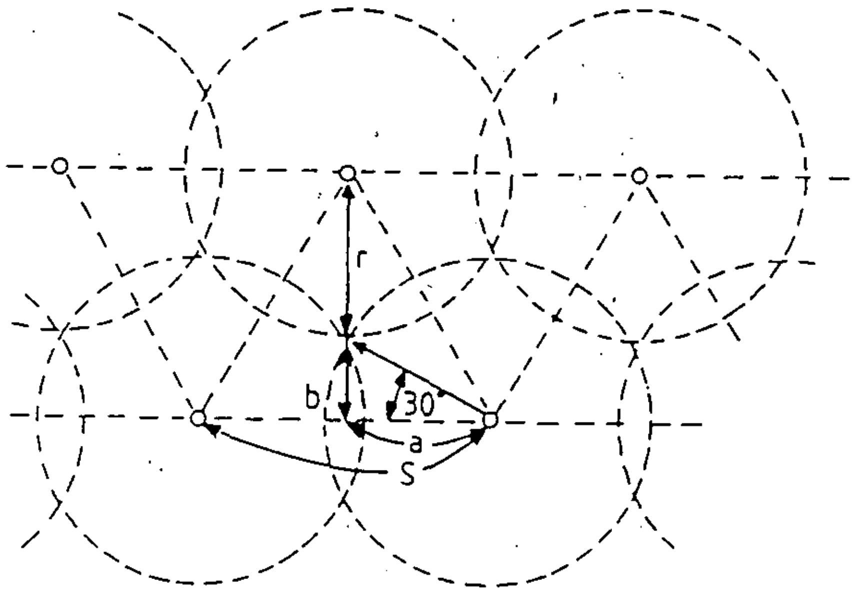
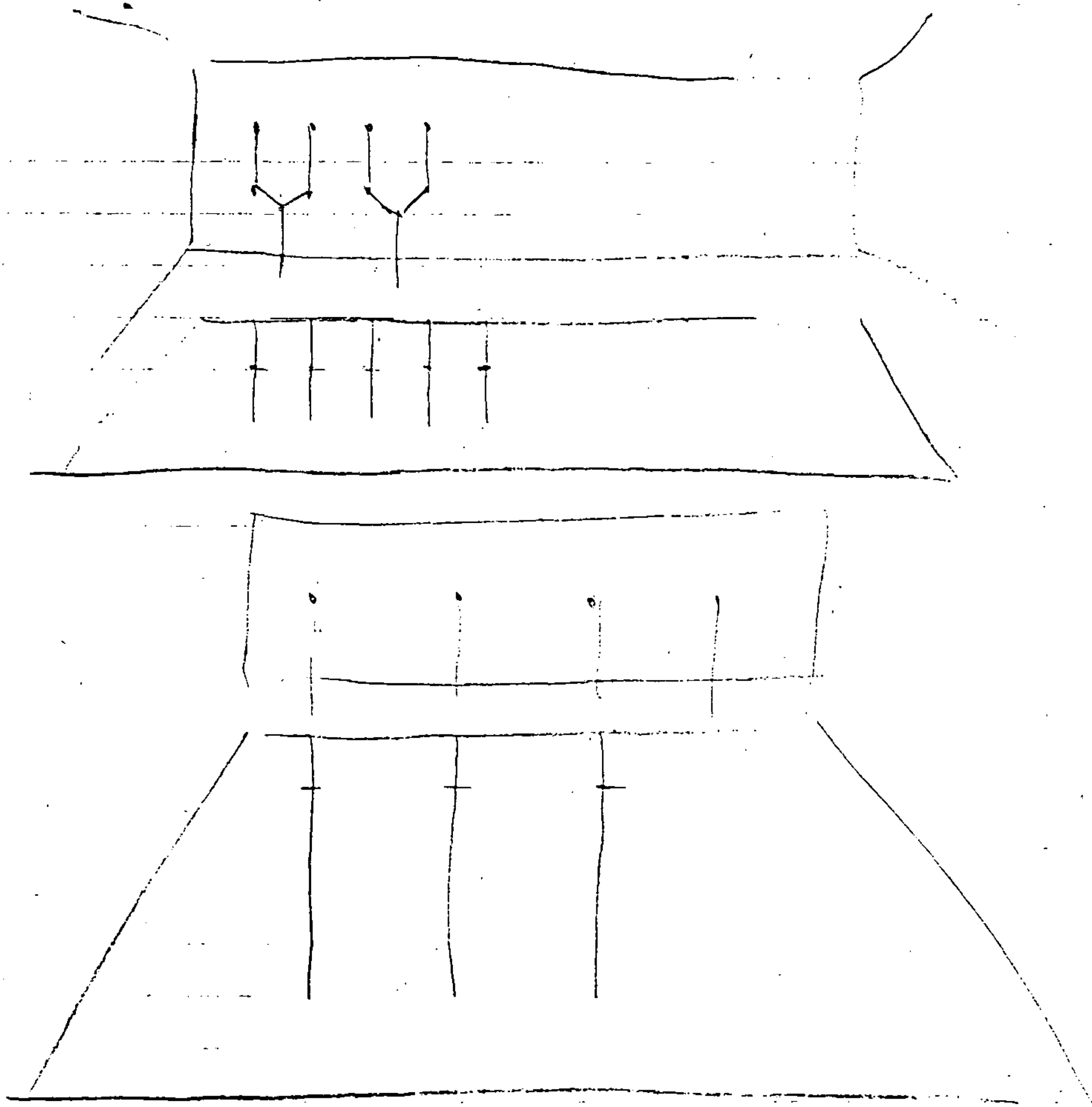


Figure II.33
Flowsheet of well spacing according to the equilateral triangle method

From Shen, 1980b, by courtesy of the author.

r = radius of influence
S = 2a = 2 (r cos 30°) = 1.732 r
Assume r = 35 ± 25 m depending on the properties of the in-place wastes



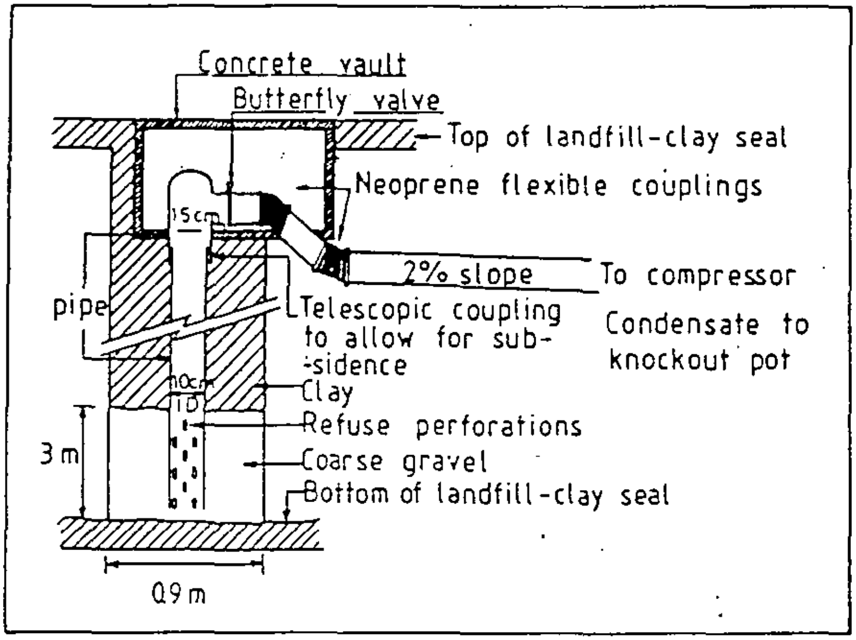


Figure II.30
Head for landfill gas extraction well with flexible coupling to the gas collection header

From Blanchet, 1976, by courtesy of the author and with permission from Penn Well Publishing Co.

Unpolluted soil should not be landfilled unless it is necessary for intermediate and/or final cover. If soil cannot be used it should be intermittedly stored separately. Rubble should not be landfilled together with MSW. It should be aimed at reusing as much of this material as possible for road construction, etc. by means of simple sieving and crushing techniques. The non-usable finer fraction could also be used as cover material for low-density landfills.

Sewage sludge should be recycled on land if the quality is appropriate. If the sludge is contaminated and has to be landfilled, it should be biologically stabilized (aerobicly or anaerobicly) and if possible dewatered. The sludge should then be landfilled in cassettes in order not to negatively influence the stability. The sludge may also be thoroughly mixed with the waste in adequate proportions (not more sludge than waste related to the inhabitants).

Bulky waste should only be landfilled after the reusable parts have been selected. This can be done by unloading the bulky waste on an area adjacent to the landfill where people and/or the operator and/or organizations etc. may have the possiblity of selection. The non-usable residues can then be landfilled at the end of the day, so that the "recycling area" looks clean.

Very often wood is landfilled. This should be avoided by separating it from the waste stream. The wood can be reused for cooking or be shredded and used for different purposes (e.g. as an additive to organic waste for composting, for landscaping). Wood pretreated by means of fungicides etc. has to be landfilled if it cannot be incinerated in MSW incinerators.

6. CONCLUSIONS

Landfills in economically developing countries are often in a very bad condition. A main reason for environmental impact is often bad siting. In addition, emission control is not practiced and the operation of the landfill is poor. Landfills in economically developing countries should be planned and operated in a controlled way, where low cost procedures should be implemented; the specific situation in the country has always to be respected. Landfill operators should have a cooperation with a University or Research Institute especially for monitoring assistance. The following mai aspects should be respected:

- Landfills should be located in appropriate areas (no surface- and ground water infiltration, low rainfall rates, not on steep slopes, preferably low soil permeability, etc.).
- Landfills should preferably be built as a mound, so that leachate can leave the landfill by natural gravity.
- The base should preferably be of low permeability with adequate slopes and drainage system.
- The installation of a first lift of composted MSW results in relatively low organic leachate concentrations.
- Leachate recirculation should be practiced in a controlled way; simple leachate treatment systems as lagoons may be used.
- MSW should be adequately compacted or covered with adequate material in order to avoid fires.
- LFG has to be controlled and can be utilized for energy production.
- Landfill design has to respect the stability of a landfill.
- Revegetation of completed landfills and surface water control have to be implemented.
- There are also in economically developing countries many possibilities in waste avoidance and recycling to which should be given high priority.

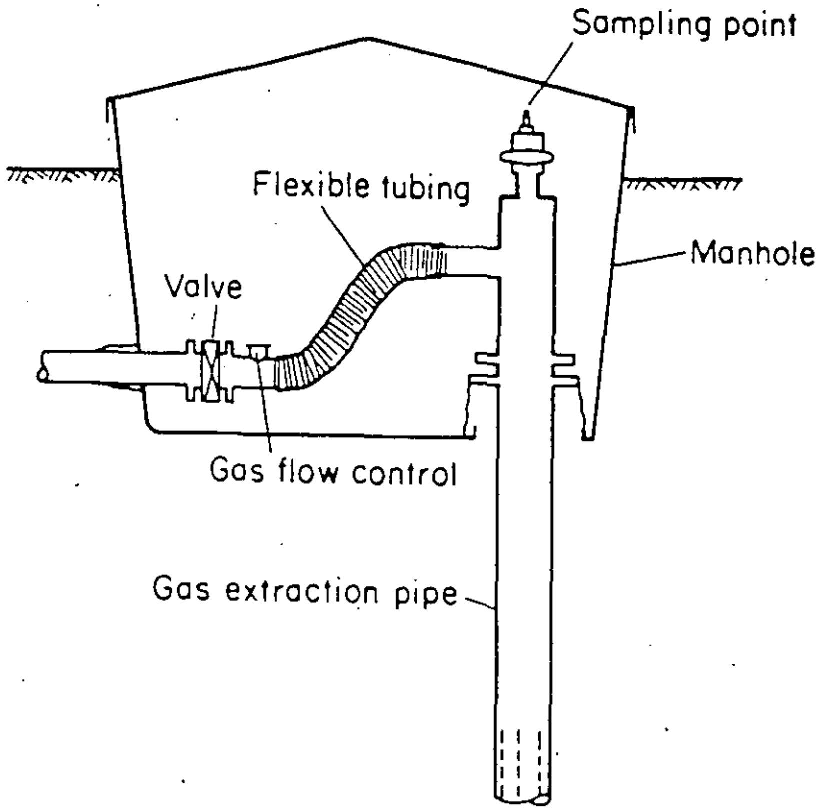


Figure 3. Gaswell head.

10:00 to 11:00 - Social and Ecological Aspects (PAHO Representative)

11:00 to 12:00 - Previous Studies (AMCRESPAC Representative)

12:00 to 12:30 - Coffee Break

12:30 to 14:00 - Interpreting Site Characteristics in Sanitary Landfill Design (Dr. Ham)

14:00 to 14:30 - Round Table Discussion

14:30 to 17:00 - Lunch Break

17:00 to 18:00 - Physico-Chemical Aspects of Biogas (AMCRESPAC Representative)

18:00 to 19:00 - Water Balance and Leachate Quantity (Dr. Lechner)

19:00 to 20:00 - Waste Acceptance, Exclusion, and Special Wastes (Speaker Needed)

20:00 to 20:30 - Round Table Discussion

WEDNESDAY, March 16

09:00 to 10:00 - Design Implementation and Construction (Mr. Vasuki)

10:00 to 11:00 - Gas Generation and Control (Dr. Stegmann)

11:00 to 12:00 - Leachate Management and Liners (Dr. Cossu)

12:00 to 12:30 - Coffee Break

12:30 to 14:00 - Ground Water Protection (Mr. Beker)

14:00 to 14:30 - Round Table Discussion

14:30 to 17:00 - Lunch Break

17:00 to 18:00 - Sanitary Landfill Operation: Equipment and Personnel (Mr. Ornebjerg)

18:00 to 19:00 - Control Systems for Operation (AMCRESPAC Representative)

19:00 to 20:00 - Landfill Closure and Long-Term Care (Dr. Diaz)

20:00 to 20:30 - Round Table Discussion

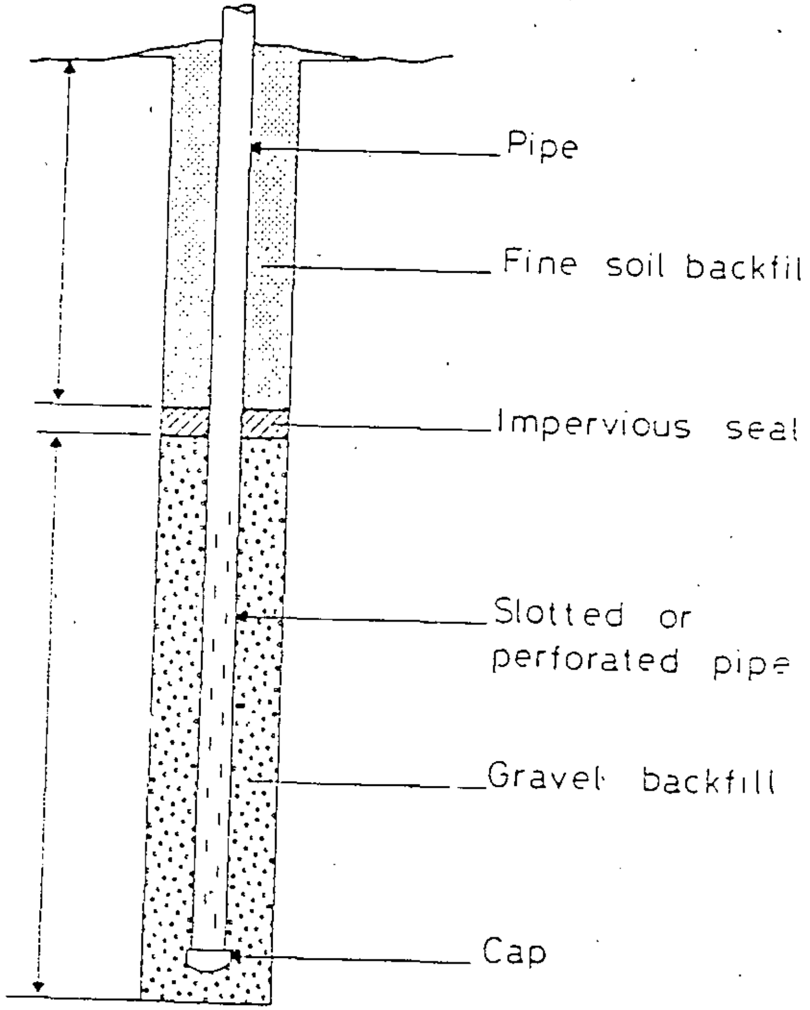


Figure II.25
Generalised design of a landfill gas extraction well

From Anonymous, 1981g, by courtesy of EMCON Assoc.

recirculated should be similar to the average weekly natural evaporation rate. Leachate recirculation should not be practiced in the working phase during the operation hours. For the distribution also tank vehicles - as they are used in agriculture to distribute manure on the fields - are appropriate. Since there may be trace organics in the leachate that should not be incorporated in the human body spraying should be avoided. In many climatic zones controlled recirculation of the biologically treated leachate may be very advantageous.

4.3 Leachate treatment

If no specific requirements have to be respected (e.g. residual COD) the collected leachate should be treated biologically. As already mentioned, dependent upon the climatic situation controlled leachate recirculation should be considered.

If a first lift of composted refuse was emplaced the concentrations of degradable organic components will be relatively low (BOD_5 concentrations of about <100 - 1000 mg/l) with COD concentrations around 500 - 3000 mg/l (degradation rate about 90%); but the ammonia concentrations will be relatively high (around 1000 mg/l) (see also Stegmann and Spendlin, 1989). These values are common in undiluted leachate from landfills in Germany.

Biological leachate treatment can take place in activated sludge plants or in lagoons (see also Christensen, Cossu and Stegmann (eds), 1992). Lagoons may be appropriate in economically developing countries for leachate treatment since this is a simple technology that can be used in most cases. Dependent upon the size of the landfill as well as climatic conditions and the specific situation (leachate quality, depth of the lagoon etc.) the lagoon may either be artificially aerated or not. During the treatment in the lagoon the BOD_5 will be further reduced and nitrification may occur. In general phosphorus has to be added to the leachate to overcome P-deficiency. If there are anoxic zones in the lagoon also denitrification may occur. In addition the pH value will rise > 7.5 and the sulfides will be oxidized. There will be iron- and carbonate precipitation. The size of the lagoon depends very much on the climatic situations, where in cold climates the lagoon will freeze and only very little degradation will take place during those periods.

The effluent of the lagoon may be further treated in a controlled wet land where reed may be planted. After this physiological upgrading of the quality leachate may be discharged into natural waters without causing detrimental effects.

In order to control the leachate simple analytical measurements should be made. E.g. the pH as well as nitrate- and nitrit values can be measured by using indicator paper. Here the cooperation with a nearby University or Research Institute or a sewage treatment plant should be aimed at.

4.4 Gas extraction, -treatment, and -utilization

At larger landfills gas extraction systems should be installed and the gas should be used to gain energy. A very good example for a simple gas utilization is described by Penido Monteiro (1991). How a gas extraction system normally is installed is described elsewhere (Anonymous, 1991). But these systems might not be applicable in every case so that simpler systems should be developed. Important is that the main principles are respected:

- no air should be sucked into the landfill or transportation pipes;
- landfills settle during their lifetime by more than 20 % dependent upon the kind of refuse landfilled and the degree of initial compaction reached;
- landfill gas is corrosive;
- landfill gas is water-saturated and condensate will be produced due to the temperature drop of the landfill gas;

Q^*w, the optimum gas extraction rate ($m^3 h^{-1}$),
R^*, the radius of influence (m),
D, the refuse density (dimensionless), and
h, the height of the refuse layer.

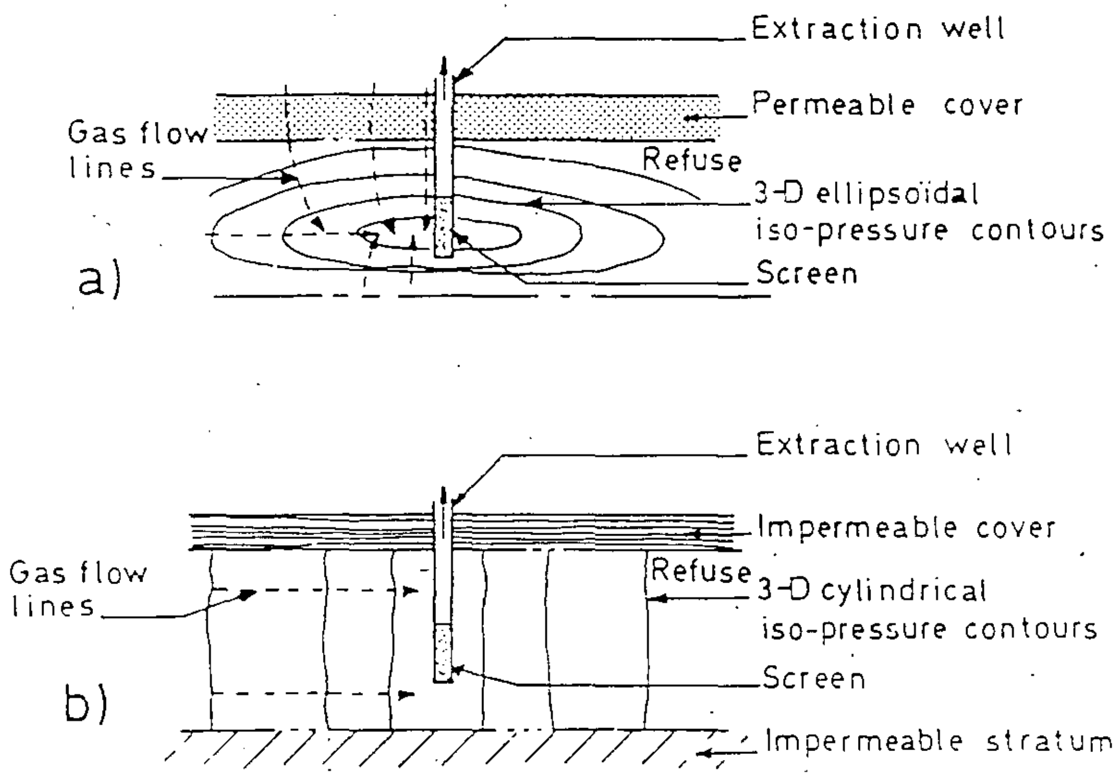


Figure II.31
Iso pressure curves upon landfill gas pumping from the extraction well
a. Zone of sucking influence in unconfined conditions
b. Zone of sucking influence in confined conditions

From Clement, 1981, by courtesy of the author.

neither for intermediate nor for the final cover of the landfill. This rule should also be obeyed at small landfills; otherwise a landfill gas extraction system should be installed and operated, where the gas is sucked by means of a blower.

Simple techniques should be used also for analyzing LFG-quality. Again there should be a cooperation with a University or a Research Institute. On the landfill simple devices as the "Orsat" should be installed instead of sophisticated gas chromatographs.

4.5. Codisposal

This subject will not be discussed in detail in this paper. It is obvious that in economically developing countries codisposal might be necessary due to the lack of secure industrial waste incinerators and/or landfills. But it should be kept in mind that no toxic, liquid and volatile waste should be codisposed. Whenever it is practiced it should be done in a controlled way, so that no industrial waste concentration takes place; in most cases a mixture of MSW with selected industrial waste is the best solution. If the industrial waste is biodegradable no major problems are expected if it is somehow mixed with the MSW (see also Anonymous, 1991).

4.6 Waste Disposal Techniques

Fires are very often observed on landfills, where the waste is not compacted to high densities by means of compactors. Air entering the landfill will initiate composting processes; as a result temperatures up to 70°C may develop. Inside the landfill anaerobic degradation takes place where methane is produced. In combination with catalytic processes self-ignition may occur and the fire may penetrate into the landfill where due to the high temperatures and the absence of air pyrolysis processes may take place. These fires cannot be extinguished by water. In contrast, due to an increase in moisture content anaerobic biological processes may be enhanced with increasing methane production rates. As a consequence high compaction of the waste should be achieved; if no adequate equipment is available, so that only low compaction rates can be reached, measures should be taken to avoid air penetration into the landfill. This can be achieved if daily cover is used; as cover material soil, compost and rubble and under certain circumstances slags from power plants may be used. Of course no new problems should be initiated, e.g. if clay-like materials are emplaced difficult driving in wet conditions, or dust formation during dry periods may take place.

5. WASTE AVOIDANCE AND RECYCLING

Also in economically developing countries there is a great potential for waste avoidance and recycling. This can be concluded from the people often seen on landfills selecting materials. For several reasons (accidents, emissions, fires, etc.) landfills should not be open for the public. Perhaps this kind of waste recycling could be practiced in a controlled way, where authorized people select the reusable materials out of the waste before it is landfilled. Site-specific simple systems should be developed. The selection of reusable materials may be much easier if the MSW is sieved so that the fines, which in general contain no reusable materials, are separated.

Another option may be the installation of small and simple recycling areas distributed all over the city and countryside, where people bring materials as bottles, plastic material, metals, etc. and may get paid for it. Doing so, a separate collection takes place and a secondary market may develop. Such a system was in operation in a simple but effective way in the former DDR (GDR). If possible also containers can be used, where people bring materials for recycling.

Non-polluted vegetative waste from homes, food industry, etc. should not be disposed of in landfills but separately composted using simple windrow systems. By this means in many countries great amount of waste can be reused as compost in agriculture etc. Again this should be done in a controlled way where University and/or Research Institutes may analyze the compost for pollutants.

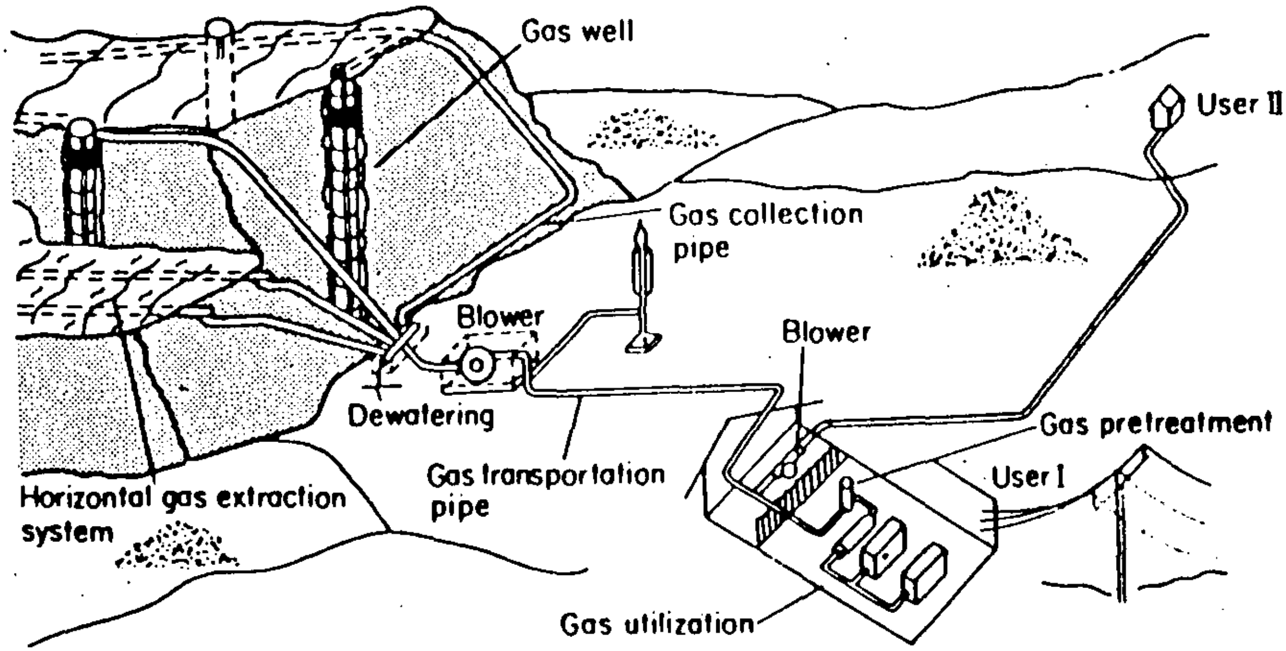


Figure 1. General scheme for a gas extraction and utilization plant (Müller and Rettenberger, 1987).

LFG - QUALITY and QUANTITY

- Due to anaerobic degradation processes organic material in biogas converted

- Gascomposition: 50-65% CH_4 ; 50-35% CO_2 (dependent on waste composition)

- Gas production per ton depends on waste composition (range: 120 - 200 m^3/t TS)
  can be calculated from C-content, heating value, components or measured in test Lysimeters, field tests

- LFG contains organic and anorganic trace components f.e. halogenated hydrocarbons, aromatics, H_2S

DISCUSSION:

TRANSFER OF LABORATORY DATA TO FULL SCALE

- Degradation of degradable MSW-fraction (~80%)
  in lysimeters : ~ 9 months
  in landfills : ~ 9 years

VALUE OF FIELD TESTS

- Gas production rates cannot be measured
- Experiences can be gained (water table, extraction vacuum, gas composition, radius of influence ?

Table 1. Concentration range of halogenated hydrocarbons in landfill gas (Müller and Rettenberger, 1987).

Gas	Formula	Concentration range
Trichlorofluoromethane	CCl_3F	1–84
Dichlorodifluoromethane	CCl_2F_2	4–119
Chlorotrifluoromethane	$CClF_3$	0–10
Dichloromethane	CH_2Cl_2	0–6
Trichloromethane	$CHCl_3$	0–2
Tetrachloromethane	CCl_4	0–0.6
1,1,1-Trichloroethane	$C_2H_3Cl_3$	0.5–4
Chloroethane	C_2H_3Cl	0–264
Dichloroethene	$C_2H_2Cl_2$	0–294
Trichloroethene	C_2HCl_3	0–182
Tetrachloroethene	C_2Cl_4	0.1–142
Chlorobenzene	C_6H_5Cl	0–0.2

PREDICTION OF GASPRODUCTION

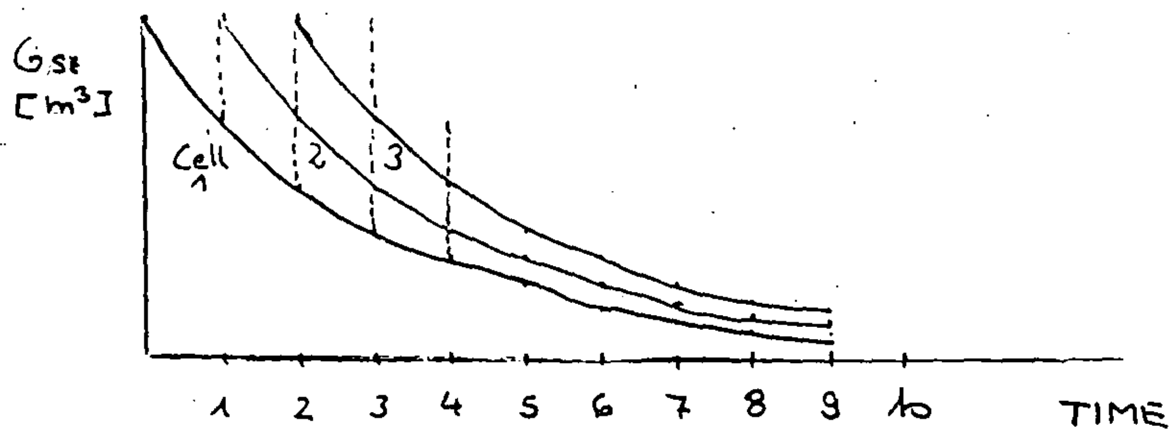
- DEGRADATION : first order kinetics

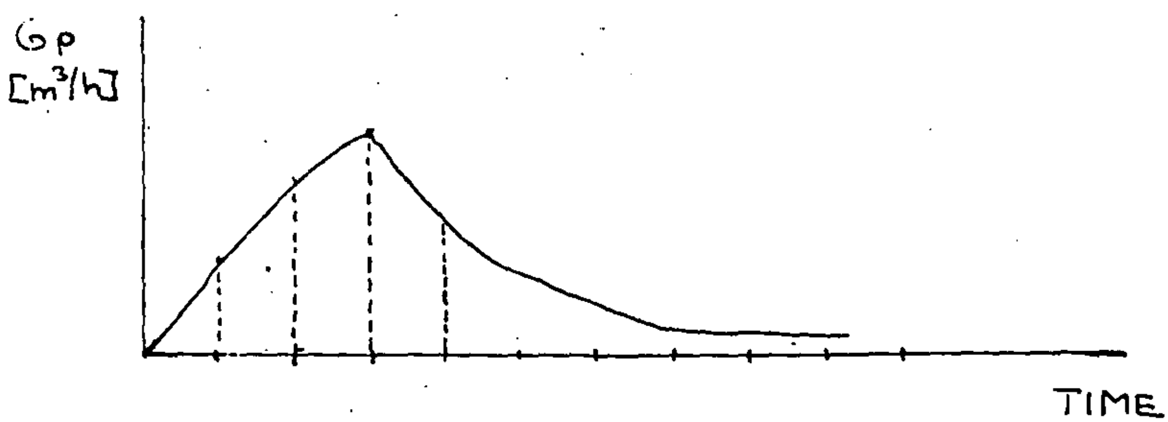
$$-\frac{dc}{dt} = kc \quad \text{(substrate limiting)}$$

The principle equation of biological degradation is given in equation (4):

$$G_{ST} = G_e * (1-e^{-k*T}) \qquad (4)$$

G_{ST} = gas sum at the time T [m^3(STP)/t MSW]
G_e = total gas amount
T = time in years
k = coefficent = - ln (0.5)/$T_{0.5}$

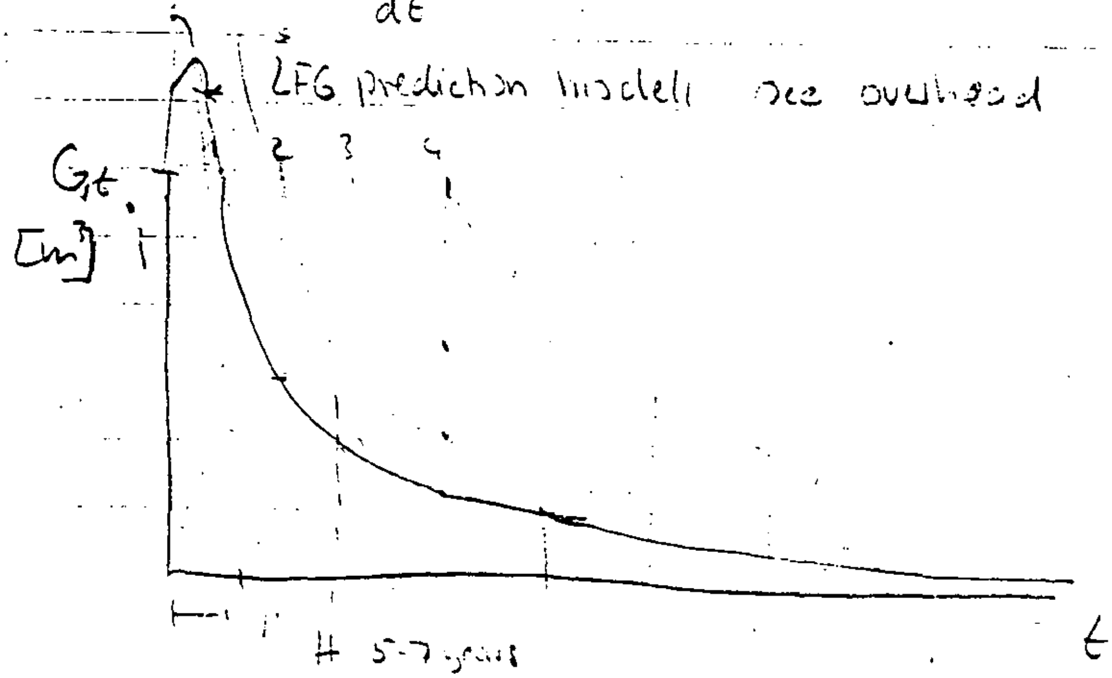


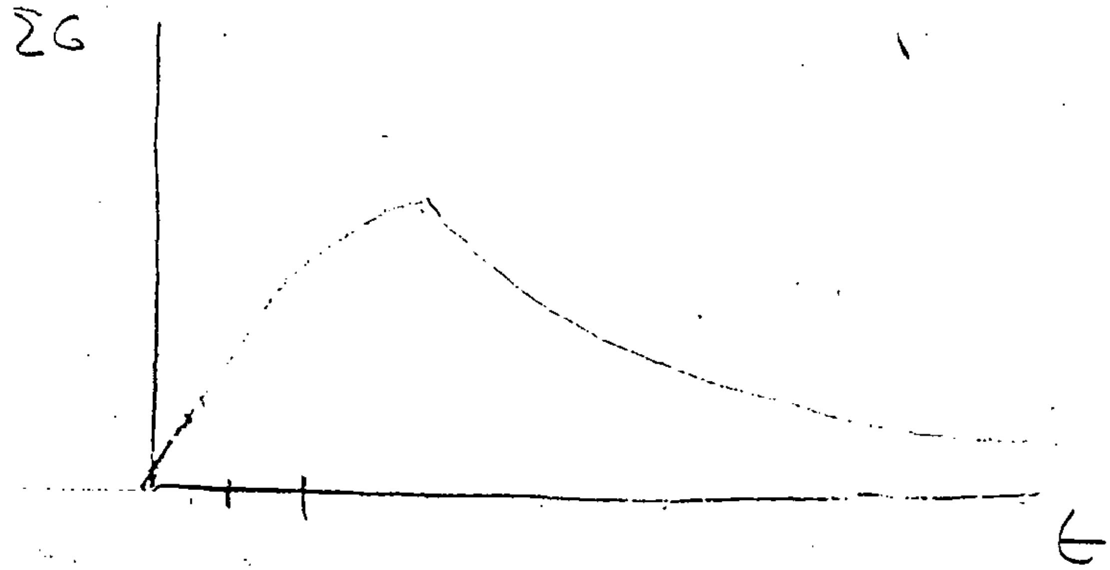


PREDICTION OF GASPRODUCTION WITH TIME

- Theoretical approach: first order kinetics:

$$-\frac{dc}{dt} = k'c$$ ↗ substrate limiting





- Gas extraction rate ~ 50 - 70 %

- About 60 years ↗ 1% of maximum gas production rate

- Half life 5-7 years

ENVIRONMENTAL IMPACT AND HAZARDS

- Trace organics, CO_2 and CH_4 are damaging the ozone layer

- Trace organics and anorganics may be toxic and some are carcinogenic (i.e. vinyle chloride, benzene)

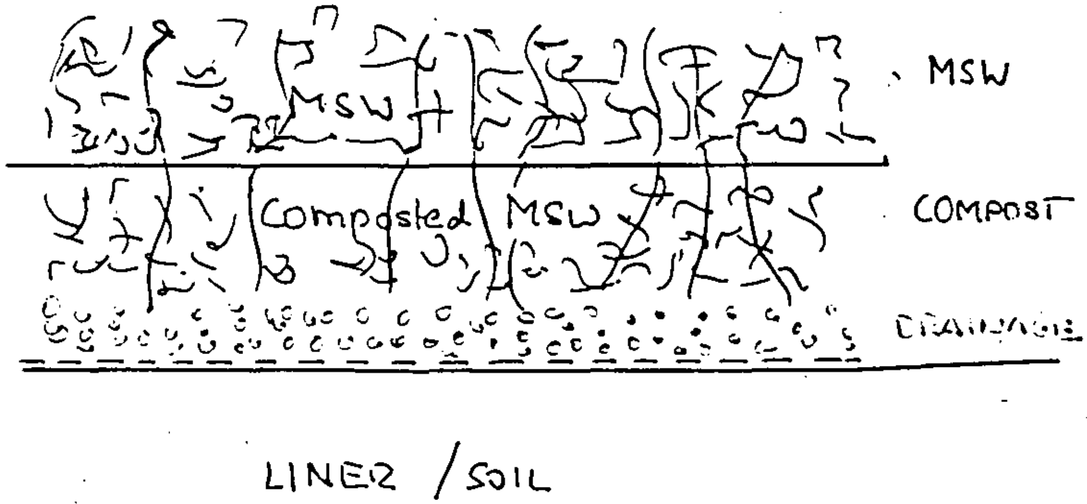
- LFG may accumulate in shafts, basements, pipes and migrate through soil; explosive mixtures may build up (CH_4 in air: 5-15%)

- LFG drives air off (i.e. in manholes, top soil), which relates in oxygen deficits (plants, people)
  CH_4 can be biologically degraded → oxygen depletion
  $$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$$

- LFG is odorous

ENHANCEMENT OF DEGRADATION PROCESSES IN THE LANDFILL

- Leachate Recirculation ?
- Aerobic Pretreatment
- Kompost Layer



LONG TERM BEHAVIOUR OF LANDFILLS

- High Pollution Potential of MSW
- Unequal Water Distribution inside LANDFILL

CONSEQUENCES:

- Landfill has to be operated over very long time
- MSW to be landfilled should be reduced
- Techniques should be devellopped to mine old landfills / reduction of waste
- MSW should be pretreated in order to reduce the emission potential

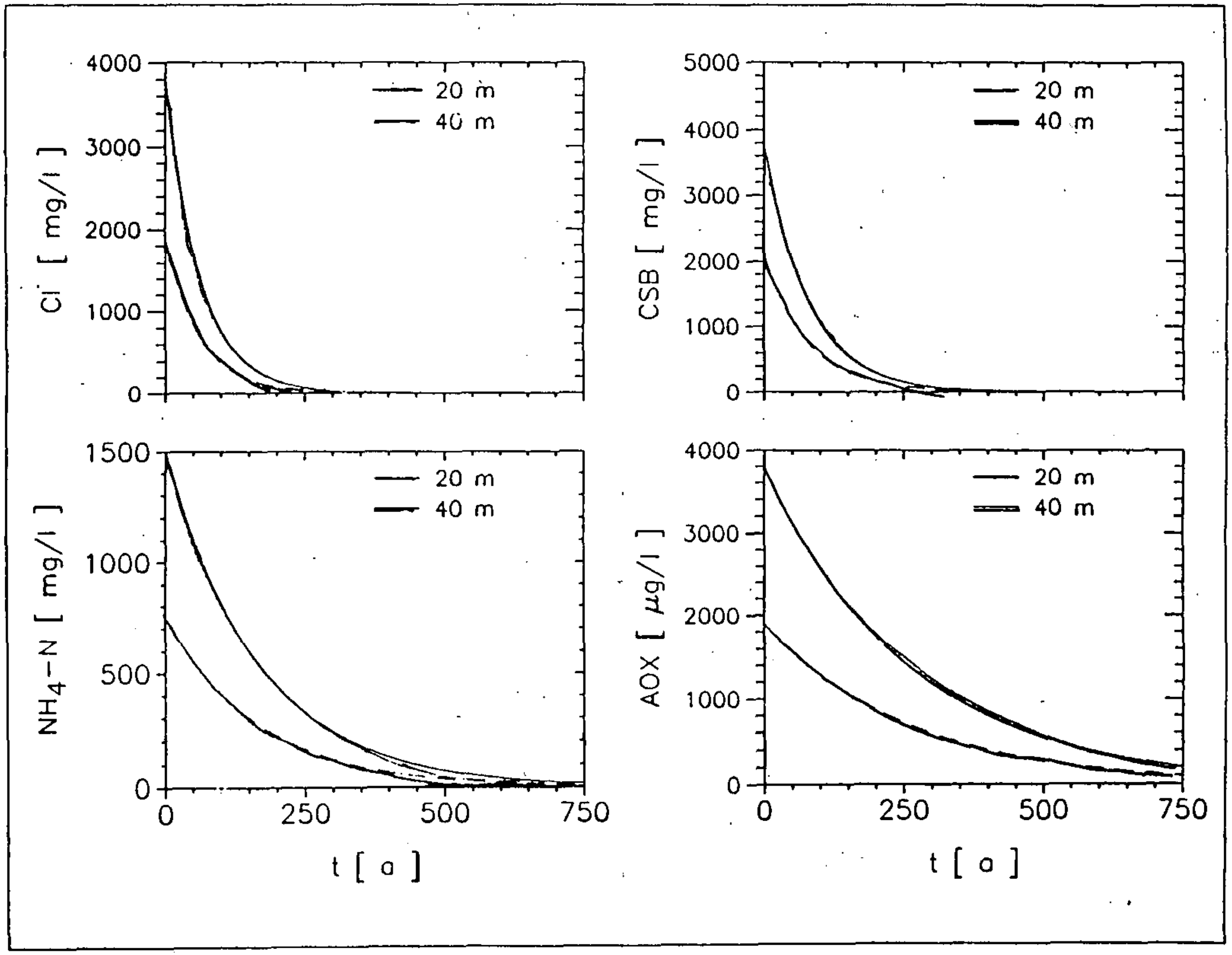
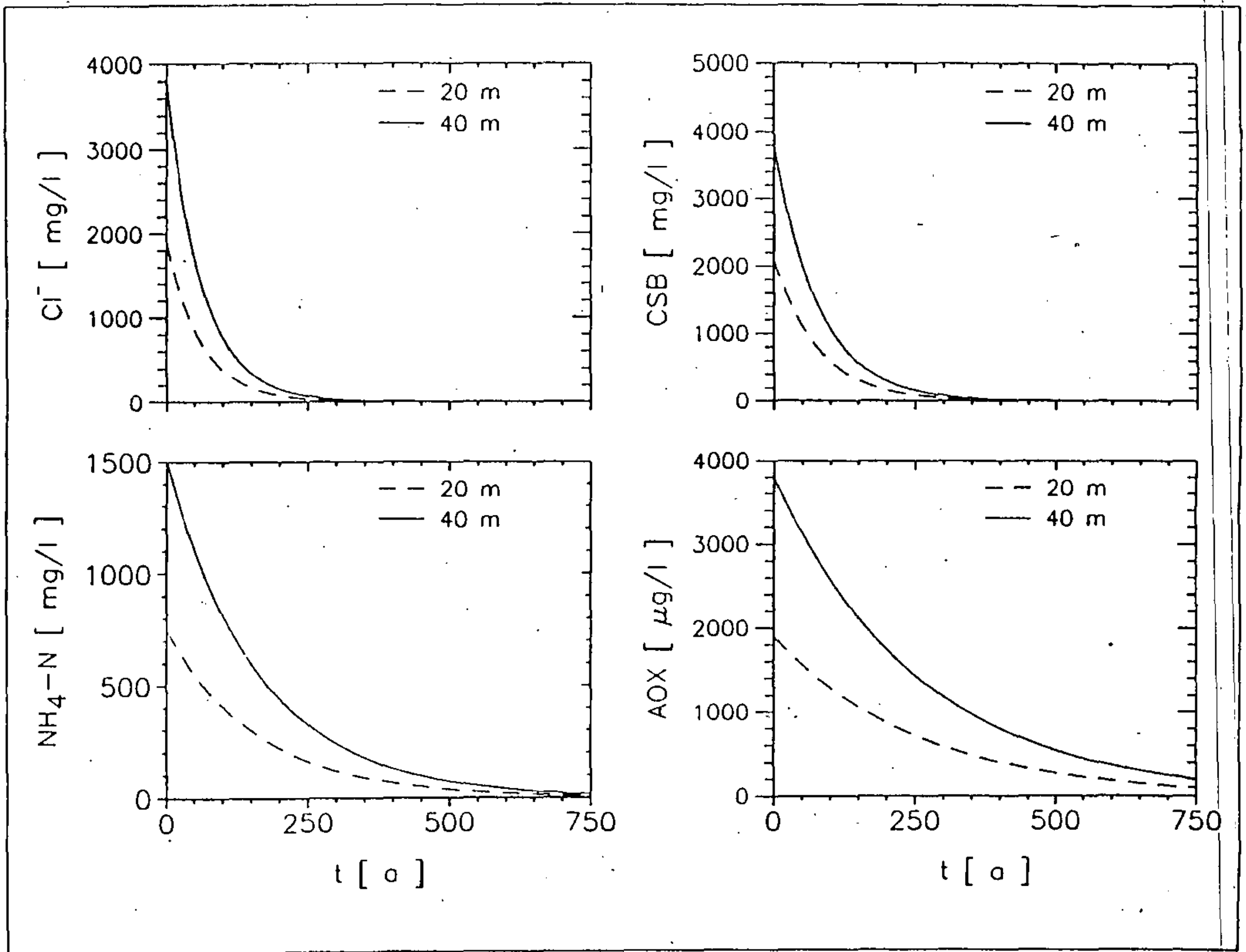


Abb. 7.9: Langfristiger Konzentrationsverlauf der Parameter Cl, CSB, TKN und AOX

Abb. 7.9: Langfristiger Konzentrationsverlauf der Parameter Cl, CSB, TKN und AOX



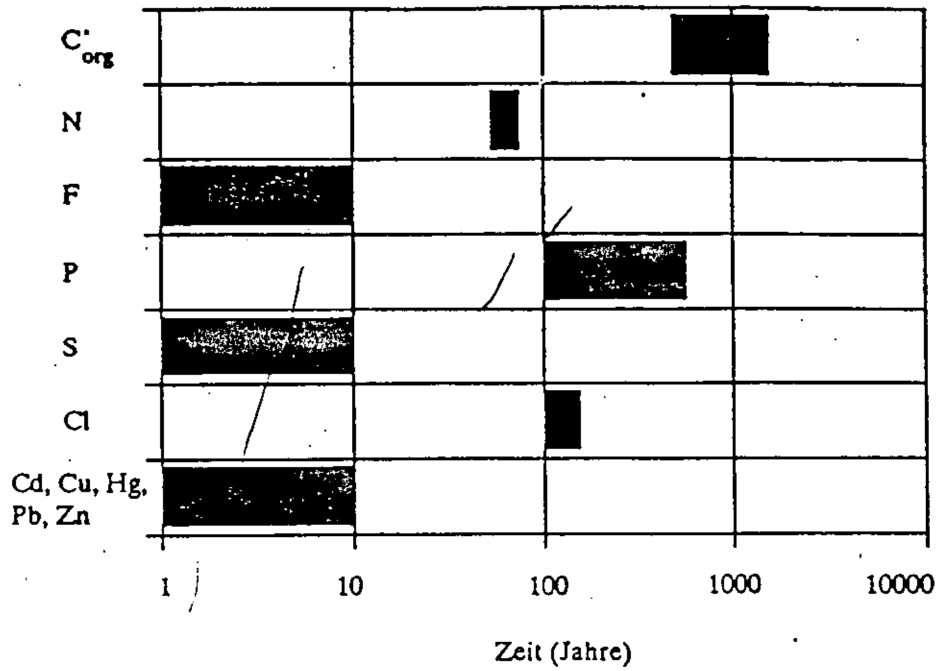
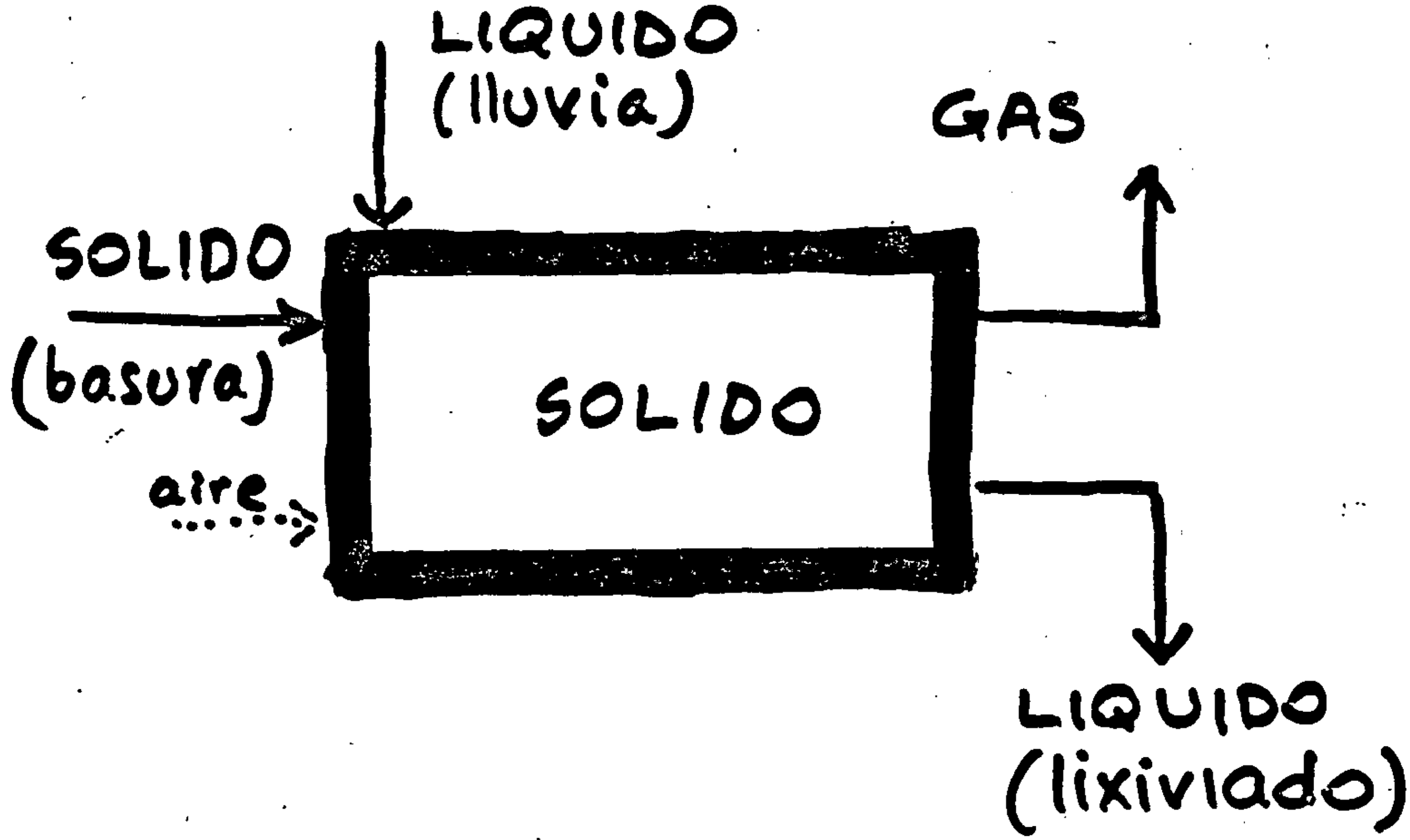
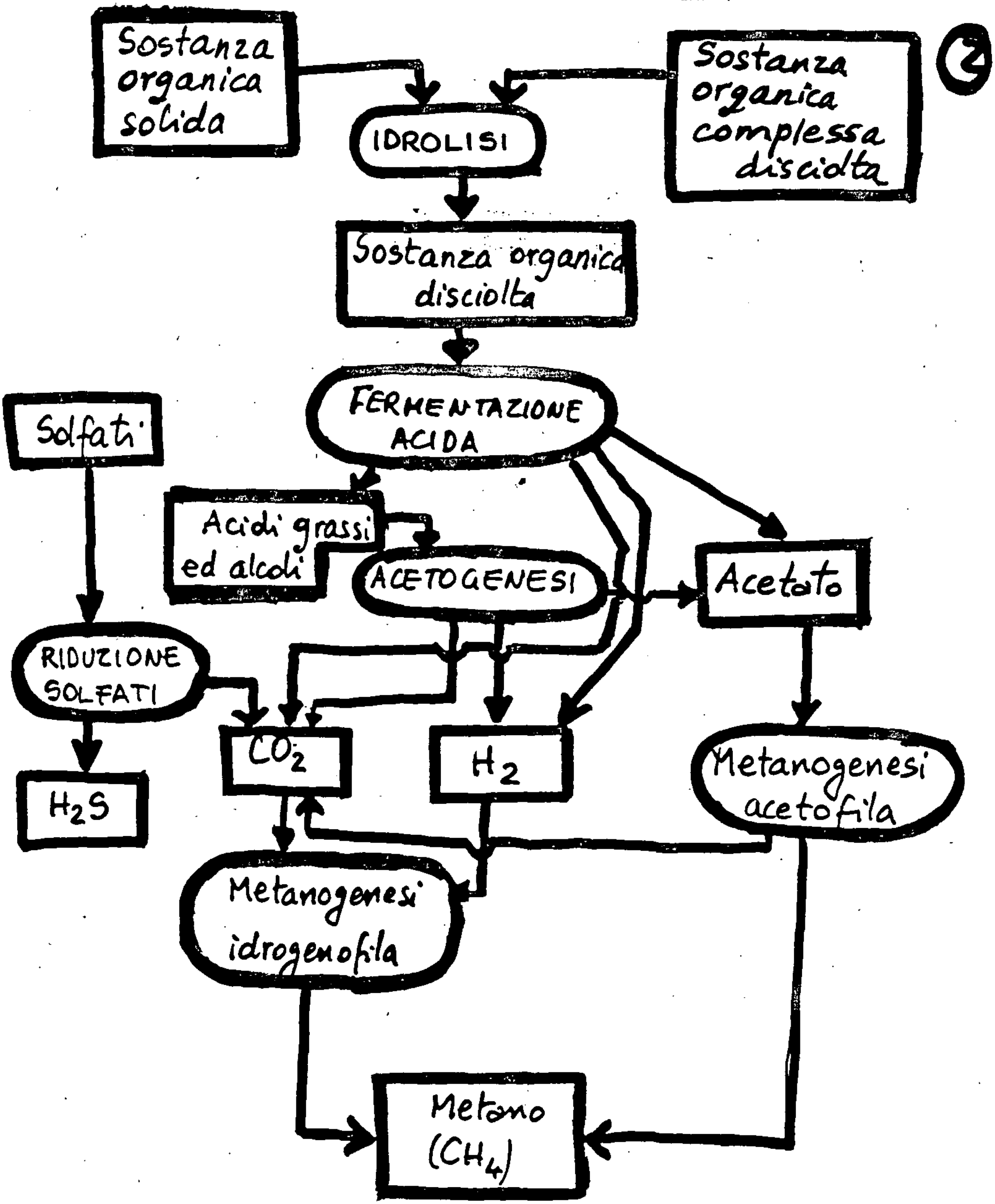


