

MODULAR LANDFILL DESIGN

by

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## **ABSTRACT**

### **MODULAR LANDFILL DESIGN**

Transition to solid waste sanitary landfilling is one the most important environmental problems of Turkey due to implementation of European Environmental Regulations. Due to the large number of the municipalities, high project costs and economical insufficiencies, transition to solid waste management system has been delayed. Besides the legislative, environmental or regional handicaps economical criteria seems to be the most deterrent factor. Most of the municipalities have difficulty in financing such projects. Also high interest rates make the financial instruments, like loan, inefficient. Lack of strategic management strategies and legislative regulations, affect the feasibilities of the forthcoming projects. The objective of this study is; to introduce a design-build-operate (DBO) model for sanitary landfill projects by which a competitive market will be constituted for the private sector and to develop a modular design method to lower the initial investment costs by which medium scaled companies can have the opportunity to compete in the market. In this study, costs of an existing sanitary landfill are compared to the proposed method. Costs of modules are calculated for varying operating life of modular landfills and a unit cost of landfilling waste is derived for each module. From comparison of unit costs of present sanitary landfills and modular sanitary landfills, under varying interest rates, according to the capacity of the area of the sanitary landfill, optimum lifespan of the modules has been estimated. Especially for countries having high interest rates, investment costs can be lowered and the amount of interest payment can be minimized by designing modular sanitary landfills with a design-build-operate (DBO) model. This way participation of medium scaled private companies will be achieved and a major step will be taken towards transition to sanitary landfilling.

## ÖZET

### MODÜLER KATI ATIK DEPOLAMA TESİSİ TASARIMI

Avrupa Birliği'nin çevresel yönetmeliklerinin, ülkemizde uygulanmasına bağlı olarak, katı atık düzenli depolamaya geçiş, Türkiye'nin en önemli çevresel sorunlarından biridir. Belediyelerin sayıca çokluğuna, yüksek proje maliyetlerine ve ekonomik yetersizliklere bağlı olarak, katı atık düzenli depolamaya geçiş gecikmektedir. Yasal düzenlemelerdeki yetersizliklerin, çevresel veya bölgesel handikapların ötesinde ekonomik yetersizlikler en önemli engelleyici faktördür. Birçok belediye bu tip projelerin finansmanında zorluk yaşamaktadır. Ayrıca, yüksek faiz oranları, kredi kullanma alternatifini verimsiz kılmaktadır. Bununla birlikte, stratejik yönetim ve yasal düzenleme eksikliği gelecekteki projelerin yapılabilirliğini etkilemektedir. Bu çalışmanın amacı, özel sektörün içinde yer aldığı rekabetçi bir pazar yaratabilmek amacıyla bir "tasarla-yap-işlet" modeli önermek ve yüksek başlangıç yatırım maliyetlerini düşürerek orta ölçekli firmaların pazarda yer alabilmelerine olanak sağlayacak, modüler katı atık depolama sahası tasarımı geliştirmektir. Bu çalışmada, modüler katı atık depolama sahaslarının maliyetleri değişen işletme ömürlerine göre hesaplanarak her bir modül için katı atık depolama birim maliyeti hesaplanmıştır. Elde edilen birim maliyetlerin, değişen faiz oranlarına göre, günümüz katı atık depolama sahası birim maliyetleriyle karşılaştırılmasından en uygun işletme ömrüne sahip modül öngörülmüştür. Sonuç olarak tasarla-yap-işlet modeliyle yapılacak olan modüler katı atık depolama sahaslarında, özellikle yüksek faiz oranlarına sahip gelişmekte olan ülkeler için, yüksek yatırım maliyetleri ve yüksek faiz geri ödemeleri düşürülebilmektedir. Bu uygulama ile katı atık düzenli depolamaya geçiş yolunda önemli bir adım atılmış olacaktır.

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**LIST OF ABBREVIATIONS**

A	Area
BLT	Build-Lease-Transfer
BOT	Build-Operate-Transfer
BT	Build-Transfer or Turnkey
DBO	Design-Build-Operate
FS	Factor of safety
$K_a$	Active earth pressure coefficient
$P_a$	Force of waste by weight
TUIK	Turkish Statistical Institute
W	Weight
WWTP	Waste water treatment plant

## 1 INTRODUCTION

Solid waste management is one of the most important problems, to be handled in Turkey. Solid waste management, globally, is an integrated process which aims to protect the public, covering the source reduction, collecting and transporting, reusing, recycling, treatment, and finally landfilling of the waste. This process should be carried out under the limitations of the current regulations and economic, engineering and environmental criteria.

According to Turkish Statistical Institutes research dated 2004, among the 3225 municipalities, only 16 of them (0,496 per cent of total), have sanitary landfills (Turkish Statistical Institute, 2004). After the declaration of the Notice dated 22.06.2006 by Ministry of Environment and Forestry, the municipalities should give their work programme on transition to sanitary landfills until 13.05.2007. The deadlines for landfill construction are listed in the Table1.1.

Table1.1 Deadlines for landfill construction

<b>Population</b>	<b>Minimum Time for Construction from Submission of Work Programme</b>
>100.000	3 years
50.000 – 100.000	5 years
10.000 – 50.000	7 years
2.000 – 10.000	10 years

(after Ministry of Environment and Forestry, 2006)

Municipalities serving for a population more than 100.000, should construct their sanitary landfills within three years, municipalities serving a population between 50.000 and 100.000 should construct their sanitary landfills within five years, municipalities serving a population between 10.000 and 50.000 should construct their sanitary landfills within seven years and municipalities serving a population less than 10.000 should construct their sanitary landfills within ten years. The time for transition to sanitary landfilling begins after the presentation of the work program of transition.

Solid waste management covers social, economic, technological, political and administrative dimensions. The social dimension of solid waste management covers the awareness of the people about waste minimization. Minimizing waste production in the source is the most important dimension of the solid waste management. Authorities providing solid waste services should develop sustainable implementations on raising the awareness of the public about the importance of the minimization of waste.

Economic dimension of solid waste management covers the recycling of the materials. Public should be aware of separation of the recyclable materials like glass, paper, pvc, etc. Collecting separated materials and reusing, minimize the need for raw materials and help to save energy.

Technology for solid waste management covers waste disposal. Authorities should develop suitable technologies according to the characterization of the waste. Composting, incineration and landfilling are the most common disposal techniques. Deciding on the technology should be a result of comprehensive feasibility studies.

Political and administrative dimensions are the decision mechanisms that should encourage the social implementations, support the environmental enterprise, to regulate and to implement management alternatives.

In developing countries, it is common for municipalities to spend 20-50 per cent of their available recurrent budget on solid waste management. Yet, it is also common that 30-60 per cent of all the urban solid waste in developing countries is uncollected and less than 50 per cent of the population is served (Worldbank, 2007).

For successful development of any solid waste project, community participation in collection, community consultation on cost recovery, and public participation in siting and design of facilities is inherently essential to sustainability (Worldbank, 2007).

Most developing countries employ open dumping as their form of land disposal. In all developing countries there is an urgent need to close existing open dumpsites and implement sanitary landfills. Because of sanitary landfill's costs, cities tend to make little

progress toward landfill implementation unless the regulatory framework and environmental agency apply enforcement pressure. Worldbank support for landfill projects has provided significant support to cities wishing to make this transition from open dumping (Worldbank, 2007).

In Turkey many municipalities use open dump areas for disposal. Landfilling costs slow down the transition to landfills. On the other hand rehabilitating the open dump areas throughout the country will cost a fortune.

Establishing public private partnership models to the solid waste management projects will accelerate the transition to sanitary landfilling and will help the municipalities to overcome the environmental problems with high expertise of the private sector while transferring the financial risks to the private company.

In this thesis a method of modular landfill design with a public private partnership model of design-build and operate will be introduced. The design method and the cost comparison of the method will be explained.

## **2 LITERATURE REVIEW**

### **2.1 Public Private Partnership Development Models**

Governments, authorities, in general, use different types of public private partnership models for different sectors, for to get the most benefit. The types of the models can be specific in some cases but in general following types are preferred:

- Build-Transfer or Turnkey (BT),
- Build-Lease-Transfer (BLT),
- Design-Build-Operate (DBO),
- Build-Operate-Transfer (BOT).

#### **2.1.1 Build-Transfer or Turnkey**

Build-Transfer or turnkey approaches involve the public sector ordering a project and the private sector delivering it on site. The private participant provides design, construction and construction financing.

#### **2.1.2 Build-Lease-Transfer**

This technique is similar to the BT option, except that the facility is conveyed to the public sector under a lease structure upon completion and acceptance of the facility.

#### **2.1.3 Design-Build-Operate (DBO)**

According to Design Build Operate (DBO) contracts, the private sector takes on full responsibility for all operations and maintenance activities and for asset infrastructure upgrade but the ownership of the facility remains to the government.

There are several advantages to the private sector involvement in operation and maintenance of landfills such as:

- Ability of the private sector to exploit opportunities in recycling and energy recovery,
- Access to international expertise in landfill operations; utilization of modern landfilling techniques to minimize environmental impacts and optimize the use of available void space,
- Transfers responsibilities and risks for activities to the private partner,
- Offers performance based payment mechanism. The public sector pays only when services are delivered (e.g. the private sector is not paid during the construction phase). These service payments vary depending on whether the services provided meet specified performance standards. If the company consistently fails to provide satisfactory services, the public agency concerned can terminate the contract.

#### **2.1.4 Build-Operate-Transfer (BOT)**

Under the Build-Operate-Transfer (BOT) model, the government turns over development and initial operation of what typically would be a public-sector project to the private sector. The private sector contractor or consortium of contractors finances the project, accomplishes the construction, and operates the new facility for some specified length of time after which it is expected to transfer ownership to the government, usually at no cost.

#### **2.1.5 Public Private Partnership Models for Landfills in USA**

Over 3,000 municipal solid-waste landfills currently operate in the United States. Figure 2.1 shows the breakdown of landfills by ownership and operation. Just over half of all landfills in cities with over 100,000 residents are operated by the public sector; another 10 percent are publicly owned but operated by private firms through a contractual arrangement. The remainder (38 per cent) are both privately owned and privately operated. Thus, private firms operate almost half (48 per cent) of this nation's landfills. (Geoffrey and Moore, 2000)

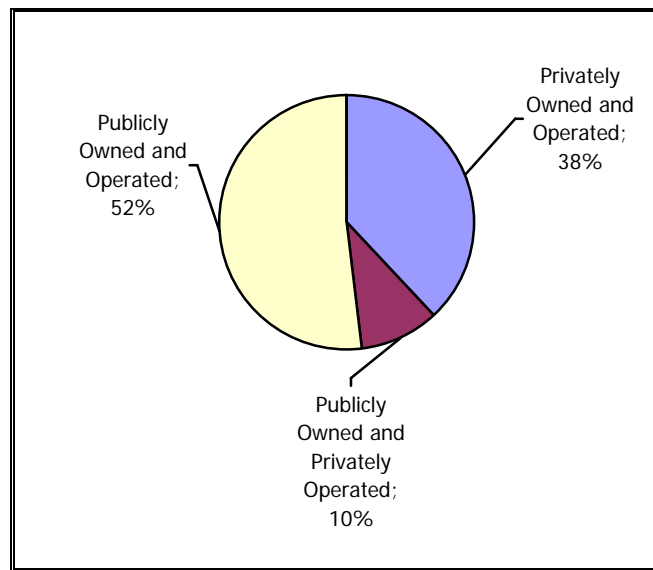


Figure 2.1 Landfills by ownership and operation (Geoffrey and Moore, 2000)

Figure 2.2 suggests that private landfills have, on average, more permitted capacity than their publicly owned counterparts. Private sector having 67 per cent waste disposal capacity and 58 percent of volume of waste disposed but on the other hand public having 33 per cent of waste disposal capacity and 42 per cent volume of waste disposed.

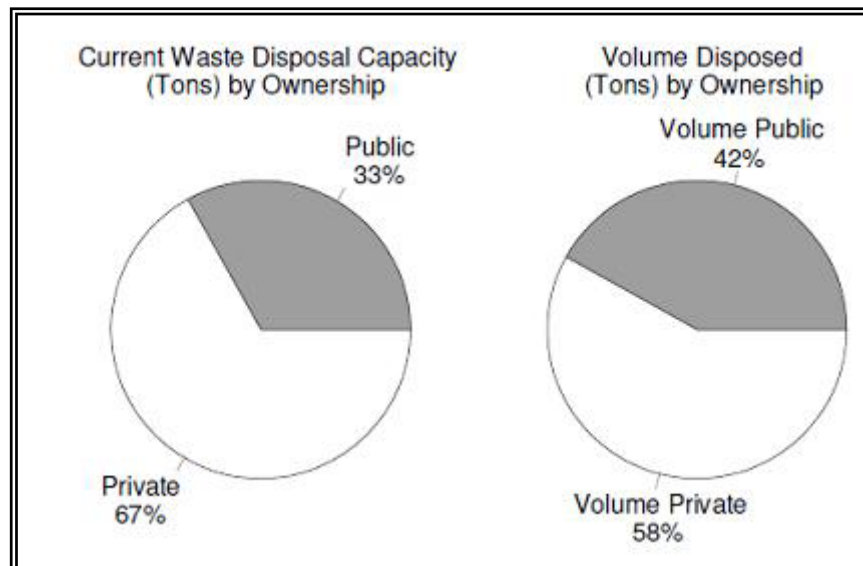


Figure 2.2 Landfill capacity comparison by ownership (Geoffrey and Moore, 2000)

### 2.1.6 Public Private Partnership Models in Turkey

First legislation about build-operate-transfer BOT, was made in 1984 for electrical energy sector, Law No: 3096, which was the first official private facility development under the name “Build Operate Transfer” in the world, (Menheere *et al.*, 1996). Second legislation was made for highway sector in 1988, Law No: 3465. Then a generalized legislation was made in 1994 covering some additional sectors Law No: 3996. These sectors are; bridge, tunnel, dam, irrigation, drinking water, sewerage systems, treatment plants, communication, mining, plants and such infrastructures, environmental pollution preventing investments, highway, railway, car parks, public marinas and airports. Later in 1997 build-operate BO legislation was made for thermal power plants, Law No: 4283.

For sanitary landfills there is not any legislative arrangement related to public private partnerships. Private sector partnership is being used for collection of wastes and landfilling operations. Collection and operating landfills are stated as public services and tenders are repeated every year.

### 2.1.7 The Benefits of Public-Private Partnerships

In a 1998 survey by the U.S. Council of State Governments, respondents were asked the reasons why they used public-private partnerships over the past five years. The results are illustrated in Table 2.1.

Table 2.1 Reasons for public private partnership usage

Cost savings	40.9%
Lack of in-house personnel and expertise	32.5%
Lack of State support of political leadership	30.8%
Flexibility and less red tape	23.8%
Speedy implementation	21.4%
Increased innovations	20.4%
High quality of service	18.5%
Other	10.6%

(after Seader, 2002)

The most frequent use of partnerships is to save costs which have a ratio of 40.9 per cent. Also lack of in house personnel expertise and lack of state support of political leadership has great influence on public private partnership usage.

Generally the most important benefits of usage of public private partnership is that countries are provided with an opportunity to finance projects without involving public funds and countries are benefited by the expertise and experience of the concession company. Additionally, investment, construction and technological risks are shifted to the concession company and investments are stimulated and privatization is promoted.

The greatest advantage of public private partnership for the government is the subcontracting of the majority of the risks to the private sector, with the latter willing to finance and assume risks in the development of a public facility. At the end of the concession period, the government will inherit a well-operated project without investing public funds and with little risks. A consequence of not investing its own money is that the project can take place even if the government's budget is limited.

In addition, utilizing public private partnership may help to accelerate the development of public infrastructure projects that would otherwise have to wait and compete for scarce public resources. One benefit of accelerating such projects is that doing so "will capture project costs in current dollars, rather than postponing portions of construction into the future when the project costs will be higher." Moreover, accelerating public projects should, in turn, accelerate the economic growth that generally accompanies the development of infrastructure.

One of the most strongly perceived benefits of the public private partnership is that private sector participants bring to such projects a know-how, innovativeness, and efficiency inherently superior to that of the public sector, which can reduce project construction costs and time and increase the effectiveness and efficiency of public facilities and infrastructure. Major BOT projects in different countries are presented in Table 2.2.

