DATA BOOK 8

FINAL DISPOSAL

8.1
TOPOGRAPHY & GEOLOGICAL CONDITIONS OF NAIROBI AREA

DATABOOK 8 FINAL DISPOSAL

8.1 Topography & Geological Conditions of Nairobi Area

8.1.1 General

Generally, the topographical features of Nairobi area are controlled by the effects of volcanic activity that dominated the geological history of Nairobi since Miocene times. Volcanic lava flows originating from the Rift flanks gave rise to prominent physiographic units named the Kikuyu Highlands, the Rift flanks the Ngong Hills and the Eastern Lava plains of Athi and Kapiti.

Faulting has dominated the Rift flanks and the Ngong Hills. The zone of Rift Faulting is an area of internal drainage where the runoff collects in the depressions and disappears in the fissures. The Lari-Ondiri fault West of Kikuyu Railway station is the only source of the groundwater which leaves the area towards the eastern zone. The Onderi Springs was at one time only source of water supply for Nairobi city. The elongated range of the Ngong Hills is the most outstanding physiographic feature, with moderate slopes towards the eastern zone which is dissected by scarps representing the end of individual lava flows.

The significant lava plains overlying the Nairobi City are the Athi plains and the northern section of the Kapiti plains with an elevation difference of above 400 meters from Athi River to the foothills of Ngong. The plains are relatively flat right through the National Park, City Centre, Nairobi Airport and Dandora areas, although the area slopes gently eastwards. The topographical feature in the Kabete and west land area have pronounced ridges formed of Pleistocene volcanic trachytes and generally sloping towards east to Nairobi City Centre and rising gently to the west towards the eastern margin of the Rift Flanks.

The terrain around the Kabete-Parklands are displays abrupt beginnings and endings of many unconnected valley depressions which indicate that drainage is parallel and consequent on the south east sloping surface which was created by the deposition of the Kirichwa Valley tuffs outcropping in the valleys of Nairobi River. Steep scarp is noticeable around the Nairobi Museum area and Upper Hill.

8.1.2 Geological Conditions

(1) Geological Formations

A description of the geological formation is given in the following this section. The area extent of the various lava flows is also shown on the **Figure 8.1-1** Geological Map.

(a) Precambrian Rocks (Base of the Nairobi City Ground)

The basement system consists of crystalline Precambrian rocks exposed in the Kitengela Valley in the Nairobi National Park, and near surface of Embakasi. These highly weathered metamorphic rocks consists of gneisses and schists. These same rocks occur at great depths below the Ngong Hills as reveled by the presence of gneissic fragments in the tributary of Kandizi River.

(b) Post-basement Volcanic Activity

Following the metamorphism, folding and faulting of the Basement system, the geological history of the Nairobi Area was subjected to a period of volcanic activity and erosion lasting for more than 400 years whereby a thick succession of phonolitic lavas, tuffs, and trachytic pyroclatics. Old erosion surfaces lies conformably below younger phonolites.

(i) Kapita Phonolite

The lavas is the oldest in the volcanic succession and overlies the irregular eroded surface of the basement rocks. The Kapit phonolite is exposed in the South-eastern corner of the area near Athi River Town. Outcrops are confined to the valley of Athi River west of the National park and for South in the valley of Stony Athi.

(ii) Athi Tuffs and Lake Beds

The Athi Tuffs and Lake beds overlie the Kapiti phonolite and consists of fine to coarse yellowish gray tuffs, bentonitic clays, pyroclastic, fossiliferous beds with chert and obsidian bands. They lie between Kapiti and Nairobi phonolites and occasionally between Kapiti phonolite and Mbagathi phonolitic trachyte where Nairobi trachyte has been eroded or is absent. The Athi Tuffs series outcrops near Athi River Toll Station on Mombasa road.

The lake beds comprise finely bonded clays, sand-stones, grit, and conglomerates together with calcareous and siliceous beds, most of the sediments evidently having been derived from volcanic rocks.

(iii) Mbaganthi Phonolitic Trachyte

The Mbagathi phonolitic trachate underlies the Nairobi Phonolite and outcrops in the Mbagathi river valley and have been encountered in the boreholes in Karen, National park(thickness about 70 meters) and in Langata (thickness about 10 meters). These trachyte flows are thin near the outcrops of basement rocks in the National Park.

(iv) Nairobi Phonolite

The Nairobi Phonlites consisting of several flows cover a large area of Athi plains from the National park northwards to Kiambu. A prominent scarp marks the eastern edges overlooking Oldnyo Sambuk and the southern edges towards Kitengela plains, where the lava overlies the Athi Tuffus and lake beds. The Nairobi phonolite differs from the Kapiti phonolite in containing larger feldspar phenocrysts and smaller nepheline crystals.

(v) Nairobi Trachyte

The Nairobi trachyte overlies the Nairobi phonolite and is separated by a thin layer of agglomerate tuff. It outcrops in the stream courses in the vicinity of the city centre and extends eastwards from Dagoretti-Karren area to Nairobi City Centre and northwards to Kiambu. Boreholes have leveled tracyte thickness of 90 meters at Upper Hill and 60 meters at Ruaruka. Small steps in the scarp overlooking the city centre indicate several flows. These tracytes resemble phonolitic rocks but they lack nepheline crystals. Fresh surfaces of this tracyate have glistening appearance caused by numerous tiny feldspar crystals.

(vi) Kirichwa Valley Tuffs

The extrusion of the Nairobi trachtes was followed by a period of erosion and deep river valleys were cut in the lava. With renewed volcanic activity, these valleys, including the Mbagathi river valley, were subsequently infilled by trachytic pyroclastic rocks currently refereed to as the Kirichwa Valley Tuffs. These welded tuffs are cut in blocks for building stones. The Kirichwa Valley Tuffs overlie the Nairobi tracyte and in Nairobi city centre the formation thickness is between 10-20 meters. It outcrops visibly at the Museum Hill in the Nairobi River Valley.

The tuffs represents three flows of upper tuff which is generally greyish brown, middle tuff which is greenish blue (the Nairobi building stone) and the lower tuff which is greysh black ashy tuff overlying the grey/green agglomerate tuff which separates the Nairobi tracyte and resembling the Athi Tuffs and Lake beds series.

It should also be noted that during this period of volcanically, the source of volcanic deposits was located somewhere in the City Centre because boreholes reveal that agglomerate tuffs are only penetrated in the city centre. Consequently, at one time during the period of this volcanic activity, there seems to have been two main drainage systems through Nairobi. One is on the line running in the general direction of Moi Avenue which possibly was an ancient valley of Nairobi river, and the other in he direction from Parliament towards the Railway Station.

These ancient valleys were subsequently filled in with upper and middle tuffs and Nairobi river changed its position to the present course. The overburden consists of greyish red clay soils with lateritic gravel and charred vegetative fragments or planthite at the base, the average thickness being about 2 meters.

(2) Geological Structure

As stated above, the Nairobi Area was a depression east of the Rift filled with volcanic lavas and sediments which rest directly on the old basement rocks. The lavas flowed down in an easterly direction dipping to the east, with exception of the Kapiti phonolite which is down in titled towards the north west of the area. Due to phases of volcanic activity and tectonic movements, deposition and erosion took place causing the resulting valleys in the Nairobi Trachyte to be buried by the younger Kerichiwa valley lava flows. The tuffs and sediments of the Athi series between the lava flows edge out completely and decrease in thickness towards the east due to deposition and erosion. The Athi series is absent under Nairobi City Centre between Nairobi and Kapiti phonolites.

The surface of the basement represents an irregular old land surface which outcrops around Athi River and National Park. The level of the basement outcrops is higher than where it is encountered in drilled boreholes beneath the Athi plains close to the edges of the phonolite, indicating that the basement surface is titled towards the north west. The younger lavas were affected by the Rift faulting as refracted by scarps to the west of the Nairobi area. There in no evidence of faulting within Nairobi and Kapiti phonolite, hence the existence of the plain topographical feature.

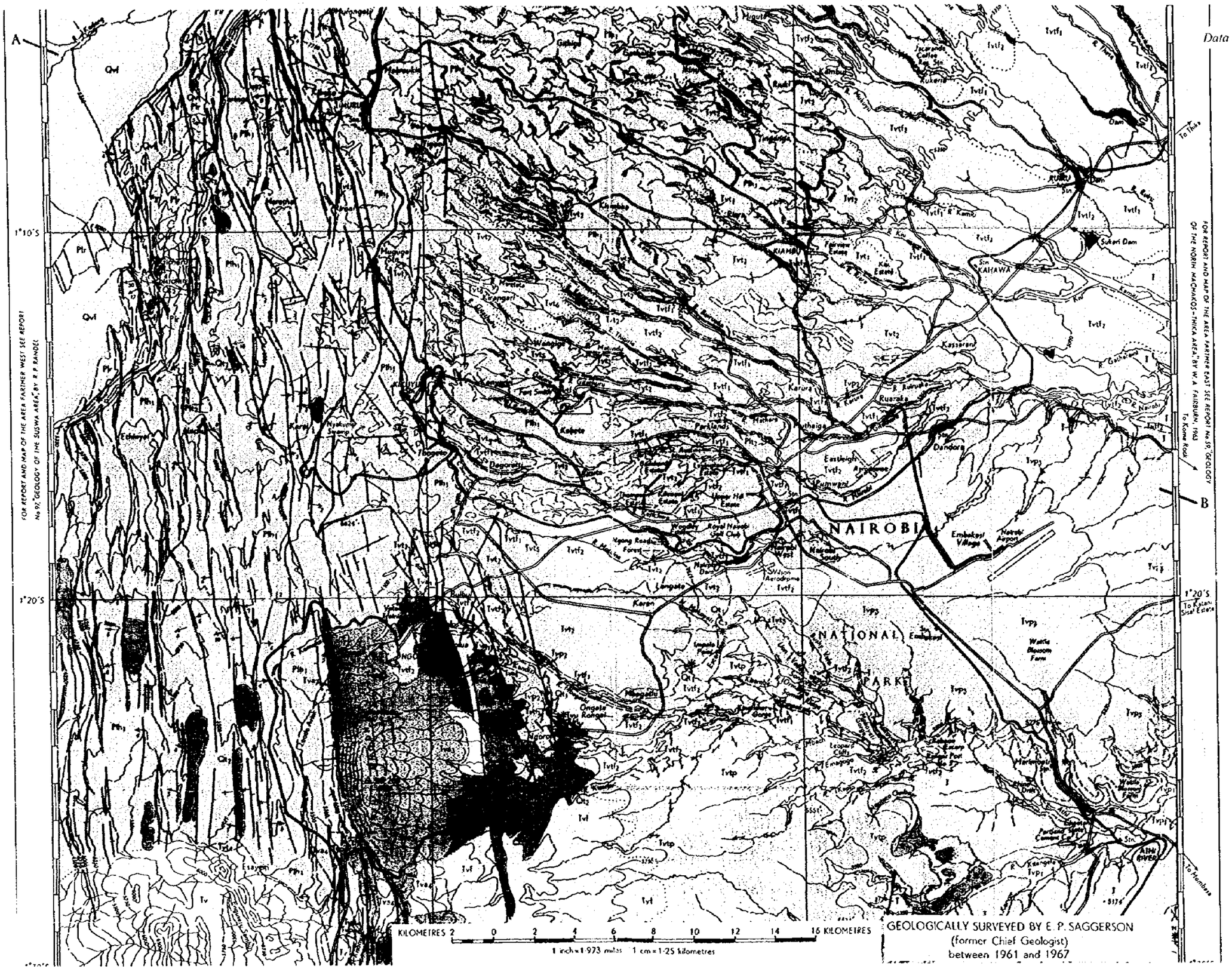


Figure 8.1-1 Geological Map (1)