Abb. 1: Abgeschätzte Zeitspannen, bis umweltverträgliche Frachten im Sickerwasser einer Siedlungsabfalldeponie erreicht werden (Baccini und Belevi, 1992)

EL REACTOR "RELLENO"




Sostanza organica solida
Sostanza organica complessa disciolta
IDROLISI
Sostanza organica disciolta
FERMENTAZIONE ACIDA
Solfati
Acidi grassi ed alcoli
ACETOGENESI
Acetato
RIDUZIONE SOLFATI
CO_2
H_2
Metanogenesi acetofila
H_2S
Metanogenesi idrogenofila
Metano (CH_4)

PROCESSOS DE IDROLISI

$$(C_6H_{10}O_5)_n + n\,H_2O \rightarrow nC_6H_{12}O_6$$

PROCESSOS FERMENTATIVOS

$$C_6H_{12}O_6 + H_2O \rightarrow 2CH_3COOH + H_2 + CO_2$$

$$C_6H_{12}O_6 \rightarrow C_3H_7COOH + 2H_2 + 2CO_2$$

$$C_6H_{12}O_6 \rightarrow C_2H_5OH$$

• PROCESSOS ACETOGENICOS

$$C_2H_5COOH + 2H_2O \rightarrow CH_3COOH + CO_2 + 3H_2$$

$$C_3H_7COOH + 2H_2O \rightarrow 2CH_3COOH + 2H_2$$

$$C_2H_5OH + H_2O \rightarrow CH_3COOH + 2H_2$$

$$C_6H_5COOH \xrightarrow{+4H_2O} 3CH_3COOH + H_2$$

• PROCESSOS METANOGENICOS

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$

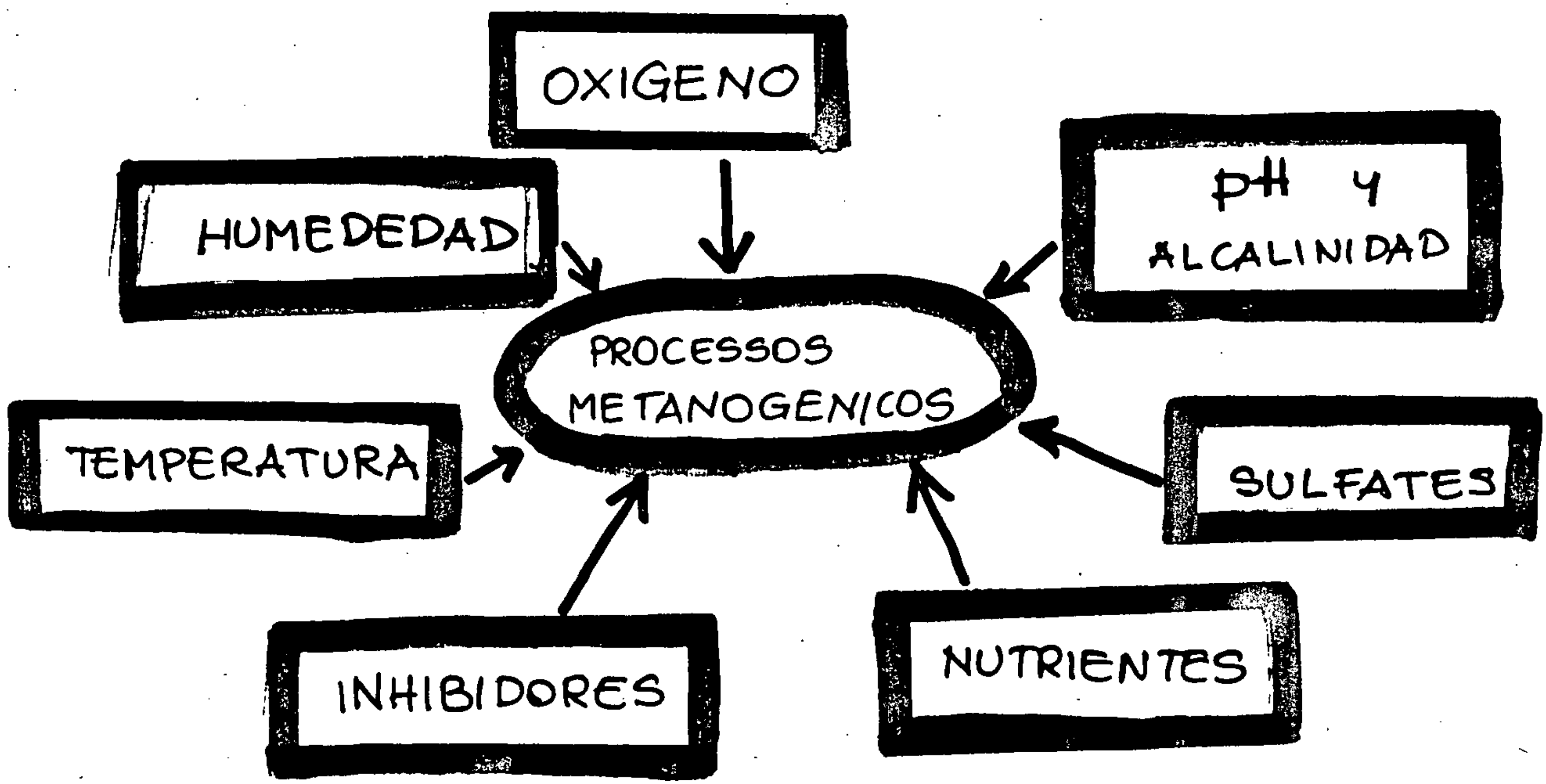
$$CH_3COOH \rightarrow CH_4 + CO_2$$

RIDUCCION DE SULFATES

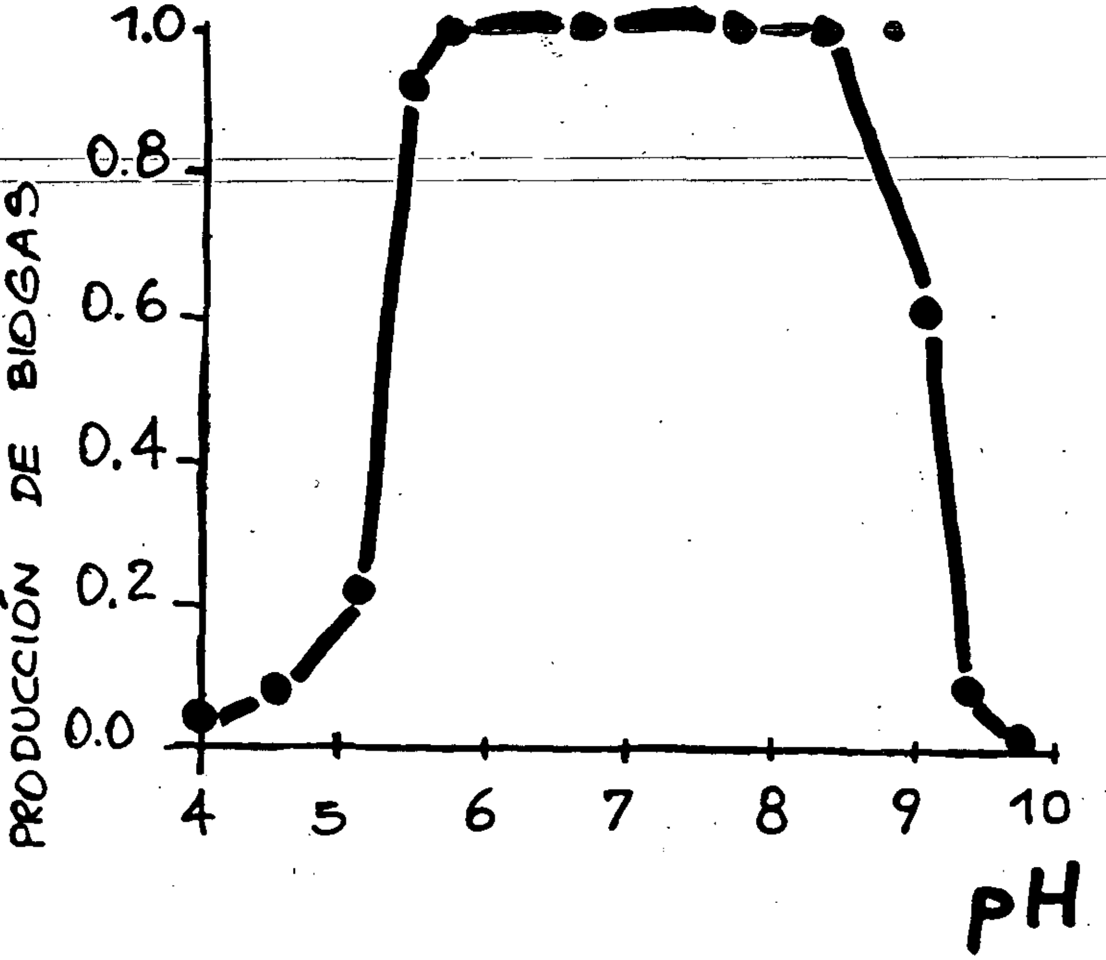
$$4H_2 + SO_4^{2-} + H^+ \rightarrow HS^- + 4H_2O$$

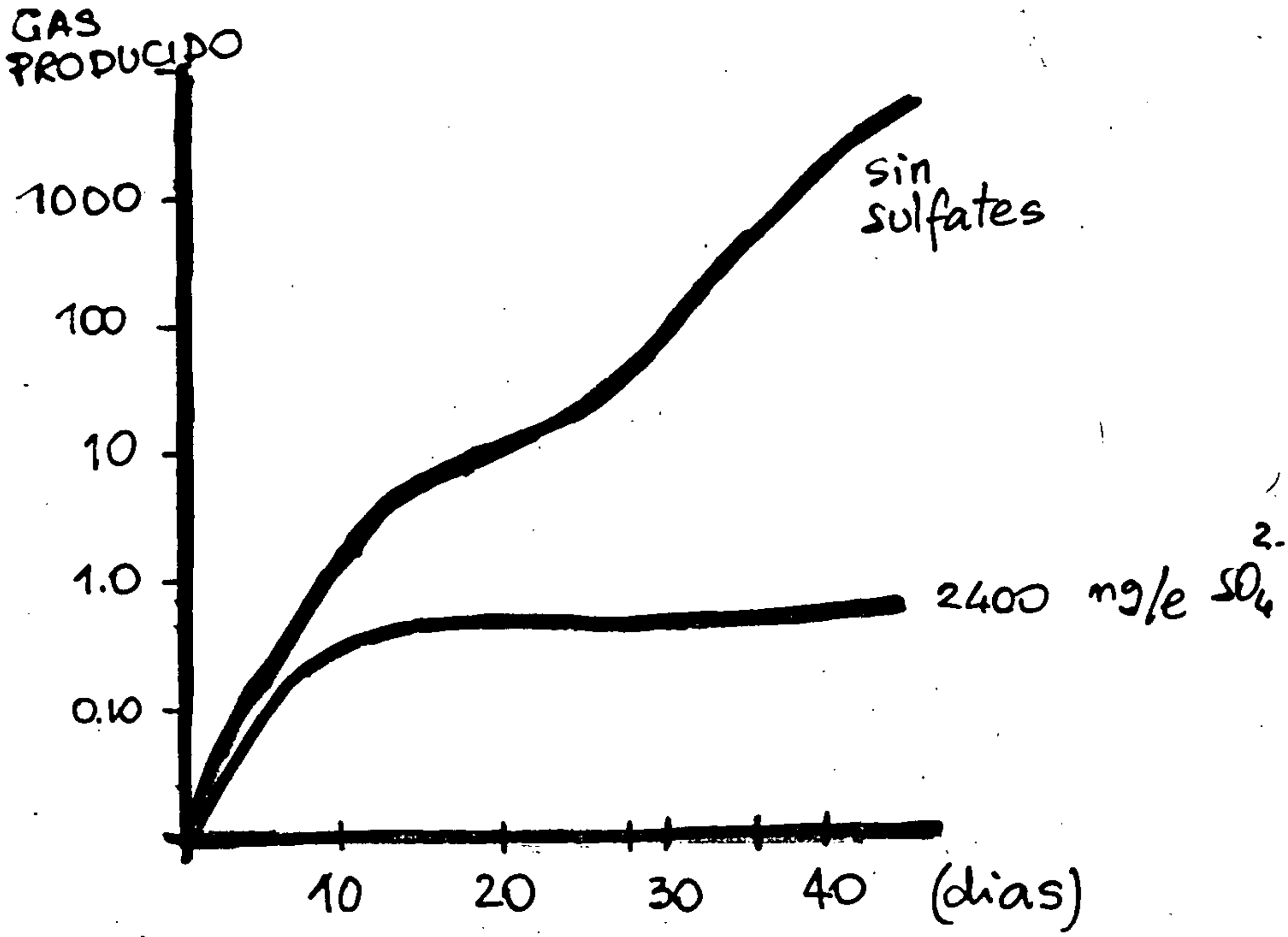
$$CH_3COOH + SO_4^{2-} \rightarrow CO_2 + HS^- + HCO_3^- + H_2O$$

$$C_3H_7COOH + SO_4^{2-} + H^+ \rightarrow 4CH_3COOH + HS^-$$

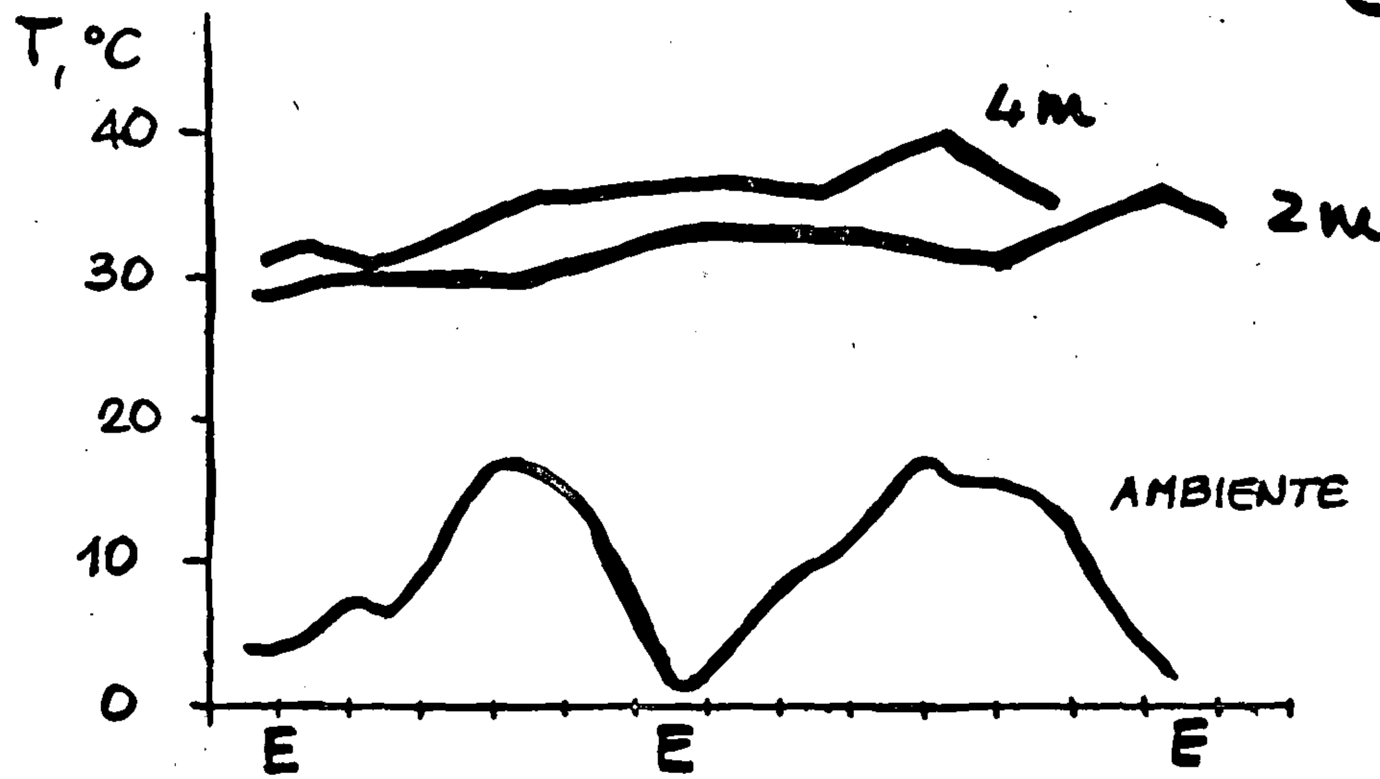

OXIGENO
HUMEDEDAD
pH y ALCALINIDAD
PROCESSOS METANOGENICOS
TEMPERATURA
SULFATES
INHIBIDORES
NUTRIENTES

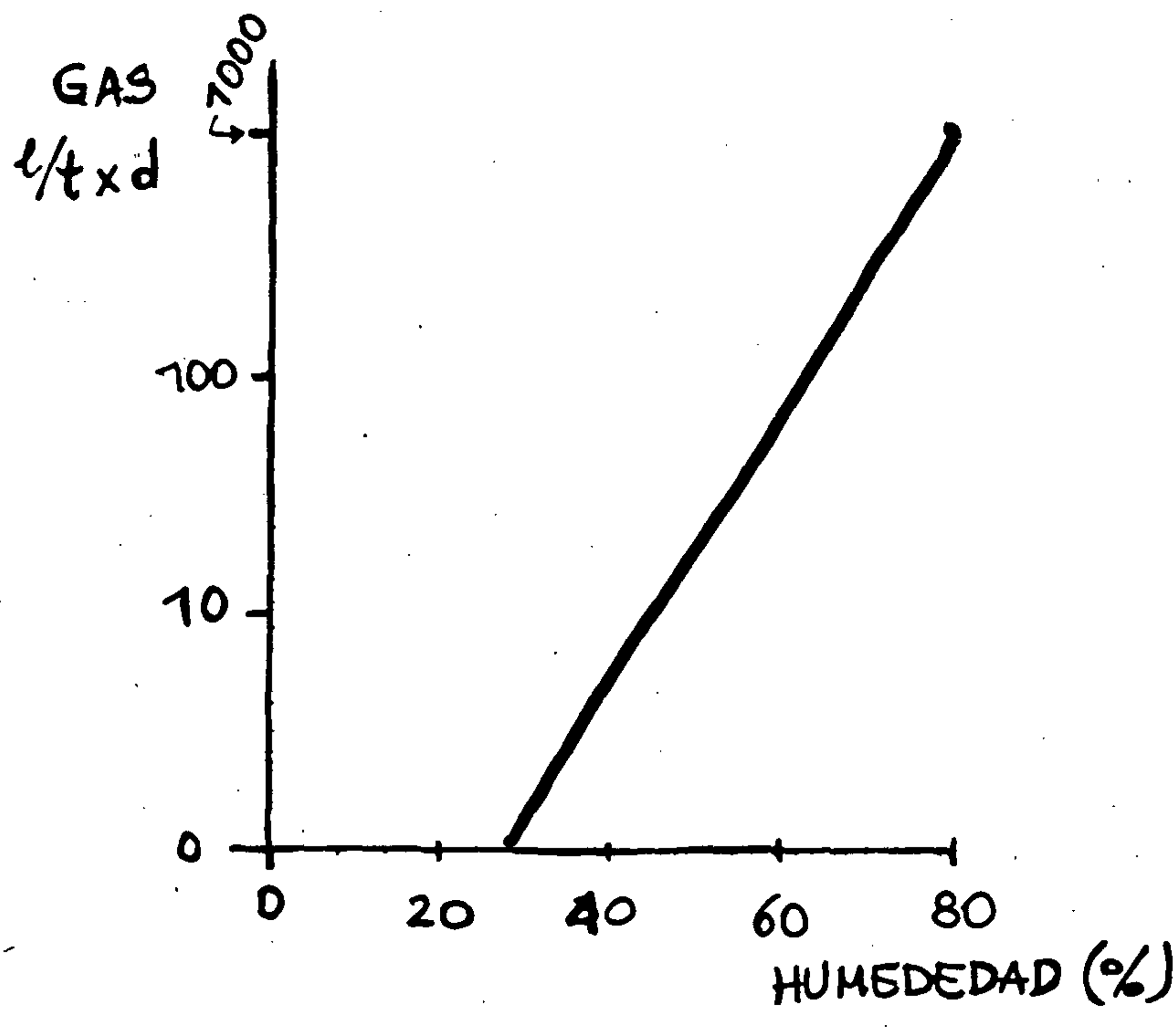
5


PRODUCCIÓN DE BIOGAS
1.0
0.8
0.6
0.4
0.2
0.0
4
5
6
7
8
9
10
pH


GAS PRODUCIDO
1000
100
10
1.0
0.10
sin sulfates
2400 mg/e SO_4^{2-}
10
20
30
40
(dias)

6


T, °C
40
30
20
10
0
4m
2m
AMBIENTE
E
E
E


GAS
l/t x d
1000
100
10
0
0
20
40
60
80
HUMEDEDAD (%)

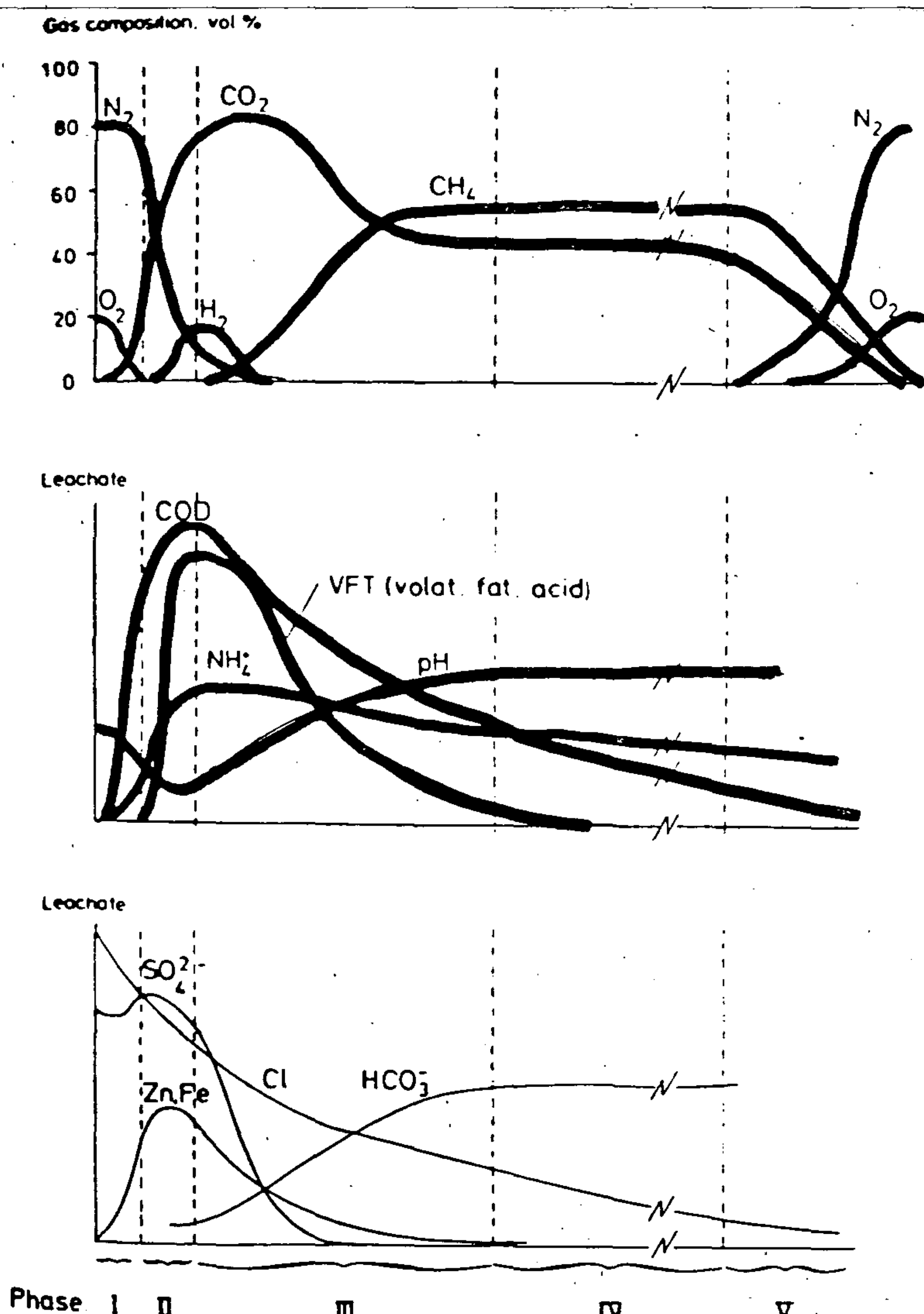
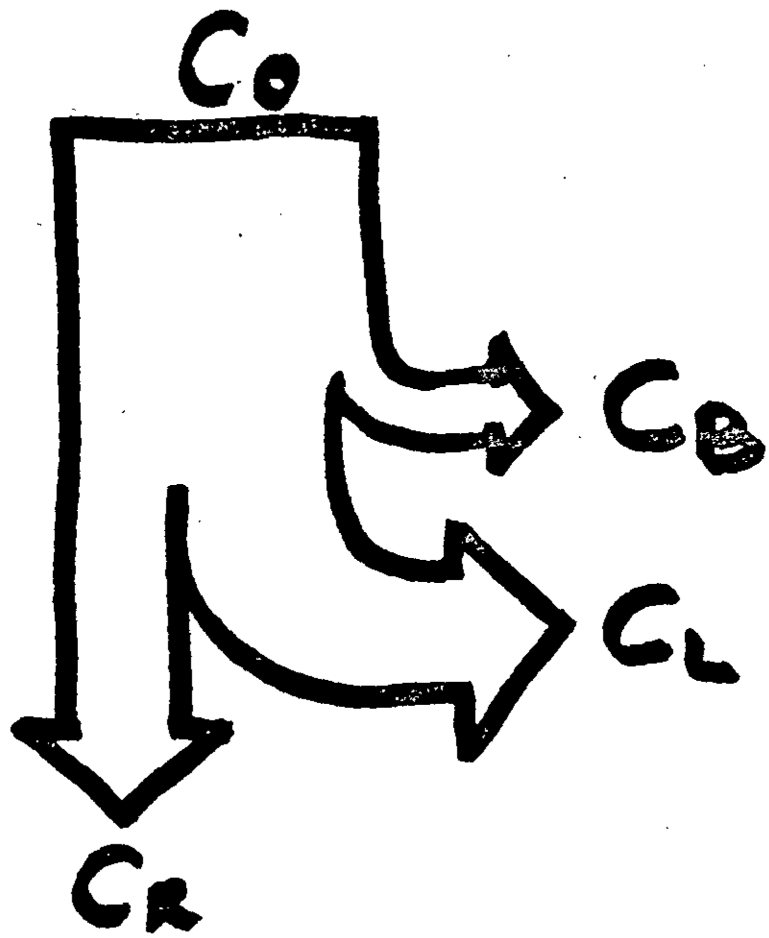
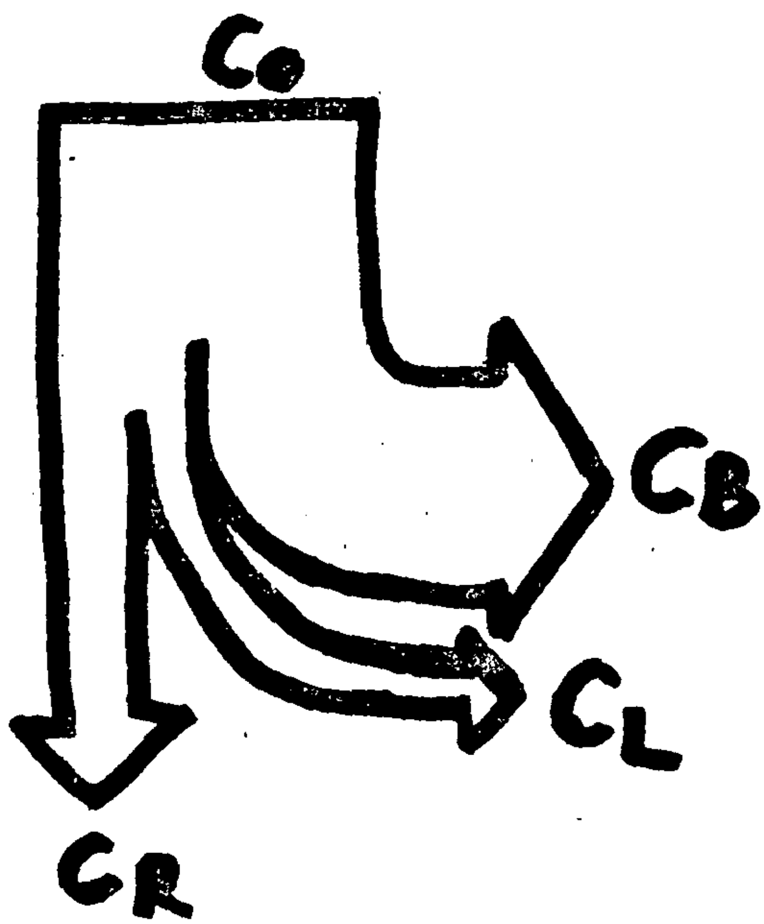


Figure 1. Illustration of developments in leachate and gas in a landfill cell (Christensen & Kjeldsen, 1989).



C_0
C_B
C_L
C_R



C_0
C_B
C_L
C_R

Tabella 8. Parametri caratteristici della qualità del percolato in relazione alla fase di degradazione del rifiuto (Ehrig, 1989)

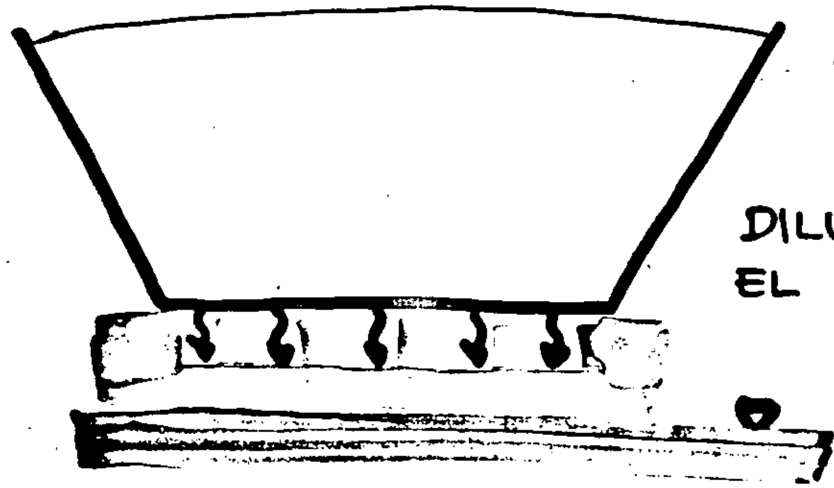
Parametri	Fase Acida	Fase Metanigena Stabile
pH	4.5÷7.5	7.5÷9
BOD5(mg/l)	4000÷40000	20÷550
COD(mg/l)	6000÷60000	500÷4500
SO4(mg/l)	70÷1750	10÷420
Ca(mg/l)	10÷2500	20÷600
Mg(mg/l)	50÷1150	40÷350
Fe(mg/l)	20÷2100	3÷280
Mn(mg/l)	0.3÷65	0.03÷45
Zn(mg/l)	0.1÷120	0.03÷4
Sr(mg/l)	0.5÷15	0.3÷7

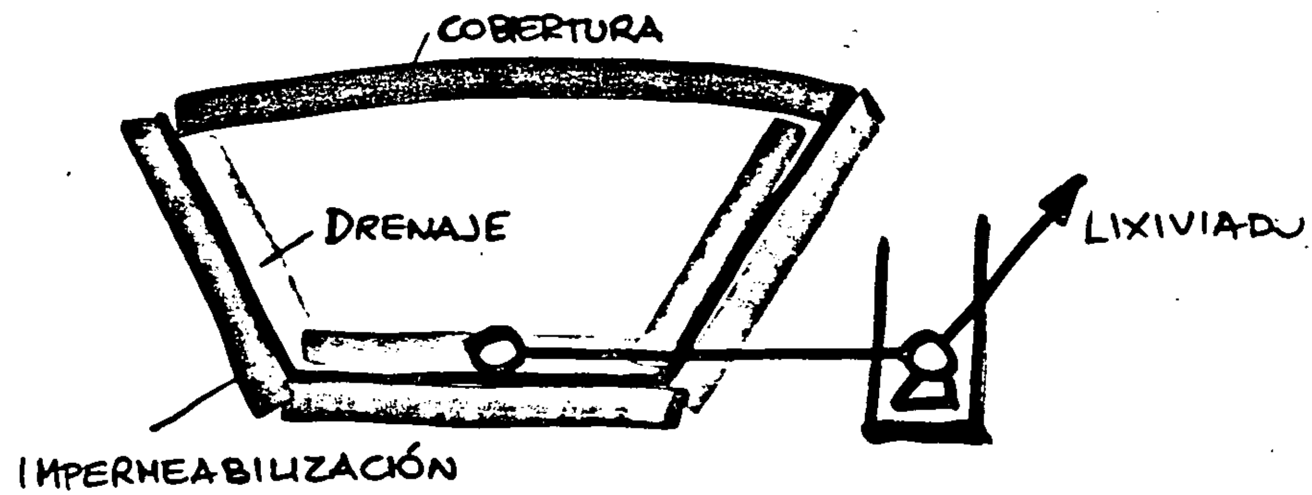
Tabella 9 Parametri caratteristici della qualità del percolato che non presentano differenze fra le fasi di degradazione del rifiuto (Ehrig, 1989)

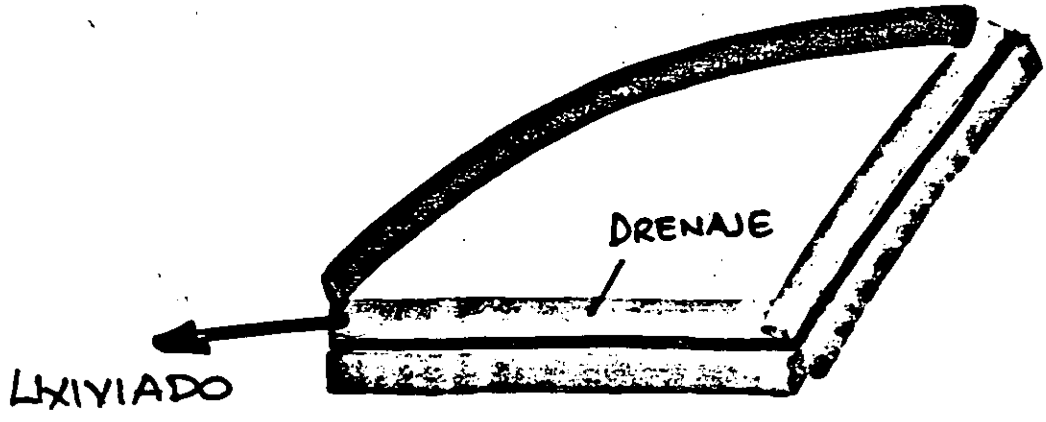
Parametri	Unità di misura	Intervalli di variazione
Cl	(mg/l)	100 ÷ 5000
Na	(mg/l)	50 ÷ 4000
K	(mg/l)	10 ÷ 2500
Alcalinità	(mgCaCO$_3$/l)	300 ÷ 11500
NH4	(mg/l)	30 ÷ 3000
Norg	(mg/l)	10 ÷ 4250
N_{tot}	(mg/l)	50 ÷ 5000
NO_3	(mg/l)	0.1 ÷ 50
NO_2	(mg/l)	0 ÷ 25
Ptot	(mg/l)	0.1 ÷ 30
CN	(mg/l)	0.04 ÷ 90
AOX*	(µgCl/l)	320 ÷ 3500
Fenoli	(mg/l)	0.04 ÷ 44
As	(µg/l)	5 ÷ 1600
Cd	(µg/l)	0.5 ÷ 140
Co	(µg/l)	4 ÷ 950
Ni	(µg/l)	20 ÷ 2050
Pb	(µg/l)	8 ÷ 1020
Cr	(µg/l)	30 ÷ 1600
Cu	(µg/l)	4 ÷ 1400
Hg	(µg/l)	0.2 ÷ 50

*Composti organici alogenati

SISTEMAS DE BARRIERA







MATERIALES

(2)

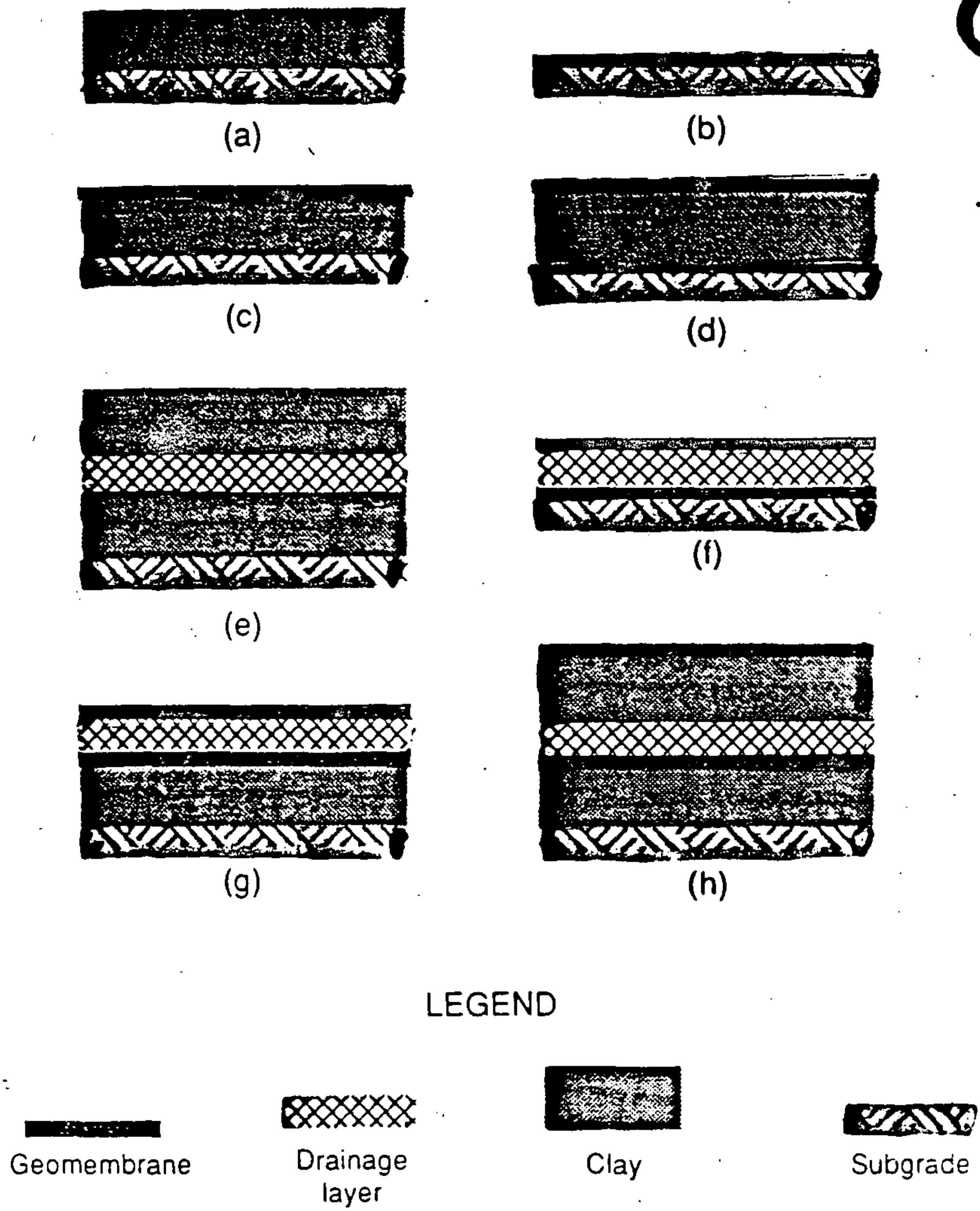
NATURALES

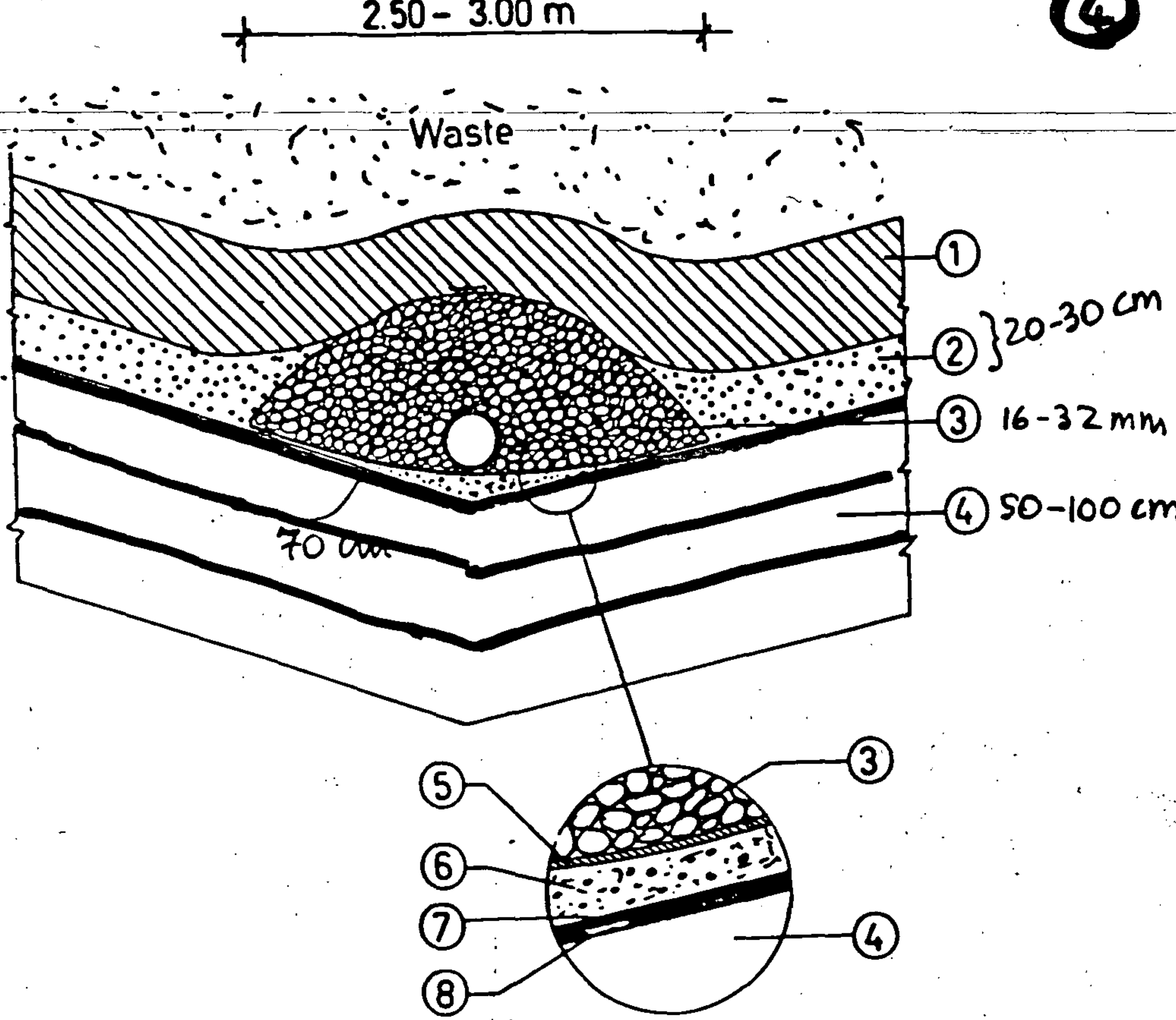
• ARCILLA	I	0,5÷1 m	10^{-7} cm/s
• ARENA + BENTONITE	I		5–10% Bentonite
• ARENA	P		15–20 cm
• GRAVA	D		16–32 mm

ARTIFICIALES

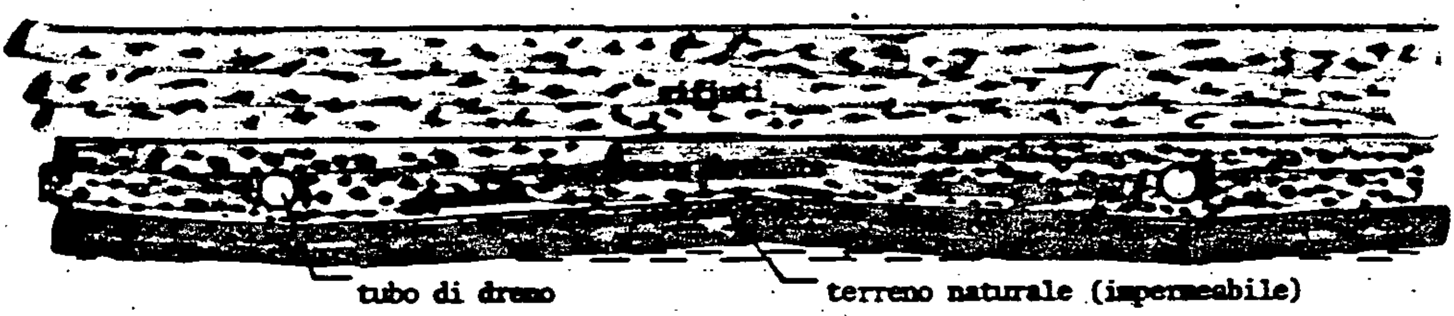
• MEMBRANES PLASTICOS	I		PE, 2 mm
• GEO TEXTILES	P		> 4.00 g/m^2
• GEOCOMPOSITES	ID		
• GEOREDES	D		
• TUBERIAS	Plasticos Ceramicos	D	ϕ > 200 mm
• POZOS DE COLLECCIÓN	- Plasticos - Concreto	C	ϕ > 1,5 m
• RESIDUOS FINES		I	

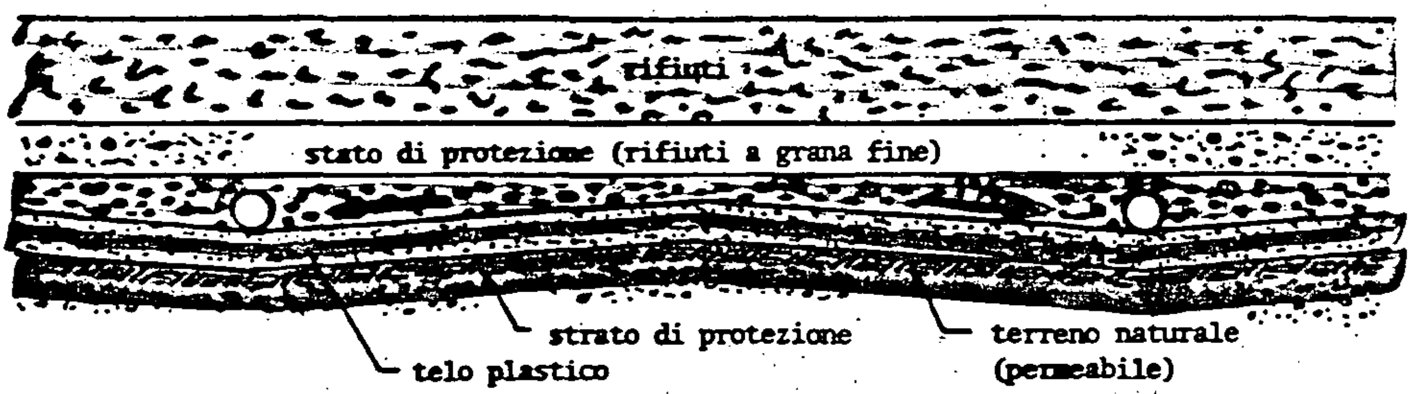
3

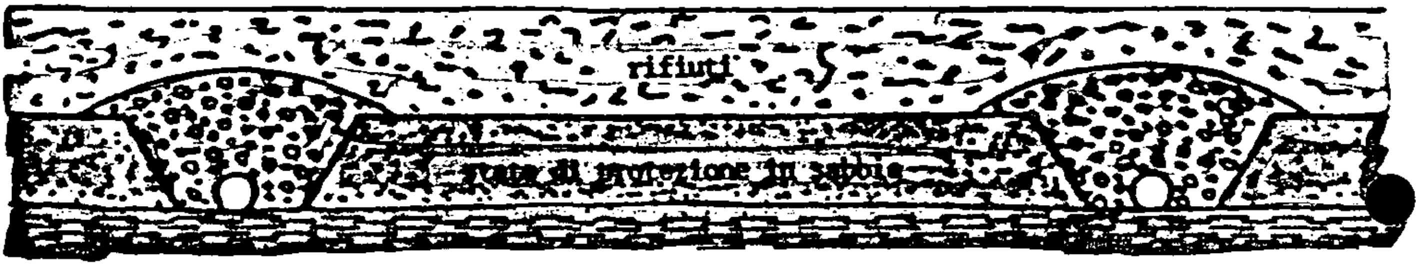

(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
LEGEND
Geomembrane
Drainage layer
Clay
Subgrade

