SITING AND DESIGN OF A MODERN SANITARY LANDFILL

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I. INTRODUCTION

Proper waste management is an important issue not only in developed countries such as the United States but also in developing countries such as the Philippines. Waste management is an all-encompassing word, and is not limited only to solid waste but also liquid waste. Various technologies and regulations have evolved continuously in the treatment and management of wastes, specifically wastewater, radioactive, toxic and hazardous wastes, and other forms of industrial wastes. In the US, regulations that deal with the management of these wastes have been in existence for a long time, and have become more stringent over the years due to knowledge gained on their harmful effects not only to the environment but also to public health in general. Only recently, i.e. less than 10 years ago, laws regulating the management of Municipal Solid Waste Landfill Facilities (MSWLF) were enacted in the US. It has been the attitude not too long ago that ordinary household waste (garbage) is not harmful therefore all one had to do was dig a hole in the ground, throw the garbage in it, cover it then forget it. Now, its been known that even ordinary garbage can cause harmful effects due to the presence of incidental household wastes and the resulting byproducts of decomposition (leachate) which can impact groundwater resources and the air that we breath (from the generation of harmful landfill gases and objectionable odors). It should be noted that hazardous wastes and liquid wastes are not allowed to be disposed of at MSWLF's in the US anymore, and violations of environmental regulations usually result in stiff monetary penalties, in the hundreds of thousands of dollars to millions, depending on the nature of violation and the resulting impact, and sometimes combined with criminal prosecution and imprisonment.

It is a well-known fact that the rate of waste generation increases disproportionately more than the rate of population growth in a society whose standard of living improves as a result of development. In the US, per capita waste generation is 2 to 4 kg/capita/day. Even with aggressive recycling and waste reduction programs, waste that ends up in the MSWLF may still be half of what is generated in that country. Soon, the Philippines will reach that threshold, and there will be more wastes to be managed. As it is now, we are in an unrecognized crisis that we take for granted, mainly because our priorities are different and we are kind of used to seeing garbage everywhere. Unless we become more sensitive to such ugly sights and cognizant of the subtle ill effects (diseases that are never heard of in developed countries) of unmanaged wastes, it will remain a problem for a long time, life expectancy will remain short, and death rates of children will worsen.

It is therefore imperative that waste should be managed properly, and proper siting and design of its ultimate destination, (sanitary landfill) is one of several important considerations.

MSWLF Planning and Development can be categorized into eight (8) phases, namely:

PHASE 1: DEVELOPMENT OF A BASELINE FOR MSWLF PLANNING
PHASE 2: MSWLF SITE RANKING AND SELECTION
PHASE 3: FINAL SITE CHARACTERIZATION/ENVIRONMENTAL INVESTIGATIONS
PHASE 4: CONCEPTUAL DESIGN
PHASE 5: DETAILED ENGINEERING AND DESIGN
PHASE 6: INITIAL CONSTRUCTION
PHASE 7: OPERATION

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PHASE 8: CLOSURE AND POST CLOSURE MAINTENANCE

This presentation deals with the first five (5) phases only, which involves the proper planning, siting, selection and design of a modern Municipal Solid Waste Landfill Facility (MSWLF).

II. PHASE 1: BASELINE FOR LANDFILL PLANNING

Prior to selecting a site for an MSWLF, there are several basic planning tools, criteria and tasks to be considered. It is a known fact that siting a facility such as a landfill is very difficult these days due to not only the NIMBY (not in my backyard) syndrome, but also to the lack of understanding or ignorance of what a properly designed and operated MSWLF is. In the Philippines, the mentality is a landfill is a dump where one finds scavengers, garbage strewn all over the place, and it stinks. No wonder why everyone is yelling "NIMBY!" at one site where an MSWLF is being considered or operated.

As a rule of thumb, an LGU should select a site that can provide as long a life and as large a capacity that it can ever provide, preferable 50 years for the simple reason that siting another replacement MSWLF will become more and more difficult in the future not only due to "nimby" but high land costs. Hopefully, even though unlikely for a developing country, waste generation will decrease or science will provide other means or technology for reducing waste.