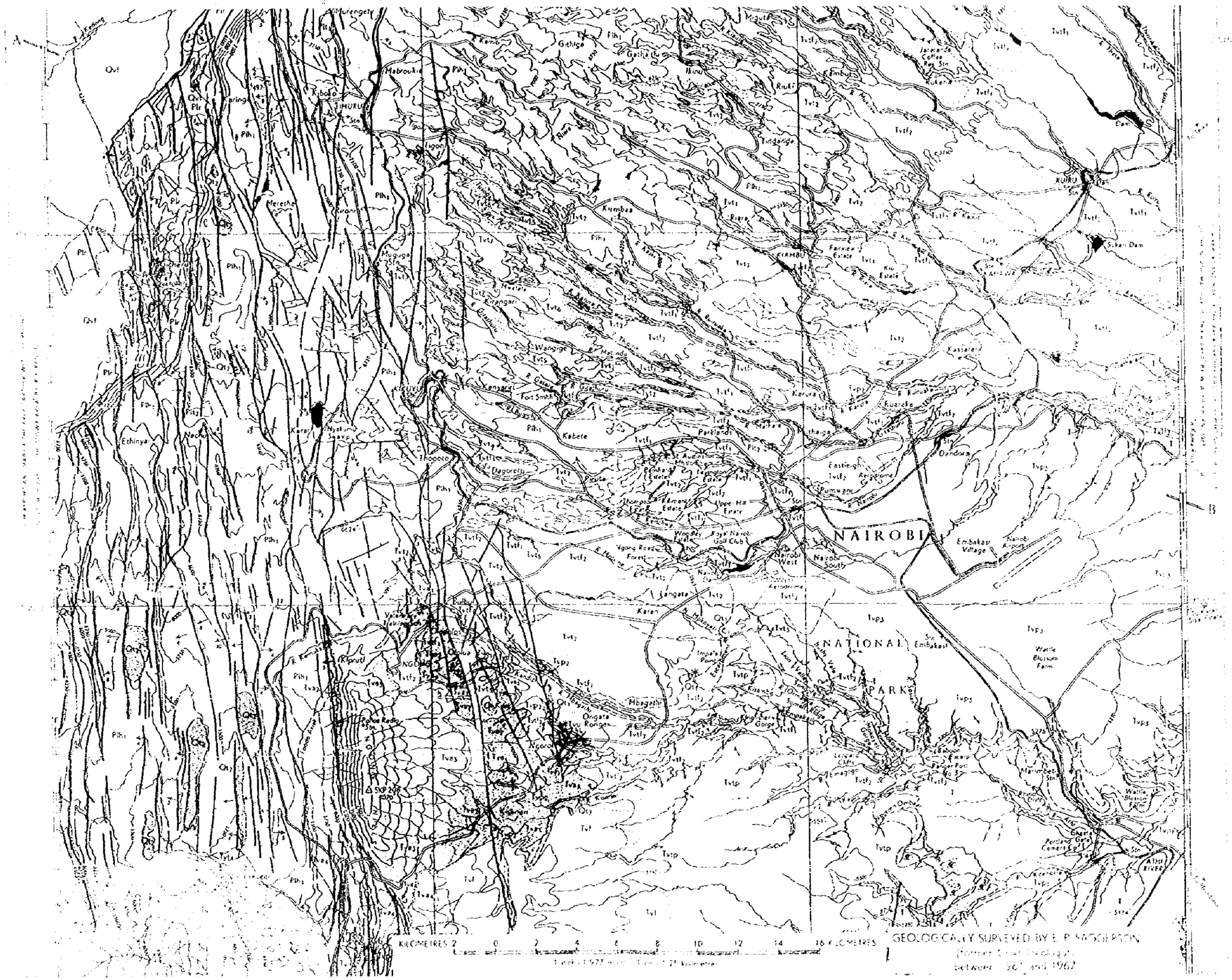
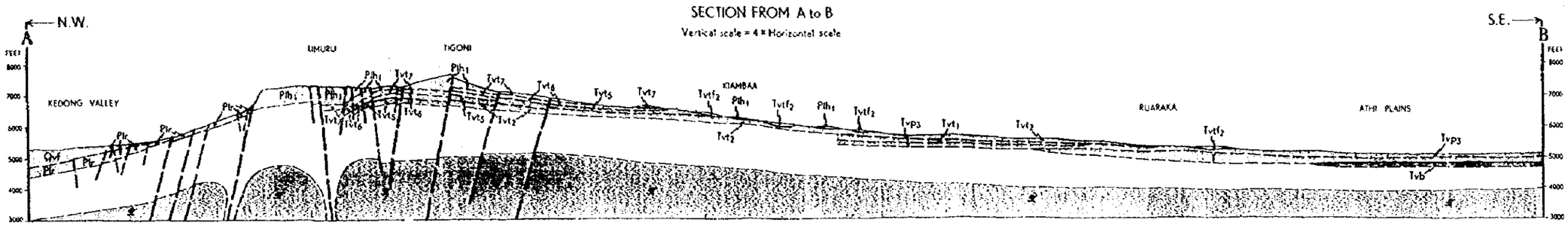


Figure 8.1-4 Geological Map (1)



EXPLANATION

QUATERNARY
- Alluvium, clays, swamp soil
- Sediments, loess, lacustrine deposits, diatomite
- Qt1 Terrestrial deposits with artefacts
- Qvf Ashes, pyroclastics and sediments of the Kedong Valley

PLEISTOCENE
- Plh2 Longonot Trachytes
- Plt2 Pyroclastics of Mt Margaret
- Plh1 Kinare Tuffs
- Plr Rhyolites, comendites, pantellerites and trachyrhyolites — Upper Trachyte Division
- Plh1 Limuru Trachytes and Quartz Trachytes — Upper Trachyte Division

TERTIARY
- Tvt7 Tigoni Trachytes
- Tvt6 Karura Trachytes
- Tvt5 Kabete Trachytes and Ruiru Dam Trachytes (Tvt5) — Middle Trachyte Division
- Tvtf2 Middle and Upper Kerichwa Valley Tuffs — Middle Trachyte Division
- Tvtf1 Lower Kerichwa Valley Tuffs — Middle Trachyte Division

OL ESAYEITI VOLCANICS
- Tv Ol Esayeiti volcanics (undifferentiated)
- Tvt4 Trachytes
- Tvp4 Phonolites
- Tva4 Ol Esayeiti Oligoclase Tephrites
- Tvp3 Ol Esayeiti Phonolites
- Tvp2 Phonolites

NGONG VOLCANICS
- Tvas Basanites, tephrites, atlantites, ankaratrites (undifferentiated)
- Tephrites
- Basanites
- Ankaratrites and tennbuschites (Kandizi)
- Tvf Ol Doinyo Nanok agglomerates
- Tvt3 Ololua Trachytes
- Tvt2 Nairobi Trachytes
- Tvt1 Kiambu Trachytes
- Tvp1 Nairobi Phonolites
- Tvp1 Kandizi Phonolites
- Mbagathi Phonolitic Trachytes
- Athi Tuffs and Lake Beds with chert band
- Simbara Basalts
- Tvp1 Kapiti Phonolites

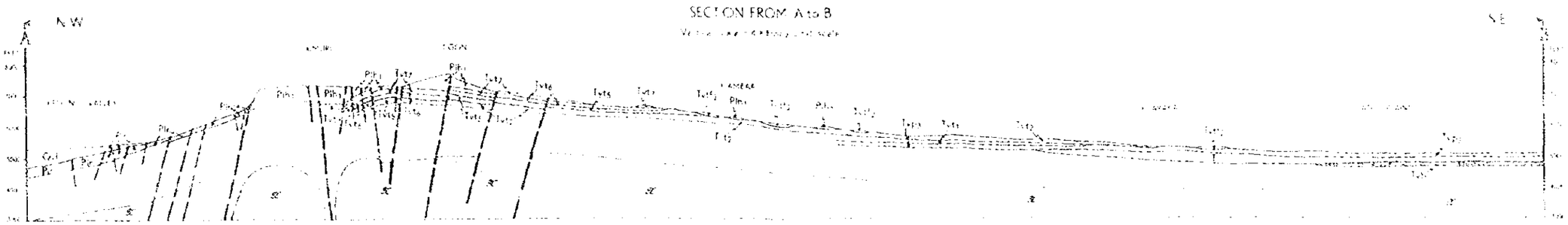
Lower Trachyte Division

PRECAMBRIAN
- Undifferentiated crystalline rocks of the Mozambique Belt

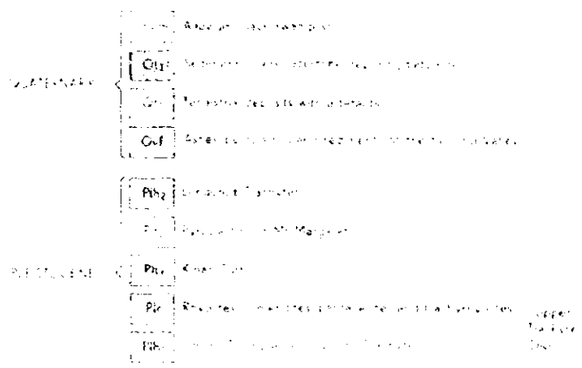
- Geological boundaries, observed
- Geological boundaries, approximate
- Geological boundaries, inferred
- Dip of bedding
- Dip of foliation
- Plunge of lineation
- Preferred orientation of phenocrysts in lava
- Faults
- Artefact and fossil localities
- Railways
- Main roads
- Trigonometrical stations
- 3654' Spot-heights in feet
- 7000 Form-lines at 250-ft vertical intervals
- Swamps
- A B Line of section

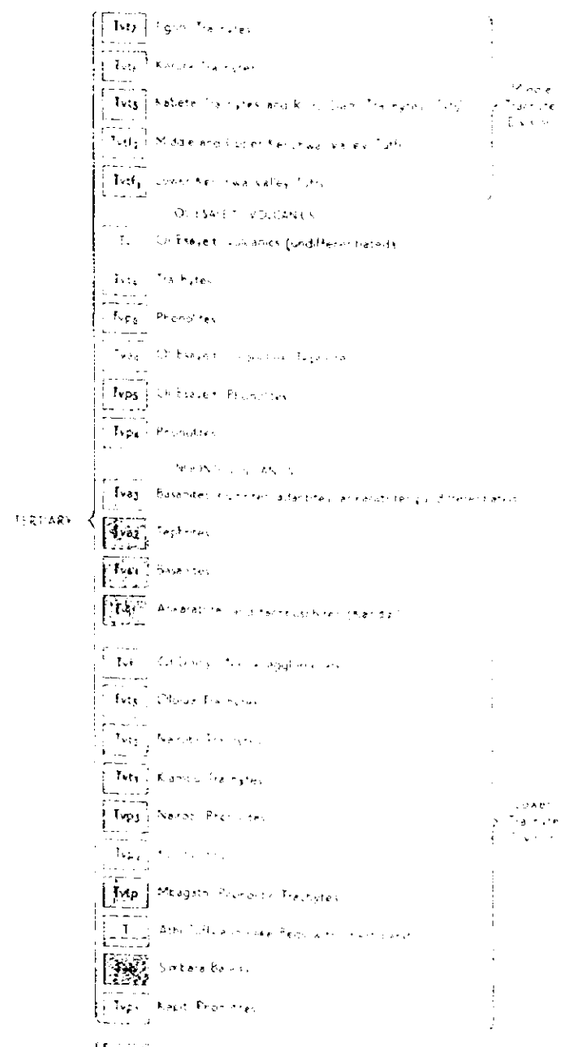
Magnetic declination 2°36'W.

Figure 8.1-1 Geological Map (2)



EXPLANATION





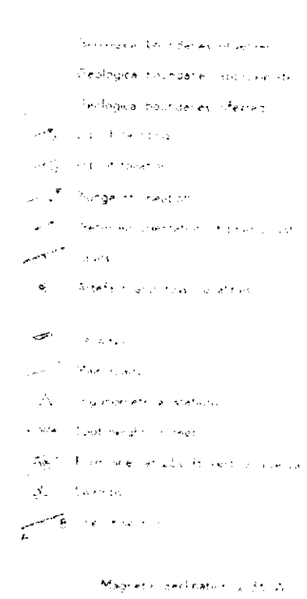


Figure 8.1-1 Geological Map (2)

8.1.3 Hydro-geology

(1) General

The hydro-geology of Nairobi City and its environs is controlled by the nature and morphological set up of various volcanic lava flows and the configuration of the old land surface of the basement rock system. The river drainage system and indeed the groundwater table gradient closely follows the easterly direction of the lava flows. Aquifers occur within the Kirichwa valley tuffs and sediments, and the interface between Nairobi phonolite and Kapiti phonolite within the Athi series of tuffs and lake sediments.

In the southern part of the Nairobi area, deep aquifers are encountered within the old land surface of the basement rocks. The old lava flows, namely trachytes and phonolite, are compact and impermeable and are as such aquicludes. The main streams and rivers draining the Kikuyu Highlands towards the Nairobi area are perennial but are fed by springs that issue within the contacts of the Kirichwa valley tuffs and the trachytic lavas. The Nairobi River is fed by the Kikuyu springs at the headwaters while Mbagarhi springs in Ololua forest feed the Mbagathi river, which later become Athi River. Numerous springs issue between lava flows where the trachates and tuffs are relatively porous and permeable.

In the City Center, water draining eastwards from the permeable tuffs and sediments accumulates above the Nairobi phonolite to from a shallow perched water table. The Kirichwa valley tuffs lying to the east of the Uhura Highway is so porous and pervious that the contact between them and the underlying impermeable Nairobi phonolite is a good aquifer. Thus a number of buried channels containing groundwater occur beneath the Nairobi City centre. These channels represent the old river courses of the Nairobi river and its tributaries and are encountered during geotechnical drilling for building foundation works.

The subsurface geological conditions underlying the City Centre and the Industrial area as far as Ngong River reveal that the Nairobi phonolite is overlain by Kirichwa valley tuffs and sediments. It is also known from drill holes that between the outcrops of Kirichwa valley tuffs of the central city area and the trachyte escarpment to the west of the Highway a buried channel of about 25 meters deep exists and filled with black cotton soils, clays and debris that accumulated at the foot of the trachyte scarp. Valley Road extending to Kenyatta Avenue follows the direction of an old buried stream course whose water flows onto the Athi Plains.