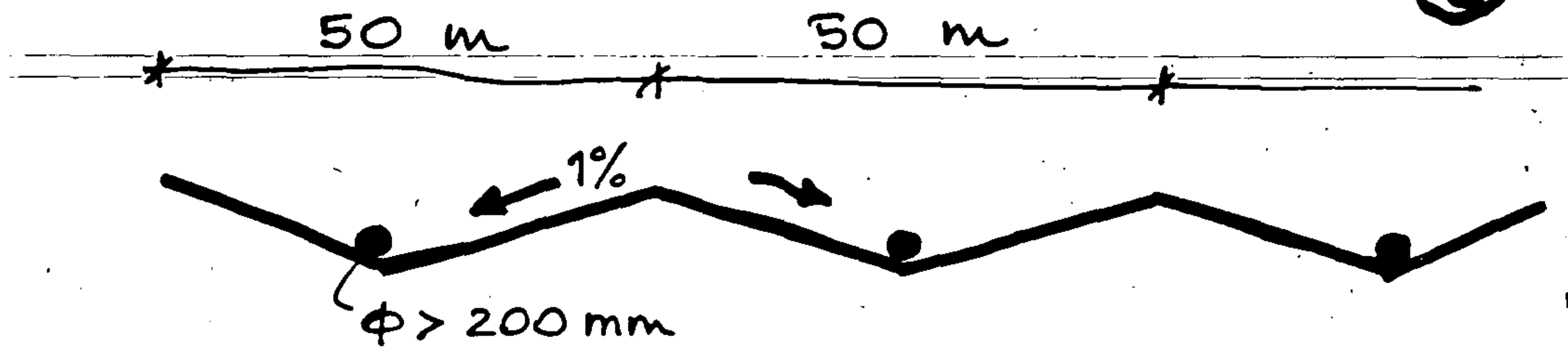

2.50 - 3.00 m
Waste
1
2
20-30 cm
3
16-32 mm
4
50-100 cm
70 cm
5
3
6
7
4
8

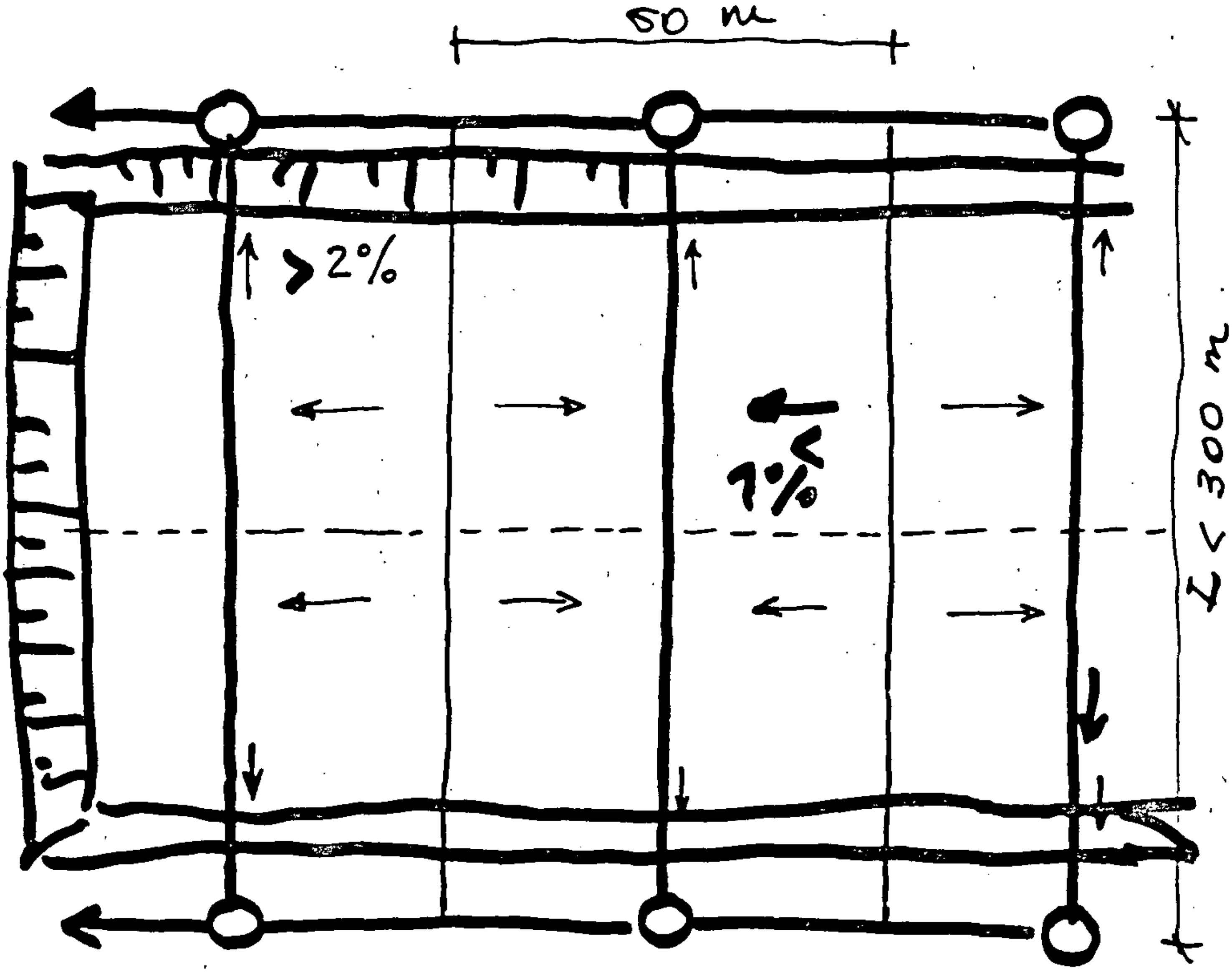
SISTEMA DE BARRIERA








50 m
50 m
1%
Φ > 200 mm


50 m
> 2%
1%
L < 300 m

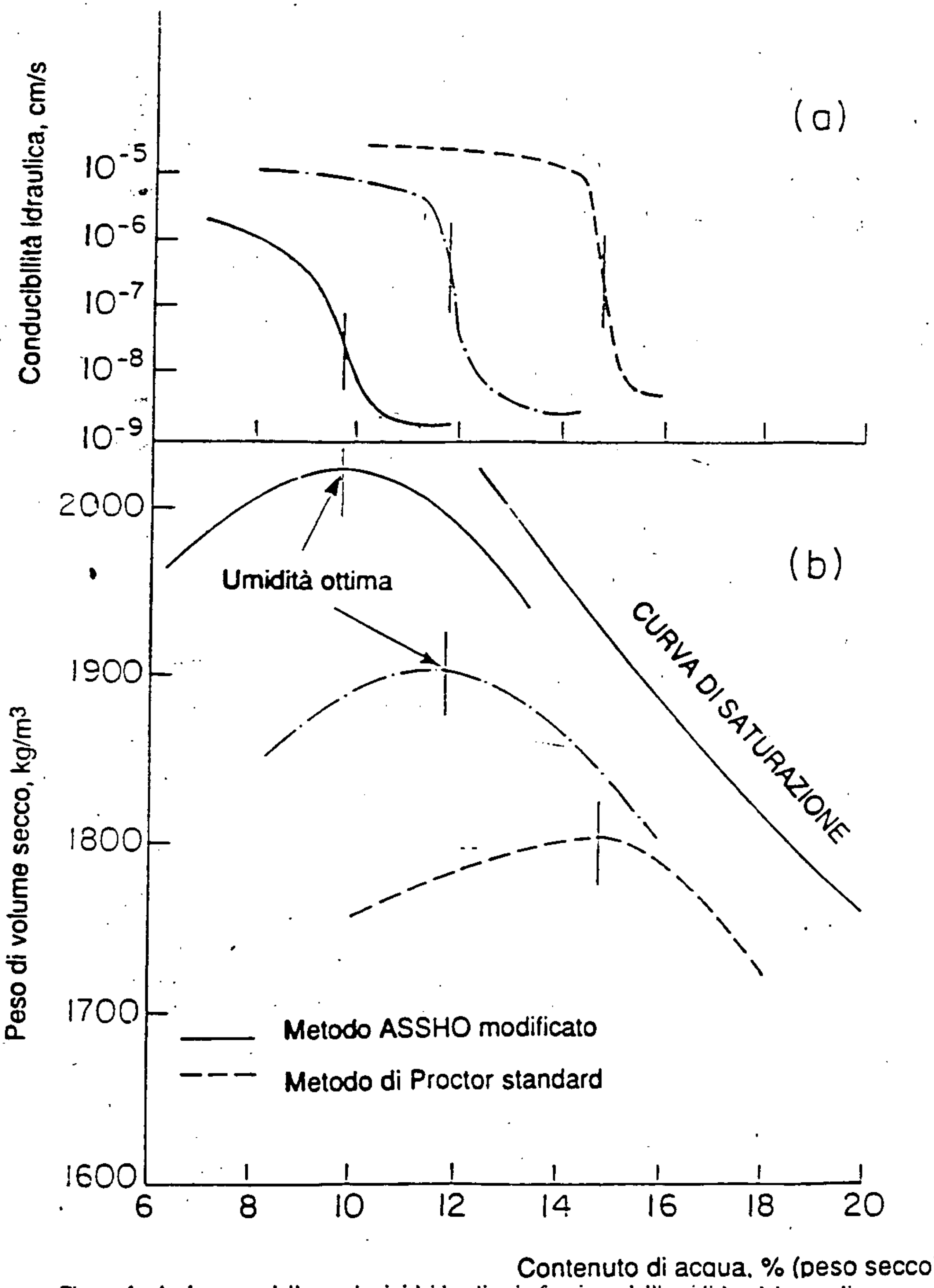


Figura 4.- Andamento della conduttività idraulica in funzione dell'umidità e del peso di volume secco dell'argilla (Farquhar, 1992)

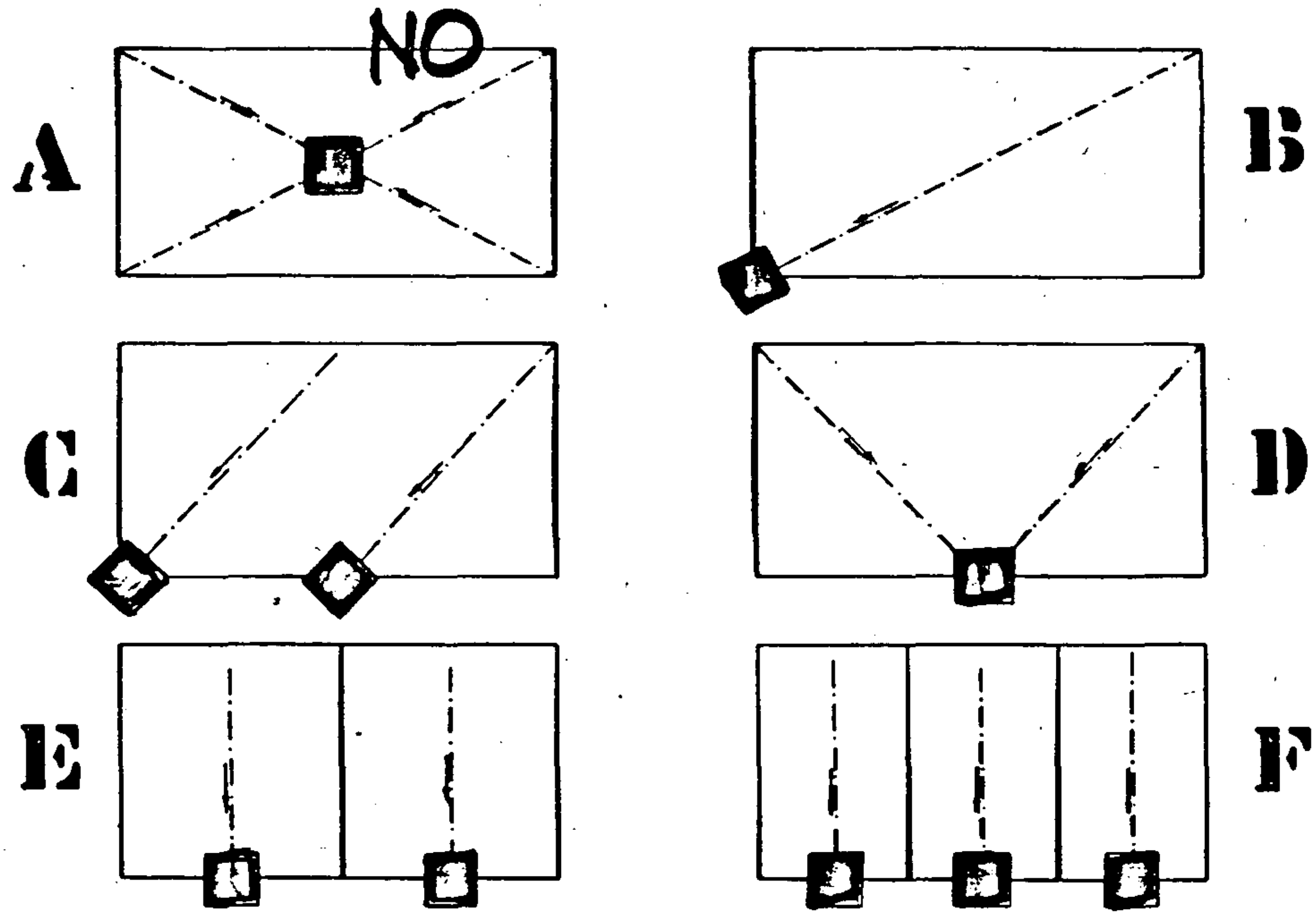


Figura 12.- Schemi alternativi della configurazione dei sistemi di drenaggio del percolato.

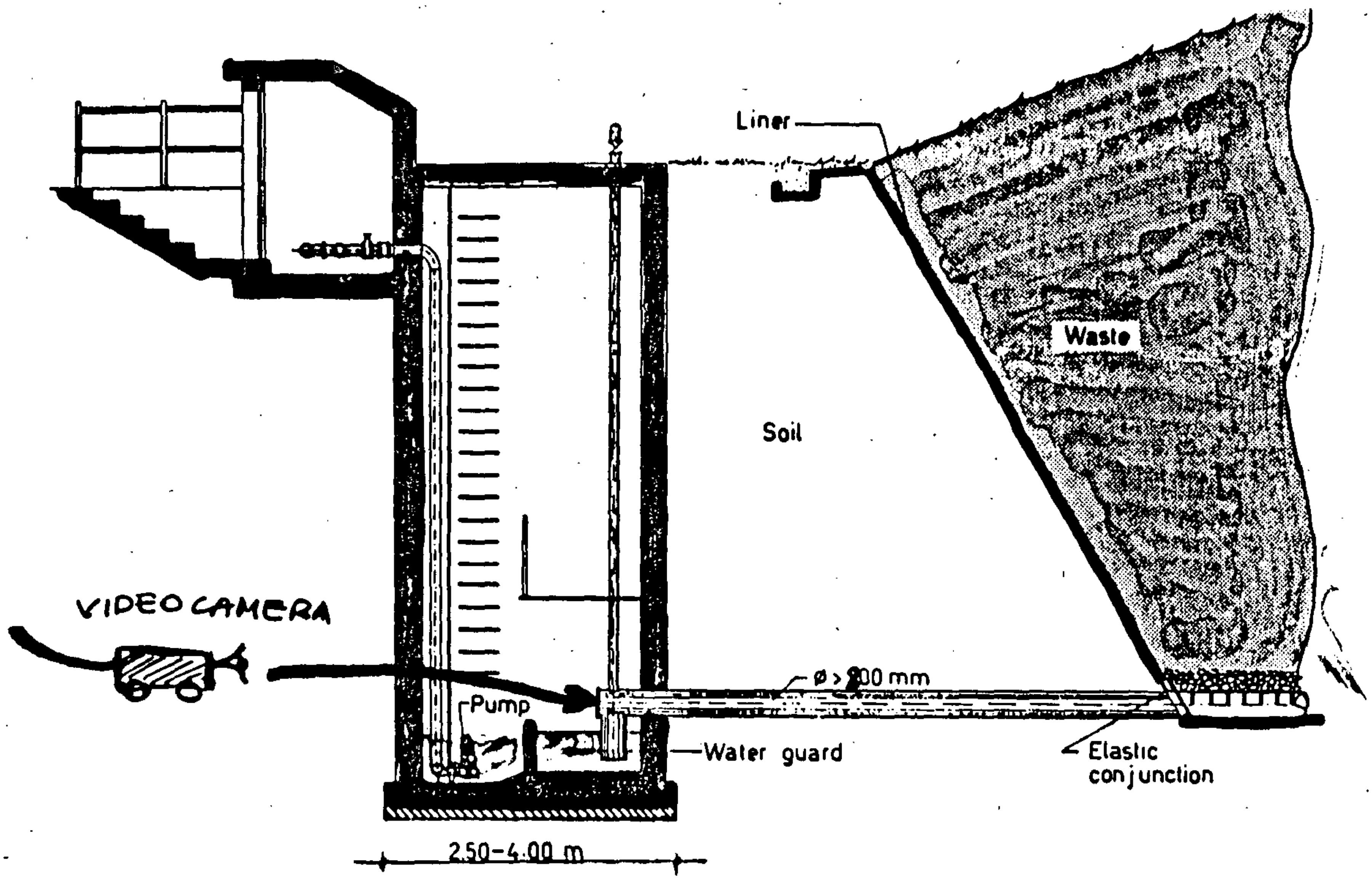


Figure 5. Example of a manhole for final leachate collection.

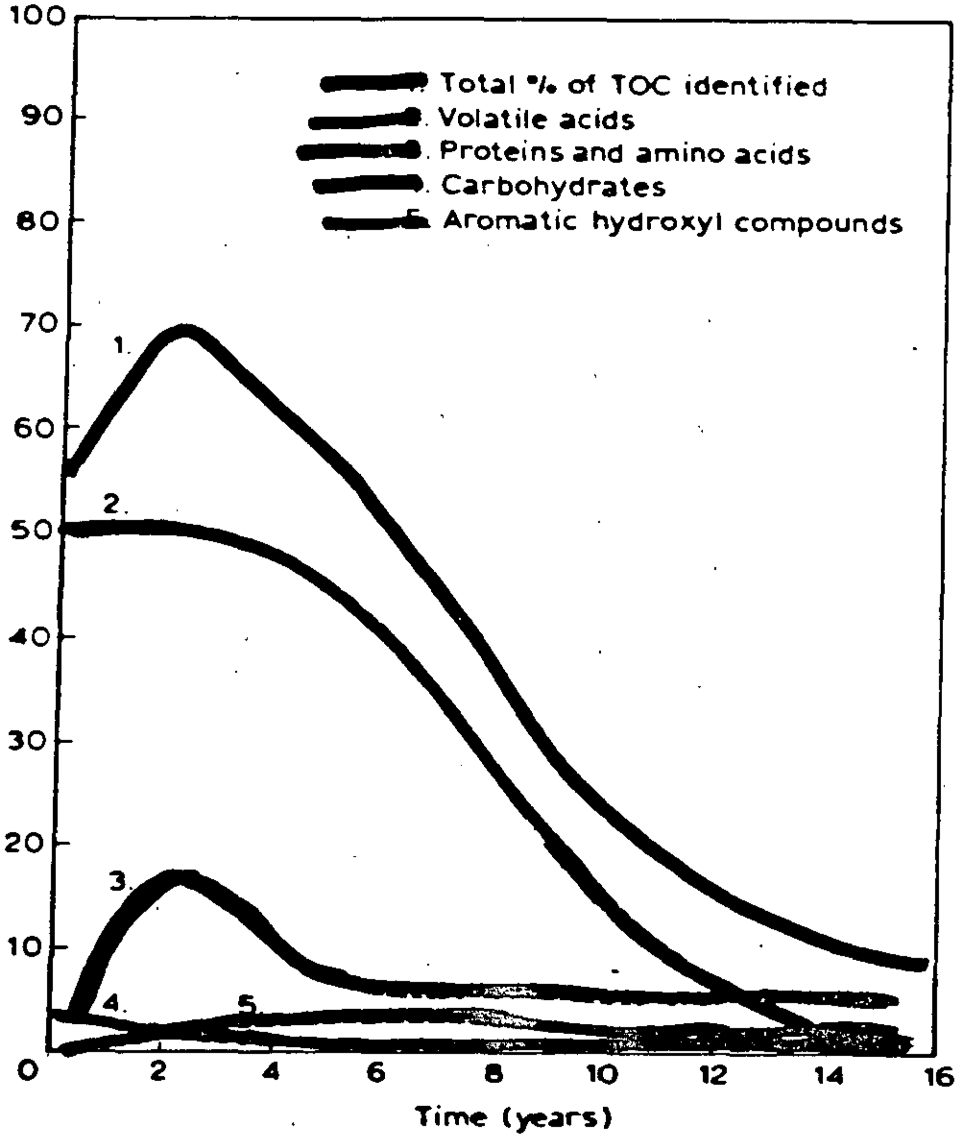


Figure 6. Trend in the identified fraction of leachate TOC versus landfill age (Chian & DeWalle, 1977).

ASPECTOS SOCIALES DEL MANEJO DE LOS RESIDUOS SOLIDOS

El manejo de los residuos sólidos es un conjunto de servicios de intrínseca naturaleza social. Esto es, pocos servicios públicos pese a su composición "pública" presentan y requieren tan altos niveles de participación social El manejo de la basura conlleva a un hecho social. Cada persona, cada familia, una colonia, una ciudad, participan directa o indirectamente en la génesis, desarrollo y posterior disposición de sus desechos.

La generación de residuos es un hecho individual que deriva de un proceso acumulativo que involucra a la sociedad en su conjunto. Todos los elementos de la sociedad tienen roles y funciones bien definidas de participación en torno al manejo de los residuos sólidos tanto individual como colectivamente. De los patrones de comportamiento personal se afectan las magnitudes, de las conductas de grupo se definen sus componentes y de todos depende su impacto en el ambiente.

Pese a esta cualidad social inherente, el manejo de los residuos sólidos no ha mostrado una orientada participación de la sociedad de manera generalizada. Diversas son las modalidades y manifestaciones de participación que se requieren. De manera individual, es necesario actuar para generar menos residuos.

En los casos cuando se han dado manifestaciones importantes, estas se refieren a aspectos particulares con características muy específicas, que convendría analizar como estudio de caso a fin de identificar modalidades que han dado resultado y bajo que condiciones éstas se han generado.

Por lo anterior se concluye que todo elemento de política de mejoramiento del manejo de los residuos sólidos debe tomar como uno de los elementos básicos la orientación de participación social.

Se pueden distinguir tres etapas en la participación ciudadana en relación al manejo de los residuos sólidos. La forma más avanzada de estas etapas es la participación individual, la actitud consciente de cada persona en favor de una racionalidad en la generación de residuos, buscando generar la menor basura posible o quizá orientándose hacia la idea ecologista de no generar residuos. En esta etapa se encuentra ubicado también el proceso de selección o separación en la fuente.

Esta etapa en la actualidad tiene pocas posibilidades de éxito si se le considera como un hecho generalizado. En la mayoría de las ciudades en las que ya se puede hablar de esta etapa se manifiesta como hechos poco sistemáticos y más bien de carácter zonal, regional o local, sin poder extender su alcance al entero de las localidades.

Una segunda etapa de transición, pero muy importante ejercicio cívico urbano, lo constituye la participación social de grupo, orientada a fortalecer y mejorar los vínculos de la ciudadanía como grupo con los servicios inherentes al manejo de los residuos sólidos. En general esta etapa se orienta a superar el reto que representa la aceptación de la infraestructura del servicio en un entorno determinado. El fenómeno mundial relacionado con las siglas NIMBY, no en mi patio, ha sido uno de los factores que mayormente han condicionado la evolución del servicio o en su caso han incrementado su costo a límites que ciudades de economías en desarrollo difícilmente pueden sufragar.

Este nivel como paso intermedio en la actualidad constituye la forma de participación social más importante en ciudades que como la nuestra que empieza un proceso de desarrollo, en donde la infraestructura básica se convierte en la plataforma de despegue de toda política o de la instrumentación de acciones de mejoramiento.

Esta etapa representa un reto a las autoridades e implica transformaciones de fondo tanto en los conceptos como en la definición de sistemas y procedimientos.

Lo anterior significa un cambio en las prácticas administrativas y una revisión a las condiciones del manejo de los residuos sólidos.

El primer obstáculo que presenta la participación ciudadana es la asociación peyorativa de la basura en su manejo. Efectivamente, a lo largo de los años en nuestras ciudades el manejo se había mantenido en condiciones de rezago con respecto a otros servicios urbanos. Presupuestal, administrativa y operativamente no se consideraba como servicio prioritario, lo que institucionalmente condicionó su manejo y sus impactos en el entorno social y en el ambiente.

En el caso de la ciudad de México la memoria urbana registra hasta hace muy pocos años las grandes montañas de basura en los tiraderos, el desprendimiento de olores y gases la proliferación de fauna nociva en su alrededor, las escenas de ventas de subproductos. Situaciones semejantes se grabaron en la población en torno a las antiguas estaciones de transferencia.

Ante este panorama toda acción de exhortación de cambio se enfrentaba a la resistencia natural de la ciudadanía, convirtiéndose la participación de grupo en un rechazo total a sus nuevas construcciones y a la operación de las ya existentes.

Por otra parte, existía una firme convicción de cambio. Los grandes requerimientos ambientales de la Cuidad de México, la dinámica urbana y la existencia de grandes deficits a nuevas formas de manejo y administración, en donde la conformación de infraestructura básica representaba el papel más importante. Y este constituia paradójicamente el mayor concepto de oposición de la ciudadania.

Derivado de lo anterior, fue necesario instrumentar políticas o acciones para lograr el apoyo ciudadano para estas acciones que actualmente constituyen uno de los elementos variables más importantes en el manejo de los residuos sólidos de esta capital.

Esta concepción implico lo siguiente:

- Considerar el manejo de los residuos sólidos como prioritario, eliminando la asociación peyorativa de la basura a las prácticas institucionales, presupuestales, administrativas, etc.

- Conferirle al manejo de la basura características ambientales sanitarias, de funcionalidad y de imagen urbana.

- Iniciar acciones para conformar casos ejemplos de operación controlada con las características antes señaladas para contar con efectos demostración efectivos.

- Establecer compromisos y responsabilidades específicas de las autoridades; y derechos y obligaciones de los habitantes.

- Establecer un mecanismo de trabajo social urbano para atender las demandas, dar respuesta a dudas y en general explicar el contenido y alcances de las acciones específicas a diferentes niveles, individual, familiar, grupal, regional, etc.

- Formar comites de vigilancia ciudadana para controlar los impactos al ambiente, los efectos en el entorne urbano, la funcionalidad vial y la imagen de las instalaciones.

Todas estas consideraciones se sustentaban en una efectiva convicción política de mejorar el manejo de los residuos sólidos asumiendo compromisos que definitivamente deberían instrumentarse, viéndose resultados en el corto plazo que paulatinamente lograrían la aceptación de la población a la infraestructura básica.

Grandes fueron los esfuerzos de concentración, múltiples demandas que atender y responder, pero finalmente, los habitantes de la Ciudad de México y las autoridades han ido ejercitando muevas formas de relación en el manejo de los residuos sólidos y con ello se há venido conformando la infraestructura básica para alcanzar nuevos estadios de desarrollo y así contar con la plataforma para atender formas más avanzadas de participación social.

Un ejemplo de caso podría ilustrar este proceso, para lo cual mencionaremos la construcción de la estación de Transferencia Tlalpan.

Finalmente, la tercera etapa de participación se refiere al nivel inicial de ubicación y concientización del problema, a la etapa de conocimiento básico a la aceptación y disposición para conocer el problema.

Esta es una fase que paralelamente se ha trabajado a nivel de unidad básica y de alguna forma de comunicación masiva.

Es por ello que a continuación se presenta una muestra de los mecanismos utilizados para estimular la participación de la población en el apoyo a la construcción y operación de estaciones de transferencia.

CURSO INTERNACIONAL SOBRE DISEÑO Y OPERACION DE RELLENOS SANITARIOS
DEL 14 AL 19 DE MARZO DE 1994

HORARIO / DIAS	LUNES (14-MARZO)	MARTES (15-MARZO)	MIERCOLES (16-MARZO)	JUEVES (17-MARZO)	VIERNES (18-MARZO)	SABADO (19-MARZO)
9:00 - 10:00	BIENVENIDA *(ORGANISMOS COORDINADORES)* (9:00 a 9:30)	METODOLOGIA PARA EL EMPLAZAMIENTO DE RELLENOS SANITARIOS *(ING. JORGE SANCHEZ GOMEZ)*	IMPLEMENTACION DEL DISEÑO Y SU CONSTRUCCION *(MR. N.C. VASUKI)*	DETERMINACION DE PARAMETROS DE DISEÑO PARA LATINOAMERICA *(ING. JORGE SANCHEZ GOMEZ)*	DESARROLLO INSTITUCIONAL *(LIC. JESUS BARRERA LOZANO)*	VISITA AL RELLENO SANTARIO BORDO PONIENTE
10:00 - 11:00	SITUACION ACTUAL MUNDIAL *(DR. LUIS F. DIAZ)* - LATINO AMERICA *(ING. FCO. ZEPEDA PORRAS)* (9:30 a 11:00)	FACTORES SOCIALES Y ECOLOGICOS *(LIC. ROSALBA CRUZ JIMENEZ)*	CONTROL Y APROVECHAMIENTO DE BIOGAS *(DR. DIK BEKER)*		MITOS Y REALIDADES SOBRE LOS RESIDUOS SOLIDOS *(ING. ARTURO DAVILA VILLAREAL)*	
11:00 - 12:00	FUNDAMENTOS DEL RELLENO SANITARIO *(DR. GEOFFREY BLIGHT)*	ESTUDIOS PREVIOS *(ING. RICARDO ESTRADA NUÑEZ)*	CONTROL Y TRATAMIENTO DE LIXIVIADO *(DR. RAINER STEGMANN)*	DISEÑO DEL RELLENO SANITARIO Y OBRAS COMPLEMETARIAS PARTE I *(ING. FELIPE LOPEZ SANCHEZ)*	MUESTREO, ANALISIS E INTERPRETACION DE RESULTADOS DE PRUEBAS DE LABORATORIO *(ING. ALVARO CANTANHEDE)*	
12:00 - 12:30	C A F E					
12:30 - 14:00	LEGISLACION - USA *(DR. W. FORESTER Y DR. LUIS F. DIAZ)* - LATINO AMERICA *(ING. FCO. ZEPEDA PORRAS)* - MEXICO *(ING. GUSTAVO SOLORZANO OCHOA)*	INTERPRETACION DE LAS CARACTERISTICAS DEL SITIO EN EL DISEÑO DE UN RELLENO SANITARIO *(DR. ROBERT K. HAM)*	PROTECCION DE AGUA SUBTERRANEA *(DR. RAFFAELLO COSSU)*	DISEÑO DEL RELLENO SANITARIO Y OBRAS COMPLEMENTARIAS PARTE II *(ING. FELIPE LOPEZ SANCHEZ)*	IMPACTO Y MINOTOREO AMBIENTAL *(ING. DOMINGO COBO PEREZ)*	
14:00 - 14:30	M E S A R E D O N D A					
14:30 - 17:00	C O M I D A					
17:00 - 18:00	CARACTERISTICAS DE LOS RESIDUOS SOLIDOS Y COMPATIBILIDAD *(DR. LEON VAN ARENDONK)*	GENERACION Y CUANTIFICACION DE BIOGAS *(ING. HUMBERTO VIDALES A.)*	OPERACION DEL RELLENO SANITARIO EQUIPO Y PERSONAL *(MR. HENRIK ORNEBJERG)*	MODELOS DE PREDICCION DE MOV DE CONTAMINANTES *(DR. ADRIAN ORTEGA)*	MESA REDONDA "LA PARTICIPACION DE LA INICIATIVA PRIVADA EN LOS SISTEMAS DE ASEO URBANO"	
18:00 - 19:00	SELECCION DE SITIOS, ASPECTOS NO GEOLOGICOS *(DR. MICHAEL J. PHILPOTT)*	BALANCE DE AGUA Y CANTIDAD DE LIXIVIADOS *(DR. PETER LECHNER)*	SISTEMAS DE CONTROL EN LA OPERACION DEL RELLENO SANITARIO *(ING. ARTURO DAVILA VILLAREAL)*	ANALISIS DE COSTOS *(ING. FCO. ZEPEDA PORRAS)*		
19:00 - 20:00	SELECCION DE SITIOS, ASPECTOS GEOLOGICOS *(DR. ISABELLE A. PARIS)*	ACEPTACION O RECHAZO DE RESIDUOS SOLIDOS Y RESIDUOS ESPECIALES *(DR. LEON VAN ARENDONK)*	CLAUSURA DEL RELLENO SANITARIO Y SU CUIDADO A LARGO PLAZO *(DR. LUIS F. DIAZ)*	IMPLICACIONES A LA SALUD PUBLICA *(CONSULTOR O.P.S. / PENDIENTE)*		
20:00 - 20:30	M E S A R E D O N D A					
COORDINACION	ING. CONSTANTINO GUTIERREZ	ING. INES SEMADENI MORA	ING. GUSTAVO SOLORZANO O.	ING. RICARDO ESTRADA NUÑEZ	ING. PAULA NOREÑA FRANCO	ING. FELIPE LOPEZ S.

DESCRIPCION DEL CURSO ISWA Y DE LOS MATERIALES INSTRUCCIONALES SOBRE LA DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

El propósito de las notas del curso es el de proporcionar material de apoyo a las conferencias que se dictarán como parte del curso ISWA sobre disposición final de residuos sólidos, para los países en desarrollo. En ellas se define a los rellenos sanitarios y su práctica para diferentes niveles de calidad y protección ambiental. Por razones claras, la práctica de disposición de residuos sólidos en los países en desarrollo debe ser económica y reflejar las condiciones de la localidad. Conforme a ello, las notas están orientadas hacia una práctica de disposición de residuos implementable bajo una variedad de situaciones, muchas de las cuales implican una severa carencia de equipo o recursos financieros y quizás falta de interés público en relación a la calidad del relleno sanitario.

El concepto general del relleno sanitario abarca una amplia gama, básicamente desde un tiradero abierto, en el cual hay muy poco insumo de ingeniería, hasta el más riguroso de los diseños, como los requeridos bajo algunas de las regulaciones ambientales actuales más avanzadas del mundo.

Propiamente, el término relleno sanitario no debería usarse para describir las operaciones más rudimentarias, pues por definición, un relleno sanitario requiere el control de todas las emisiones e impactos estéticos a niveles aceptables. Los requerimientos para una práctica aceptable pueden cambiar de acuerdo al tamaño del relleno, los tipos de residuos y la práctica local en relación a su aceptablidad ambiental y estética. En este sentido, el curso considera la práctica del relleno sanitario aplicable a la situación predominante y no sólo los requerimientos del relleno sanitario clásico.

El tamaño del relleno sanitario deber ser tal que sirva para alojar la cantidad de desperdicios generados por las personas para un periodo de, al menos, 5 a 10 años. Los desechos sólidos a ser manejados deben conocerse o proyectarse en relación a su cantidad y composición, de tal manera que el volumen a llenar con los desperdicios sea suficiente, asi como el material para su cobertura, el equipo y los procedimientos de manejo. La geología y localización del sitio son factores importantes. El espectro de la geologia puede variar desde suelos muy porosos que pueden permitir el flujo de gran cantidad de gas y lixiviado proveniente del relleno sanitario, y **no proporcionar virtualmente ninguna protección ambiental al agua subterránea, o a las áreas** circundantes, hasta suelos relativamente impermeables tales como arcillas, las cuales limitan el flujo de gas y lixiviado y de esa manera permitir que éstos sean manejados en el lugar. El sitio debe estar localizado apropiadamente con respecto al agua de la superficie y áreas inundables, de manera tal que el agua superficial no resulte afectada por ninguna contaminación que surga de las operaciones del relleno sanitario.

En el diseño de un relleno sanitario se debe tener en consideración el tipo de suelo disponible, la cantidad y caracteristicas de los residuos, la geologia del lugar, su accesibilidad, y otros factores que permitan la disposición de desechos, libre de molestias, y de una manera lógica y continua. Esto se logra por medio de la adecuada ubicación del relleno sanitario en relación a las carreteras, cuerpos de agua superficiales, colinas, estratos rocosos, aguas subterráneas y los tipos de suelo del lugar, a fin de aprovechar al máximo las propiedades únicas de cada lugar. De la misma manera, algunos sitios pueden ser tan inadecuados por cualquiera de las consideraciones mencionadas, que sencillamente no deberian usarse a menos que fuera absolutamente necesario. En este curso se describirán las condiciones de ubicación y métodos empleados para minimizar problemas.

El sitio debe funcionar y ha de proporcionarse también el equipo y el personal necesario a fin de que se dé la operación diaria bajo todo tipo de condiciones climáticas y para manejar el flujo de desechos. Muy a menudo se cree que son necesarios grandes equipos para tener un buen relleno sanitario. Esto no es necesariamente el caso, pues con frecuencia el uso óptimo del equipo disponible puede proporcionar una buena operación del relleno sanitario.

Se presenta en el curso la manera de determinar las cantidades y la composición del gas y el lixiviado, incluyendo los principales factores para su control. Los sistemas para cubrir el relleno son especialmente importantes a este respecto. En algunos casos se requerirán controles de gas y lixiviado. El primer método para controlar el gas y la migración de lixiviados del relleno sanitario y que se discutirá, es a través de sistemas de revestimiento (liners).

Los revestimientos pueden hacer uso de suelos del lugar o suelos importados para minimizar el flujo de emisiones y gas provenientes del relleno. Los sistemas de revestimiento se discutirán en relación a su necesidad, y se presentarán diferentes diseños de acuerdo a las condiciones locales. Una vez que se retarda el flujo de lixiviados a través de los sistemas de revestimiento o por el uso de los materiales disponibles naturalmente, se tiene que controlar el lixiviado, lo cual típicamente implica su recolección y tratamiento. De manera similar si el flujo de gas se retarda, tendrá que proporcionarse un control de éste en el lugar, el cual puede incluir la ventilación del gas a la atmósfera o aún el uso del gas como una fuente de energía.

Es necesario diseñar el relleno para su cierre como parte del diseño inicial. Debe determinarse asimismo el uso final del relleno y su diseño debe cumplir con los requerimientos para ese uso, incluyendo la topografía o forma. Los recursos financieros y de suelos deben estar disponibles a la clausura de tal manera que el lugar pueda cubrirse y reforestarse apropiadamente. El hecho de que ya no se trasladen los residuos y el relleno sanitario haya sido tapado con la cubierta final no libera de responsabilidad al operador, por lo que no puede abandonar el lugar. Se debe proporcionar un cuidado a largo plazo que de cuenta, tanto del monitoreo, como de las reparaciones de cualquier erosión, asentamiento, agua estancada u otros problemas que pudieran desarrollarse al paso del tiempo en un relleno sanitario cerrado. El monitoreo debe empezar antes de la construcción del relleno, para establecer la calidad presente del agua subterránea y del gas. El monitoreo continúa a lo largo de las operaciones del relleno y sobre un largo periodo después del cierre para estar al tanto de cualquier impacto significativo que pudiera afectar el uso del agua subterránea, la calidad del agua superficial o usos potenciales del área. El monitoreo continúa hasta que es claro que el lugar se ha estabilizado y no presenta peligro.

Finalmente, debe disponerse tanto de un financiamiento apropiado como de una voluntad política para asegurar que el relleno sanitario pueda continuar operando a lo largo de toda su vida útil, desde su concepción y diseño, hasta su operación, clausura y cuidado de largo alcance. Esto significa que el público debe apoyar el sitio y el sitio debe estar apoyado politicamente y por las necesarias organizaciones, para estar seguros que el lugar cuenta con un adecuado respaldo financiero.

Por lo anterior puede verse que el diseño, operación, clausura y cuidado de larga duración no son tareas simples. Para la gente es rutinario subestimar las demandas para minimizar los efectos adversos de la eliminación de los residuos.

En resumen, este curso y los materiales que lo acompañan, están dirigidos a interpretar las condiciones locales y recursos en la medida en que se puedan diseñar el mejor relleno sanitario posible y pueda ser operado para minimizar los efectos adversos tanto de la gente de los alrededores como del medio ambiente.

CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

SISTEMA DE CLASIFICACION MEDIANTE EL EMPLEO DE ESTANDARES PARA RELLENOS SANITARIOS DE CIUDADES EN DESARROLLO

Dr. Geoffrey Blight

International Solid Waste Association

ISWA

PALACIO DE MINERIA. MEXICO D.F. 14-19 de Marzo de 1994

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Date: 28 January 1994

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Dear Bill

1. Many thanks for your letter of January 7, 1994 and also for the minutes of the WGSL for the Sardinia meeting.

2. I have unfortunately developed a health problem and may not be fit enough to go to Mexico City in March. I went to a conference in India (Delhi) in early January. While there I caught an infection from the hotel air-conditioning. The infection had developed into pneumonia by the time I got home. So it was out of the plane and straight into hospital for me. Now, ten days later, I am almost clear of the pneumonia. However, the infection has "scrambled" my heart valves and my heart is beating irregularly and inefficiently. I don't know how long it will take to get this sorted out, but a few months is possible.

3. I should have time to rewrite chapter 2 of the instruction manual, and will start on this as soon as I feel up to it. However, you should line up someone else to give my lecture in Mexico. (By the way, you have not given a deadline for receipt of the chapters.)

4. I should be able to come to Torbay in June.

5. I am sending you my draft of the "Graded Requirements" paper that I finished in December before going to India. Will you please circulate to the WGSL, asking for their comments.

With kind regards and best wishes for 1994.

Yours sincerely

G E BLIGHT

A SYSTEM OF CLASSIFICATION TO ALLOW FOR GRADED STANDARDS TO BE APPLIED TO LANDFILLS IN DEVELOPING COUNTRIES

G E Blight
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Johannesburg, South Africa

(Written on behalf of the Working Group on Landfilling, International Solid Wastes Association)

Synopsis

In developing countries, the affordability of environmental control measures for sanitary landfilling is a key issue. There is no fundamental reason why standards for landfilling in developing countries should match corresponding standards in developed countries. Also, there is no fundamental reason why standards required for landfills serving large towns and cities should be the same as those required for small villages. This paper explores three factors that can be used to classify landfills, in order to allow graded standards for landfilling to be applied in a rational way. The three factors are

- the type of waste,
- the size of landfill, and
- the climatic conditions at the site.

The classification is suitable for use in a developing country, but could equally well be used in a developed country, particularly one in which conditions vary considerably from one region to another. The classification was originally developed for South Africa, the development being initiated and funded by the State Department of Water Affairs and Forestry.

Introduction

If waste treatment and disposal is not carried out by a community to an adequate standard, a severe risk to health can arise, and serious degradation of the environment will usually also result. When considering the disposal of sewage and waste water, the above statement is a self-evident truth to members of all but the least educated of communities. However, while the environmental degradation resulting from inadequate disposal of domestic refuse is evident to all, it is not always plain that inadequate disposal of solid wastes can also pose a serious health hazard. For example, during the politically motivated stayaways and boycotts in South Africa during the 1980's, health workers such as nurses and sewage treatment works operatives were allowed to continue working (Nkosana, 1992). Garbage workers, however, were not regarded as health workers and were forced to stay away from work.

The title refers to "developing countries". What distinguishes a "developing" country from a "developed" one? The usual definition (Campbell, 1993) is that a developing country is one where the gross domestic product is lower than the average for the world. Thus a developing country is one where the people are poor, on average. However, there are many countries for which this definition may be inadequate, because industrialized urban areas in a country may be "developed", while country areas are still "developing". It is rare to find wealth evenly distributed between town and country.

Communities in developing countries, just as in developed countries, can vary in size from a few hundred to several million inhabitants. Whereas developed countries can usually afford to apply the highest standards to refuse disposal, regardless of the size of the community, this does not usually apply in developing countries or developing areas in developed countries. Communities in developing countries are poor, by definition. Large cities in a developing country although poor, may yet have a tax base that is sufficient to enable them to apply adequately high standards to the disposal of their solid waste. However, smaller communities can usually not afford to dispose of their refuse to the standards required in large cities.

There are a number of reasons why it may not be necessary to apply developed-world standards to the developing world:

1. The generation rates and composition for refuse in developed countries may be very different to those in developing countries:

For example **Table 1** (based on Rushbrook and Finnecy, 1988 and Mayet, 1993) shows that the putrescible (vegetable and paper) content of refuse in a developed country may be much the same as in a city in a developing country (Delhi) or it may be vastly different (Wuhan and Soweto). The proportion of dust, ash and other non-putrescible components is usually much higher in a developing country than in a developed country. Although data is not available on this point, it appears from personal observation, that the putrescible content of refuse in small developing communities is even lower than that shown in Table 1 for China and South Africa.

Most, if not all studies of the decomposition of refuse and the composition of leachate (e.g. Christensen, Cossu and Stegmann, 1992) have, however, been carried out on refuse from developed countries. It is very likely that low-putrescible content refuse in a developing country will produce a less concentrated leachate than high-putrescible content refuse in developed countries, and therefore will have a lesser pollution potential. The lesser concentration of the leachate would be enhanced by the fact that the field capacity of a low-putrescible content refuse would be lower than that of a high-putrescible refuse.

TABLE 1

Composition of Municipal Refuse in
Developed and Developing Countries

<table>
<tr><th rowspan="2">Composition in % by Mass</th><th colspan="2">Developed Countries</th><th colspan="3">Developing Countries</th></tr>
<tr><th>USA</th><th>UK</th><th>India (Delhi)</th><th>China (Wuhan)</th><th>South Africa (Soweto)</th></tr>
<tr><td>Vegetable</td><td>22</td><td>25</td><td>47</td><td>16</td><td>9</td></tr>
<tr><td>Paper</td><td>34</td><td>29</td><td>6</td><td>2</td><td>9</td></tr>
<tr><td>Metals</td><td>13</td><td>8</td><td>1</td><td>0.5</td><td>3</td></tr>
<tr><td>Glass</td><td>9</td><td>10</td><td>0.6</td><td>0.6</td><td>12</td></tr>
<tr><td>Textiles</td><td>4</td><td>3</td><td>-</td><td>0.6</td><td>1</td></tr>
<tr><td>Plastics</td><td>10</td><td>7</td><td>0.9</td><td>0.5</td><td>3</td></tr>
<tr><td>Wood</td><td>4</td><td>-</td><td>-</td><td>1.8</td><td rowspan="2">63</td></tr>
<tr><td>Dust.Ash. other unidentified</td><td>4</td><td>18</td><td>44.5</td><td>78</td></tr>
<tr><td>Refuse Density kg/m^3 (uncompacted)</td><td>100+</td><td>150</td><td>420</td><td>600 (estimated)</td><td>400</td></tr>
<tr><td>Refuse Generation Rate Ton (1000kg) /Person/year</td><td>0.65</td><td>0.65</td><td>0.14</td><td>0.20</td><td>0.15</td></tr>
</table>

2. As Table 1 shows, refuse generation rates in poor developing countries are smaller by a factor of 3 or 4 than in developed countries:

Thus a community of a certain size in a developing country will produce far less refuse than in a corresponding community in a developed country. Because less refuse is produced, landfills will be smaller, or have a longer life, and will therefore represent a smaller source of potential pollution.

3. The climate in many developing countries is humid and the potential for leachate production high. However, there are also developing countries that have arid climates with little potential for producing leachate:

Whereas in developed countries, the same standards can be applied to landfilling regardless of climate, in developing countries, standards may be relaxed if little or no leachate is likely to be generated in landfills. This relaxation can make landfilling more affordable without compromising protection of the environment.

The purpose of this paper is to set out a method for classifying landfills that will enable graded standards to be applied, without compromising environmental protection. The scheme is suitable for either developed or developing countries, but will probably be more attractive in developing countries, where affordability is always a key issue.

The paper will deal only with landfills for domestic and commercial refuse and dry-non-hazardous industrial wastes. The disposal of hazardous wastes will not be considered.

Components of the Classification System

The classification depends on an assessment of three components:

1. the waste type,
2. the landfill size, and
3. the climatic characteristics.

The components of the overall classification relating to these three factors will now be described:

1. **Waste Type** : For the purpose of the system, waste is classified according to its putrescible (vegetable and animal matter and paper) content. If the content of putrescible material exceeds 20% by dry mass the waste is classified as"P" or high-putrescible waste. If the putrescible content is less that 20%, it is classified as "p", or

low-putrescible waste. While this is unproved at present, it appears reasonable to relax standards required for p refuse, as compared with these required for P refuse. The dividing point of 20% of putrescible material between p and P wastes is tentative at present, and must be refined by future research.

2. **Landfill Size** : All landfills grow in size with the passing of time. The one characteristic that has the biggest influence on the operation of the landfill, and therefore, the need for facilities, plant and operating skills, is the rate of deposition of refuse. A landfill with a small final volume, but a large rate of deposition, should, if standards are to be maintained, be operated in exactly the same way, and to the same standards as a landfill with a large final volume and a large rate of deposition. Vice-versa, a landfill where the rate of deposition is small, can be properly operated with lesser skills, plant and facilities, even if it has a long life and, therefore, will ultimately occupy a large volume. The classification is based on the Maximum Rate of Deposition (MRD) in tons of refuse deposited per year. The MRD is the projected rate of deposition at the end of the life of the landfill, and is calculated from the Initial Rate of Deposition (IRD) and the estimated annual growth rate or development rate for the community that the landfill is intended to serve. The IRD can be estimated by the amount of refuse entering the site at present, or in the case of a new site, from the current rate of deposition at the site or sites it is intended to replace. Failing this, a suitable generation rate (such as those tabulated in Table 1) multiplied by the number of people presently in the community can be used to estimate the IRD. Care should be taken to estimate the IRD for an appropriate working year. This is usually 260 days (52 weeks x 5 days) if the landfill is operated on 5 days of the week.

If D is the annual development rate estimated for a landfill, then the MRD can be calculated from the IRD by:

$$(MRD) = (IRD)\ (1 + D)^T \tag{1}$$

where T is the estimated life of the landfill site in years.

M_T, the mass of refuse deposited after T years of operation is then:

$$M_T = \frac{(IRD)}{D}\left[(1 + D)^T - 1\right] \tag{2}$$

As an example : A site is required having a life of about 15 years, and (IRD) = 350 Tons/day. D is expected to be 3% per year. What will be (MRD) and M_T?

$$(IRD) = 350\text{Tons/day} = 350 \times 260 = 91\ 000 \text{ Tons/year}$$
$$(MRD) = 91\ 000\ (1 + 0.03)^{15} = 142\ 000 \text{ Tons/year}$$

$$M_T = \frac{91\ 000}{0.03}\left[(1.03)^{15} - 1\right] = 1\ 692\ 500\text{Tons}$$

The required total deposition volume, or air space can then be estimated by dividing the tonnage M_T by an assumed compacted unit mass or density. If a unit mass of 0.75 Ton/m^3 is chosen, the deposition volume required for the compacted refuse will be:

$$V_T(\text{net}) = \frac{1\ 692\ 500}{0.75} = 2\ 257\ 000 m^3$$

Allowing for a ratio of compacted refuse to cover material of 1 to 6, the total air-space réquired will be

$$V_T(\text{gross}) = 1\frac{1}{6} \times 2\ 257\ 000 = 2\ 633\ 000 m^3$$

The complete size classification is illustrated by Table 2.

Table 2
Size Classification for Landfills

LANDFILL SIZE CLASSIFICATION		MAXIMUM RATE OF DEPOSITION (MRD) (Tons per year)	
Communal	C	less than	250
Small	S	up to	5000
Medium	M	up to	150 000
Large	L	over	150 000

In this classification, a "Communal" landfill would be one serving a village, typically of

1000 to 1500 persons. A "Small" landfill would serve a town of up to 30 000 inhabitants, while "Medium" and "Large" landfills would serve cities and large towns of over 30 000 inhabitants.

3. Climate : It has been well established (e.g. Christensen, Cossu and Stegmann, 1992) that the quantity of leachate generated in a landfill depends on the climate in which the landfill is situated. The effects of climate can be quantified by the water balance for a landfill. The water balance compares the quantities of water entering the landfill as part of the refuse and as infiltrating rain and snow-melt, with the quantity of water stored in the landfilled refuse, and leaving the landfill as evaporation or evapotranspiration. The difference between the net water input and the water stored in the refuse will be available to form leachate.

In humid climates, the difference between net water input and water stored will be positive over a year or season. In arid climates the difference will be negative, whether over the complete year, or seasonally. In other words, in arid climates, landfills will either not produce any leachate at all, or will only produce leachate seasonally.

In cases where no leachate is ever produced, it is possible to reduce the standards required for the design of a landfill, by omitting the leachate collection system and underliner.

However, even in an arid climate, there are occasional wet years or wetter than normal wet seasons. When extreme weather conditions occur, some leachate may be generated. If there is no leachate collection system, this leachate will be available to seep into the soil underlying the landfill. Provided that this does not occur more frequently than (say) once in 5 years, the consequences of such an escape will not be serious and can be ignored.

The classification system uses a "climatic water balance" as a means of deciding on whether or not a landfill will generate significant quantities of leachate and therefore whether or not a leachate collection system and underliner should be provided. The climatic water balance is expressed as

$$B = R - E$$

where R is the rainfall in mm of water
E is the evaporation from the landfill cover surface.

E is taken as 0.7 x A-pan evaporation or 0.9 x S-pan evaporation.

To allow for seasonal influences and variable weather patterns, B is calculated for the wet season of the wettest year on record. (The wet season would usually be taken as the wettest six month period in a year, based on long-term averages). If the value of B is positive the indication is that the landfill will generate leachate in a wet year. Vice-versa, if B is negative the indication is that the landfill will not generate leachate even in a wet year.

As the rainfall and evaporation in any one year do not necessarily correlate, B is re-calculated for successively drier years to establish if

(i) B is positive in less than one year in 5 for which data is available, or

(ii) B is positive in more than one year in 5. (If (i) applies, the site is classified as B^- and a leachate collection system and underliner can safely be omitted from the landfill. If (ii) applies, the site is classified as B^+. In this case, regular generation of leachate can be expected, and a leachate collection system and underliner would need to be provided.

The Complete Classification System

Table 3 illustrates the complete landfill classification system. Examples of the application of the classification are as follows:

1. A landfill receives waste having a putrescible content of 53%. (MRD) is 300 000 Tons/year and the landfill is situated in a climate where B is positive in 4 years out of five. The landfill would be classified as

   PLB^+

   and would have to be constructed and operated to the highest standards.

2. A landfill receives waste having a putrescible content of 18% (MRD) is 190 Tons/year and the landfill is situated in a climate where B is positive once in 11 years. The landfill would be classified as

   pCB^-,

   and could be constructed and operated to lesser standards without risks to health or the environment.

Application of the Classification System

The detailed application of the classification system would depend on the requirements and conditions in the country in which it would be applied. For example, the climate in a country may be such that the entire country would be classified as B^+. In such a case, the climatic consideration could be omitted, as it would be the same for all sites. A study of thé types of waste might indicate that all waste would be classified as "High Putrescible" or P. In such a case the right hand half of Table 3 could be omitted.

Once the classification has been carried out, the graded requirements can be set under each of the headings of:

site selection
site investigation
environmental impact assessment
landfill design
site preparation and commissioning
operation and operational monitoring
rehabilitation, closure and end-use
post-closure monitoring

Table 4, for example shows some of the minimum requirements under the heading of "Landfill Design" for a hypothetical country that does not differentiate between P and p waste, but which has both B^+ and B^- climatic zones.