Table 2.2 Major BOT projects in different countries

Australia	F4 Toll Road F5 Toll Road Sydney Airport Link Sydney Water Treatment Plants Loy Yong Power Plant Colie Power Plant Victoria Toll Road Melbourne Tolled Bypass
Canada	Northumberland Strait Crossing Bridge Toronto Airport Extension
Hong Kong	Eastern Harbor Crossing Tate's Cairn Tunnel Western Harbor Crossing
Hungary	M1 Toll Road
Indonesia	Cikampck-Padatarang Tollway
Malaysia	Johor Water Supply North-South Highway Ipoh Water Supply KL Toll Interchanges
Philippines	Hopewell's Gas-Turbine Power Plant Hopewell's Coal-Fired Power Plant Manila Light-Rail Train
Thailand	Second-Stage Expressway Third-Stage Expressway BMA Light Rail Hopewell's Road Rail Don Muang Tollway Skytrain
United Kingdom	Channel Tunnel Dartford Bridge Second Severns Bridge Sky Bridge Manchester Metro Link Birmingham Relief Road
United States	Caltrans Transport Projects Florida High-Speed Rail Texas High-Speed Rail Honolulu High-Speed Rail Arizona Transport Projects Dulles Toll Road

(after Askar and Gab-Allah, 2002)

Australia, Thailand, United Kingdom, and United States used the BOT model more than others. Main usage of BOT model seems to be in highway sector, because of the majority of highway projects from others relatively. Also BOT usage in power plant investments is common.

## 2.2 Solid Waste Management in Turkey

Although there are no recorded data, collected by the municipalities, Turkish Statistical Institute has been making studies about solid waste. The main solid waste indicators of municipalities in Turkey are presented in Table 2.3.

Table 2.3. Main solid waste indicators of municipalities

Main Solid Waste Indicators of Municipalities	Years								
	1994	1995	1996	1997	1998	2001	2002	2003	2004
Number of municipalities receiving solid waste services	1 985	2 126	2 172	2 275	2 579	2 915	2 984	3 018	3 028
Rate of population receiving solid waste services in total population (%)	71	72	71	71	72	75	76	77	77
Amount of solid waste collected (1000 ton/year)	17 757	20 910	22 483	24 180	24 945	25 134	25 373	26 118	25 014
Amount of solid waste per capita (kg/capita-day)	1,10	1,27	1,37	1,48	1,51	1,35	1,34	1,38	1,31
Amount of solid waste per capita in summer season (kg/capita-day)	1,04	1,19	1,29	1,42	1,46	1,32	1,32	1,37	1,30
Amount of solid waste per capita in winter season (kg/capita-day)	1,15	1,31	1,42	1,51	1,54	1,36	1,34	1,38	1,29

(after TUIK, 2004)

Number of municipalities receiving solid waste services is increased from 1985 municipality to 3028 municipality between 1994 and 2004. Also amount of solid waste per capita is increased to 1,31 kg/capita-day in 2004 from 1,04 kg/capita-day in 1994. Rate of population receiving solid waste services in total population increased six per cent in 10 years. Rate of population receiving solid waste services in total population in 2004 was 77 per cent, this shows that 23 per cent of the total population did not receive solid waste services in 2004. In Table 2.3 and , it is clearly seen that urgent rehabilitation of the current disposal techniques should be done and transition to solid waste management processes should be made.

Table 2.4. Solid waste disposal plants in Turkey

Solid waste disposal plants	Years								
	1994	1995	1996	1997	1998	2001	2002	2003	2004
<b>Controlled landfill</b>									
Number	2	6	6	8	8	12	12	15	16
Capacity (1000 ton)	9 250	202 527	202 527	206 690	206 690	261 282	277 195	278 015	278 060
Amount of solid waste disposed of (1000 ton/year)	809	1 444	2 847	4 364	5 258	8 304	7 047	7 432	7 002
<b>Composting plant</b>									
Number	2	2	2	2	2	3	4	5	5
Capacity (1000 ton/year)	245	245	245	245	245	299	664	667	667
Amount of waste composted (1000 ton/year)	192	159	179	180	166	218	383	326	351
<b>Incineration plant</b>									
Number	0	1	1	2	2	3	3	3	3
Capacity (1000 ton/year)	0	9	9	44	44	44	44	44	44
Amount of medical waste incinerated (1000 ton/year)	0	0,3	3	9	15	7	7	9	8
Rate of population served by solid waste disposal plants in total population (%)	4	5	9	13	15	24	24	24	25

(after TUIK, 2004)

Number of controlled landfills was two in 1994. In 10 years this number increased to 16 and amount of solid waste disposed became 7.002.000 ton/year in 2004 while it was 809.000 ton/year in 1994. The most important point that Table 2.4 shows that the rate of population served by solid waste disposal plants in total population is 25 per cent which is very low.

Because design and construction of modern landfills is more expensive than simple dumping and because of the limited budgets, the municipalities are preferring this dumping option. It is simple and relatively cheap but harmful to environment and public health. After the declaration of the Notice dated 22.06.2006 by Ministry of Environment and Forestry, they are prohibited from such applications. Distribution of solid waste disposal methods by population, is presented in Figure 2.3.

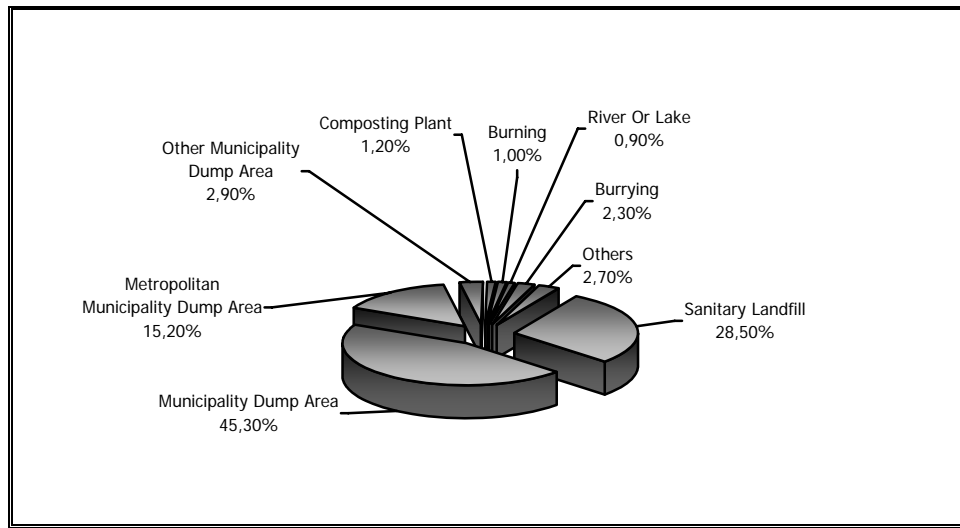


Figure 2.3. Distribution of solid waste disposal methods by population

Total ratio of disposing waste to sanitary landfills and compost plants is 29,7 per cent by population. Remaining 70,3 per cent of wastes are being disposed by non-conventional methods. Use of uncontrolled, open dump areas, having a ratio of 63,4 per cent, are very common among municipalities.

The municipalities that has sanitary landfill are; Ankara, Antalya, Antalya-Patara, Aydın-Didim Balıkesir, Bursa, Denizli, Gaziantep, Istanbul, Izmir, Izmir-Foça, Kocaeli, Mersin, Muğla-Marmaris, Muğla-Göcek, Samsun,. The municipalities that has the approval for their environmental impact assessment (EIA) reports are; Adapazarı, Muğla-Fethiye, Isparta, Izmir -Çeşme, Konya, Nevşehir, Rize, Trabzon. The municipalities that are working on environmental impact assessment (EIA) report are; Adıyaman, Afyon, Antalya-Belek, Antalya-Kekova, Batman, Diyarbakır-Bismil, Diyarbakır-Silvan, Gaziantep-Nizip, Kilis, Mardin-Kızıltepe, Mersin-Göksu, Muğla-Gökova, Nevşehir-Ihlara, Siirt, Şırnak, Şanlıurfa – Viranşehir (Turkey map, 2004).

Construction of Antakya, Erzurum, Nevşehir, Trabzon-Rize, Kars, Bolu, Adapazarı, Sinop, Kırklareli, Aksaray landfills, which will cover 182 municipalities and 3.000.000 population, are still in progress. Also solid waste management studies began in Adıyaman, Afyon, Artvin, Bayburt, Düzce, Giresun, Hatay, Kars, Kırıkkale, Kırklareli, Manisa, Nevşehir, Ordu, Osmaniye, Rize, Sivas, Trabzon, Van, Yalova, Yozgat, (Information of Applications of Solid Waste Management, 2006).

### **2.2.1 Istanbul K m rc oda Landfill Example**

In Istanbul K m rc oda, the sanitary landfill was planned to operate for 20 years in a 61 ha area in 1996. Initial lot was constructed on a 6 ha area for 1.500.000 ton waste storage for four years. Second lot was constructed in year 2000 for 5.900.000 ton waste storage and the third lot was constructed for 11.300.000 ton waste storage in year 2005. The total constructed landfilling area from 1996 up today is about 40 ha. There is not a development model like BOT, DBO or similar (Ista A.S., 2007).

## **2.3 Current Legislation**

At present 2872 numbered environmental law, sanitary landfill construction and operation has been set to the control of the municipalities. Therefore municipalities can call out a third party waste collector or operator instead of doing it by themselves. According to this law; people that will benefit the service are obliged to participate by paying the fee that the municipality commission states. According to the Environment Law - number 2872 item 11, subsection 3 and paragraph 10, Municipalities can not use the collected fees for other purposes (Turkish Environment Law, 2006.). Municipality can call out a third party waste collector or operator.

Based on Regulation of Control of Solid Waste Management item 25 subsection 1, it is stated that in the regions which has a population greater than 100.000 the sanitary landfill should be designed to have a minimum 500.000 m<sup>3</sup> waste storage capacity and in the regions which has a population smaller than 100.000 the sanitary landfill should be designed to have a minimum 10 year lifespan (Regulation of Control of Solid Waste Management, 2006). Landfill area should be protected by a perimeter fence.

Wheel washing unit should be constructed within the landfill area for cleaning wheels of the waste transportation trucks. In the main entrance of the landfill plant scale unit and a scale unit building, gate control and operating buildings should be installed.

Based on Regulation of Control of Solid Waste Management item 26 subsection 1, landfill base should be minimum 1m above the ground water level(Regulation of Control of Solid Waste Management, 2006).

According to Regulation of Control of Solid Waste Management item 26 subsection 2, a minimum 60 cm of compacted clay or a membrane having at least  $1.10^{-8}$  m/sec hydraulic conductivity as a landfill liner should be installed. In places closer to drinking water resources, minimum 60 cm compacted clay and over it 2 mm thick HDPE membranes should be installed (Regulation of Control of Solid Waste Management, 2006).

According to Regulation of Control of Solid Waste Management item 26 subsection 3, over the liner system, minimum 100 mm diameter perforated drainage pipes should be installed without any bends and having a minimum one per cent slope degree. The pipes should be covered with a minimum 30 cm sand or gravel as a filter layer. Outside the landfill area monitoring wells should be installed (Regulation of Control of Solid Waste Management, 2006)

According to Regulation of Control of Solid Waste Management item 27, landfill gas should be collected by horizontal and vertical collection systems and should be either given to atmosphere or burned to gain energy

### 3 DESIGN OF SANITARY LANDFILLS

#### 3.1 Landfilling Methods

Typically, a regular and environmentally safe constructed landfill cross section is shown in the Figure 3.1.

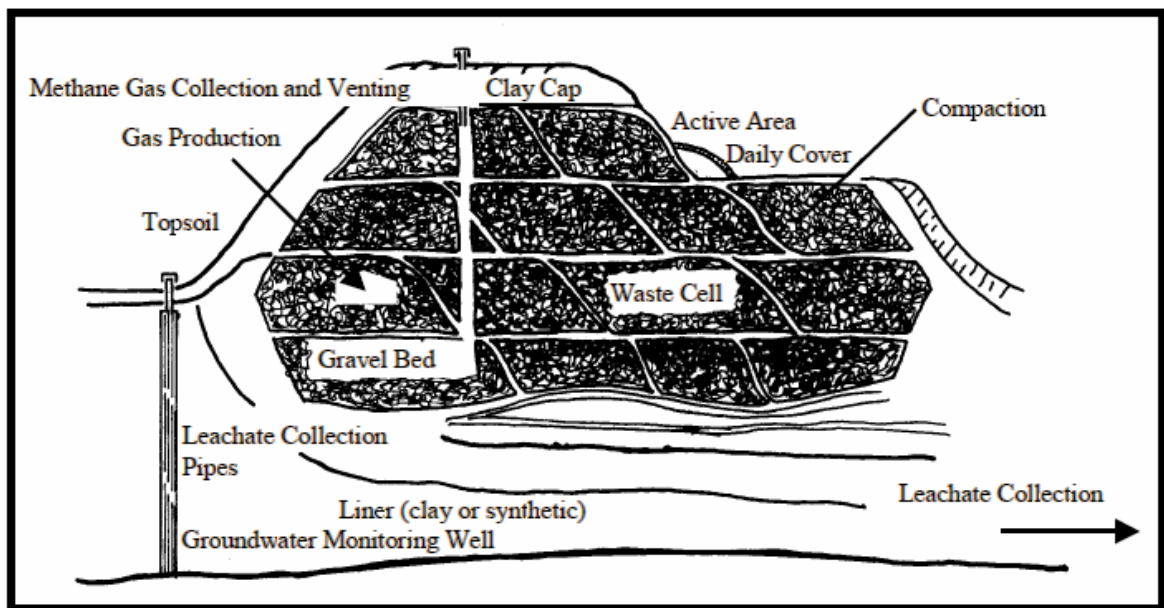


Figure 3.1. Schematic diagram of basic aspects of a sanitary landfill (UNEP, 2005)

When to study the landfilling methods applied in landfills; it is seen that no one method of landfilling is best for all sites, and a single method is not the optimum for any given site. Selection of a method depends upon the physical condition of the site, amount and types of solid waste to be disposed, and the relative costs of the options. There are two basic types of landfill methods; the trench method Figure 3.2 and the area method Figure 3.3.

The trench method is best suited for sites that have a flat or gently rolling land surface, a low groundwater table, and a soil layer thicker than 2 m.

Some of the disadvantages of the trench method are;

- Lower efficiency of land use (ton/acre),
- Difficult to cost effectively implement leachate management systems (liner and collection system) (Solid Waste Landfill Design Manual, 1987).

The area method is suitable for most topographies and better than trench method for sites that receive large quantities of solid waste (UNEP, 2005).

Disadvantages of the area method are;

- Larger overall area/volume ratio results in higher leachate production and higher capital costs,
- Higher daily cover requirements,
- Cover material may have to be imported,
- Higher litter problems (Solid Waste Landfill Design Manual, 1987).

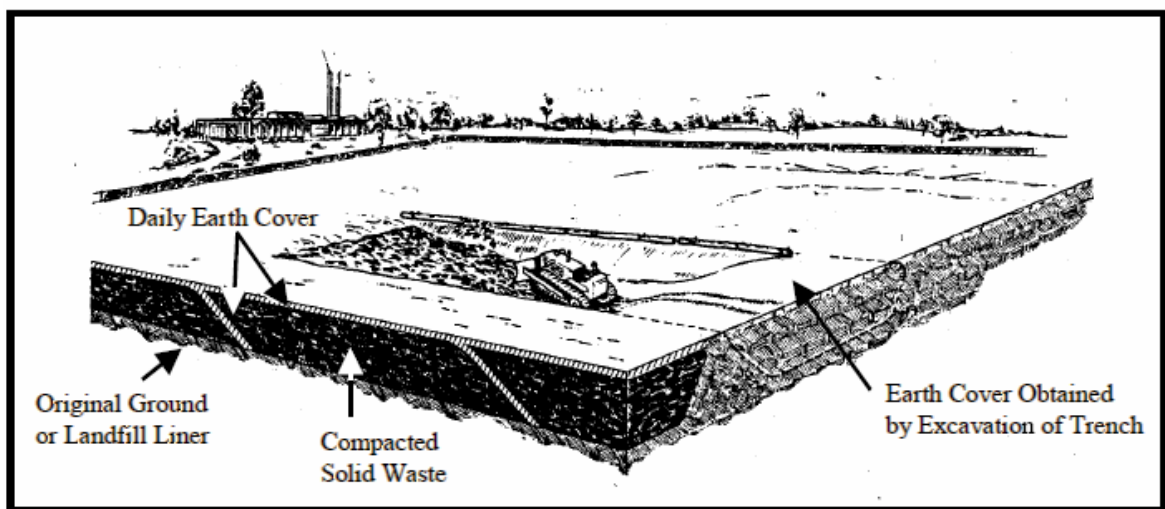


Figure 3.2. Trench method (Solid Waste Landfill Design Manual, 1987)