(2) Groundwater Level

To locate the direction of ground water flow in an area, a water level contour map is prepared for a specific time or season. Such a map indicates that in Nairobi the direction of flow of groundwater is from west to east and more or less parallel to the direction of flow of the rivers in the area. The flow gradient also reflects the general topography of the area and rainfall and recharge patterns.

The complex vertical and lateral variations of the volcanic formation sequence results in vertical hydraulic discontinuities which give rise to the erratic water levels observed in the Nairobi area. Groundwater levels are generally deep, and for the main aquifers the depth to water levels average 60 to 90 meters. Although in some areas, such as Ruaraka where water levels have declined due to over pumping, recorded water levels in other areas indicate that water table is deep under most areas of Nairobi namely: - Karen 20-35 meters, Langata 70-100 meters, Kamiti 15-60 meters, Spring Valley 15-25 meters, City Centre and Athi plains (Airport) 15-90 meters.

Shallow groundwater occurs in specific areas close to river valleys or swamps and the groundwater levels are close to the ground surface. For instance, water levels in the city centre and Adamus Arcade on Ngong road, for the shallow perched aquifer, are 4 meters and 6-8 meters respectively.

For the design and construction of landfill site, the risk of aquifer contamination is lessened by the careful siting of the facility, which should be located in terrain where groundwater flows is constrained by low soil permeability which inhabits the infiltration of the contamination.

8.2

THE TOPOGRAPHIC SURVEY AND GEOLOGICAL INVESTIGATION FOR NEW TWO FINAL DISPOSAL SITES

8.2 The Topographic Survey and Geological Investigation for New Two Final Disposal Sites.

8.2.1 Purpose

The topographic survey and geological investigation provide the required data for the design of final disposal site.

The survey are done at the Ruai Area and the Ngong Road Forest where the both sites are proposed as candidate landfill sites for the Nairobi City.

8.2.2 Topographic Survey

A 1:1000 topographic survey was carried out at the proposed landfill sites as shown in **Figure 8.2-1.** The surveyed area is approximately 40 ha for each site including access road.

The survey interval is 100 m grid points and where the topography changes. Contour interval is 1m and 0.5m supplementary.

The height indication is used by the standard mean level of the sea and indicated in cm on the topographic map.

Level survey is based on fifth class station marker designed by the Government of Kenya. New station marker was constructed by using concrete and positioned near the site. And several temporary level points was marked beyond the perimeter of the site.

The topographic survey provided the following results;

- Topographical map (1:1000)

- Cross sections

- Longitudinal sections

8.2.3 Geological Survey

The quantities of geological investigation of both site is shown in the table below. The locations of machine boring are shown in **Figure 8.2-1.** The exact locations are noted in topographic map.

Table 8.2-1 Quantity of Geological Investigation in Ruai Area and Ngong Road Forest

Work Item	Work Quantity of Each Site
Machine Boring (D=86mm)	6holes, 15m x 4 holes, 30m x 2 holes, 120m in total
Standard Penetration Test	Every 1m of top soil
Measurement of RQD	Every 1m of rock
In-situ Permeability Test	6 times (5m depth x 2 times, 10m, 15m, 20m, 30m)
Laboratory Test (1)	6 samples, Density, Specific Gravity, and Particle Size Analysis
Laboratory Test (2)	3 Samples, Compaction Test

The investigation report is consist of drill logs and records of SPT and RQD, ground water level and following information.

- General geological descriptions of the investigation area
- In-situ permeability test result
- Geological cross sections
- Laboratory test result

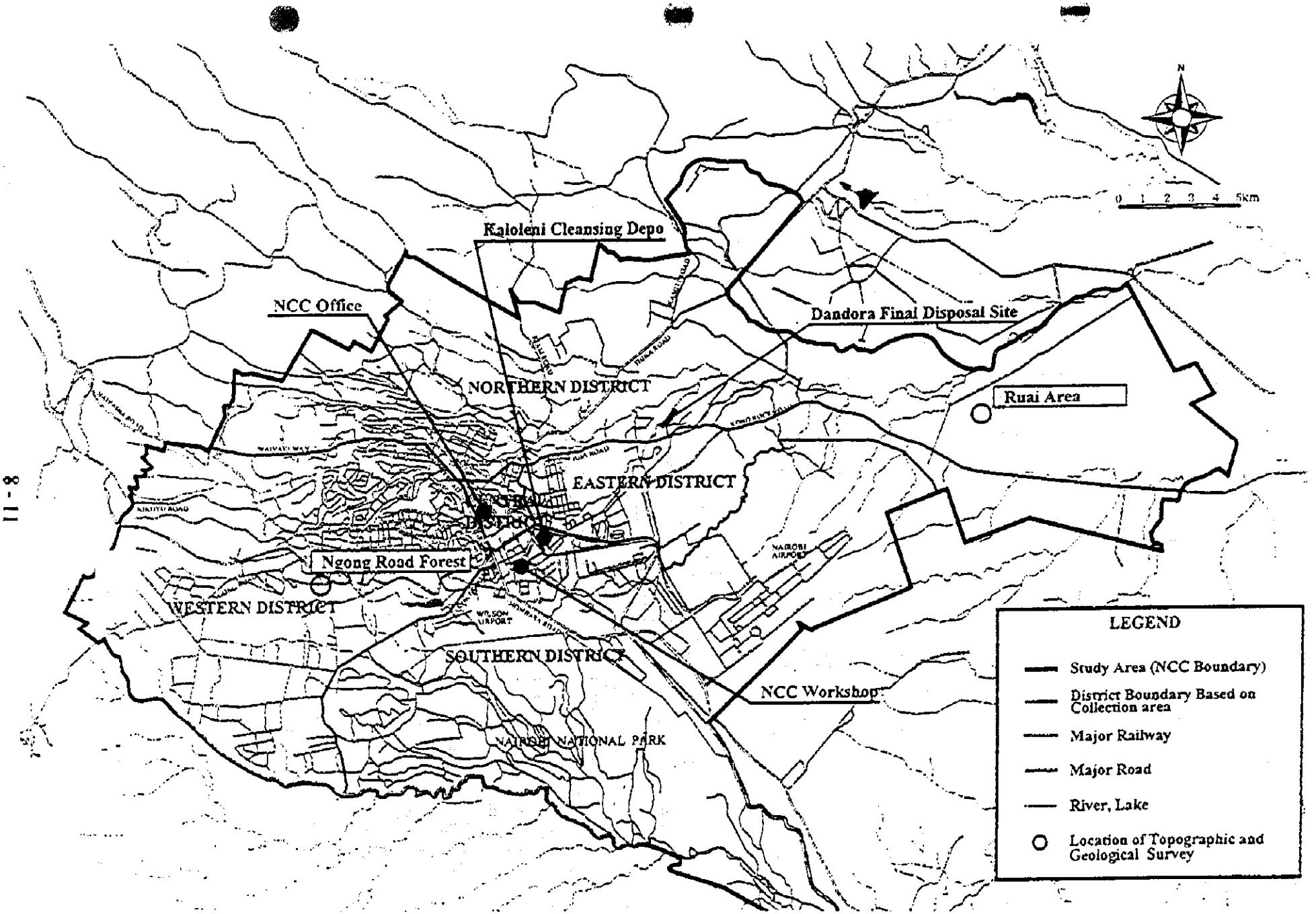


Figure 8.2-1 The location Map of Topographic Survey and Geological Investigation

8.2.4 Survey and Investigation Results

The topography map was used for the design drawings. The geological investigation detail result is shown in "*GEOLOGICAL SURVEY OF THE PROPOSED WASTE DUMPING SITES IN NAIROBI, KENYA*" (JANURARY, 1998), the investigation result provide the basic data for the design of final desposal site.

8.3

SELECTION CRITERIA OF FINAL DISPOSAL SITE

8.3 Selection Criteria of Final Disposal Site

8.3.1 Landfill Site Selection

In selecting a sanitary landfill site, it is necessary to ensure that the site has a sufficient capacity to accept the planned landfill volume. In addition, the following aspects should also be jointly considered:

(1) Landfill area is of sufficient size

(2) Efficiency of collection and transport

(3) Surrounding conditions

(4) Topography and geological conditions

(5) Satisfy against disaster

(6) Ultimate land-use plan

(7) Availability of cover soil

In the construction of a landfill system it is necessary to plan with sufficient consideration each of the following factors. It is also important to carry out a preliminary assessment of the site.

(1) Landfill Area is of Sufficient Size

It is necessary to ensure that the area proposed for the landfill should be utilized for a number of years. This is because the construction costs of facilities, which include approach and access road, leachate collection and treatment facilities, drainage system, guard house, etc. will be approximately the some expense of the area of its landfill site. If the landfill has short life because the area is small, this will mean that capital investment cost to build new landfill will increase.

(2) Efficiency of Collection and Transport

Collection and transport costs from a large portion of the solid waste management cost. This among varies with the collection method, the area of coverage, the location of the treatment plant and road traffic conditions. Generally, the larger the city, the lager the share of collection and haulage cost becomes. Therefore, in selecting a site, it is important to examine each of these items carefully so that collection and transport can be provided efficiently.

There is traffic jam in Nairobi central area ordinary, therefore two sites should be selected, one at the eastern and one at the western side or one at the southern and one at the northern of the city to avoid traffic jams and minimize the transportation distance.

(3) Surrounding Conditions

The disposal site and traffic generated by collection and hauling vehicles can potentially cause environmental problems. Therefore, in order that the landfill system does not become a source of pollution in the surround area, it is desirable to carefully consider the following points and at the same time ensure that the system also contributes to regional improvement.

(a) Appropriate adjustment to all relevant urban planning regulations.

(b) Effluent discharge point.

(c) Haulage route, approach road and access road.

(d) If a housing area is locate nearby, the conditions of the buffer zone (green belt) should be assessed for: noise, vibration, and offensive order.

(e) Check the location of the housing area and public facilities such as schools and hospitals

(f) Availability of utilities such as electric power, telephone and water.

Sanitary conditions of landfill sites depend upon the level and standard of daily site care and management. Therefore the site management system is very important to ensure that the surrounding environment is protected.

It is also necessary to get the agreement of local people to the proposed management of scavengers and to any countermeasures to scavenging activities.

(4) Topography and Geology

It is preferable to choose a site with good geological conditions to reduce construction and maintenance costs. As for as possible the landfill system should be built on non-permeable ground, but not on soft ground or places where subsidence may occur. However, if such a situation is unavoidable it will be necessary to take countermeasures to prevent land subsidence.

Moreover, a site should not be chosen in an area with high rainfall or a watercatchment area, and where there is a water intake point located immediately downstream of the landfill site. As for underground water, it is important to study the conditions of the aquifer, the water level and water level and water usage.

(5) Safety Against Disaster

It is necessary to make a preliminary study to ensure that the landfill site is form, for example the risk of landslides, flooding subsidence or avalanches in the site.

(6) Ultimate Land-use Plan

It is desirable that the landfill system should not only be seen to support environmental conservation, but should also contribute toward improving the well-being of people in the region.

In recent years, public consent has become a very important in the construction of landfill sites and their facilities. The effective use of the completed landfill has also become an important factor in obtaining public consent. A landfill system implemented regional improvement, and which is based on the present situation of the surrounding area and the future plan for urban development.

(7) Location of Related Facilities

In principle, solid waste treatment consists of the process of collection/hauling and treatment/disposal of wastes which must be done quickly without causing environmental problems and at the same time economically. Therefore, the related facilities should be located in a functional manner.

The location of landfill system should preferable be:

(a) near the cleansing office and activity base of intermediate treatment facilities.

(b) near the pit where cover material is kept.

(8) Availability of Cover Soil

In Identifying the suitability of a landfill site, it is important to consider the availability of cover material in the vicinity, to facilitate the soil covering. Ideally speaking, one fourth of the total volume of the landfill site should be assigned for cover soil.

Therefore, a large volume of cover soil material is needed and cost of transporting the material for some distance will be quite significant.

8.4
DESIGN CRITERIA OF FINAL DISPOSAL SITE

8.4 Design Criteria of Final Disposal Site

8.4.1 Landfill Disposal Concept

The aim of solid waste disposal is to immediately remove solid waste from urban community and reduce its volume, making it stable and hygienic. In choosing the process of proper treatment and disposal, not only the geographical area should be considered but also the financial situation and the level of technology within the organization responsible for solid waste management. This management process can usually be divided into three process such as collection/transport, intermediate treatment and final disposal. Basically landfill disposal process which finally restores solid wastes to the nature.