The following are the tasks that should be performed under this phase:

1. Identify Cluster, Define and Delineate Service Areas
2. Obtain Geographic Data and Identify Service Area Size
3. Obtain Population Base and Demographics Data
4. Estimate Waste Volumes and Ongoing Waste Diversion Programs
5. Obtain Climatic Information
6. Review User Records
7. Identify Large Waste Generators
8. Obtain Existing Landfill Data
9. Define Existing Collection System
10. Waste Sampling and Analysis

For economies of scale, communities should "cluster" or regionalize. This is common sense. For example, 5 neighboring LGU's that own and operate their individual MSWLF's will create 5 potential problems, 5 sets of heavy landfill equipment and five sets of operating personnel. The overall cost per ton to develop and operate each landfill will be very high. Whereas if all 5 will join together and develop and operate one regional facility, the savings is a "no-brainer", and can be as high as 3/4th of the cost to own and operate all 5 facilities.

Geographic data is needed for transportation cost considerations and will serve as a tool in deciding whether to direct haul to a regional facility or put up a transfer station. Waste volumes and ongoing waste diversion programs are important data since the information gathered will be used in sizing the MSWLF to meet or predict its design life. Population base and demographics data are needed in order to quantify and qualify waste volumes. A good source of these information and data are LGU socio-economic profiles, which are readily available. Information obtained from the tasks listed above can be condensed or summarized into one valuable planning document that will be used later in the design of a new

MSWLF. A waste sampling analysis will provide information for consideration in other potential waste reduction techniques such as composting, in addition to already ongoing waste reduction programs.

III. PHASE 2: MSWLF SITE RANKING AND SELECTION

Concurrent with the tasks described above, using a regional map, preferably a topographic map such as a NAMRIA map, potential sites should be identified. Once these potential sites are identified, information should be researched and a checklist developed for evaluating the suitability of each site. Each potential site is then evaluated and ranked. The items listed below are the basic tasks to accomplish or complete this phase of MSWLF siting and selection process:

1. Develop Criteria Checklist for Each Potential Site
2. Review Regional Information
3. Review Socio-Economic Conditions
4. Identify Potential Sites on Existing Maps
5. Review Available Soils Data
6. Review Available Soils/Geologic Studies
7. Review Available Meteorological Data
8. Review Available Drainage/Sanitation Maps
9. Review Existing/Planned Water Supply/Resources
10. Review Transportation Studies
11. Review Land Use and Development Plans
12. Review Proximity to Residential Developments
13. Identify Land Ownership and Values
14. Review Human Settlement Programs
15. Conduct Reconnaissance Survey
16. Determine Distance to Service Areas
17. Summarize Results
18. Select Best Three candidate Sites

Once all the above information are obtained, each site can now be evaluated and rated according to the following criteria:

- Ownership/Acquisition
- Zoning
- Road Access
- Topography
- Capacity
- Soils
- Depth to Groundwater
- Proximity to Water Wells
- Surface Water
- Flood Hazard
- Airport Safety
- Holocene Faulting
- Seismic Impact zone
- Site Stability

- Run-On/Run-Off Controls
- Landfill Gas Control
- Land Use
- Agricultural Land
- Habitat Value
- Visual Impacts
- Downwind Impacts

All of the above criteria are important in the development of a MSWLF. Some criteria, however, are more important than others. To account for this, a multiplier should be assigned to each of the criteria. While many of the above criteria can be mitigated via engineering solutions, some criteria can result in a fatal flaw to the successful development of a landfill. Such items as Holocene faulting, airport safety, flood hazard, stability, and habitat value could result in the potential MSWLF site being rejected. The total score of each site is developed by adding the individual scores for each criterion. The sites with the highest scores are then selected for further study. A description of each of the criteria is discussed below:

Ownership/Acquisition

The present ownership of the property affects the site's availability for purchase and landfill development. The ideal site would be on land presently owned by the LGU. Also, a single owner, rather than multiple owners, simplifies the acquisition.