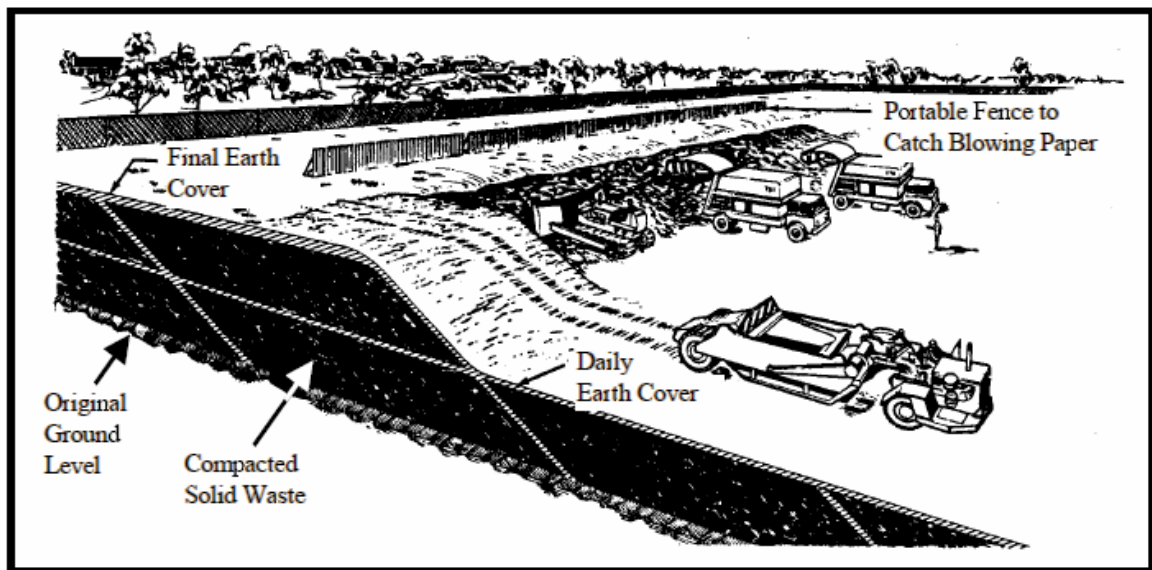


Figure 3.3. Area landfill (Solid Waste Landfill Design Manual, 1987)

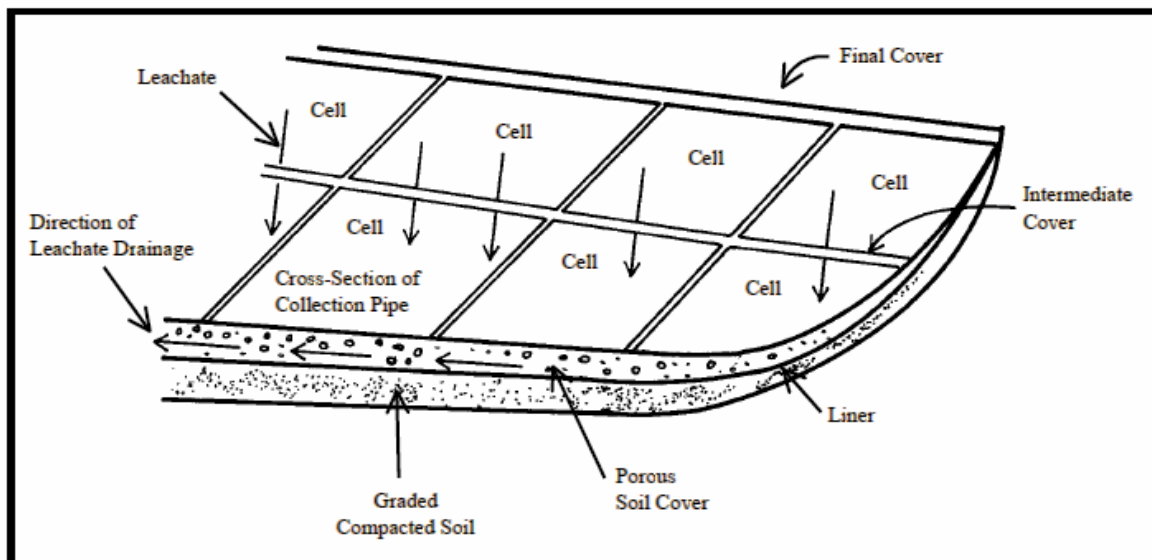


Figure 3.4. Cellular structure of a landfill (UNEP, 2005)

The cells are designed based on the quantity of wastes requiring disposal Figure 3.4. The basic elements of a cell are: height, length, width of working face, slope of sidewalls, and thickness of daily cover. The height of a cell is a function of the quantity of waste, thickness of daily cover, stability of slopes, and degree of compaction. Typical heights vary between 2 and 4 m. (UNEP, 2005).

The width of the working face is one of the major weaknesses in the operation of a landfill in economically developing countries. Generally, the working face is excessively wide in order to accommodate the maximum number of vehicles and to avoid long delays. But in operation the smallest practical area must be provided for the working face (UNEP, 2005).

The maximum recommended slope is 1 to 3 (vertical to horizontal). Slopes less than about 1 to 6 result in an undesirably large area for the working face (UNEP, 2005).

### **3.2 Liners**

Liner is the main element of the landfill that prevents movements of harmful pollutants out of the landfill boundaries. Therefore liners should be carefully designed and constructed. Groundwater level, soil characteristics, precipitation, seismology of the region should be carefully examined and the results should be carefully adapted to the design procedure.

Selection of the liner material depends on;

- Type of waste and composition,
- Required operating life of the landfill,
- Required life of the liner after closure of the landfill,
- Soils on or nearby site, including subsoil,
- Hydrology and hydrogeology,
- Significant environmental factors,
- Acceptable leakage of leachate,
- Permeability of available clay soil if any,
- Analysis of material which appear to be potentially compatible,
- Compatibility tests of specific materials with sample of the waste to be contained,
- Costs of candidate materials and installation,
- Reliability of materials, seams and joints and documented experience in the technology.

Flexible membranes, natural soils and geosynthetic clay liners are the most common liner materials.

### **3.3 Leachate Collection System**

A leachate collection system is essentially a highly permeable layer that overlies the bottom liner and directs the flow of leachate percolating into it from overhead toward an outlet from the landfill. A typical leachate collection system consists of the following:

- A layer of highly permeable aggregate material, either sand or gravel (drainage layer),
- A network of perforated pipes laid within the aggregate layer (collection pipes),
- Filter layers of aggregate or geotextile to prevent piping and clogging,
- A main transmission line which directs the collected leachate to the leachate lagoon.

### **3.4 Gas Collection System**

Due to the decomposition of the waste gas generation occurs. Landfill gas contains methane gas, which is flammable and explosive and can have undesirable environmental impacts. Gas control system consists of gravel filled gas venting trenches and/or perforated gas venting pipes. Generally this type of control systems is called, passive system.

Where passive gas venting is ineffective active gas collection may be used to collect landfill gas. Active systems remove landfill gases by creating a vacuum.

Gas extraction wells either can be drilled after the waste has been dumped or can be installed as the waste dumping operation continues. Typical cross section of a landfill gas extraction well is presented in Figure 3.5.

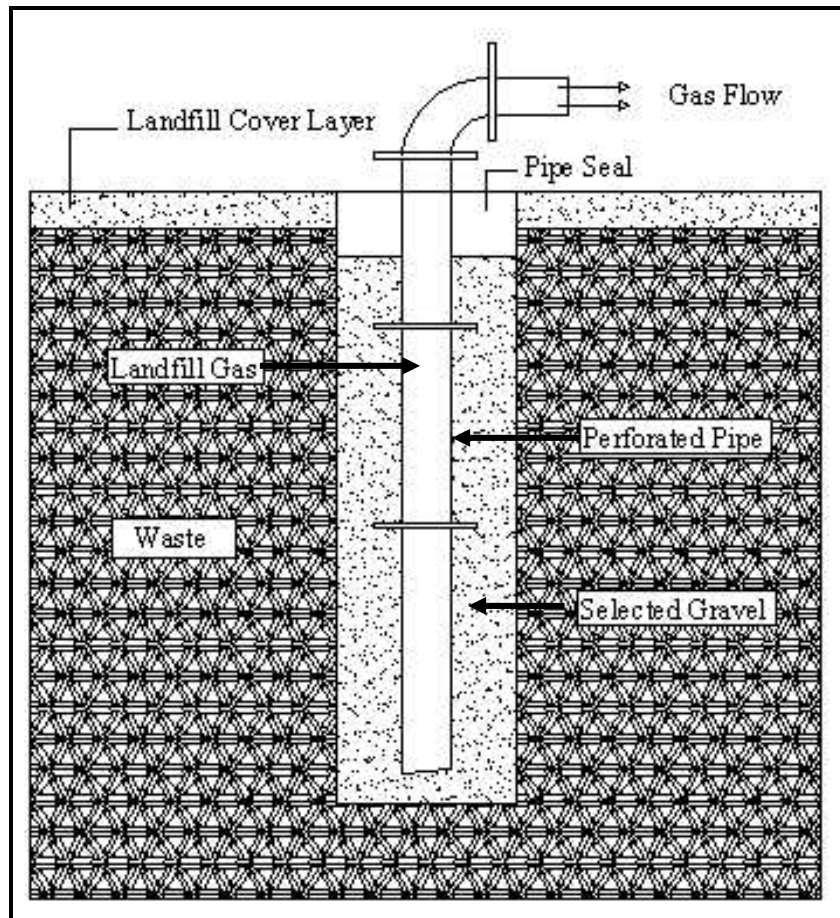


Figure 3.5 Gas extraction well

Gas released from extraction wells is either burned with flares installed on each extraction well or collected with gas collection systems. Due to the gas generation levels electrical energy can be achieved from landfill gas flaring.

### 3.5 Final Closure

One of the most important processes in modern landfilling is post closure construction and operations. At the design period of the landfill investment, post closure applications should be considered and planned. Aftercare programs should include monitoring operations and after use conditions.

Closure material should have low hydraulic conductivity. Over the barrier layer drainage layer installed. Vegetative layer installed over the drainage layer. Final cover layers are illustrated in Figure 3.6.

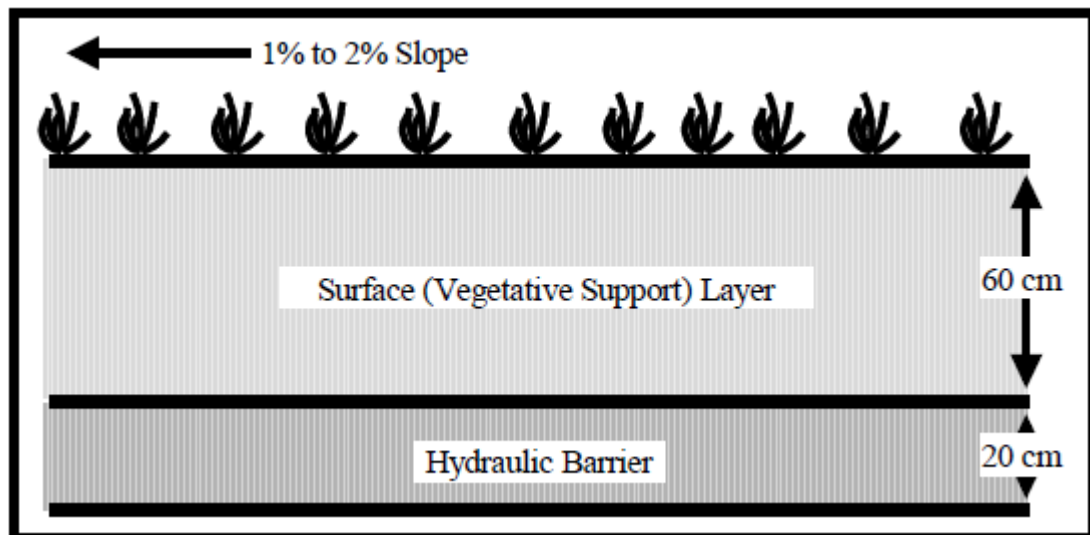


Figure 3.6. Final cover cross section (UNEP, 2005)

The simplest design of a final cover system for a sanitary landfill consists of two layers; the surface layer, and the hydraulic barrier. The hydraulic barrier is the first layer of the cover specifically designed to prevent the passage of liquids into the waste. In order to prevent the surface water flow into the waste the surface layer designed to have slopes of one or two per cent.

### 3.6 Construction Costs of Sanitary Landfills in Turkey

Construction cost of sanitary landfills is a function of many parameters like population, geotechnical properties of the landfill area, distance of the landfill area to the residential area and etc. Although the construction methods are defined in the present regulations, they may vary from one municipality to the other. The sanitary landfill construction tender results within the past two years are shown in the Table 3.1. Total cost prices are only the construction costs, pre-development cost, land purchase cost and operating cost are not included.

Table 3.1. Construction costs of sanitary landfills

Municipality	Date of Tender	Waste Capacity (m <sup>3</sup> )	Area (m <sup>2</sup> )	Project Life (year)	Total Amount of Tender (x 1.000 €)
Manavgat MATAB Sanitary Landfill Construction	27.02.2004	2.000.000	256.000	30	3.879
Datça Sanitary Landfill Construction	29.11.2004	315.000	20.000	13	1.357
Aksaray Sanitary Landfill Construction	18.09.2005	3.976.000	N/A	20	2.376
Bolu Sanitary Landfill First Lot Construction	21.11.2005	315000	20.000	13	607
Alanya Sanitary Landfill Construction	08.11.2005	N/A	300.000	10	1.548
Sinop Shared Sanitary Landfill Construction	23.12.2005	N/A	N/A	N/A	1.198
Zonguldak Sanitary Landfill Construction	28.04.2006	N/A	150.000	25	1.103
Aydın Sanitary Landfill Construction	08.05.2006	N/A	163.000	25	4.359
Adapazarı Sanitary Landfill Construction	24.05.2006	1.800.000	N/A	20	4.017
Şereflikoçhisar Sanitary Landfill Construction	12.06.2006	660.000	N/A	20	2.113
Tekirdağ Sanitary Landfill Construction	31.07.2006	N/A	N/A	N/A	524
Şanlıurfa Sanitary Landfill Construction	18.08.2006	N/A	N/A	N/A	2.837

(after www.ihalenet.com, 2006)

The number of the sanitary landfill project tenders from the year 2004 until 2007 is 12. Total price of the tenders is € 25.918.000. The data in the Table 3.1 show that landfill costs are specific for each landfill. For example, Zonguldak Sanitary Landfill which has 150.000 m<sup>2</sup> area, costs € 1.103.000. Aydın Sanitary Landfill, which has an area of 163.000 m<sup>2</sup>, costs € 4.359.000. Also Alanya Sanitary Landfill with an area of 300.000 m<sup>2</sup>, doubles Zonguldak, costs € 1.548.000. In more than two years only 12 projects were completed by municipalities. This number is quite small for a country like Turkey.

### 3.7 Construction Costs of Sanitary Landfills in Some European Countries

#### 3.7.1 Finland

The cost of landfilling municipal solid waste varies across Finland. There are a number of local reasons affecting the treatment costs but no clear correlation between the regions and the costs exists. A typical breakdown for capital and operational costs for a newly constructed landfill in Finland is shown in Table 3.2. The capacity of the present landfill is approximately 140.000 m<sup>3</sup>.

Table 3.2 Costs for 1,4 hectare landfill in Finland

<b>Landfill (1,4 ha Area)</b>	<b>Costs (€)</b>
<b>Investment Costs</b>	
Site Acquisition	108.000
Detailed Design	161.000
<b>Buildings</b>	
Office	259.000
Weigh office	80.000
Machine room	136.000
Others (e.g. hazardous waste storage, pumping station)	217.000
<b>Machines and equipment</b>	
Weighbridge	64.000
Others (e.g. waste containers)	63.000
<b>Construction works</b>	
Site development	594.000
Water supply	290.000
Sewerage	131.000
Liner	839.000
Asphalting	20.000
Leachate water compensation basin	415.000
Fencing	4.000
Total investment,	3.381.000
<b>Operational costs</b>	
Investment payment <sup>1</sup>	319.000
Surface water control <sup>2</sup>	4.000
Waste water fees <sup>2</sup>	15.000
Landscaping <sup>2</sup>	113.000
Total operational costs plus depreciation	451.000
<sup>1</sup> Calculated with Payback period of 20 a and Rate of 7 %	
<sup>2</sup> Accounts 2000 of the waste management company	

(after Eunomia Ltd, 2002)

Costs of a landfill having an area of 14.000 m<sup>2</sup> with a capacity of 140.000 m<sup>3</sup> are presented in Table 3.2. Total cost of initial investment including building costs, machines and equipment cost and construction costs is € 3.381.000. Unit cost of construction becomes 24,15 €/m<sup>3</sup>. Total operational costs plus depreciation is € 451.000. Unit cost of operation becomes 3,22 €/m<sup>3</sup>. Total unit cost of landfilling waste becomes 27,37 €/m<sup>3</sup>.

### 3.7.2 Germany

Landfills in Germany normally are equipped with gas and seepage water collection equipment. A typical breakdown for landfill construction costs in Table 3.3 is given for a landfill where municipal wastes are disposed during 20 years. The size of the facility corresponds with a tipping rate of 300.000 ton per year. Landfill gas is captured for electricity generation and seepage water is treated.