TABLE 3

LANDFILL CLASSIFICATION SYSTEM

WASTE TYPE	High Putrescible Waste P								Low Putrescible Waste p							
LANDFILL SIZE AND TYPE	C Communal		S Small		M Medium		L Large		C Communal		S Small		M Medium		L Large	
CLIMATIC WATER BALANCE	B^-	B^+	B^-	B^+	B^-	B^-	B^-	B^+	B^-	B^+	B^-	B^+	B^-	B^+	B^-	B^+

TABLE 4
Example of Graded Standards Applied to the Design of a Landfill Receiving Only One Type of Waste

R = Requirement NR = Not a requirement F = Flat: special consideration to be given by expert	C Communal Landfill		S Small Landfill		M Medium Landfill		L Large Landfill	
	B^-	B^+	B^-	B^+	B^-	B^+	B^-	B^+
Conceptual design:								
Estimate unsaturated zone thickness after cover excavation	NR	NR	NR	R	R	R	R	R
Assess cover volume	NR	NR	R	R	R	R	R	R
Determine available airspace	NR	NR	R	R	R	R	R	R
Estimate airspace utilisation	NR	NR	R	R	R	R	R	R
Estimate site life	NR	NR	R	R	R	R	R	R
Confirm site classification	R	R	R	R	R	R	R	R
Surface hydrology design	R	R	R	R	R	R	R	R
Development Plan	R	R	R	R	R	R	R	R
Rehabilitation Plan	R	R	R	R	R	R	R	R
Design of leachate management system	NR	NR	NR	R	NR	R	NR	R
Ground water monitoring system design	NR	NR	NR	R	R	R	R	R
End-use and Closure Plan	NR	NR	R	R	R	R	R	R
Testing of soils and materials	NR	NR	NR	NR	F	F	F	F
Technical design:								
Validation of Surface hydrology	NR	NR	NR	NR	R	R	R	R
Lining system	NR	NR	NR	R	NR	R	NR	R
Leachate management system	NR	NR	NR	R	NR	R	NR	R
Gas Management system	NR	NR	NR	NR	F	F	F	F
Final cover design	NR	NR	NR	NR	R	R	R	R

Conclusions

Although it is usual to set standards for solid waste landfilling practice that are uniform for all sizes of landfill and all climatic conditions (as with the 1993 U.S. EPA Subtitle D Municipal Waste Regulations), (Daniel et al, 1993), there are good reasons why standards should be graded depending on the type of waste, the size of the landfill and the climatic conditions in which the landfill is situated. There is a particularly good case for applying graded landfill standards in developing countries, where affordability to the community is an important, and may be an over-riding consideration.

The classification scheme outlined in this paper provides a way of grading standards in a scientifically sound manner that need not compromise standards for environmental protection.

Acknowledgements

This paper is based on an earlier paper (Ball, Blight and Bredenhann, 1993) that deals with the intention to introduce graded standards for landfilling in South Africa.

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CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

LEGISLACION MEXICANA EN MATERIA DE RELLENOS SANITARIOS

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PALACIO DE MINERIA, MEXICO D.F. 14-19 Marzo de 1994

LEGISLACION MEXICANA EN MATERIA DE RELLENOS SANITARIOS.

El marco legal para el manejo **general** de los residuos sólidos municipales existe en México en los niveles federal, estatal y municipal. Sin embargo, a nivel particular, aún resta mucho por hacer en materia normatividad relativa a la ubicación, diseño, construcción, operación y monitoreo de rellenos sanitarios.

Por otra parte, si bien puede decirse que la normatividad en este ámbito no es todavía la que se requiere, se cuenta con los ordenamientos básicos necesarios, de los que se efectúa a continuación una breve descripción para cada uno de los niveles de gobierno antes mencionados.

1. NIVEL FEDERAL.

La Constitución Política de los Estados Unidos Mexicanos establece en su artículo 115, fracción III que "Los municipios, con el concurso de los estados cuando así fuere necesario y lo determinen las leyes, tendrán a su cargo los siguientes servicios públicos:

a) Agua potable y alcantarillado;
b) Alumbrado público;
c) **Limpia;**
d) Mercados y centrales de abasto;
..."

En cuanto a un ordenamiento más específico que establece criterios relativos al manejo de los residuos sólidos municipales, en el nivel Federal se tiene fundamentalmente a la **Ley General del Equilibrio Ecológico y la Protección al Ambiente** de 1988.

Existen además, las normas oficiales mexicanas expedidas por las dependencias del Ejecutivo Federal.

1.1 Ley General del Equilibrio Ecológico y la Protección al Ambiente (LGEEPA).

Esta Ley **General**, publicada por la extinta Secretaria de Desarrollo Urbano y Ecología en 1988 (SEDUE) abroga la Ley **Federal** de Protección al Ambiente publicada en 1982, dando así una mayor flexibilidad para su aplicación en el territorio nacional.

La LGEEPA establece inicialmente una delimitación de responsabilidades que corresponden a la autoridad federal por una parte, y a las entidades federativas por otra. En forma específica, establece las responsabilidades tanto de los estados de la República como del Distrito Federal, capital del país. Asimismo, define una serie de criterios relativos a la prevención de la contaminación del suelo originada por el mal manejo de los residuos sólidos.

A continuación se citan los articulos más relevantes de esta Ley en materia de residuos sólidos municipales, resaltando en negritas las referencias particulares a la etapa de disposición final (señalamiento no incluido en el texto original). Cuando se hace mención a "la Secretaria", se refiere a la ya mencionada SEDUE.

Artículo 3o.- Para los efectos de esta Ley se entiende por:

...

XXVI. **Residuo:** Cualquier material generado en los procesos de extracción, beneficio, transformación, producción, consumo, utilización, control o tratamiento cuya calidad no permita usarlo nuevamente en el proceso que lo generó.

...

Artículo 6o.- Compete a las entidades federativas y municipios, en el ámbito de sus circunscripciones territoriales y conforme a la distribución de atribuciones que se establezcan en las leyes locales:

...

XIII. La regulación del manejo y **disposición final de los residuos sólidos** que no sean peligrosos, conforme a esta Ley y sus disposiciones reglamentarias; y

...

Artículo 9o.- En el Distrito Federal la Secretaría ejercerá las atribuciones a que se refiere el artículo anterior y el Departamento del Distrito Federal ejercerá las que se prevén para las autoridades locales, sin perjuicio de las que competan a la Asamblea de Representantes del Distrito Federal, ajustándose a las siguientes disposiciones especiales:

A. Corresponde a la Secretaría:

...

VIII. Expedir las Normas Técnicas para la recolección, tratamiento y disposición de toda **clase de residuos**, en coordinación con la Secretaría de Salud;

...

B. Corresponde al Departamento del Distrito Federal:

...

IX. Proponer al Ejecutivo Federal la expedición de las disposiciones que regulen las actividades de recolección, tratamiento y **disposición final** de residuos sólidos no peligrosos, observando las normas técnicas ecológicas aplicables;

X. **Establecer los sitios destinados a la disposición final de los residuos sólidos** a que hace referencia la fracción anterior;

...

XVIII. Observar las normas técnicas ecológicas en la prestación de los servicios públicos de alcantarillado, **limpia**, mercados y centrales de abasto, panteones, rastros, tránsito y transportes locales; y

....

Artículo 134.- Para la prevención y control de la contaminación del suelo, se considerarán los siguientes criterios:

...

II. Deben ser controlados los residuos en tanto que constituyen la principal fuente de contaminación de los suelos;

III. Es necesario racionalizar la generación de residuos sólidos, municipales e industriales; e incorporar técnicas y procedimientos para su reuso y reciclaje; y

...

Artículo 135.- Los criterios para prevenir y controlar la contaminación del suelo se considerarán, en los siguientes casos:

...

II. La operación de los sistemas de limpia y de disposición final de residuos municipales en rellenos sanitarios;

III. Las autorizaciones para la instalación y operación de confinamientos o depósitos de residuos; y

...

Artículo 136.- Los residuos que se acumulen o puedan acumularse y se depositen o infiltren en los suelos deberán reunir las condiciones necesarias para prevenir o evitar:

...

Artículo 137.- Queda sujeto a la autorización de los gobiernos de los estados o, en su caso, de los municipios con arreglo a las normas técnicas ecológicas que para tal efecto expida la Secretaría, el funcionamiento de los sistemas de recolección, almacenamiento, transporte, alojamiento, reuso, tratamiento y disposición final de residuos sólidos municipales. Los materiales y residuos peligrosos se sujetarán a lo dispuesto en el Capítulo V de este mismo Título.

Artículo 138.- La Secretaría promoverá la celebración de acuerdos de coordinación y asesoría con los gobiernos estatales y municipales para:

I. La implantación y mejoramiento de sistemas de recolección, tratamiento y **disposición final de residuos sólidos municipales**; y

II. La identificación de alternativas de reutilización y **disposición final de residuos sólidos municipales**, incluyendo la elaboración de inventarios de los mismos y sus fuentes generadoras.

3.2 Normas oficiales mexicanas.

En el ámbito federal, existen también diversas normas relativas a la determinación de diversos parámetros de los residuos sólidos municipales. La mayoría de las normas relacionadas con los residuos sólidos municipales fueron elaboradas y publicadas por la Secretaría de Comercio y Fomento Industrial (SECOFI) con la denominación Norma Oficial Mexicana (NOM); posteriormente, la extinta SEDUE elaboró un cierto número de Normas Técnicas Ecológicas (NTE), aunque enfocadas fundamentalmente al manejo de los residuos peligrosos. Cabe mencionar que a la fecha existe una carencia de normas relativas al barrido, recolección, transferencia, tratamiento y disposición final de los residuos sólidos municipales, debido posiblemente a la atención prioritaria otorgada a los residuos peligrosos, campo en el que se carecía totalmente de normas.

La Ley Federal sobre Metrología y Normalización de junio de 1992 ha unificado criterios respecto a la nomenclatura de las normas en México, modificando la antigua denominación utilizada por la SEDUE. En materia de residuos sólidos municipales, la SECOFI ha elaborado y publicado un cierto número de normas desde hace unos diez años, que si bien no se refieren a los rellenos sanitarios en particular, se enlistan a continuación por considerarse de interés y en estrecha relación con el tema del presente capítulo:

NOM-AA-16-1984	Determinación de humedad
NOM-AA-18-1984	Determinación de cenizas
NOM-AA-24-1984	Determinación de nitrógeno total
NOM-AA-25-1984	Determinación de pH. Método potenciométrico
NOM-AA-92-1984	Determinación de azufre
NOM-AA-15-1985	Método de cuarteo
NOM-AA-19-1985	Peso volumétrico "in situ"
NOM-AA-21-1985	Determinación de materia orgánica
NOM-AA-22-1985	Selección y cuantificación de subproductos
NOM-AA-33-1985	Determinación de poder calorífico
NOM-AA-52-1985	Preparación de muestras en laboratorio para su análisis
NOM-AA-67-1985	Determinación de la relación carbono/nitrógeno
NOM-AA-68-1986	Determinación de hidrógeno
NOM-AA-90-1986	Determinación de oxígeno

2. NIVEL ESTATAL

Existen diversos ordenamientos que a nivel estatal regulan el manejo de los residuos sólidos municipales. En primer lugar, en prácticamente la totalidad de las entidades federativas del país se cuenta ya con la Ley Estatal equivalente a la LGEEPA, variando su nombre dependiendo de la entidad de que se trate.

Además de la mencionada Ley Estatal, algunas entidades federativas cuentan con ordenamientos adicionales que varían de un estado a otro; queda fuera de los alcances de este manual el efectuar una revisión de estos ordenamientos. Como ejemplo al azar se puede citar el caso del Estado de Sonora, que cuenta con la "Ley (estatal) que Regula la Prestación de Diversos Servicios Públicos Municipales" del 6 de agosto de 1987, así como la Ley (estatal) Orgánica de Administración Municipal, entre otras (Ley de Hacienda). Estos ordenamientos tienen aplicación ya sea en forma directa o bien indirecta en la prestación del servicio de limpia en todos los municipios del Estado.

Por su parte, el Departamento del Distrito Federal (DDF), cuenta con el "Reglamento para el Servicio de Limpia en el Distrito Federal", publicado en el Diario Oficial de la Federación el 27 de julio de 1989. Este reglamento abroga al anterior, que data del 6 de junio de 1941. Asimismo, el DDF cuenta con el "Reglamento de la Ley sobre justicia en materia de faltas de policía y buen Gobierno", que contempla aspectos relacionados con los residuos sólidos municipales.

Para el caso particular del Distrito Federal, existe la "Ley de Salud para el Distrito Federal" del 19 de enero de 1987, que si bien fue emitida mediante decreto del Congreso de la Unión, se incluye en este apartado ya que su aplicación se limita al Distrito Federal. Entre otros, esta Ley establece:

Artículo 5o.- En materia de salubridad local corresponde al Departamento la regulación y control sanitario de:

...

IV. Limpieza pública;

...

Artículo 21.- Para los efectos de la presente ley se entiende por:

...

V. Limpieza pública, el servicio de recolección y tratamiento de basuras;

...

Artículo 39.- El Departamento, por conducto de las Delegaciones, proveerá de depósitos de basura en los parques, jardines, paseos públicos y en otros lugares de la vía pública que estén dentro de su jurisdicción, además de ordenar la fumigación periódica de los mismos; asimismo, **fijará lugares especiales para depositar la basura**, tomando en cuenta lo que sobre el particular disponga la legislación aplicable en materia de contaminación ambiental.

La basura deberá incinerarse periódicamente o destruirse por otros procedimientos, excepto que sea industrializada o tenga empleo útil, siempre que no signifique un peligro para la salud.

Artículo 40.- El Departamento ordenará la construcción de depósitos generales y hornos de basura en los mercados, hospitales y establecimientos públicos que los requiera y se encuentren en su jurisdicción.

3. NIVEL MUNICIPAL

En el nivel municipal, un cierto número de los ayuntamientos del país cuentan con un "Reglamento de Limpia", como es el caso del Ayuntamiento de Hermosillo, para continuar con el ejemplo del Estado de Sonora. Para este municipio, se denomina "Reglamento para el Servicio Público de Limpia, Recolección, Manejo y **Disposición Final de Residuos Sólidos** en el Municipio", del 29 de julio de 1987. Esta municipalidad cuenta asimismo con el "Bando de Policía y Buen Gobierno para el Municipio".

Estos ordenamientos son la base para el control del manejo de los residuos sólidos en el tercer nivel de gobierno; desafortunadamente es frecuente observar que estos reglamentos adolecen de carencias o bien no son aplicados como sería de desearse, por diversas razones cuya discusión queda fuera de los alcances de este trabajo.

4. SITUACION ACTUAL

Si bien existe una carencia de normatividad en México en materia de diseño, construcción y operación de rellenos sanitarios, como ya se ha mencionado, por otra parte actualmente se cuenta con los avances para que estas carencias puedan satisfacerse gradualmente y en el corto plazo.

En México, el Instituto Nacional de Ecologia (INE), dependiente de la Secretaría de Desarrollo Social, es la entidad responsable de la elaboración de normas en materia de protección ambiental. Dentro de esta dependencia se creó el Comité Consultivo Nacional de Normalización para la Protección Ambiental, tal como lo establece la Ley Federal sobre Metrologia y Normalización de 1992. A su vez, y dependiente de aquél, existe el Subcomité de Residuos Municipales, Materiales y Residuos Peligrosos; finalmente, este Subcomité comprende al Grupo de Trabajo sobre Manejo de Residuos Industriales No Peligrosos y Municipales.

Este Grupo de Trabajo se reúne periódicamente en la sede del INE, de manera tal que el programa correspondiente a 1994 contempla la realización de un total de 18 reuniones de trabajo en el ámbito de la elaboración de normas relativas a residuos sólidos municipales, entre las que se encuentran contempladas las correspondientes a la ubicación, diseño, construcción y operación de rellenos sanitarios.

De hecho, se cuenta ya con un avance en la elaboración de varios anteproyectos de normas, correspondientes a algunas de las etapas antes mencionadas, por lo que se espera que en el corto y mediano plazos se logre la publicación definitiva de estas normas.

Cabe mencionar que en el Comité Consultivo y en sus diferentes niveles, participan instituciones de índole diversa, tales como universidades, centros de investigación, cámaras (de comercio, industria, etc.), asociaciones gremiales y otros, con lo que se conforman grupos de trabajo interdisciplinarios.

CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

CARACTERISTICAS DE LOS RESIDUOS SOLIDOS Y PROCEDIMIENTOS PARA SU ACEPTACION

Dr. Leon Van Arendonk

International Solid Waste Association
(ISWA)

PALACIO DE MINERIA, MEXICO D.F. 14-19 de Marzo de 1994

BRP

ISWA WORKING GROUP ON SANITARY LANDFILLS

Mexico conference 1994

WASTE CHARACTERIZATION AND WASTE ACCEPTANCE

Grontmij - B.R.P. - The Netherlands
ir. L.A.A.M. van Arendonk

OUTLINE

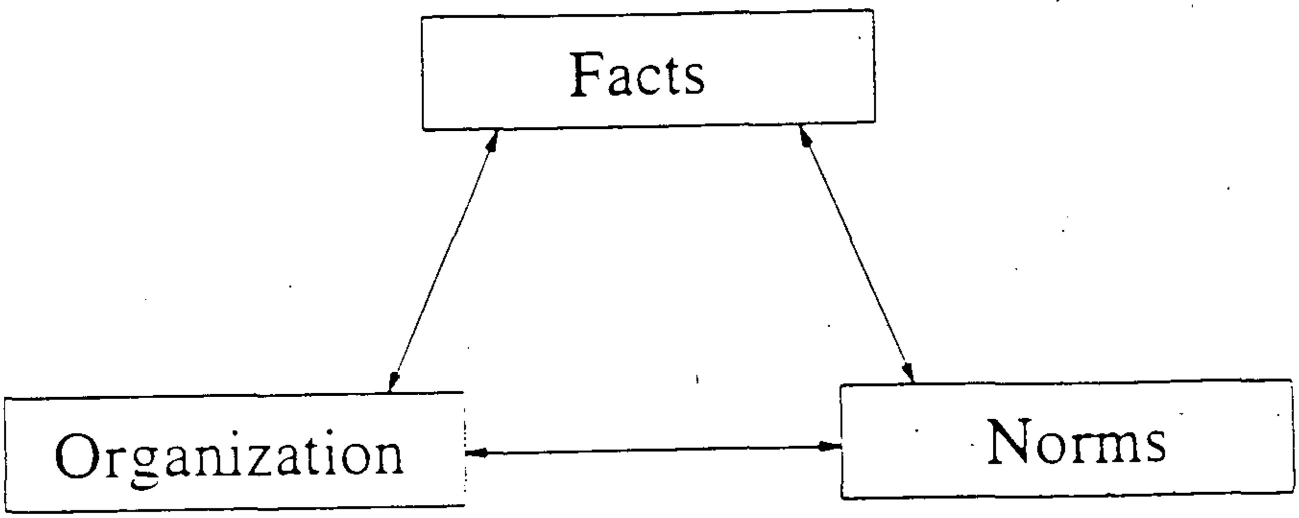
1. General
   a. introduction
   b. some figures and trends

2. Waste characterization
   a. why?
   b. waste generation
   c. waste composition
   d. data and sampling
   e. major classes and special wastes

3. Waste acceptance
   a. why?
   b. relation to landfill-processes
   c. acceptance criteria
   d. acceptance policy
   e. flow-diagrams

4. Slides and discussion

Policy field



COMPOSITION OF WASTE

Physical characterization

- moisture content
- bulk density
- size distribution

Chemical characterization

- pH
- organic
- etals

WASTE FLOW

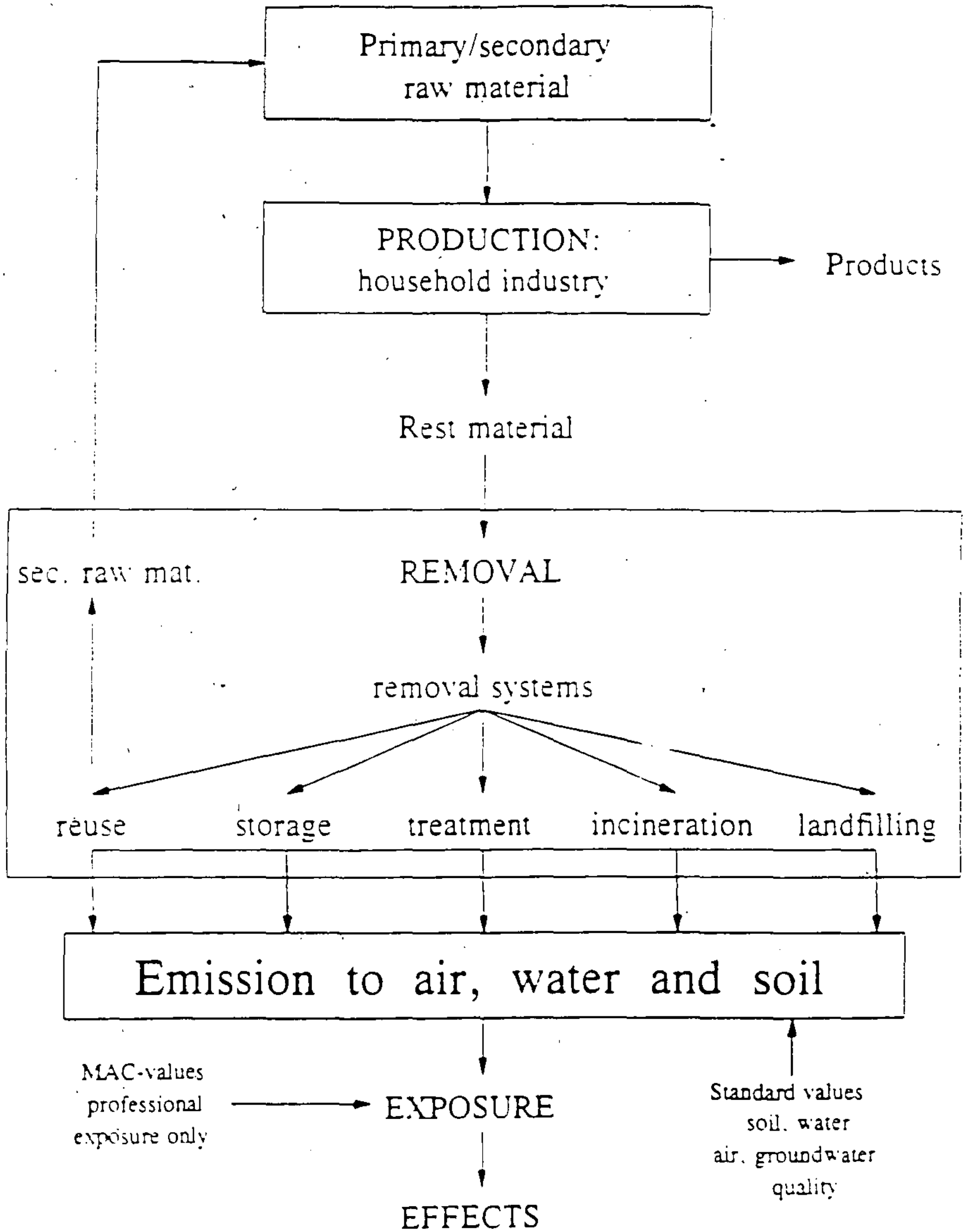
1. Waste arising
   - municipal waste
   - commercial/industrial waste
   - hazardous waste

2. Collection/Transportation
   - private
   - public
   - import/export
   - no-collection

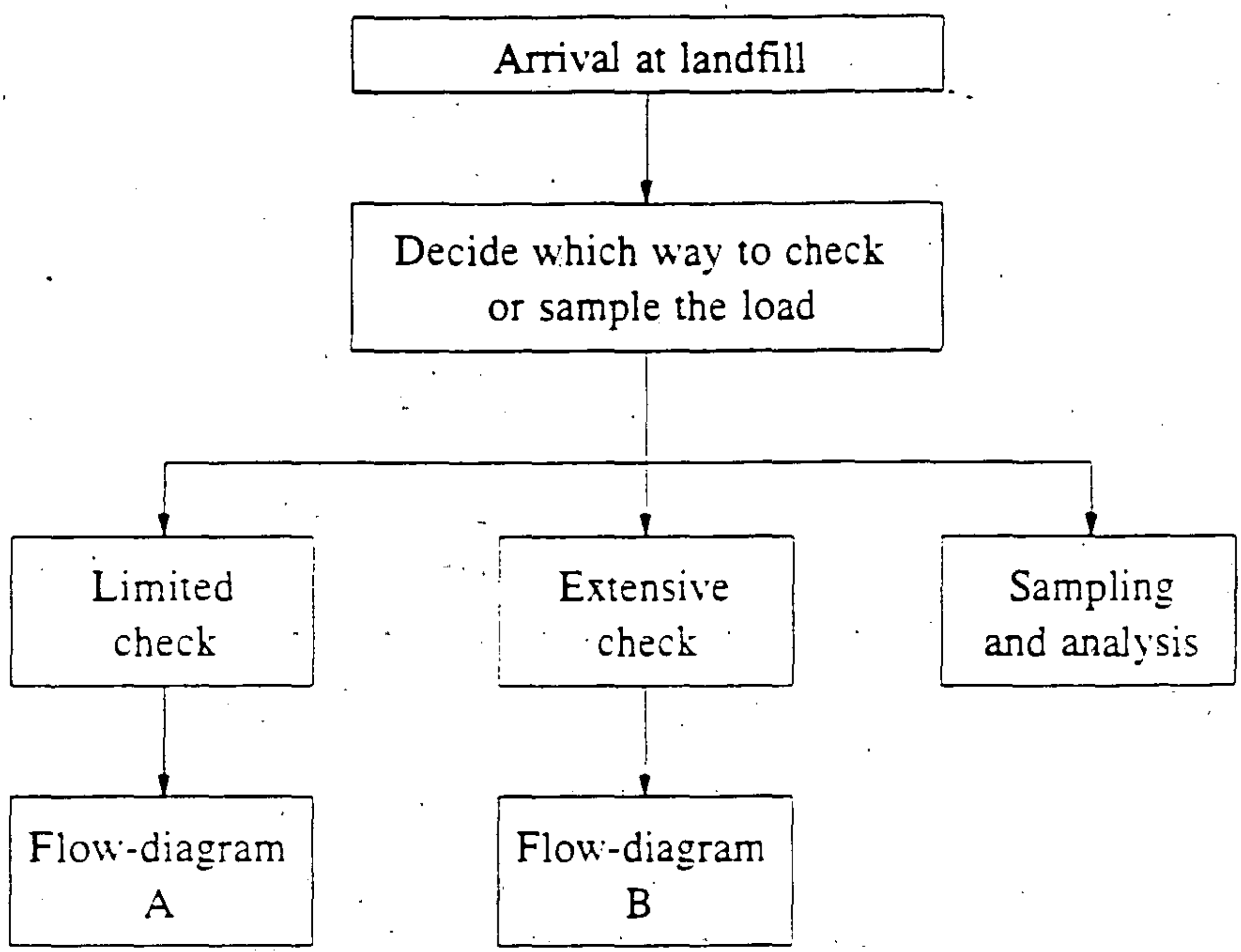
3. Treatment
   - recovery
   - treatment
   - final disposal

4. New products
   - secondary materials
   - energy

Exposure routes of environment to hazardous materials



Check at landfill



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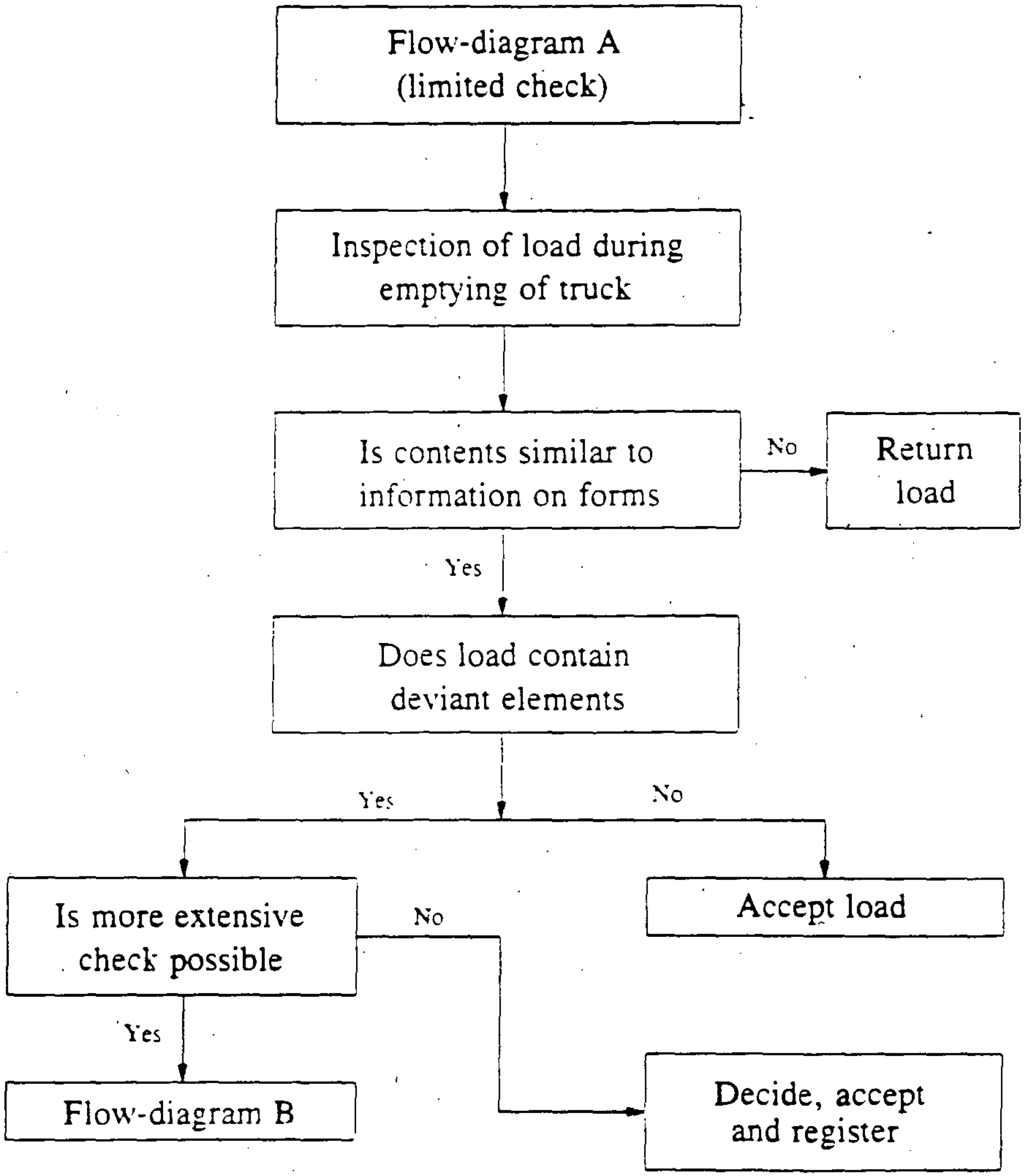

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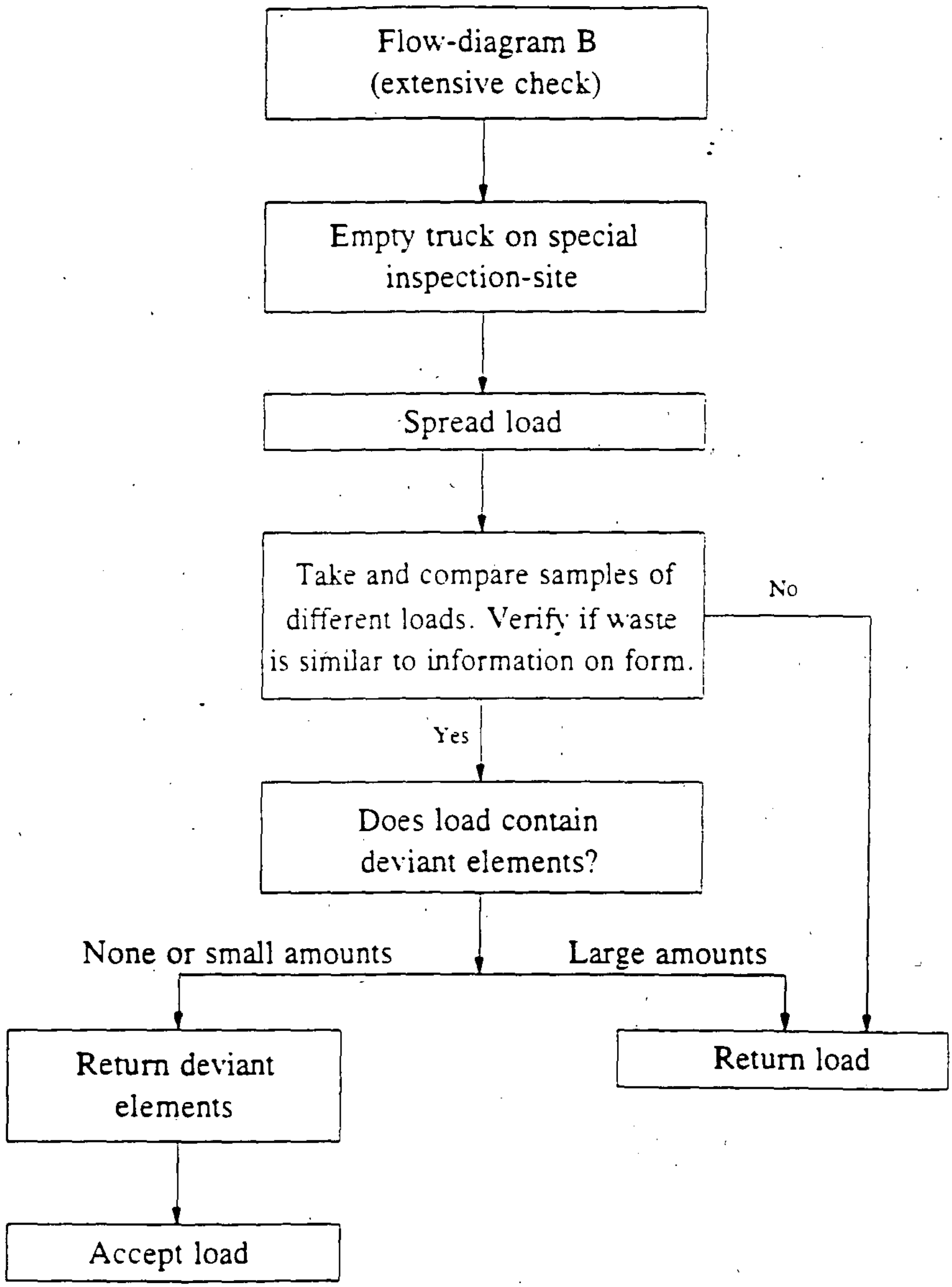


CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

SELECCION DE SITIOS, ASPECTOS GEOLOGICOS Y NO GEOLOGICOS

Dr. Isabelle A. Paris

International Solid Waste Association
(ISWA)

PALACIO DE MINERIA. MEXICO D.F. 14-19 de Marzo de 1994

Landfill Course

Geological Aspect

I.A. PARIS

I. Introduction

Geology, hydrogeoly and hydrology are all different subjects which need several year of study and years of experience before an engineer can practise it with confidence. The aim of this one hour lecture therefore is not to teach these subject and even less to be comprehensive. It is merely intended as an aid to understanding the factors that need to be taken into account for assessing potential landfill siting, their design, operation and monitoring.

The risks of water and ground contamination due to landfilling depend largely upon the geology and hydrogeology of the site chosen.

During the site selection phase, the geology and hydrogeology of the area must be thoroughly investigated and taken into account both at the regional and local level.

This knowledge will then be used in two ways :

1) first to select the most favorable areas (where the risks of negative environmental impact are lowest),

2) once a given area is chosen, to design the landfill in order to further minimize the potential for contamination.

This lecture will deal successively with the following points :

- ⇨ definition of major relevant geological, hydrological and hydrogeological concepts,
- ⇨ why and how waste can contaminate the environment,
- ⇨ how to conduct a geological-hydrogeological study,
- ⇨ description of best case and worse case scenario,
- ⇨ conclusion.

II Definitions

2.1 Geology

Geology can be defined as the systematic study of the matérial, processes, environments and history of the earth.

Although the three are complementary, it is the nature and structure of the materials themselves that have the greatest bearing on landfill and which therefore will be dealt with here.

a) *Rock types*

The rocks present on the surface of the earth can be broadly subdivised into three categories, each corresponding to it's own mode of formation ; all three categories being linked to one another through the "geological cycle" (see figure 1).

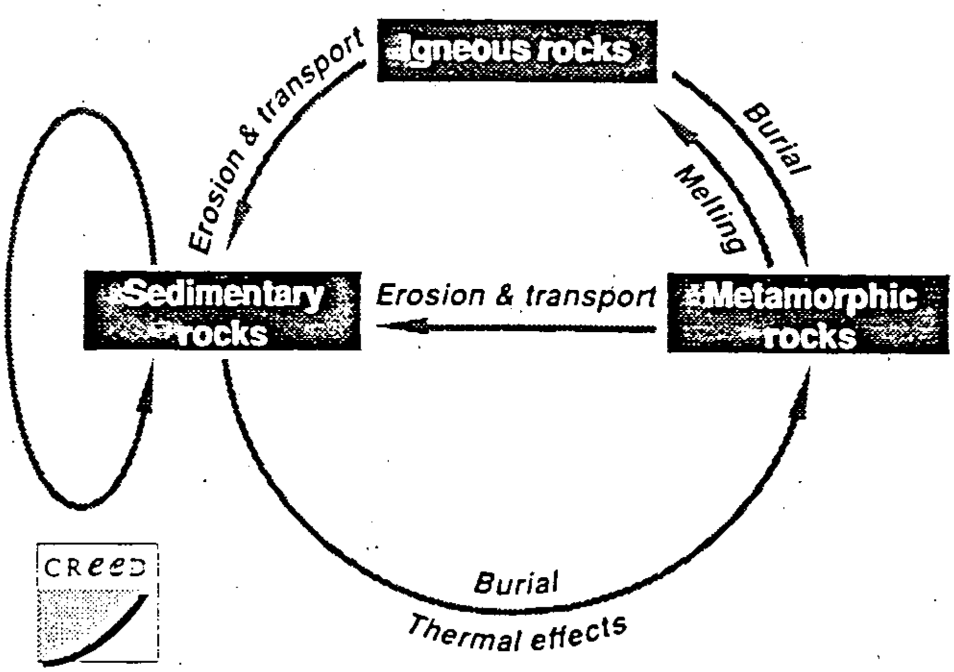


Fig. 1:The geological cycle

Sedimentary rocks

Sedimentary rocks are mostly derived from the destruction (erosion or chemical dissolution) of preexisting rocks, transport and deposition in layers generally at the bottom of seas or lakes and rivers (sometimes directly on surface as with aeolian sandstones).

Sedimentary rocks include conglomerate, sandstones, limestones, chalk, clay...

Igneous rocks

Igneous rocks are formed through the rising and cooling of melted magma up to the surface of the earth. The original composition will determine the final characteristics of the cooled rocks and it's resistance to weathering and fracturing.

Rapidly moving low viscosity magma generate the classic volcanic eruptions (basalts, tuffs). Cooler, thicker magma do not move so easily and stop below surface where they form coarser rocks. These become exposed on surface through erosion. Granites are formed in this manner.

Metamorphic rocks

Metamorphic rocks result from the transformation thought heating or regional pressure of preexisting rocks (igneous or sedimentary). The heat and/or pressure can results from the burying of sediments into the depth of the crust, from deformation during the creation of mountain ranges or from the proximity of rising igneous rocks.
Example of metamorphic rocks include schists, marbles (transformed limestones rocks) and gneisses (transformed igneous rocks).

A very important distinction can also be made between the "hard rocks" (basalts, limestones, granits, some sandstones) and soft rocks (chalk, clays,soft sand, gravel, weathered granites or basalts...).

The hard rock areas are not easily amenable to earth moving equipement and thus more expensive to deal with than the "soft rocks" which can be removed using earth moving equipment.

b) *Geological hazards*

As we have seen before, geology, comprises the study of processes involved in the development of the earth. Most of theses processes are slow (erosion, mountain formation). However, some are very rapid and drastically alter the surface of the earth. The probalility of such processes, grouped under the term geological hazards, to occur must be assessed when looking for a potential landfill site. The most common geological hazards are listed below :

- flood,
- avalanches and lahars (for obvious reasions but avalanches paths can be easily be forgotten, as was the case recently in a french ski resort !),
- active seismic zones,
- fault zones even inactive as these would act as preferential water pathways.

c) *Rock permeability*

Permeability is a term expressing the rate at which water passes through a given body. It can be used to describe fluid movement in rocks, cement, plastics...

Permeability is expressed as K, in m/s and the higher the figure, the more permeable is the substrate.

For example, a very permeable rock, like a gravel formation, has a : $K = 10^{-2}$ m/s.

At the other end of the spectrum, clay is poorly permeable, (commonly termed, incorrectly, impermeable) : $K = 10^{-9} \text{--->} 10^{-12}$ m/s. Water can still percolate through but very slowly.

Rocks can be broadly classified on a permeability scale as follows.

Hightly permeable	Permeable	Poorly permeable	Impermeable
--------------------	--------------------	--------------------	-------------------->
Gravels	Sand fractured rocks	Sandy clays weathered rocks	Clays

Examples of typical permeability values are given for these rock types in figure 2.

However a given rock type cannot be automatically assigned a strict definite K value. This will depend on its local homogeneity (clay with sand lenses or vice versa), it's degree of fracturing and it's state of alteration. K must therefore always be checked and mesured in situ.

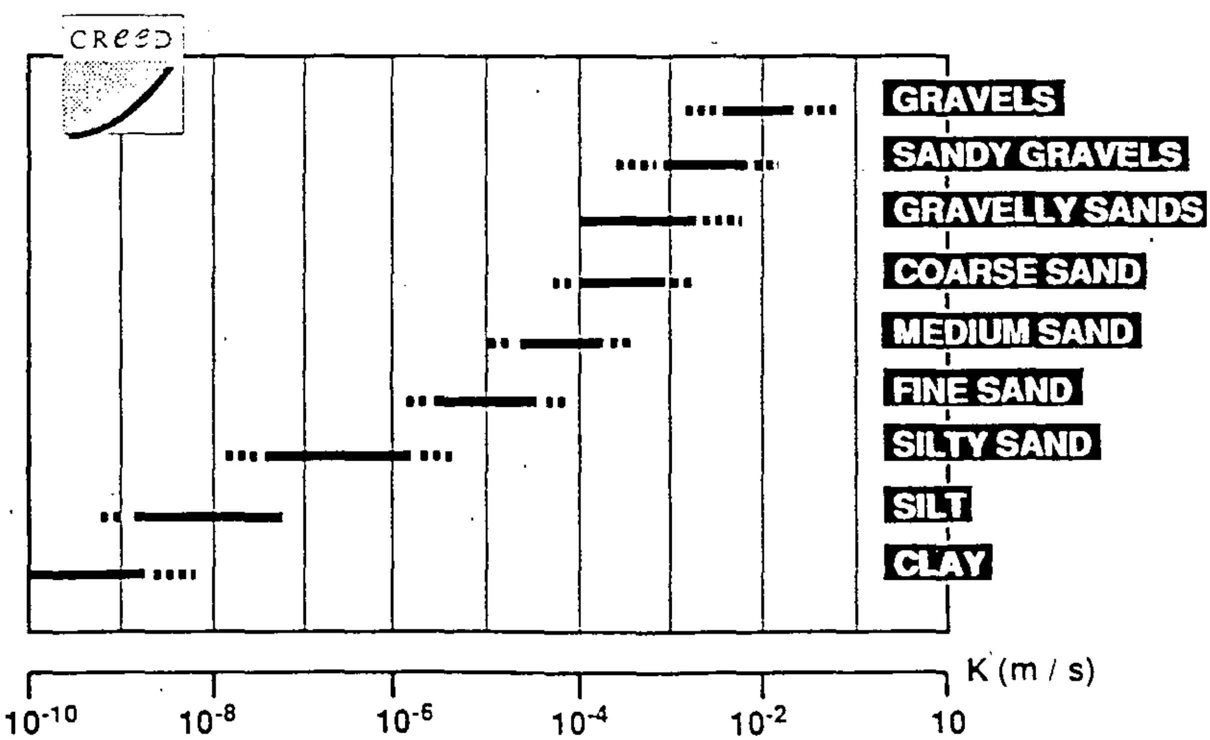


Fig. 2: Examples of permeabilities

d) *Geological history*

In order to identify the most favorable area for the siting of a landfill, an understanding of how and why the present geological features were developped is necessary. Such an understanding allows the identification of the geological hazards previously mentionned.

The unravelling of the geological history of an area is achieved through the careful analysis of geological maps, and when these are inadequate or unexistant, through geological mapping and drilling.

Examples :

- ⇨ The study of a geological map can show the existence of faults under a thin sedimentary cover (not visible on surface).
- ⇨ Analysis of sedimentary patterns indicates which zones are likely to be homogeneous, permeable, impermeable,...
- ⇨ A study of the geomorphology or rivers terraces and recent deposits indicate flood plains...

2.2 Hydrology

Hydrology is the science that deals with the processes involved in the depletion and replenishement of the water resources. Thes processes can best be understood by looking at the water cycle (Fig. 3).

The driving force for this circulation is radiant energy from the sun. This causes evaporation from water surfaces, the resulting water vapour comprising part of the atmosphere. With favourable atmospheric conditions, the water will condense to form clouds from which precipitation may occur. The latter may return directly to storage in lakes and oceans, it may accumulate as snow in high mountains and in polar regions, or it may fall as rain over land. In the latter case some precipitation may be intercepted by vegetation and return to the atmosphere by evaporation. The remainder of the rainfall may collect to form surface run off or it may enter the ground as in filtration. The surface run off may then return to storage in lakes and oceans. The water that infiltrates the soil will either be taken up by plant roots and transpired to the atmosphere, or it will percolate downwards through the unsaturated zone to the water table.

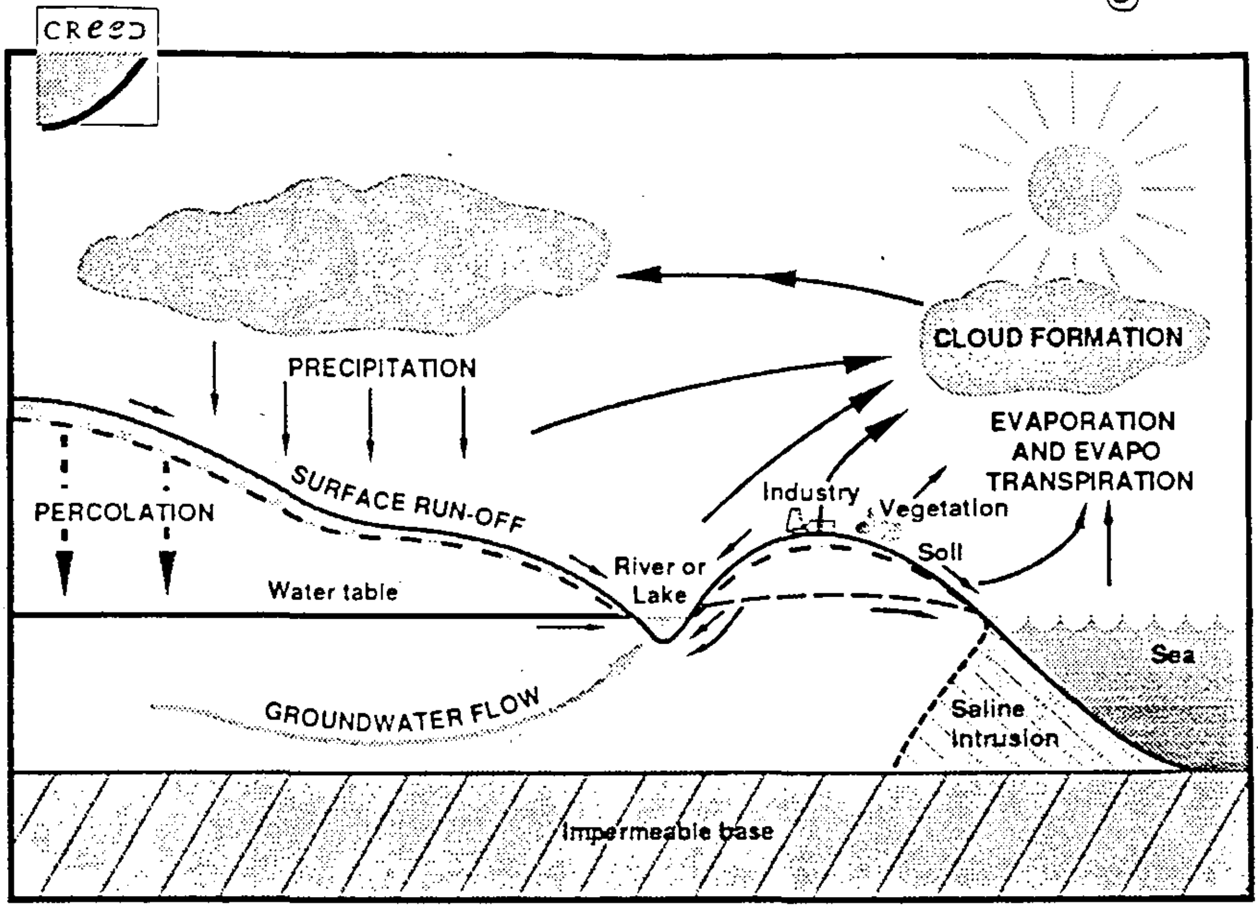


Fig. 3:The water cycle

This groundwater may then move towards surface discharge points (spring etc) where it will become a component of surface runoff moving towards oceans and lakes.

As far a landfill siting and designing is concerned, the following data needs dot be recorded and assessed :

Climate

Wind, rain or snow, and temperature are climatic conditions that may mandate the type of operation, amount and placement of soil cover, kinds of roads needed, and type of structures constructed on a landfill. Hence, it is imperative to have information on the number of days of wind, freezing temperature, rain or snow, to aid in selecting a site for a sanitary landfill.

Rain or snow

Precipitation must be considered with regards to surface water runoff, drainage system required for its control, leachate generation, feasibility of sustaining operations at all times on site, movement of equipment, and access to and from site. For instance, low lying sites that might frequently flood or become muddy during rainy weather should not be chosen in areas having high rainfall.

Climate and degree of infiltration

Climate is significant because of its direct bearing on the amount of rainwater that may infiltrate through the unsaturated zone and into a groundwater system. Degree of infiltration is a function of the amount of precipitation, volume of surface ponding and runoff, and the evapotranspiration rate. (Evapotranspiration refers to the water released into the atmosphere by plants - in this case, the vegetation growing on the landfill cover). Ambient temperature and relative humidity also have an impact on infiltration, evaporation, and evapotranspiration. The potential for groundwater degradation from a well-designed and constructed landfill in arid and semi-arid regions is quite low, whereas the potential is quite high in humid regions. Another decision factor in selecting a suitable site is the quantity and seasonality of rainfall. For example, if rainfall is highly seasonnal (e.g. Mediterranean type climate), the quantity of rainfall during the wet season may be relatively low.

Stream Density

The likelihood of surface water contamination increases in areas in which an unusally short underground flow path precedes discharge of contaminants into an area in which streams are closely spaced. However, the overall extent of any grounwater contamination may be limited by subsurface media. Alternately, widely spaced streams may also lead to the development of larger and longer-term groundwater contamination zones.

2.3 Hydrogeology

Hydrogeology can be defined as the study of groundwater, its chemistry, mode of migration and relation to the environment. The relationship of groundwater to the water cycle can be seen in figure 3. Therefore the possible impact of a landfill on the groundwater regime must always be carefully answered.

Let us define the mains terms and parameters necessary to understand and assess the groundwater systems :

- ⇨ aquifers,
- ⇨ recharge and discharge zones,
- ⇨ saturated/unsaturated zones,
- ⇨ hydraulic conductivity,
- ⇨ porosity and velocity.

What is an aquifer ?

An aquifer is a body of rocks containing water with sufficient permeability for the water to flow. Three sorts of aquifer can be distinguished :

1) Sandy aquifers : In these aquifers, water flows through the voids in between the grains : the intergranular porosity.(Fig.4). Such aquifers can be found in sands and gravels.

2) Fractured aquifers : these aquifers occur in fractured poorly permeable rocks such as sandstones, chalks, limestone, volcanic rocks ... The water flows through communicating fractures and cracks : the fissure porosity. (Fig. 5).

3) Mixed aquifers : Theses aquifers contain both fissure and intergranular porosity and occur in karstic environment. (Fig. 6).

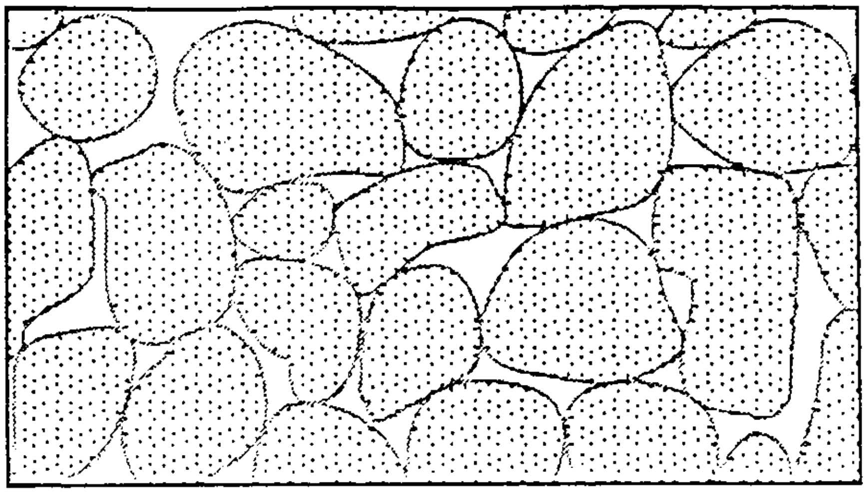
The infiltrated water reaches the "aquifer" more or less rapidly depending on the permeability of the rocks it encounters. Through chalk, for example infiltrated water can take up to one year to reach the underground water. In schist and granite, in principle impermeable rocks, water can still percolate very quickly through the fractured or weathered zones.

Different configurations of aquifer

Aquifers are classified as unconfined or confined depending how they are bounded.

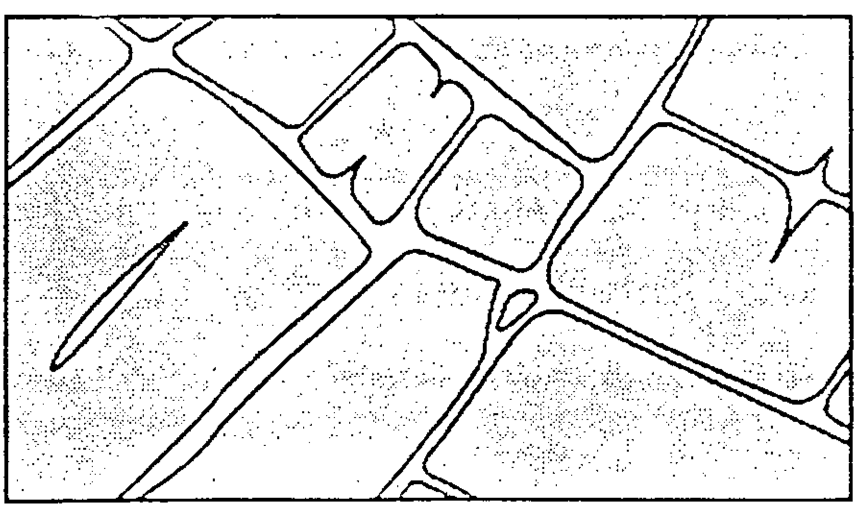
A confined aquifer is bound by two impermeable layers. The water is under pressure and the water level goes up when a bore hole is dug in such an aquifer or if part of the surface is dug out. The level to which the water rises in a bore hole is called the piezomètric level. (Fig. 7).