Zoning

An ideal site is within an area that is currently zoned by the local government for this type of land use. A use permit may be needed, but no zoning changes would be necessary. A less desirable site would require a zoning change. Resistance to such a change should be subjectively considered. Very significant resistance to a zoning change could be a fatal flaw of the site

Road Access

The existing roads and access to the site should be considered. The highest score would be assigned to a site that is easily accessible from a main highway and has an access road that is presently maintained year-round. A poor site would require over 1.5 kilometers of road construction to provide access, with additional maintenance costs of the new road being added to the existing MSWLF budget.

Topography

The topography of the site affects the efficiency of the cut and fill operations as well as equipment movement at the landfill. The "waste to cover soil" ratio is the volume of waste that may be landfilled at the site to the volume of soil that will be excavated during landfill development and used for cover. The topography of a site will impact this ratio. Accessibility to waste disposal areas will also be affected by the topography. A site inspection is needed to evaluate this criterion.

Site Capacity

The capacity of a site can be estimated, based on the site's size, shape, and topography. The design life (number of years) is based on the projected waste volume that the landfill will receive. The "air space" (volume available for waste disposal) can be estimated from the topography and site area, and then the design life can be calculated. The DENR requirements call for a minimum of 10 years of capacity. The minimum capacity evaluated for a project should be more than 10 years, if at all possible, more than 50 years.

Soils

Deep deposits of fine-grained soils are ideal for a landfill site. They can provide attenuation of any potential contamination from leachate, optimize the options for cut and fill excavations, and provide an on-site source for daily and intermediate cover material. Also, a thick, low permeability soil layer may, in rare cases, allow the developer to use a less stringent design standard. Poor soil conditions exist where coarse-grained materials and/or thin soil cover are present. However, in some cases, having non-fractured bedrock near the surface might be desirable. This particular ranking system considers sites that have less than three meters of soil cover to be fatally flawed.

Depth to Groundwater

As the depth to groundwater increases, the probability that the groundwater quality will be contaminated by leachate decreases. Well logs for wells at the sites and/or surrounding areas are the best resource for making the initial determination if they are available. A depth of at least 1.5 meters to groundwater is required by the "Sanitary Landfill Siting Criteria" by the DENR. The depth to groundwater is an important factor regarding landfill siting.

Proximity to Wells

A landfill should be sited so that if any potential contamination from leachate migrates to the groundwater, the impacts to down-gradient receptors will be slight. The ideal landfill site would have a maximum distance from the MSWLF unit to the nearest down gradient well. DENR requires that the landfill be sited over 500 meters up gradient of water supply wells.

Surface Water

In the United States, there are requirements that prohibit the siting of a MSWLF within wetlands or within a certain distance from lakes or perennial streams. Greater distance away from such surface water is desirable to minimize any potential impacts to surface water quality. A site that is located within wetlands, less than 100 meters from a perennial stream or less than 300 meters from a lake is fatally flawed. The DENR requirements state that the site should be 300 meters from a stream, but allow closer distances with engineering measures. For this reason, 100 meters should be used as the fatal flaw criterion for streams.

Flood Hazard

The ideal site would be located outside of a 500-year floodplain. A site located within a 100-year floodplain would have to demonstrate that the unit would not restrict the flow of the 100-year flood, reduce the temporary water storage capacity of the floodplain, or result in a washout of solid waste so as to pose a threat to human health or the environment.

Airport Safety

A landfill site must not pose a bird hazard to aircraft. In the US, MSWLF's located within 2,000 meters of piston-type aircraft or 4,000 meters of turbojet aircraft runways must demonstrate that they are designed and operated so as not to pose a bird hazard to aircraft. The DENR requirements call for a site to be located 13 kilometers from an airport. If meeting this criteria may not be feasible, the site should be located to reduce bird strike hazard as a mitigation measure allowed in the DENR requirements.