Table 3.3 Landfill construction costs

Total Investment	Investment (€)	Payback Period (year)	Rate %	Annualized Cost €/year	Specific Costs €/t
Site Costs	4.231.000		7	296.200	0,99
Development of Site	1.627.000	20	7	153.600	0,51
Construction Costs	3.003.000	4	7	886.700	2,96
Gas Collection	301.000	4	7	89.000	0,30
Other Construction	4.612.000	20	7	435.300	1,45
Technical Installations and Machinery	3.212.000	15	7	352.700	1,18
Mobile Machinery	555.000	8	7	92.900	0,16
Electro Technical Installations	430.000	15	7	47.200	0,31
Fees	3.120.000	19	7	301.900	1,01
Pre Financing	629.000	19	7	60.800	0,20
Total				2.716.400	9,05

(after Eunomia Ltd, 2002)

Total annualized construction cost for the landfill with a tipping rate of 300.000 ton/year is € 2.716.400 and the corresponding specific cost is 9.05 €/ton. The payback period is 20 years. The payback amount for construction is € 3.552.000. The interest payment for construction is € 548.000 in four years.

A detailed operational cost analysis for a landfill with a tipping rate of 300.000ton/year is presented in Table 3.4.

Table 3.4. Landfill operational costs

Operational Costs	Total Cost €	Percentage %		Annual Costs €/year	Specific Costs €/t
Construction	20.972.000	1		209.700	0,70
Technical Installations and Machinery	3.212.000	4		128.500	0,43
Mobile Machinery	555.000	8		44.400	0,15
Electro Technical Installations	430.000	2,5		10.700	0,04
Taxes and Insurances	29.401.000	1		294.000	0,98
Management	429.000	10		42.900	0,14
Auxiliary Materials	393.000	5		19.700	0,07
Restoration of Site (4 years)	2.409.000			602.300	2,01
Aftercare (20 years)	1.205.000			1.205.000	4,01
		<b>number</b>	<b>€/person</b>		
Labor		12	35.800	429.500	1,43
Guard				38.300	
Analysis				72.600	
		<b>kWh/year</b>	<b>€/kWh</b>	<b>€/year</b>	<b>€/t</b>
Credits for Electricity		644.900	0,08	52.800	0,17
		<b>m<sup>3</sup>/year</b>	<b>€/m<sup>3</sup></b>		
Fuel		150	486	72.900	0,25
		<b>m<sup>3</sup>/a</b>	<b>€/m<sup>3</sup></b>		
Chemicals for Seepage Water Treatment		38.707	3,94	152.400	0,51
	<b>kg/m<sup>3</sup> water</b>	<b>t/year</b>	<b>€/t</b>		
Treatment of Sludge	1,2	46,40	281	13.000	0,05
Total				3.388.400	11,29

(after Eunomia Ltd, 2002)

Construction that will be made every year, technical installations, taxes and insurances, management, restoration of the site, aftercare, labor, electricity, fuel and treatment expenditures are all included in operational cost analysis for the whole lifespan of the landfill. Unit operational cost is 11,29 €/ton. Adding unit construction cost to unit operational cost, unit total cost becomes 20,34 €/ton for the whole facility for 20 years.

The costs for different sized landfills vary widely. Costs of landfills with varying tipping rate in Germany are presented in Table 3.5.

Table 3.5. Costs of landfills with varying tipping rate

Capacity (ton/year)	Specific Costs (€/ton)
50.000	51
100.000	34
150.000	28
300.000	20
500.000	17

(after Eunomia Ltd, 2002)

Specific cost for 50.000 ton/year capacity landfill is 51 €/ton while it is 17 €/ton for a 500.000 ton/year capacity landfill. As the capacity of the landfill increases unit cost for landfilling decreases.

### 3.7.3 Greece

The most important parameters influencing the cost of sanitary landfill for municipal solid waste in Greece are; the contours of the location, the geology, which defines the lining method, the size of the landfill, which defines the required degree of leachate and biogas treatment and the size of the population served by the landfill, which influences the cost of landfilling. Typical costs for landfill construction, for a number of varying scenarios, are provided in the Table 3.6.

In Table 3.6 cost/head of population served is given depending on the lining system, the type of the subsoil, and the number of population served. For 20.000 population, a landfill on rocky subsoil with the geomembrane liner system costs € 100 while it is € 43 for a landfill having the same subsoil and liner conditions. As the population increases the unit cost decreases. Table 3.6 includes all construction costs, such as earthworks, building costs, equipment, as well as monitoring costs. They do not include land acquisition costs, and restoration and aftercare costs

Table 3.6. Typical costs for landfill construction

Population served	Soil conditions	Lining	Cost/head of population served €
20.000	Semi-rocky	Geomembrane	64
	Earth	Layer of Clay	36
	Rocky	Geomembrane	100
50.000	Semi-rocky	Geomembrane	46
	Earth	Layer of Clay	27
	Rocky	Geomembrane	73
150.000	Semi-rocky	Geomembrane	30
	Earth	Geomembrane	26
	Rocky	Geomembrane	43

. (after Eunomia Ltd, 2002)

Typical capital and operational costs for landfill sites, due to the population served, in Greece are presented Table 3.7.

Table 3.7. Typical capital and operational costs for landfill sites

Population served	Capital costs (€/ton)	Operational costs (€/ton)
5.000	15	15
10.000	12,5	7,5
>10.000	7,5	1,5

(after Eunomia Ltd, 2002)

As the served population increase both the capital costs and the operational costs decrease. Operational costs is 1,5 €/ton for population higher than 10.000 while it is 15 €/ton for a 5.000 population. For places having population less than 10.000 a regional sanitary landfill can be developed.

### 3.7.4 Ireland

Since the mid-1990s a system of Waste Licensing has been enforced by the Environmental Protection Agency, which has led to improved design and operation of sites and therefore an increase in costs due to the investment required. Other factors contribute to increased costs are; municipal landfill capacity is increasingly scarce, prices are sometimes raised to conserve void space, or to prevent waste tourism from more expensive areas, low landfill costs are preventing recycling efforts, increased landfill fees can help to subsidize other waste management services and the cost of developing a new landfill site has risen due to objections, delays, and rising land costs.

The estimated development costs for a new 2,000,000 m<sup>3</sup> municipal landfill are outlined in the Table 3.8.

Table 3.8. Capital costs for conceptual 2 million m<sup>3</sup> landfill

Item	Comments	Costs €
Land acquisition	(incl. 250m buffer zone)	7.142.857
Infrastructure	Civil works, structures, equipment, surface water, gas etc.	7.755.556
Cell development	Earthworks and composite lining, in 10 phases	20.317.460
Restoration	In 10 phases	5.079.365
Aftercare	30 year period	1.523.810
Planning and design		3.505.714
Total		45.324.762

(after Eunomia Ltd, 2002)

Land acquisition, cell development and infrastructure costs are 77,7 per cent of total costs. Assuming unit weight of waste 0,85 ton/m<sup>3</sup>, unit cost of cell development becomes 11,95 €/ton . Some Irish landfills are located in wet areas, this increases construction costs. Furthermore, if in-situ clay must be imported for the base liner, this also increases costs. Additionally, difficulties in providing new areas, affects the landfill costs.

The assumptions made for the Table 3.8:

- Total capacity - 2 million m<sup>3</sup>,
- 20 year life,
- Disposal area 20 ha (average 10m high),
- Total site area 90 ha (20 disposal/70 buffer and operational),
- 10 phases, two years per phase,
- Aeration of leachate on site, leachate pumped to treatment plant.

### 3.7.5 England

Gate fees for landfilling municipal waste vary across the UK in accordance with geology and the availability of void space. Costs for recently proposed landfill extension are presented in Table 3.9. Considerations for energy recovery excluded in the table.

Table 3.9 Costs for recently proposed landfill extension

Fill Rate	175.000 ton			
<b>Capital Costs</b>	<b>Total Cost €</b>	<b>Lifespan</b>	<b>Annualized Cost €</b>	<b>Unit Cost €/ton</b>
Site Assessment	320.000	10	45.560	0,26
Acquisition	1.600.000	10	227.804	1,30
Capital Expenditures and Development	14.088.729	10	2.005.918	11,46
Restoration	960.000	10	136.682	0,78
Aftercare	4.924.582	10	701.149	4,01
<b>Total</b>	<b>21.893.312</b>		<b>3.117.115</b>	<b>17,81</b>
<b>Operating Costs</b>				
Operation			1.920.000	10,97
<b>Total Costs</b>			<b>5.037.115</b>	<b>28,78</b>

(after Eunomia Ltd, 2002)

Capital expenditures and development unit cost is 11,46 €/ton, which makes 64,3 per cent of the total construction costs. This unit cost is close to the unit cost calculated for Ireland. Annualized capital cost is € 3.117.115 and operational cost is € 1.920.000 and annualized total cost is € 5.037.115 for 10 year lifespan.

### 3.7.6 Italy

Based on 1999 numbers, the National Environmental Protection Agency recently reported 74.4 % of MSW landfilled. The large share of landfilling might be a reason of very low gate fees applied in the past. Until a few years ago, it was quite common to dispose of MSW at landfilling sites for as little as € 15, above all in southern regions of Italy. Such fees did not obviously allow for all needed environmental standards and were just covering operational costs linked to tipping and covering.

According to the analysis model, the landfill has the following features:

- Useful height 15 meters,
- 1,5-2 meters waterproof layers and lining materials compacted clay not less than 100 cm,
  - A double HDPE membrane, 2 cm. Thick,
  - Protecting layer (around 50 cm) constituted of gravel and stabilized,
  - Organic material, including piping for the drainage of leachate,
  - 14 cells,
  - Total area covered: 113.000 m<sup>2</sup>,
  - Overall volume: 1.250.000 m<sup>3</sup>,
  - Thickness of daily cover: 30 cm,
  - Leachate pre-treated on site (chemical-physical treatment) then sent out to a wwtp for biological treatment,
    - Biogas drained through vertical wells with slotted pipes, then combusted.

Table 3.10. Landfilling costs for Italy

Capacity (m <sup>3</sup> )	1.250.000		Yearly Capacity (m <sup>3</sup> )			
Duration (years)	10		125.000			
	<b>Unit</b>	<b>Unit Cost €</b>	<b>Total Cost €</b>	<b>Payback Period year</b>	<b>Interest Rate %</b>	<b>Yearly Depreciation €</b>
<b>Investment Costs</b>						
Land Purchase (m <sup>2</sup> )	300.000	7,748	2.324.380	10	7	330.939,44
Preparation of the Site						
Land Preparation (m <sup>2</sup> )	300.000	0,878	263.430	10	7	37.506,47
Excavation (m <sup>3</sup> )	550.000	1,808	994.328	10	7	141.568,54
Wall			578.512	10	7	82.367,15
Accessing Roads	27.120	25,826	700.413	10	7	99.723,09
<b>Utilities and Technological Supplies</b>						
Curtaining (m <sup>2</sup> )	4.840	51,653	250.000	10	7	35.594,38
Wells, Internal Water						
Supply, Imhoff Pit, Sewage Lines			362.087	10	7	51.553,01
<b>Civil Works</b>						
Weighing Bridge	2		99.690	10	7	14.193,53
Prefabricated Offices			103.306	10	7	14.708,42
Roof For Vehicles			180.785	10	7	25.739,73
Instruments						
Others			619.835	10	7	88.250,52
<b>Biogas Drainage and Treatment</b>						
			774.793	10	7	110.313,15
<b>Collection and Treatment of Leachate</b>						
			1.549.587	10	7	220.626,30
<b>Vehicles and Equipment</b>						
			1.807.851	10	7	335.452,62
Paving (m <sup>2</sup> )	125.700	51,653	6.492.769	10	7	924.424,18
Closure Works	127.948	50,176	6.419.870	10	7	914.045,09
<b>Post-Closure Care</b>						
			20.551.157	10	7	1.495.413,31
<b>TOTAL</b>						<b>4.922.418,93</b>
<b>Specific Cost (€/ton)</b>						<b>39,38</b>
<b>Operating Costs</b>						
<b>Maintenance</b>						
Civil Works						
			33.219			
Machinery and Equipment						
			165.289			
<b>Manpower</b>						
Accountant	2	35.000	70.000			
Technical Director	1	60.000,	60.000			
Workers	10	30.000	300.000			
<b>Consumables</b>						
			82.645			
<b>Daily Covering</b>						
			51.653			
Treatment of Leachate(m <sup>3</sup> )	27.500	25,83	710.227			
<b>General Expenses</b>						
			61.751			
<b>Others</b>						
			103.306	<b>Specific Cost (€/ton)</b>		
<b>Total Operating Costs</b>			<b>1.638.090</b>	<b>13,10</b>		
<b>TOTAL COSTS</b>			<b>6.560.508,93</b>	<b>52,48</b>		

(after Eunomia Ltd, 2002)

Costs for a landfill with a capacity of 1.250.000 m<sup>3</sup> and ten years of lifespan is presented in Table 3.10. Initial investment costs including land purchase, land preparation, earthworks, wells and access roads, for the landfill is € 4.861.063. Corresponding yearly depreciation cost for ten years period at seven per cent interest rate is € 692.104,69. Total cost including initial investment costs, utilities and technological supplies, civil works, biogas drainage and treatment, collection and treatment of leachate, vehicles and equipment, paving, closure works, post-closure care, is € 44.072.793 and corresponding yearly depreciation € 4.922.418,93. For 1.250.000 ton waste the specific unit cost for construction becomes 39,38 €/ton. Total operating cost including maintenance, manpower, consumables, daily covering, treatment of leachate, general expenses and others, is € 1.638.090. Unit cost for operation becomes 13,10 €/ton. Total unit cost for landfilling waste becomes 52,4 €/ton.

### 3.7.7 Summary of Landfill Costs for European Countries

Costs for landfill construction and operation, as it is presented in the previous sections, vary from country to country, even from city to city within a country. The way the governments handle the solid waste management, geological conditions of the selected area, the socio-economic status of the country, the available technology for sanitary landfilling, etc. can be examples of the factors that affect the costs. Some countries in Europe try to implement mechanisms that will reduce the landfilling of waste. The most common implementation in the countries for reducing the amount of landfilling waste is waste minimization and recycling. Also incineration and composting of waste are widely used. Summary of costs for countries are presented in Table 3.11.

Table 3.11 Summary of costs for European countries

Country	Unit construction cost (€/ton)	Unit operational cost (€/ton)	Total unit cost (€/ton)
Finland *	19,32	2,58	21,90
Germany	9,05	11,29	20,34
Greece (population greater than 10.000)	7,50	1,50	9,00
Ireland *	19,26	N/A	
England	17,81	10,97	28,78
Italy	39,38	13,10	52,48
* Unit weight of waste is 0,85 ton/m <sup>3</sup>			

Unit construction costs and unit operation costs are different for each country. Unit construction cost in Finland is higher than in Germany but unit operation cost of Finland is lower than Germany. Unit operation cost in England and Germany are close to each other. Unit construction costs in Finland and Ireland are almost same. Greece is the cheapest country for landfilling among the countries with a total unit cost of landfilling of 9,00 €/ton. The chart of unit costs for countries is presented in Figure 3.7.

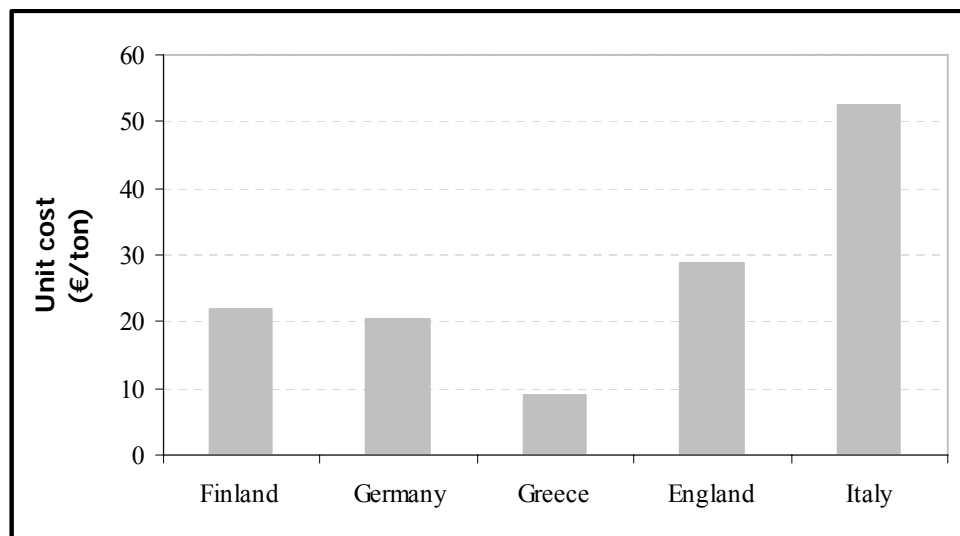


Figure 3.7 Unit cost of landfilling waste for European countries

Unit cost of landfilling waste in Italy is very high when compared to the other countries and unit cost of landfilling waste in Greece is the lowest.