An unconfined aquifer is an aquifer where the water table (or piezometric level) is free to fluctuate up and down, generally seasonally. (Fig. 8).



Sand
gravel
clay

Fig. 4: Intergranular porosity



Chalk
sandstone
limestone

Fig. 5: Fissure porosity

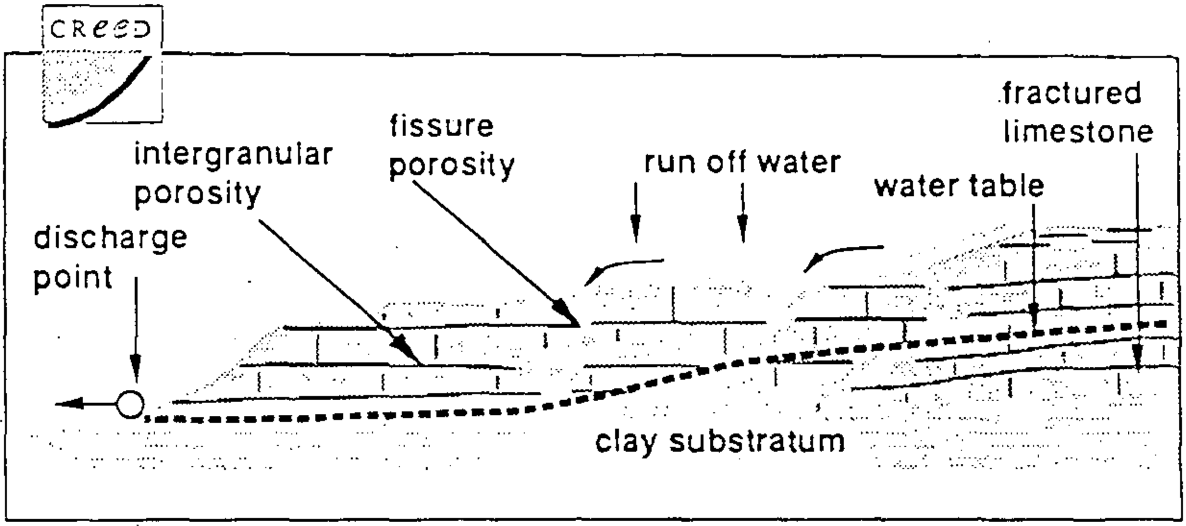


Fig. 6: Karstic aquifer

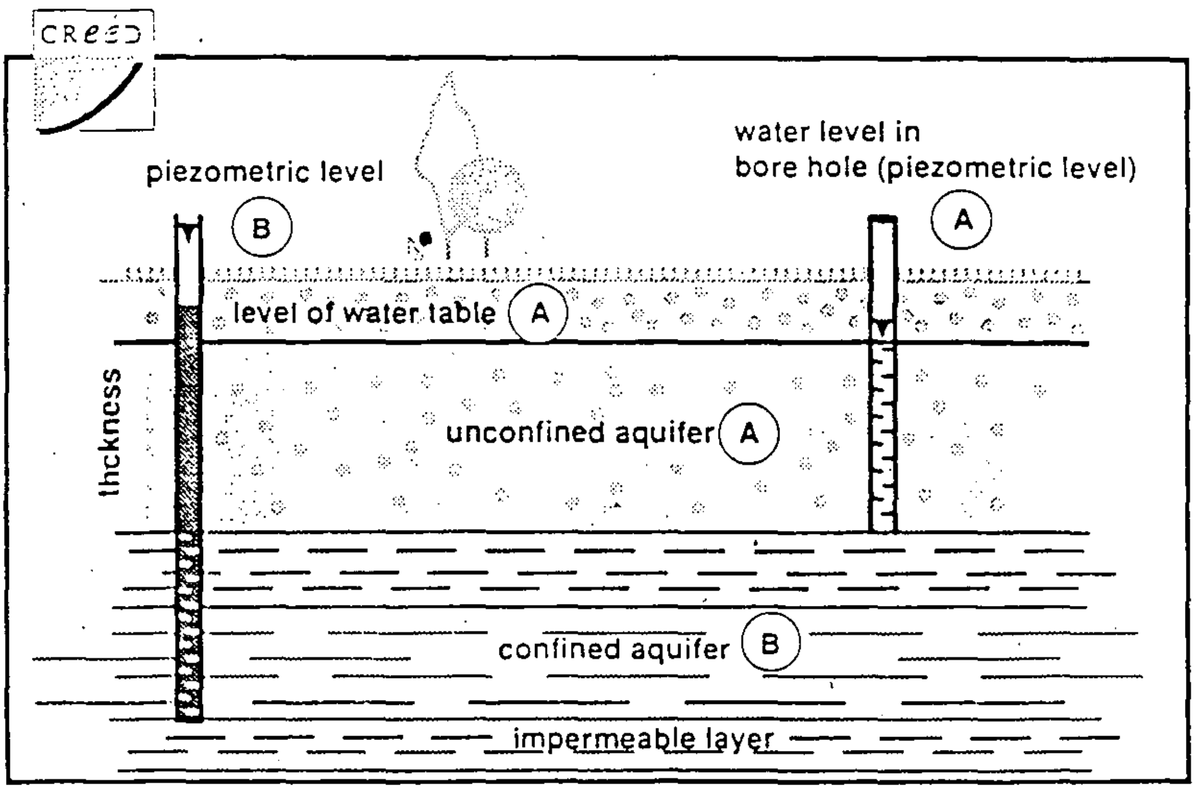


Fig. 7: Schematic example of confined and unconfined aquifer

Recharge and discharge zone

As seen in the water cycle (Fig. 3), aquifers are filled (recharged) up through the infiltration of rain water through permeable strata. (Fig. 8).

Upon reaching the aquifer, the water flows under the regional hydraulic gradient and gets discharged again at springs, from seepages into river and pumped wells.

Thus, within an aquifer, water is not stagnant but flows from the recharge to the discharge zone. Rates of flow vary according to the type of aquifer : for example 1.500 m/y in alluvium and 3.5 to 9 km/y in a karstic system.

Saturated/Unsaturated zone

In an unconfined aquifer, two successive zones are encountered by the water percolating downwards from the surface.

The unsaturated zone when the rock interstices are partially occupied by water and partially by a gaseous phase (air). In this zones different complex mechanisms can interact with a percolating fluid (leachate or other pollutant) : sorbtion, neutralisation, precipitation, oxydo-reduction, biodegradation.
Although these mechanisms have been observed, they are yet to be precisely quantified and understood.

The saturated zone starts at the level of the water table when the rock interstices are entirely filled with water. In this zone, the groundwater flows under regional hydraulic gradient to the discharge zone.

Hydraulic conductivity, porosity, velocity

These terms are the most commonly used to characterise aquifers. Before defining them, one must first of all understand the most important law governing aquifers. Darcy's law :

Darcy's law : (figure 9)
Darcy's law allows the calculation of the discharge (Q) that is flowing through a given cross sectional area of a rock.

The equation is :

$$Q = kSi.$$

Where
- Q = discharge (m3/s or m3/d)
- k = permeability (m/s) or hydraulic conductivity (m/d)
- S = cross sectional area
- i - hydraulic gradient

Example of how Darcy's law is applied (Fig. 10) :

If we imagine 2 m of water logged waste over a surface of 1 km^2 overlying 5 m of clay with a permeability $K = 10^{-12}$ m/s, the flow of water through the "impermeable" layer is : Q = ksi

$$Q = 10^{-12} \text{ m/s} \times 10^{6} \text{ m}^2 \times \frac{2}{5} = 4.10^{7} \text{ m}^3\text{/s} = 12 \text{ m}^3\text{/year.}$$

Hydraulic conductivity is synonimous for permeability (K) previously defined. It describes the capacity of rocks to transmit water and is generally expressed in m/day while K is expressed in m/s.

Porosity is the measure of the interstial pore space, expressed as the relative volume (in %) of rock occupied by voids. In fact, part of the water present in the voids is retained by forces of molecular attraction, adhesion and cohesion. So, in terms of real storage potential, the use of effective porosity (n), ie the free storage space, is more appropriate. For example, while clay has a high total porosity, it has a low effective porosity. (Fig. 11).

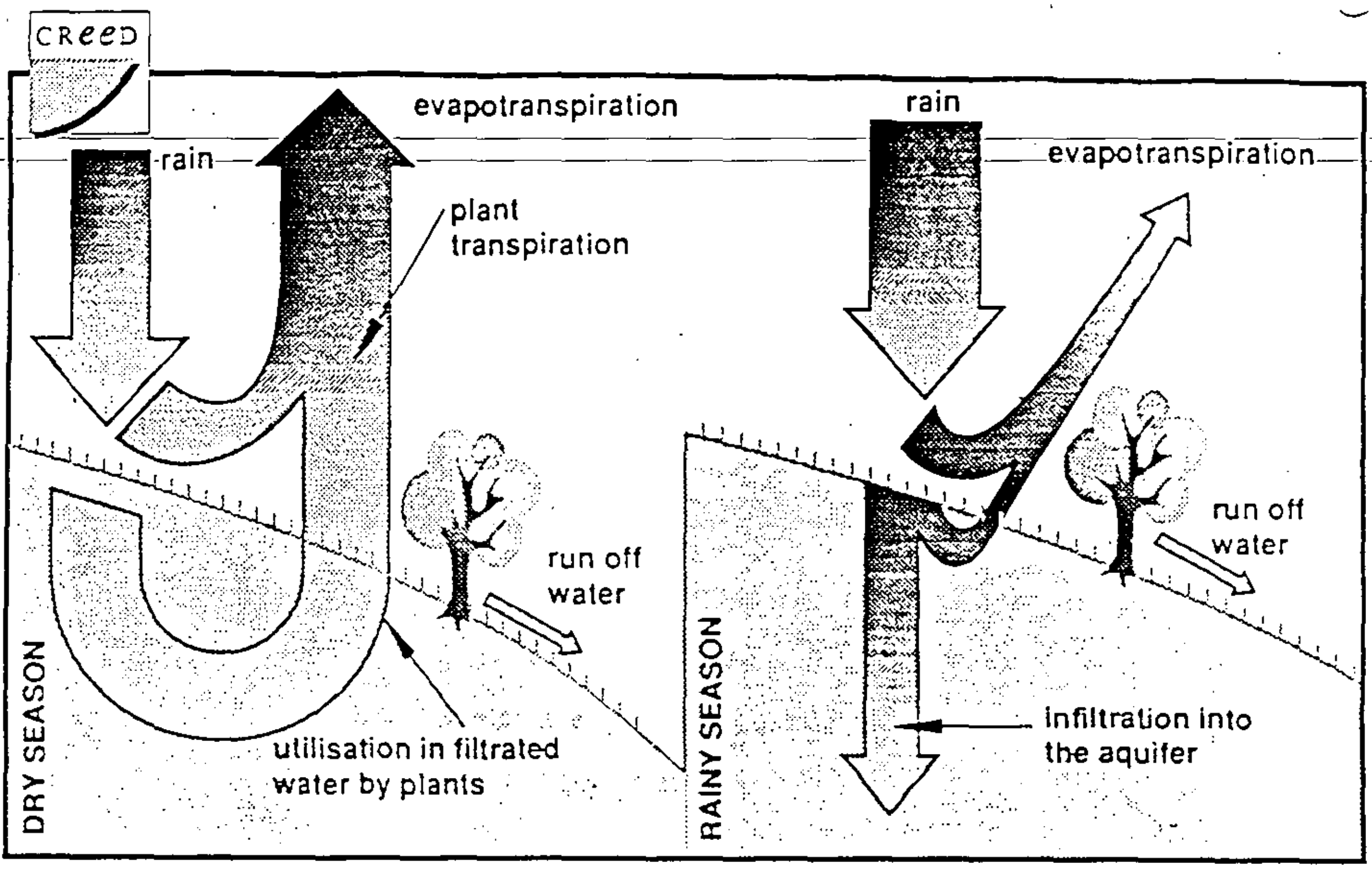


Fig 8: Recharpe of aquifers by rain

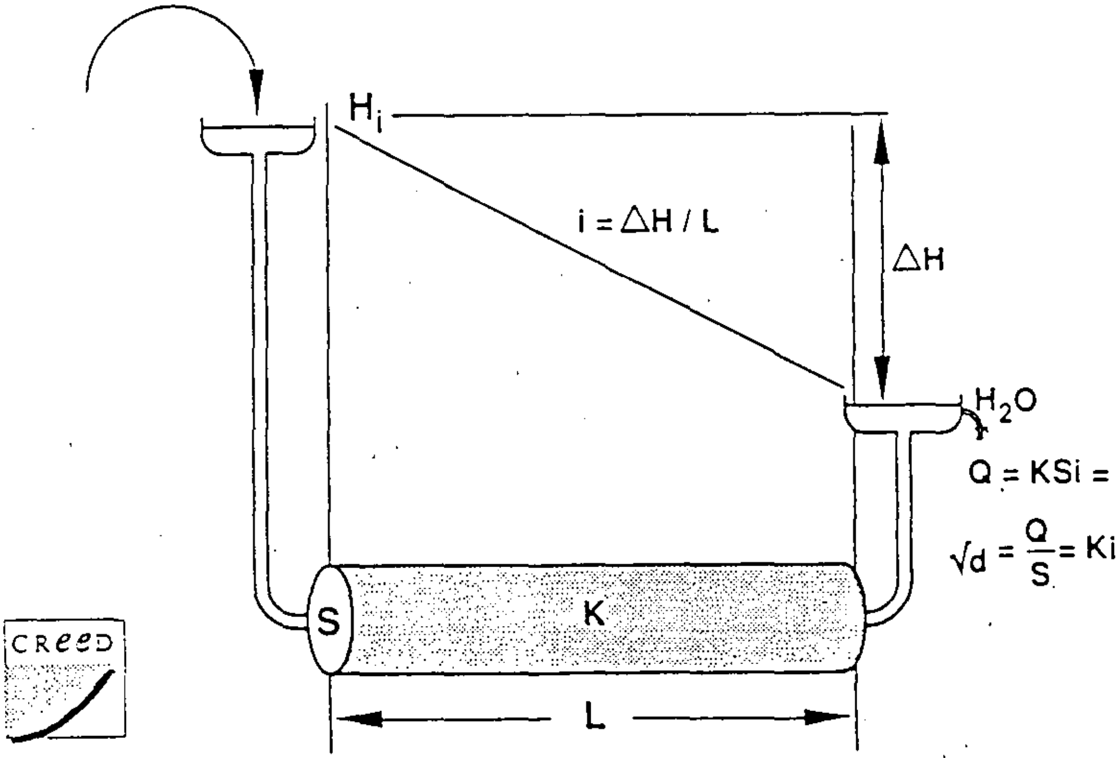
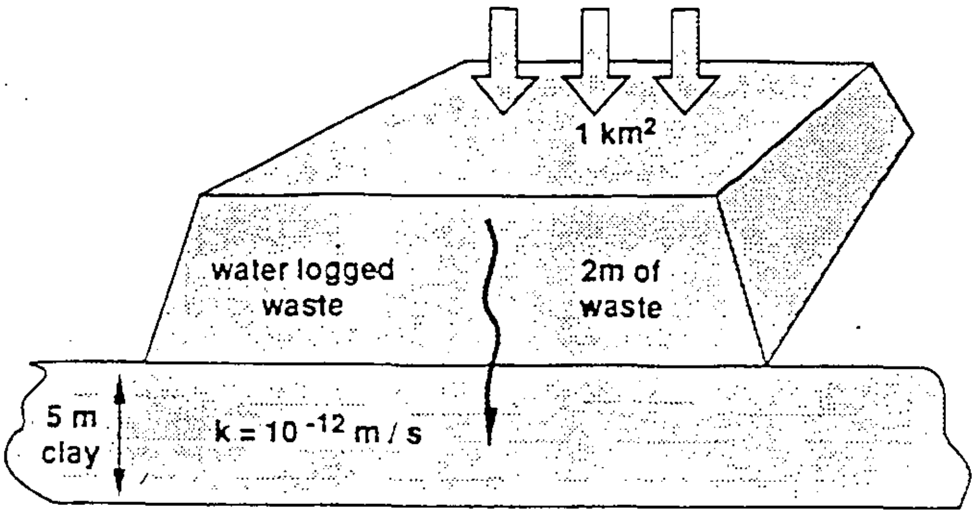


Fig. 9: Darcy's law



$$Q = k\,S\,i$$

$$k = 10^{-12}\ m / s$$

$$S = 1\ km^2 = 10^6\ m^2$$

$$Q = 10^{-12} \times 10^{+6} \times \frac{2}{5} = 4.10^{-7}\ m^3 / s$$

$$Q = 12\ m^3 / an$$

Fig. 10: Application of Darcy's law

Rock type	Total porosity range %	Effective porosity range %	Flow type	Saturated hydraulic conductivity range m / d
Clay	45 - 55	1 - 10	i	$10^{-2} - 10^{-5}$
Chalk	35 - 50	0.5 - 5	F + I	$10 - 10^{-3}$
Sand	35 - 40	10 - 30	I	10 - 1
Gravel	30 - 40	15 - 30	I	$10^{2} - 10$
Sandstone	10 - 20	5 - 15	F + I	$10 - 10^{-1}$
Shale	1 - 10	0.5 - 5	F + I	$10^{-1} - 10^{-7}$
Limestone	1 - 10	0.5 - 5	F (+ I)	wide
Igneous and Metamorphic	(probably less than 1)		f (+ I)	wide

F = fissure flow, I = Intergranular flow

Fig. 11: Porosity ranges, flow types and saturated hydraulic conductivities for various rock types

III. Risks of water contamination by waste

Surface water contamination (Fig. 12)

The main risks of surface water contamination are listed below :

1) If a landfill is located below flood level, each flood will penetrate the waste, flow across the landfill and disseminate polluted water and in some case even waste into the river system and surrounding area (so flood plain levels must be identified).

2) A landfill close to sea level, similary, can pollute sea water and nearby beaches during high tides.

3) A landfill close to a river can pollute it with seepage of leachate from the base of the landfill to the river.

Groundwater contamination

Several types of situation can result in ground water contamination :

1) A landfill with a permeable base and close to the water table. The unsaturated zone is non existant and the leachate percolates directly into the aquifer, creating a plume of pollution that can be very extensive.

2) A landfill located above a fractured zone. Even if the rock itself is unsaturated, leachate will reach the aquifer directly and quickly through the fractures.

3) Similary, leachate can reach the aquifer through heterogenities and discontinuities in an otherwise impermeable zone (for example along a fault zone, or along a thin limestone layer within a clay horizon).

IV. How to conduct a geological/hydrogeological study

4.1 Regional study

What needs to be known :

⇨ The geology of the area in order to identify fault zones, impermeable areas, heterogeneities ....

⇨ The geomorphology of the area, to identify geological hazards such as flood plains and to delineate the water basins,

⇨ The hydrology : all the aquifers must be identified together with the surface water network and the water flowing direction.

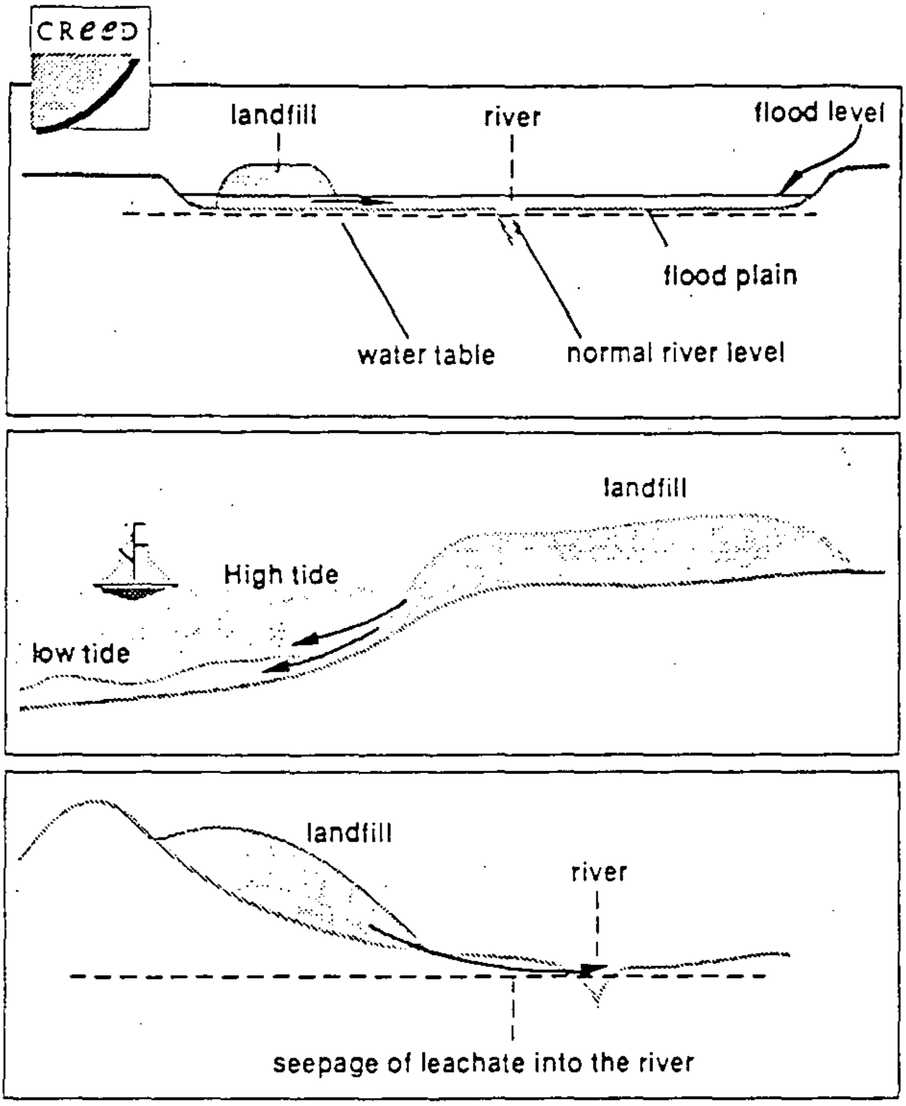


Fig. 12: Risks of surface water contamination

These informations can be gathered from existing maps, aerial photos, boreholes, and reconnaissance f··d work.

4.2 Local study

What needs to be known :

⇨ Detailed geology,

⇨ An inventory of springs and water boreholes,

⇨ Detailed hydrogeology (depth to aquifers, piezometric levels, quality of water),

⇨ Permeability of the differents formations.

Such data is obtained through :

⇨ Detailed geological mapping,

⇨ Drilling and carefull logging of the core.

⇨ Installing "Piezometers" in several boreholes and monitoring the water mouvement (existing piezometers can also be used if available).

⇨ Analysing the water in the piezometer.

- It must be pointed out that the drilling and installing of a piezometer needs to be very carefully supervised by a specialits as if suffisant care is not taken, very costly mistakes can be made (like missing an aquifer, tapping and thus measuring the wrong aquifer ...).

⇨ Measure in situ of permeability, on surface and inside boreholes. These measures must be made and interpreted by specialists and the interpretation must be linked to the geological mapping (a layer of material with $K = 10^{-9}$ m/s can occur within a formation of siltstone ($K = 10^{-6}$ m/s) and a thick clay formation ($K = 10^{-12}$ m/s) can be locally fractured which lowers K dramatically, or contain sand lenses ($K = 10^{-4}$ m/s).

SITE SELECTION - NON-GEOLOGICAL ASPECTS

1. INTRODUCTION

The purpose of this section is to work through the process that leads to the development of a site for landfill. It can be a very long process. It may take five, ten or even more years to complete the process from first consideration to depositing the first load of waste in the site. This section is based on the idea that we are in charge of waste disposal in a region of a country and we have the task of ensuring that its waste disposal needs are met.

2. DEFINING THE NEED FOR A SITE

It may be obvious that new facilities are necessary but it is advisable to follow a logical process in evaluating the need and the proposals to answer that need.

Different types of waste to be accommodated

First we must define the types of waste that we are going to be concerned with. Unless there are special requirements the list of wastes will include the following:

* Domestic or household waste.
* Waste from shops or offices.
* Yard and garden waste.
* Construction and demolition waste.
* Excavated soils.
* Some industrial waste.
* De-watered sludges from waste water treatment.

Local circumstances may add other types of waste to this list. **Many industrial wastes will not be suitable for landfill and will require treatment or incineration.**

Measuring the quantities of each type of waste

The next stage is to find out how big the problem is. We need to know how much waste is being produced now and how much is likely to be produced in the future. The best method of measuring waste quantities is to weigh vehicles entering existing disposal sites. It is important to ensure that no scavenging or illegal disposal is taking place before the waste arrives.

The weighing scales may be permanent scales - part of the site infrastructure - or they may be portable. If it is impractical to weigh all vehicles then a random sample should be weighed, preferably over periods of several weeks at different times of the year.

If a well-established disposal system does not exist, then it is probably better to rely on tackling the problem at the other end - where the waste arises. Again, it will be necessary to set up a sampling system covering different socio-economic areas, so that quantities per head of population can be calculated.

Either way, the objective is to arrive at a total quantity of waste to be disposed in tonnes/year.

We then move on to forecasting the future. Lots of estimates of future waste generation have been given, but few are based on accurate records because generally such records have not been reliable. Also, waste generation is very dependent on forecasting the behaviour of the economy and if we were good at that we probably wouldn't be involved in waste disposal!

The safest prediction is simply to allow for population change and increase or decrease on a pro-rata basis. If the population is forecast to double in 10 years then the quantity of waste is likely to double as well.

Composition of the waste

Because we are looking at a landfill strategy, composition is less important than where recycling or treatment by incineration or composting is being considered.

Samples of not less than 100 kg have to be taken and hand sorted and the individual constituents weighed. The sampling needs to be carried out on at least 2 and preferably 4 occasions during the year to catch seasonal variations. Recent field work has shown that, over a 5 year period, significant changes in refuse composition can take place.

The quantity of waste dictates factors such as volume, frequency and number of vehicles using a site, land area required and the amount of cover material needed.

The composition of the waste has an impact on the area requirements for each cell since we normally try to deposit waste in small cells which will not become saturated with rainfall. It also affects the number of passes required to achieve proper compaction and the type of equipment needed.

3. REVIEW EXISTING FACILITIES

The next stage in planning the strategy and selecting a suitable site is to review all the existing facilities.

It is necessary to look at all existing sites and to calculate the remaining capacity.

Some form of surveying will be required. There should be plans showing the extent of existing landfills and contour drawings showing the eventual restored landform. If these don't exist then they need to be prepared. Surveying for waste disposal landfill sites does not need to be carried out to the nth. degree of accuracy. Allowing a reasonable degree of accuracy can save costs and speed up field work.

In some cases, aerial survey may be the most efficient way of measuring volumes particularly if a large number of sites are involved.

It is common experience that landfills last longer than you think they are going to and then suddenly they run out! We need to have realistic figures for existing capacity.

When we have carried out our surveys we add the capacity of all our facilities together and divide by the total quantity of waste produced per year and this should give us the number of years we have available before a new site is required.

This little sum requires some knowledge of the volume occupied by 1 tonne of refuse. It is a figure which varies with type of waste, method of compaction and over time and with depth in the landfill. In the absence of better information a figure of between 0.8 and 1.0 tonne per cu. m. may be used if reasonable compaction is being applied. If not, then densities may be down to 0.5 tonne per cu.m.

4. PROGRAMME

Having worked out the life of existing facilities it is useful to draw up a programme of work. By the time the existing facilities are full we must have our new site in operation. There are several procedures which have to be undertaken depending on the particular legal and administrative requirements of the area. Typically:

* We have to select the site.
* We have to prepare an application for its use to the authorities.
* We have to comply with the permitting procedures.
* We have to carry out the engineering works.

These procedures can take a very long time!

5. ASSESSMENT OF POTENTIAL LANDFILL CAPACITY

We are now in a position to start looking for our new landfill site.

Firstly we must establish the overall boundaries of our search area. This will be based on demographic and physical limitations such as political or regional boundaries, mountain ranges and rivers.

Next, we must establish suitable study areas on the basis of haul distance, topography, geology and surface and groundwater conditions.

Haul distance

The distance of the landfill site from the area where the waste arises and is collected is known as the haul distance.

If the landfill is close to the collection area then collection vehicles can travel directly to the landfill.

If the landfill is remote from the collection area, some form of transfer station is needed. Collection vehicles are expensive pieces of equipment and should spend most of their time collecting waste!

At a transfer station the waste is "transferred" from the collection vehicle to a bulk transport system. This is most likely to be bulk lorries, but in an extreme case could be rail.

A lot of financial factors come into play here. What we are concerned with is the total system cost. That is the cost of collection + transfer + landfill.

Landfill sites benefit greatly from economies of scale and so a very large remote landfill may be less expensive than a very small local landfill.

Identification of sites

Having identified our study areas, bearing in mind the boundaries and the access constraints and the physical limitations, we are now in a position to identify suitable sites.

These will be of two types:

* Mineral excavation areas where waste can be used to restore the ground.

* Areas of virgin land where a new landform can be created.

A lot can be achieved from maps and by travelling around looking. We should produce a list of every potential site with a few notes about its major features.

6. PRELIMINARY SELECTION PROCESS

We are now in a position to start eliminating many of the potential sites.

It is common experience that there are four critical factors in the selection of a potential site:

* **Availability** - If it isn't going to be possible to acquire the site there's not much point proceeding with it.

* **Planning Constraints** - There may be some form of zoning or special planning requirements. There may be a water protection zone. Such sites should be rejected.

* **Access** - It has often been found that access is a critical factor. The public sometimes seem to be more concerned with lorries than the actual landfill, so there must be an adequate access. Landfill is the one engineering operation that has to go on regardless of weather, so access is critical.

* **Capacity** - Because of the long time required and the considerable expense involved in developing a new landfill site it must have adequate capacity. A minimum of ten years is often considered desirable.

There may be other critical factors in other situations, but the aim is to get to a position where there is a short-list of about 4-6 possible sites, which pass the critical factor test.

7. ENVIRONMENTAL ASSESSMENT

The next stage is to carry out an environmental assessment of our preferred sites.

This will require the preparation of designs for each site and we should also calculate the total system costs of running each site. From this we can identify the effects of each site on all elements of the environment.

It is useful to draw up some form of evaluation sheet - listing each site and each factor and assigning a wieghting for each. Different elements of the environment may be ranked as more or less important. We thus end up with scores for each site and some sort of ranking order.

8. EVALUATION SHEET

The evaluation sheet needs to identify all the possible impacts of the site together with certain other information already described such as costs, access, and capacity. The impacts to be considered include:

* The effects on human beings living near the proposed landfill.

The foremost thing municipal officials can do to solicit public support is to convert any existing bad sites into well run sanitary landfills with a clear useful end purpose.

Objectives of a public awareness campaign

In going public about a new proposal it is necessary to have clear objectives. These objectives may be as follows:

* To make certain that the public understands the proposals.
* To assure the public that their views will be listened to.
* To ensure that the government or public authority is responsive to the public.
* To provide opportunities for public involvement in decisions.

The advantages of a campaign with these objectives are:

* It increases the likelihood of agreement with the plans.
* It provides useful information which may have been missed.
* It gives assurance that all views have been considered.
* It ensures accountability by decision makers.
* It provides an effective mechanism to ensure decision makers take into account issues around the project.

The disadvantages of such a campaign are:

* There is the potential to create confusion because new issues are introduced.
* Uninformed participants may distribute erroneous information.
* Public involvement adds cost to project.
* There may be delays to the project.
* The project may become a platform for politicians.

It is considered that none of these disadvantages are sufficient to outweigh the benefits of an effective public awareness campaign.

11. STEPS IN THE CAMPAIGN

The following steps are appropriate for a public information campaign:

* **Inform the public** of all the details of the scheme.

* **Establish the need** for the new site by explaining the situation in respect of existing facilities and why a new site is therefore needed.

* **Explain the alternatives** that have been considered and why they have not been selected.

* **Explain the operations**, how the site will be managed, how gas and leachate will be controlled, and how the site will be restored and managed in the aftercare period.

* **Be honest about the impacts of the site** on the local environment and the people who may be affected.

* **Try to understand the concerns of people** who live nearby and don't try to confuse them with "science".

* **Keep options open** so that if new information emerges as a result of the consultation it may be taken into account and the proposals may be modified.

* **Review previous assessments of environmental impact** as more information is gathered by talking to people affected by the proposal.

Finally, we should be able to make our final selection and we are now in a position to make our formal application to use the site. Much of the work already carried out will be of use in preparing the final design and operational plans.

Reference:

Waste Monitoring and Planning - A description of the regional waste planning system developed for London and South-East England. 1987.

WASTE MONITORING AND PLANNING

by M J Philpott, AKC, CEng, BSc(Eng), MICE, MInstWM,
Assistant County Surveyor (Waste Disposal), Oxfordshire County Council

(This presentation was accompanied by a series of slides. Some of these are reproduced as Tables or Figures; the content of others has been incorporated into the text).

Introduction

In my presentation, I intend to deal with three aspects of our work in the Waste Disposal Working Group. Firstly, I will explain how we developed a comprehensive waste monitoring scheme for the region. Secondly, I will show how the results of the monitoring are an essential part of every authority's waste disposal planning process. Finally, I will make some observations on the predominant role of landfill as the means of waste disposal in the south-east.

The Monitoring Survey

In 1985 we carried out our first monitoring survey.* The survey was in two parts. Firstly, we asked every authority to identify every single existing or potential void space in their area. We then asked them to make a subjective judgement for each site as to its suitability for waste disposal.

We asked officers to assess the sites into six categories:

Category 1 included all sites which have planning consent for disposal;

Category 2 covered sites which were likely to be supported;

Category 3 was for those sites which did not appear to have major problems;

Category 4 comprised sites with severe problems;

Category 5 was for sites where the problems were thought to be insuperable; and

Category 6 was for sites already committed for alternative development.

So the final three categories were all sites where waste disposal was not felt to be possible because of serious or overwhelming problems or because the site was committed for something else such as an industrial estate or a hypermarket.

* *Footnote:* The results of this survey are fully reported in 'Waste Disposal in the South East Region' (RPC SS5R: May 1988).

We ended up with 500 million cubic metres of possible void space, as shown on **Table 1**. Nearly 300 million cubic metres is in major consented sites and these are located in the areas shown on **Figure 1**. Individual sites are shown by the dots. Groups of major sites are shown within the shaded areas. It will be seen that there are areas with no major sites such as West Berkshire and north-west Hampshire and of course, most of London.

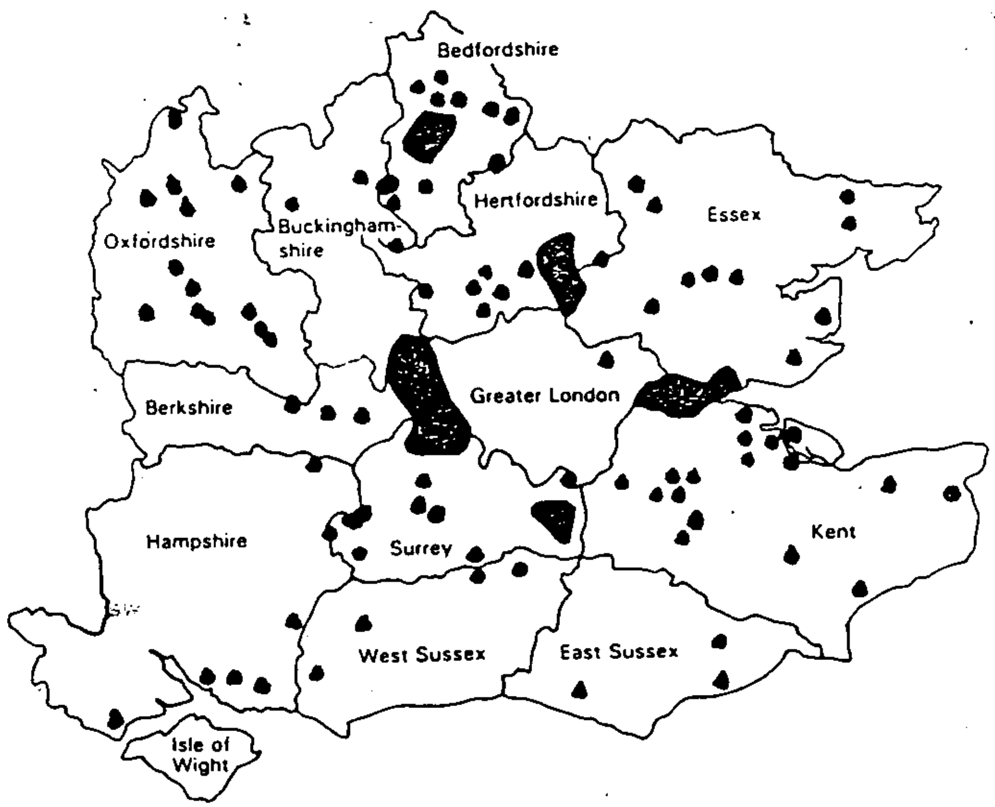
Table 1

Void space by category up to 2000

	(cubic metres)
Category 1 – consented	295,000,000
2 – potentially supported	132,000,000
3 – without apparent major problems	74,000,000
Total	501,000,000

Figure 1

Location of sites with consent for landfill.



The second part of the survey was concerned with the waste arisings in the region. **Table 2** shows the overall figures for the south-east. Public authorities have, in the past, tended to concentrate very much on the first two figures only. These are the wastes which they have a statutory duty to dispose of. However, they represent less than 20% of the total. Over half the total waste is inert waste – that is, soil or waste from the construction industry. The other 30% is commercial or industrial waste, comprising packaging and paper or waste from industrial processes.

Table 2

Waste arisings in the South East region	(tonnes/year)	(% of total)
Household	4,852,000 }	
Civic amenity	1,307,000 }	19
Industrial and commercial	9,213,000	29
Inert	16,884,000	52
Total	32,256,000	100

Table 3 shows that nearly half the total waste in the region arises in London. Again the proportions of waste in the different categories are very significant. When we think of the rail transfer stations, the river-based schemes and the giant Edmonton incinerator, it is important to realise that all these schemes were designed to cater for just part of one element of the total – the household waste element. All the rest, the other 80%, is controlled by the private sector and is hauled out of London each day by thousands of lorries to landfill sites in and around the capital.

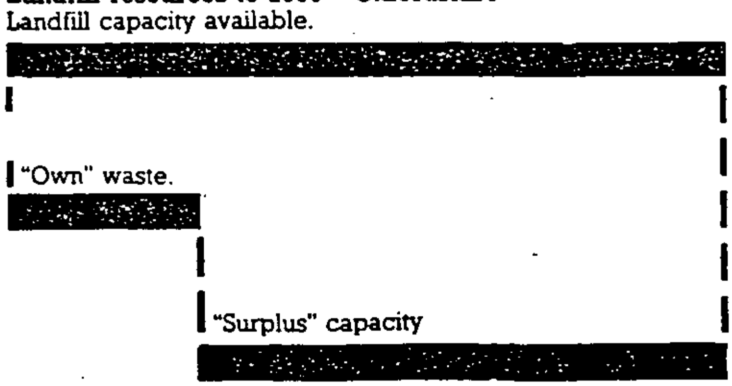
Table 3

Waste arisings in London	(tonnes/year)	(% of total)
Household	2,000,000 }	
Civic amenity	360,000 }	16
Industrial and commercial	4,820,000	32
Inert	7,770,000	52
Total	14,950,000	100

Having assembled all this data, what next? If I take my own county as an example. In **Figure** 2, the upper line represents the void space likely to be available up to the year 2000. The short line represents the volume of that void space which will be taken up by our own waste – both public and private sector. The long lower line then represents the theorectical volume which might be available for imported wastes.

Figure 2

Landfill resources to 2000 – Oxfordshire



Not all counties are in the same position as us and if I take another example – Hampshire – you can see why. **Figure 3** shows that capacity of available landfill space and incineration capacity falls short of the need in Hampshire itself. There is a shortfall of capacity which either has to be met by exporting waste or by using less-favoured sites or by landraising schemes.

Figure 3

Landfill resources to 2000 – Hampshire

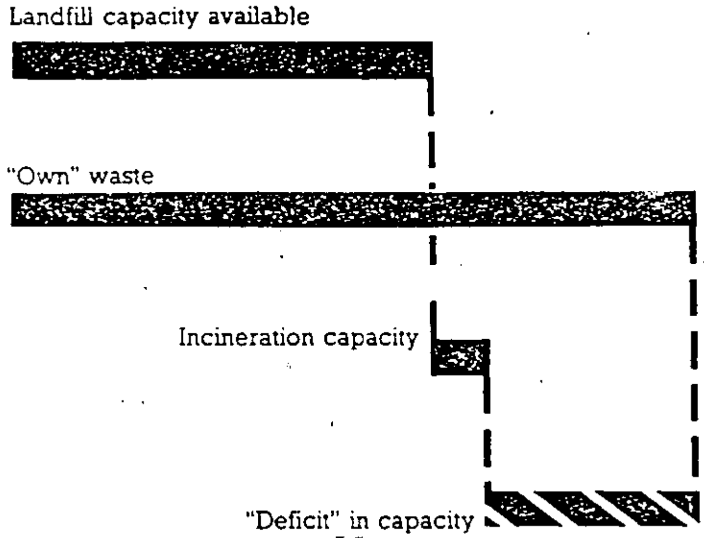
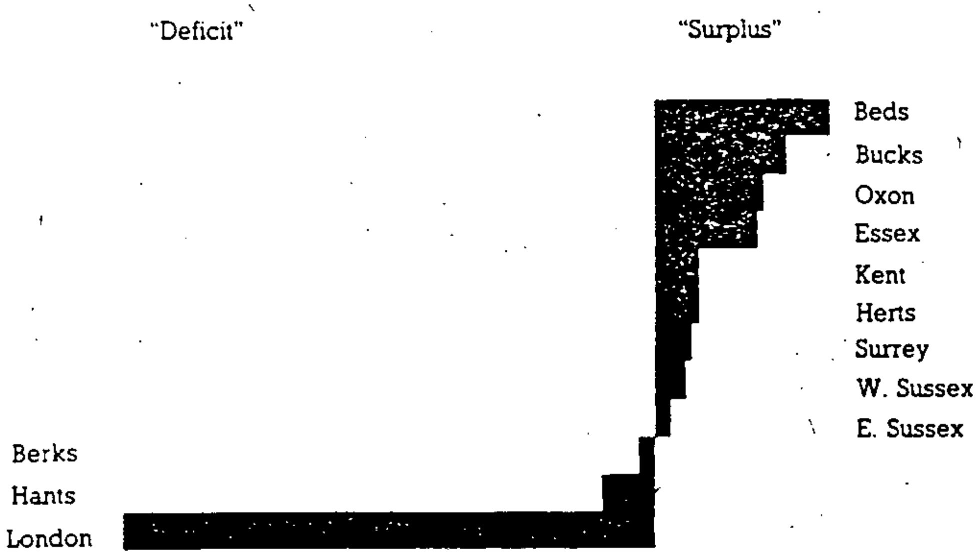


Figure 4 represents the overall waste disposal situation for the whole of the south-east over the next 12 years. It shows those areas which will be "in the red" and it shows those counties which have theoretically available space to accommodate the deficit. It shows very clearly how the nub of the regional problem is what to do with London's waste!

Figure 4

Overall waste disposal situation to 2000



Planning for the Future

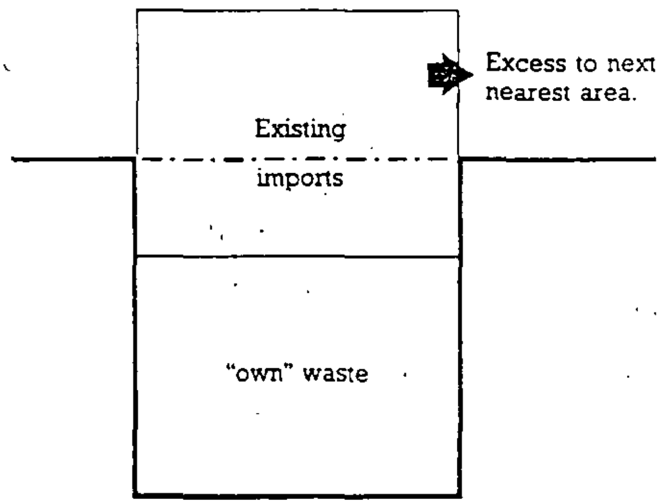
In 1986 and 1987 it was the next stage of the work that caused the greatest problems. What we wanted to do was to estimate how much waste would be likely to be imported into each a year by year.

The way the waste disposal system works in the South East is that waste from those areas in deficit is transported to those areas which have surplus capacity. Market forces in the private sector ensure that generally the cheapest, shortest solution is found. So, for example, waste from London is taken out by lorry to Essex or Herts or other counties bordering London. The public sector, on the other hand, has somewhat different perceptions. It is particularly concerned with security of disposal. Therefore in London we have the large transfer stations and the long-term contracts transporting waste to massive sites on the edges of the region. As sites near to London are filled, it is thus the private sector that will have to adapt the most.

How do we estimate how much waste each county is likely to have to dispose of in the next 10–15 years? Following the 1985 survey we put forward one model as a suggestion. **Figure 5** is designed to illustrate this model. The thick line represents a void equal to the total capacity available within a county. As a priority, it is then partially filled with its own waste as shown by the lower area. The remainder is then filled with imported waste; when no more capacity exists, the flow of imported waste is diverted to the next nearest area.

Figure 5

Model of waste movements



In the view of the Waste Disposal Working Group, that is a reasonable scenario. There are other ways of looking at the problem but the end result will not be too different. The exercise is a logical one. Waste is produced every day. It has to be disposed of. It occupies space. That space has to exist somewhere!

As a consequence of this exercise we produced a table showing how much waste would need to be disposed of in each county. **Table 4** gives the figures that were produced for my own county. They show an enormous growth in imported waste after 1995. At the moment we take one train a day from London. the final figure showing imports between 1995 and 2000 is equivalent to over ten trains a day.

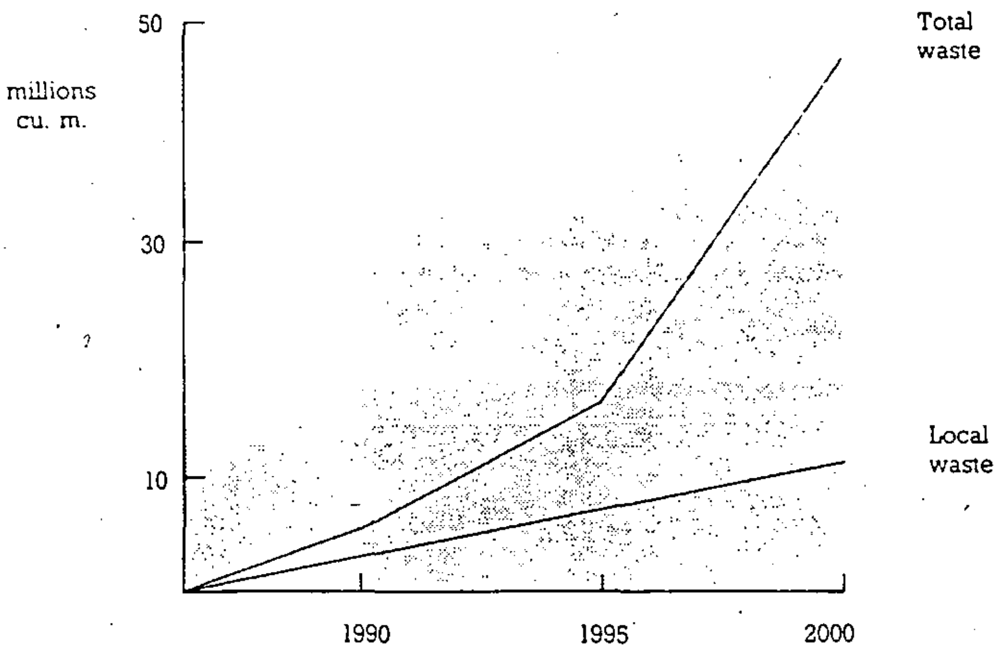
Table 4

Waste requiring disposal: Oxfordshire
(cubic metres)

	Local	*Imports*
1986 – 90	3,727,000	2,482,000
1990 – 95	3,727,000	6,410,000
1995 – 2000	3,727,000	22,501,000

Figure 6 shows how such imports would affect the landfill resources in our county. The lower shaded area represents the space which is already consented. The middle shaded area represents the space in potentially supported sites and the upper hatched area represents the sites without major problems. If we only consider local waste then we have sufficient consented capacity to meet all our requirements into the next century. When we add in the extra competing claims of imported waste then we begin to use up all our readily available space so that we could need to be thinking about less favoured sites. A similar situation applies in all of the counties surrounding London since the total quantity of waste to be disposed of in the next 12 years is only just short of the total void space likely to be readily available.

Figure 6 Landfill requirement – Oxfordshire



The regional planning process can be summarised thus:

The WDAs carry out surveys of void space and waste arisings;
SERPLAN estimates the likely flows;
The WDAs consider the implication of these flows;
SERPLAN reports on any particular problem areas.

It is intended that this process of monitoring and analysis should be repeated every two years. The second monitoring survey has just been completed and we are now beginning to analyse the results. It is intended to report on this survey later this year and then the third monitoring survey will take place in November 1989. In this way, waste disposal authorities will always have an up-to-date context within which to plan and make decisions.

I have spent some time describing the process that occurred as we carried through the first survey. This is the process that is outlined in the Guidelines in paragraph 36. I now want to turn to the way in which this process will be integrated into the formal waste disposal planning system.

Waste disposal planning is implemented through waste disposal plans as described in the Control of Pollution Act. The waste disposal plan is the means by which each authority ensures that sufficient resources exist for the disposal of wastes which will arise or will become situated for disposal in its area. Nearly all the plans so far produced concentrate on the household waste which the particular authority is directly responsible for.

Planning for the Future

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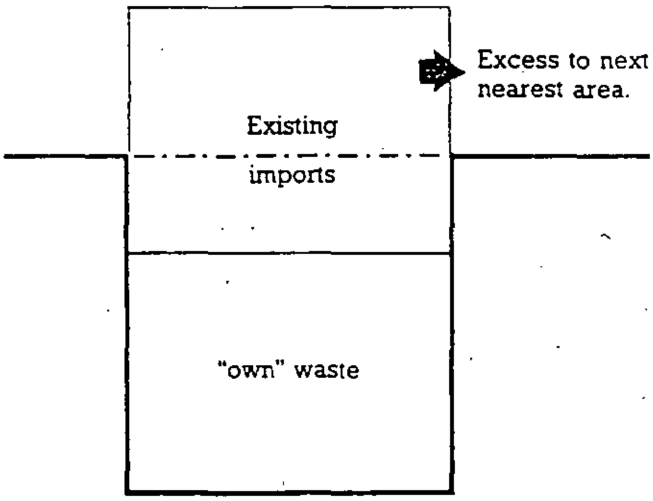

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CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

FACTORES SOCIALES Y ECOLOGICOS

Lic. Rosalba Cruz Jimenez

Asociación Mexicana para el Control de los Residuos Sólidos y Peligrosos, A.C. (AMCRESPAC)

PALACIO DE MINERIA, MEXICO D.F. 14-19 de Marzo de 1994

CURSO INTE ·ACIONAL SOBRE DISEÑO Y DISPOSICION ·NAL DE RESIDUOS SOLIDOS (RE · NOS SANITARIOS)

·DIOS PREVIOS

·ardo Estrada Núñez

Asoci. Mexicana para el Control
de los · ·os Sólidos y Peligrosos, A.C.
(AMCRESPAC)

PALACIO DE MINERIA, ME · F. 14-19 de Marzo de 1994

CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

INTERPRETACION DE LAS CARACTERISTICAS DEL SITIO EN EL DISEÑO DE UN RELLENO SANITARIO

Dr. Robert K. Ham

International Solid Waste Association
(ISWA)

PALACIO DE MINERIA, MEXICO D.F. 14-19 de Marzo de 1994

INTERPRETING SITE CHARACTERISTICS IN LANDFILL DESIGN

INTRODUCTION

No single landfilling method is suited for all types of sites, and no single approach is exclusively optimal for any given site. Selection of landfill technology depends on the physical conditions of the site, the amount and types of solid waste to be accommodated, comparative costs of various options, and the physical and financial resources of the municipality. This document begins with a general description of basic landfill design choices, followed by the rather detailed design requirements, which must be considered in developing a good landfill. The two basic types of landfill methods are the trench (Figure 1) and the area (Figure 2) method. The trench method involves excavation of the site to obtain cover soil and to provide some of the space for the solid waste. It is best suited for sites characterized as follows:

- flat or gently rolling land surface
- low ground water table (at least 3 meters below ground surface for small landfills; at least 5 meters in general)
- soil layer or depth to bedrock at least as deep as groundwater

The area method involves minimal excavation of the site as cover is obtained elsewhere, often from a nearby hill. It is appropriate for most topographies and is the preferred choice for sites that receive large quantities of solid waste. A combination of the two methods is often used, especially, for large landfills extending more than perhaps 10 meters above the original ground elevation. In this case cover is obtained both from on-site excavation and from off-site sources. The trench and area methods will be discussed in detail later.

CELL AND WORKING FACE DESIGN AND CONSTRUCTION

All true sanitary landfills consist of basic units, commonly termed "cells" (Figure 3). A cell is formed by spreading and compacting incoming solid waste in layers within a confined area. By the end of each working day, the compacted refuse is covered completely (including the working face) with a continuous layer of soil which is also compacted. The compacted waste and its daily soil cover make up a "cell" (Figure 3). A series of adjoining cells at the same height constitute a "lift" (Figure 3). A completed fill consists of several vertical lifts, and may extend 30 meters or more above the initial ground surface.