Holocene Fault

The landfill site must be located more than 100 meters from a fault that has experienced displacement during the present Holocene Epoch. The DENR requirements call for no landfill construction within 500 meters of an active fault unless stringent engineering design measures are taken. Landfill sites that are within 100 meters of a fault could experience ground rupture affecting even the specially engineered structures within the landfill. For this reason, 100 meters should be used as the fatal flaw distance. Location information of known active faulting within the Philippines is available from PHILVOLCS

Seismic Impact Zone

The siting of a landfill cannot occur in a seismic impact zone where it cannot be demonstrated that all containment systems (including liners, leachate collection systems, and surface water control systems) are designed to resist the maximum horizontal acceleration in lithified earth material for the site. An ideal site would be located where minimal seismic risk occurs (90 percent probability that 0.1g or greater horizontal acceleration not be exceeded in 250 years). A poor site would be located where a significant risk occurs and strict engineering controls are needed to mitigate any seismic impacts.

Site Stability

The stability of a site needs to be considered in the site evaluation. A site with no slope stability problems, no expansive soils, or no subsurface instabilities (such as Karst terrains) rates the highest. A site where engineering controls (such as slope stabilization) are needed to maintain the integrity of structural components of the landfill is less desirable. A site where inherent instabilities cannot be mitigated is fatally flawed.

Run-on/Run-off Controls

Both run-on and run-off must be controlled. If significant controls are needed to control storm water events at the site, higher development and construction costs will result. Areas of low precipitation, slight relief, and small potential for collection of regional drainage are the most suitable.

Landfill Gas Control

The potential for landfill gas to migrate off the site and the impacts of the gas migration need to be considered. Soil conditions, the presence of man-made enhanced gas transport zones (such as underground cables or pipelines), and any buildings located nearby affect the migration and possible hazards of landfill gas. An ideal site will have fine-grained soils with no geologic or man-made pathways present, and will be located at a sufficient distance from structures where gas could accumulate

Land Use

This criterion considers the impacts on the long-term land uses other than agricultural. An ideal site would be located where residential, industrial, or recreational land uses are improbable.

Agricultural Land

This criterion considers the potential of the site for agricultural uses. If the site is located on prime farmland, landfill development will take the land out of production and is likely to receive a negative public response. A site with little agricultural value would be viewed more favorably.

Habitat Value

Sites where landfill development will have little or no impact on wildlife or plant habitat are ideal. A fatal flaw exists if the site is designated as a critical migratory route for protectively managed species or if it is located in areas designated as critical habitat for endangered or threatened species of plants, fish, or wildlife.

Visual Impacts

The visual impacts of developing a landfill should be considered. It is preferable that landfill operations be kept out of view from present or future residences near the site. A fatal flaw exists if the landfill is within 300 meters of any park, or land reserved or withdrawn for scenic or natural use.

Downwind Impacts

The impact to residences downwind can be minimized by siting the landfill further upwind of residences. The concerns are blowing litter and nuisance odors. Greater public opposition will be evident where a landfill is sited nearby and upwind of a residential development.

Utilizing the above criteria, a field reconnaissance should be conducted for each of the sites. The results of the field reconnaissance, along with a review of available published and unpublished information, is used to prepare numerical rankings of each of the proposed landfill sites. Table 1 is an example of a site ranking summary from an actual project conducted by Vector.

Table 1 - LANDFILL SITING RANKING

Scoring Criteria	***Max. Score***	***Site 1***	***Site 2***	***Site 3***	***Site 4***	***Site 5***	***Site 6***
Ownership/Acquisition	50	20	50	50	50	50	50
Zoning	30	30	30	30	30	30	30
Road Access	40	16	40	40	40	40	40
Topography	40	28	40	40	40	40	40
Site Capacity	50	50	50	50	50	50	50
Soils	50	25	25	25	25	25	25
Depth to Groundwater	50	5	5	5	5	5	5
Proximity to Wells	30	30	30	30	30	30	30
Surface Water	50	50	20	25	25	25	25
Flood Hazard	50	50	50	50	25	50	50
Airport Safety	20	14	2	2	2	2	14
Holocene Fault	10	10	10	10	10	10	10
Seismic Impact Zone	30	21	21	21	21	21	21
Site Stability	40	28	40	40	40	40	40
Run-on/Run-off Controls	40	40	40	40	20	20	40
Landfill Gas Control	30	30	21	21	21	21	30
Land Use	40	20	20	20	20	20	20
Agricultural Land	40	20	40	40	40	40	40
Habitat Value	30	30	0	10	0	15	30
Visual Impacts	20	10	20	0	20	20	20
Downwind Impacts	30	15	30	30	3	30	15
SCORE	**770**	**542**	**584**	**579**	**517**	**584**	**625**