The purpose of landfill disposal is to stabilize the solid waste and to make it hygienic through proper dumping of waste and use of natural metabolic function. Therefore, it is important to have a practical method of disposal which can be decided upon by regional condition and organizational situation. In making this decision, it is important to take into account the type, form, composition of waste, location of landfill site, regional, hydrological and climate condition.

In planning the final disposal, it is necessary to determine the types and volume of waste for landfill and to formulate an effective master plan for solid waste management based on actual needs of the region. The final disposal plan should also be formulated in such a manner as to be organic with the collection or hauling plan and intermediate treatment plan.

8.4.2 General Requirement for Landfill

(1) Definition of Landfill

"Landfill" means a waste disposal site used for the controlled deposit of waste onto or into road, and the landfill system has been prepared many facilities and equipment to protect the surround secondary pollution from the site.

"Landfill" consists of eleven basic contents as follows:

(a) Considered location;

(b) Planned access road from service areas;

(c) Fencing sufficiently to prevent free access to the site;

(d) Considered landscaping;

(e) Identification and information boards must be provided;

(f) Control of access and information;

(g) Water control and leachate management;

(h) Protection of soil and ground water;

(i) Gas control;

(j) Monitoring system;

(k) Control of stability.

(2) Basic Contents

(a) Considered Location

The location of a landfill must take into consideration requirements that is shown as "Selection Criteria of Final Disposal Site".

(b) Road and Service area

(i) Access to a landfill shall be planned in such a way that it creates minimal hindrance to existing public road.

(ii) The landfill shall be equipped so that dirt originating from the site is not dispersed onto public roads and surrounding land.

(iii) All the roads are service areas within boundary of landfill must be built and maintained to comply with the water control and soil and ground water protection measure required for the site itself.

(c) Fencing

The landfill shall be surrounded by fencing sufficient to prevent free access to the site.

The gates shall be locked outside operating hours.

(d) Landscaping

Measures shall be taken in order to reduce the visual impact of landfill, in particular when easily visible from residential area, recreation area and roads.

(e) Site Identification and information

(i) At the entrance of a landfill an identification and information board must be provide displaying the following information:

- name and class of the site;

- name of the owner and or operator;

- licensing identification;

- operating times;

- contact and emergency telephone;

- authority responsible for the operating permit and control of the site;

(ii) The additional information must always be available to be public on request:

- type of wastes for which the site has received an operating permit;

(f) Control of access and operation

(i) An appropriate system for control of access must always be provided at the entrance of the site.

(ii) All waste delivered shall always be controlled on its

- origin

- type of characteristics

- quantity weight or volume

- the appropriate identification

(iii) The system of control and access to each facility should contain a program of measures to detect and discourage illegal dumping.

(iv) During operation hours, a suitability qualified person in charge of the landfill operations must always be present.

(g) Water control and leachate management

(i) Appropriate measures shall be taken in order to control surface and or ground water entering into the landfill waste.

(ii) All water or leachate emanating from the landfill shall be collected by means of an efficient drainage system, so as to ensure that no water accumulates at the bottom of the site, unless, though an environmental impact assessment, it is determined that collection is not required.

(iii) Contaminated water and leachate collected from the landfill shall be treated to the appropriate standard required for its discharge.

(h) Protection of soil and groundwater

(i) A landfill must meet the necessary conditions, naturally or artificially achieved to prevent pollution of the soil or groundwater.

(ii) The non-saturated geological formations consisting the substratum of the landfill base and sides shall satisfy the following permeability coefficient, K(cm/s), for a substratum thickness of three meters measured under conditions of water saturation:

- Landfill for hazardous waste: k=1.0x10-9 m/s

- Landfill for municipal and non-hazardous waste and for other compatible wastes :K=1.0x10-7 (cm/s)

- Landfill for inert waste: K=no limited value

(i) Gas control

(i) Appropriate measures shall be taken in order to control the accumulation and migration of landfill gas.

(ii) Landfill gas shall collected and properly treated and preferably used in such a way as to minimise damage to or deterioration of the environmental unless by an environmental impact assessment it is determined that collection is not required.

(j) Nuisances

Measure shall be taken to prevent arising from the landfill through:

- emission of odors and dust

- wind blown materials

- noise and traffic

- birds, and vermin and insects

- formation of aerosols

(k) Control of stability

To provide for stability of the mass of waste and associated structures, particularly in respect of avoidance of slippages, the emplacement of waste on the site shall take place under suitable system of quality assurance.

(3) Sanitary Level of Landfill System

Complete landfill system requires a large amount of capital investment. Taking into consideration the size of the local government's annual budget and its financial situation, we can expect various problems with regards to the funding for the complete landfill system.

It is thus more realistic at the moment to complete landfill system. It is also important that at the same time to consider the need to achieve a balanced urban infrastructure improvement and aspects of urban environmental preservation.

The sanitary level of landfill system can be classified in four stages, namely:

Level 1:Controlled tipping

Level 2:With a bund and daily cover soil

Level 3:Effluent control of leachate

Level 4:Leachate treatment system

The primary target of the Improvement Plan for Landfill System in Kenya should be target at level 3. The implementation program should contain a plan for continues upgrading of the system in link with financial and technical capability of the local government so that Level 4 may be obtained as early as possible.

The sanitary level of landfill system, its target, etc., are further described as below:

(a) Level 1

(i) Target

- Introduction of controlled tipping

(ii) Achieved Level

- Establishment of access to site

- Introduction of cover material in order to prevent fire, littering of wastes and odor

- Introduction of inspection, control and operational records of incoming wastes

(iii) Further Improvement to Next Level

- Establishment of site boundary

- Introduction to environment protection facilities

- Introduction of amenities for the staff such as sanitary facilities and locker room

- Introduction of semi-aerobic landfill

(iv) Environmental issue

In this level, environmental protection measures are not established except the provision of cover material. Impact on the surrounding by the landfill operation are great and may include the following:

- Surface and groundwater pollution by leachate

- Littering and dust

- Breeding of insects and rodents

- Unpleasant view of landfill

- Noise

- Odor

(b) Level 2

(i) Target

- with a bund and daily cover soil

(ii) Achieved Level

- Establishment of site boundary in order to distinguish the disposal site and to eliminate scavenging

- Application of sufficient cover for waste disposal

- Establishment of disposal site by construction of enclosing bund

- Introduction of divider for unloading areas and working face

- Establishment of drainage system in order to divert storm-water and seepage from surrounding areas and to reduce leachate

- Introduction of environmental protection facilities in order to lesson direct impact on surroundings such as buffer zone, litter control and gas removal facilities

- Introduction of semi-aerobic landfill through the installation of gas removing facilities

- Introduction for amenities for staff

(iii) Further Improvement to Next Level

- Improvement of semi-aerobic landfill

- Establishment of leachate control

- Establishment of leachate treatment

(iv) Environmental Issue

In this level, since disposal site and drainage system are already established, Landfill operation can be controlled efficiently. Furthermore, with the application of sufficient cover and introduction of some environment protection facilities, impacts from landfill operation are much reduced than Level 1. Besides, the installation of gas removal facilities introduces a semi-aerobic landfill system. However, leachate is still not controlled and a monitoring system has yet to be established.

(c) Level 3

(i) Target

- Effluent control of leachate

(ii) Achieved Level

- Establishment of leachate control by the installation of effluent collection, storage and monitoring facilities

(iii) Further Improvement to next level

- Introduction of leachate treatment system

- Establishment of semi-aerobic landfill

(iv) Leachate accumulated at the bottom of landfill is discharged through drainpipes, i.e. leachate collection pipes. These pipes also permit the natural inflow of air to promote semi-aerobic condition for the decomposition of waste. To achieve favorable improvement, the monitoring and control of leachate levels and checking for malfunctioning of leachate collection pipes are essential.

(d) Level 4

(i) Target

- Leachate treatment

(ii) Achieved level

- Establishment of leachate treatment by the installation of oxidation pond, etc.

- Establishment of seepage control

- Establishment of semi- aerobic landfill

(iii) Further improvement to next stage

- Establishment of high-level treatment system

- Introduction of service system to the surrounding residents

(iv) Environmental Issue

The installation of seepage control facilities and oxidation pond with aerator for the leachate treatment would achieve landfill sanitary level.

(4) Operation and Maintenance

Operation and maintenance of Landfill system is described in 8.5 OPERATION AND MAINTENCEMANUAL OF SANITARY LANDFILL.

8.5

OPERATION AND MAINTENANCE MANUAL OF SANITARY LANDFILL (DRAFT)

8.5 Operation and Maintenance Manual of Sanitary Landfill (Draft)

8.5.1 Landfill Control Facilities

(1) Structure of Control Facilities

For the proper management of sanitary landfill system, facilities to control operations and monitoring, a site office and access roads, etc. must be constructed.

(a) Management of Sanitary Landfill System

This involves the proper control of solid waste quality and quantity. Landfill operations, management of landfill layers, facilities included in the sanitary landfill system as well as other facilities as shown as in **Table 8.5-1.**

Table 8.5-1 Checklist of Sanitary Landfill System

	Management Items	Remarks
Sanitary Landfill Control System	Landfill Waste	Record of waste quality and quantity
	Landfill Work	Cover material, landfill plan, keep plan of health safety and sanitary health
	Landfill Layer	Leachate and gas generation, ground settlement, etc.
	Facilities	Proper maintenance and repair of all facilities
	Others	Countermeasure for fire, disaster and etc.

(b) Component of Control Facilities

Control facilities include the site office to that records and controls the quality and volume of landfill waste, landfill vehicles used for landfill operations, petrol storage tanks, places for washing those vehicles, monitoring facilities, roads for management, etc. as shown in **Table 8.5-2.**

Table 8.5-2 Classification of Control Facility

	Main Facilities
Control Facilities	Incoming vehicles control facility
	Monitoring facility
	Site office
	Access road
	Others (Garage, Fuel Fan, Vehicle washing facility, etc.)

(i) Weigh-bridge Facility

Checking Landfill Waste

Landfill waste must be checked for smooth operations as well as to prevent land pollution due to inclusion of harmful substances. Therefore, the type, components, quality, etc. of the solid waste must be carefully checked.

Landfill waste without passing through the intermediate treatment facility are usually checked by its outward appearance. Therefore it would be convenient if a platform is built near the weighbridge such that the components on the truck can be inspected. When necessary, the solid waste should be first unloaded and then inspected. A place for inspection is thus necessary.

Weigh-bridge

At the sanitary landfill system, a weigh-bridge should be constructed at the entrance to the landfill site so as to be able to weigh and record the landfill waste.

Function of the Weigh-bridge

The weigh-bridge weighs the truck loaded with the landfill waste into the landfill site. The systems are mechanical system, load cell systems and the revere load cell system. The mechanical system has a scale face with a pendulum or digital indications. The load cell and lever load cell also have digital scales. The load cell weigh-bridge are becoming popular recently as the mechanism is simple and thus is easy to maintain.

(ii) Weigh-bridge Design

The following factors must be considered before selecting the weigh-bridge system.

Number of Weigh-bridges to be installed

The total number of collection vehicles per day, solid waste collection systems and maximum number of collection vehicles at peak delivery hours etc. have to be considered before deciding on the number of weigh-bridge to be installed. In particular, when the weigh-bridge is near the public roads, the maximum number of collection vehicles at the peak hours should be carefully considered at intervals of 15 to 30 minutes.

Maximum Weighing Capacity of Weigh-bridges

The maximum weighing capacity of the weigh-bridges should be several times more than the total weight of the collection vehicle so as to provide room for unusually heavy collection vehicles, etc.

Location of Weigh-bridges

The weigh-bridges must be placed at the strategic locations where the vehicles will pass through whenever entering and leaving the landfill site.

Automatic Weighing System

Automatic weighing systems using computers produce an effect to reduce the time of making daily, monthly and annual report.

Regular Inspection

When a weigh-bridge is used as a toll gate, regular inspection of the system should be made to ensure proper measurements.

(iii) Investigations of Solid Waste Quality

Beside checking to see if the solid waste meet the requirements set, the quality of the solid waste must also be investigated. By knowing the quality of the landfill waste, the type of gas generated in the landfill, the leachate quality, the amount of settlement due to compaction of the landfill layer, etc. can be understood. This is also important data when designing the usage of the completed landfill site as well as for future landfill sites. When samples of the solid waste are to be taken, an inspecting place to take the samples after the landfill waste is dumped should be prepared.

(iv) Analysis of Control Data

The data on the weights and results of the inspection of the garbage should be analyzed on a regular basis for each type of solid waste and the site filled.

Daily, monthly and annual reports are usual. The times of deliveries are on daily reports, the dates of deliveries on monthly reports while the monthly information are included in the annual reports.

(v) Landfill Records

The landfill waste volume, quality, place, time of land-filling, solid waste type, etc. are all very important data which should be recorded.

