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22419

12 September 2000

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

US/RAS/92/120

Regional Programme for Pollution Control in the Tanning Industry in South-East Asia

Manual on LANDFILL FOR TANNERY SLUDGE

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FOREWORD

UNIDO's Regional Programme for Pollution Control in the Tanning Industry in South East Asia has been focusing on introduction of cleaner technologies in the tanneries of the region with a view of reducing the pollution load generated by them and providing technical assistance for installation of cost effective effluent treatment systems. In many countries of the region, however, it has not yet been recognised that treatment of liquid effluent from tanneries also involves disposal of the sludge generated in the process.

The presence of chromium in the sludge generated by tannery effluent treatment plants has necessitated it being classified as a hazardous waste in many countries. It may, however, be mentioned that there are a number of countries, e.g. the USA and European Union, where sludge from tannery effluent treatment plants has been delisted from the category of hazardous wastes. Most countries of the South East Asia region, as of now, regard sludge from tannery effluent treatment plants as hazardous.

Many trials are currently on-going for possible conversion of sludge into usable by-products. Composting of sludge by combining it with organic wastes, biomethanation of sludge by combining it with organic wastes, solidification of sludge by combining it with clay, fly ash, etc. are some of these. The acceptance and wider application of these conversion technologies will depend, to a great deal, on the attitude of the pollution control authorities and the acceptance of the products by the customers. It is, however, expected that a sizeable quantity of sludge will remain to be disposed in safe landfill, even if a part of it could be converted as by-products.

Accordingly, a safe landfill for disposal of tannery sludge may be designed cost effectively if only tannery sludge is disposed there. This manual sets out how to set up, operate, maintain, monitor and close the safe landfill site for tannery effluent sludge. In preparation of this manual contributions have been made by experts of CTC, France and UNIDO's own specialists.

It is hoped that this publication will be found to be of use by the pollution control authorities, tanners, Research and Development organisations and others interested in the subject.

Suggestions for improvement are welcome.

Chennai
July 1999

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LIST OF SYMBOLS & ABBREVIATIONS:

BOD_5	:	Biochemical oxygen demand, 5 days
COD	:	Chemical oxygen demand
CETP	:	Common effluent treatment plant
Cr (III)	:	Trivalent chromium
Cr (VI)	:	Hexavalent chromium
^{o}C	:	Degree Celsius
DS	:	Dry solids
d	:	Day
dia	:	Diameter
d.w.	:	Dry weight
EC	:	Electrolytic conductivity
EIA	:	Environmental impact assessment
ETP	:	Effluent treatment plant
h	:	Hour(s)
H	:	Height
ha	:	Hectare
HDPE	:	High density polyethylene
HP	:	Horse power
kg	:	Kilogram
kJ	:	Kilojoule
kW	:	Kilowatt
l/s	:	Liter per second
m	:	Meter
m/s	:	Meter per second
m^3	:	Cubic meter (1000 liters)
mg/l	:	Milligrams per liter
min	:	Minute
no.	:	Number
PVC	:	Polyvinyl chloride
ppm	:	Parts per million
pc	:	Piece(s)
pH	:	Negative logarithm of hydrogen ion concentration
S	:	Sulphide
s	:	Second
SS	:	Suspended solids
SWD	:	Side water depth
TNPCB	:	Tamil Nadu Pollution Control Board
t	:	Tonne (1000 kg)
TDS	:	Total dissolved solids
UNEP	:	United Nations Environmental Programme
USEPA	:	United States Environmental Protection Agency
UNIDO	:	United Nations Industrial Development Organization
W	:	Watt
WHO	:	World Health Organization

Definitions

« **Access road** » a road that leads from a public road to a waste disposal site
« **Active life** » the period of operation beginning with the initial receipt of waste and ending at completion of closure activities
« **Approved** » means authorised in writing or specified in writing with or without conditions or requirements, by the relevant authority
« **Aquifer** » includes any soil or rock formation that has sufficient porosity and water yielding ability to permit the extraction or injection of water at reasonably useful rates
« **Buffer zone** » land used to separate a facility from other land
« **Cell** » a compartment within a landfill isolated from other compartments by appropriate cover material and of such size so as to be considered manageable in the context
« **Cover material** » soil or other material approved for use in sealing cells in landfills
« **Design volume** » the maximum volume of waste, including cover material, to be discharged at the solid waste management facility during its active life
« **Final cover** » a layer consisting of soil and, in some cases, other natural or synthetic material that is placed on the landfill surface where no additional solid waste will be deposited and serves to restrict infiltration of precipitates, to support vegetation, to restrict access by wildlife, and to promote surface drainage
« **Floodway** » the channel of the watercourse and those portions of the floodplains which are reasonably required to discharge the flood flow of a designated flood. Minimum required floodway is equal to the width of the channel within the natural boundary plus a minimum setback of 30 meter from the natural boundary on each side of the channels unless otherwise approved
« **Groundwater** » water below the ground surface in a zone of saturation.
« **Infiltration** » is the entry into the soil or waste of water from the soil or solid waste surface
« **Intermediate cover** » compact layer of at least 0.3 meter of soil or functionally equivalent depth of other cover material placed where no additional waste has been or will be deposited within a period of x days (frequency to be decided by project manager and local authorities)
« **Leachate** » any liquid and suspended materials within it, which has percolated through or drained from the solid waste disposal facility
« **Liner** » a continuous layer of synthetic material, natural clay or earth material, placed beneath and at the sides of landfill and intended to restrict the downward or lateral escape of waste or leachate or in some cases to restrict the upward movement of ground water into the landfill
« **Scavenging** » uncontrolled removal of material from a solid waste facility
« **Stress cracking** » micro-fissures generated when welding, that may get bigger in time, mechanical pressure, chemical reaction and variation in temperature

1 INTRODUCTION

It is believed that landfill is the ultimate destination of tannery sludge in many countries. This is generally due to environmental legislation, quantity of sludge generated and limited conversion technologies currently available and / or acceptable. Under the Regional Programme for pollution control in the tanning industry it was decided to prepare a manual for use by the industry and environment authorities on design, operation and maintenance of a safe landfill for tannery sludge.

Chapter 2 briefly outlines sources of sludge generation and its characteristics. Data presented in this chapter is based on field samples collected in many countries.

Chapter 3 describes the regulatory requirements for the disposal of chrome containing tannery sludge.

Chapter 4 briefs the various treatment and disposal alternatives available for chrome containing tannery sludge.

Whatever be the method of treatment adopted for chrome containing tannery sludge, a residue always results. This residue has to be disposed in a safe landfill (with the notable exception of USA). One of the key issues is in proper selection of disposal site, its procedure is explained in Chapter 5. Also, it presents the salient features of design criteria for safe landfill with possible technical specifications.

Chapter 6 gives the construction and operation procedures of a safe landfill.

Chapter 7 gives the tentative cost analysis of safe landfill.

Chapter 8 presents the lay out details of landfill site.

As this manual has been planned to serve as a guideline for tanners, regulatory agencies and consultants, salient features only have been outlined. For further detailed study and information, readers are advised to refer to the bibliography given.

To sum up, design, construction, operation and monitoring of a landfill for tannery sludge will primarily be influenced by the legal requirements, site and sludge characteristics. This manual attempts to provide general guidelines, but for each selected site, specific design will have to be prepared. Considerations of investment and operational cost are very important factors. It is hoped that this manual will meet a felt need of the tanning industry, particularly in South East Asia, where environmental regulations are becoming stricter day by day.

2. QUANTITY AND CHARACTERISTICS OF TANNERY SLUDGE

2.1 Quantity of sludge

The solid waste generated from the tanning process is not considered in this manual. During the waste water treatment, two types of sludges are generated viz. sludge from primary treatment and (biological) sludge from secondary treatment (see Table 2.1). In general, both sludges are subjected to dewatering process to reduce the water content. This makes the sludge handling easier. The sludge volume generation depends mainly on the tanning process adopted.

As a rule of thumb, the amount of sludge (dry matter) generated from effluent treatment plant is:

- 2 to 4 kg per m^3 of effluent for wool skins
- 4 to 10 kg per m^3 of effluent in conventional bovine tannery

Table 2.1 Sludge generation in tannery effluent treatment plants

Type of tannery effluent treatment	kg DS/ tonne of raw hide
PRIMARY TREATMENT	
Mixing and sedimentation	80
Mixing + chemical treatment + sedimentation	150 – 200
Mixing + chemical treatment + flotation	150 – 200
BIOLOGICAL TREATMENT	
Primary + extended aeration	70 - 150
Primary + extended aeration + nitrification and denitrification	130 - 150
Primary + aerated facultative lagoons	100 - 140
Anaerobic lagoon	60 - 100

Source: The Environmental Commission of the IULTCS

A numerical example of the computation of sludge quantity from a typical tannery and a conventional effluent treatment plant (ETP) is given in **Annex 1.**

2.2 Characteristics of sludge

The characteristics of sludge depends on the tanning process and the effluent treatment methods. General characteristic of sludge is presented in **Table 2.2.**

Table 2.2 Characteristics of sludge from tannery ETP (dry basis)

Parameter	Raw to finish (chrome)	8 CETPs in Tamil Nadu
Source Country	**France**	**India**
Dry Matter (%)	18 - 40	9 - 33
Volatile solids (%)	50 - 60	32 - 69
Calorific value(kJ/kg)	10,000	--
pH	7 - 8	7.9 - 8.8
COD (mg/kg DS)	--	268,000 - 600,000
Chromium (mg/kg)	8,000 - 20,000	2,700 -39,100
Cadmium(mg/kg)	6	--
Aluminium (mg/kg)	5 - 15,000	--
Barium (mg/kg)	360	--
Chloride (mg/kg)	1,000 - 30,000	10,000 - 77,000