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Once all the potential sites are evaluated, visited and ranked, the three best sites should be shortlisted for further evaluation, with the ultimate goal of selecting one superior site. Under this phase, the following tasks should be accomplished:

1. Select at Least 3 Highest Ranking Sites
2. Conduct Topographic Survey at 3 Best Sites
3. Confirm Potential Capacity of Each Site
4. Select Highest Ranking Site

The topographic map should be prepared at least on a scale of 1:3000 at 1 meter contour intervals. This would facilitate the preparation of a conceptual configuration of the MSWLF and provide for a better estimate of its potential capacity. This will also show salient features of the site including location of steep slopes, major drainage channels and potential location of access, leachate and run-off management facilities. From this further evaluation, the most suitable and superior site can be selected.

PHASE 3: FINAL SITE CHARACTERIZATION/ENVIRONMENTAL INVESTIGATIONS

This phase is one of the most critical aspects in determining the technical suitability of a site for a sanitary landfill and its potential environmental and socio –economic impacts. If subsurface conditions are not characterized accurately, it could lead to potential failure of the landfill and result in significant impacts to the underlying groundwater and the general environment as a whole. Tasks include the following:

Subsurface Investigations
Identify Borehole and Test Pit Locations
Borehole Drilling, Test Pit Excavation And Soil Sampling
Monitoring Wells
Groundwater Sampling and Analysis
Geotechnical and Geologic Investigations
Soils Testing
Soils Availability Evaluation
Preparation of Site Characterization Report
Environmental Investigations
- Field Surveys, Investigations and Analysis
- IEE/EIS Analysis and Report

The subsurface investigation phase will entail several steps in order to fully characterize the geotechnical, geologic, and hydrogeologic character of the selected sites, as follows:

1. Field investigations including borehole drilling, test pit excavations, and soil sampling must be conducted at each site to characterize the subsurface geology. In addition, field testing and geologic investigations should be conducted to verify the presence of faults and other geologic structures. Boreholes are drilled down to at least 10 meters to 20 meters below ground surface, until bedrock or hard material is encountered, and penetrating at least 5 meters further into bedrock. At least three boreholes should later be converted to groundwater monitoring wells with 100-millimeter (4-inch) diameter PVC casings with at least a 3m-4m length of perforated screen at the lower end. If possible, depending on the size of

the selected areas, soil borings should be supplemented with test pit excavations using a backhoe to obtain additional soils information.

2. After the boreholes are completed and reamed, monitoring well casings are installed. A slug test at each well to determine hydraulic conductivity of the underlying soils should be performed. After the wells are tested and developed, obtain water samples using standard protocol for water sampling and sample preservation techniques, and ship the samples to a qualified ce rtified laboratory for analysis. Parameters to be tested should be based on DENR requirements, supplemented with other parameters, which are necessary in order to fully characterize the underlying groundwater. Field parameters such as pH and specific conductivity should be measured in the field. Proper sampling and preservation techniques are very critical in water sampling, in order to accurately determine background water quality.

3. During the drilling of the initial series of boreholes, a detailed investigation should be initiated to determine the geologic characteristics of the subsurface features, as well as the geotechnical properties of the soils at depth. Samples retrieved during the drilling operations are collected and logged for future geotechnical testing to define the soil strength parameters and properties (shear and compressive strengths, permeability, particle size and gradation, moisture density relationships) of the pertinent geologic strata beneath the landfills. The drilling investigation will also provide considerable information regarding the availability and quantity of soils to be used for the design and construction of the soil liner and cover layers, as well as daily cover and operations. The following tests at a minimum, are performed on soils:

   Atterberg Limits
   Shear and Compressive Strengths (triaxial and direct shear tests)
   Moisture Density
   Gradation/Particle Distribution
   Proctor Tests
   Permeability Tests

The results of the tests will establish geotechnical parameters to be used in the design of the foundation, base, and maximum cut and fill slopes of the landfill. The results will also enable one to estimate the availability of soil liner and cover materials onsite.