The required input information and output record are shown in Tables **8.5-3, 8.5-4.**

Table 8.5-3 Input Information (Example)

Items
(1) Date
(2) Entry Time
(3) Departure Time
(4) Contractor's Name
(5) Driver's Name
(6) Vehicle Registration Number
(7) Waste Type
(8) Collection Points (Route)
(9) Gross Load
(10) Unloden Weight
(11) Net Load

Table 8.5-4 Required Information for Management of Sanitary Landfill

Required Information
(1) Number of collection vehicle
(2) The total waste amount brought into the site
(3) Classification of waste type and each amount
(4) Classification of waste generation in each collection area
(5) Waste charge calculation and publication of bill
Daily report, Monthly report, Annual report for (1) to (5)

(c) Monitoring Facilities

(i) Purpose of Introduction of Monitoring Facilities

Monitoring the Landfill Layers

The landfill waste during the course or after a landfill operation checks the changes in the solid waste component, traces and measures the amount of settlement in the landfill layers and the data obtained can be used for designing future leachate treatment plants or considering use for completed landfill site, etc.

Monitoring the Environment

The environment is monitored during and after land-filling operations so as to measure the environmental impact or to equip the sanitary

landfill system from the point of environmental conservation so as to prevent pollution.

Reflection of Future Plans

The amount of data collected or analyzed will determine how well future projects can be planned. Therefore, it is important that data on solid waste component, leachate, underground water, gas, bad odors, etc. be regularly collected.

(ii) Regular Monitoring

Landfill Layers

The landfill waste will change with the years. Therefore, it is important that a certain specified landfill layer be sampled, analyzed and its quality change record at the regular intervals.

However, since the landfill waste is not homogeneous, a typical landfill waste sample would be very difficult to obtain. As such, monitoring of the waste quality change has to be taken on a macro basis. For example, landfill layer settlement due to waste decomposition decay(gasification or leachate formation). If sink plates can be placed so that dynamic movements like the amount a layer sinks due to pressure or due to organic matter decomposition, the landfill waste quality changes can be traced.

Leachate and Discharged Water

As part of the management and maintenance of a sanitary landfill system, The quality and frequency of the discharged water should also be checked. In the case of leachate, this should be done for the water flowing into the leachate treatment facility. The amount of pollutants and harmful substances in the water flowing out of a landfill site must be measured. However, the discharged water quality and harmful substances must be monitored in order to prevent pollution of water in the areas where treated water is discharged. The proposed monitoring scheme is shown in **Table 8.5-5.**

Table 8.5-5 Proposed Monitoring Scheme (Leachate)

Sampling place	Monitoring Parameters	Frequency
Leachate reservoir pond and discharged water	pH, CN, Pb, T-Hg, Cd, BOD, COD, SS, MPN, Color	1/month

Ground water

The monitoring of ground water in areas surrounding the sanitary landfill system are for the following reasons;

- To check if the natural or artificial liner system in the site are effective or not.

- If in the case when the natural or artificial liner system are not effective, to prevent the extent of effects of pollutants discharged on the ground water and lives of inhabitants in the area.

Therefore, the monitoring facilities established will enable us to determine the possible usage and the quality of grand water in the areas around the sanitary landfill system. With those concept in mind, the number, location and monitoring wells required must be carefully calculated.

(Locations and Number of Monitoring Wells Required)

Before considering the above, a well must be placed directly below the direction of flow of the subterranean water in the landfill for the purpose of monitoring the amount of seepage before the pollutants in the water are dispersed into the ground water.

In addition, a second monitoring well should be built down stream where the dispersion of pollutants has the highest possible and fastest effects. The monitoring wells should be as deep as possible but in reality, they are usually due to a water table. The wells should be about more than 100 mm in diameter with a strainer at the water table.

(Items to be monitored and Frequency of Inspection)

The water quality inspection by monitoring cells can be divided into regular and routine inspection.

Regular inspection includes inspections on the land-use in the neighboring areas.

Routine inspection requires immediate detection of pollutant leakage and therefore, instruments like pH meters or electric conductivity meters, to measure changes in the water quality are usually built at the subterranean water collection and discharge facility or the monitoring well which are directly below the landfill site. Future monitoring methods will be recorded on paper. On the other hand, regular inspections are for checking seasonal changes in the subterranean water quality. As such, the water quality should be checked at the same time each year at each monitoring well. **Figure 8.5-1** shows some observed

results and **Table 8.5-6** shows proposed monitoring scheme of ground water.

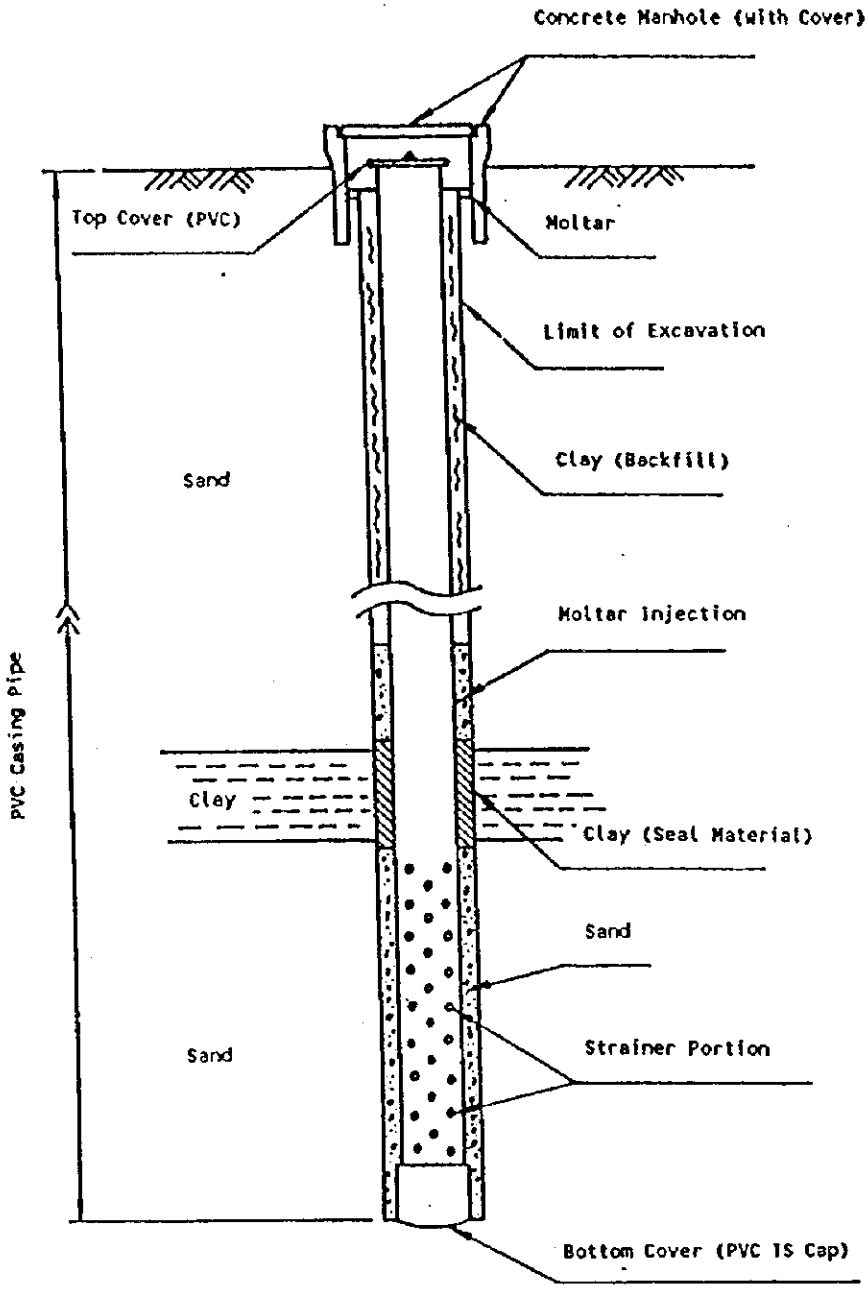


Figure 8.5-1 Monitoring Well

Table 8.5-6 Proposed Monitoring Scheme

Sampling Points	Monitoring Parameters	Frequency
Monitoring Well	pH, CN, Pb, T-Hg, Cd, BOD, COD, SS, MPN, Color	1/month

Gas

When waste with organic substances is buried in a landfill site, monitoring of the gas generated will help to determine the decomposition condition of the landfill waste. Even in a landfill which uses mainly incombustible waste, the landfill waste should also be monitored since the waste may include organic substances.

The gas generated can be monitored by using the gas venting facilities in the landfill. The gas generated must be monitored more frequently when active generation occurs and during stable periods, monitoring frequencies can be reduced. In other words, a flexible monitoring system should be installed. The **Table 8.5-7** shows the monitoring scheme of gas.

Table 8.5-7 Monitoring Scheme of Gas

Sampling Point	Monitoring Parameters	Frequency
Gas out-let pipe	Temperature and humidity of original air, Temperature and volume of gas, component analysis (CH_4, CO_2, O_2)	1/month

Bad Odors

The observation points and times for bad odors must be done after giving considerations to the living conditions in the surrounding area as well as weather conditions. Bad odors monitoring is usually done once a day in 3 months at 2 to 3 places on the landfill site boundaries.

Observation methods and items include the analysis of 8 parameters such as ammonia, thiorumethane, hydrogen sulfide, methyl sulfide, triethylamine, acute aldehyde, styrene, methyl disulfide and tests on their effects on human senses (comparison of 3 test bags by smell), but the method should be selected after considering the solid waste quality and the local conditions.

Others

Besides the above, other effects on the environment like noise, vibrations, animals, plants and appearance, etc. must also be considered when necessary.

(d) Site Office

The inspection and weighing of the landfill waste, checking of landfill progress and conditions, securing of cover soil materials, installation of section walls, operation, maintenance and monitoring of leachate treatment facilities at the sanitary landfill system must be systematically performed so as to protect the environment, promote safety of the plant and improve the cost effectiveness. The site office should include management office, test laboratory and analytical room, worker's rest room, locker room, showers, a room for boiling water, canteen, toilets, conference room, etc. Ventilation, telecommunication and etc. should also be considered.

In any case, the type of facility or room required at a site will all depend on the scale of the landfill site and management policies, the number of employees and managers at the site, etc.

The site office should be placed in a convenient position so as to enable easy control landfill waste or landfill operation itself. Measures to prevent noise or bad odors must also be taken into consideration.

In order to prevent the collection vehicles from carrying dirt onto the public roads, a vehicle washing facility should be installed at the existing roads. Whenever necessary, garages, petrol station, warehouses, machine inspection and maintenance facilities, lights, telecommunication facilities, etc. should be installed too.

(2) Safety Measures

A landfill site should be fenced off to prevent the general passers-by from trespassing as most parts of the landfill are dangerous. The fencing off is also to prevent other people from illegal dumping their own waste on the landfill. Net fences or barred wire fences are usually used around the sanitary landfill system while corrugated plates are used to fence off the area from the public roads or general housing. They will then be easily damaged and therefore, it will be important that they are regularly inspected and maintained. Since the area to be controlled is wide, the names of landfill sites, supervisors, addresses, contact numbers, etc. should be clearly indicated on a no trespassing sigh. The sanitary landfill system should be also clearly indicated.

Inspection and maintenance of landfill site should also be done to prevent scavengers from climbing over the fences and entering the enclosed area.

The following dangerous places and their measures should be carefully considered;

- Dangerous substances or insecticides etc. should be placed under lock and key under a roof.

- Leachate treatment facilities and leachate control pond should be fenced off and the entrance to them is properly locked.

- Manholes must have heavy lids.

- Gas venting facilities must be fenced off with barbed wires, etc. and a danger sigh is placed on the fence.

- Landfill equipment must be steered in specified places and when necessary, a buffer area established.

- The sand and earth used in the cover soil should be piled to a safe height.

- Depending on the progress of the land-filling, surface drainage should be elaborately performed since potholes are easily formed and water easily collects.

Corrugated plates must also be regularly inspected since they are easily damaged by heavy rains and winds. Lighting during nights are also important for safety and to prevent illegal dumping. Light bulbs or electrical wiriness must be regularly inspected. Guardsman must always be stationed during nights and Sundays and holidays when necessary.

If the leachate treatment plant with chemical treatment, chemicals like sodium hydroxide, aluminum sulfate, soda bypochlorite, etc. are used and these are dangerous to the human skin. If in case these chemicals get onto the skin, it should be rinsed off with lots of water. When it gets into the eyes, a doctor should be consulted. When dismantling or repairing the chemical pump, rubber gloves, protective glasses or face masks should be used.

8.5.2 Related Facility

(1) Composition of Related Facilities

The related facilities are necessary for the effective management and operation of the landfill site. Depending on the size of the landfill site, land conditions, etc. related facilities should basically include the following;

(a) approach roads or access roads for effective delivery of waste or building materials into the landfill site,

(b) facilities to prevent littering of waste at the landfill site

(c) signs with clear indications of owner doors and/or gates for preventing illegal entrance or illegal dumping in the area, fencing off facilities,

(d) fire prevention and/or fire fighting measures within the landfill site,

(e) bunds, walls to prevent rocks, earth, drainage, etc. from slipping or crumbling down slopes due to heavy rain, temporary rain water control and to prevent rivers from flooding.