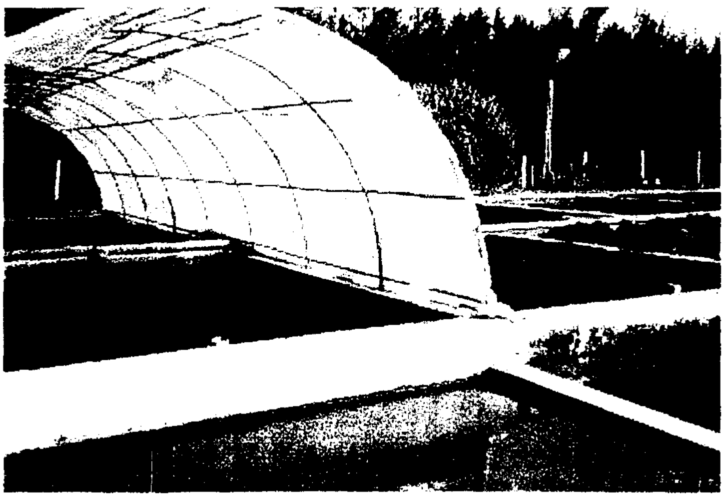
Parameter	Raw to finish (chrome)	8 CETPs in Tamil Nadu
Source Country	**France**	**India**
Sodium (mg/kg)	4,000 - 11,000	13,000 - 82,000
Calcium (mg/kg)	8,000 - 100,000	17,000 - 31,000
Carbon(%)	22	--
Sulphate (mg/kg)	--	2.3 - 14.8
Sulphide(mg/kg)	--	0.04 - 0.07
Sulphur(mg/kg)	500 - 2,000	--
Phosphorous(mg/kg)	1,000 - 4,000	17 - 840
Nitrogen(mg/kg)	10,000 - 60,000	--

In any case the sludge has to be dewatered before further handling. Climatic and space requirements will be among the most important factors to decide whether mechanical or natural dewatering methods are appropriate or a combination of both. In **Table 2.3** typical methods applied in case of tannery sludge and resulting solid contents are given.

Table 2.3 Typical solid content of sludge after various dewatering processes

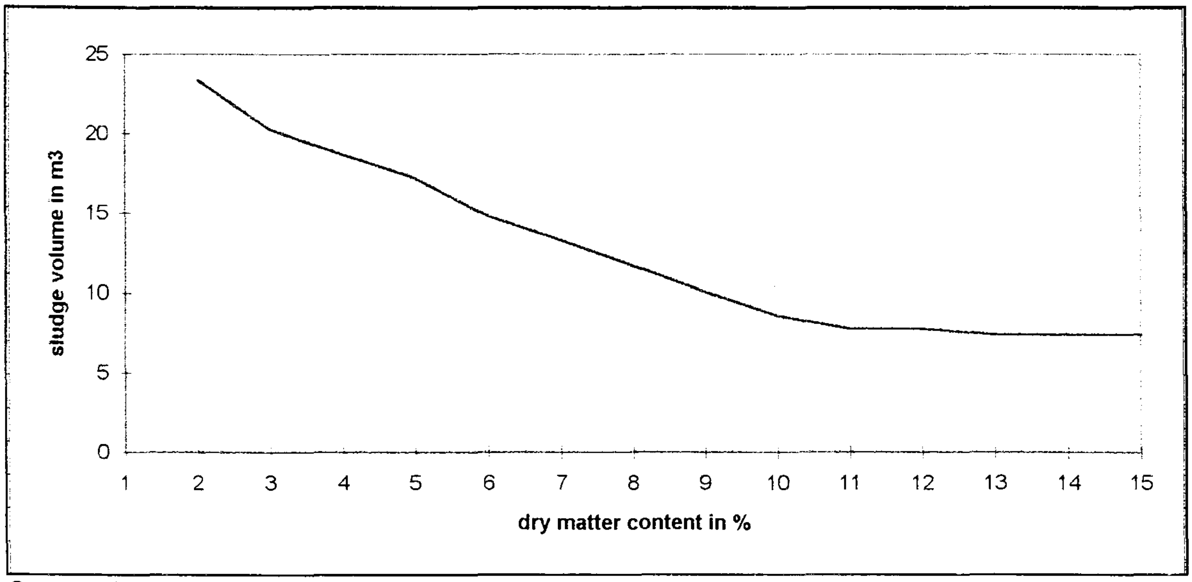
Dewatering system	*Solid content (% of dry solids)*
Primary sedimentation (liquid sludge)	**3 to 6**
Secondary sedimentation (aerobic)	**1 to 2**
Upflow anaerobic sludge blanket	**6 to 8**
Thickened sludge (by gravity)	**4 to 7**
Thickened sludge (mechanically)	**6 to 10**
Belt filter press	**20 to 25**
Centrifuge	**20 to 25**
Plate filter press	**30 to 35**
Sand drying beds (highly variable)	**30 to 50**
Drying in lagoons	**15 to 30**
Thermal drying	**90**

Photo 1: Sand drying beds at tannery ETP with trial to improve drying through partial cover



Chemicals may be added to expedite thickening and / or conditioning process of sludge. The lower the moisture content the less volume of sludge to be disposed, as is evident from the graph below.

Graph 2.1 Relation between sludge volume (m^3) and dry matter content sludge



Source: Sagana tannery, Kenya

3. LEGISLATION AND REGULATIONS CONCERNING DISPOSAL OF TANNERY SLUDGE

Only a few countries have regulations specifically concerning disposal of tannery sludge. In general, the sludge is categorised as hazardous waste due to presence of chromium. The impact due to indiscriminate disposal of chrome laden tannery sludge is presented in **Annex 2.**

China: In 1995, the Government of the People's Republic of China had prepared a national legislation for waste landfilling. The law contains general statements and basic principles for the matter but does not establish either technical criteria to be adopted nor standards to be respected for tannery sludge.

European Union: Chrome containing tannery sludge is considered as non-hazardous waste. A European Directive on landfill is under preparation and it is expected that restrictions will be placed on amounts and composition of waste (e.g. biodegradability) going to landfill. For the time being, tannery sludge is mostly disposed in landfill. Within the EU countries may have their own legislation too. For instance, in Germany, sludge with less than 900 mg/kg Cr (dry solids) may be applied directly on land. Even so, in 1998 less than 10 % of tannery sludge was applied on land and 90 % was disposed separately at municipal landfill sites. From 2005 onwards not more than 5 % organic matter in sludge is allowed. In France, dry content has to be above 30%.

India: Sludge from tannery effluent treatment plants is categorised as hazardous waste because of its chromium content and therefore has to be disposed of as per stringent environmental regulations pertaining to disposal of such hazardous waste. However, a new legislation is under consideration in which the level of chromium content will determine whether the sludge is hazardous or not. To be categorised as hazardous waste, chromium should be in excess of 5,000 mg/kg of chromium III and 50 mg/kg of chromium VI.

United States of America (USA): Based on a detailed scientific review, studies and as per verdict of courts of law, all the tannery solid waste materials including tannery sludge were delisted from the US list of regulated hazardous waste and there is no limit for chromium III in land-applied bio-solids. No ceiling limits (mg of Cr III/kg of dry sludge), no cumulative limits (kg of Cr III/ha) and no limits for Cr III in marketed bio-solids products. Landfilling (in solid waste disposal sites) and land-application are now the main options for tannery sludge in the United States.

The method of treatment and disposal specifically for tannery sludge, or the standards to comply, is not given in any other country.

Ocean disposal has been banned in all countries.

4. SLUDGE TREATMENT AND DISPOSAL OPTIONS

It is advantageous to prevent sludge from being generated and if generated, to convert the sludge into a by-product instead of disposing into a landfill.

The feasibility of conversion depends on the following conditions:

1. Sludge characteristics (moisture, chromium content etc.)
2. Environmental regulations
3. Quantity of sludge to be converted
4. Other factors for any technology: land, investment, operational as well as opportunity cost.

Following conversion methods are currently being applied / studied:

- Land application (application of sludge for agricultural purposes),
- Composting (aerobic biological treatment for biodegradable organic constituents),
- Biomethanation (in combination with other organic wastes such as fleshing) - anaerobic biological treatment breaking down organic molecules to methane (CH_4) and carbon dioxide (CO_2),
- Thermal treatment (any closed device using controlled flame combustion: fluidized bed, multiple bed incinerators, rotary kiln, pyrolysis),
- Utilisation as raw material for brick kiln (addition of sludge, clay and eventually lime or fly ash in order to produce brick in a thermic process),
- Production of light weight aggregates (addition of sludge, clay and eventually lime to produce light weight aggregates in a thermic process).

In **Annex 3** a more elaborate description of conversion methods is given with advantages and disadvantages of the most commonly used conversion technologies.

In most cases the residues from any sludge treatment units or sludge from ETPs will be disposed in safe landfill. The safe landfill is likely to be an important element in the sludge management.

If feasible, it is preferred to have a specific landfill for tannery sludge only, for various reasons such as:

1 Possible technical developments in conversion methods of sludge.
2 Co-disposal may increase the solubility of chromium present in the sludge.
3 Avoidance of mixing with other potentially hazardous and / or toxic wastes, which will increase investment and operational cost.
4 Without household refuse the chances of scavenging are greatly reduced.

Photo 2: Pilot safe landfill for tannery sludge set up at a tannery CETP in India

5 SAFE LANDFILL

5.1 Principle The main purpose of safe landfill is to prevent generation of leachate and to minimise the adverse impact on soil and water environment. Intermediate and final covers do not allow exposure of waste to water resulting in minimum leachate generation. The liners and drainage layer at the bottom of the landfill do not allow leachate to leave the landfill and thus prevent ground water contamination. Leachate has to be treated before disposal. Air pollution is not significant due to the absence of volatile organic compounds in tannery sludge. However, odour is likely to be present in case of insufficiently dewatered tannery sludge.