The cells are designed based on the volume of compacted wastes requiring disposal. This in turn, depends on the density of the in-place solid waste. The field density of most compacted solid waste within the cell should be at least 595 kg/m^3 (1000 lb/yd^3). It should be considerably greater if sizable quantities of demolition rubble, glass, and well-compacted inorganic materials are present.

The working face is usually the most obvious indication of good landfill operations. Unfortunately, the reverse is also true, as it is usually also the most obvious indication of a lack of good operations, which in turn can then be traced to a lack of professional ability or concern. There is no excuse for not confining incoming waste to the working face, keeping

Figure 7

Waste disposal plans

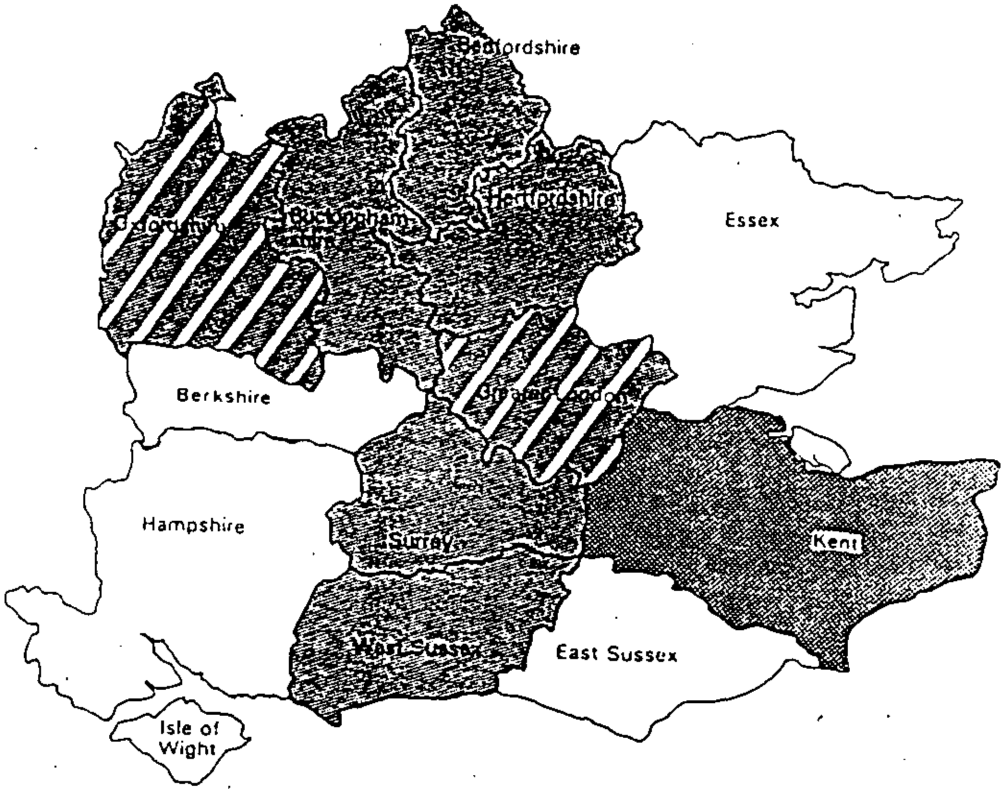

Figure 7 shows (shaded) those authorities that have produced plans to date. The hatched counties are those that have published limited plans. But the point I want to make is that so far very few of the plans fully address the problems facing commercial or industrial waste producers and little attention has been paid to the regional dimension. This is not surprising for three reasons:

— Section 1 of COPA has not been implemented, and this has taken the pressure off Waste Disposal Authorities having to consider *all* wastes in their areas;

— The time limit which was to have applied for their production has been withdrawn - this was probably done to avoid pressures for additional staff to produce waste disposal plans;

— Information on the regional flows of waste was not available.

The Guidelines are designed to supply the information required on inter-authority flows of waste but they go further than that. In addition to the discussion of the issues in waste disposal that Mr Selfe will describe they also set out a basic format for analysing the waste disposal situation in each authority. This format is shown in Appendix 2 of the Guidelines. It is suggested that each authority should include a section in its plan covering these four headings:

Potential space includes a survey and assessment of the total void plus any additional space from landraising schemes;

Waste arisings covers all wastes arising in the authority's area together with forecasts of future arisings;

The regional context comprises the information supplied by SERPLAN on likely imports and exports;

The overall situation is obtained by putting all these ingredients together and looking at the implications for the authority concerned, the private sector, and also other authorities.

It is hoped that all authorities will adopt this approach in their waste disposal plans.

the working face as small as possible, and in general operating the working face properly. The working face is the area of the landfill where incoming solid waste is placed and compacted, so nearly all site activity is focused here. It is also the source of many of the environmental and aesthetic problems resulting from bad practice.

Waste is usally placed at the bottom of the working face. The exception to this practice is if road access makes it difficult to bring waste to the bottom, in which case waste can be placed at the top of the working face. A tracked crawler, dozer, or steel-wheeled compactor, then spreads the waste into layers 30 to 60 cm thick over the entire sloped working face and moves up and down the face several times to compact waste to 15 to 30 cm thick layers. Compaction studies suggest 3 to 5 passes are necessary to achieve good compaction. Layers are constructed over each other until the end of the working day, when daily cover is placed and compacted to complete the daily cell.

The slope of the working face is a compromise between obtaining maximum compaction if it was nearly horizontal, and minimizing daily cover requirements if it was nearly vertical. The best slope is no steeper than 3/1 (horizontal to vertical), and most operators prefer 4/1 or even 5/1 to give better equipment stability and good compaction. The width of the working face is that required to accomodate the number of vehicles placing the solid waste, at any time, allowing approximately 4 meters per vehicle. It is not necessary to have a very wide working face to accomodate the maximum number of vehicles expected at any time during the day; some waiting by a few trucks during heavy periods is preferred over having a very wide working face, and the problem of maintaining it. All else being equal, the smaller the working face, the better the operation and the better the control of the waste. The height of the working face or the lift thickness is then whatever is necessary, within reason, to accept the waste and allow smooth operation of equipment. It generally ranges from 3 to 5 meters, with 4 to 5 meters preferred for large landfills receiving several hundreds of tons of waste per day. In practice, 3 meters is usually best.

It should be emphasized that there should be only <u>one</u> working face receiving <u>all</u> of the waste. The only exceptions would be if conditions are such that certain wastes must be placed at a different working face. Bad weather can require use of a second working if, for example, wastes not likely to blow can be placed at a working face open to the wind on windy days and light waste placed in a more sheltered working face. Another reason would be to make better use of equipment if, for example, non-compactable inorganic waste is placed separately so compaction equipment is used only on compactable wastes. A second working face should rarely be used, and only with clear justification, because in practice it is very difficult even for experienced operators to divide operations and work properly more than one working face.

Once the working face dimensions have been set, the height and width of the daily cells are also set. The remaining dimension, the length of the cell, is set by the amount of waste entering per day.

TYPES OF LANDFILLS

Trench Method

As implied, the trench method requires the excavation of trenches into which waste is disposed by spreading and compaction (Figure 1). The waste is deposited at the working face, compacted, and covered with the excavated soil. Excavated soil not used for daily

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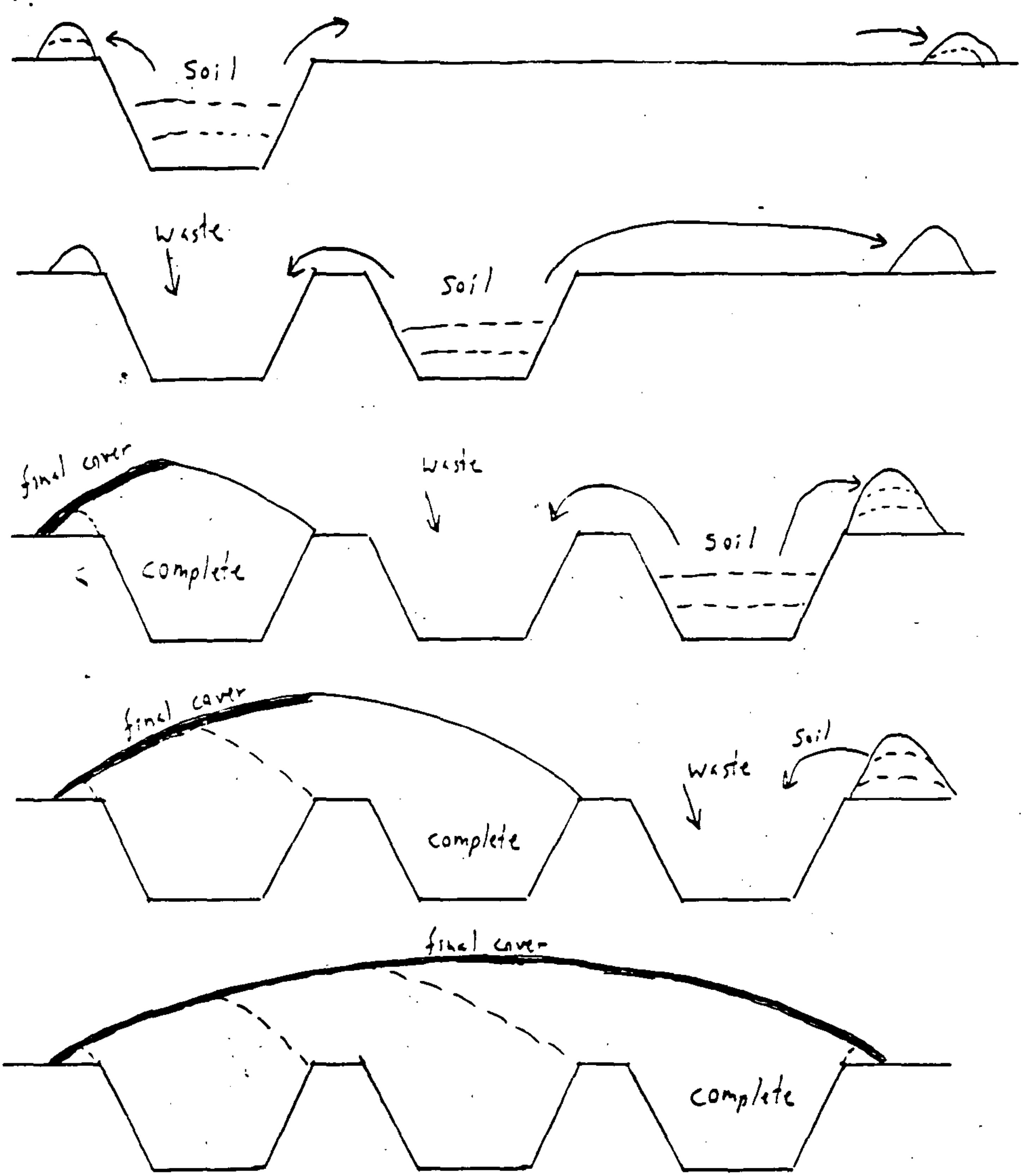

Figure 1: Trench Landfill

cover can be stockpiled for later use in upper lifts or for final cover, or may be used for berms to control surface water or visibility.

Determination of the depth of excavation is an important engineering decision. Clearly, with a deeper cut, more volume is available for solid waste and more soil is obtained for cover and other construction activities. On the other hand, a deep cut makes it more difficult to get waste and equipment to the working face, at least initially, and will place the waste closer to groundwater, increasing the potential for contamination. A deep cut also exposes more surrounding soil to potential gas migration and can make gas control more difficult. Finally, side slope stability can become more of a hazard with deep cuts.

Usually the depth of cut is limited by groundwater or bedrock. Even in landfills lined with relatively impermeable soil such as clay, or located in clay, it is common to leave a minimum of 3 meters of undisturbed soil above the groundwater to provide some protection against contamination and to certainly avoid placing waste directly in groundwater even at its seasonal or yearly highest elevation. Similarly, because bedrock is often fractured, providing no attenuation of contaminates in leachate, it is common to excavate no closer than 3 meters to bedrock. Another geological reason to limit the depth of cut is to place the waste in the most impermeable soils available. If a clay or silt soil is located over a sand or gravel layer, it is wise to not excavate into the more permeable soil because the soils will form a conduit for gas and leachate flow. If it is necessary to cut through such a permeable layer, it is necessary to excavate more than needed for the waste itself, backfilling with one or more meters of compacted clay at the bottom or side or both of the excavation to seal off the permeable layers.

If the depth of cut is not limited by geological features, it is necessary to make an engineering judgment decision by comparing estimated soil requirements to complete the landfill and the depth of cut to obtain the soil, considering access difficulties as the trench gets deeper. Other factors are the value of the land and the difficulty of obtaining new landfills, proximity to waste generators, and the surrounding land use. If the landfill area is valuable and it is difficult to obtain a new landfill, one will want to maximize the space available by cutting deeper, etc.

There is a special landfill concept that can arise when determining the depth of excavation for a trench landfill. If the cut extends into groundwater, below the water table, and the leachate is not allowed to build up in the landfill by pumping it out, the landfill is called an inward gradient site. The concept is to control the leachate level within the landfill so it is always less than that of the groundwater surrounding the site. Groundwater flow will be into the landfill instead of having leachate flow out of the landfill to contaminate the groundwater. A leachate collection system is required (along with leachate treatment and controlled discharge as to a wastewater treatment plant, etc.), and if such a site is not in silt or clay soil, a liner of such soil will be necessary to limit the inward flow of groundwater. This design concept is to be used only after careful study and upon assurance of continued leachate control over many years.

Sidewall stability is a critical factor in trench design and is a function of the characteristic strength of the soil, depth of the trench, distance between trenches, and the slope of the sidewall. It is best to have a geotechnical engineer determine the sidewall slope to avoid slippage and the attendant hazard to workers, but in general the slope should be no steeper than 1/1 in clays and 2/1 (horizontal to vertical) in less stable soils. Other factors that may affect soil stability and permissible steepness of sidewall slope are weather, soil moisture content, erosion potential, and the length of time the trench is to remain open.

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The remaining dimension of the trench is length. Typically, this is a function of the volume desired, where the volume is such as to accommodate one to two years of solid waste per trench. In this way, most of the excavation for each trench can be timed to be performed during the months considered best for excavation (not wet or not freezing, for example) or when excavation equipment is more available on a regular basis. If the area is subject to seasonal windy conditions, waste can be placed at the lowest and most protected portions of the trench during that period, etc. Knowing the approximate volume of landfill space required per year, the depth of cut, and the width of the working face, the design engineer can adjust trench width and length to produce a reasonable shape within the overall dimensions of the site. It is common, but by no means necessary, for the length to be 5 to 10 times the width of the trench.

Since the amount of required cover material is a function of the width of trench, theoretically the trench should be as narrow as possible. However, because width must be adequate to permit dumping and accommodate the compaction equipment, practicality demands that the trench be sufficiently wide to accommodate the number and types of vehicles that use the fill. Because of the cost and difficulty of road access to the lower portions of the trench and in consideration of the cost of excavating deeper trenches to gain volume if the trench is narrow, it is common for the trench to be several times wider than the working face. In general, the width of a trench should be an even multiple of the width of the working face.

Alignment of the trenches relative to the prevailing wind exerts a significant influence on amount of blowing litter. The alignment most effective in terms of reducing the amount of blowing is one that is perpendicular to the prevailing wind.

To ensure drainage, the bottom of the trench should be sloped along its length. If the climate is wet, the first lift will involve bringing the waste to the top of the working face, and it is probably best to start landfilling at the higher end of the trench where it should be drier. This is especially true if reasonably impermeable cover soils promote runoff of clean water over the completed cells to the base of the trench, where it can be collected and pumped out to the low end. Water falling on the open working face will be absorbed by the waste. Any water that is collected at the bottom of the trench should be tested and pumped out of the trench to surface water if uncontaminated, or perhaps onto the working face, or it should be treated prior to discharge to surface water. Refuse should not be deposited into standing water. Surface water can be diverted from around the trench by constructing temporary berms on the sides of the excavation.

Depending upon the projected size of the fill, trench excavation may be done either continuously at a rate adjusted to landfilling requirements, or periodically on a contract basis.

The completed trench landfill will typically have 1/2 to 1/3 of its refuse depth below the original ground surface with the remainder above the original surface. It must project above the surface to assure slopes to promote surface runoff of precipitation. Accordingly, the last phase of a trench landfill involves placing waste over portions of the previously filled trenches to bring the site to its final grade as shown in Figure 1. The designer must assure that sufficient cover soils are obtained from trench extraction, or from other sources, to complete final cover and berm requirements.

Daily cover is used on the working face to seal it until the next operating day. It may also be used on top and sides of the daily cell if these areas are to be exposed less than perhaps 30 days. Since it is a temporary cover, daily cover is only a thin layer sufficient to improve the appearance of the landfill and control the waste to reduce odors and to slow down or discourage access. Depending on the smoothness of the compacted waste, 15 cm of compacted soil may be sufficient to hide the waste. Adequate cover in general, but daily cover in particular, is an obvious indication of a well-run landfill. It reflects the level of competence and concern of the owner and operator, and greatly affects the morale of workers and acceptance by the public. It is critical to sustained acceptable landfill practice.

If cover is exposed to erosion or traffic, or is meant to protect the waste for more than a few weeks, additional soil should be used. This cover is called intermediate cover. A thickness of 30 cm is common. Such cover should be sloped to promote runoff. In dry areas or seasons, or in areas not subject to wind erosion, daily cover may provide adequate protection for longer periods; however, such is usually not the case and intermediate cover should be used on all waste except at the working face.

Daily or intermediate cover can use virtually any type of soil, although a silty sand or loam is often considered best. Clay or fine silts can be used, but can be difficult to spread and compact under wet or dry conditions, and access can become very difficult under wet conditions.

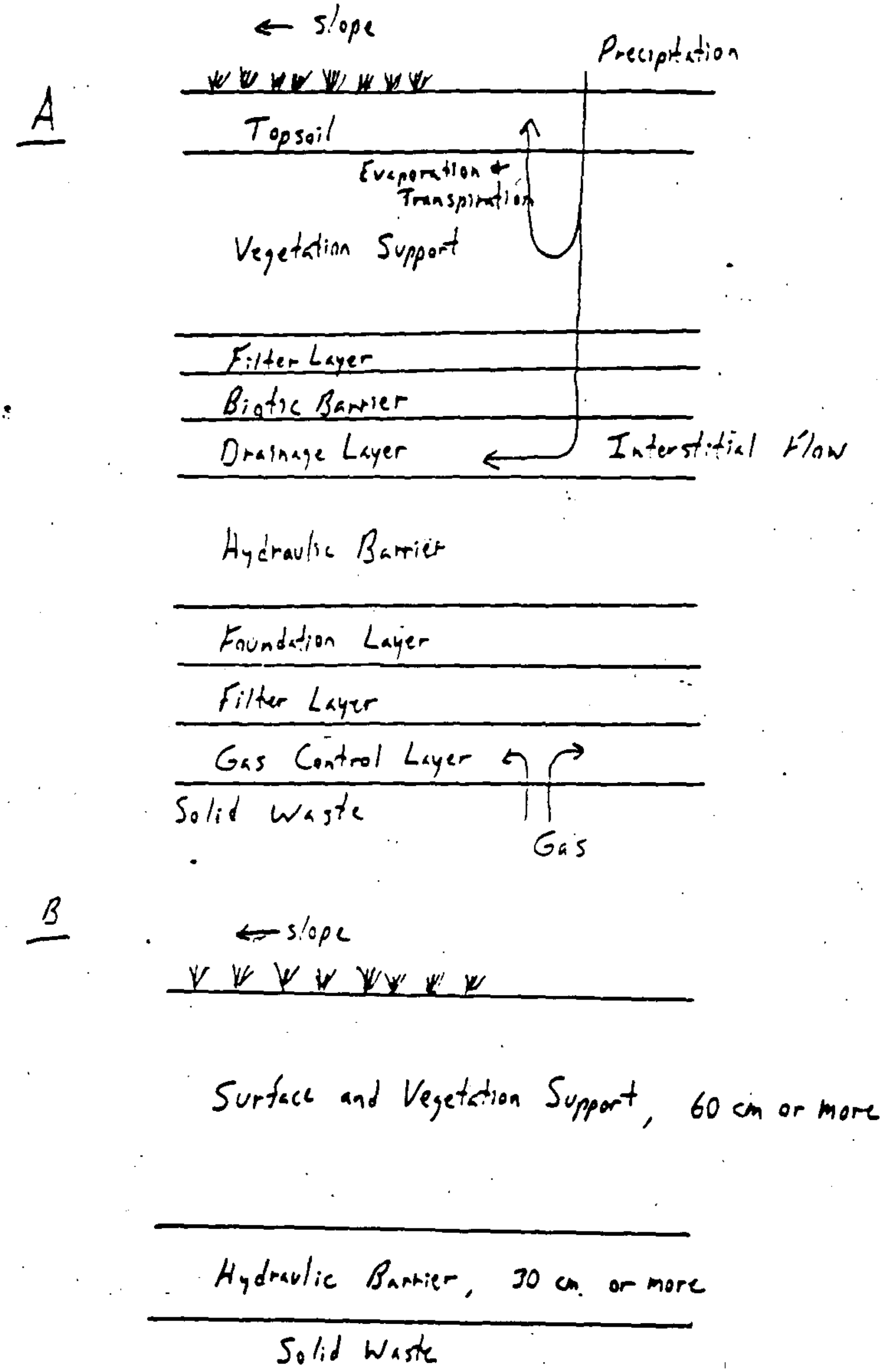
Final cover provides the top and sides of the landfill with a seal to protect the solid waste from the environment "forever", in other words over geologic time. Accordingly, it must be carefully designed and placed to minimize long-term problems and provide maximum protection. It can be a complex system of different soil layers, ranging in function to support vegetation, minimize erosion, promote surface water runoff, promote moisture or gas flow and retard moisture or gas flow. Some layers are there simply to protect other layers. As suggested from this list of sometimes contradictory functions, final cover must be designed based on climate, size of the landfill, surrounding land use, final use of the site, etc.

One of the most critical functions of final cover is to promote surface runoff and to retard downward flow of water into the solid waste where it becomes leachate. To minimize leachate formation, final cover is designed to minimize doward flow of precipitation.

Figure 4 shows nine different layers that can be considered for final cover, depending on the situation..

The most basic design of a final cover, however, only contains two layers: 1) the surface or vegetative support layer, and 2) the hydraulic barrier layer (Figure 5). It is advisable to use a thickness of at least 60 cm for the surface layer and 30 cm for the hydraulic barrier. This design would be acceptable in areas with high evaporation and low rainfall, (i.e., warm and dry) and is depicted in Figure 5. In other climates where additional protection is needed as in humid areas, it may be necessary to include additional soil or additional layers. In particular, the hydraulic barrier in wet climates should be at least 60 cm thick.

In order to prevent the downward flow of water, the cover must be designed such that the major fraction of rainfall and melting snow become run-off. This can be accomplished by building a cover having a slope no less than 5 percent. This incline promotes the flow of water over the cover; however, this slope is not so steep as to promote erosion. Erosion is also reduced by establishing vegetation. Vegetation, in turn, promotes evapotranspiration (where moisture from the soil is released to the atmosphere through plant uptake and evaporation). Thus, slope and vegetation play an important role in the performance of the



Figures 4 and 5 (A and B): Complex and Minimum Final Cover

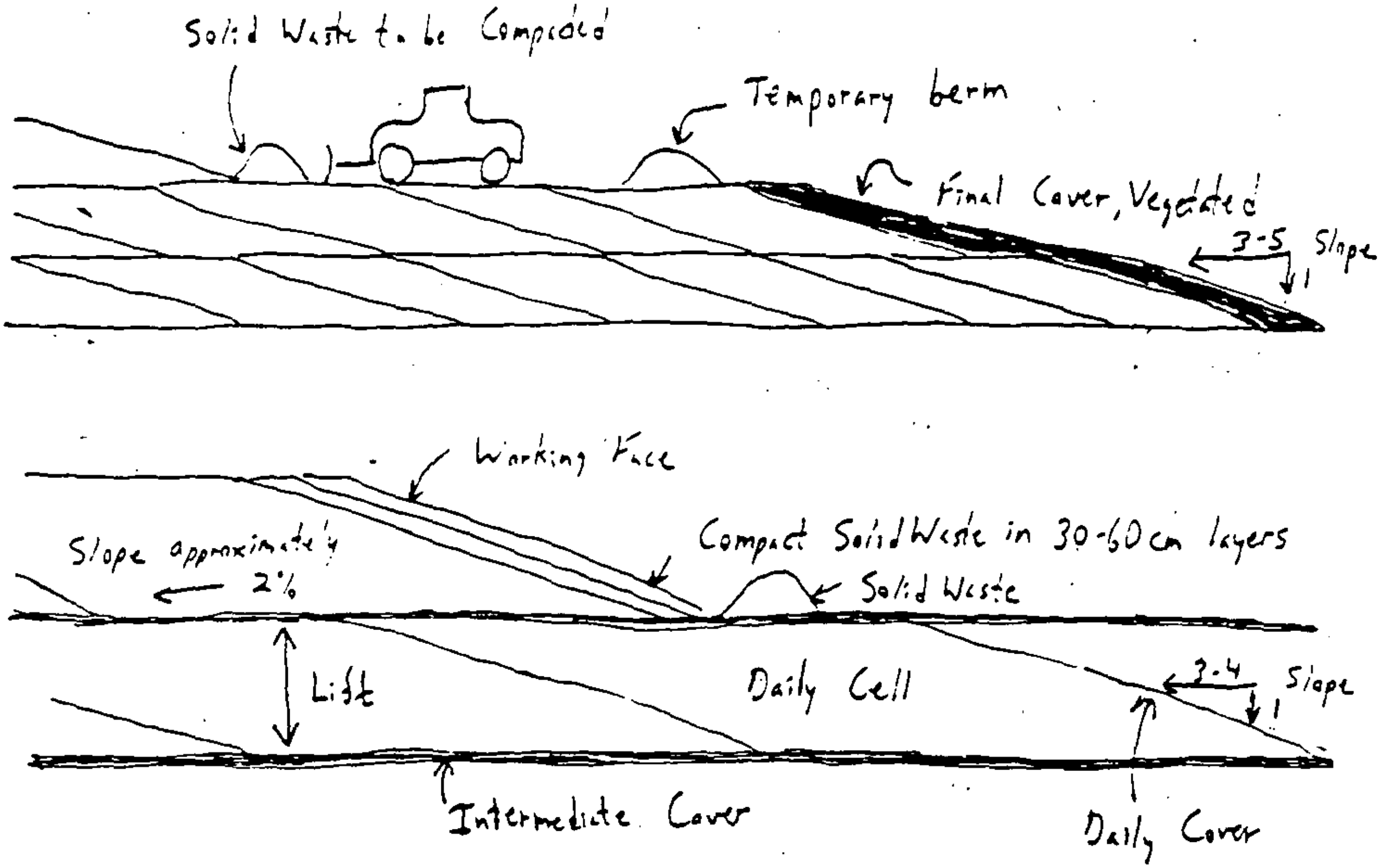


Figure 3: Cell and Working Face Concept

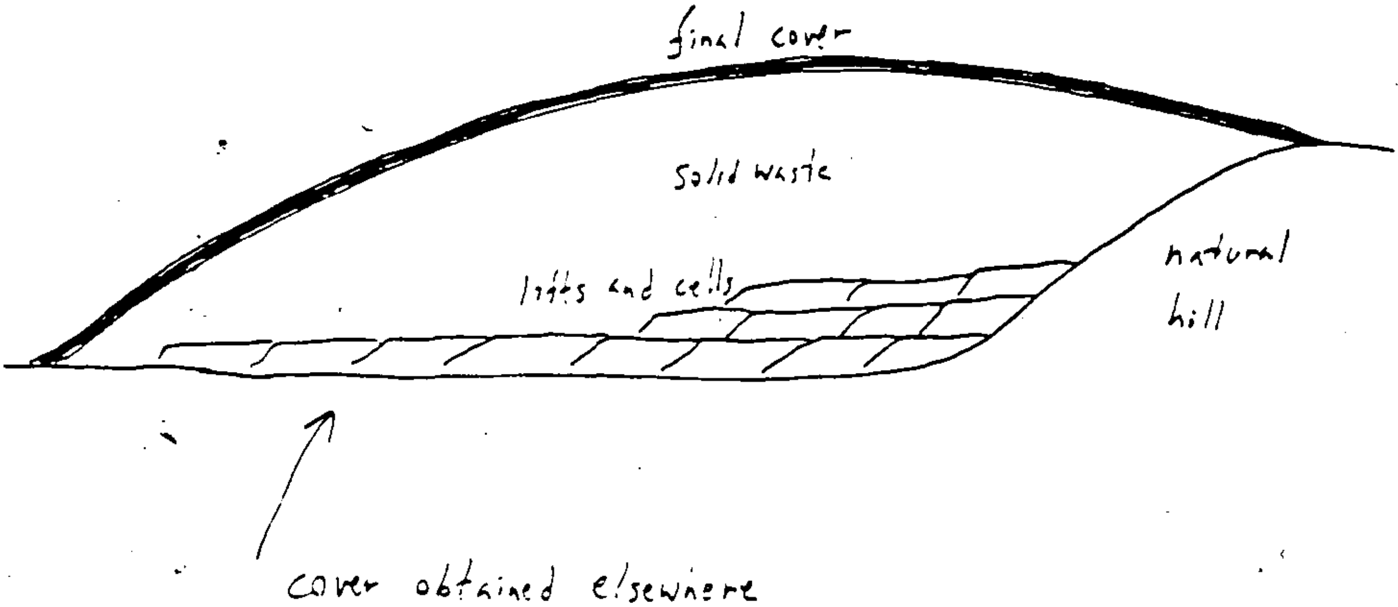


Figure 2: Area Landfill

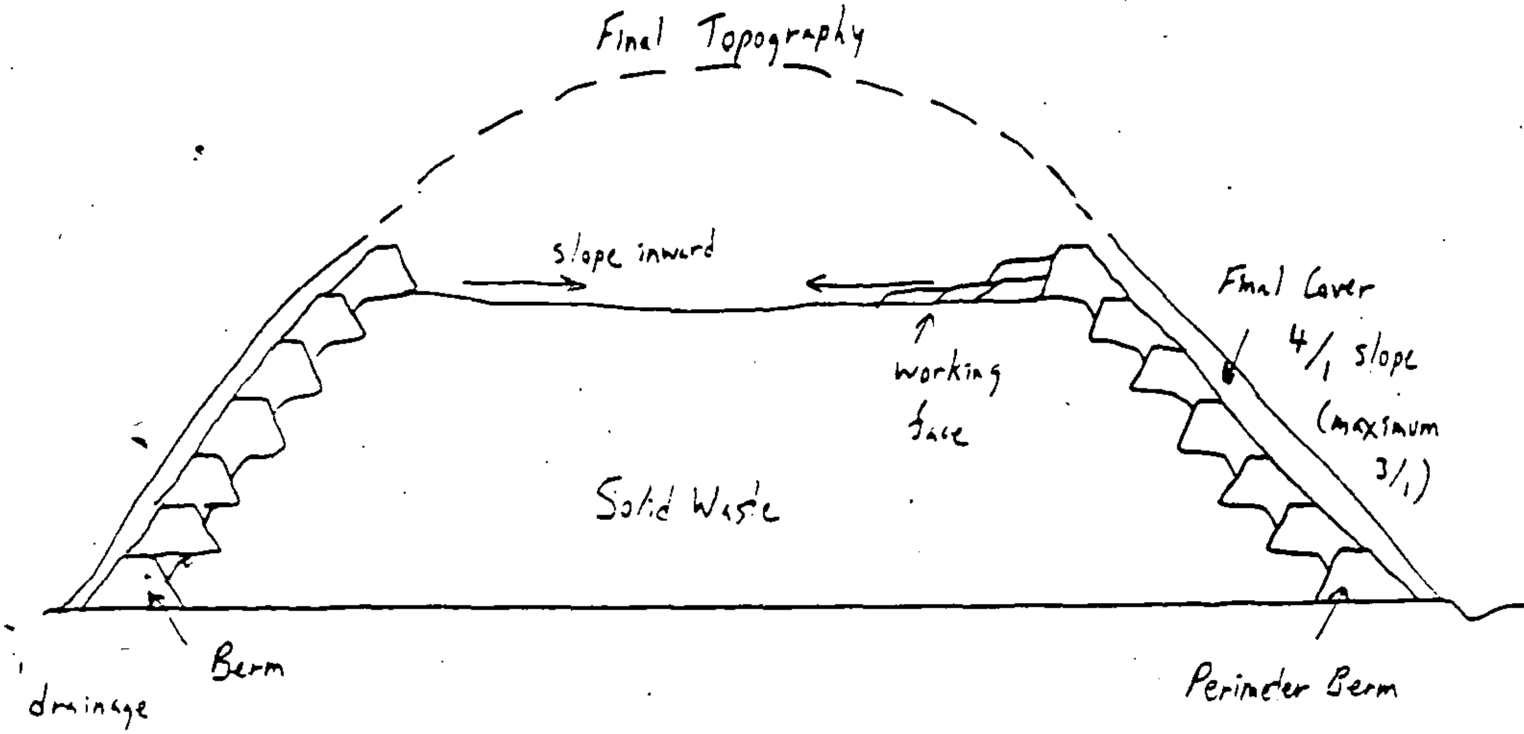


Figure 6: Hill Construction With Perimeter Berms

- Although the slope may be within the angle of repose, some slippage takes place during normal operation. The slippage intensifies the difficulty of achieving the degree of compaction required for the refuse and cover material.

- Blowing of litter is accentuated.

- Abrasion of soil cover by wind, and erosion by downflowing surface water during rainfall easily reaches problem levels.

- To the usual problems encountered in establishing a vegetative cover on a completed fill must be added those of planting and maintaining vegetation on a hillside.

- Scavenging activities will be hindered as access to landfill site is made difficult by an incline. Also, problems may arise in transporting containers, pushcarts and other vehicles which may be used to convey items retrieved from the site.

Land Reclamation for Agriculture

Sanitary landfilling designed to accomplish land reclamation for agriculture combines satisfactory waste disposal with very practical land reclamation. The approach is applicable to a wide variety of situations. Examples are abandoned quarries, problem canyons, strip mined areas, agricultural lands no longer workable because of excessive soil erosion, and other land areas severely degraded through exploitation of natural forces.

Despite the diversity suggested by the preceding list of examples, the method of sanitary landfilling recommended in all cases is essentially the area method adapted to fit the specific situation. For nonworkable agricultural land, a single lift may be sufficient, whereas, several lifts would be required for abandoned quarries, canyons, and exhausted strip mines. In all cases, the depth of the final cover should be such that plant roots do not enter the buried waste mass before the wastes have been sufficiently stabilized. Required depth and type of soil will vary with the crop to be grown on the fill, but a common depth is 0.6 to 1.6 m.

Measures must be taken to prevent or minimize unfavorable impacts upon the environment. Precautions against groundwater contamination by leachate are the same as those applicable to all sanitary landfills in general. Design concepts addressed to minimize or prevent adverse environmental impacts from leachate generation are described elsewhere, but note that landfills in sand or gravel mines or in rock quarries have caused some of the worst groundwater contamination problems from improper landfill practice in the past. Such sites must have liners, or otherwise protect against groundwater contamination because of location in an arid climate or having a large depth to groundwater, etc. A good final cover with a well constructed hydraulic barrier layer is especially critical to minimize leachate generation.

If the landfill is to be used for agricultural purposes, the final cover should be sloped to drain properly, and the vegetation layer should be thick to support crops. A thickness of 2 meters or more should be adequate for this purpose. Steps must be taken to prevent or dissipate accumulations of biogas because of the safety hazards (fire and explosions) associated with such accumulations. In addition to the safety hazards, accumulated biogas is likely to inhibit root development. Gas control is presented in more detail elsewhere.

Refuse is often dumped into rivers on the pretext of land reclamation (examples in China and India abound). Solid waste should not be disposed near potential sources of water supply. In some cases it may be acceptable to reclaim marshes and areas with pockets of water having high salinity. In these situations, the water should be removed or allowed to evaporate and the appropriate evaluations carried out (geological, hydrological, etc.). Consideration should be given to the ecological conditions of the site. Since this practice can result in severe contamination of surface water, it should be used only when necessary and with careful consideration of the design and operation to minimize and control impacts.

Surface Water Drainage

Good landfill design and operation requires surface water management. Placing cover and contouring the land to promote surface water runoff will greatly improve operations, especially in wet weather, and will automatically improve the appearance of the site and force planning, which will in turn improve other aspects of site management. Access roads that are muddy, washed out, flooded, or generally inaccessible certainly impair operation of a landfill and may force the use of a separate, unplanned dump area, or even worse, cause random dumping of solid waste. Mud tracking on nearby public roads will result, with the danger of accidents on slippery surfaces etc. Water not drained from the working face will make access to the working face difficult or impossible, and will make it difficult to place and compact both the solid waste and cover soil. Ponding of water at the cover soil source will make excavation difficult. All of these problems can be minimized or avoided with good surface water control.

The overall requirement in surface water control is that all surfaces in the landfill should be sloped a minimum of 1 to 2% on natural, undisturbed soil, and 4 to 5% on surfaces over solid waste which are subject to settling over a period of time. Intermediate cover, which will be exposed for only a few months at most, may be sloped less, but even then should be sloped at least at 2 to 3% and smoothly graded to promote runoff.

The landfill designer will normally choose to use pre-landfill surface water drainage paths, and route landfill generated surface water to them. Obviously, they will be at topographic low points around the landfill property boundary. A check should be made to be sure these pre-existing streams, channels, culverts, ditches, etc., have the capacity to continue to take surface water from the landfill property, and if the landfill design calls for changing drainage paths compared to the natural, pre-landfill situation, a careful check on the ability of these pathways to take additional surface water must be made.

Once off-site drainage locations and capacities are determined, berms and drainage ditches are designed, certainly around the base of the landfill but at other areas such as soil excavation or stockpiling areas, berms, etc., to allow <u>no</u> unplanned ponding of surface water on-site. Ditches draining large areas and subject to large flows may have to be lined or protected, and may need rocks or other devices to slow the water velocity and limit damage. Roads should be graded with a crown or high point in the center and ditches on both sides, with culverts under the road as necessary to drain water freely off-site.

One of the most difficult parts of landfill design is to plan surface water drainage every day of the life of the landfill. At all times the landfill and working face, access roads, soil excavation areas, and soil stockpiles must be located to promote runoff. When low points are unavoidable, as when landfilling below the surface elevation in a trench, or excavating cover soil below the original surface, slope the excavation so even here surface water will run to a low point from which it can be pumped to the nearest (and planned) drainage path. In order to minimize the amount of water to be pumped, surfaces around the excavation are sloped away from it so only water falling directly on the trench or excavation needs to be pumped.

For the portion of the landfill above the surrounding land surface (hill), special care to minimize surface water contamination and erosion is necessary. In the past it was common to have each lift, and its intermediate cover, horizontal. The problem was that if this cover was less permeable than the solid waste, which is common, or as leachate and its constituents reduce the permeability of the cover soil, which is also common, water can accumulate in layers on intermediate cover. This leachate builds up and eventually can flow out the side of the hill, leading to "leachate seeps" or "leachate weeps". The result is surface water contamination, staining of the cover, limited vegetation growth and odors. Once this happens, it is expensive and difficult to repair, as a subsurface drainage system is required which may require additional repairs for many years. To avoid this problem, lifts should be designed to slope towards the center of the hill, keeping any leachate accumulation as far as possible from the sides of the landfill. Further, it may be useful in wet climates to excavate some intermediate cover, or use gravel, at designed low areas to promote downward flow and to limit ponding.

The other difficulty regarding surface water control in hill landfills is the problem of bringing large amounts of runoff from upper elevations to the drainage system at the base of landfill without causing erosion. Experience has suggested that cutoff berms and ditches be located every 30 meters or so along the steeper slopes, and that these structures be sloped at 5% or so to gradually collect and bring the runoff down to the base of the hill. For large landfills, a series of enclosed culverts or lined spiraling ditches with velocity lowering devices, such as rocks, will be necessary. No one ditch alone spiraling around the hill will be able to handle the required volumes of water. Even with these runoff control features, a slope steeper than 4/1 horizontal to vertical will likely lead to erosion problems in wet climates and should be avoided.

The last surface water control device to be discussed is the sedimentation or equalization pond. Surface water runoff will unavoidably carry sediment, which may eventually clog off-site surface water drainage systems. A simple pond, with removal of sediment as necessary, will solve the problem. In addition, depending on rainfall intensity patterns and the ability of surface water pathways on and off site to handle water volumes associated with major storm events, it may be cheaper, or necessary, to promote on-site storage of surface water. Such a pond should be designed to handle a major storm, perhaps accepting the runoff from the entire landfill for release over time. Creative planning can place such ponds at locations where cover soil is to be excavated anyway, and will also locate and shape the ponds to improve the appearance of the landfill. A good location, if land topography makes it possible, is near the entrance road, or along a major road, etc. The pond will need to be designed to allow pumping as well as access for sediment removal.

Phasing

It is not possible to construct the entire landfill over many years with all activities operating continuously. Trenches are prepared, areas of land are cleared and graded, cover soil excavations move from location to location, and portions of the landfill are completed periodically over the life of the landfill. To spread the cost over time, to minimize the area of the site exposed to excavation or filling, and to generally provide better control, the landfill is constructed in phases. A phase is typically a portion of the landfill taking one to three years to complete. Two years is common. If climate is seasonal, so one season is better for excavation, for example, this allows most of the excavation to be done at the best time of the year, etc.

Each phase is designed as a small landfill, coordinating all the activities such as excavation and base preparation; construction of berms, roads, and drainage systems; waste placement; soil excavation and stockpiling; and final cover of part or all of the phase within the two year active lifetime, for example. The phases are designed to work together in sequence so the entire landfill meets final contours and specifications at closure. Prompt final covering of each phase seals portions of the landfill as they are completed, promoting runoff and limiting leachate generation and providing excellent opportunities for visibility control and improved appearance during much of the operational life of the landfill. For this reason, earlier phases can be placed along major roads or on the most sensitive sides of the area. Once completed with final cover and vegetation, these earlier phases provide excellent protection throughout the remainder of site operation.

Fencing and Entrance Design

The function of fencing and the entrance area is to limit site access to people and vehicles with reason or permission to be there, to limit access to the designated entrances, and to facilitate movement of traffic into the site. It is possible to achieve good and safe landfill operation without limiting access, as in remote sites far from housing areas, but generally fencing or natural boundaries (such as railroad tracks or steep hills) will be necessary. If there is a charge for waste disposal, or if the site is open only part of the day, people will bring in waste after hours or without paying, and will undoubtedly not place the waste in the working face. This leads to piles of exposed waste around the landfill, and the accompanying difficulty of maintaining a good operation. Fencing also helps control blowing litter, providing it is cleaned frequently so litter does not blow over the fence. A 3 meter mesh fence around the site is good for both access and liter control.

The access area should be clearly marked with the landfill name, owner or operator, hours of operation, fee structure, and any special rules regarding acceptable or prohibited waste, etc. It should have a lockable gate and should have adequate space for vehicles to wait in line on-site and not on public roads. The road should be paved to minimized mud tracking and problems with vehicle movement in wet weather. There will usually be a gate house, with a scale in some cases, to control access, collect fees and provide instruction. The entrance area gives a great opportunity for innovative design to improve the appearance of the landfill to the public and to promote a sense of pride for persons using or working at the facility. A clean, well-maintained entrance area is related to the care people will take to maintain the rest of the landfill. Berms, vegetation, fencing, curved roads, sedimentation ponds, and topography should be used to maximum advantage. Gardens and a park-like atmosphere are common at well-designed and operated entrances, and can be used innovatively for special floral displays, etc., if carefully designed so as to not interfere with landfill operation and vehicle movement.

The turn-in area from public roads to the landfill should be designed to minimize accidents and promote traffic movement. Special turn lanes may be needed at some larger landfills. The on-site entrance road should be at least 8 meters wide to accommodate two-way traffic, and should be sloped to promote runoff with drainage ditches on one or both sides. It should be cleaned frequently, especially on wet or very dry and dusty days.

Roads to the working face will range from semi-permanent over portions of the landfill to be used throughout the life of the site, to temporary in areas providing only access to the working face. This presents a design problem, for the road system must allow easy vehicle movement under all weather conditions, yet be financially and technically feasible. Roads to be used for several years, especially if they are included in the final use of the site, should be permanent and will normally be paved. In some cases a gravel road will be satisfactory, but note that gravel roads are more difficult to clean as mud and dirt is tracked onto them. Temporary roads to the working face can be gravel, or in dry areas hard packed soil. Semi-permanent roads, between these two extremes, may be used over a period of months to years, according to the landfill phasing sequence. Depending on weather, the amount of traffic, and eventual use, if any, they may range from paved to gravel, but oftentimes may be constructed with selected incoming wastes, such as broken road pavement, broken concrete, demolition debris, excavated soil, or certain industrial wastes such as combustion residues, etc. The designer should evaluate wastes entering the site, and wastes which could enter the site if necessary, and be sure proper procedures and adequate equipment are available to make prompt and controlled use of such wastes. Piles of road-building materials stored for later use can be unsightly and should be controlled accordingly.

All roads should be clearly marked to route traffic to and from the working face. They should be elevated and sloped or crowned to promote runoff to ditches on both sides, and culverts should be placed under them to move surface water to a sedimentation pond or directly off-site. They should be watered on dusty days, and cleaned, especially nearer the entrance area, to avoid mud tracking and to promote vehicle movement. They should be at least 3 to 4 meters wide for one-way or small amounts of traffic (with passing areas as appropriate), or 7 to 8 meters wide for two way traffic. Some landfills prone to mud tracking problems may have special wheel cleaning locations, so trucks don't track mud from the working face. These devices can include a wash pond, a water spray, mud knock-off bumps, or a long paved road (which is frequently cleaned). With sticky clays, however, even these devices may prove inadequate. Local experience is the best guide for what will work - - the function here is to simply point out that the designer must consider the need for such devices.

Groundwater and Gas Migration Monitoring

Depending on local regulations, groundwater use, the proximity to buildings and built-up areas, and the types of soil and location of groundwater, it may be important for the designer to place monitoring probes around the landfill. Monitoring wells should be placed at least up and down gradient of the landfill, and in the direction of any nearby wells, and gas probes should be placed in the directions of nearby buildings. The design of wells and probes is covered elsewhere; the point here is to emphasize the importance of getting background soil gas and groundwater quality information before any landfill activity takes place. If problems develop in the future, it will be known whether the landfill is the likely source, which in turn will help determine who is responsible and how to best solve the problem.

PROVISIONS FOR SCAVENGING

Introduction

Since sanitary landfilling is the subject of this course, the present section focuses on material recycling (scavenging) performed at the landfill site and does not include scavenging at the point of waste generation, during collection, or during transport.

Presently, the sequence commonly followed with respect to scavenging at the disposal site is as follows:

1. Incoming refuse is dumped, as usual, at or near the working face, i.e., immediately behind or at the foot (toe) of the working face.
2. Scavengers sort through the dumped load.
3. Scavengers separate the retrieved materials into organized lots.
4. Machinery spreads and compacts the waste remaining after the scavenging activity.

Although this discussion of scavenging is restricted to that which takes place at the disposal site, it does not affect fundamental arguments for or against the practice as a whole. Typical materials recycled in this manner include: unbroken bottles, metals, plastics, cardboard, paper products, textiles, and glass.

Associated Issues

The case for scavenging must be strong enough to counterbalance the objections that can be raised against it at the site. These objections stem from the safety hazards to personnel of both the scavenging group and the landfill employees, and from the interference caused by scavenging activity that prevents the efficient conduct of work at the fill. Scavenging activities have severe negative impacts on the productivity of equipment as well as the efficiency of operations in general. Hazards caused by the intermingling of manual scavenging activity and equipment-oriented sanitary-landfilling activity increase when heavy equipment is involved. Furthermore, scavenging results in delays and often interferes with compaction and application of soil cover. Therefore, the problem is essentially one of developing a safe interface between scavenger and landfill equipment that allows for efficient operation of the landfill.

Designation of a Separate Scavenging Area

The problem of developing an interface between scavenging and landfill operations can be minimized or even eliminated by treating the scavenging activity as a first step in a sequence of steps that make up the landfill activity. Such an approach makes feasible a physical separation of the two activities of perhaps one or more kilometers. Unfortunately, such a separation adds a step to the overall operation. Solid waste handling now has two parts: 1) discharge of incoming wastes at the scavenging area of the disposal site, and 2) transfer of the residue remaining after scavenging to the burial site.

If the scavenging area is kept relatively close to the burial site, transfer of residue from one site to the other may be done quickly by means of a bulldozer. Such an arrangement would demand that the scavenging area be movable to be close to the working face. Unfortunately, this is probably so close as to cause mutual interference between man and machinery. The other extreme would be to locate the scavenging area a kilometer or more away from the working face. In this case, the waste to be disposed could be transported by means of dump trucks.

A fixed scavenging site for the life span of the fill would be desired when transfer by bulldozer is no longer feasible. A fixed scavenging area would be neither feasible nor advisable for a small disposal site. Dedication of a fixed portion of the disposal site for scavenging takes on many of the characteristics and advantages of a transfer station. For instance, scavenging done in a fixed area can be sheltered from the elements (wind, rain, etc.) and undesirable impacts upon the environment can be avoided or minimized. The operation itself can be kept orderly and controlled closely, and abuses can be discouraged. Furthermore, efficiency can be improved by including a certain amount of mechanization (e.g., conveyor belts and screens). Best of all, encounters between scavengers and landfill equipment are more easily avoided. Theses advantages combine to enhance efficiency. This alternative also allows for sanitary facilities and a better working environment for the scavengers.

The strongest objection to designating a fixed site is probably the added step of pick up and transfer of waste to the working face. This objection does not come into play until the distance between the scavenging and burial sites becomes great enough to make transfer by bulldozing no longer feasible. Of course, the capital expenditure associated with the erection of a building and introduction of added equipment would be another disadvantage. From the preceding discussion it can be noted that the size of the disposal site is the decisive factor regarding the advisability and necessity for dedicating a portion solely to scavenging. In general, a minimum life span of 10 years would justify the incorporation of a fixed scavenging area.

Management of Scavenging Activity

Important factors when managing scavenging activities are the relative priorities of the scavenging and waste burial activities. Burial should have precedence over scavenging since the main purpose of the fill is the effective disposal of wastes. Therefore, scavenging must be managed in a way that does not unduly interfere with the disposal activity of the landfill. Alternately, consideration must be given to the potential income from scavenging for the scavengers, who are generally at the bottom of the economic ladder, as well as the importance of secondary materials to local industry.

Traffic

Unless carefully managed, traffic to and from the disposal site can be disruptive to the interface between scavenging and burial (disposal). Among the obvious causes of disruption are the increase in number of vehicles using the same road and the different moving speeds that result from the different types of vehicles involved. Scavenger vehicles may be as small as a pushcart or as large as the vehicles used to transport the larger loads of recycled materials. Conversely, waste collection and haul vehicles normally surpass scavenger vehicles in terms of size, weight and speed. Unfortunately, the best way to separate the traffic is to provide separate access roads, but this could be an expensive approach.

The degree of access to the disposal site by scavengers depends upon the magnitude of separation between scavenging traffic and disposal traffic. If separation is complete, the access could range from unlimited to somewhat limited. Alternately, if the two traffic patterns are not separated, unlimited access is immediately ruled out because of the excessive interference with disposal traffic. If access is to be restricted, the problem arises as to which individuals are to be excluded. In arriving at such decisions, it should be remembered that political and social expediency would inevitably enter into any decision that would limit access.

Supervision

The scavenger activity should be under the direction of a supervisor who has the responsibility to see to it that the activity proceeds efficiently and fairly, yet with a minimum of interference with the disposal operation. Accomplishing the latter implies working closely with the director of the disposal operation. The latter should have the final say in decisions that affect the disposal operation (landfilling). The supervisor of the scavenging activity may be assisted by subordinates, if efficiency of operation requires such a provision. Efficiency and safety demand that good housekeeping be rigorously enforced.

Guidelines

A relatively fixed set of guidelines should be established. Among the subjects that could be regulated are:

1. Assignment of space, refuse loads, etc., to individual scavengers or groups thereof.
2. Removal of scavenged material from the site - - i.e., the promptness, frequency and manner in which everything from separation of scavenged material to loading and hauling by cart or motorized vehicle is performed.
3. Ideally, the municipality should be responsible for the sale of the recovered materials.
4. The laborers should be provided with uniforms and safety equipment, bathrooms, showers, eating facilities, and first aid equipment.

The above guidelines should be enforced by the supervisor in a fair and responsible manner. As the supervisor may come under pressure to take bribes, however small, from different groups or individuals, the person in this position should be a scrupulous individual who is rewarded according to the quality and performance of scavenging activity.

PROVISIONS FOR SPECIAL WASTES

Baling

Because of the technology involved and its high costs, the baling of municipal wastes is generally not a practical disposal option for a developing country. However, because it may be possible under specific circumstances, this section briefly describes landfilling baled wastes.

Waste characteristics, in particular, moisture content, determine the cohesiveness and density of the bales. The optimum moisture content is between 15 and 25 percent. With the present baling technology and suitable moisture content, densities of bales range from 950 kg/m^3 to 1130 kg/m^3. Bale dimensions range between 0.9 and 1.2 m in the minimum dimensions and from 1.2 to 1.8 m in length. To keep recoil (expansion after pressure is released) at a minimum, baling pressure should be greater than $1.4 \times 10^7 N/m^2$. Even under optimum baling conditions, the volume of the bales eventually expands 10 to 15 percent.

The bales should be tightly stacked in the fill, usually with a fork lift, and covered with cover material. Equipment efficiency dictates that each lift be no higher than three layers of bales. Stability is attained by arranging the layers in a manner similar to bricklaying, in which each layer is offset so that the ends of bales in one layer are not directly under those in the next layer. Maximum stability requires that bales be stacked cross-wise from layer to layer or lift to lift. Each lift would then consist of three layers of bales covered with a thin layer of soil to accommodate truck and equipment traffic. The contours of the floor of the site should reflect the contours desired for the completed site.

Proponents of balefilling (landfilling of baled wastes) claim that the following advantages can be attributed to the use of baling in MSW disposal when the site is designed and operated properly:

1. Baling ensures a higher effective density, thereby reducing the land requirement and extending the useful life of a landfill.
2. The use of on-site equipment and personnel is less intensive in a balefill.
3. Damage to the environment is diminished. For example, leachate strength is reduced because some percolating water is diverted to the spaces between the bales, diluting the leachate.
4. Problems related to vectors, dust, blowing litter, traffic, and moisture are considerably reduced in number and severity. For example, vector (birds, rats, flies, etc.) activity is notably diminished at balefills due to the smaller working face and the ease of achieving complete daily soil cover.
5. Baling of solid waste improves the future usefulness of the disposal site by enhancing foundation - bearing factors. Also, the waiting period for land to stabilize is lessened.