Whenever necessary, depending on the local characteristics of the landfill site, noise shut-out walls, measures against insects, crows, etc. must also be considered.

A portion of these related facilities should be build during landfill operations while the rest can be built even after completion of landfill if they are for control and management of a completed landfill site.

(a) Approach Road

The approach roads to the landfill site can be divided into two parts; Public roads and roads leading from the public roads up to the landfill site.

Surveys on the use of existing public roads must be made so as to grasp an idea on the characteristics of the locality. The road width and structure, etc. must also be checked to ensure that it is suitable for the transportation of solid waste. When a public road is also used as a route for transporting solid waste, signs to indicate this dual purpose must also be erected. The junction should also be designed as not to obstruct the free flow of the existing public road.

Most of the roads leading from the public roads up to the final landfill site are usually newly built roads.

Roads construction (route, alignment, width, structure, etc.) must be done with the site application of the landfill area in mind. In particular, if the approach roads are to become public roads in future, then they must be built such that no problems occur when solid waste is accidentally dropped onto the road, repairs are to be made on the approach road itself or all other necessary measures to prevent accidents from occurring.

(b) Littering Prevention Facility / Buffer Zone

To prevent solid waste from littering or flowing out of the landfill site, cover soil should be laid as soon as possible. Sometimes for some reasons like insufficient cover soil, etc. this is not possible. In this case, littering prevention facilities/buffer zones must be installed. Littering prevention fence should be about 3 to 4 times the height of the perimeter fencing. During strong winds or seasonal winds, trees must be planted to act as wind breakers.

In the case of ash which disperses easily. Water should be sprayed to prevent dust from rising but care should be taken not to over spray. When most of ash

or incombustible substances or when the solid waste is in the form of plastic films, etc. care must also be taken.

However, the structure and height of a hence has its limits when preventing solid waste dispersion. Therefore, it would be more effective if the solid waste is divided into dispersible and non-dispersible waste when it is delivered into the landfill. If that is not possible, then the landfill area should be controlled and covered immediately.

Fences are constructed for preventing illegal trespassing, littering as well as to camouflage the unsightly site. The fences must be strong against the wind but from the cost effectiveness point of view, a height of less than 3m should be sufficient.

In the landfill site where there are a lot of trees, these may also be used as a fence or buffer zone.

(c) Notice Boards, Doors / Gates, Etc.

Notice board must be built to clearly indicate the purpose of the landfill site. The following items must be clearly marked. **Figure 8.5-2** shows a typical design for notice board.

Name : Ruai Sanitary Landfill Site (NCC)			
Generic Type of Waste			
Landfill Period	From	To	
Supervisor		Contact Address	

Figure 8.5-21 Notice Board (Example)

Doors/Gates must be built at all entrances or exits to the landfill site. At the end of a day's work, they must be closed and locked.

(d) Fire Prevention Facilities

Fire at the sanitary landfill system usually spread out because of the generation of methane gas due to decrease of combustible waste or other substances containing organic matter. To prevent outbreaks of fire, it is therefore advisable that gases generated must be removed as fast as possible and covered with soil. By releasing the gas into the atmosphere, explosion can be prevent and trees can be stopped from dehydrating. Since fires may start due to gas leakage from within the ground via cracks or holes in a landfill site and the glass pieces in the waste may act tiny lenses to focus the sun's energy and start fires.

It will be extremely difficult to extinguish fires within the gas ventry facility. If water is poured into the gas venting pipes, the very dangerous subterranean explosion may occur. Fire breaks must be build around the landfill area. Fire extinguishers, water, sand, etc. must be fully equipped. In the sanitary landfill system, it would be better if the cover soil itself is fire-proof. Stokes of cover soil must be made available such that when a fire break out, the fire can be extinguished by covering it and stopping oxygen from reaching the fire. Dump trucks, dozer shovels, etc. should also be used when necessary.

When starting inflammable fuel or insecticides, they should be handled in accordance with the rules on the handling of dangerous items.

Extinguishing of fires at the initial stages are most important. As such, daily routine inspection is important. Fire drills must also be regularly arranged.

(e) Disaster Prevention Pond

Since leachate control facilities for runoff overflow are installed at the sanitary landfill system, it will be incorrect to assume the same kind of facilities in an area developed for residential area. Rain water in a landfill site are temporarily stored in the leachate control facility.

The sanitary landfill system should also have a flood control facility and in a plain area, a trench type is usually used where rain water has to be pumped out. In this case, the overflow area becomes smaller and as a result, a disaster prevention area is not always necessary since the peak flooding control functions are always available.

When the final or the immediate cover soil is effective in removing surface runoff which will then be removed by the rain water collection and removal facilities, the outflow of rainwater from the landfill site will be greater than the expected discharge volume. Therefore, the rain water control facility at the landfill site will be most important after landfill is copiloted.

The necessity of a disaster control facility should be determined after considering the geography of the area, earth quality, use of the completed landfill site, size of landfill site, storage facilities, etc.

8.5.3 Landfill Works

(1) Landfill Works

The landfill works means the whole series of works which include the delivery of solid waste into the landfill site, spreading, mixing, final cover soil and all those related temporary measures. A summary of this is shown in **Table 8.5-8** and this includes landfill works, cover soil works, road works as well as constructing the load slopes.

Table 8.5-8 Landfill Works

	Major Work	Items
Landfill Works	Land-filling	- Land-filling method - Order of land-filling - Spreading and compaction - Separate land-filling
	Covering	- Daily cover - Intermediate cover - Final cover - Selection of cover material - Application of cover material - Control of cover soil
	Access road	- Main road - Branch road
	Mount up	-

The solid waste is placed within the landfill site so as not to cause environmental problems in the sanitary landfill system. Stabilization of the landfill layer must also be promoted. At the same time, it would also be important that effective and economic solid waste disposal within a limited landfill space be considered. Natural conditions such as the surrounding environment, geography of the landfill site, weather, the type and amount of solid waste generated per day, financial and technical aspects, etc. have to be considered before proceeding with the landfill work.

The close relationship between factors affecting the landfill work and the function of the sanitary landfill system is shown in **Table 8.5-9.** Landfill works should not only depend on the natural instincts and experiences of the supervisor of the works, decisions on the works should also be based on results of surveys on the technical and economic aspects. When the landfill disposal efficiency is to be given priority, landfill period, ability to compact solid waste, the thickness of the landfill waste, cover soil thickness, etc. must be given due consideration.

In the case when stabilization of the landfill waste is to be given priority, the landfill method, selection of cover soil material and compaction method that will not hinder the landfill waste stabilization process and when necessary, solid waste component must be considered.

On the other hand, when leachate and gas quality or quantity is important, the odor of landfill cover soil work, maintenance facilities must be considered. In the particular case when liner facility are used in the landfill, care must be taken so as not to ruin the sheet liner during landfill work like when spreading or compacting the solid waste.

Table 8.5-9 Landfill Works and Their Purpose

Landfill Works	Landfill Work				Covering				In-site Road		Others
Purposes	A	B	C	D	E	F	G	H	I	J	K
Efficiency of landfill work	a		a			a	a	a	a	a	a
Stabilization of waste	a	b	a	a	a	b	b	b			
Leachate quality		b	b	b	a	b	b	b			
leachate volume		b	b	b	a	a	a	a			
Gas quality			b	b	a	b	b	a			
Settlement	b		a	b	b	b	b	b			
Littering of waste			a		b	a					
Physical characteristics	a		a	a	b	b	a	a			
Post-closure land-use	a	b	a	a	b	b	b	a			a
Workability	a	b	a	b	a	a	a		a	a	a
Cost effectiveness	a	b	a	a	a	b	b	b	b	b	b
Maintenance		b	a	a					a	a	
Fire prevention		b	b		b	a	b	b			a

Note: a-Strong Role, b- Related Role
A: Landfill Method
B: Order of Landfill
C: Spreading and Compaction
D: Separate Landfill
E: Selection of Cover Material
F: Daily Covering
G: Intermediate Covering
H: Final Covering
I: Main Road
J: Branch Road
K: Embankment slope reclamation

(2) Landfill Method

The method and order of landfill must be carefully selected so as to improve stabilization of the landfill, create a physically strong foundation, improve the usability of completed landfill site, etc. at the same time, proper landfill equipment must be used to sufficiently compact the landfill waste. To improve the potential usage of the completed landfill site, separate landfill methods should also be used when necessary. Data on the amount and type of landfill solid waste, their changes with time must also be noted for future reference or for maintenance of the landfill site.

(a) Landfill Method

(i) Area Method

The area method is used when the terrain is used when the terrain is unsuitable for the excavation of trenches. Earth dike with a height of one lift (2-3m) is first constructed to get the support for compaction.

The waste are unloaded at the toe of the earth dike and spread and compacted on the slope of the dike in a series of layers that vary in depth from30cm to 60cm. The recommended slope of these layers is 1 to 3. The width of the working face should be as narrow as possible to confine the waste to the smallest possible area but at the same time it should be wide enough to give necessary maneuverability to bulldozers. At the end of each day's operation, a 15 cm to 30 cm layer of cover soil is placed over that day's completed fill. This one day's completed fill including the cover soil is called a cell. However, in the case of large landfill with the amount of solid waste more than 200 ton per day, two or more cells should be constructed each day to avoid the decrease of structural stability to be caused by large cells. The waste should be unloaded at the top of the last cell and spread and compaction. When all the area is covered by one layer of cells it is called a lift. One more lift can be constructed on the top of the preceding lift whenever it does not surpass the final topography set by the design. If a small amount of usable cover soil is available at the landfill site, the ramp variation of the area method is used as shown in **Figure 8.5-4.** In this method solid waste are placed and compacted as described for the area method and are partially or wholly covered with earth scrapped from the bottom of the ramp.