The key design criteria in establishment of a landfill are :

5.2. Site selection
5.3. Design period
5.4. Lay out
5.5. Liner systems
5.6. Drainage layer
5.7. Closure
5.8. Leachate treatment and disposal
5.9. Monitoring

5.2 Site Selection

The design of landfill is site specific. The proper site selection not only dictates its suitability but its economic viability too. Thus, this is a very important step. Elements to be considered are:

- <u>Land area required:</u> A typical landfill has an operational life span of 20 years and must be monitored for another 20 years after closure.

- <u>Location:</u> As close as possible to the sludge generation facility to reduce transport cost and avoid risks in transportation but away from habitation zone, minimum distance of 200 meters. A buffer zone has to be included (see Figure 9.1) and if feasible a green belt to separate the landfill from land under cultivation or used in any other manner. Must be located away from water supply sources (minimum suggested distance 1 km).

- <u>Access</u> should be an all weather road with adequate width and loading capacity and minimal congestion with easy access to major high and/or railways.

- <u>Topography:</u> Minimal earth movement preferred but avoidance of natural depression and valley, where water contamination is likely. A slope of 1-5 % is considered ideal. A slight sloping land prevents stagnation of rain water on the landfill sites (ponding). Excessive sloping (i.e. >5%) may result in erosion, run-off as well as the possibility of sludge not being contained and / or hamper the physical integrity of the site.

- <u>Geology:</u> Avoid areas prone to earthquakes, slides, faults, underlining mines etc.

- <u>Hydro-geological aspects:</u> Depth ground water table (minimum distance between highest groundwater table and bottom of landfill should be 1-2 meters, preferably more); located away from water supply sources (wells, aquifer); direction and rate of flow, hydraulic gradient, water quality, present and planned use etc. Recommended to be tackled through hydro-geological survey.

- <u>Soils:</u> Natural clay base or clay available for liner, final cover material available; stable soil/rock structure. Avoid sites with thin soil above groundwater, highly permeable soil above shallow groundwater and soils with extreme erosion potential. Recommended to be tackled through soil geological survey. **Permeability** is the amount of water that per time unit penetrates an area perpendicular to the flow. The permeability rate of different soils and travel time are presented in **Tables 5.1 & 5.2** respectively.

Table 5.1 Permeability of soil in meter / second (log scale)

Permeability m/s	**10^{0}**	**10^{-1}**	**10^{-2}**	**10^{-3}**	**10^{-4}**	**10^{-5}**	**10^{-6}**	**10^{-7}**	**10^{-8}**	**10^{-9}**
Drainage material	**Good**						**Poor**			**Almost impervious**
Soil types	**Clean gravel**	**Clean sands, clean sand and gravel mixtures**					**Very fine sands, organic and inorganic silts, mixtures of sand, silt and clay, stratified clay deposits**			

Source : USEPA

Table 5.2 Permeability and Travel Time

Soil Types	Permeability (m/s)	Time to travel 1 m
Fine gravel	10^{1} to 10^{-1}	less than 10 seconds
Sandy till	10^{-3} to 10^{-5}	17 minutes to 28 hours
Clayey till	10^{-7} to 10^{-9}	4 months to 31.7 years

Source: USEPA

- Hydrology: Areas with low rainfall and high evaporation rate, not affected by tidal water movements and seasonal high water table are preferred.

- Drainage: Areas with good surface drainage and easy control of runoff are preferred.

- Surface water: Protection of the site against floods is required. Avoid wetlands or other areas with high water tables.

- Groundwater: No contact with groundwater must be ensured. Base of landfill must be above high groundwater table by at least 1-2 m. Avoid sites above sole-source aquifers and areas of groundwater recharge.

- Air/wind direction: Areas where prevailing wind will carry-away any dust, emissions and odour to populated areas or ecologically sensitive areas should be avoided.

- Public health: Construction and operation should not adversely affect public health.

- Aesthetic: Isolated sites with minimum visual impact during construction and operation are preferred; sites should be designed considering surrounding landscape.

- Noise: Truck traffic and equipment operation noise should not create nuisance in nearby areas.

- Land use: Avoid populated areas and areas of conflicting land use such as parks, scenic areas, labour intensive industrial sector, recreational reserves, camp sites, sporting reserves, intensive agricultural area, areas zoned for future urban development etc..

- Cultural resources: Avoid areas of unique archaeological, historical and paleontological interest.

- Power and water: Areas with easy access to adequate power and water supply are preferred.

- Terrestrial and aquatic ecology: Avoid unique habitat areas (important to propagation of rare and endangered species) and wetlands. Avoid national parks, forests, flora and fauna reserves, and coastal areas.

In the USA, the site suitability for hazardous landfill is based on DRASTIC principles.

In India, the site selection procedure is based on screening and constraint mapping process. After initial screening process, the site is evaluated for its suitability based on the score obtained from 35 attributes.

The site selection procedure as developed by UNEP is presented in **Annex 4.**

A conceptual design of landfill is made to evaluate leachate generation and its impact. The probable impact due to proposed landfill is then assessed through EIA studies.

5.3 Design period

In general, the landfill is designed for an active period of 20 to 30 years. However, the landfill is constructed in modules of 3 to 5 years. While designing any landfill anticipated increase in sludge volume is considered. In addition, the volume of intermediate cover is also added to the anticipated sludge volume.

Figure 5.1.A. Landfill below ground level

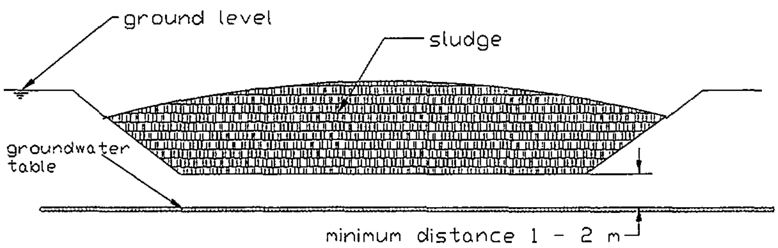


Figure 5.1.B. Landfill above ground level

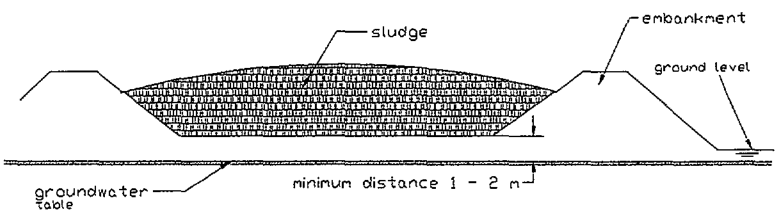
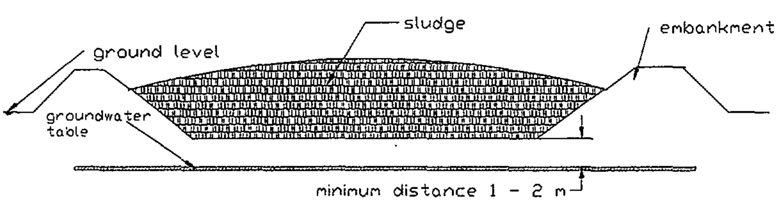


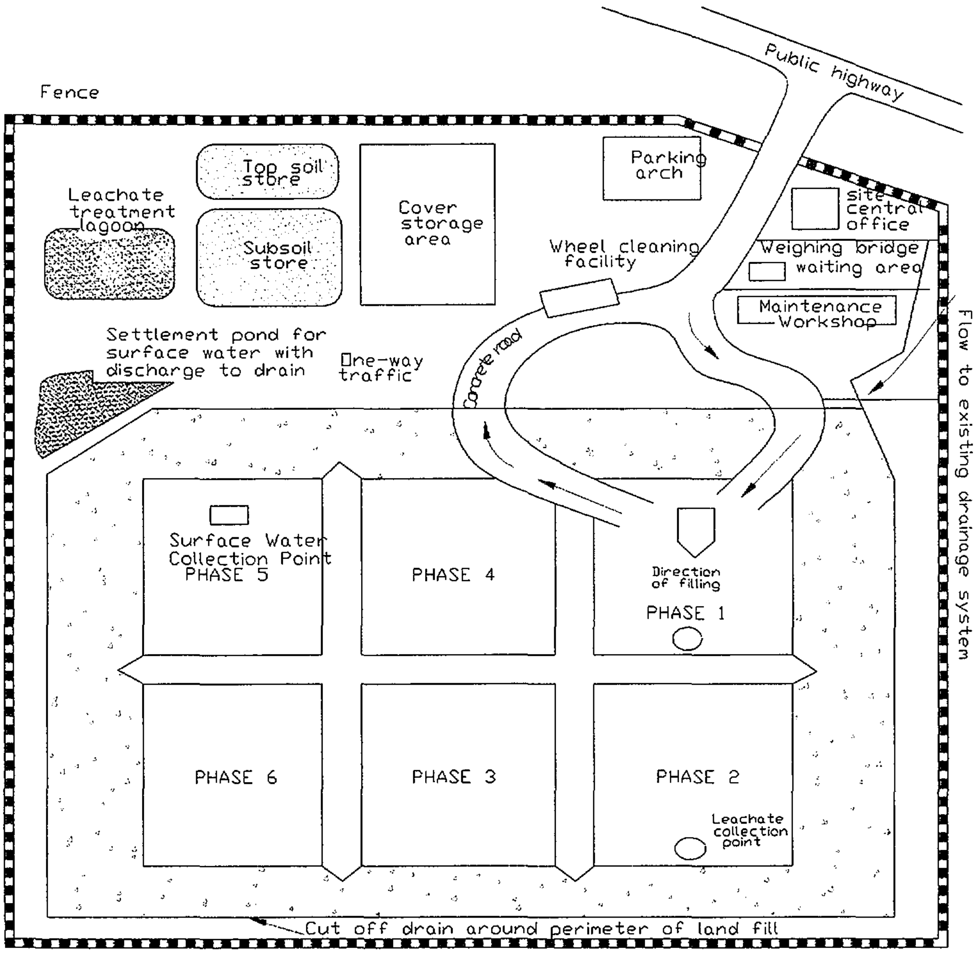
Figure 5.1.C Landfill partly above and partly below ground level