4. Hydrogeologic analyses to establish groundwater flow gradients and direction should be conducted. The slug test will provide the hydraulic conductivity of the water bearing strata, which is essential in determining the magnitude and direction of groundwater flow. Water levels in the monitoring are measured once a month during the study to verify direction and velocity of groundwater. These are important parameters to be established in order to predict the direction and impact of potential contaminants in case of a release, so that proper remedial action would be taken to prevent any major impacts to groundwater downgradient of the facility.

It is essential that **topographic maps** be available prior to the commencement of subsurface characterization of the site. The general terrain and topography, location of drainage channels and other bodies of water, and, accessibility of drilling locations, are important considerations in determining the specific proposed locations of boreholes, test pits, and groundwater monitoring wells.

Quality and quantity of soils for liner and cover materials should be determined after soil sampling and analyses are completed. If liner and cover materials are not of sufficient quantity from the selected site, offsite borrow areas should be identified. These offsite borrow areas should be inspected, quantities of material estimated, and their locations shown in the plans. It should be noted that if a borrow area is identified as a potential source of liner materials that meet specifications, additional soil sampling maybe required to determine if such material actually meets specifications and quantity requirements. An alternate, if no soil liner is available that meets specifications, is of course the use of geosynthetic liner materials such as High Density Polyethylene (HDPE) geomembrane liners. HDPE, underlain by compacted soil, is an excellent material for leachate containment. It is recommended that if this option is selected, HDPE with a minimum thickness of 60-mils (1.5mm) be used.

The limits of excavation in the borrow area are provided on the conceptual design drawings and the quantities of the specific materials identified are established. The quantity of available borrow material is used as one of many parameters used in defining the site life and final configuration of the landfill.

The Environmental/Socio-Economic investigations and analysis should be conducted concurrent with the above tasks. Data obtained from all field investigations are used in the preparation of the IEE/EIS report. In addition, any mitigation requirements that will require construction are incorporated into the design of the facility. The IEE report or EIS (whichever the DENR requires) is pre-requisite to issuance of an Environmental Compliance Certificate by the DENR, which is required prior to commencement of construction activities.

PHASE 4: CONCEPTUAL DESIGN

A conceptual (preliminary) design is needed for purposes of planning the facility. Conceptual plans will provide information which will include but are not limited to: Site topography, potential landfill capacity and life, preliminary grading and filling plan, location of appurtenant facilities, plan of access, major drainage routes, monitoring locations and other environmental control facilities and proposed buffers.

This phase will entail performance of the following tasks:

- Develop Seismic Criteria
- Static and Dynamic Landfill Slope Stability Analysis
- Leachate Generation Analysis
- Access and Drainage Analysis
- Prepare Conceptual Plans
- Preliminary Cost Estimate and Analysis
    - Capital and Equipment Costs
    - Operation and Maintenance Costs
    - Preliminary Closure and Post Closure Costs
    - User Fees and Cash Flow Projections

Information obtained from the field investigations, document review, and surveys will be used in the development of conceptual plans. The following engineering analysis must be performed during preparation of conceptual plans:

Develop Seismic Criteria

An earthquake hazard analyses should be performed for the sites to examine how historical earthquakes may have affected the site locations and determine the design event. The earthquake hazard analysis for the site should be performed using two methods. These methods include performing a search of the earthquake record for all recorded earthquakes that have occurred within a 160 km radius around the site, and a deterministic analysis of all known active faults within a 160 km. radius of the site.