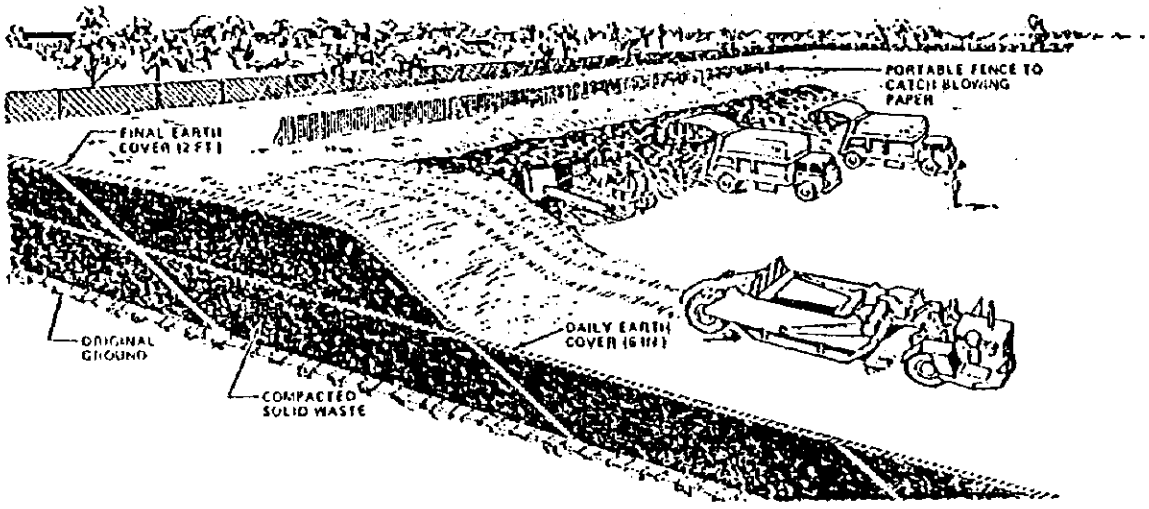


Figure 8.5-3 Area Method

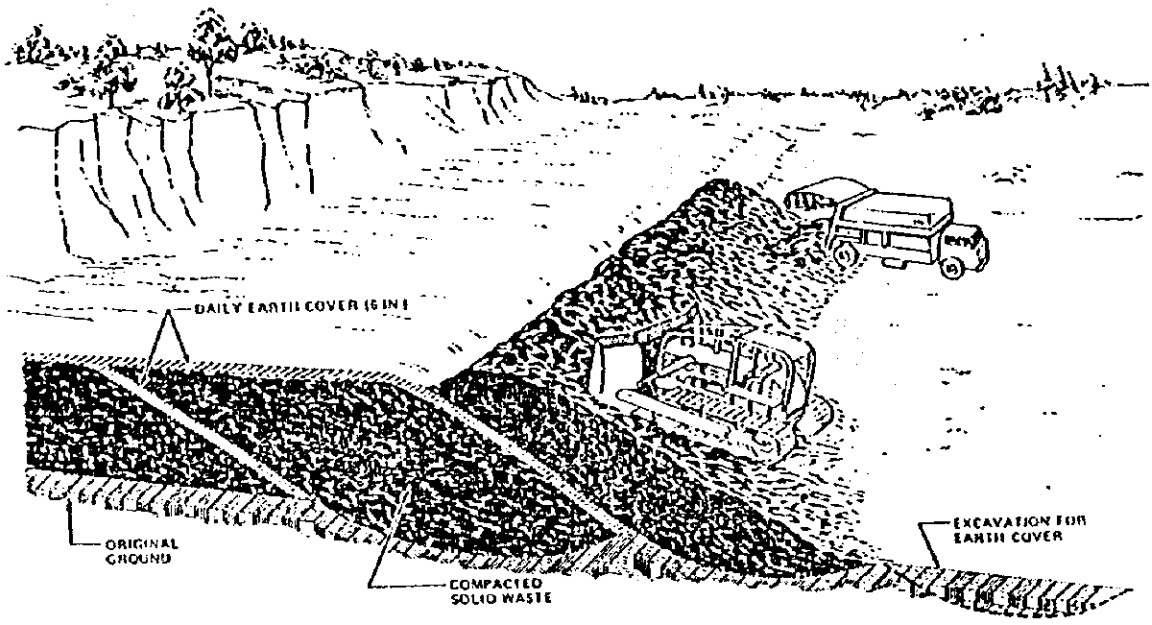


Figure 8.5-4 Progressive Slope or Ramp Method

(ii) Trench Method

This method is suited where the terrain is relatively level and the water table is not near the surface. In this case the excavation of trenches give on-site cover soil as well as support for compaction. Solid waste is placed in trenches varying from 30 to 120 m in length, 1 to 2 m in depth and 5 to 8 m in width. To start the process, a portion of the trench is dug and the earth is stockpiled to form an embankment behind the first trench. Waste is then placed in the trench, spread into thin layers from 30 to 60cm with the slope of 1 to 3 and compacted. As descried for the area method, cover soil is placed near the completed soil at the end of each day's operation. Cover soil is obtained by excavating an adjacent trench or continuing the trench that is being filled.

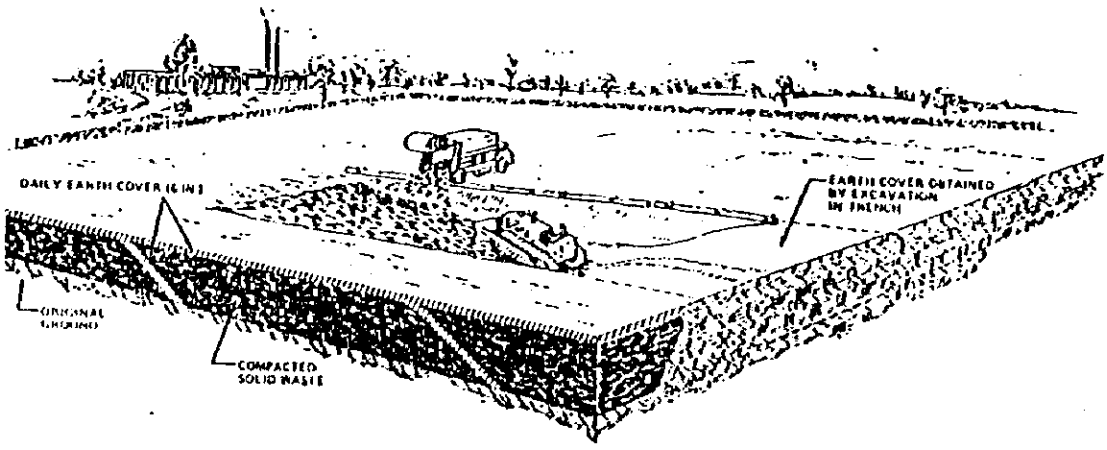


Figure 8.5-5 Trench Method

(b) Cell Construction

(i) Sandwich Method

This method is shown in **Figure 8.5-6** where the solid waste is laid horizontally with a cover soil layer added over each solid waste layer. This method is usually used to landfill narrow valleys. When a wide area is to be landfill narrow valleys. When a wide area is to be filled-up, the methods as shown in **Figure 8.5-7.**

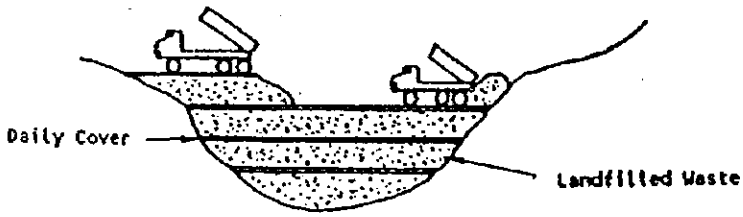


Figure 8.5-6 Sandwich Method

(ii) Cell Method

This method, shown in **Figure 8.5-8** has a cell of solid waste topped with a layer of cover soil and is the most popular method today. The size of each cell is determined by the amount of solid waste used per day. Since each cell is an independent landfill area, each cell acts as a fire-breaker. It also prevents the solid waste from being scattered, emission of bad odors and harmful vectors from breeding. The disadvantage is that gas generation and water flow within the landfill will be hindered.

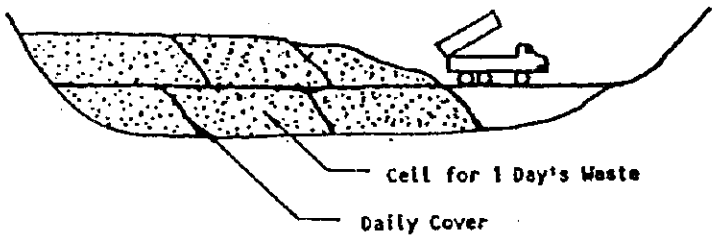


Figure 8.5-7 Cell Method

(c) Order of Landfill

(i) Order of Landfill on Landfill Site

There are 2 orders;

- Landfill from upstream down
- Landfill from downstream up

In the former method, easy access to the landfill via the already filled-up area is possible. The rain water absorbed into the inner landfill layers during the early stages of landfill would be difficult to remove rain water from the unfilled areas. Slipping of the landfill layer due to rain water on the liners on the bottom of the landfill site results. Sometime the liners may even be damaged.

On the other hand, the latter method enjoys these points which are demerits in the former method. Therefore, when considering the order of landfilling, the geography of the area, the rainfall patterns, water treatment methods as well as rain water treatment methods must be given enough attention.

(ii) Spreading and Compaction

Method

This is depicted in **Figure 8.5-8** where the solid waste is dumped from the collection vehicles are "Push Down" or "Push Up" a slope by bulldozer or a loader. " Mounting Up" method is shown in **Figure 8.5-9.**

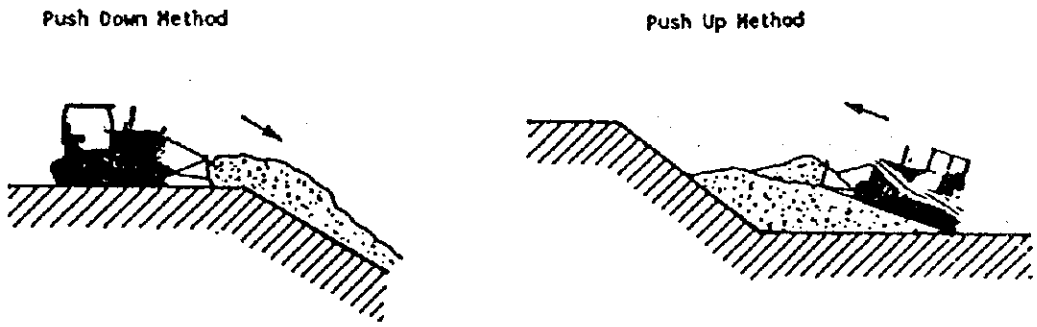


Figure 8.5-8 Spreading/Compaction Method

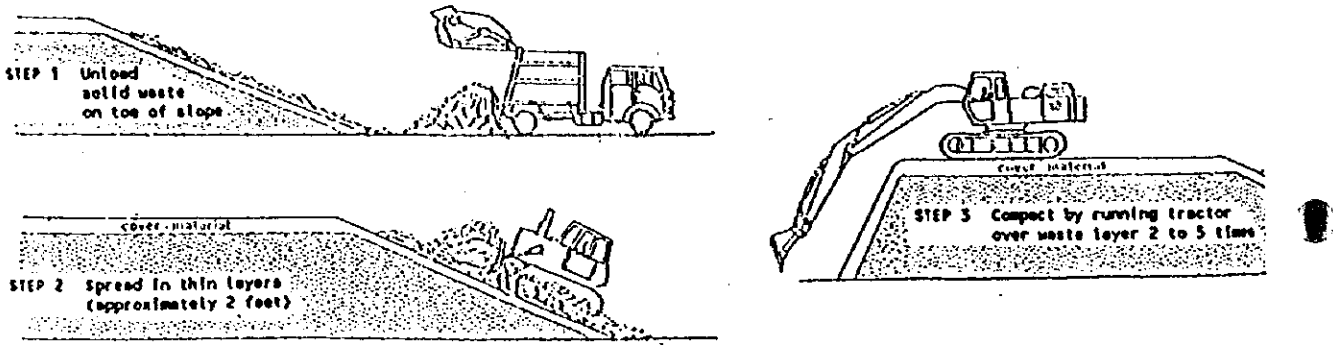


Figure 8.5-9 Mounting Up Method

In the case of pushing the solid waste down the slope, it is difficult to spread the solid waste into a uniform thickness. The bottom part of the slope tends to be thicker. Mixing and compaction is also difficult. On the other hand, it is easier to make uniform landfill layer when it is pushed up slope. Compaction is also easier.

Therefore, when the compaction layer has to be established as soon as possible, then the push-up method is preferred. Even so, the solid waste component type, method and odor of landfilling, equipment of landfill and land structure must also be given due consideration.

The spreading and compaction of the solid waste delivered will affect the capacity of landfill, stabilization of landfill layer, usability of the completed landfill site, environmental conservation, etc. It is therefore important that when spreading and compacting the solid waste, its component, landfill type, landfill structure, landfilling method, order of landfill, types of machines used, etc. be considered together with the following item;

- The spreading is not too thick. For example, normal thickness is about 30 to 50cm when normal spreading and compaction machines are used.

- The landfill layer should be made as uniform as possible and when necessary, the solid waste can be pushed up a slope when separating and compacting the solid waste. A slope gradient of about 3:1 (about 20 degrees) is normal.

- The thickness of each layer should be determined after considerations given to the component and type of waste, the post-closure land-use, etc. but each layer is usually less than 3 m thick. When the site is to be

used as early as possible or when technically advanced usage of the completed landfill site considered, the layers should be about 2m thick.

The spreading and compaction is shown in **Figures 8.5-10 and 8.5-11.**

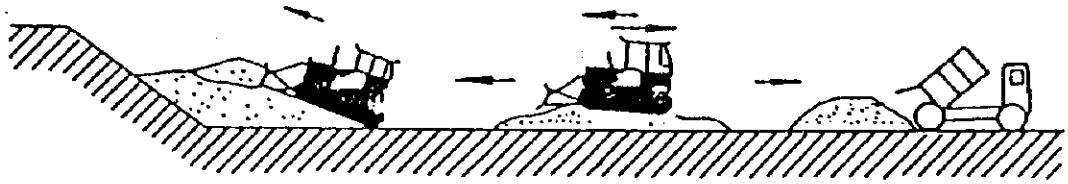


Figure 8.5-10 Spreading/Compaction Method

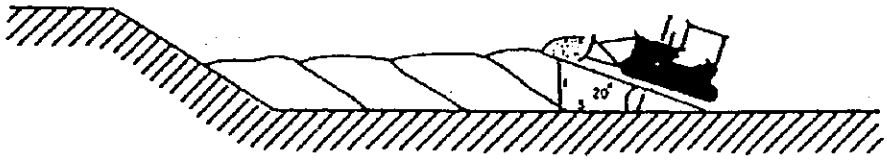


Figure 8.5-11 Pushing Up and Compacting the Waste Simultaneously

(d) Landfill Equipment

(i) Selection of Landfill Equipment

Landfill equipment should be selected after considerations given to the land structure, size, landfill method, solid waste type used in the sanitary landfill system. Landfill machines can be classified according to their functions into the following;

- Equipment to spread and compact a landfill layer of uniform thickness
- Digging equipment, cover soil spreading equipment
- other machines required for smooth landfill operations.

Tractors such as crawler tractors and wheel tractors are usually used in (i) and (ii). The crawler tractors is called a bulldozer or tractor shovel depending on the type of arm attached to the crawler tractor like for instance, buckets or blades. These have different purposes.

In this manner, different equipment has different characteristics and therefore has to be properly selected according to its usage.

Besides this ,equipment relevant to (iii) like watering trucks, disinfecting trucks, fire fighting trucks, etc. may also required on large scale landfill sites.