5.4 Lay out

The landfill can be constructed below (Figure 5.1.A), above (Figure 5.1.B) or partly above and partly below ground level (Figure 5.1.C). This depends on the soil and ground water table conditions. A typical landfill lay out with all facilities is given in **Figure 5.2.**

Figure 5.2 Typical operational landfill with facilities



5.5 Liner systems

A main purpose of landfill is to minimise ground water contamination i.e. leachate, once generated, should not be allowed to enter the soil media below landfill. This can be achieved through providing security barrier. Security barriers are known as liners. The liner materials to be used could either be natural clayey soil or synthetic flexible membrane liners (FMLs). The liners are provided at the bottom and on the sides of landfill. Among all the parameters, permeability or hydraulic conductivity of the liner material and compatibility with the wastes are of prime importance. The recommended permeability rate is 1 x 10^{-9} m/s. The type of soil that can be considered as liner material can be selected based on Table 5.1 and 5.2. In many countries USEPA legislation has been adopted. It specifies that if hydraulic conductivity is less than 10^{-9} m/s for 1 meter depth or 10^{-6} m/s for five meter depth, there is no need for an active security barrier.

From Table 5.1, it can be seen that in a few cases only no active security barrier is required. In other words, an active security barrier is required in most cases. Typically this comprises a liner with protection on both sides to avoid piercing / stress-cracking of liner. The specifications for liner materials are given in **Tables 5.3 and 5.4.** The testing methods are given in **Annex 5.**

Table 5.3 Specifications for Natural Clayey soil

Parameter	
Liquid limit	**25 – 35%**
Plasticity Index	**10 – 15**
Optimum Moisture Content	**16 to 20%**
Particle size (40-50%)	**0.06 – 0.08 mm**
Clay fraction	**20 – 25%**

Source : USEPA

Table 5.4 Specifications for high density polyethylene (HDPE)

Parameter	
Thickness	**>1 mm**
Colour	**Black**
Permeation rate	**< 0.9 g/m^2.h**
Density	**> 935 kg/m^3**
Thermal coefficient of expansion	**< 12.5 x 10^{-5}**
Tensile stress	**> 3,375,000 kg/m^2**
Puncture	**< 1.2 g/m**
Change in weight	**<10%**
Change in volume	**<10%**
Change in tensile strength	**<20%**
Change in elongation at break	**<30%**
Change in modulus	**<30%**
Change in hardness	**< 10%**

Source : USEPA

Two recommended liners for tannery sludge are high density polyethylene (HDPE) and asphalt or bentonite. A comparison between the these is given in **Table 5.5.** The liner is normally protected on both sides with layers of fine sand (sieved) or clay of at least 7.5 cm thickness. Fig. 5.3 (a - f) shows various liner systems.

Table 5.5 Comparison between HDPE and asphalt or bentonite liner

	High density polyethylene (HDPE)	**liner with asphalt or bentonite**
Welding of the liner	Not so easy due to waste dilatation	Quite easy
Chemical resistance	Compatible with most chemicals	Asphalt not compatible with hydrocarbons and solvents. Bentonite not compatible with alcohol.
Mechanical resistance	Stress cracking possible	Mechanically resistant
Thickness	1 to 2.5 mm (1 mm may suffice for tannery sludge)	2 to 4 mm for asphalt membranes
Hydraulic conductivity	10^{-14} m/s	10^{-14} m/s
Cost (per m^2)	≈ 10 US$ (depending on thickness)	10 to 15% more expensive than HDPE
Used for	Bottom of the landfill Sometimes landfill cover	Bottom of landfill when there is no chemical incompatibility with the waste. Landfill cover.

Fig. 5.3 a Natural clay liner

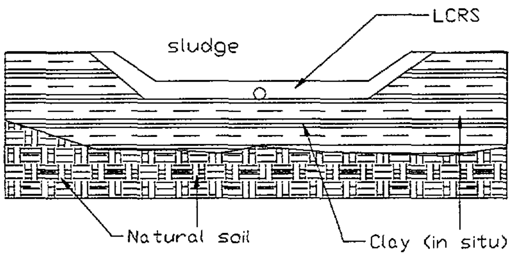


Fig 5.3 b Compacted clay liner

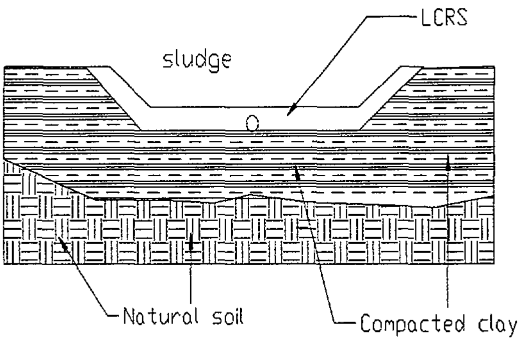


Figure 5.3 c Single synthetic liner

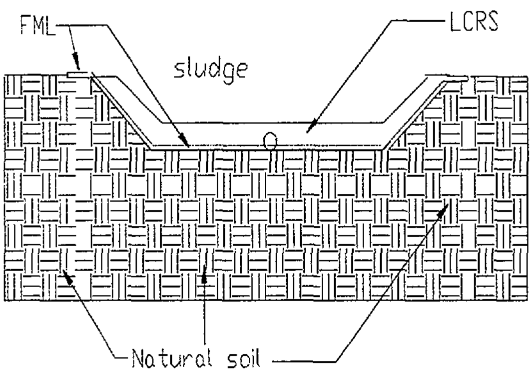


Fig 5.3 d Synthetic/clay double liner

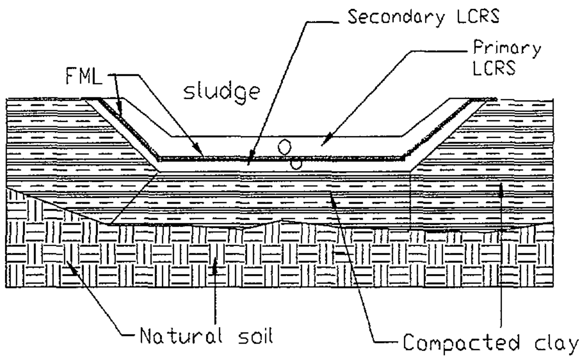


Fig 5.3 e Composite liner system

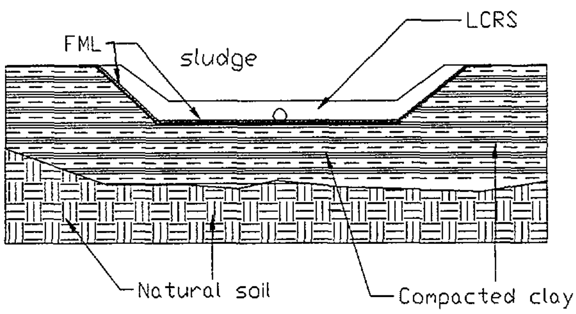
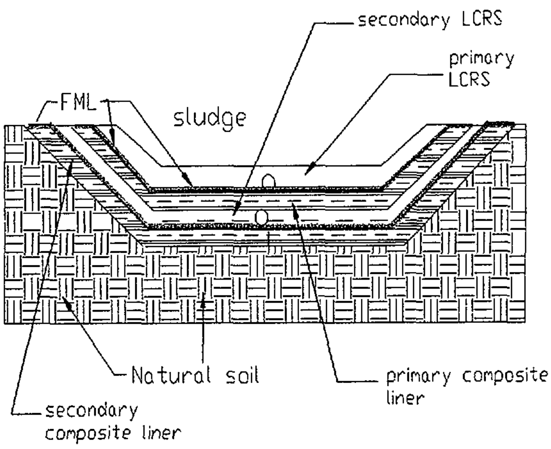


Fig 5.3 f Double composite liner



LCRS: leachate collection & recovery system
FML : flexible membrane liner

5.6 Drainage Layer

The leachate that is generated has to be collected. This is achieved through a drainage layer provided between the waste layer and native soil foundation.

The various drainage layer liner alternatives are given in **Figure 5.3.** The design of drainage layer may consist of gravel, sand, main & lateral pipes depending on the leachate generation. The leachate generation is directly proportional to rainfall and sludge moisture content. Based on the data generated in one of the pilot demonstration landfills in India, the sludge mass balance is computed and is presented in **Table 5.6.**

Table 5.6 Mass balance in sludge land fill (all values in tonne)

Item	Sludge being disposed		Sludge available in the disposal bed after 3 months		Loss due to leachate		Loss due to evaporation		Others	
	Value	%*	Value	%*	Value	%*	Value	% *	Value	%*
Water	434.4	63.6	319.0	46.7	1.2	0.2	117.5	17.2		
Organic matter	82.5	12.1	80.8	11.8	0 **		0		1.7	0.3
Chromium	0.5	0.1	0.5	0.1	0		0		0	
Others	162.6	23.8	162.6	23.8	0		0		0	
Total sludge	680.0	99.5	562.8	82.4	1.2	0.2	117.5	17.2	1.7	0.3
Rainfall during period	3.4	0.5								
TOTAL % (rounding off errors)		**100**		**82. 4**		**0.2**		**17.2**		**0.3**

* % value is taken over total value of 683.4 tonne i.e. including rainfall in period

** Percentage of organic matter in the leachate is < 0.001%

<u>**In the opinion of the authors a double liner system for tannery sludge is not required and therefore, unless insisted upon by the environmental authorities, it need not be considered (Fig 5.3 a - c suffices).**</u>

5.7 Closure

The main objective of landfill is to prevent leachate generation. This is possible only if the landfill is closed at the end of design period. The type of cover depends on the rainfall of the area. If rainfall is high or regulatory standards are very stringent, a comprehensive cover is required. If rainfall is moderate or low, there will be no need for flexible membrane liner or drainage layer.