The search of the earthquake record should be done using several of the existing world earthquake databases. Specific databases that should be researched include the International Seismological Summaries, the Bureau Central International Seismologique, the World Data Center for Solid Earth Geophysics (NOAA), the Catalogue of Large Earthquakes, the Japan Meteorological Agency, and the International Seismological Center and PHILVOCS. The earthquake events that affect the proposed site should be attenuated appropriately to the site location. Evaluation of the frequency distribution of historical earthquakes should be done and develop a design earthquake event for the proposed MSWLF. From the historical earthquake information, perform a statistical evaluation for the earthquake occurrence frequency for the MSWLF. A design earthquake conforming to the design parameters should have a 90% or greater probability that the acceleration will not be exceeded within the period of record.

Static and Dynamic Landfill Slope Stability Analysis

Foundation soils information and local seismic criteria will be used in establishing cut and fill slopes. The established slopes and configuration of the landfill, including liner and cover components, will be used in verifying the static and dynamic stability of the landfill, using industry established standard factors of safety. Static and dynamic slope stability analyses should be performed using the latest available and most commonly used computer programs.

A stability analyses should be performed for the selected landfill in accordance with the applicable design standards for MSWLF's. Task should include a review of the available literature, seismic hazard analyses as required to determine the design earthquake acceleration, material property determination, limit equilibrium, slope stability analyses of the critical section or sections, and a dynamic displacement analyses if required.

The stability of the landfill should be evaluated under both static and pseudo-static (earthquake) conditions. Failure surfaces through the cover, waste, and subgrade, and failures involving cover sliding must be evaluated using limit equilibrium methods. Material properties of the waste should be based on previous studies, and published literature. Properties of the foundation layer, clay liner, and cover soil should be based on information obtained during the geotechnical testing program.

Leachate Generation Analysis Using the HELP Model

A Hydraulic Evaluation for Leachate Prediction (HELP) model analysis to predict and quantify the amount of leachate generated by the landfill should be performed. The results are used in the design of the MSWLF's leachate collection and removal system (LCRS) and treatment facilities. The HELP program is a computer program developed by the US Army Corps of Engineers for this purpose and is used by all landfill designers in the US. It requires various inputs such as soils characteristics, porosity, precipitation (rainfall) data, and thickness of media (refuse, cover and foundation materials) to predict quantities and flow of leachate.

Surface Water Drainage Analysis

Perform a drainage analysis to quantify volume of run-off that will require management prior to discharge off-site. Proper stormwater management is very essential in the design of landfills to minimize generation of leachate. Unmanaged storm run-off is the biggest generator of leachate in landfills, resulting in costly leachate management and handling and potential releases or discharges of contaminated water into nearby water channels or streams.

Facilities such as storm diversion ditches/conveyances and sedimentation/detention basins should be sized in accordance with the results of the drainage analysis, and their locations should be indicated in the conceptual plans.

Conceptual Plans

The conceptual plans should have the following components at a minimum:

Existing Topography and Layout Plan with a scale of 1:1000
Layout of Access Roads
Initial Estimate of Cut and Fill
Peripheral Drainage System
Landfill Base Preparation
Proposed Leachate Management Facilities
Base Grading and Liner Plan
Final Grading Plan
Proposed Drainage Facilities and Support Facilities

Furthermore, provide several drawings that show the cross sections of the proposed landfill, some typical design details showing the liner and cover system, and a plan that shows the environmental monitoring facilities such as monitoring wells, etc.

Preliminary Cost Estimate and Analysis

The primary cost considerations in planning for a MSWLF include the following:

Capital and Equipment Costs
Operation and Maintenance Costs
Preliminary Closure and Post Closure Costs
User Fees and Cash Flow Projections

Capital costs include all costs incurred in planning and development of the facility such as engineering, construction and other costs incurred prior to the operation of the facility such as monitoring and mitigation facilities. While initial landfill equipment cost is considered a capital expenditure, it is normally treated differently and separately.

Operation and maintenance (O&M) costs are recurring cost items including management and administrative costs (management, salaries, wages, overhead), equipment operation (fuel), maintenance and repair, utilities, monitoring and compliance costs.