## 4 MODULAR LANDFILL DESIGN AND CONSTRUCTION

### 4.1 Pre-design Assumptions

Because there is a big difference between every sanitary landfill, it is hard to find out the common indicators and to state common design parameters for every landfill. Therefore, in order to focus on the main modular design thesis, some assumptions will be used for the method.

The assumptions accepted are;

- Land acquisition and environmental reports, permits, etc. will not be questioned,
- Support facilities of the sanitary landfill and the other units will not be cited,
- A sample area topography will be accepted,
- Landfilling of special wastes like hazardous and clinical waste will not be included,
- Operational design and operational costs will not be cited,
- Height of the waste will be 18 m,
- Post closure works and costs will not be included.

### 4.2 Design of The Modules

The design of the module is the function of lifespan of the landfill area and the annual waste to be disposed at landfill.

For the calculation of useful lifespan of a sanitary landfill, following formula can be used:

$$L = V_T / (365(Q_p(1 + F_{Q_p}))) \quad (4.1)$$

where:

- $L$  = useful lifespan in years,
- $V_T$  = volume of selected site in  $m^3$ ,
- $Q_p$  = quantity of solid wastes in  $m^3/day$ , and
- $F_{Qs}$  = quantity of cover material expressed as a fraction of  $Q_p$  in  $m^3/day$ .

The quantity of waste can be projected using estimates of population. The estimate can be carried out by using the following formula:

$$Q_i = Q_p (1 + r)^n \quad (4.2)$$

where:

- $Q_i$  = quantity of wastes to be collected in year “i”
- $Q_p$  = present annual quantity of wastes collected
- $r$  = average annual growth rate in population as a decimal fraction, and
- $n$  = number of years.

The amount of the waste is well known and recorded by the local governments. The present and the future quantities of waste can be calculated.

### 4.3 Layout of the Site

The selected site, according to the lifespan of the project and the topography of the area, will be divided into modules depending on the waste disposal rates and pre-stated operating years. The module will be designed and constructed as a small scale landfill. All the legislative and constructive rules will be fulfilled. Therefore for the initial module, the most economical construction method and operating concerns should be the main goal. Figure 4.1 shows the layout of the modular landfill area.

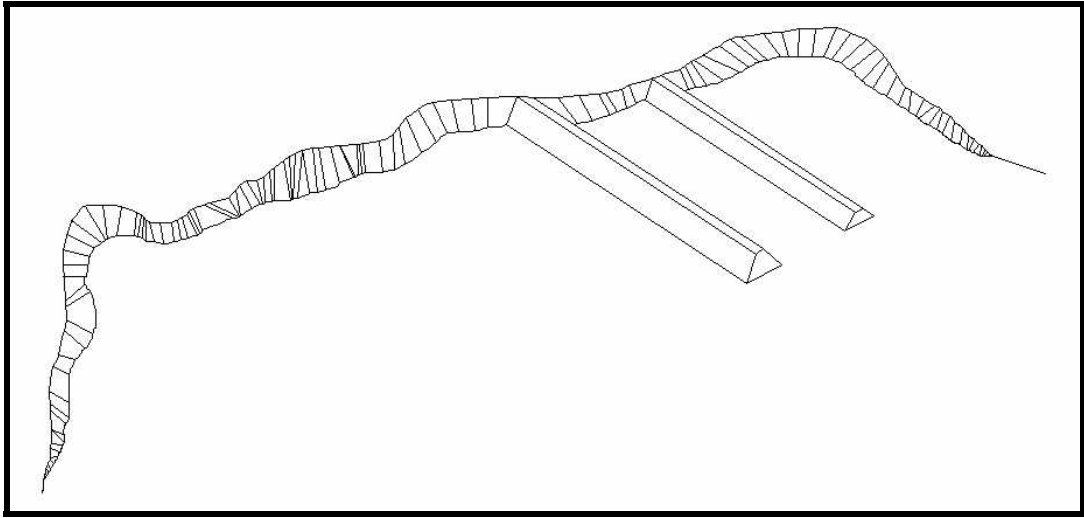


Figure 4.1. Site layout plan

In the selected landfilling area, Figure 4.1, a module will be constructed. According to the topography of the area, perimeter of the module will be constructed by installing embankments, in case of necessity. Dimensions of the embankments will be derived from the stability analysis calculations.

#### 4.4 Earthworks

After the pre-construction works, like drawings, topographic applications etc., module area should be excavated to remove of the vegetative layer and to provide a smooth subgrade. Excavated material should be stockpiled for future uses. During the excavation works, to the lowest point of the module where the main leachate line will be installed, minimum one percent slope should be maintained. Also the trench of the main transmission line should be excavated.

The completed subgrade should be checked for density, and if it is less than the required density, the subgrade material should be compacted in order to bring it up to the required density.

#### 4.4.1 Embankments and Design

According to the topography of the area of module embankment construction may need to provide a separated waste disposal area. The main design considerations are the maximum height of the waste to be disposed, protection of the side slopes against erosion and slope stability.

Available soil types should be tested to determine their strength and compatibility. Soils that retain more than 66 percent of the No. 4 standard sieve size should not be used, and any rock larger than six inches should be removed from the fill (Krynine and Judd, 1957). Field compaction densities should be 95 percent of the maximum standard Proctor dry density.

In order to find out the friction angle of the waste, Figure 4.2 will be used. The relationships between waste strength parameters and the density are presented.

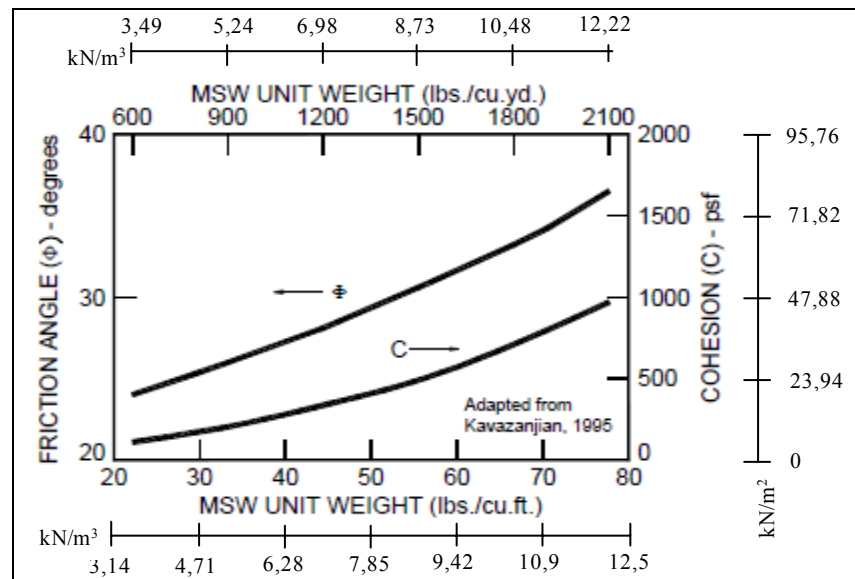


Figure 4.2. The relationships between municipal solid waste strength parameters and density (Boutwell, G.P., 2004)

In order to find the dimensions of the embankments, stability analysis should be made. Using the Figure 4.2 the friction angle of the waste can be derived. Calculation steps of the embankment dimensions are as follows:



Resisting forces ;

$$P_{ay} = P_a \sin \theta \quad (4.7)$$

$$\Sigma F = W \cdot \mu \quad (4.8)$$

$$\mu = \tan \phi \quad (4.9)$$

$$W = A \cdot \gamma_s \quad (4.10)$$

$$P_{ay} = 1,824 \cdot \sin 24^\circ$$

$$P_{ay} = 0,56 \text{ kN/m}$$

$$A = (1,5 + 0,5) / 2 \cdot 1 = 1 \text{ m}^2$$

$$W = \frac{1}{2} \cdot 1 \cdot 18 = 9 \text{ kN/m}$$

$$\Sigma F = 0,56 + 9 \cdot \tan 22^\circ$$

$$\Sigma F = 4,20 \text{ kN/m}$$

$$FS = 4,20 / 1,74$$

$$FS = 2,42 > 1,5$$

A 1 m high embankment with the side slopes of 1:3 and 1 m top width is sufficient to resist sliding.

The construction of the embankment should be in layers having a maximum height of 15cm. Each layer should be compacted. The minimum required density is 95% of maximum dry density with moisture content within  $\pm 2\%$  of the optimum, unless otherwise specified by the engineer.

Both faces and the bottom of the embankment will be covered with the liner material so that the flowing water will not affect the faces of the slopes. Also at the toe of the outer side of the face of embankment drainage ditch should be installed to avoid the impacts of surface waters. Simple cross section of the embankment is shown in the Figure 4.4

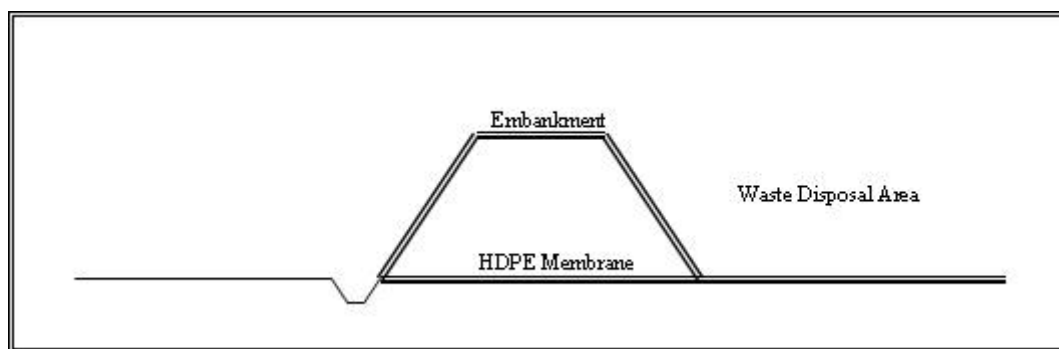


Figure 4.4. Cross section of embankment

Membrane will be covering sides, top and bottom of the embankment. This will protect the embankment against the surface waters effects.

#### 4.5 Liner Design and Construction

The selection of a liner material is mostly depends on type of waste and composition, required operating life of the landfill, required life of the liner after closure of the landfill, soils around the site, including subsoil, hydrogeology of the area and other significant environmental factors.

Generally, as it is stated in the current environmental legislation, liner systems consist of a minimum 60 cm thick of compacted clay or and a 2 mm HDPE(High Density Polyethylene) membrane over it.

After the embankment construction completed, 60 cm of clay will be laid to the bottom of the module which will be compacted in every 15 cm. HDPE membranes will be installed over the clay covering the sides of the module. Membrane will also cover the embankment top and the opposite face. This is done for protection against storm waters affects on embankment slopes. Over the membrane, for protection and for drainage a minimum 60 cm thick of sand and gravel layer should be installed.

After the liner layer installation completed, for protection of the liner, a geotextile, usually 500 gr/m<sup>2</sup>, must be installed. Typical cross section of the bottom of the landfilling area is shown in Figure 4.5.

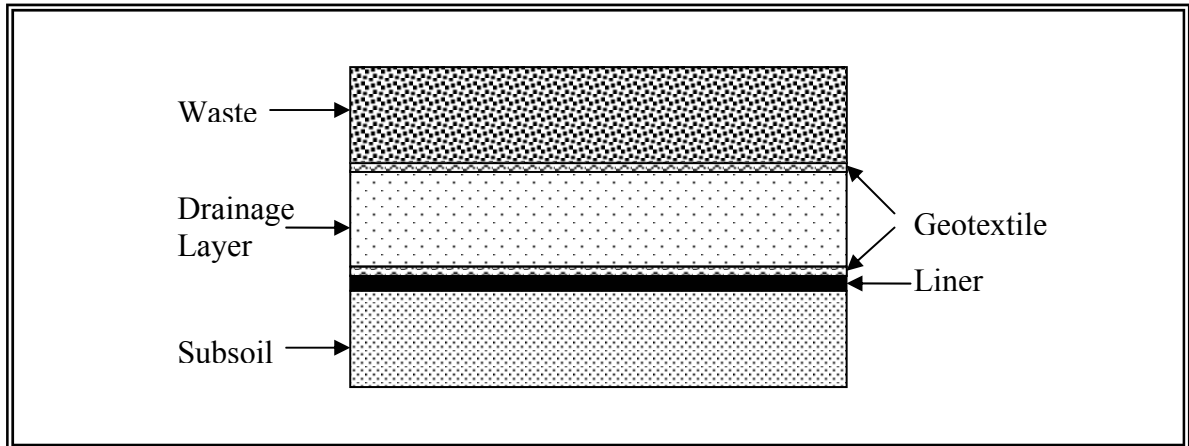


Figure 4.5. Schematic of liner design.

Liner material lay on compacted clay. Geotextile used for protection of membrane against damage. Gravel material laid over the geotextile and another geotextile layer is installed for separation of drainage layer and waste to prevent waste to clog the drainage layer.

#### 4.6 Leachate Collection System Design and Construction

The gradation of an aggregate drainage layer is important because migration of soil particles from the drainage layer into the gravels surrounding the collection pipe should be prevented, if not clogging of the collection system is inevitable. Typically, filter fabrics are used between the two aggregates to prevent the clogging of one by the other.

Perforated pipes, minimum 100 mm diameter, installed over the protection layer of liner system. The collection pipes are placed about 10 to 20 m apart and are covered with a drainage layer of sand and gravel Figure 4.6. All pipes should have a minimum slope degree of one percent (Regulation of Control of Solid Waste Management, 2006). The main transmission line should be installed 60 cm deep at topographical low point of the landfill area (Solid Waste Landfill Design Manual, 1987).

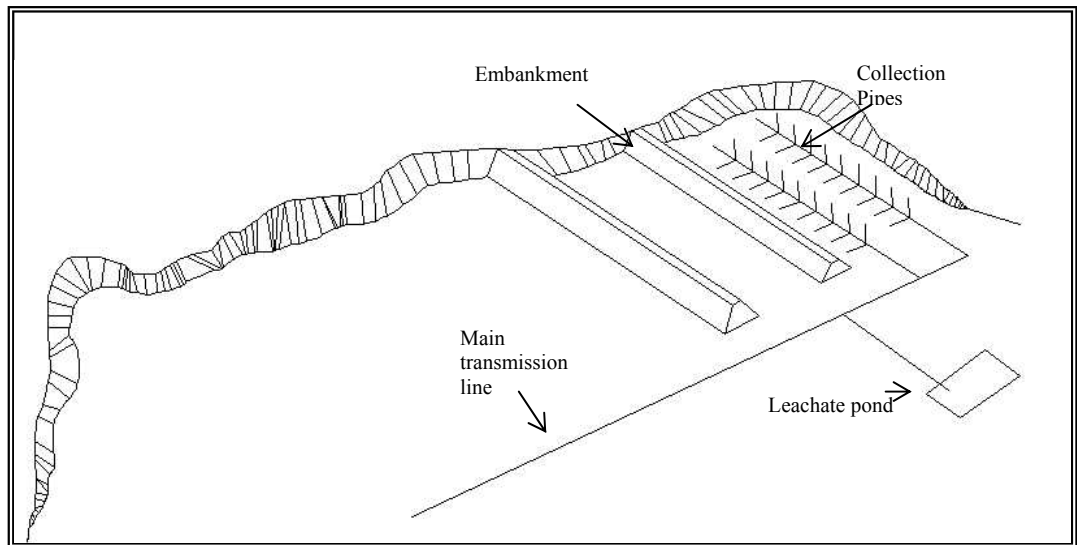


Figure 4.6. Layout of the leachate collection pipes

After the installation of liner system, leachate collection pipes will be installed. Collection pipes will be perforated and will have a minimum 100 mm diameter. Collection of leachate will be by gravity therefore each branch of collection pipe system will be installed in slopes. At the end of each collection line, outside the landfilling area, manholes will be constructed. Manholes will help to clean the line in case of clogging. Main transmission line pipe diameter will be greater than the collection lines. Diameter of the main transmission line depends on the leachate that will be produced from waste and regions precipitation. Main transmission line will also be modular. Line will be expanded with each module. Collected leachate will be transmitted to the leachate pond. Leachate pond dimension depend on the amount of the leachate and the type of the treatment technique, whether the leachate will be transported to a treatment plant away from the facility or will be treated in a treatment plant constructed in the facility.

Collection pipes placed in a trench as shown in the Figure 4.7. Aggregates used for pipe bedding. Over the trench a layer for drainage installed using graded materials. Geotextiles may be used to prevent piping of the fine particles.