Levelling of the sludge deposited. Placement of compacted clay layer 30 - 50 cm (with recommended permeability of 10^{-5} m/s) followed by local compacted soil layer 15 - 60 cm (recommended permeability 10^{-3} m/s) and vegetation. The slope to be maintained on top should be 2 % (1 in 50) to drain rainwater.

A typical closure of landfill is depicted in **Figure 5.4 & 5.5.**

Figure 5.4 Typical final cover

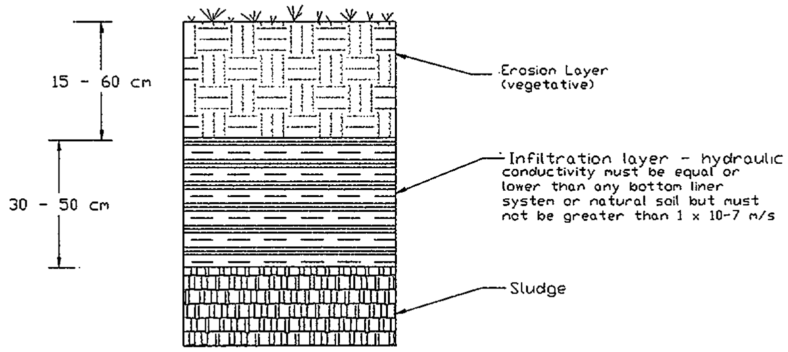
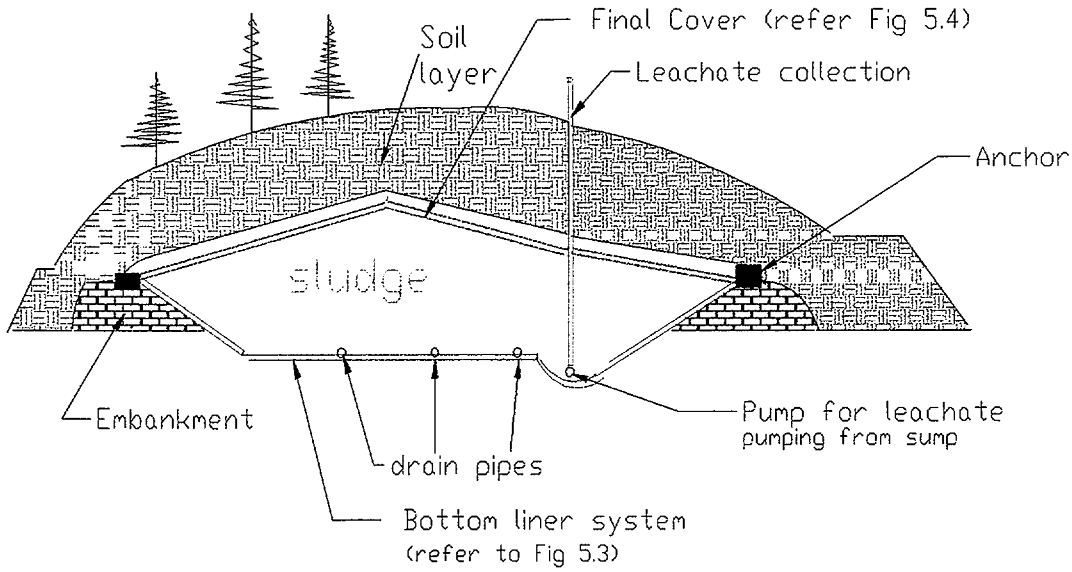


Figure 5.5 Typical closed landfill



5.8 Leachate Treatment and Disposal

The leachate generated in the landfill is collected in the drainage layer and conveyed to a sump. This has to be treated and disposed following the water pollution control existing in the country. Following are the possible methods:

a) Pumping the leachate from the collection pit back over the sludge deposited. Depending on climatic conditions part or all leachate will evaporate. Alternatively it may be used to moisten sludge before compacting.
b) Leachate may be pumped back to the effluent treatment plant.
c) Mostly in hot and dry climatic conditions leachate may be evaporated in pans.
d) The leachate may be treated in natural treatment system (reed bed), for instance in Switzerland in case of a hazardous land fill site.

5.9 Monitoring

Piezometers **(Figure 5.6)** are constructed around the landfill. The piezometers can be considered as leak detectors. If there is any seepage in landfill, the leachate is seen in piezometers. Corrective measures[1] are taken immediately to prevent the spread of contamination. The water from piezometer is analysed periodically.

In addition to piezometers, a few bore wells in the vicinity of landfill (within 2 to 3 km) are to be located as per **Figure 5.7**. These bore wells are identified as monitoring wells.

The water in the piezometers and borewells will be monitored for selected parameters, pH, EC, TDS, chloride, Cr (III), Cr (VI) & COD only.

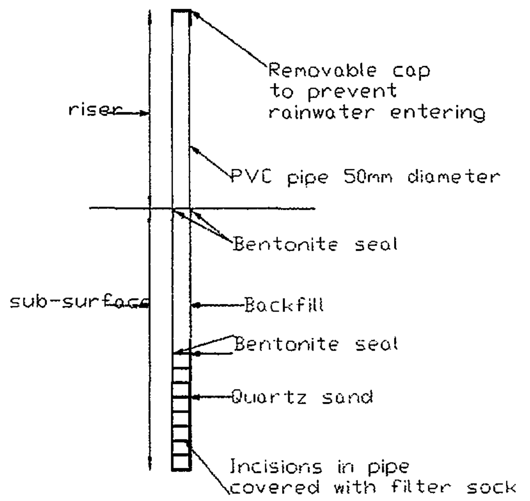


Figure 5.6 Piezometer used for monitoring

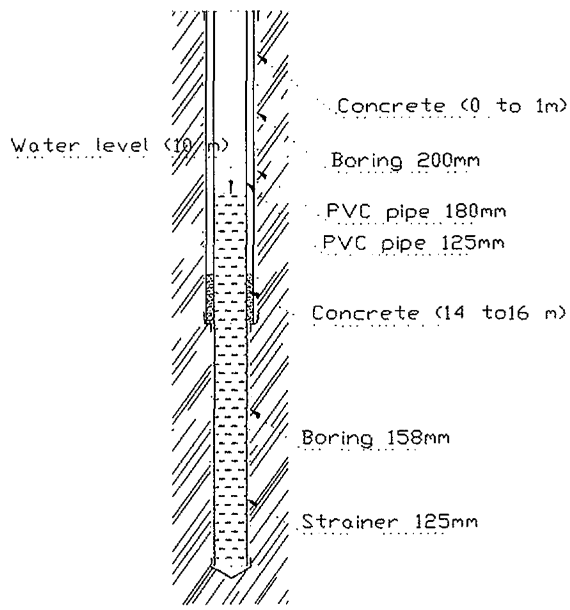


Figure 5.7 Borewell used for monitoring

6. Construction and Operation of Landfill

6.1 Construction

The major work is the earthwork excavation and embankment formation. Typical construction involves, after earth is excavated, clay foundation (0.6 to 1.5 m thick) is laid at the bottom to act as barrier of leachate movement. Above clay foundation, HDPE liner with a clay cover / fine sand (sieved) is placed both at the bottom and sides. PVC pipes are laid with 2% slope to collect leachate. On top of sand, a geonet or clay is laid. The synthetic liner is anchored at the embankment. Generally 1 m above waste layer top is kept as free board. The embankment is constructed at different layers and compacted. A drain along the outer periphery of landfill is

[1] It has to be noted, however, that identification of the source(s) of contamination from within the landfill and particulalry remedial measures are complex in practice and beyond the scope of this manual.

provided. The piezometers and monitoring wells (Fig 5.6 & 5.7) are constructed. All other facilities as per design are executed.

6.2 OPERATION

Operation of a landfill typically comprises :

- Truck with sludge reaching site : weighing and checking operation (origin and type, possibly moisture content). Wastes other than tannery should not be disposed in the same landfill.

- Filling procedure: The landfill is divided into cells. Disposal is organised in successive horizontal layers. Cells are filled up one after the other (not at the same time).

- Sludge is properly placed in the filling area. The bulldozer then spreads and compacts it to the required slopes and levels specified in executive landfill project plan.

- In order to reduce leachate, sludge disposed off in the landfill should have a low water content. Dry content of the sludge has to be checked. If the climatic conditions are not suitable for the drying of the sludge in beds, the threshold should be around 30% dry matter.

- During the monsoon or heavy rain, intermediate covers (clay layers of 30 cm) should be placed frequently on the deposited sludge. If a facility exists for temporary storage of sludge before landfill this may be a preferred alternative.

- Proper logging on sludge receipt and disposed should be maintained

- Groundwater and surface water have to be monitored to provide early warning for developing problems (see Section 5.9 Monitoring)

- Leachate treatment (refer to 5.8 Leachate treatment and disposal)

- The surface and storm-water run-off should be taken away from landfill.