Preliminary closure and post-closure costs should be identified at this stage in order to have an idea on future expenditures when it comes time to close the facility. This will determine amounts to be set aside on an annual basis over the life of the landfill such that there will be sufficient funds to close it and maintain it for several years (minimum 15 years) after closure. Closure cost items include decommissioning of facilities, final cap engineering, construction and CQA. Post closure cost items typically include operation and maintenance costs of leachate and gas control facilities, groundwater and gas monitoring, drainage and vegetation maintenance and security.

User Fee and Cash Flow Projections

Once the above costs items (capital, equipment, O&M, closure and post-closure) have been determined, they will become the basis for setting user fees (tipping fees) and cash flow projections. Details on how tipping fees are determined are not included in this discussion but the general procedure is discussed. Once capital costs are determined, these costs are amortized over a determined period at a nominal annual interest rate. The sum of amortization (current and future), O&M, taxes, annual closure and post closure fund set-aside, other interest and miscellaneous annual costs, divided by the annual waste volume received, is the cost per ton to own and operate an MSWLF. In other words, with no profit, this would be the minimum gate fee or "tipping fee". This amount should be evaluated and adjusted periodically to reflect current costs and the effects of inflation, currency fluctuation, etc.

The above costs should be verified and revised as necessary during final design.

PHASE 5: DETAILED ENGINEERING AND DESIGN

Construction of a sanitary landfill will involve several phases over its design life. It is common practice in the industry that each phase of liner construction should not exceed a capacity of 5 years. Sometimes, depending on the size of the facility, 2 years is used. Therefore, construction phases will occur in 5-year increments or less. This practice enables the owner to spread development expenditures or costs over a longer period. This will necessitate therefore two sets of design plans initially, as follows:

Landfill Master Design and Operations Plan (LMDOP)

The LMDOP will indicate the overall general excavation and final grading plan, closure plan and various construction and fill sequencing operation of the landfill, along with future facilities such as leachate and landfill gas management facilities, and closure drainage/containment facilities. The LMDOP will not be part of the initial construction bid documents but will become the planning document to be used by the LGU over the life of the landfill and will be the basis of construction of future phases and waste fill operational sequencing.

The LMDOP should include the following components:

- Support Facilities
  - Gatehouse/Admin/Scale Facilities
  - Utilities
  - Maintenance Facilities
- Landfill Master Design Plan
- Control Facilities
  - Leachate Management
  - Drainage Management
  - Gas Management
  - Monitoring Facilities
- Fill Sequencing (Operations) Plan

The following analyses need to be verified and finalized during this stage using additional field data gathered:

Verify Seismic Criteria
Perform More Detailed Static and Dynamic Landfill Slope Stability Analysis
Leachate Generation Analysis and Detailed Sizing of LCRS
Detailed Design of Leachate/Gas Management and Appurtenant Facilities
Detailed Analysis and Sizing of Roads and Drainage Facilities
Detailed Design and Analysis of Other Support Facilities and Utilities
Stockpiling and Soil Cover Requirements

Initial Phase Design (Initial Construction Plans and Specifications)

The Initial Cell Construction Plans should contain the following components:

- Initial Cell Layout and Size
- Excavation and Liner Design
- Leachate Management System
- Temporary Drainage Facilities
- Soil Stockpile Locations
- Support Facilities
- Typical Liner and Miscellaneous Details

The initial Construction Plans and Specifications will become the main components of the Construction Bid Documents.

Construction Quality Assurance (CQA) Manual

The CQA Manual is an important technical document that prescribes the type, quantity, and methods of testing during construction to ensure compliance to requirements of the plans and specifications, review and tracking of submittals, construction supervision and monitoring procedures. CQA should be performed by a third party Engineer that has extensive experience in the design/construction of modern sanitary landfills. The CQA manual also prescribes the qualifications of CQA personnel which include the certifying engineer, CQA monitors and technicians.

REFERENCES:

Vector Engineering Inc., “Second Interim Report, Site Selection Study for a New Sanitary Landfill, Subic Bay Metropolitan Authority”, May 2000

Vector Engineering Inc., “Final Report, Site Selection Study for a New Sanitary Landfill, Subic Bay Metropolitan Authority”, June 2000