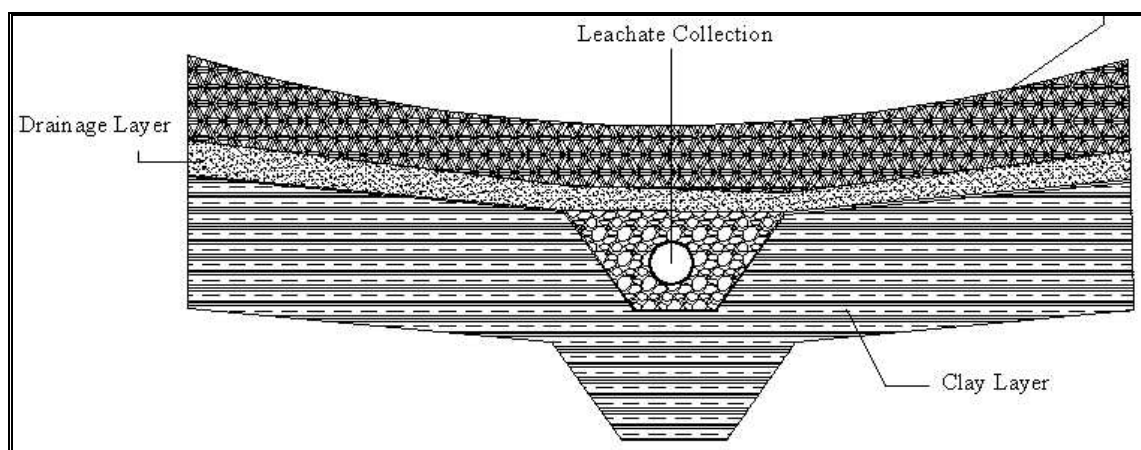


Figure 4.7 Cross section of typical leachate collection pipe.

#### 4.6.1 Collection Pipes

Leachate collection pipes are made of polyethylene (PE). The leachate collection pipes will have a diameter of 10 cm, and the perforations will cover about 50% of the pipe's circumference. Typical installation layout of the collection pipes is illustrated in the Figure 4.8.

Collection pipes will not have any bends or junctions. They will be installed having a minimum of one per cent slope degree. The collection pipes are placed about 10 to 20 m apart from each other.(UNEP , 2005). They will be connected to a transmission line within the module and leachate will be transmitted out of the landfilling area. Plan of a collection system is presented in Figure 4.8.

According to the amount of leachate produced, number of collection lines and branches can be calculated. Pipes laid in trenches in slopes in order to maintain the leachate flow by gravity. Pipes circumference will be graded material to prevent clogging. Manholes will be installed outside the disposal area for future maintenance of pipes in case of clogging.

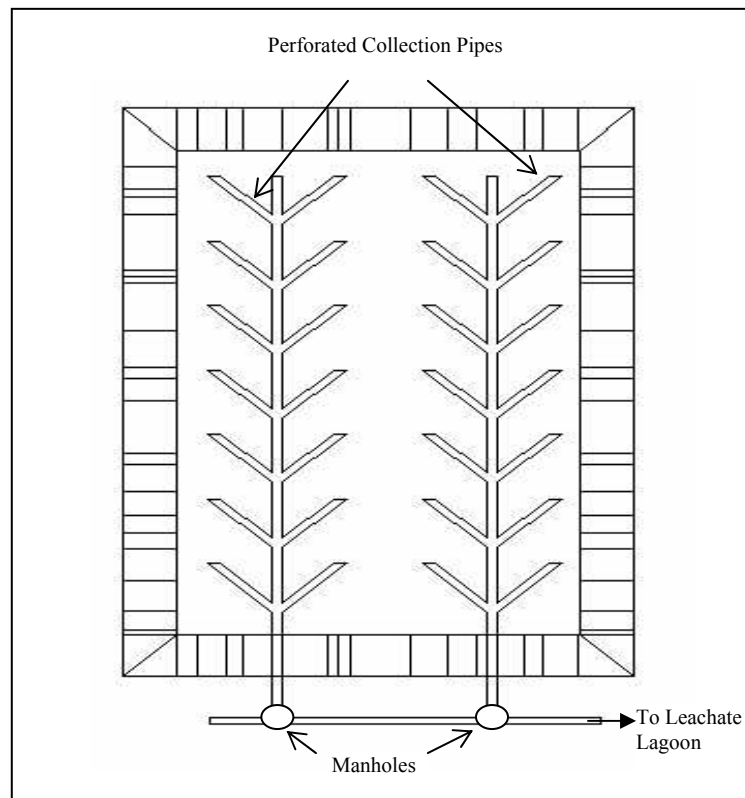


Figure 4.8 Layout of the leachate collection pipes.

#### 4.6.2 Transmission Line

A manhole will be constructed out of the module for cleaning and inspection of the inner pipe system of the module. From manhole to the leachate pond main transmission line will be installed. Main transmission line pipes will be HDPE having a diameter of 150 mm. Main transmission line pipes will not be perforated.

#### 4.7 Gas Extraction Wells

Generally, the radius of influence of a gas extraction well is approximately 150 per cent of the depth of the refuse (Solid Waste Landfill Design Manual, 1987). According to this generalization the distance between extraction wells will be 30 m in the module, the depth of the waste is accepted as 20 m. Mostly the wells are placed at a depth of 80 per cent of the waste height.

Perforated pipes having a 10 cm diameter vertically installed. In order to provide high permeable zone, gravel will be backfilled into the well around the pipe. Lastly, to prevent the clogging of the pipe geotextile will be used around the gravel backfill. Typical cross section of a gas extraction well is shown in Figure 4.9.

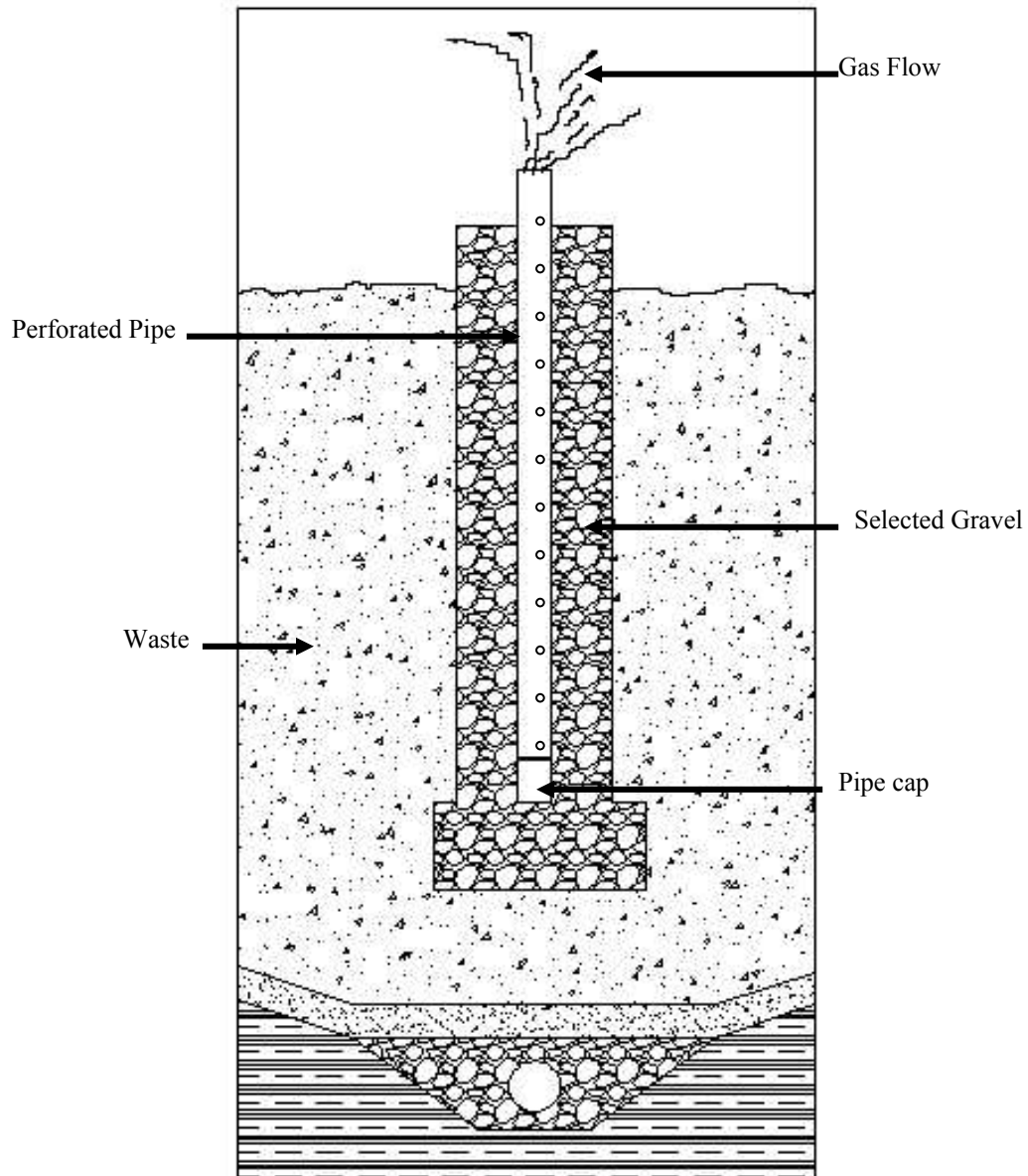


Figure 4.9. Gas extraction well cross section

Selected gravel installed around the perforated pipe to let the gas flow into the pipe. A cap is placed at the bottom of the pipe to prevent clogging. Bottom of the pipe is placed 1 m above the waste bottom to prevent the leachate flow into the pipe.

Gas extraction well construction handled parallel to the landfilling of the waste. As the height of the waste increases the height of the gas extraction well increases. Figure 4.10

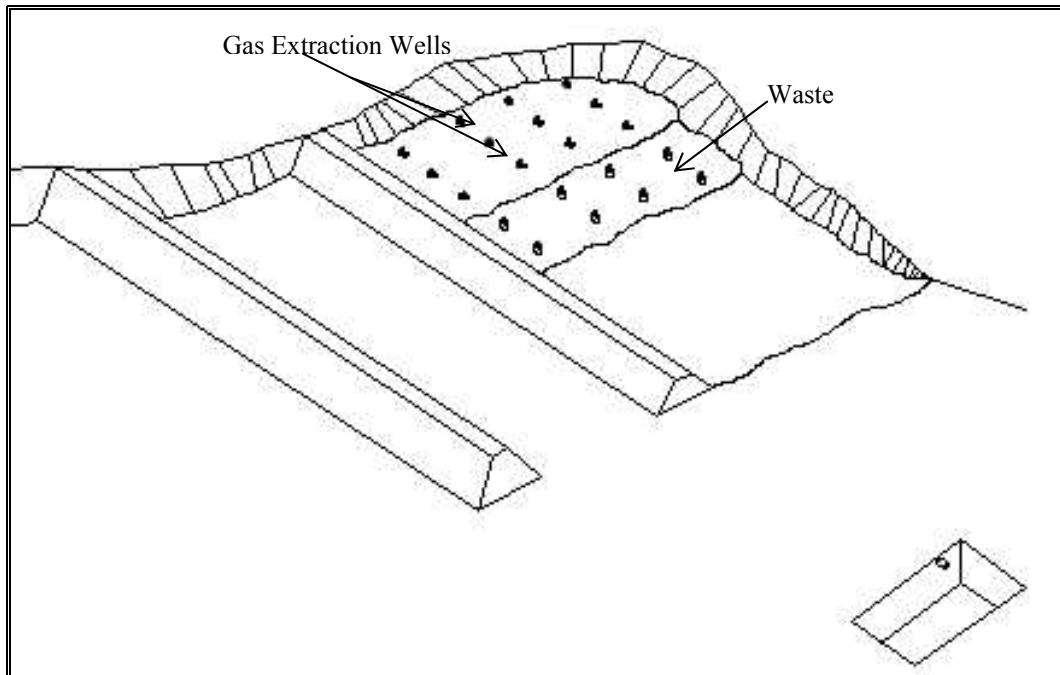


Figure 4.10. Gas extraction wells.

Gas extraction wells placed at a distance of 150 per cent of the height of the waste from each other. Therefore number of wells is a function of the height of the waste. After the height of the waste laid and compacted at the disposal area reaches one meter gas extraction well construction begins. Number and places of the wells are planned before the construction. Well construction continues up to the final cover.

According to the concentration of the gas production, the gas is collected and burned to get electrical energy. Methane burning systems can be installed in the future if feasible. If the rate of the production is low, the gas can be burned by using flare burner heads placed at the top of each well.

## 5 COST ANALYSIS OF MODULAR SANITARY LANDFILL

In order to find out the feasibility of the proposed method, an estimated cost analysis will be introduced within this chapter. This analysis will not be a detailed cost analysis and will be based on assumptions, for to point out the high interest payments and high initial construction costs.

The small number and low reliability of the available data in developing countries makes it difficult to do a reliable cost analysis. The logical approach would be to use the available site specific data and make an assumption, if necessary, in case of necessity.

In order to show the implementability of the proposed method, an ongoing project, for comparison, Aydın Sanitary Landfill Construction Project, will be studied.

### 5.1 Aydın Sanitary Landfill

Aydın, a city in western Turkey, is located 90 km southeast of Izmir, more specifically in the Aegean Region. The center or the capital of the province is the city of Aydın with a population of approximately 248.705 (Serdar Mühendislik, Ankara 2005).

The present waste disposal area is in an old river bed having 30 m width, 30 m depth and 600 m length. The area is being used since 1989 and approximately 540.000 m<sup>3</sup> waste have been disposed.



Figure 5.1 Present landfill of Aydın Municipality (Serdar Mühendislik, Ankara 2005)

The current disposal area of municipal waste disposal site is presented in Figure 5.1. There is no liner system, leachate collection system or any kind of pollution prevention construction. Waste is being dumped to the area without any control. Groundwater pollution and healthy risks are inevitable.

The new sanitary landfill area is located in Doğanköy and Kalfaköy villages, approximately four and a half kilometers from the city center at northeast of Aydın. The landfill will be constructed on an area of 162.826 m<sup>2</sup>.



Figure 5.2 Location of new sanitary landfill (Serdar Mühendislik, Ankara 2005)

The location of the sanitary landfill is highlighted in Figure 5.2. The landfill will be constructed in a valley between two hills of 250 m high. The valley lies in north – south direction.

The construction of new sanitary landfill is on going and will be completed in the second quarter of 2007. The landfill will serve for about 25 years.

Sanitary landfill will be used by the member municipalities of Aydın Environmental Services Union. The member municipalities are; Aydın Municipality, Incirlioiva Municipality, Acarlar Municipality, Germencik Municipality, Köşk Municipality, Umurlu Municipality, Tepecik Municipality, Çeştepe Municipality, Ovaeymir Municipality. (Serdar Mühendislik, Ankara 2005)

When operating landfills some support facilities are needed. Office buildings for management personnel, equipment repair shed for equipments that will be used in the operation, laboratories, water tank, garage and others. These support units should be designed according to the density of the operational actions, lifespan of the landfill and the operational plan of the operating company or authority. The facilities that will be constructed in Aydın Sanitary Landfill project are presented in Table 5.1.

Table 5.1 The facilities that will be constructed (Serdar Mühendislik, Ankara 2005)

Sorting unit (250 ton capacity)
Leachate pond
Scale unit
Office building
Laboratory
Equipment repair shed
Garage
Water tank
Wheel washing unit
Clinical waste sterilization unit
Monitoring well
Fence
Landscaping

A 250 ton capacity of sorting unit will be constructed. According to the waste characterization, if feasible, sorting units for recycling of the waste will be installed. Leachate pond is designed to have a 855 m<sup>3</sup> capacity. A scale unit will be installed at the entrance of the facility to weigh the trucks. Office buildings will be constructed for the

management personnel, equipment repair shed will be constructed for the equipment that will be used during operation, garage, water tank, wheel washing unit for trucks will be constructed. Clinical waste sterilization unit will be installed to sterilize the waste collected from hospitals and other health services. Monitoring wells will be installed to monitor the groundwater pollution. Samples will be taken from these wells and will be analyzed in the laboratory within the facility. The area will be surrounded by a fence to prevent the animal and human entrance to the facility. Landscaping of the facility is important to minimize the negative prejudice about such facilities.

## 5.2 Cost Estimation of Modular Landfill

Aydın municipality made the tender of the new sanitary landfill project on date 08.05.2006. The municipality planned the completion of the construction 300 days. The construction is still on going and will be completed in the second quarter of 2007. General indicators of the project are presented in Table 5.2.

Table 5.2 General indicators of Aydın (Serdar Muhendislik, Ankara 2005)

Population	248.705
Annual waste (ton/year)	54.750
Total area (m <sup>2</sup> )	162.846
Landfilling area (m <sup>2</sup> )	94.754
Landfill life (year)	25
Tender price (YTL)	7.338.000
Date of tender	08.05.2006
Euro-YTL parity at date of tender	1,6835

The sanitary landfill will serve a population of 248.700. Daily waste amount in Aydın, today, is 130 ton per day. Taking Worldbank's growth rate for Turkey 1,3 per cent, average annual waste amount, for 25 years becomes 54.750 ton per year. Landfilling area is 94.754 m<sup>2</sup> which means remaining 68.092 m<sup>2</sup> will be used for support facilities and other units. Total price of the tender is 7.338.000 YTL. Taking the Euro-YTL parity at date of tender 1,6835 total amount becomes € 4.358.776.