7. COST

Landfill cost comprises following components:

1) Land
2) Site assessment , including EIA
3) Design and detailed engineering cost
4) Construction/Site development
5) Construction of liner and leachate collection system
6) Operating cost
7) Closure cost including final cover system cost
8) Post closure care cost including long term monitoring cost.

Table 7.1 gives two examples of cost (Italy and India).

Table 7.1 Landfill Cost in Italy and India (Example)

Description	**Indicative cost US$ / m^2 (Italy)**	**Indicative cost US$ / m^2 (India) ** **
Land purchase	Depends on the location	Depends on the location
Digging 5 metre depth	13	5
Ground level adjustment	2.5	0.6
Inert material for landfill bottom	9	0.3
Impermeable clay layer (*)	11	0.6
Embankment of lateral walls	4	6.5
Non-woven fabric layer (*)	2	0.8
Synthetic geo-membrane (*)	11	2.1
Non-woven drainage layer	7	0.4
Gravel for drainage system and perforated plastic pipes	12	0.1
Landfill fence, illumination, signboard etc.	15	not given
Additional works	7	0.2
Total (excluding land)	93.5	16.6

* These costs can be avoided if the disposal site presents optimal hydrogeological conditions.
** Exchange rate 1 US $ = Indian Rupees 40.

In some European countries the cost of tannery sludge disposal is about 70% of the operational cost of effluent treatment.

8. EXAMPLES OF LAND FILL DESIGN

Schematic views of landfill at different stages of construction and a typical operating system are presented in this section. Drawing and photos below indicate how the landfill may look like.

Photo 3 : Pilot tannery sludge landfill site, India

Figure 8.1 Landfill site lay-out for tannery sludge (CTC)

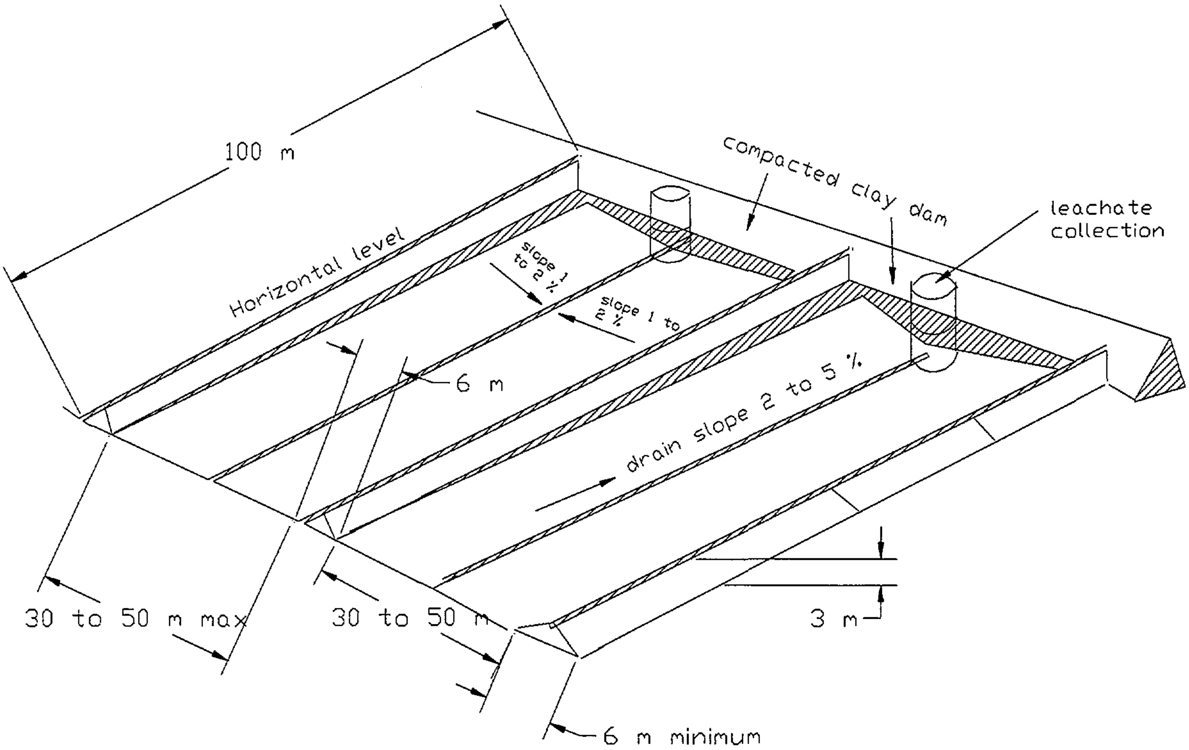


Figure 8.2 Impression of landfill for tannery sludge

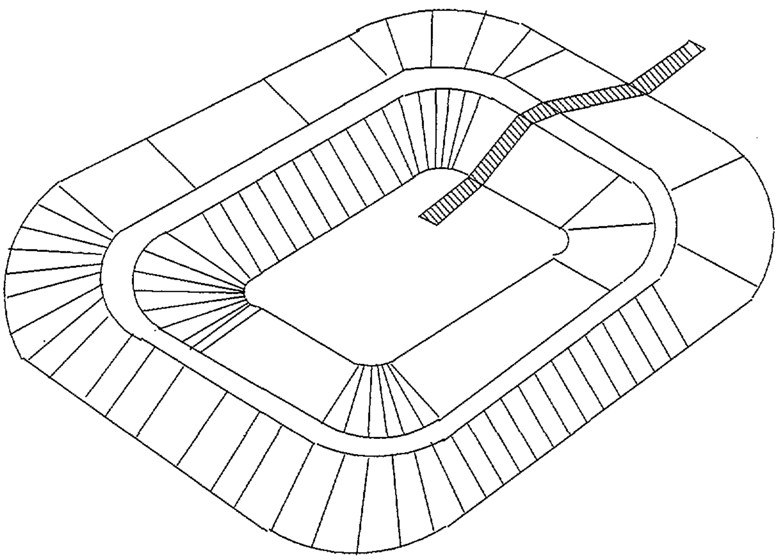


Figure 8.3 Hazardous waste landfill site lay-out in Rotterdam, the Netherlands (UNEP)