Co-disposal

As the term implies, "co-disposal" involves the mixing of one type of waste with another and the subsequent disposal of the mixture. Although co-disposal as described in this section applies to most types of non-industrial sludges, the following is directed primarily to sludges associated with the storage, treatment, and disposal of human body wastes (primarily fecal wastes). Examples of such sludges and wastes are those produced by a conventional wastewater (sewage) treatment facility, septic tank pumpings, sludge from the storage pits of unsewered public toilets, and nightsoil in general.

Despite the many hazards to public health and nuisances attributed to the practice, untreated nightsoil is frequently co-disposed with municipal solid wastes in developing countries. These hazards and nuisances are amplified by the presence of scavengers and the prevalence of the open dump method of disposal. Although not as pronounced, the same hazards attend the open dump co-disposal of primary (i.e., raw) sewage sludge from a sewage treatment facility. The hazards can be substantially reduced by using good sanitary landfill practice.

In an operation involving co-disposal by sanitary landfilling, one approach is to deposit the sludge (20 to 30 percent solids) on top of the refuse at the working face of the landfill. The sludge and refuse are then thoroughly mixed and the mixture is spread, compacted, and covered. Liquid in the sludge is absorbed by the refuse. The mixing of the wastes must be done with care so as to not exceed the liquid holding capacity of the solid waste, otherwise a wet, muddy landfill will result. Sludges having a low solids content (2 to 4 percent solids) may be spray-applied from a tank truck to a layer of refuse at the working face. The refuse serves as a bulking agent, but once again care must be taken to not exceed the holding capacity of the solid waste.

It is clear that it is not easy to co-dispose sludges without greatly affecting the success of the facility as a solid waste landfill. The handling, placement and mixing of the sludge in reasonable proportions is key, requiring special design and operational provisions. Note that scavengers should not be permitted to come in contact with the wastes.

A different approach involves the use of sludge/soil mixture as an interim or final cover over completed areas of the refuse landfill. The approach has some advantages:

1. Sludge is removed or reduced from the working face of the fill.
2. Because of the nitrogen and phosphorus contents of the sludge, the mixture promotes the growth of vegetation over the completed fill area, thereby reducing fertilizer requirements.
3. The development of sanitation and erosion problems may also be mitigated.

   A major disadvantage is the limitation of this approach to well-stabilized, digested, sludge. The limitation arises from the incomplete burial of the sludge and its resulting exposure to the atmosphere and people.

An operational difficulty that may be encountered is vehicle movement problems due to the presence of and the high moisture content of the sludge. A possible solution is to mix sludge with ash from power plants or similar sources.

Hazardous Wastes (Secure Landfill)

Introduction

Hazardous wastes (mercury and arsenic based wastes, pesticides, heavy metal waste, acid wastes, oil-based wastes, cyanides, etc.) are equally dangerous and toxic whether in developed or developing countries. The place of origin or occurrence has no bearing on the degree of hazard inherent in a particular hazardous waste. The possibility exists that a given hazardous waste may pose a greater threat in a developing country, since "legal" definitions, standards, and safeguards tend to be more relaxed than those specifications found in a developed country, and because of the accessibility of sites to more people if located in congested areas or if scavenging is practiced. The result is that: 1) measures required in the disposal of hazardous wastes in developing countries should not differ materially from those imposed in developed countries; and 2) the "secure landfill" approach described in this section applies equally in developed and developing settings. The only differences would be those arising from conditions peculiar to the individual sites.

Definition and Specifications

A "secure landfill" is a sophisticated engineered earthen excavation especially designed to contain and prevent hazardous wastes from escaping into the environment. Therefore, a genuinely secure landfill must have the following features:

1. Waste disposed is completely enclosed by a layer or liner of impervious material.
2. The distance between the bottom of the liner and the groundwater is sufficient to prevent contamination of the groundwater.
3. Leachate and all other liquids are not allowed to accumulate inside the containment layers.
4. Groundwater is monitored such that leakage from the fill can be detected.
5. The fill is located such that it is isolated from surface and subsurface water supplies; is free from flooding, earthquake, or other disruptions; and the site is not needed for other uses after the facility is closed.

Design

As with all sanitary landfills, design is largely dependent upon the hydrogeological characteristics of the site. Thus, if the distance to the groundwater table is substantial and the soils are very impermeable, compaction of the soils at the site coupled with the placement of single liner either of natural or of synthetic material would be sufficient to contain hazardous wastes. In such a case, soil or bentonite could serve as a natural material and polyvinyl chloride, high density polyethylene, or chlorinated polyethylene could serve as a synthetic material. If conditions are not ideal, but do meet minimum standards, it would be necessary to excavate the soil presently at the landfill site and replace it with a sand/gravel layer followed by a compacted clay liner, a synthetic liner, a leachate drainage layer, and perhaps even a second clay and drainage layer combination to form a so-called double liner system. In all cases, provision should be made for preventing the various wastes from mixing together and thereby triggering a chemical reaction (e.g., highly caustic waste with a strong acid waste). This is done by separating different areas from one another by forming subcells using earthen dikes.

Arrangements must be made for collecting and withdrawing leachate as it accumulates in the basin. This is done through a network of pipes installed in the drainage layer. Groundwater quality should be monitored by means of monitoring wells placed along the perimeter of the fill. Monitoring of groundwater should begin prior to any disposal of waste and should be continued thereafter until the chances of a pollution problem become non-existent.

The design, operation, and monitoring of a secure fill is a highly sophisticated process which requires the participation of skilled professionals. Details of the various requirements of a secure landfill are given elsewhere.

The closure of a secure landfill must be designed such that total and complete decontamination of the facility is assured, and the completed fill does not pose a threat to the public safety and the environment. This objective is attained by adhering to the following procedure:

1. At termination, cover the upper surface of the completed fill with impermeable soils, e.g. clays. This layer should be at least 0.6 m thick.
2. Cover this layer with a synthetic liner, if available, and then with at least 0.3 m of sand to provide horizontal drainage of percolate and to protect the impermeable soil layer and underlying wastes.
3. Cover the sand layer with a minimum of 0.6 m of vegetation support soil, of which at least the top 10 cm is topsoil. Then seed the topsoil to produce vegetation and to complete the closure operation. Leachate and gas collection pipes should protrude through the final cover.

The functions of a final cover with respect to hazardous waste containment are as follows:

a. minimize infiltration of precipitation
b. prevent contamination of surface run-off
c. deter wind scatter of waste
d. prevent contact of waste with humans and animals
e. promote surface drainage
f. minimize erosion
g. prevent build-up of gas pressures in the fill
h. accommodate settling and subsidence

i. protect the impermeable or barrier layer from freezing, drying, or any other surface effects, and

j. support vegetation growth.

Finally, it is extremely important that the completed fill not be excavated in any way since most buried hazardous wastes continue to be dangerous for extended periods of time, and the consequences of untimely exposure could be disastrous. A properly closed hazardous waste landfill may be utilized for general purposes, such as parking areas and open spaces. However, it is advisable that a hazardous waste site be closely monitored for surface cover quality, gas emissions, leachate collection, groundwater, erosion and other events for at least 30 years. This is an arbitrary time period which can be extended or shortened depending on site characteristics, the wastes disposed, monitoring results, and other pertinent technical information available.

CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

WATER BALANCE AND LEACHATE QUANTITY

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International Solid Waste Association
(ISWA)

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WATER BALANCE AND LEACHATE QUANTITY

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1. Introduction

As precipitation infiltrates through the landfill leachate is produced.

Leachate results from the biological, chemical and physical processes taking place within the landfill, coupled with a leaching effect as water thrickles through the landfill. The product of these processes is a more or less highly polluted leachate whose constituents are heavily dependent on the condition of the landfill. Harmful germs may also be contained in the leachate (Table 1).

Table 1: Leachate analysis values for parameters with differences between acetic and methanogenic phase of a domestic waste landfill (EHRIG, 1989).

Parameter		Average	Range
Acetic phase			
pH	-	6,1	4,5 - 7,5
BOD_5	mg/l	13.000	4.000 - 40.000
COD	mg/l	22.000	6.000 - 60.000
BOD_5/COD	-	0,58	-
SO_4	mg/l	500	70 - 1.750
Ca	mg/l	1.200	10 - 2.500
Mg	mg/l	470	50 - 1.150
Fe	mg/l	780	20 - 2.100
Mn	mg/l	25	0,3 - 65
Zn	mg/l	5	0,1 - 120
Sr	mg/l	7	0,5 - 15
Methanogenic phase			
pH	-	8,0	7,5 - 9,0
BOD_5	mg/l	180	20 - 550
COD	mg/l	3.000	500 - 4.500
BOD_5/COD	-	0,06	-
SO_4	mg/l	80	10 - 420
Ca	mg/l	60	20 - 600
Mg	mg/l	180	40 - 350
Fe	mg/l	15	3 - 280
Mn	mg/l	0,7	0,03 - 45
Zn	mg/l	0,6	0,03 - 4
Sr	mg/l	1	0,3 - 7

2. Generation of leachate from landfills in water-deficient areas

Water is a scarce commodity in arid and semi-arid areas and pollution of surface and underground water resources can be disastrous to communities and households depending on these sources for domestic supply.

As many states of Mexico are largely water deficient areas concern must arise if landfills have the potential to cause unacceptable water pollution. Such pollution is also most costly and difficult to clean up once it has occurred. If nothing is done to ameliorate the situation, the pollution may persist in the groundwater for a long time, even though the source of the pollution has been removed.

Landfills receiving more than 750 mm of precipitation per annum will produce leachate, while in arid regions where annual precipitation is less than 300 - 400 mm, virtually all precipitation is evapotranspired.

Water Balance of a Landfill

The main factors influencing the water balance of a landfill are (see figure 1):

- Precipitation
- Surface run-off
- Evaporation and evapotranspiration
- Retention by the cover
- Storage by the refuse
- (Water production by biochemical processes)
- (Water losses through natural gas venting)
- Water output by leachate

Water losses through natural venting gas out of the landfill will condensate to a high degree in the surface area.

Figure 1: Main factors influencing the water balance of a landfill

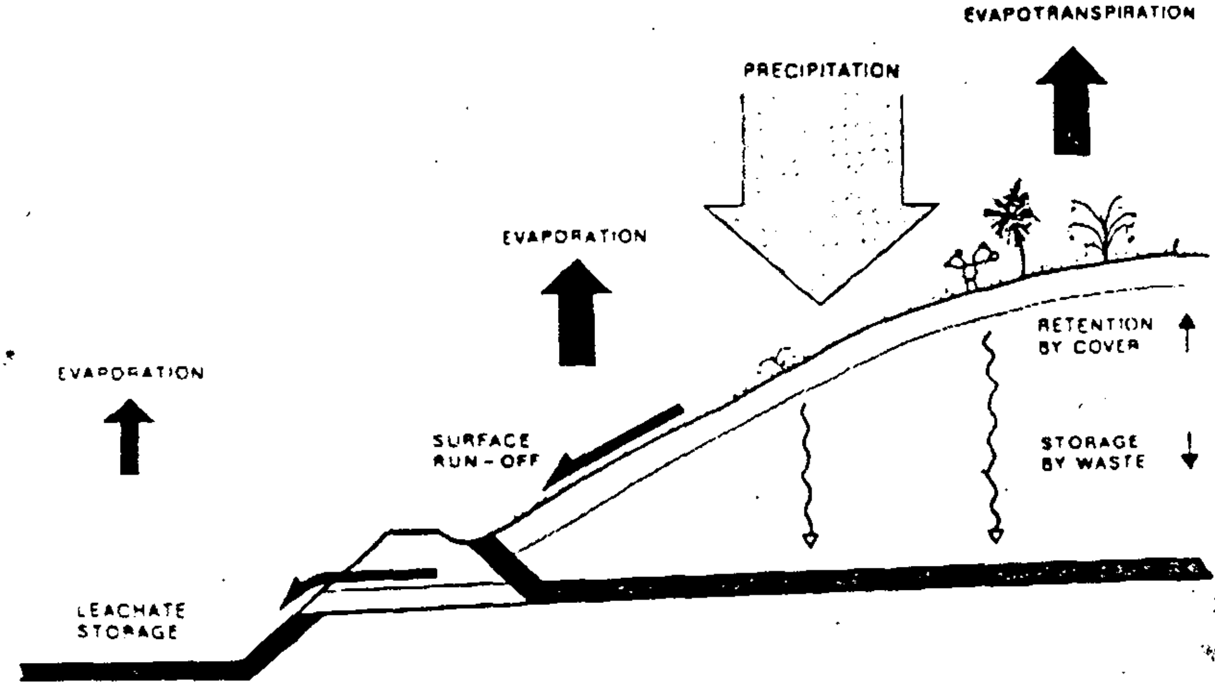
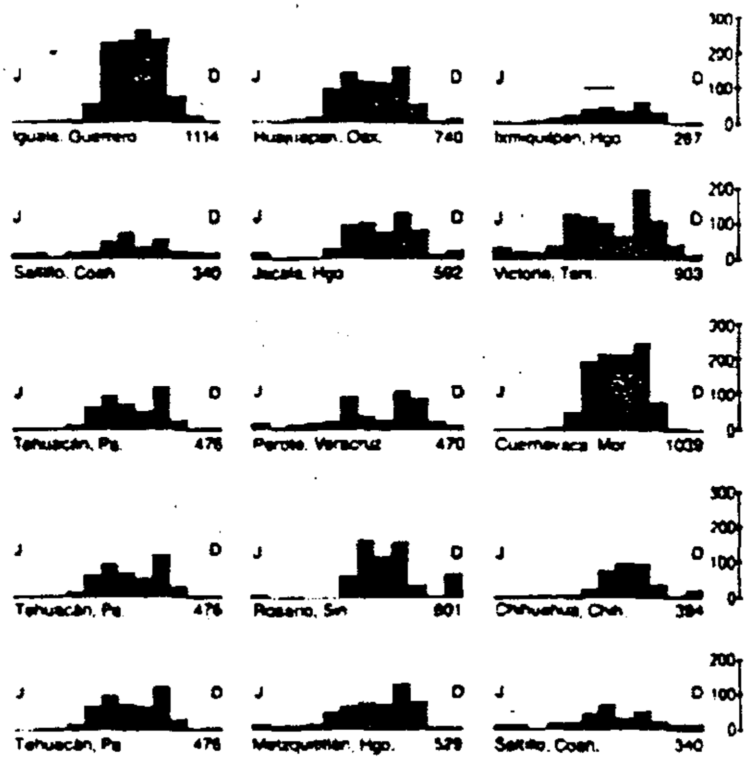


Figure 2: Some meteorological stations with average annual rainfall in millimeters (Atlas Climatológico de México, 1939)



Once precipitation has passed through the cover layer, it will become leachate. It is a phenomena, that under common landfill practice, precipitation, respectively leachate migrates on special interconnected zones through the landfill long before an overall field capacity is reached. The existing of a main wetting front in the landfill, anticipated in some water balance models, is therefore not exactly right. Only if the field capacity of the waste is reached - with the age of a landfill it might become homogeneous - the water content in the refuse will not become lower than this field capacity.

It must also be recognised that good engineering and management of a landfill can be used to maintain a perennial water deficit within the fill even though there may actually be an excess of precipitation over potential evaporation. This can be done by

- Maximizing run-off and
- Minimizing infiltration into the refuse.

A suitably sloping surface and the installation of a carefully designed impervious cover layer can achieve this.

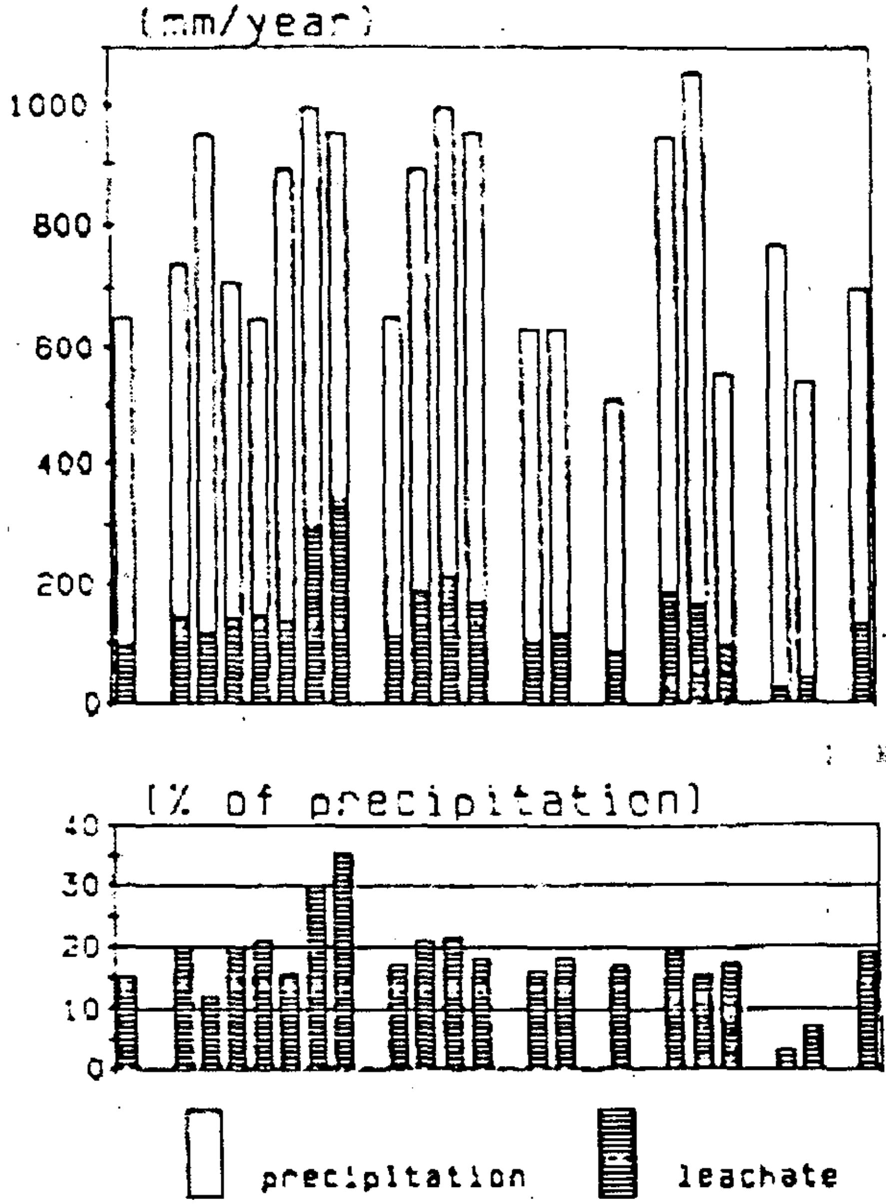
The infiltration rate is strongly influenced by the kind of cover material that is used. Materials with a high field capacity should be preferred, for example waste compost.

Compost is a material with a very high content of organic matter (15 to 30 % DS!), which enables a very high field capacity (80 to 120 % DS!). On the other hand the very permeable surface and a possible strong vegetation prevents a good surface runoff, but forces evaporation resp. evapotranspiration.

Obviously the smaller the precipitation and the larger the evapotranspiration and runoff, the less the potential for the generation of leachate. These terms are particularly favourable in water deficient areas.

Leachate production is high from low compacted landfills without a soil cover. In case of highly compacting, at the landfill surface often ponding of rainwater can be observed. Under humid climatic conditions the average difference between precipitation and evaporation - independent from different vegetation types - is positive. The following figure presents leachate data from different landfills in the northern part of Europe (Federal Republic of Germany/EHRIG, 1989).

Figure 3: Precipitation (mm/year) and leachate flow (mm/year and % of precipitation) at different landfills and years in the middle of Europe (EHRIG, 1989)



In water deficit areas, evaporation exceeds precipitation (figure 4).

Studies made in South Africa (BALL & BLIGHT, 1989; BLIGHT, VORSTER & BALL, 1987) produced strong evidence that if climatic conditions are such that a perpetual water deficit exists at the site of a landfill, no or very little leachate will be formed and exit the base of the landfill. Hence, if there is an adequate separation between the lowest level of refuse and the highest level of the regional phreatic surface, no groundwater pollution may occur (figure 5).

Figure 4: Water balance in water deficit areas

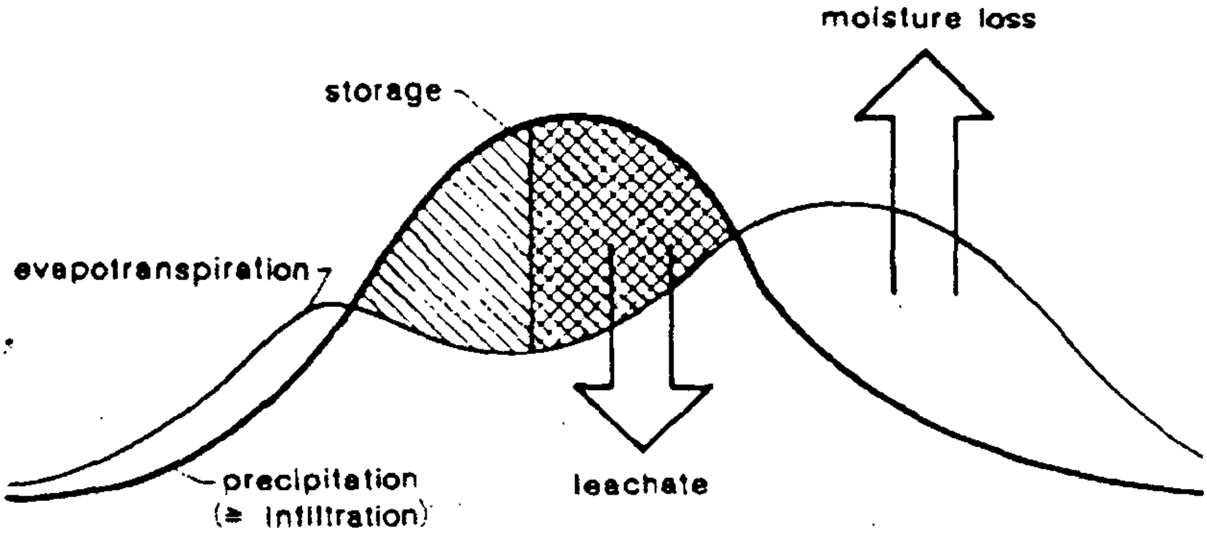
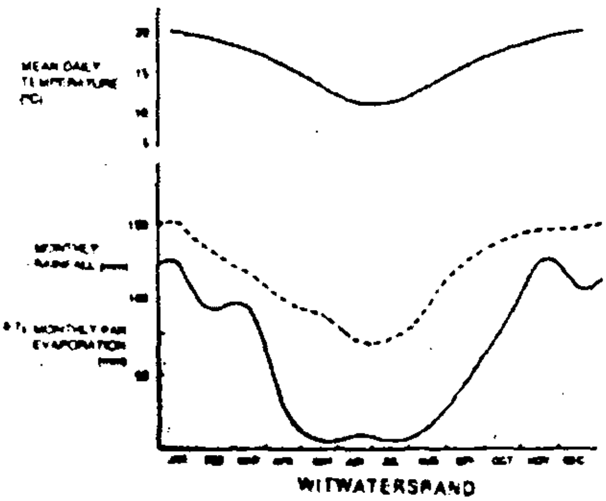
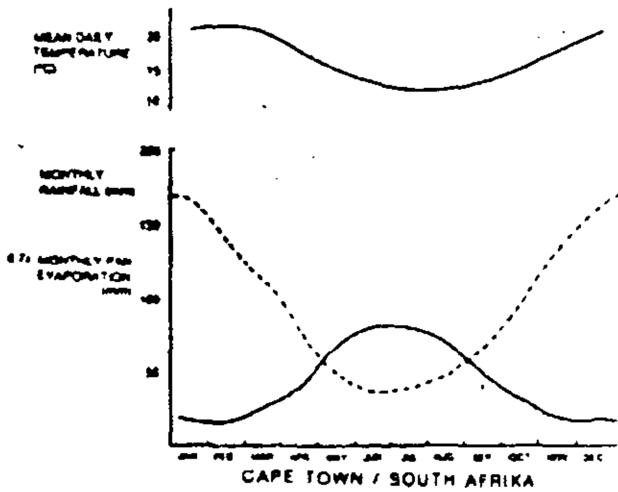


Figure 5: Different climate-types in water deficit areas

<u>Example 1</u> - Witwatersrand/South Africa, a winter rainfall area (BLIGHT et al., 1989)



<u>Example 2</u> - Cape Town/South Africa, a summer rainfall area (BLIGHT et al., 1989)



Precipitation (Rainfall)

The most critical situation occurs in the case of low rainfall intensity over a long period of time; cloud bursts, e. g. rains of extraordinary intensity result in a quick saturation of the cover material, with the result of a high surface run-off, so there is little infiltration into the landfill.

Rainfall data should be preferable obtained from measuring on site or alternatively from the nearest meteorological station (see figure 6).

Surface Run-off

The important facts, which influence the surface run-off are:

- Topography of the landfill
- Type of soil cover material
- Morphology of the soil cover
- Vegetation

A simple method for estimating the surface run-off is based on the general formula:

$R = c \times P$

R . . . run-off
P . . . precipitation
c . . . coefficient

Table 2: Run-off coefficients proposed by SALVATO et al. (1971) for different soil cover materials and different vegetation types

Soil cover	Slope (%)	Soil texture		
		Sandy loam	Loamy clay	Clay
Grassed soil	0 - 5	0,10	0,30	0,40
	5 - 10	0,16	0,36	0,55
	10 - 30	0,22	0,42	0,60
Bare soil	0 - 5	0,30	0,50	0,60
	5 - 10	0,40	0,60	0,70
	10 - 30	0,52	0,72	0,82

Evaporation and Evapotranspiration

The vegetation growing on the final cover of the landfill needs water for building plant tissue and causes a water loss by transpiration. In addition, water is evaporated from the soil depending on soil texture and climatic conditions. A distinction should be made between the period of landfill operating - maybe with intermediate cover - and the finished landfill with a final cover and revegetation.

Leachate Circulation

In regions with low annual precipitation (< 750 mm) a leachate circulation system reduces the quantity of leachate by evaporation and accelerates the biochemical decomposition process in the landfill. This leads to a drop in the decomposible organic content of the leachate and accelerates the production of methane gas.

3. Free Leachate Flow

Steps must be taken to ensure that under no circumstances - even in the long term - it will be possible for a build-up of leachate to occur in a landfill. Leachate must be able to exit from the area of the landfill following the natural gradient (LECHNER et al., 1993).

If a pit is completely filled, in other words, if there is no free leachate flow, there is a build-up of leachate as soon as the pumping system fails, even if the leachate collection system is optimally constructed. In an extreme case, at the relevant depth of filling or height of build-up, all the free water in the mineral base liner begins to permeate the liner. Permeation is now governed by the relationship $v = k \times (i-i_0)$. In other words, there is laminar flow through the liner. The mineral barrier liner is thus no longer "technically impermeable".

v ....filter velocity (m/sec)
k ....hydraulic conductivity in the linear range (m/sec)
i ....hydraulic gradient
i_0.......start gradient for the linear relation

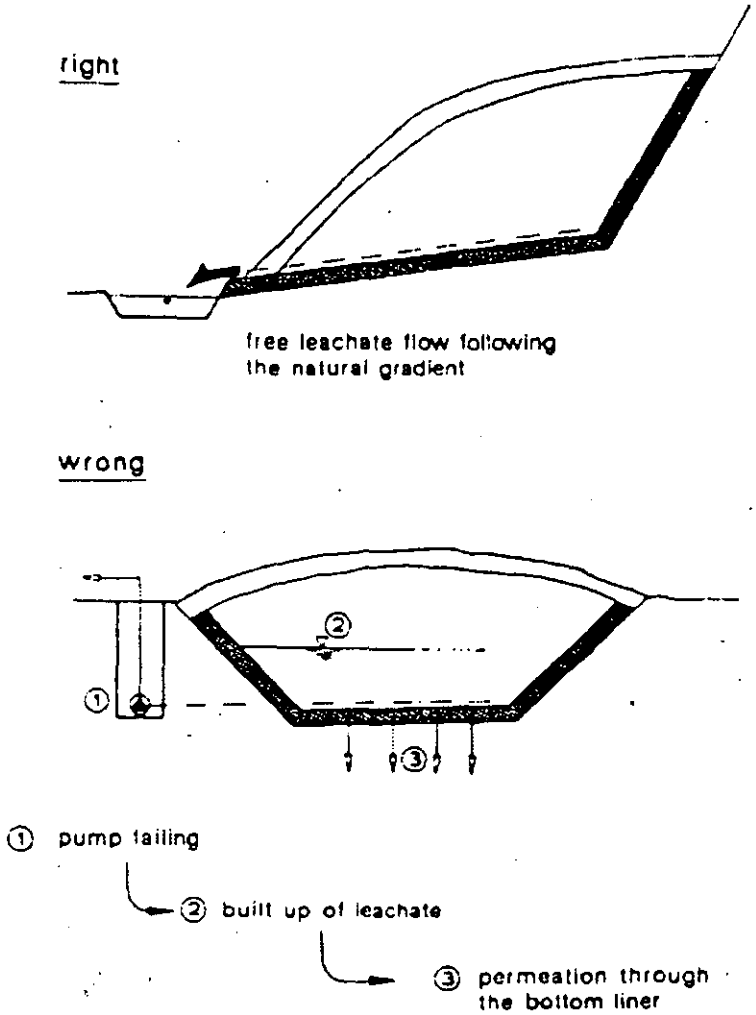
In case of a free leachate flow the hydraulic gradient results only from the controlled flooding of the drainage system according to the hydraulic requirements for the runoff of the leachate. The hydraulic gradient will not generally exceed a value of 1,5. The value of $k_{i=1,5}$ relevant for the actual percolation through the base liner is thus much lower than $k_{i=30}$, which is the value used for the determination of the coefficient of permeability in the laboratory. At low hydraulic gradients the effect of the binding forces results in a non-linear relation between the filter velocity (v) and the hydraulic gradient (i), in mineral materials of low permeability ($k_{i=30} < 10^{-8}$ m/sec).

In other words, the resistance to the percolation of leachate is virtually infinitely large at a low hydraulic gradient. This exponential relationship is explained by the fact that the adsorption water only contributes to the flow at an increasing hydraulic gradient. Only then does cross-sectional area of flow - and with it permeability - increase. As long as this is not the case, a mineral barrier liner of low permeability can therefore be described as "technically impermeable".

This is the reason for the decisive importance attached to free leachate flow. The necessity for free leachate flow is in most European countries now generally accepted.

Above ground landfill mounds have a potential for erosion of the topsoil layer in the cover. The appearance of leachate in the drainage system of such a landfill, especially in water deficient areas will signal the need to investigate the cover and, if necessary, to repair it.

Figure 6: Necessity for the free leachate flow



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CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

GENERACION Y CUANTIFICACION DE BIOGAS

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PALACIO DE MINERIA, MEXICO D.F. 14-19 de Marzo de 1994

GENERACION Y CUANTIFICACION DE BIOGAS

Generalidades

De todos es conocido que los rellenos sanitarios producen cantidades importantes de biogás debido a la descomposición biológica de los materiales orgánicos contenidos en los desechos sólidos depositados en los rellenos sanitarios.

El proceso de degradación que ocurre en el interior del relleno es un proceso anaeróbico similar al que ocurre dentro de un digestor de lodos con proceso anaerobio, siendo la diferencia únicamente que este último es operado bajo condiciones óptimas, condición que raramente ocurre en un relleno sanitario.

Composición del Biogás

La composición del biogás es muy variada y puede encontrarse en cualquier libro o publicación sobre el tema, pero el componente sobre el que fijaremos nuestra atención será el Metano, ya que típicamente se le detecta en concentraciones del 40 % aproximadamente, el resto es atribuible al CO_2 y gases adicionales en concentraciones de partes por millón en volumen.

Los gases adicionales que ocurren en concentraciones de ppmv, son típicamente el H_2S formando Mercaptanos y otros gases sulfurados olorosos, otros alcanos como el Etano y otros Compuestos Orgánicos Volátiles siendo los principales dentro de los Hidrocarburos Aromáticos el Benceno, Tolueno, Etilbenceno, Ortoxileno y algunos Hidrocarburos Halogenados.

Peligrosidad del Biogás

El biogás debido al Metano puede ser explosivo en concentraciones entre 5 y 15 % en volumen con aire atmosférico, es corrosivo por el porcentaje de CO_2 que contiene, y su condensado también lo es por el H_2S, su olor ofrende al sentido del olfato y afecta a la comunidad que vive en los alrededores del sitio creando tensiones dentro de las familias, pérdida del apetito, induciendo ira en las personas y propicia el sentimiento de no desear regresar al hogar al fin del trabajo, es tóxico y puede producir asfixia.

La mayor contribución al olor del biogás viene de dos grupos de compuestos, el primer grupo está denominado por Esteres y Organosulfuros incluyendo también ciertos solventes depositados con los desechos sólidos, el segundo grupo incluye Alquilo y Limoneno. La mayoría de los compuestos mal olientes se forman durante las etapas de descomposición nometanogénica y anaeróbica. Durante las primeras etapas de descomposición los alcoholes son particularmente notables. Los olores dulces afrutados y pútridos de estos compuestos se hacen menos potentes con el tiempo. Los gases formados en la etapa anaeróbica no son olorosos de por si, pero la presencia de Metano incrementa la percepción de otros gases molientes.

Existe también una cantidad muy grande de compuestos orgánicos no metánicos en el biogás, entre los que figuran el Benceno, Tetracloruro de Carbono, Cloroformo, Dicloruro de Etileno, Cloruro de Metileno, Percloroetileno, Tricloroetileno, Cloruro de Vinilo, Cloruro de Vinildeno calificados con identificación peligrosa, que es el paso cualitativo para determinar si la exposición a una substancia dada está o no asociada con efectos adversos a la salud, en general se les considera como cancerígenos.

La migración subterránea del biogás desde los rellenos sanitarios hacia terrenos vecinos puede resultar en la contaminación del agua subterránea debido a los Compuestos Orgánicos Volátiles si el biogás entra en contacto con el agua subterránea.

Por tanto las **emisiones** de este biogás por la superficie y la migración a través de los lados y el fondo de los **antiguos** y nuevos rellenos, cuando no cuentan con cubierta final y membranas flexibles, causan o contribuyen significativamente a la contaminación del suelo, y atmosférica debido a que los Compuestos Orgánicos no Metánicos reaccionan con los rayos ultravioletas del Sol generando Ozono.

Tasa de Producción

Una manera de controlar dicha contaminación requiere primeramente que se conozca la cantidad y calidad del biogás generado. A continuación haremos una reflexión sobre la cantidad posible de generación.

Primeramente se ocurre encontrar un volumen de biogás posible de generarse por peso de basura usando la estequimetria correspondiente a una digestión anaerobia como la siguiente:

$$C_a H_b O_c N_d + (4a-b-2c+3d)/4\ H_2O \rightarrow (4a+b-2c-3d)/8\ CH_4 + (4a-b+2c+3d)/8\ CO_2 + dNH_3$$

Pero los resultados proporcionan valores no reales del biogás producido por masa de basura debido a que se consideran productos finales y existen componentes de la basura como Ligina, Celulosa y Grasa que no se biodegradan completamente.

En los últimos años se ha medido en varios rellenos sanitarios y en lisimetros abiertos, que aparentemente proporcionan una buena generación debido a que la eficiencia en la recolección del biogás es desconocida; y en lisimetros cerrados donde se pueden medir las tasas de generación de biogás y su composición, pero no se pueden duplicar las condiciones de los rellenos sanitarios en lo que al clima en general se refiere y que usualmente proporciona muy poco o ningún contenido de Metano; por esto la producción de biogás generado en ellos y los valores encontrados para la tasa de producción han sido muy variados, en un rango que fluctúa entre 0.75 a 34 litros de biogás por kilográmo de basura húmeda por año, pero hay investigadores que llegan a valores teóricos llamados de última productividad, tan altos como 450 lt/KG, y valores medidos en laborátorio de 260 Lt/kg. Esto obedece a los factores que afectan dicha producción como son: la composición de la basura, la temperatura, el pH y alcalinidad y la cantidad y calidad de nutrientes principalmente Nitrógeno, Fósforo y Potasio contenidos en los desechos sólidos, y finalmente la presencia de algunos inhibidores dentro del relleno.

Es conocido que su tasa de producción varia con el tiempo por lo que el método estequimétrico requiere de ayuda interviniendo la cinética de la reacción y también es conocido que la producción continúa por varias décadas por lo que se hace difícil predecir la cantidad de gas generado. Hay investigadores que dan "vidas medias": a los desechos rápidamente putrecibles, como los provenientes de desperdicios de comida, basura de jardín, etc., entre medio y un año; para los desechos sólidos refractarios se les asigna una vida media teórica infinita.

Modelos

En un intento para conseguir lo anterior varios modelos se han programado usando: cinética de orden cero, es decir que la tasa de generación de Metano es independiente de la cantidad de sustrato que permanece, el modelo sería según Ham y Barlaz:

$$-\,dc/dt = k$$

El modelo de cinética de primer orden establece que la tasa de pérdida de materia putrecible es proporcional a la cantidad de materia putrecible que permanece y su modelo sería:

$$-\,dc/dt = kc$$

y finalmente el modelo de cinética de segundo orden puede escribirse como:

$$-\,dc/dt = kc^2$$

Sin embargo, EPA está recomendando un modelo muy simple de aplicar y que parece predecir con suficiente aproximación a la realidad la cantidad de biogás generado en los rellenos sanitarios.

Es mi experiencia haberlo aplicado en al menos 8 distintos rellenos sanitarios en el sur y centro de California y 3 en el área de Phoenix, Arizona, habiéndose comprobado los valores medidos para los años 1992 y 1993 en los sitios, debido a que existe un sistema de extracción de biogás, incluyendo un medidor de flujo en la mayor parte de ellos.

La generación total de Metano del sitio toma en cuenta la masa de basura recibida anualmente aceptando la misma tasa anual en el tiempo de operación del relleno, sin embargo si se conocen las entradas de basura con el tiempo puede establecerse un promedio anual y con estos valores, variando anualmente, correr el modelo.

El modelo es como sigue:

$$Q = Lo\, R\, (\exp(-kc) - \exp(-kt))$$

Donde:

Q	=	Tasa de generación de Metano con el tiempo. m^3/año.
Lo	=	Capacidad potencial de la basura de generar Metano, m^3/Mg.
R	=	Tasa de aceptación promedio de basura durante la vida activa del relleno, Mg/año.
k	=	Tasa de generación de Metano se supone constante, 1/año.
c	=	Tiempo desde la clausura del relleno, año.
t	=	Tiempo desde el inicio de colocación de la basura en el relleno, año.

Note que 1 Mg = 1,000,000 gramos = 1 tonelada métrica.

En la formulación no se ha incluido ningún término de vida media o porcentaje de desechos rápida, o moderadamente putrecibles, pero es evidente que los valores de Lo y k los toman en cuenta.

El modelo acepta un tiempo de retraso durante el cual las condiciones anaeróbicas se establecen, para climas semi-áridos con baja precipitación y alta evaporación puede aceptarse 1 año como tiempo de retraso, para las condiciones de otros climas, no incluidos los Aridos, con alta precipitación, alta temperatura y cualquier condición de evaporación; este tiempo tal vez no deba concederse.

En su obligación EPA indica que en ausencia de información usar 230 m/Mg para Lo y 0.02

1/año para k, sin embargo los últimos valores recomendados por EPA son:

	Climas Semi-Aridos	Otros Climas
Lo	90 m^3/Mg	175 m^3/Mg
k	0.05 1/año	0.05 1/año

Debe hacerse notar que el biogás generado es el doble del obtenido mediante la fórmula anterior, ya que se acepta que el Metano y Bióxido de Carbono se encuentran en parte iguales.

Aplicación de Resultados

Para esta aplicación se eligió un relleno sanitario en operación desde 1978 y que recibe basura en la actualidad, pero se espera clausurarlo al fin de 1994, con duración desde su inicio de 17 años recibiendo un promedio de 1,400 toneladas de basura por día durante este tiempo.

En las tablas y gráficas anexas simulando para dos sitios localizados uno en clima semi-árido y el otro en clima distinto sin ser árido, la misma cantidad de basura recibida, se pueden apreciar los resultados del modelo para predecir la cantidad de biogás generado y la tasa de producción variando con el tiempo.

En 1984 ocurre la máxima generación de biogás, la tasa de producción se incrementa muy rápidamente al principio y disminuye con el tiempo, alcanzando su valor máximo en los años 7 y 8.

Se sugiere aplicar este modelo al medio mexicano siguiendo algunos criterios como los siguientes:

La composición de la basura mexicana tiene un alto contenido de desperdicios de comida pero no muy alto contenido de basura de jardín, como es el caso donde este modelo nació.

El agua de lluvia que se infiltra en rellenos mexicanos clausurados o en operación es muy alta debido a que pocos tienen cubierta final o diaria, o la tienen escasa.

No existe en el medio mexicano un periodo de tiempo prolongado de contacto del agua de deshielo ocasionada por la nieve con la cubierta del relleno.

Si bien los valores del asoleamiento en México son similares a los de Estados Unidos las temperaturas de invierno son más benignas y propician la generación de biogás.

Finalmente la publicación de la EPA sugiere la manera de obtener los valores de Lo y k directamente en el sitio, cosa que podría realizarse en alguno de los rellenos sanitarios clausurados como San Lorenzo Tezonco o algún otro.

Agradecimiento

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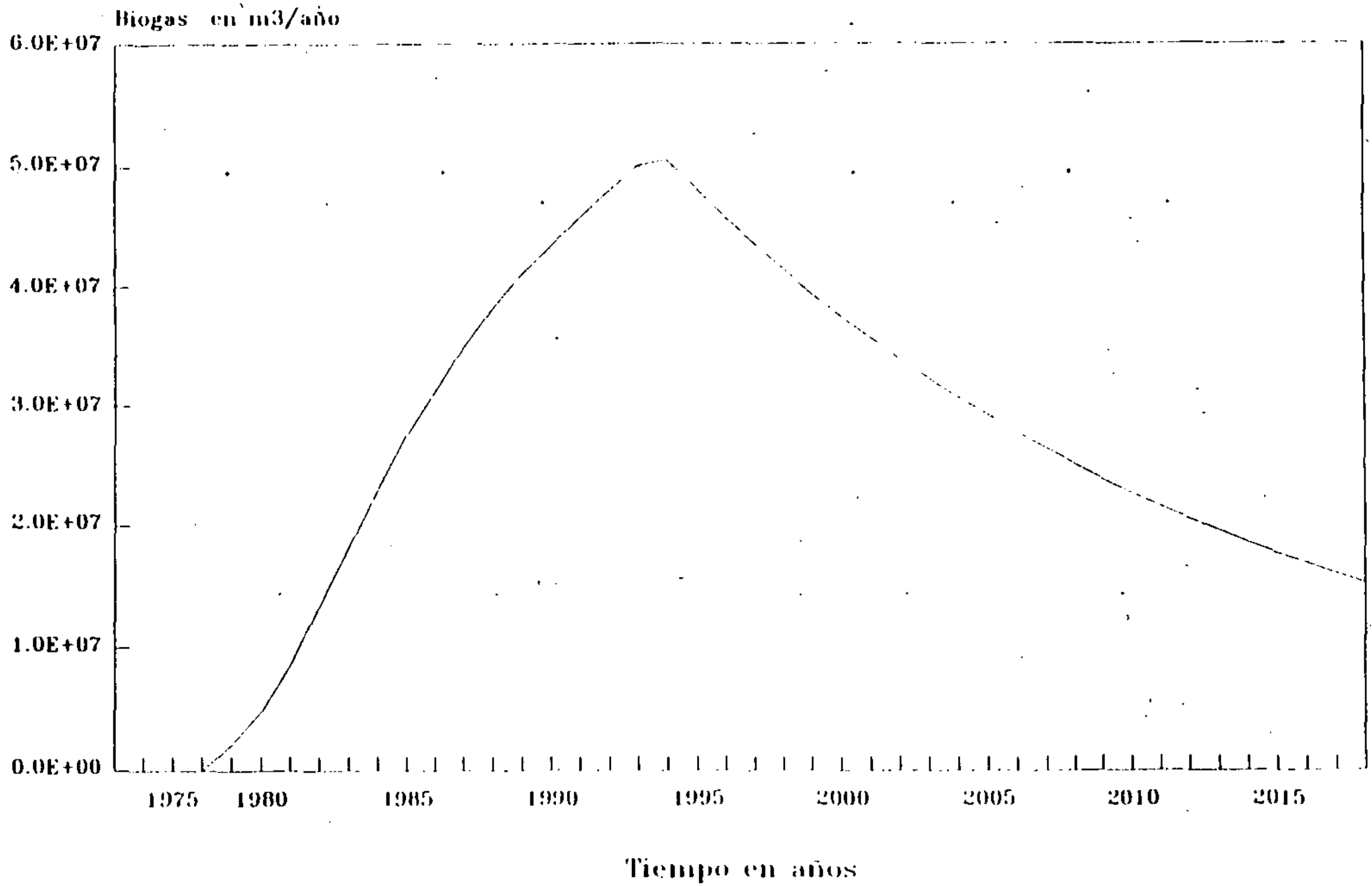
ESTIMACION DE LA PRODUCCION DE BIOGAS EN UN RELLENO SANITARIO

Lo = 90 m^3/ton.

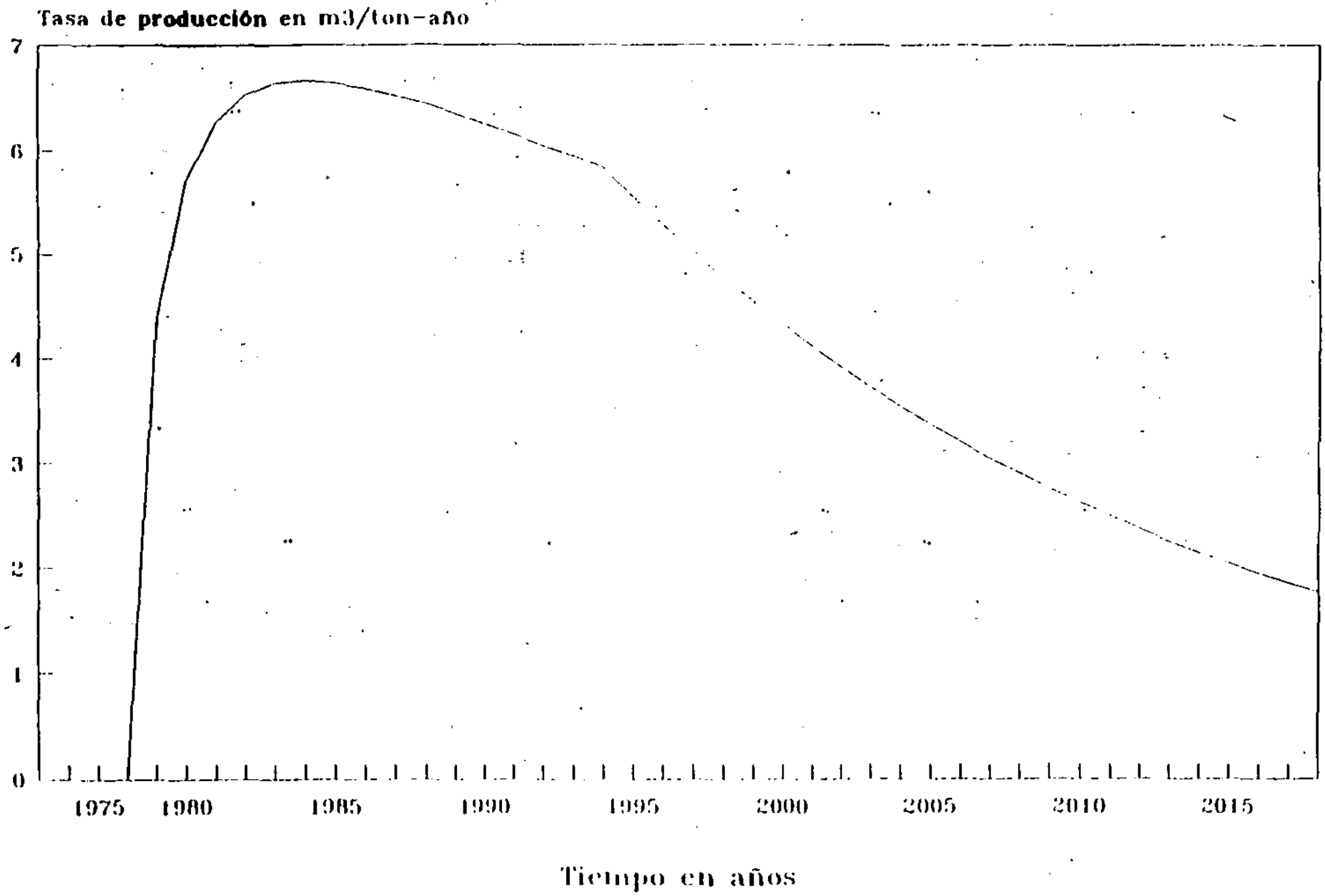
K = 0.05 1/año

AÑO	DESECHOS SOLIDOS ton año	DESECHOS ACUMULAD. Ton.	c años	t años	BIOGAS GENERADO m^3/año	TASA DE PRODUC. m^3/ton-año
1978	43,877	43,877	0	0	0.00E+00	0.00
1979	430,988	474,865	0	1	2.08E+06	4.39
1980	355,845	830,711	0	2	4.74E+06	5.71
1981	523,028	1,353,739	0	3	8.49E+06	6.27
1982	687,240	2,040,979	0	4	1.33E+07	6.53
1983	708,836	2,749,815	0	5	1.82E+02	6.64
1984	694,088	3,443,903	0	6	2.30E+07	6.66
1985	689,009	4,132,912	0	7	2.75E+07	6.64
1986	587,724	4,720,636	0	8	3.11E+07	6.59
1987	616,699	5,337,335	0	9	3.48E+07	6.52
1988	577,040	5,914,375	0	10	3.81E+07	6.44
1989	550,569	6,464,944	0	11	4.10E+07	6.35
1990	470,410	6,935,354	0	12	4.33E+07	6.25
1991	493,536	7,428,890	0	13	4.57E+07	6.15
1992	506,382	7,935,272	0	14	4.79E+07	6.04
1993	498,902	8,434,174	0	15	5.01E+07	5.94
1994	249,451	8,683,625	0	16	5.06E+07	5.83
1995	0	8,683,625	1	17	4.82E+07	5.55
1996	0	8,683,625	2	18	4.58E+07	5.28
1997	0	8,683,625	3	19	4.36E+07	5.02
1998	0	8,683,625	4	20	4.15E+07	4.77
1999	0	8,683,625	5	21	3.94E+07	4.54
2000	0	8,683,625	6	22	3.75E+07	4.32
2001	0	8,683,625	7	23	3.57E+07	4.11
2002	0	8,683,625	8	24	3.39E+07	3.91
2003	0	8,683,625	9	25	3.23E+07	3.72
2004	0	8,683,625	10	26	3.07E+07	3.54
2005	0	8,683,625	11	27	2.92E+07	3.36
2006	0	8,683,625	12	28	2.78E+07	3.20
2007	0	8,683,625	13	29	2.64E+07	3.04
2008	0	8,683,625	14	30	2.15E+07	2.90
2009	0	8,683,625	15	31	2.39E+07	2.75
2010	0	8,683,625	16	32	2.27E+07	2.62
2011	0	8,683,625	17	33	2.16E+07	2.49
2012	0	8,683,625	18	34	2.06E+07	2.37
2013	0	8,683,625	19	35	1.96E+07	2.25
2014	0	8,683,625	20	36	1.96E+07	2.14
2015	0	8,683,625	21	37	1.86E+07	2.04
2016	0	8,683,625	22	38	1.69E+07	1.94
2017	0	8,683,625	23	39	1.60E+07	1.85
2018	0	8,683,625	24	40	1.52E+07	1.76