In order to make a cost comparison between Aydın Sanitary Landfill Project and modular landfill an approximate waste height will be calculated and for the same height the costs will be presented. Waste height estimation is presented in Table 5.3.

Table 5.3. Waste height estimation

<b>General Indicators</b>			
	Construction cost (€)		4.358.776
a	Landfill area (m <sup>2</sup> )		94.754
b	Lifespan of landfill (years)		25
c	Average daily waste amount for 25 years (ton)		150
d	Yearly waste amount (ton)	c x 365	54.750
e	Waste density (ton/m <sup>3</sup> )		0,8
f	Yearly waste amount (m <sup>3</sup> )	d / e	68.438
g	Waste amount at the end of 25 years (m <sup>3</sup> )	f x 25	1.710.938
h	Approximate waste height (m)	g / a	20,00

In the waste estimation, waste density is assumed 0,8 ton/m<sup>3</sup>. Converting yearly waste amount from tons to cubic meters the amount becomes 68.438 m<sup>3</sup>. For 25 years total waste amount is 1.710.938 m<sup>3</sup>. Dividing total waste amount to landfilling area, approximate waste height is calculated as 20 m.

After estimating the waste height of Aydın Sanitary Landfill Project, modules can be designed according to the same height. Design of the modules in varying lifespan is presented in the following tables. Modules are designed for different lifespan to make a cost estimation analysis and to find out the feasible module.

Table 5.4 Design of module for one year lifespan

<b>Module design for 1 year lifespan</b>			
i	Waste amount at the end of 1 year (m <sup>3</sup> )		60.000
j	Area of the module	i / h	3.000
k	Module area (length x width) (m <sup>2</sup> )	100X30	3.000

For one year lifespan module, total waste amount at the end of the year is divided by the waste height and module area is calculated as 3.000 m<sup>2</sup> in Table 5.4.

Table 5.5 Design of module for three years lifespan

<b>Module design for 3 years lifespan</b>			
l	Waste amount at the end of 3 years (m <sup>3</sup> )		182.370
m	Area of the module	l / h	9.119
n	Module area (length x width) (m <sup>2</sup> )	100X100	10.000

For three years lifespan module, total waste amount at the end of the year is divided by the waste height and module area is calculated as 10.000 m<sup>2</sup> in Table 5.5.

Table 5.6. Design of module for five years lifespan

<b>Module Design For 5 Years Lifespan</b>			
o	Waste amount at the end of 5 years (m <sup>3</sup> )	f x 5	307.900
p	Area of the module	o / h	15.395
q	Module area (length x width) (m <sup>2</sup> )	100X160	18.000

For five years lifespan module, total waste amount at the end of the year is divided by the waste height and module area is calculated as 18.000 m<sup>2</sup> in Table 5.6.

Table 5.7 Design of module for seven years lifespan

<b>Module Design For 7 Years Lifespan</b>			
r	Waste amount at the end of 5 years (m <sup>3</sup> )		436.740
s	Area of the module	r / h	21.837
t	Module area (length x width) (m <sup>2</sup> )	100X220	22.000

For seven years lifespan module, total waste amount at the end of the year is divided by the waste height and module area is calculated as 22.000 m<sup>2</sup> in Table 5.7.

Table 5.8 Design of module for nine years lifespan

<b>Module Design For 9 Years Lifespan</b>			
u	Waste amount at the end of 5 years (m <sup>3</sup> )		568.950
v	Area of the module	u / h	28.448
w	Module area (length x width) (m <sup>2</sup> )	100X290	29.000

For nine years lifespan module, total waste amount at the end of the year is divided by the waste height and module area is calculated as 29.000 m<sup>2</sup> in Table 5.8.

Table 5.9 Design of module for twelve years lifespan

<b>Module Design For 12 Years Lifespan</b>			
x	Waste amount at the end of 10 years (m <sup>3</sup> )		773.775
y	Area of the module	x / h	38.689
z	Module area (length x width) (m <sup>2</sup> )	100X390	39.000

For twelve years lifespan module, total waste amount at the end of the year is divided by the waste height and module area is calculated as 39.000 m<sup>2</sup> in Table 5.9

### 5.3 Economic Analysis

#### 5.3.1 Estimation of Costs

Because the quantities and the costs of the facilities and support units of Aydın Sanitary Landfill Project could not be obtained, the estimation will be based on unit construction cost assumption. Overall costs of the project will be divided to the landfilling area and unit construction cost of the whole project will be achieved Table 5.10.

Table 5.10 Calculation of estimated unit construction

Investment cost (€)	4.358.776
Landfilling area (m <sup>2</sup> )	94.754
Unit cost (€/m <sup>2</sup> ) ( <i>Investment cost / landfilling area</i> )	46,00

Investment cost is divided to the landfilling area, to find the unit cost of landfilling of waste. Unit cost for Aydın Sanitary Landfill Project is 46 €/m<sup>2</sup>.

Using the estimated construction unit cost in Table 5.10, total estimated construction costs for modular landfills can be obtained Table 5.11.

Table 5.11 Modules estimated total construction costs

<b>Area</b>	<b>Unit price €</b>	<b>Investment amount €</b>
3.000	46	138.000
10.000	46	460.000
18.000	46	828.000
22.000	46	1.012.000
29.000	46	1.334.000
39.000	46	1.794.000

As the area of the landfill increases from 3.000 m<sup>2</sup> to 39.000 m<sup>2</sup> the cost increases from € 138.000 to € 1.794.000.

The facilities and the support units that will be constructed within the modular landfill, have the same decrease ratio with the landfilling area according to the calculated total construction costs in Table 5.11. This means that modular landfill will have modular facilities and support units.

Estimated investment amounts of the modules and the future values of investment amounts for varying interest rate are presented in Table 5.12. The financial periodic payment of a loan is used to find out the investment amounts under varying interest rate. The formula is;

$$p = i.A.(1+i)^n / ((1+i)^n - 1) \quad (5.1)$$

where;

p : amount of payment per period

i : interest rate

A : amount of loan

n : period

Using the equation (5.1) total amount to be paid at the end of the given period can be calculated as:

$$T = p * n \quad (5.2)$$

where;

T : total amount to be paid at the end of given period

p : amount of payment per period

n : period

The total amounts of investments of modules in varying interest rates using the equations (5.1) and (5.2) are presented in Table 5.12.

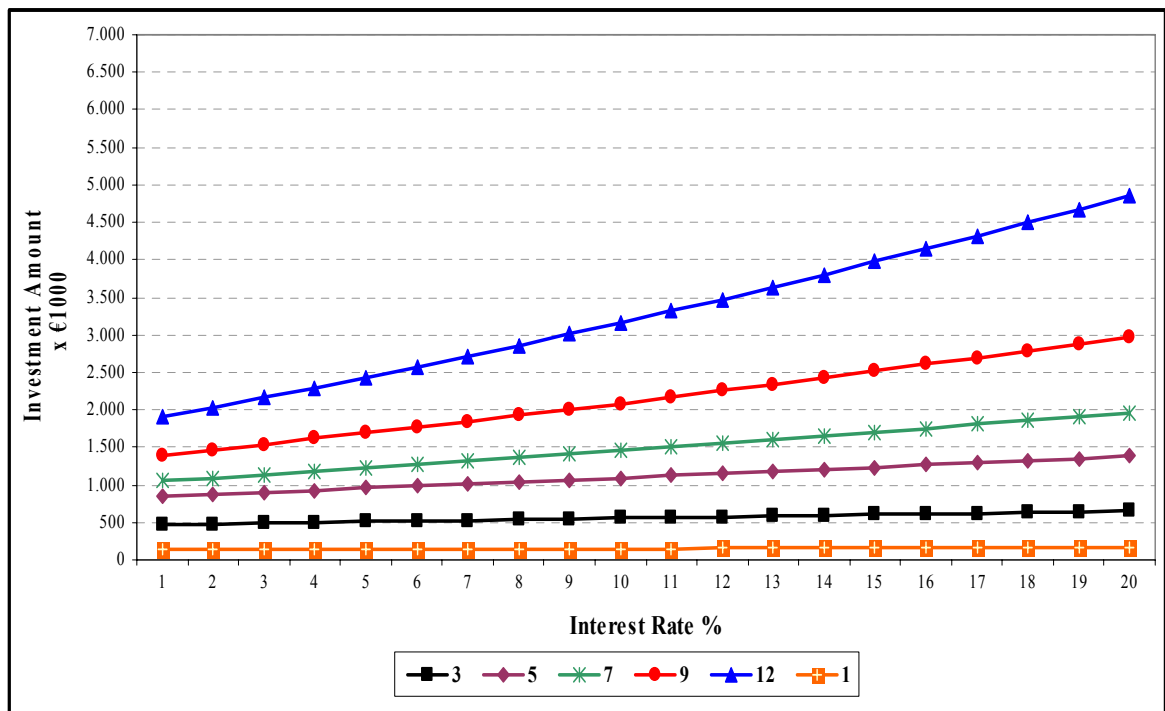
Table 5.12 Investment amounts for varying interest rates

<b>Module Lifespan (years)</b>	1	3	5	7	9	12	
<b>Area (m<sup>2</sup>)</b>	4.000	12.000	18.000	25.000	32.000	43.000	
<b>Annual Waste (ton)</b>	48.000	48.600	49.300	49.900	50.600	51.600	
<b>Investment Amount (x €1000)</b>	138	460	828	1.012	1.334	1.794	
<b>Investment Amounts (x €1000)</b>							
<b>Interest Rates %</b>	1	139	469	853	1.053	1.402	1.913
	2	141	479	878	1.095	1.471	2.036
	3	142	488	904	1.137	1.542	2.163
	4	144	497	930	1.180	1.615	2.294
	5	145	507	956	1.224	1.689	2.429
	6	146	516	983	1.269	1.765	2.568
	7	148	526	1.010	1.314	1.843	2.710
	8	149	535	1.037	1.361	1.922	2.857
	9	150	545	1.064	1.408	2.003	3.006
	10	152	555	1.092	1.455	2.085	3.160
	11	153	565	1.120	1.503	2.168	3.316
	12	155	575	1.148	1.552	2.253	3.475
	13	156	584	1.177	1.602	2.340	3.638
	14	157	594	1.206	1.652	2.427	3.803
	15	159	604	1.235	1.703	2.516	3.972
	16	160	614	1.264	1.754	2.606	4.142
	17	161	625	1.294	1.806	2.698	4.316
	18	163	635	1.324	1.859	2.790	4.491
	19	164	645	1.354	1.912	2.884	4.669
	20	166	655	1.384	1.965	2.978	4.850

As the lifespan of the module increases, as a consequence, the initial investment amount increases. While the investment amount for one year module is € 139.000 at one per cent interest rate it is € 1.913.000 for 12 years module at the same interest rate. When interest rate is taken into account, especially in developing countries high interest rates are faced, initial investment amounts are much higher. For 17 per cent interest rate investment of three years module is € 1.294.000 and for 12 years module investment amount is € 4.316.000 which is more than three times.

The change in future values of investment amounts with varying interest rates are presented in Figure 5.3

Figure 5.3 Change in investment amounts with varying interest rates



For 12 years module initial investment amount is € 1.794.000 and for three years module initial investment amount is € 460.000. High investment amounts end up in high interest payments. The total interest payment for 12 years module with the interest rate 17 per cent is € 2.522.000 and for three years module with the same interest rate, is € 160.000. The difference is considerable.

According to the calculated investment amounts with varying interest rates, estimation of unit price can be calculated. The estimated unit prices of landfilling waste are presented in Table 5.13.

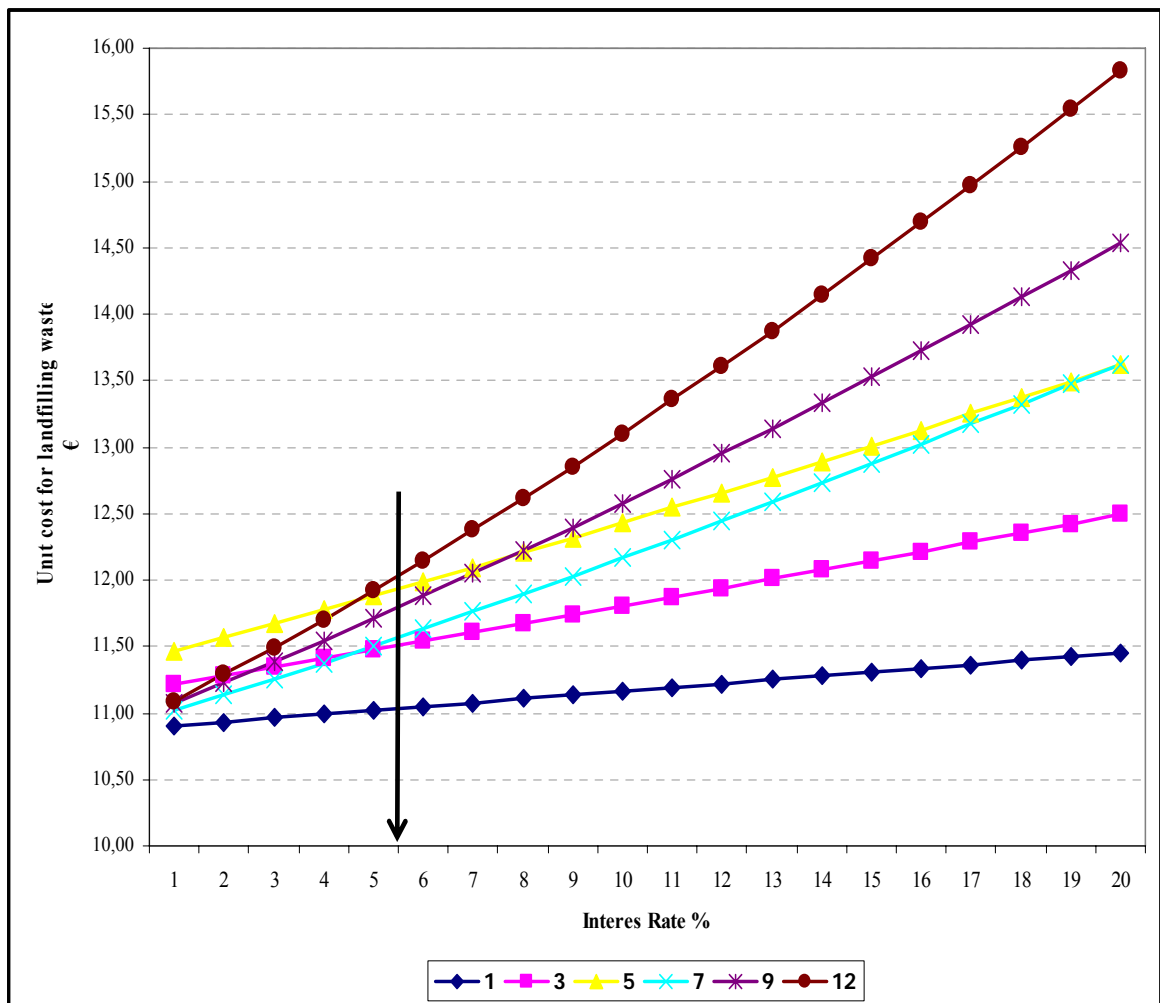
Table 5.13 Unit cost of landfilling waste for varying interest rates

Unit Cost for Landfilling Waste (€/ton)							
Module Lifespan (years)		1	3	5	7	9	12
Interest Rates %	1	10,90	11,22	11,46	11,01	11,08	11,09
	2	10,93	11,28	11,56	11,13	11,23	11,29
	3	10,96	11,35	11,67	11,26	11,39	11,49
	4	10,99	11,41	11,77	11,38	11,55	11,70
	5	11,02	11,48	11,88	11,50	11,71	11,92
	6	11,05	11,54	11,99	11,63	11,88	12,15
	7	11,08	11,61	12,10	11,76	12,05	12,38
	8	11,11	11,67	12,21	11,90	12,22	12,61
	9	11,13	11,74	12,32	12,03	12,40	12,86
	10	11,16	11,81	12,43	12,17	12,58	13,10
	11	11,19	11,87	12,54	12,30	12,76	13,36
	12	11,22	11,94	12,66	12,44	12,95	13,61
	13	11,25	12,01	12,78	12,59	13,14	13,88
	14	11,28	12,08	12,89	12,73	13,33	14,14
	15	11,31	12,15	13,01	12,87	13,53	14,41
	16	11,34	12,21	13,13	13,02	13,72	14,69
	17	11,36	12,28	13,25	13,17	13,92	14,97
	18	11,39	12,35	13,37	13,32	14,13	15,25
	19	11,42	12,42	13,49	13,47	14,33	15,54
	20	11,45	12,49	13,62	13,63	14,54	15,83

At four per cent interest rate unit cost for landfilling waste is calculated as 10,99 €/ton for one year module, it is 11,77 €/ton for five years module. A 0,78 €/ton increase in the unit cost is obtained. When the interest rate is eight per cent, the unit cost of landfilling waste for one year module increases to 11,11 €/ton and unit cost of landfilling waste for five years module increases to 12,89 €/ton. The difference increases to 1,10 €/ton. In Turkey current annual real interest rate for foreign loans turned out to be 17 per cent. At this rate when comparing unit costs of landfilling waste of three years module and 12 years module, it is seen that unit cost of 12 years module is 22 per cent higher than the three years module. For a facility receiving 54.750 ton of waste per year, the difference of 2.69 €/ton unit cost of landfilling waste between 12 years module and three years module gives a total amount of € 147.000 additional payment per year.