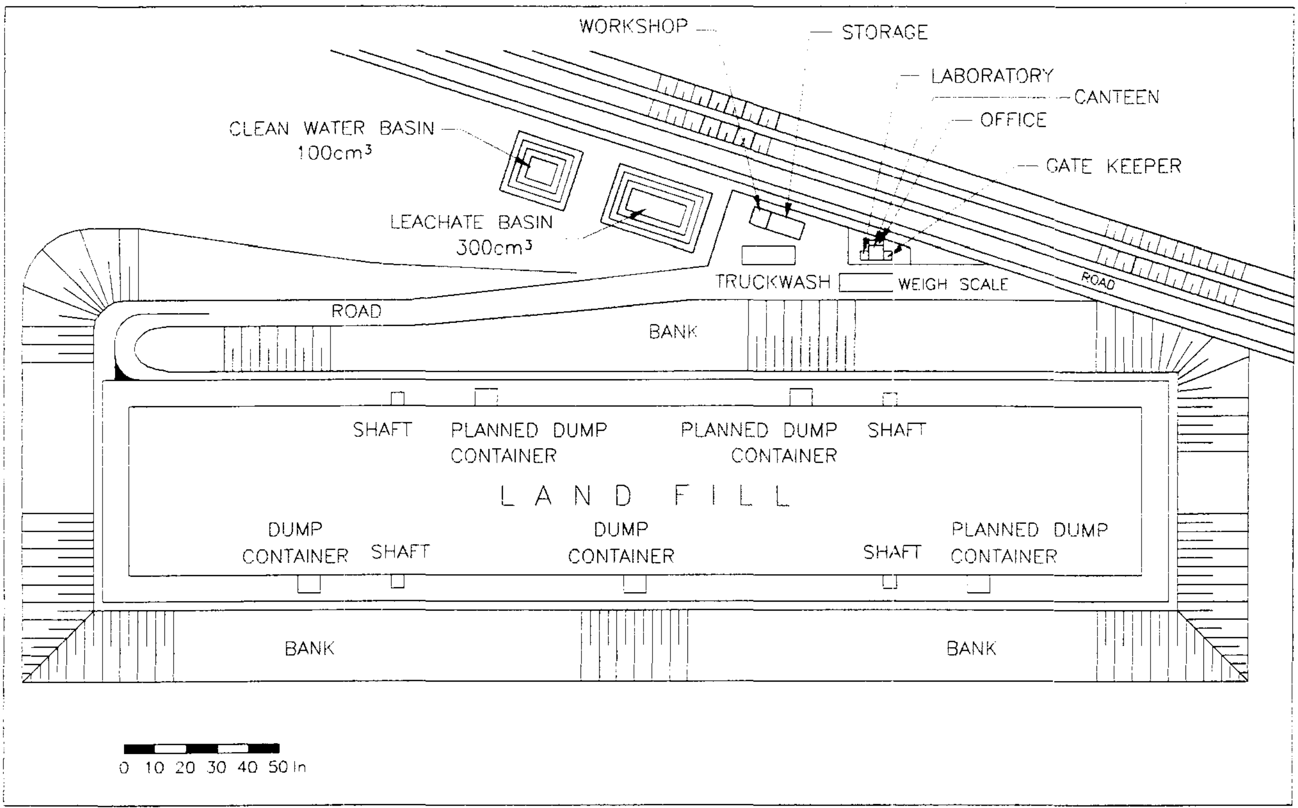


Photo 4: Pilot landfill for tannery sludge, India

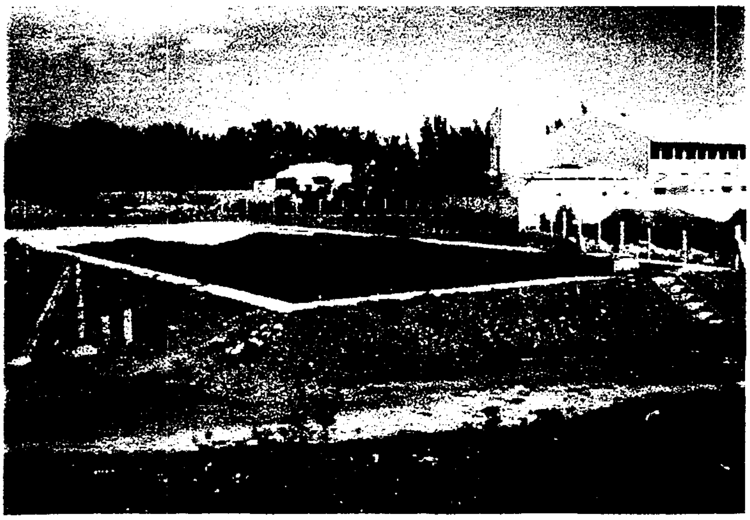



Photo 5: Preparation of landfill site / dike

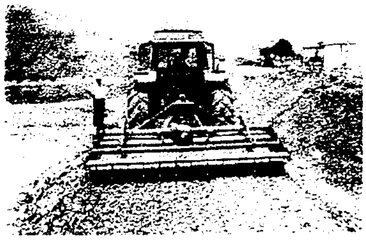


Photo 6: Milling of the clay

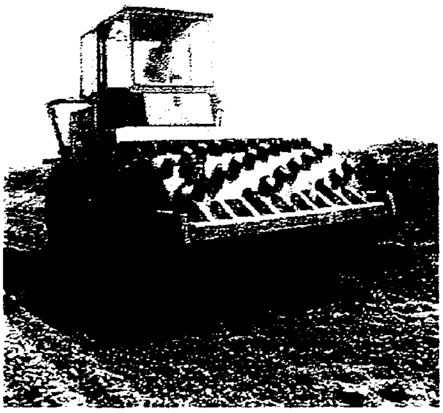


Photo 7: Final raming of clay (leachate prevention)


Photo 8 : Laying of synthetic liner


Photo 9 : Synthetic liner


Photo 10: General view of a landfill

Annex 1
Calculation of sludge quantity

It must be kept in mind that for effluent with other characteristics and/or treated with non-conventional treatment system(s), separate calculations have to be made of sludge produced. The amount of sludge generated can be calculated using the formula given below for a conventional biological treatment process (at any case sludge generation, dewatering and disposal form an integral part of the design parameters of any tannery effluent treatment plant).

Typical calculation of sludge generated in a tannery effluent treatment plant using conventional treatment system

Primary treatment (physical-chemical): Important raw effluent characteristics

1) Average effluent flow
2) pH (for chemical treatment)
3) Suspended solids
4) Biochemical oxygen demand (BOD_5)
5) Chemical Oxygen Demand (COD)
6) Chromium
7) Chemicals used in treatment process

Values assumed of influent characteristics for calculation of sludge generated:

Average flow :	1,000 m^3 / d
pH:	9.0
BOD_5 :	2,050 mg/l
COD :	4,270 mg/l
Suspended solids :	4,500 mg/l
Chromium III :	180 mg/l

Efficiency primary treatment : 85 % of suspended solids removed. Chromium 95 % removed

Lime addition :	100 mg/l
Alum addition :	200 mg/l

No other chemicals added

Solids generation: 1,000 m^3/d x 4,500 mg/l = 4,500 kg/d from effluent + 100 kg/d lime + 200 kg/d alum gives 4,800 kg/d dry solids, with average removal of 85 % gives about 4,000 kg /d dry solids.

Efficiency primary treatment suspended solids is usually around 85 % and BOD_5 and COD removal is generally between 45 - 55 % (60 % upper limit).

Thus sludge generation per day is 4000 kg of dry solids from primary treatment + 400 kg of dry solids from biological system (400 kg is assumed, based on the average of data from many CETPs) thus totalling 4,400 kg of dry solids. It is further assumed that the average solid concentration in the sludge is 3 % (30 g/l) giving a total sludge volume of 147 m^3 per day. This further implies that on a daily basis 12.6 m^3 of sludge with average solid concentration of 35 % has to be disposed.

Annex 2
Chromium impact

1 Health effects

Review of the reports on effects of chromium on human health establishes quite clearly the difference in toxicity between Cr (III) and Cr (VI).

Table A.2.1: Comparison of toxicity of chromium III and chromium VI

	NOAEL *
Cr (VI)	2.4 mg/kg/day
Cr (III)	1468 mg/kg/day

** NOAEL = No-Observed-Adverse-Effect-Levels for chronic oral exposure to chromium*

2 Impact on the water

According to a Canadian scientific bibliography, in an aqueous medium of neutral pH, chromium (III) compounds form oxides, hydroxides and highly insoluble phosphates, which bind themselves to solids in suspension. This is why soluble chromium (III) compounds are rapidly eliminated from surface water into sediments. This chromium complex is relatively stable. This aptitude for precipitation was confirmed in a study carried out in Costa Rica on a river polluted by several tanneries. Work was carried out by the CTC on activated sludge in an effluent treatment plant. Using the respirometry method, the purpose was to measure the toxicity of chromium. It was shown that whilst chromium is maintained in an insoluble form (pH neutral or alkaline), its toxicity on activated sludge cannot be detected.

To measure the effect of chromium (III) compounds, studies were carried out on living species in water. They showed that because of its low solubility (under experimental conditions with pH 7), chromium (III) did not prove to be toxic to bacteria, seaweed or fish. Only daphnia showed a marked sensitivity to concentrations in the order of 6 to 9 mg/l. World Health Organisation's (WHO), total chromium value for drinking water is 50 micrograms per litre (50 µg/l).

3 Impact on the ground

The US Environmental Agency (USEPA) has conducted an extensive risk evaluation of chromium (III) in sludge used for agriculture land application and could find no adverse effect for any pathway of exposure. Therefore, chromium limits for land applied sludge have been eliminated in the USA.

When chrome-containing sludge is mixed with earth, the appearance of chromium (VI) could theoretically cause a redox potential found in well-aerated soils. However, in practice, oxidation of chromium (III) to chromium (VI) does not occur in earth even under experimental conditions combining maximum aeration and high pH.

4 Ground life and micro-organisms

On micro-organisms, the inhibitory effects of chromium (III) (concentration upto 1,000 ppm) were noticed on short-term exposure but were no longer evident after a period of six weeks. However, 10,000 ppm of chromium (III) completely blocked nitrogen transformation. Earthworms could survive even with a chromium (III) concentration in their stomachs of 100 ppm. With higher concentrations, toxic effects were noticed: the individuals were less numerous and their size decreased. However, after excessive risk evaluation, the USEPA has established guidance cleanup for chromium (III) at land disposal sites of 78,000 mg/kg DS.

5 Vegetables and animals

Many studies have been carried out to determine the impact of chromium (III) compounds on different crops: chicory, wheat, peas, tomatoes, fennel, etc.. particularly with respect to the spreading of sludge onto agricultural ground. These studies concluded that chromium (III) compounds could be considered as non-toxic for content upto 500 mg/kg. No toxic effect was detected on rats consuming water containing 25 mg/l of chromium (III) over a six-month period.

6 Conclusion

- Regarding flora and fauna, high accumulation in the environment must be avoided.
- Care should be taken to avoid high accumulation that could produce harmful effects.

7 Other impacts

Chromium is the first criterion usually checked in tannery effluents. However, it is not the only pollutant that might cause adverse effects. Accumulation of salts might have a strong impact on the water quality. In groundwater nearby tanneries, Total Dissolved Solids (TDS) concentration reaches 8 g/l (comprising about 60 % sodium chlorides). It is not fit for human consumption anymore and it is not possible to use it for the tanning process. Table A.2.2 summarises the values adopted for drinking water by WHO.

Table A.2.2: WHO recommendations regarding salinity

Parameters	**WHO Recommendations**
Dry solids (at 180^{0}C)	1500 mg/l
Chlorides	250 mg/l
Sodium	200 mg/l
Sulphate	400 mg/l

Ground water and surface water have to be protected against salts. Total Dissolved Solids have to be monitored near tanneries or sludge landfilling sites.

Annex 3
Alternative Technologies for Sludge Disposal / Conversion

Landfilling is not the only option for disposal of tannery sludge. Other alternatives may be considered depending on legal regulations & situations. These alternatives are listed hereafter but not developed in this manual (though for land application more details are given in Annex 3.1).

- Land application (application of sludge for agricultural purposes):
    - Low investment cost.
    - Low running cost.
    - Provides nitrogen and calcium to the soil.
    - Sludge has to be stored for several months.
    - Has to be monitored carefully.
    - Depends on local legal regulations (chromium limitations).
- Composting (aerobic biological treatment for biodegradable organic constituents)
    - Low investment cost.
    - Low running cost.
    - Odour limitation (compared to sludge).
    - Provides nitrogen and calcium to the soil.
    - Chromium dilution with other materials.
    - Depends on local legal regulations (chromium limitations).
- Biomethanation (anaerobic biological treatment breaking down organic molecules to methane (CH_4) and carbon dioxide (CO_2),
    - Energy recovery.
    - Reduction of sludge volume.
    - Odour limitation.
    - Relative high investment cost.
    - Moderate running cost.
- Incineration (any enclosed device using controlled flame combustion: Fluidized bed, multiple bed incinerators, rotary kiln, pyrolysis..),
    - Reduces sludge volume by 85% (depending on sludge water content).
    - Destroys organic matter.
    - Risk of transformation from Cr (III) to Cr (VI).
    - High investment cost.
    - High running cost.