(ii) Number of Equipment Required

The number of machines required in a landfill project depends on:

- The daily amount of wastes used at the landfill
- amount delivered at peak times
- size of sanitary landfill system
- efficiency of landfill equipment
- number of operation hours per day
- maintenance and repair measures
- financial availability

(iii) Notes on the Use of Landfill Equipment

Most landfill equipment used are equipment for construction purpose. For that reason, these equipment sometimes breakdown in a manner different as compared to equipment in other construction sites. Machine breakdowns due to corrosive gases like hydrogen sulfide or ammonium salts produced during the decomposition process, usually occur.

Further, wear and tear in caterpillars due to wires or metal parts, or even clogging of the mesh of radiator due to dust or dirt also occur. It is therefore always advisable that spare equipment should be made available in good condition.

(iv) Separate Landfill

In this method, the landfill site is divided into small sections and filled with different type of solid waste. This is different from section landfill method where the unfilled sites is selected from the filled site and then landfill in order to limit the amount of leachate generated.

There are very few examples of separate landfills. This type of landfill produces an easy-to-manage foundation and render easy applications as landfill sites. The leachate quality can also be easily monitored.

(e) Cover Soil

(i) Efficiency and Necessity of Cover Soil

The cover soil prevents bad odor from dispersing, the littering and flowing out of waters, breeding of vectors and other animals. It also prevent fire from spreading and for that matter, acts as a firebreak. It will provide good appearance as it acts as a means of protecting the environment. Further, that it also allows easy solid waste spreading and compaction works, prevent rain water from seeping into the inner layers of the landfill site (thus reducing leachate volume). However, when a large amount of cover soil is used, the capacity of landfill becomes lesser and it also reduces the permeability of the landfill such that the filled-up waste may not decay as well. Therefore, the thickness and type of cover soil must be properly selected depending on the use of the completed landfill, etc. and the type of filled-up waste.

The availability of cover material may depend on the location condition of the landfill site and the financial capability of the NCC. If new cover soil material is not available, the old filled-up waste buried for about 3 to 6 months ago can be utilized effectively as cover soil.

- The filled-up waste should never be left as it is. It must always be covered with a soil whose thickness depends on the type of waste and cover soil used.

- Cover soil must be laid in a specified area to prevent gas dispersion, fire and also for movement of collection vehicles, when necessary.

- A final cover soil must be laid on the top most layer of the landfill site. In this case, the thickness of the final cover soil depends on the way in which a completed landfill site is used.

- Cover soil material should be selected depending on its purpose.

- The cover soil must properly cover the landfill wastes, sufficiently spread and compacted with a proper thickness and gradient in specified places.

(ii) Type of Cover Soil

Depending on the purpose, cover soil can be classified into daily, intermediate and final cover soil.

Daily Cover Soil

When the landfill layer has reached the specified thickness or when one day's portion of the landfill works is completed, a cover soil is laid to prevent;

- littering of wastes

- bad odor from spreading

- harmful vectors like flies from breeding.

Intermediate Cover Soil

This is laid as the landfill works progress. Unlike the immediate cover soil, this is to create the foundation for roads for the collection vehicles or for draining rain water away from those landfill sites which are to be left for considerably long period.

Final Cover Soil

When all the landfill works have finished, this top most final cover soil is laid, bearing in mind the post-closure land-use of the completed landfill site, and leachate volume reduction purposes.

(iii) Selection of Cover Soil

In general, cover soil is classified into grainy type and clayish type. The consistency or the permeability of the cover soil will then differ according to different types used.

In most cases, earth is used as this is easily available. As for as possible, do avoid extremely acidic or alkaline type, or which contains harmful substances, or even anything that deteriorates the leachate quality. Earth which contains substances which are harmful to plants should also be avoided.

The different types of soil are listed below;

Daily Cover Soil

As far as possible, permeable and porous sand types should be used to render easy spreading and compaction of the solid waste, stabilize the landfill layer as well as do not hinder waste decomposition. But a porous cover soil is not suitable for preventing bad odors from dispersing. Therefore, when such types of soil are used, the cover layer should be made as thin as possible so as to prevent the soil from becoming anaerobic.

Intermediate Cover Soil

Clayey soil is suitable to prevent gases from dispersing or rain water from seeping but when the cover soil is to be used as a foundation for roads, then crusher stones are recommended.

Final Cover Soil

The final cover soil should be resistant to corrosion by rain water, low permeability and suitable for plants.

(iv) Selection of Thickness

The thickness of the cover soil is determined by the purpose, solid waste component type and structure used, environmental conservation, etc. The thickness are as follows;

Daily Cover Soil

- When the solid waste is mainly combustible and large in size

  30 to 50 cm

- Crushed waste and ash

  15 to 20 cm

When impermeable soil such as silt or clay is used, the cover soil should be as thin as possible.

When uncrushed waste is used, it should be about 45 cm thick while crushed waste cover soil should be about 20m thick.

Intermediate Cover Soil

When the cover soil is to be exposed for a fairly long time about 50cm

- Final Cover Soil When plating grass or low plants and bushes more than 50 cm.

- When planting grass or low plants and bushes more than 50cm

- When medium height to tall trees are planted more than 1 m

Until the time when the landfill site can be used as a completed landfill site, the proper cover thickness should be laid for trees planting.

When the construction debris is to be used as for a final cover soil, the root conditions of plants are checked after 7 to 8 years and it roots are almost similar. Root growth has a great effect on drainage conditions of the landfill site. Depending on the type of tree, the roots are within a depth of 1m. Therefore, when medium or tall trees are planted, the final cover soil should be 1m deep.

(v) Cover Soil Works and Maintenance

The cover soil must be uniformly spread and compacted by using the appropriate type of landfill equipment depend on the thickness of the cover soil, the area and quality.

In particular, it takes some time before the final cover soil on a slope stabilizes and as such, care must be taken to prevent this final layer from being eroded by rain water.

One measure is to have the slope of gradient 20 to 30 degrees while on the plain areas, a gradient of about 2 to 3 % is reasonable.

Cover soil is usually laid with the help of landfill layer, Spreading and compaction equipment. But in the case of the final cover soil, graders or rollers used in making roads are suitable.

Cover soil maintenance which is a part of landfill site maintenance, besides leachate and gas treatment, etc. The surface of the final cover soil may sink, crack and forming potholes. This will result in increase in leachate volume, gas leakage, erosion of the cover soil, landslides, fires, etc. The survey revealed the following;

- the site subsides deeper when combustible waste is used and shallower when incombustible waste (construction debris) is used.
- The deeper the landfill the deeper the site subsides
- the ground settlement continues for several years
- there have been reports on settlement from a few percent to 30% of the landfill thickness.

In particular, when the surface of the landfill site depresses or cracks, rainwater will seep into the inner layers via these areas thus increasing the amount of estimated leachate volume. These areas will also be the points for gas release and for these reasons, the surface of the final cover soil should always be checked and repaired.

8.6
COST ESTIMATION

8.6 Cost Estimation

8.6.1 Closure Work of Existing Dumping Site

Dandora existing dumping site should be closed when the new site will be constructed. The main closed work consist of land reclamation and soil cover work. The closed wok is shown in **Figure 8.6-1.** The quantity of complete closure works and cost estimation is described in **Table 8.6-1.** The table shows the work is required the approx. 302 million Ksh and one years construction period. Even if NCC will not able to ensure the enough budget for complete closure work, NCC has to carry out the minimum closure work that is shown in **Table 8.6-2.** The work is required the approx. 227 million Ksh and half year construction period.

Table 8.6-2 Cost Estimation of Minimum Closure Work of Dandora

Items	Unit Cost (m^3/Ksh)	Quantity (m^3)	Cost (x1000Ksh)	Remarks
1.Land Reclamation	105	90,000	9,450	30 ha x 0.3m= 90,000m^3
2.Loading & Compaction	64	123,750	7,920	24.75ha x 0.5m= 123,750m^3
3.Cover Soil Material	1,221	123,750	151,099	- Same as above -
Sub Total	-	-	168,469	-
Overhead Cost	-	-	58,531	Sub Total x Approx. 35%
Total	-	-	227,000	-

Table 8.6-1 Cost Estimation of Complete Closure Work of Dandora

Items	Unit Cost (m^3/Ksh)	Quantity (m^3)	Cost (x1000Ksh)	Remarks
1.Land Reclamation	105	90,000	9,450	30.0 ha x 0.3m= 90,000m^3
2.Loading & Compaction	64	123,750	7,920	24.75ha x 0.5m= 123,750m^3
3.Cover Soil Material	1,221	123,750	151,099	- Same as above -
4. Enbankment	1,285	5,260	6,759	1,315m x 4m^3/m
5. Rain water drainage ditch	6,500	1,910	12,415	
6. Leachate Collection Work				
6.1 Material & Install Work (Main Pipe)	12,182	930	11,329	
6.2 Material & Install Work (Branch Pipe)	3,441	6,500	22,367	
7. Gas Out-let Equipment	128,600	20	2,572	
Sub Total	-	-	223,911	-
Overhead Cost	-	-	78,089	Sub Total x Approx. 35%
Total	-	-	302,000	-

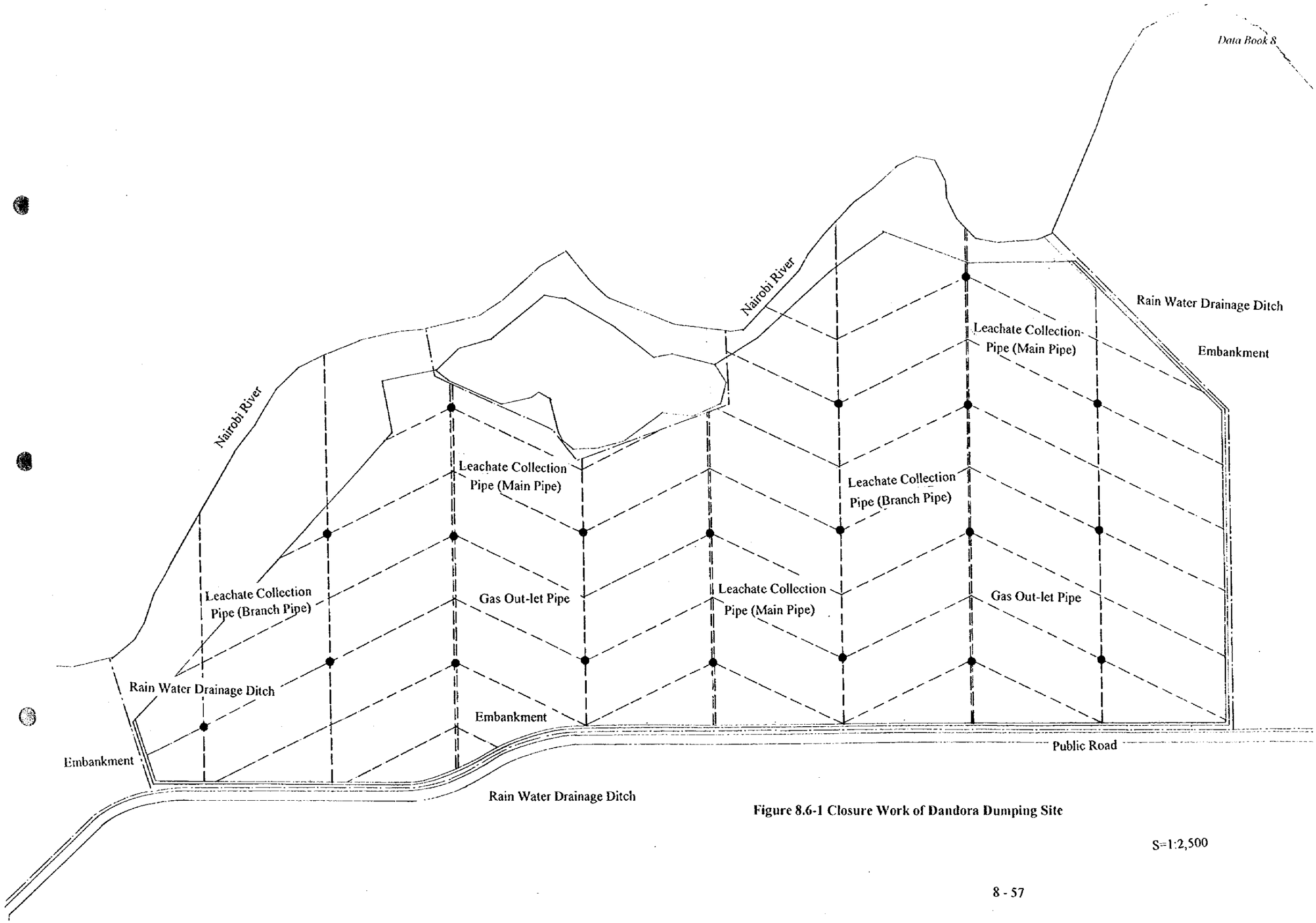


Figure 8.6-1 Closure Work of Dandora Dumping Site

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