The chart of estimated unit costs for landfilling waste varying with interest rates is presented in the Figure 5.4.

Figure 5.4 Estimated unit costs for landfilling waste varying with interest rates



At low interest rates the unit cost of landfilling waste of modules are close to each other. Unit costs for landfilling waste increase when the interest rate increases. For interest rates over five per cent, unit cost of landfilling for modules begins to diverge from each other. For this reason, it may not be feasible for developing countries having high interest rates to invest such projects using loans.

In order to make a rational comparison of landfills some parameters for both landfills should be common. Basic indicators for both landfills are presented in Table 5.14. Projects are assumed to be invested using loans.

Table 5.14 Basic indicators of landfills

	Aydın sanitary landfill	Modular landfill					
		1	3	5	7	9	12
Lifespan (year)	25	1	3	5	7	9	12
Loan amount (€)	4.358.776	138.000	460.000	828.000	1.012.000	1.334.000	1.794.000
Construction duration (year)	0,8	0,1	0,2	0,3	0,3	0,4	0,4
Interest rate %	8	8	8	8	8	8	8
Inflation rate %	5	5	5	5	5	5	5
Cost of operation (€/ton)	8	8	8	8	8	8	8

The common indicators of the landfills for cost analysis calculations are presented in the Table 5.14. Both projects will be invested using loans for this reason a common interest rate of 8 per cent. The inflation rate is taken as five per cent per year for 25 years. Operational unit cost for both landfills assumed as 8 €/ton.

### 5.3.2 Aydın Sanitary Landfill Estimated Cost Analysis

Using the data in Table 5.14, with the help of a simple computer program estimated loan payback amount, annual operational cost can be achieved. Annual cost analysis of Aydın Sanitary Landfill is presented in Table 5.15

Table 5.15 Unit cost estimation of landfilling waste

a	Annual amount of waste (ton)	54.750
b	Loan amount (x € 1000)	4.359
c	Payback period (years)	25
d	Interest rate (%)	8
e	Total amount to be paid at the end of 25 years (x € 1000)	10.208
f	Annual cost of investment (x € 1000)	408
g	Operational costs (x € 1000)	438
h	Total costs (x € 1000)	846
k	Minimum unit price of landfilling waste (h/a) (€/ton)	15,45
l	Total interest payment at the end of 25 years (e-b) (x € 1000)	5.849

The main indicator of the results is; for € 4.359.000 loan, the lender will pay € 5.849.000 estimated interest amount in 25 years. Also the landfilling price of waste becomes € 15,45 per ton, which is quite high for the current sanitary landfilling market.

When the annual interest rate is taken as 17 per cent, which is the interest rate for Turkey for foreign loans, the results are presented in Table 5.16.

Table 5.16 Unit cost estimation of landfilling waste for 17 per cent interest rate

a	Annual amount of waste (ton)	54.750
b	Loan amount (x € 1000)	4.359
c	Payback period (years)	25
d	Interest rate (%)	17
e	Total amount to be paid at the end of 25 years (x € 1000)	18.898
f	Annual cost of investment (x € 1000)	756
g	Operational costs (x € 1000)	438
h	Total costs (x € 1000)	1.194
k	Minimum unit price of landfilling waste (h/a) (€/ton)	21,81
l	Total interest payment at the end of 25 years (e-b) (x € 1000)	14.539

When the annual real interest rate increases to 17 per cent, the total amount to be paid at the end of 25 years becomes € 18.898.000 and the total interest payback for € 4.359.000 loan becomes € 14.539.000, which is very high. The estimated unit price of landfilling waste 21,81 €/ton and operational costs € 438.000 makes the total annual operational costs € 1.194.000.

### 5.3.3 Modular Landfill Estimated Cost Analysis

For modular landfill estimated costs analysis, unit costs of modules with the interest rate of eight per cent and 17 per cent are compared with Aydın Sanitary Landfill unit costs. Estimated unit costs of modular landfills and Aydın Sanitary Landfill are presented in Table 5.17.

Table 5.17 Estimated unit costs of modular landfills and Aydın sanitary landfill

<b>Estimated unit cost for landfilling waste (€/ton)</b>		
	Unit cost for landfilling waste (€/ton)	
Modules	8 % Interest rate	17 % Interest rate
1	11,11	11,36
3	11,67	12,28
5	12,21	13,25
7	11,90	13,17
9	12,22	13,92
12	12,61	14,97
Aydın sanitary landfill	15,25	21,81

When the unit disposal cost of three years module is compared to that of Aydın for eight per cent rate of interest, the unit cost of landfilling is approximately 31 per cent higher than that of Aydın. When 17 per cent rate of interest is taken into account the difference becomes approximately 78 per cent. For 12 years module, the difference becomes 21 per cent and 46 per cent for eight per cent and 17 per cent interest rates respectively.

In order to show the interest payment for the modular landfill, a module having a three years lifespan is chosen. The future values of investments and credit paybacks are presented in Table 5.18.

Table 5.18 Future loan amounts for eight per cent interest rate

<b>Year</b>	<b>Future value of investment costs (x € 1000)</b>	<b>Loan payback (x € 1000)</b>
0	460	
1		178
2		178
3	535	178
4		208
5		208
6	623	208
7		242
8		242
9	726	242
10		282
11		282
12	845	282
13		328
14		328
15	983	328
16		382
17		382
18	1.145	382
19		444
20		444
21	1.333	444
22		517
23		517
24	1.551	517
25		1.551
<b>Total</b>	<b>8.201</b>	<b>9.292</b>

For three years module loans are used every three years. The inflation rate effect is neglected. The total interest payment, subtracting the total investment amount from loan payback amount, becomes € 1.041.000 at the end of 25 years. The interest payment for Aydın Sanitary Landfill is € 5.849.000 at the end of 25 years. The difference is € 4.808.000.

Again for three years module at the annual rate of 17 per cent, future values of loans are presented in Table 5.19.

Table 5.19 Future loan amounts for 17 per cent interest rate

Year	Future value of investment cost (x € 1000)	Credit payback (x € 1000)
0	460	
1		212
2		212
3	637	212
4		288
5		288
6	865	288
7		392
8		392
9	1.175	392
10		532
11		532
12	1.595	532
13		722
14		722
15	2.166	722
16		980
17		980
18	2.941	980
19		1.331
20		1.331
21	3.993	1.331
22		1.807
23		1.807
24	1.807	1.807
25		2.114
Total	15.641	20.910

The total interest payment, for three years module at 17 per cent rate of interest becomes € 5.269.000 at the end of 25 years. The interest payment for Aydın Sanitary Landfill is € 14.539.000, at the end of 25 years at the interest rate of 17 per cent. The difference is € 9.270.000.

## 6 RESULTS AND DISCUSSION

### 6.1 Cost Analysis Results

For the unit cost of landfilling waste and the loan payback amounts, the proposed modular landfill modules and the comparison project Aydın Sanitary Landfill Project studied in the previous chapter. Estimated results of the calculations are summarized in the Table 6.1.

Table 6.1 Cost analysis results

	8 % Interest rate		17 % Interest rate	
	Aydın Sanitary Landfill	Modular Landfill 3 years lifespan	Aydın Sanitary Landfill	Modular Landfill 3 years lifespan
Lifespan	25	25	25	25
Unit cost for landfilling waste (€/ton)	15,25	11,67	21,81	12,28
Estimated total interest payment at the end of 25 years (€)	5.849.000	1.041.000	14.539.000	5.269.000

Although the values in Table 6.1 are estimated and may vary if a detailed analysis is made, high interest payment and high unit cost for landfilling waste makes the loan alternative inefficient. Techniques that may help to reduce landfill costs should be developed and/or construction alternatives that require low investment amount should be improved.

In Table 6.2 difference of unit costs between the module and Aydın Sanitary Landfill and the modules are presented.

Table 6.2 Difference of unit costs with Aydın sanitary landfill

<b>Unit cost difference (€/ton)</b>		
<b>Module</b>	<b>Interest rate 8 %</b>	<b>Interest rate 17 %</b>
1	4,15	10,45
3	3,58	9,53
5	3,04	8,56
7	3,35	8,64
9	3,03	7,89
12	2,64	6,84

Unit costs of landfilling waste for modules compared to the unit cost of landfilling of waste for Aydın Sanitary Landfill. The unit costs of landfilling waste for five years module is 3,04 €/ton cheaper than Aydın Sanitary Landfill at eight per cent interest rate. This means that five years module will save € 148.048 per year for an average annual 48.700 ton of waste. At the 17 per cent interest rate five years module will save € 416.872 per year for the same amount of waste.

## **6.2 Discussion of the Method**

Designing and operating a modular landfill area, will give the municipality and the public private company, the opportunity to achieve constructive and operative environmental goals.

Constructing a small landfill area has the following advantages:

- Short construction duration will help to receive waste in a short time,
- The municipality will have full control on construction and operation,
- Quick response from the company because of relatively less constructive material needs and equipment needs,
- Improvement of the facility can be done while operation continues,
- Quality controlling of operations will be easy for both the municipality and the operating company,
- Less personnel needs gives additional cost savings,

- Material supply can quickly be done by the operating company in case of needs for the landfilling area because of the small quantities,
- Improvement continues from one module to the other. The problems and risks faced during the operation can be eliminated in the next module. This gives a great chance to the company to minimize the unforeseen cost,
- Gives the opportunity to establish new techniques and operation methods. Learned or experienced operation methods can be adapted to the current module or can be planned for the next module. This gives a great chance of improving operational skills and search for modern technologies to the operating company.

Generally construction of the landfill and operating are held individually in Turkey. Municipality calls out for a company to construct the facility and then either the municipality or a company operates the landfill. The disadvantages of such implementation can be listed as;

- High investment amounts prevents the medium scaled companies joining to the tenders,
- Dealing with bureaucratic works may cause delays in actions,
- Municipality pays profit for construction and operation respectively,
- Quality control of construction is not efficient as the company itself. If the construction company will operate the facility construction will be better.

Establishing a design-build-operate model and modular landfill design for sanitary landfill projects will end up with the following advantages;

- Investment costs will be low,
- Medium scaled companies can take part in such projects,
- Modular landfill gives the opportunity of designing their own facilities to small scaled municipalities,
- Municipalities are provided with an opportunity to finance projects without involving public funds,
- Municipality will transfer all risks to the private company,

- Modules will be affected less from disasters when compared to the risks involved in larger landfills,
  - Competition between companies will lower costs,
  - Municipality will be the quality controlling authority,
  - Service quality will be high,
  - Access to international expertise in landfill operations; utilization of modern landfilling techniques to minimize environmental impacts and optimize the use of available void space by raising compaction ratios,
    - The construction period will be shortened as possible,
    - Data collection will be available.

One of the most important benefits of the proposed method is, during the operation, the private company will try to store as much waste as possible into the modules. The key to store much waste to the module is to pre-treat the waste and to achieve high compaction rates. Pre-treatment will force the company to sort the waste and recycle the material like glass, paper, pvc etc. In the Table 6.3 the relation between compaction ratios and the landfill life is presented. Landfill capacity 1.500.000m<sup>3</sup> and yearly volume is 104.000ton.

Table 6.3 Example of increased compaction on potential landfill life

<b>Compaction</b>	<b>Landfill life</b>	<b>Gain</b>
0,59 ton/m <sup>3</sup>	9,6 years	0,0 years
0,71 ton/m <sup>3</sup>	11,5 years	1,9 years
0,83 ton/m <sup>3</sup>	13,4 years	3,8 years
0,95 ton/m <sup>3</sup>	15,3 years	5,7 years
1,07 ton/m <sup>3</sup>	17,2 years	7,6 years

Better compaction means packing more waste into less space. Several benefits of better compaction are:

- Extends the life of the site,
- Decreases settlement,
- Reduces voids,
- Reduces wind-blown litter,

- Discourages insects and rodents,
- Reduces possibility of waste washing away or being exposed during a rain,
- Reduces amount of daily cover needed, thereby reducing machine excavation work,
- Reduces leachate and methane migration,
- Provides a more solid travel surface for refuse trucks, reducing maintenance and repairs.

Once the waste disposal ends in the module, subsequent module is used for disposal. The storage of waste is illustrated in the Figure 6.1.

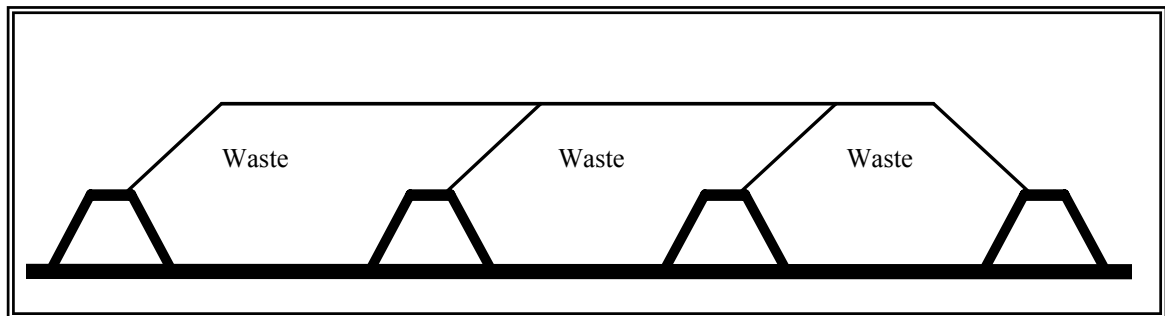


Figure 6.1 Waste storage in the modules

After the completion of waste storage in the initial module second module begins to receive waste. Waste can be stored over the embankment between the first module and the second. By this way volume loss because of the embankments will be kept at minimum.

One of the other useful alternative results of the proposed method is the applicability of modular landfills to small villages. For a small village, if the transporting the waste to another city or town is an high cost implementation or because of the legislative barrier to open dumping, the municipality of the village can plan a modular landfill project. With the public private partnership models implementation of such projects can be a good solution of solid waste problem. Municipality should select the area, have the EIA report approval of the area and let the private companies design, build and operate the modular landfill.

Also proposed method can be an alternative solution of waste management for large

plants located outside the city center. If a plant, factory or any kind of large facility located outside the city center spending a part of the budget for the transportation of waste produced within the facility, modular landfill method can be good solution. The facility owners can cooperate with the municipality to develop a modular landfill close to the facility. With the support of the municipality, the owners can design, build and operate the facilities modular landfill. This way the facility will lower the costs, the city landfill will not receive waste from the facility and energy will be saved, no transportation.

## 7 CONCLUSIONS

Public private partnership models are introduced and current legislation in Turkey about environmental regulations and general design criteria of landfills has been covered. Estimated costs of modular landfill method are calculated belonging to the proposed method, modular landfilling, and the results are compared to the estimated costs of Aydın Sanitary Landfill Project. Obtained results showed that, in countries with high annual real interest rates, financing projects requiring high investment amounts using loans, end up with high interest paybacks. Also absence of usage of public private partnership models, prevent the municipalities to transfer all the responsibilities, construction risks and financial risks to a third party. Legislative constraints on transition to sanitary landfilling and high project costs in Turkey, complexes the situation for municipalities. Municipalities with small budgets face the problems of financing such projects. Results show that modular landfill requires small investment amounts and as a result of small investment amount, unit cost for modular landfilling of waste is low when compared to the sanitary landfilling. Modular landfilling can be an optimum solution for municipalities having financial problems. Also a public private partnership model design-build-operate (DBO) should be established to the modular landfill method. By this way municipality will transfer all the risks to the private company and will become a quality control authority. With public private partnership models, private sector participants bring to such projects a know-how, innovativeness, and efficiency, which can reduce project construction costs and time and increase the effectiveness and efficiency of public facilities and infrastructure.

Although Turkey was the first country that established BOT model in the world, no action was taken in public private partnership in sanitary landfilling.

The reality is that municipalities have huge infrastructure needs, which if not met will continue to affect their economic growth. It is quite clear that municipalities are no longer able to meet all these needs. The needed infrastructure, can be built without employing public funds.

With relatively low initial investment costs and with privatization, transition to sanitary landfilling of solid waste can be achieved in a short period. With the advantage of modular landfilling method, sanitary landfilling can be implemented even within the small municipalities.

Governments should leave the manager role and should become a customer. This will allow the city to receive the best service for the lowest price.

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