PRODUCCION DE BIOGAS
RELLENO SANITARIO EN CLIMA SEMI-ARIDO
BIOGAS GENERADO



PRODUCCION DE BIOGAS
RELLENO SANITARIO EN CLIMA SEMI-ARIDO
TASA DE PRODUCCION

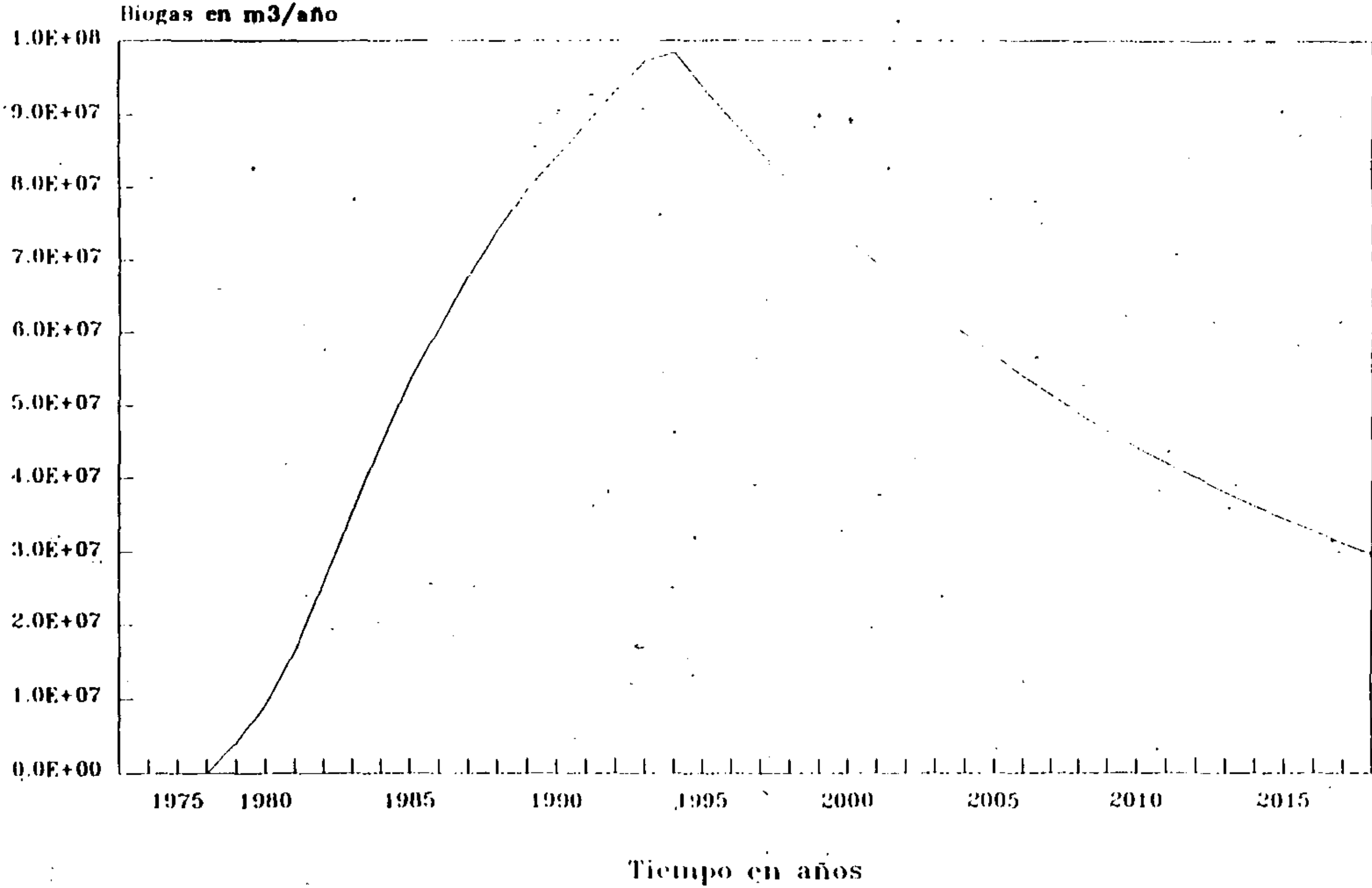


ESTIMACION DE LA PRODUCCION DE BIOGAS EN UN RELLENO SANITARIO

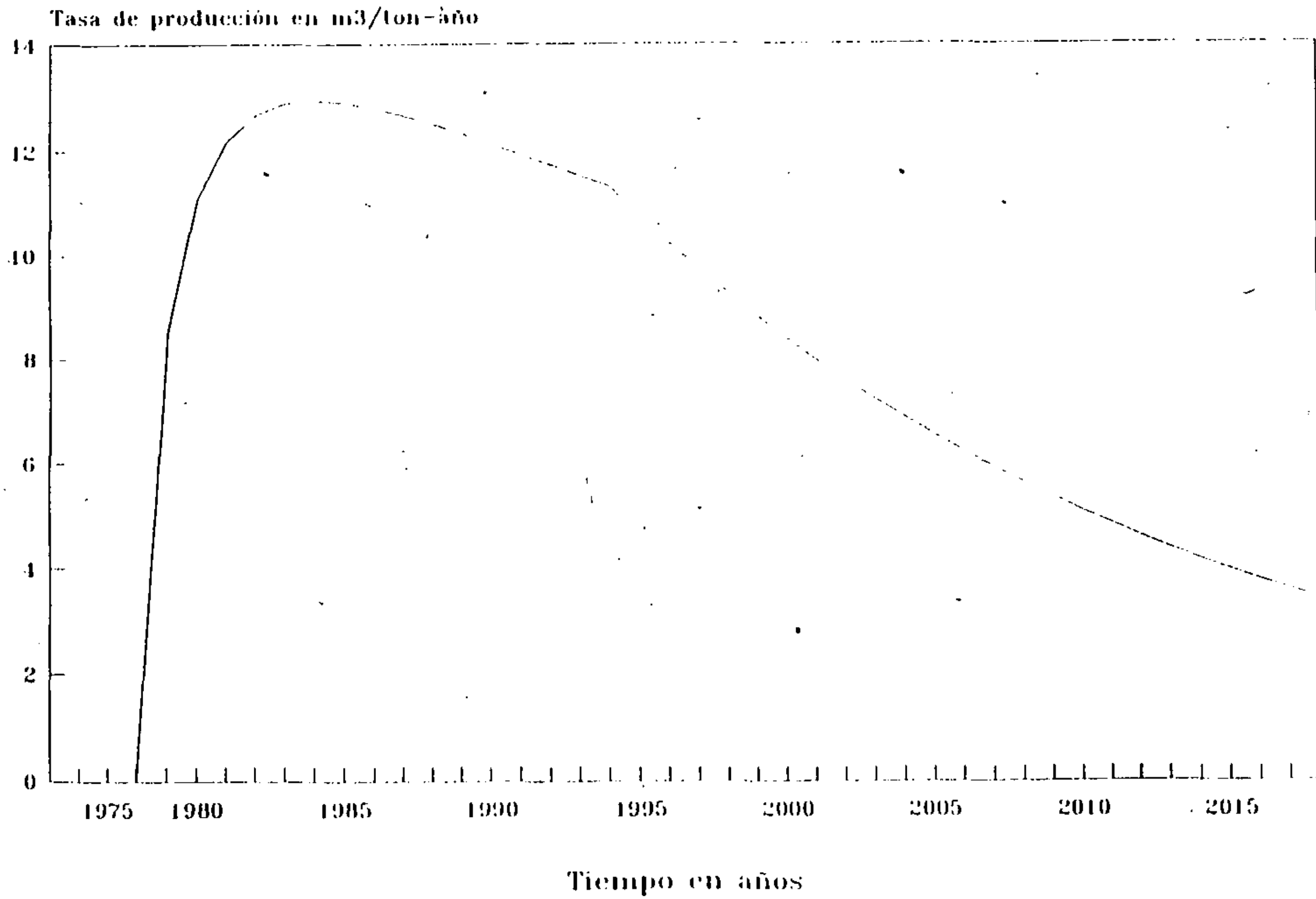
Lo = 175 m^3/ton.
K = 0.05 1/año

AÑO	DESECHOS SOLIDOS ton/año	DESECHOS ACUMULAD. Ton.	c años	t años	BIOGAS GENERADO m^3/año	TASA DE PRODUC. m^3/ton-año
1978	43,877	43,877	0	0	0.00E-00	0.00
1979	430,988	474,865	0	1	4.05E-06	8.53
1980	355,845	830,711	0	2	9.22E-06	11.10
1981	523,028	1,353,739	0	3	1.65E-06	12.19
1982	687,240	2,040,979	0	4	2.59E-07	12.69
1983	708,836	2,749,815	0	5	3.55E-02	12.90
1984	694,088	3,443,903	0	6	4.46E-07	12.96
1985	689,009	4,132,912	0	7	5.34E-07	12.92
1986	587,724	4,720,636	0	8	6.05E-07	12.82
1987	616,699	5,337,335	0	9	6.77E-07	12.68
1988	577,040	5,914,375	0	10	7.40E-07	12.52
1989	550,569	6,464,944	0	11	7.98E-07	12.34
1990	470,410	6,935,354	0	12	8.42E-07	12.15
1991	493,536	7,428,890	0	13	8.88E-07	11.95
1992	506,382	7,935,272	0	14	9.32E-07	11.75
1993	498,902	8,434,174	0	15	9.73E-07	11.54
1994	249,451	8,683,625	0	16	9.84E-07	11.34
1995	0	8,683,625	1	17	9.36E-07	10.78
1996	0	8,683,625	2	18	8.91E-07	10.26
1997	0	8,683,625	3	19	8.47E-07	9.76
1998	0	8,683,625	4	20	8.06E-07	9.28
1999	0	8,683,625	5	21	7.67E-07	8.83
2000	0	8,683,625	6	22	7.29E-07	8.40
2001	0	8,683,625	7	23	6.94E-07	7.99
2002	0	8,683,625	8	24	6.60E-07	7.60
2003	0	8,683,625	9	25	6.28E-07	7.23
2004	0	8,683,625	10	26	5.97E-07	6.88
2005	0	8,683,625	11	27	5.68E-07	6.54
2006	0	8,683,625	12	28	5.40E-07	6.22
2007	0	8,683,625	13	29	5.14E-07	5.92
2008	0	8,683,625	14	30	4.89E-07	5.63
2009	0	8,683,625	15	31	4.65E-07	5.36
2010	0	8,683,625	16	32	4.42E-07	5.09
2011	0	8,683,625	17	33	4.21E-07	4.85
2012	0	8,683,625	18	34	4.00E-07	4.61
2013	0	8,683,625	19	35	3.81E-07	4.38
2014	0	8,683,625	20	36	3.62E-07	4.17
2015	0	8,683,625	21	37	3.45E-07	3.97
2016	0	8,683,625	22	38	3.28E-07	3.77
2017	0	8,683,625	23	39	3.12E-07	3.59
2018	0	8,683,625	24	40	2.97E-07	3.41

PRODUCCION DE BIOGAS
RELLENO SANITARIO EN OTRO CLIMA
BIOGAS GENERADO



PRODUCCION DE BIOGAS
RELLENO SANITARIO EN OTRO CLIMA
TASA DE PRODUCCION



CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

MANEJO Y CONTROL DE LIXIVIADOS

Dr. Rafaello Cossu

International Solid Waste Association
(ISWA)

PALACIO DE MINERIA, MEXICO D.F.

14-19 de Marzo de 1994

CURSO INTERNACIONAL SOBRE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS (RELLENOS SANITARIOS)

PROTECCION DEL AGUA SUBTERRANEA

Dr. Dik Beker

International Solid Waste Association
(ISWA)

PALACIO DE MINERIA, MEXICO D.F.   14-19 de Marzo de 1994

FACULTAD DE INGENIERIA U.N.A.M.
DIVISION DE EDUCACION CONTINUA

C U R S O S   A B I E R T O S

CURSO INTERNACIONAL DE DISEÑO Y DISPOSICION FINAL DE RESIDUOS SOLIDOS
(RELLENOS SANITARIOS)

DISEÑO DE RELLENO SANITARIO
(APUNTES COMPLEMENTARIOS)

ING. FELIPE LOPEZ

MARZO DE 1994.

Palacio de Minería   Calle de Tacuba 5   Primer piso   Deleg. Cuauhtémoc 06000   México, D.F.   APDO. Postal M-2285
Teléfonos: 512-8955   512-5121   521-7335   521-1987   Fax 510-0573   521-4020 AL 26

FRENTE DE TRABAJO

DEFINICION: El frente de trabajo es el espacio destinado a la recepción de desechos mediante distintos vehículos en el sitio de disposición final.

Su dimensionamiento debe considerar:

- El espacio necesario para las maniobras de los vehículos.
- El espacio necesario para el acamellonamiento del material de cubierta (dependiendo del método de operación).
- Las dimensiones de la celda diaria.
- Descarga simultánea de vehículos en la hora pico

La longitud del frente de trabajo se calcula como:

$$L = a \frac{n}{t}$$

donde:

L : longitud del frente (m)
a : ancho necesario por vehículo (m)
n : número de vehículos llegando en la hora pico
t : tiempo necesario para maniobras y descarga

El dimensionamiento del frente debe responder a los siguientes requerimientos:

a) Permitir el movimiento de la maquinaria que cubre desde arriba los desechos con tierra (se recomienda no disminuir por debajo de 10 m, aproximadamente el ancho de dos bulldozers).

b) Permitir la descarga simultánea de vehículos en la hora pico para evitar encolamientos.

DISEÑO DEL RELLENO SANITARIO

- Selección del Método de Operación
- Diseño del Frente de Trabajo
- Diseño de la Celda Diaria
- Necesidades de Material de Cobertura
- Diseño Detallado
  - Proyección de la Generación de los Residuos Sólidos
  - Dimensionamiento de la Celda Diaria
  - Requerimientos Volumétricos del Relleno Sanitario
  - Cálculo de la Capacidad Volumétrica del Sitio
  - Cálculo de la Vida Util del Sitio
  - Calendarización del Relleno Sanitario
- Curva Altura-Volumen
- Superficie Final
- Nivel de Desplante
- Diseño de Interfase, Análisis de Contaminación, del Suelo y Acuíferos
- Impermeabilización
- Generación y Control de Biogás
- Generación y Control de Lixiviado
- Drenajes Pluviales
- Obras Complementarias
  - Caminos Exteriores e Interiores
  - Cerca Perimetral y Caseta de Vigilancia
  - Báscula y Caseta de Pesaje
  - Cobertizo y Taller de Mantenimiento
  - Señalamientos
  - Oficinas y Areas de Servicios

CELDA DIARIA

DEFINICION: Es la unidad de depositación que cada día se generará en un mismo frente de trabajo y misma que debe cubrirse con material adecuado al caso.

El dimensionamiento de la celda diaria partirá de:

- El volumen crítico de residuos recibidos al día en el sitio.
- El frente de trabajo necesario.
- El peso volumétrico de los desechos, considerando la compactación que reciban por la maquinaria existente.
- La altura que operacionalmente se pueda alcanzar.

Las dimensiones de la celda diaria se pueden expresar como:

$$D = \frac{V}{Lh} + c \qquad \text{con} \qquad V = \frac{\text{peso total de residuos recibidos}}{\text{peso volumétrico}}$$

donde:

D : desarrollo de la celda (m)

V : volumen de recepción de residuos al día (m^3)

h : altura de la celda (m)

L : longitud del frente de trabajo (m)

c : espesor de la cobertura diaria (usualmente 20 cm.)

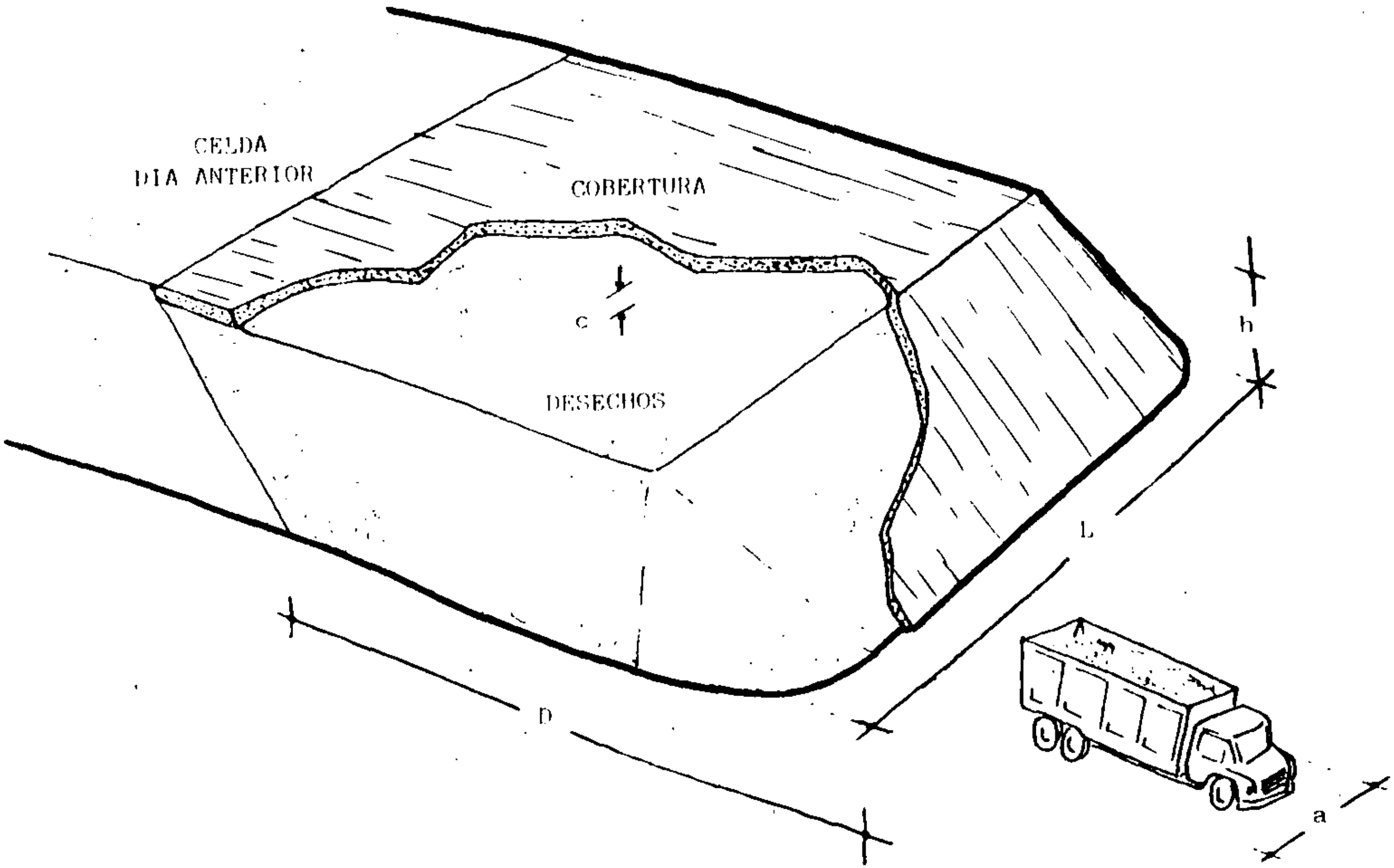
Adicionamente debe calcularse el volumen de tierra necesario para la cobertura, considerando para esto:

a) la geometría de la celda

b) los taludes a emplear

c) el espesor de la cubierta

FRENTE DE TRABAJO Y CELDA DIARIA



Cobertura Diaria

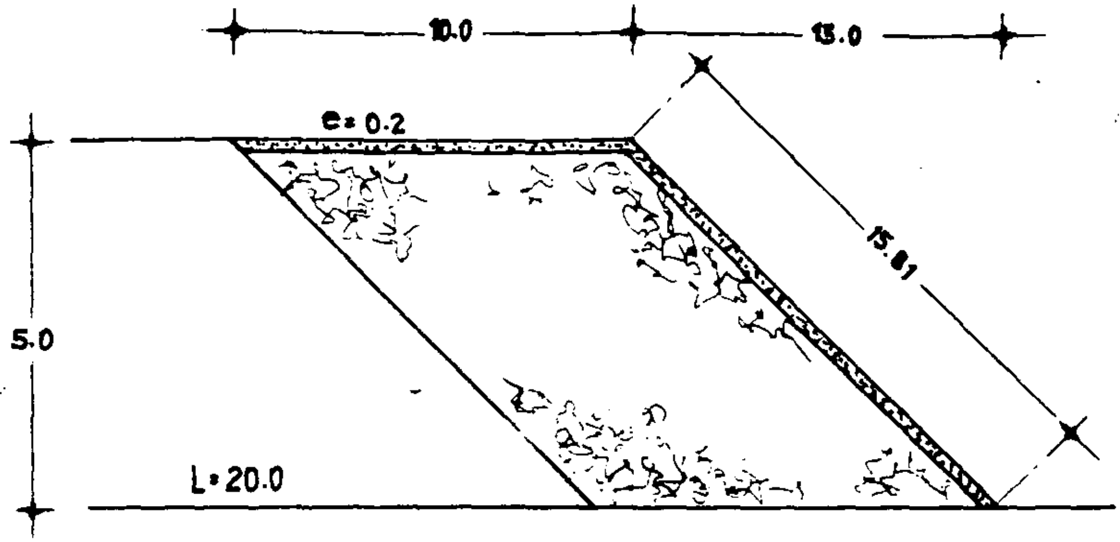
La finalidad de la cobertura diaria es evitar los impactos causados por:

- La proliferación de fauna nociva
- La dispersión de basura ligera por el viento
- Los malos olores
- La infiltración de agua pluvial
- Presencia de biogás y riesgo de incendios
- Estética.

El tipo de material a emplear (arcilloso o granular) se propondrá de acuerdo a la función de control de impactantes que tenga mayor jerarquía.

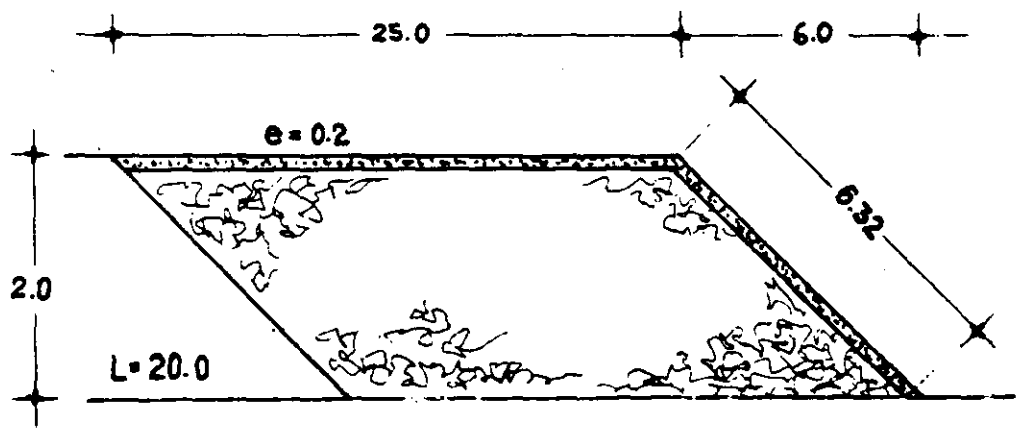
El espesor de la cubierta diaria suele considerarse entre 15 y 25 cm, haciéndose mayor en zonas en las que no se operará por más de un mes (unos 30 cm.). La cobertura final del relleno suele llegar a un espesor de 60 cm.

La relación entre el volumen de material de cubierta y el volumen de residuos varía entre el 10 % y 25 %, siendo menor a mayor altura de la celda, aunque esta altura debe mantenerse dentro del rango de eficiencia operativa.



Vol. Residos:	5.0 X 10.0 X.20 =	1,000 m^3
Vol. cubierta frontal	0.2(15.81)(20.0) =	63.2 m^3
Vol. cubierta lateral	0.2(10.00)(5.0) =	50.0 m^3
Vol. cubierta superior	0.2(10.00)(20.0) =	40.0 m^3
		153.2 m^3

$$\% = \frac{153.2}{1000} \times 100 = 15.3$$



Vol. Residos:	20 X 25.0 X 20 =	1,000 m^3
Vol. cubierta frontal	0.2(6.32)(20.0) =	25.3 m^3
Vol. cubierta lateral	0.2(25.0)(2.0) =	50.0 m^3
Vol. cubierta superior	0.2(25.00)(20.0) =	100.0 m^3
		175.3 m^3

$$\% = \frac{175.3}{1000} \times 100 = 17.5$$

Una estimación del volumen total de cobertura se calcula:

$$V_t = (Vcd \times V.U.) + C$$

Donde:

V_t : Volumen total de cobertura

Vcd : Volumen de cubierta de la celda diaria

V.U : Vida útil del relleno (dias hábiles)

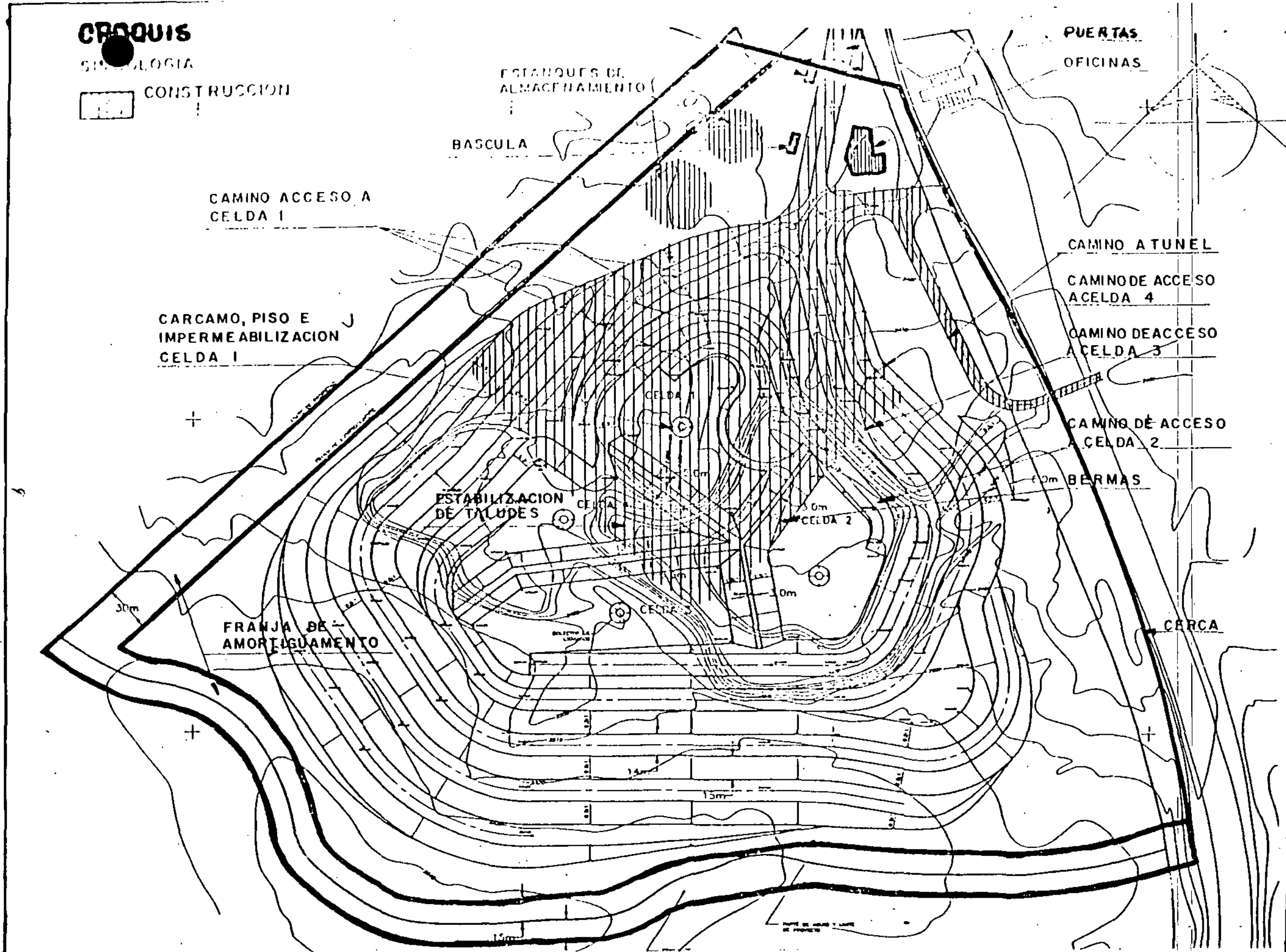
C : Volumen de la cobertura final

La obtención del material de cubierta es un aspecto fundamental de la operación de un relleno. Algunas fuentes son:

a) Compensación con excavaciones in-situ
b) Despalme de la superficie del terreno
c) Cortes en laderas de algún cerro colindante
d) Acarreo desde bancos de material
e) Uso de escombro u otros residuos de construcción.

VIDA UTIL

- Altimetría y planimetría del sitio con el objeto de encontrar el volumen disponible.
- Proyección de población para años futuros.
- Generación pér-capita en Kg/hab-día (incluyendo los residuos de origen no domiciliario). Y considerando un incremento del 1% anual en el valor de ésta generación.
- Peso volumetrico alcanzado por los residuos sólidos en un relleno sanitario (750 - 900 kg/m^3).
- Material de cubierta depende de la altura de la celda diaria.


CROQUIS
CONSTRUCCION
ESTANQUES DE ALMACENAMIENTO
BASCULA
CAMINO ACCESO A CELDA 1
CARCAMO, PISO E IMPERMEABILIZACION CELDA 1
PUERTAS
OFICINAS
CAMINO A TUNEL
CAMINO DE ACCESO A CELDA 4
CAMINO DE ACCESO A CELDA 3
CAMINO DE ACCESO A CELDA 2
BERMAS
ESTABILIZACION DE TALUDES
CELDA 1
CELDA 2
FRANJA DE AMORTIGUAMENTO
CERCA
30m
15m

DISEÑO DEL RELLENO

- Proyección de la Generación de los Residuos Sólidos
- Dimensionamiento de la Celda diaria
- Requerimientos Volumétricos del Relleno Sanitario
- Cálculo de la Capacidad Volumétrica del Sitio
- Cálculo de la Vida Util del Sitio
- Calendarización del Relleno Sanitario

1.-PROYECCION DE LA GENERACION DE LOS RESIDUOS SOLIDOS

AÑO	POBLACION	GENERACION	PROYECCION DE LA GENERACION (2)			
	EQUIV.	PER-CAPITA	DIARIA	MENSUAL	ANUAL	
		(1)			PARCIAL	ACUMULADO
1992	2194044	1	2194.044	65821.32	800826.1	800826.1
1993	2222105	1.01	2244.326	67329.78	819179	1620005
1994	2251025	1.0201	2296.271	68888.12	838138.8	2458144
1995	2280863	1.030301	2349.975	70499.26	857741	3315885
1996	2311691	1.040604	2405.555	72166.65	878027.6	4193912
1997	2343583	1.05101	2463.129	73893.88	899042.1	5092955
1998	2376613	1.06152	2522.823	75684.68	920830.2	6013785
1999	2410868	1.072135	2584.777	77543.31	943443.6	6957228
2000	2446438	1.082857	2649.142	79474.26	966936.8	7924165

NOTAS:

(2): Valores en toneladas.

2.-DIMENSIONAMIENTO DE LA CELDA DIARIA

AÑO	GENERACION DIARIA DE BASURA (1) EN TONS.	GENERACION DIARIA DE BASURA (1) EN M3.	DISEÑO DE LA CELDA DIARIA (2) ALTURA -D-	FRENTE -F-	FONDO -P1-	ALT. TOTAL -H- (3)	NO. CELDAS POR HECTAREA(4)
1992	2194.044	2194.044	2.85	50	15.3968	3	12.98971
1993	2244.326	2244.326	2.85	50	15.74966	3	12.69869
1994	2296.271	2296.271	2.85	50	16.11418	3	12.41143
1995	2349.975	2349.975	2.85	50	16.49106	3	12.12779
1996	2405.555	2405.555	2.85	50	16.88109	3	11.84758
1997	2463.129	2463.129	2.85	50	17.28512	3	11.57065
1998	2522.823	2522.823	2.85	50	17.70402	3	11.29687
1999	2584.777	2584.777	2.85	50	18.13879	3	11.0261
2000	2649.142	2649.142	2.85	50	18.59047	3	10.7582

NOTAS:

(3): Incluye tanto a la altura de la celda (D),como al espesor de la cubierta diaria de tierra (E1).

(4): Este número de celdas,es por cada capa de relleno sanitario.

3.-REQUERIMIENTOS VOLUMETRICOS DEL RELLENO SANITARIO.

AÑO	VOL. REAL DE CELDA -V1- (1)	SUP. HOR. DE CELDA -A- (2)	VOL. DIARIO MAT. CUBTA. -V2- (1)(3)	VOL. TOTAL DE CELDA -V- (1)	REQUERIMIENTOS VOLUMETRICOS ANUALES (1)					
					BASURA		MAT. DE CUBIERTA(4)		SUMA	
					PARCIAL	ACUMUL.	PARCIAL	ACUMUL.	PARCIAL	ACUMUL.
1992	2194.044	769.84	177.9901	2372.034	800826.1	800826.1	64966.37	64966.37	865792.4	865792.4
1993	2244.326	787.4828	180.9738	2425.3	819179	1620005	66055.43	131021.8	885234.4	1751027
1994	2296.271	805.709	184.0562	2480.327	838138.8	2458144	67180.5	198202.3	905319.2	2656346
1995	2349.975	824.5528	187.243	2537.218	857741	3315885	68343.7	266546	926084.7	3582431
1996	2405.555	844.0544	190.5411	2596.096	878027.6	4193912	69547.5	336093.5	947575	4530006
1997	2463.129	864.2559	193.9575	2657.087	899042.1	5092955	70794.5	406888	969836.6	5499843
1998	2522.823	885.2009	197.4997	2720.322	920830.2	6013785	72087.4	478975.4	992917.6	6492760
1999	2584.777	906.9392	201.1761	2785.953	943443.6	6957228	73429.26	552404.6	1016873	7509633
2000	2649.142	929.5235	204.9955	2854.137	966936.8	7924165	74823.35	627228	1041760	8551393

NOTAS:

(1): Valores en m3.

(2): Valores en m2.

(3): La cobertura de la celda diaria, incluirá los siguientes elementos:

- Talud inclinado del frente de trabajo.
- Piso superior de la celda (superficie superior terminada).
- Costado derecho de la celda, respecto al ataque del frente de trabajo. El otro costado, quedará implícitamente cubierto al ejecutar el relleno sanitario en forma adecuada, siguiendo el metodo operativo seleccionado.

(4): Debe considerarse un incremento en los requerimientos de material de cubierta, del 4 %, por Ha. y por capa del relleno, para la cobertura de los taludes.
Considerese además un volumen aproximado de 40500 m3. de material de cubierta, para la cobertura o sello final del relleno. Esta cubierta se [redacted], aplic[redacted] solo en las superficies horizontales de dicho relleno, hasta alcanzar un espesor promedio de: .45 m.

4.- CALCULO DE LA CAPACIDAD VOLUMETRICA DEL SITIO.

PARA TERCERA

CURVA DE NIVEL	AREA SUPERFICIAL	VOLUMENES EN M3. (1)			
ELEVACION	PROMEDIO	DE RELLENO		DISP. DE BASURA	
(MTS.)	(M2.)	PARCIAL	ACUMUL.	PARCIAL	ACUMUL.
2431	54300	0.0	0.0	54300	54300
2432	54900	0.0	0.0	54900	109200
2433	55500	0.0	0.0	55500	164700
2434	56100	0.0	0.0	56100	220800
2435	56700	0.0	0.0	56700	277500
2436	57300	0.0	0.0	57300	334800
2437	57900	0.0	0.0	57900	392700
2438	58500	0.0	0.0	58500	451200
2439	59100	0.0	0.0	59100	510300
2440	59750	0.0	0.0	59750	570050
2441	60400	0.0	0.0	60400	630450
2442	61000	0.0	0.0	61000	691450
2443	61600	0.0	0.0	61600	753050
2444	62350	0.0	0.0	62350	815400
2445	62900	0.0	0.0	62900	878300
2446	63350	0.0	0.0	63350	941650
2447	64000	0.0	0.0	64000	1005650
2448	64600	0.0	0.0	64600	1070250
2449	65200	0.0	0.0	65200	1135450
2450	65800	0.0	0.0	65800	1201250

NOTAS:

(1): Los volumenes de la tabla, tienen como limite superior en el sitio, la curva de nivel indicada.

Nivel de Desplante, propuesto para el relleno sanitario en la etapa que se analiza : 2430 mts.
Elev. de piso menor, para esta etapa: 2430 mts.
Elev. de piso mayor, para esta etapa: 2450 mts.
Equidistancia entre curvas de nivel: @ 1 mts.

5.-CALCULO DE LA VIDA UTIL DEL SITIO

PARA TERCERA

DEMANDA VOLUMETRICA PARA DISPONER LA BASURA					**	OFERTA VOLUMETRICA DEL SITIO PARA LA DISPOSICION DE LAS BASURAS				
AÑO	POBLACION (HABS.)	REQUERIMIENTOS VOLUMETRICOS (1) DIARIOS(M3.)	ANUALES(M3.) PARCIAL	ACUMUL.	**	ELEVACION (MTS.)(2)	CAPA No.	AREA PROM. SUPERFICIAL (M2.)	OFERTA VOLUMETRICA DEL SITIO PARCIAL (M3.)	ACUMUL. (M3.)
1992	2194044	2372.034	865792.4	865792.4	**	2433	1	54900	164700	164700
1993	2222103	2425.3	885234.4	1751027	**	2436	2	56700	170100	334800
1994	2251025	2480.327	905319.2	2656346	**	2439	3	58500	175500	510300
1995	2280863	2537.218	926084.7	3582431	**	2442	4	60387.5	181162.5	691462.5
1996	2311691	2596.096	947575	4530006	**	2445	5	62300	186900	878362.5
1997	2343583	2657.087	969836.6	5499843	**	2448	6	63987.5	191962.5	1070325
1998	2376613	2720.322	992917.6	6492760	**					
1999	2410565	2785.953	1016873	7509633	**					
2000	2446435	2854.137	1041760	8551393	**					

NOTAS:

(1): Valores que incluyen tanto al material de cubierta, como a los residuos sólidos.

(2): La elevación corresponde en el sitio, al límite superior de la capa indicada en la tabla.

La cantidad total de basura y material de cubierta que puede recibir el sitio en esta etapa, será de: 1070325 m3.

La cantidad total de basura generada entre: 1992 y 2000 , la cual deberá ser dispuesta sanitariamente, incluyendo al material de cubierta, será de: 8551393 m3.

6.- CALENDARIZACION DEL RELLENO SANITARIO.

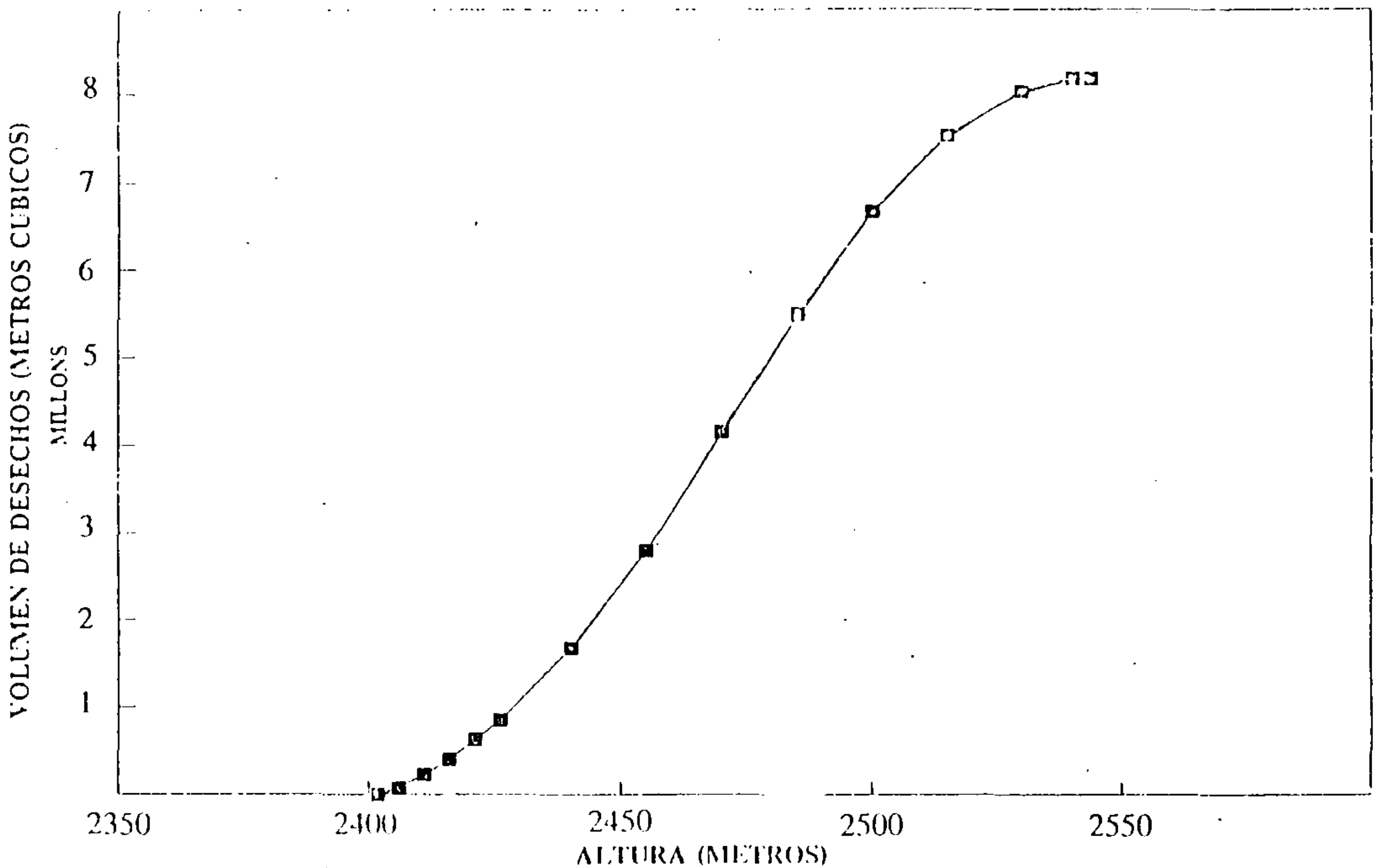
PARA TERCERA

AÑO	CAPA No.	No. CELDAS DIARIAS	VOL. DE LA CELDA DIARIA(M3.)	ELEVACION (MTS.)
1993	1	68	2425.3	2433
1993	2	70	2425.3	2436
1993	3	61	2425.3	2439
1994	3	11	2480.327	2439
1994	4	73	2480.327	2442
1994	5	75	2480.327	2445
1994	6	77	2480.327	2448

NOTAS:
Necesitas buscar otro sitio para disponer: 6649655 m3. de basura, que serán generados entre: 1994 y 2000

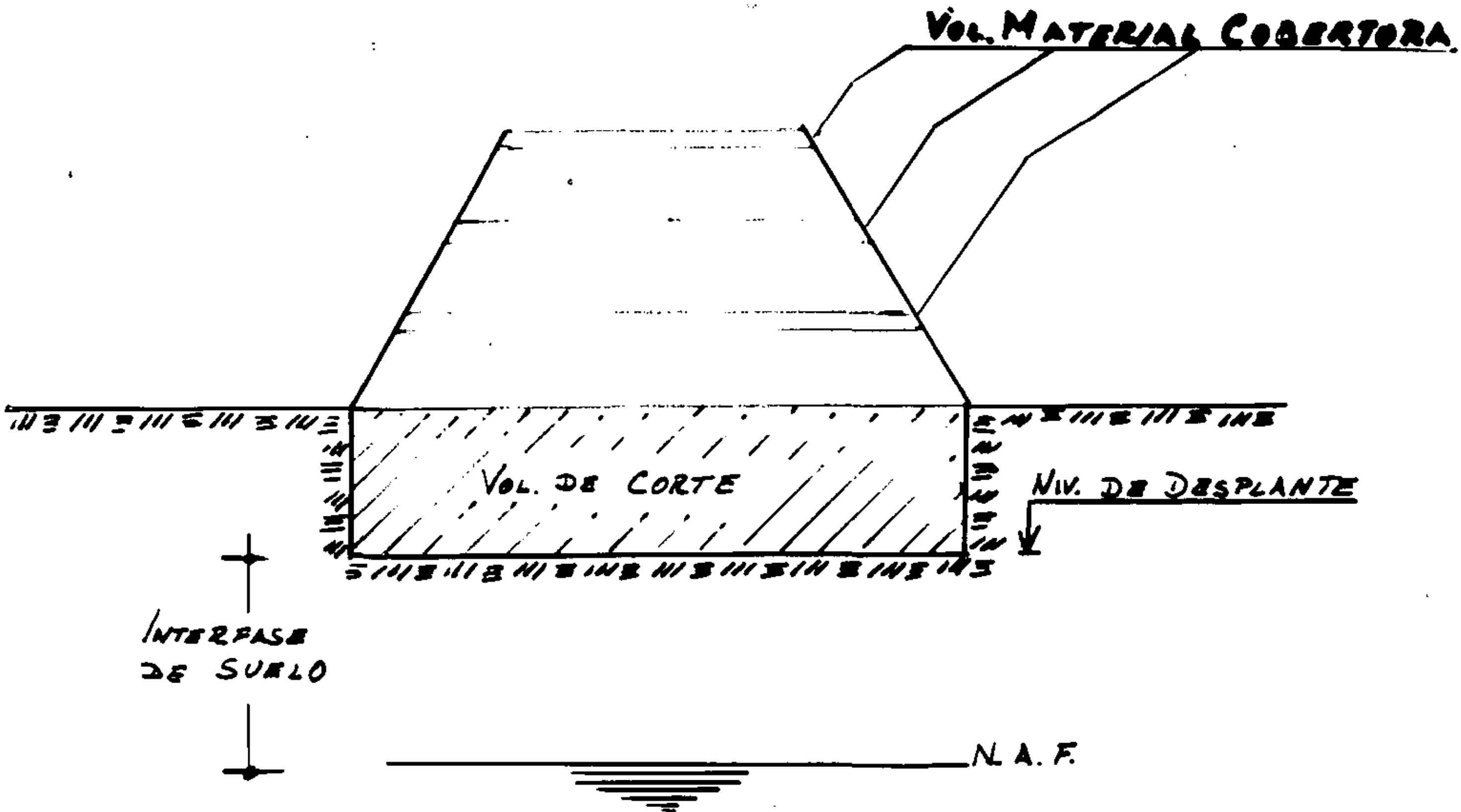
FIG -3.9.1 CURVA VOLUMEN - ALTURA

PARA EL RELLENO SANITARIO DE HUIXQUILUCAN



NOTA: SE CALCULA QUE EL 90 PORCIENTO DEL VOLUMEN CONSISTE DE LOS DESECHOS Y EL 10 PORCIENTO CONSISTE DE LOS MATERIALES DE COBERTURA Y DE BERMAS.

ESTABLECIMIENTO DEL NIVEL DE DESPLANTE



a) CRITERIO CONSTRUCTIVO

EL NIVEL DE DESPLANTE IDEAL ES AQUEL QUE PRODUZCA UN VOLUMEN DE CORTE IGUAL AL VOLUMEN DE MATERIAL REQUERIDO PARA LA CUBIERTA DIARIA Y FINAL

b) CRITERIO PREVENTIVO DE CONTAMINACION

1.- CALCULO DE LA INTERFASE DE SUELO PARA LA REMOCION DE LA CONTAMINACION INORGANICA.

2.- CALCULO DE LA INTERFASE DE SUELO PARA LA REMOCION DE LA CONTAMINACION ORGANICA.

MECANISMO DE CONTAMINACION DEL SUELO

- ADVECCION
- DISPERSION
- DIFUSION MOLECULAR
- INTERACCION HIDROQUIMICA

- ADVECCION

Transferecia de contaminantes con la misma velocidad y dirección con que se mueve el agua que los transporta. Es el principal macanismo de tal manera que si se eliminan los otras procesos, el módelo casi no se altera.

La advección por el flujo de agua subterranea tiene un rango:

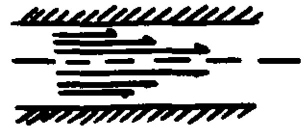
10^{-6} cm/seg. $\leq V \leq 10^{-1}$ cm/seg.

- DISPERSION

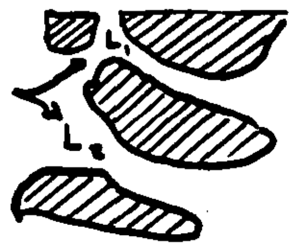
Fenómeno de aspersado causado por las variaciones de velocidad.

La dispersión es función de la acción mecánica.

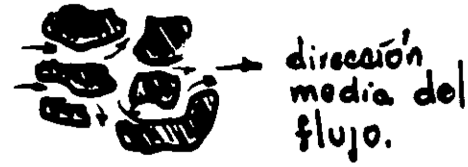
ACCION MECANICA



El hecho de que el fluido es viscoso implica una velocidad nula sobre la superficie sólida, creando un gradiente de velocidad en la fase líquida de los tubos capilares.



Las variaciones de las dimensiones de los poros crean discrepancia entre las velocidades a lo largo de los ejes de los poros. Si $L_1 < L_2 \Rightarrow V_1 > V_2$



Las lineas de corriente fluctuan con respecto a la dirección media del flujo.

- DIFUSION MOLECULAR

Tiene validez (aplicabilidad) cuando la velocidad del agua subterránea es casi nula.

Está regida por la 1a. Ley de FICK

$$F = -Dm \frac{dc}{dx}$$

La masa de contaminantes difundida, que pasa por una sección transversal, dada por unidad de tiempo, es proporcional al gradiente de concentración del contaminante.

- INTERACCION HIDROQUIMICA

Entre el fluido y el suelo a veces ocurren procesos importantes que cambiarán la calidad del agua subterranea por los constituyentes químicos disueltos.

MECANISMO DE ATENUACION DE LA CONTAMINACION DEL SUELO

- FILTRACION
- ABSORCION
- ADSORCION
- ACCION BACTERIOLOGICA

- FILTRACION

La capa de suelo que existe entre la SUPERFICIE [redacted] y el nivel de aguas freáticas actúa como un filtro natural. Los sólidos orgánicos retenidos son estabilizados por la acción bacteriana, y los inorgánicos pueden cambiar sus características por acción química.

Limitante: sólo retiene partículas suspendidas dependiendo de la porosidad del suelo.

- ABSORCION

Este mecanismo funciona reteniendo la humedad y varios elementos contenidos en el lixiviado, el tiempo suficiente para que un proceso químico y/o bacteriológico se presente.

MECANISMO DE ATENUACION DE LA CONTAMINACION DEL SUELO

(Continuación)

- ADSORCION

Ocurre cuando una molécula cargada (ión) del lixiviado pasa sobre una partícula de suelo que contiene una carga contraria, a la cual se adhiere.

Un suelo teniendo una buena característica de intercambio catiónico, tiene un gran potencial de retención de los contaminantes presentes en el lixiviado.

(2) —

- ACCION BACTERIOLOGICA

Básicamente la acción bacteriológica actúa acompañada de los mecanismos antes descritos, cuando se presenta material orgánico.

(3) —

EJEMPLO:

Determinar la cantidad de suelo necesario para intercambiar los cationes de 15 m^3 de líquido percolado, si el peso volumetrico del suelo es de 1,800 Kg/m^3 y su capacidad de intercambio cationico CIC es de 25 meq. por 100 grs. La composición del líquido percolado es la siguiente:

(4)

Ca^{++} = 800 mg/Lt.
Mg^{++} = 1,000 mg/Lt.
Na^{+} = 150 mg/Lt.
Fe^{++} = 60 mg/Lt.
Zn^{++} = 600 mg/Lt.

1er. PASO CALCULO DE LA CONC. CATIONICA

Catión	Conc. mg/ℓ	PEquiv. (P.A/valencia)	Conc. meq/ℓt
Ca^{++}	800	20 mg/ℓ	40.00.
Mg^{++}	1,000	12.15	82.30
Na^{+}	150	23.00	6.50
Fe^{++}	60	28.00	2.14
Zn^{++}	600	32.60	18.64
			149.58~150 meq./ℓ

2o. PASO GRAMOS DE SUELO REQUERIDOS/LT DE LIXIVIADOS

$$= \frac{150 \text{ meq}/\ell}{25 \text{ meq}/100 \text{ gr. suelo}} = \frac{15{,}000 \text{ gr suelo}}{25\ \ell \text{ de lix}}$$

= 600 grs. de suelo/ℓ de lixiviado

= 600 Kg. de suelo/m^3 de lixiviado

3o. PASO M^3 DE SUELO NECESARIO

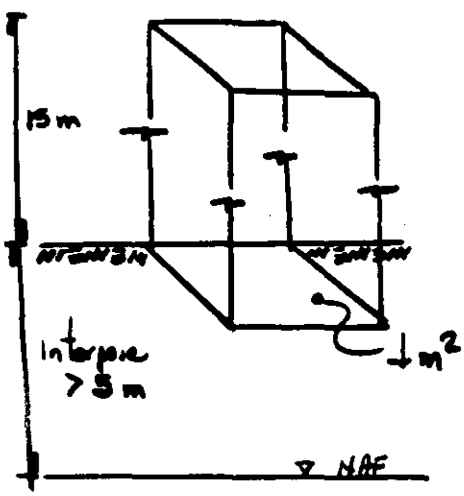
$$= \frac{600 \text{ Kg. de suelo/m}^3 \text{ de lixiviados}}{1{,}800 \text{ Kg/m}^3 \text{ de suelo}}$$

= 0.33 m^3 de suelo/m^3 de lixiviado

Finalmente para remover la carga cationica contenida en los 15 m^3 descargados al suelo requerimos:

$$= 0.33 \frac{\text{m}^3 \text{ de suelo}}{\text{m}^3 \text{ de lixiviado}} \times 15 \text{ m}^3 \text{ de lixiviados}$$

= 4.9 m^3 de suelo ≈ 5 m^3 de suelo



2.2.- Análisis de la Contaminación del Suelo por Carga Catiónica.

Este análisis, se realizará empleando la siguiente formulación:

$$I = 4 \frac{C}{CIC(PV)} i \quad \text{- - - - - - - - -} \quad (2.2.1)$$

Donde:

C = 411 meq/l., que es la concentración catiónica del lixiviado.

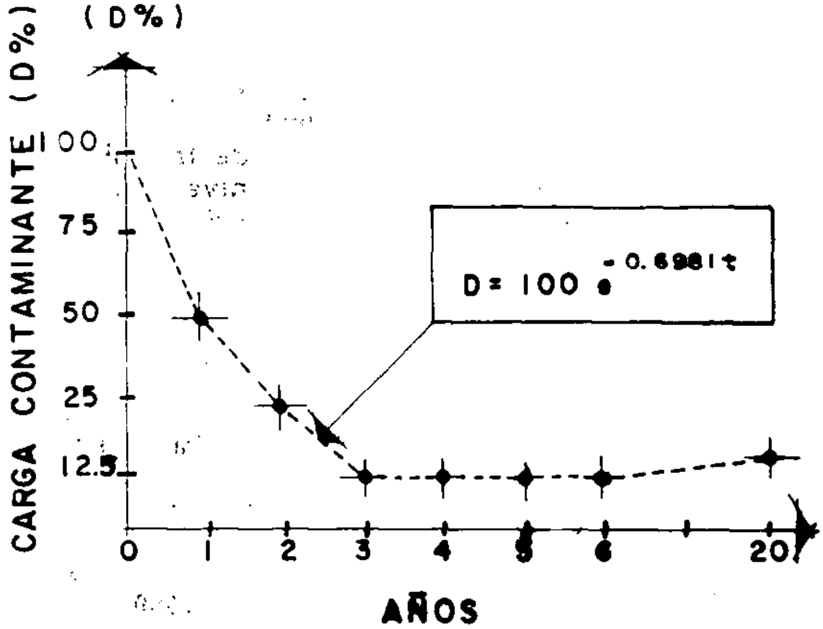
CIC = Capacidad de intercambio catiónico del suelo, en meq/100gr. de material.

PV = Peso Volumétrico del Suelo (kg/m^3)

i = Humedad lixiviable de los residuos sólidos, en m/m^2 - año.

I '= Interfase de suelo requerida para atenuar la contaminación por carga catiónica, en mts.

2.3.- Análisis de la Contaminación del suelo por Carga Orgánica.



t(AÑOS)	D %	Σ D%
0	100	100
1	50	150
2	25	175
3	12.5	187.5
4	12.5	200
.	.	.
.	.	.
.	.	.
20	12.5	400

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