- Utilisation as raw material for brick kiln (addition of sludge, clay and eventually lime or fly ash in order to produce brick in a thermic process),

    - Reduces sludge volume.
    - Final product can be used. Possibly, commercial value too.
    - Destroys organic matters.
    - Risk of transformation from Cr (III) to Cr (VI).
    - Stability (leachate) of the final product (on both short term and long term basis) has to be carefully tested.
    - High investment cost.
    - High running cost.

- Production of light weight aggregates (addition of sludge, clay and eventually lime to produce light weight aggregates in a thermic process).

    - Reduces sludge volume.
    - Final product can be used and possibly, has commercial value.
    - Destroys organic matters.
    - Limited risk of transformation from Cr (III) to Cr (VI).
    - Very high investment cost.
    - High running cost.

Some of these technologies might be combined with sludge pre-treatment technologies, especially because of the water content of the sludge.

Annex 3.1 : Land application

Less than 10 % of the sludge generated by tannery ETPs in Germany is applied on land (1998 estimate). Land application has many advantages over landfill. For instance, sludge does contain several nutrients and also a landfill site occupies space that can not be used alternatively for many years.

3.1.1 Regulation

The concentration of chromium in tannery sludge is often a limiting parameter for land application. Comparison of sludge re-use standards for land application in several countries is presented in Table A.3.1.3.

China has implemented chromium limits for land application of tannery sludge (Table A.3.1.1).

Table 3.1.1 Chromium limits for the application of tannery sludge in China

Component	Limit	Unit
Cr (for land pH < 6.5)	600	mg/kg dry sludge
Cr (for land pH > 6.5)	1000	mg/kg dry sludge

In order to reduce the concentration of chromium in the sludge, chromium management within the process is the best alternative. It might be:

- Tanning products that improve the exhaustion rate.
- Direct recycling of chrome tanning floats.
- Recycling after precipitation of tanning floats.
- Chromium replacement (e.g. vegetable tanning or wet white production).
- A combination of the above.

Clean technologies are not presented in this document, though these aid considerably in sludge volume reduction.

Another more theoretical alternative would be to separate primary and biological sludge. Biological sludge (about 25% of the total sludge) is more easily used for land application, due to absence of, or negligible presence of chrome.

3.1.2 Application rates

Typical application rates for different land application of municipal sludge are presented in next table.

Table A.3.1.2 Application rates for municipal sludge

Land disposal options	Time period of application	Application rates	
		Range in tonnes (dry solid)/1000 m^2	Typical value in tonnes /1000 m^2
Agricultural use	Annual	0.2 - 7	1
Forest	One time or at 3 to 5 time intervals	1 - 20	5
Land reclamation	One time	0.7 - 45	10

In case of tannery sludge, the above may be used as a reference before the final land area requirement is established.

3.1.3 Examples

The following examples have been extracted from the literature.

The Milwaukee Metropolitan Sewage District (USA) receives effluent from tanneries. The sludge produced is dried and marketed as fertiliser. The product contains approximately 5000 mg/kg of chromium. Used for more than 50 years, no reported incident of adverse effects on plants, human or the environment has been reported.

A natural organic fertiliser material is produced from the hydrolysis of leather scrap. The chromium concentration of the fertiliser is 27,000 mg/kg. It has been used as a slow release nitrogen source on citrus, tobacco and vegetable crops since the beginning of the century without any adverse effect on the environment.

Table A.3.1.3. Sludge re-use standards for land application (Compilation of different legislation)

Parameter	China	Denmark	France	Germany	Netherlands	Belgium	Norway	Sweden	Switzerland	United Kingdom	USA
mg chromium per kg of dry soil	90 - 400 *	100	150	100	100 **	150				600	No limit
mg chromium per kg of dry sludge		100	1,000	900	500	500	200	150	1,000		No limit
Suggested annual chromium loading (kg/ha/year)			6.0	2.0	1.0	2.0	0.4	1.0	2.5		No limit
Maximum recommended chromium loading (kg/ha)			360	210	100		4			1,000	
Suggested maximum annual sludge solids application (t/ha/year)		1.5	3.0	1.7	2 (arable) 1 (grass)		2	1	2.5		
Maximum sludge solids loading (t/ha)				167	200		20	5 in 5 years			
Minimal soil pH			6.0							6.5 (arable) 6.0 (grass)	

Source: CTC, France

** In China tolerance limits for trivalent chromium contained in soil depend on quality standard of soil, whether its is dry or paddy land and pH of the soil. Most strict is for soils with limited value of soil quality for protecting natural background and resources irrespective of pH and use. Most lenient are soils with critical value of soil quality for maintaining normal plant growth and pH . 6.5 with 400 mg/kg (paddy) and 300 mg/kg (dry land) of trivalent chromium contained in soil.*
*** Varies according to clay content.*

Annex 4 : Details for site selection (Rating chart for screening as per UNEP)

SCREENING/SELECTION CRITERIA	RELATIVE VALUE: 6 Ideal – 5 Excellent – 4 Above average – 3 Average – 2 Below average – 1 Marginal – 0 Unacceptable	Actual value	= Relative value	X Weight of criterion	= Weighted value
Office Review					
Precipitation *(inches/year)*	< 5 — 6, 7, 8, 9, 10, 15 — > 18			10	
Nearest surface water or stream *(miles)*	> 20 — 15, 10, 5, 4, 3, 2 — < 1			5	
Nearest use (discharge point) *(miles)*	> 20 — < 1			5	
Seismic activity *(miles)*	> 15 — 10, 5 — < 2			2	
Preliminary Field Reconnaissance					
Slope *(percent)* *	1.5, 2, 3, 4, 5, 10 — > 15 / 1.5, 1.2, 1.0, 0.9, 0.8, 0.7, 0.6 — < 0.5			4	
Geomorphic stability *(qualitative)*	Stable — Unstable			4	
Flooding potential *(qualitative)*	Low — High			4	
Wind erosion potential *(qualitative)*	Low — High			2	
Depth to water table *(feet)*	> 1000 — 700, 500, 400, 300, 200, 100, 80, 70, 60 — < 50			5	
Depth (distance) to fractured bedrock *(feet)*	> 1000 — 500, 400, 300, 200, 100 — < 50			5	
Type of burial media *(qualitative)*	Very fine sands & silts — Gravel / Clay			4	
Subsidence *(feet)*	0 — < 5			3	
Optimum wind direction *(qualitative)*	Good — Bad			2	
Intermediate Field Reconnaissance					
Distance to known fault *(feet)*	> 5000 — 4000, 3000, 2000 — < 1500			3	
Burial media and underlying strata: Sorption capacity *(me/100gm)*	> 50 — 40, 30, 20, 10, 5 — < 2			4	
Burial media and underlying strata: Thickness *(feet)*	> 500 — 400, 300, 200, 100 — < 50			4	
Burial media and underlying strata: Engineering properties *(qualitative)*	Good — Bad			4	
Burial media and underlying strata: Permeability *(gal/day/ft²)*	0.1 — 0.2, 0.3, 0.4, 0.5, 1.0, 2, 3, 4, 5 — > 10 / 0.5, 0.2, 0.001, 0.005, 0.002 — > 0.001			4	
Burial media and underlying strata: Effective porosity *(percent)*	Intermediate — High / Low			4	
Burial media and underlying strata: Structure *(qualitative)*	Simple — Complex			4	
A ratio of pan evaporation to precipitation minus runoff	> 84 — 80, 70, 60, 50 — < 40			5	
Hydrogeologic complexity *(qualitative)*	Simple — Complex			5	
Suitability for control of water table *(qualitative)*	Easy — Dificult			2	
Monitorability *(qualitative)*	Easy — Dificult			3	
Remediability *(qualitative)*	Easy — Difficult			3	
Hydraulic gradient *(feet/mile)*	< 10 — 20, 30, 40, 50, 70 — > 100			4	
	6 – 5 – 4 – 3 – 2 – 1 – 0			Total	

* If the slope is less than one percent and the site does not lie in the defined floodway of a stream course or lake and all other criteria have relative values above average, disregard chart values for '*slope*' and substitute an arbitrary value of '6'. In all other cases use chart values

Annex 5
Liner testing methods

Clayey Soil :

Test : Permeability Method (USEPA Method 9100)

Principle : Determine the permeability of the soil to be used as liner material with water and also with the leachate of the waste to be impounded. If the increase in permeability rate of soil with leachate is less than 10% of the soil with water, the soil is reported to be compatible with the waste and suitable as liner material.

Parameters :

Liquid Limit
Plastic limit
Particle size distribution
Optimum moisture content

Flexible Membrane Liner (FML):

Test : Immersion Test (USEPA Method 9090)

Principle : The synthetic liner materials are cut into coupons about 30 cm x 60 cm in size. Water and the leachate obtained from the waste are stored in two immersion tanks made of MS with corrosive protection coatings. In each tank, about 8 coupons are hanged. The coupons are immersed for 120 days. At the end of 30, 60, 90 and 120 days two coupons from each tank are taken for analysis. In addition, one coupon without exposure is also analysed. The coupons are analysed for various parameters as given below. If the change in the properties exceeds 10% to 30%, the liner material is reported to be incompatible with the waste and the liner cannot be used as liner material.

Parameters :

Parameters	**Test Method**
Density	ASTM D792
Volatiles	ASTN D3030-84
Extractables	ASTM D3421-75
Thermal Gravimetric Analysis (TGA)	ASTM D4275
Tensile stress	ASTM D412
Hardness	ASTM D2240
Tear Strength	ASTM D 624
Water vapour permeability	ASTM E96

Annex 6
Brief bibliography

(other references may be obtained from reports given below) :

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