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SANITARY LANDFILL DESIGN AND SITING CRITERIA

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For two decades, solid waste components in World Bank projects have focused on collection of solid wastes, with equipment provided to upgrade operations at existing open dumps. Since early 1990, the private sector has become increasingly being involved in the collection, disposal, and treatment of solid waste and World Bank projects have placed greater priority on implementation of new sanitary landfills. The following guidance provides an examination of some of the issues which need to be addressed in landfill siting and design.

Sanitary landfill is the most cost-effective system of solid waste disposal for most urban areas in developing countries. Composting of solid waste costs 2-3 times more than sanitary landfill, and incineration costs 5-10 times more.

A sanitary landfill is a contained and engineered bioreactor and attenuation structure, designed to encourage anaerobic biodegradation and consolidation of compacted refuse materials within confining layers of compacted soil. At a proper sanitary landfill, there are no nuisance impacts of constant burning, smoke, flies, windblown litter, and unsightly rubbish heaps.

Refuse in a proper sanitary landfill is not directly exposed to rainfall, surface runoff or groundwater. Leachate generation is derived only from a limited quantity of infiltration which reaches the waste deposit and captures the byproducts of waste biodegradation. While little leachate is generated in a sanitary landfill compared to an open dump, leachate concentrations are much higher -- organics are higher by a factor of more than 10 -- and thus leachate needs to be properly treated.

Sanitary landfills located in arid areas, where there is minimal potential for leachate generation, may have more relaxed design requirements than those located in wet areas. Similarly, sanitary landfills located on coastal lands underlain by naturally saline and unpotable groundwater may have more relaxed design requirements than those in inland areas overlying potentially usable groundwater regimes. In these areas of lower impact potential, impermeable lining of the landfill may be unnecessary. Instead, measures to enhance natural attenuation by soil's adsorption, precipitation, filtration, and ion exchange capacities need to be considered.

Sanitary landfill design needs to provide for daily cover of fresh refuse, incorporate mitigative measures to manage leachate and gas produced within the landfill cells, provide for a final soil and vegetative cover, and establish an environmental monitoring system of upgradient and downgradient groundwater monitoring wells and surface water sampling locations. Typically the daily cover material is soil; however, tarps or inert materials (i.e., construction debris or compost residuals) could be used.

Since the sanitary landfill is the most important control node of the refuse collection system, a gate-house for record-keeping operations and a weighbridge are recommended. A weighbridge generally costs no more to purchase than one refuse collection truck, and assures the productivity of the entire collection fleet.

Minimizing Leachate Generation. A sanitary landfill is a step by step construction activity involving daily layering, compacting, soil covering of refuse into cells, and routing surface runoff away from waste cells. The space wherein the refuse would be placed should not be subject to seasonally high groundwater levels or to periodic flooding. The site preparation and landfilling operation must be designed to minimize contact of surface runoff and percolating rainwater with the refuse. This requires diversion of upgradient surface drainage away from the landfill operational area, sloping of the cells to avoid ponding of waters on top of them, and compaction of refuse and daily soil cover as each cell is being constructed so that infiltration potential is minimized.

Soil used for lining, interim cover, and final cover should be wetted with water (usually from a water tank truck) to reach optimum moisture (about 50%) so that good compaction can be obtained. Final soil cover needs to be sloped (2-3%) to avoid ponding of waters on top of the refuse filled area and to minimize infiltration. Grass is planted in the final soil cover to limit erosion.

Leachate Management. At sites where potentially usable groundwater exists in unconfined layers, any rain and surface runoff waters which percolate through the refuse and become contaminated leachate need to be collected. The leachate collection system typically consists of a network of perforated plastic pipe within a gravel bed which is placed over the landfill liner. The perforations holes need to be small enough that the encasement stones do not enter the pipes. The gravel bed may be protected from clogging by a geotextile liner above. Leachate pipes need to be selected to withstand the compression forces of the waste deposit and equipment operating at the landfill. Slopes of the pipe should never transition from a steeper upstream slope to a shallower downstream slope, otherwise sediment could collect at the transition point and lead to clogging. The landfill liner and the leachate collection network need to be properly sloped (about 2% slope) to enable gravity flow of contaminated waters to treatment ponds.

For sites in developing countries, the landfill liner would typically consist of relatively impermeable clay soil placed in thin layers (of about 25 cm depth each) at optimum moisture content and compacted with a roller. Good compaction of the base material is essential, to avoid uneven settling of the overlying leachate collection pipe network. Sites with only a clay soil liner may require the leachate collection pipes to be placed at closer intervals than sites with additional plastic liners, to optimize the capture of most leachate.

At large landfills receiving municipal refuse for major metropolitan areas, where hazardous waste quantities could be received in significant quantities, additional impermeable plastic liners may be necessary to protect sensitive groundwater resources.

In countries with low levels of precipitation, a leachate drainage pipe network under the refuse might not be needed and leachate may be collected by providing a dike at the toe of the site and a gravel trench with a leachate interception pipe. In these dry countries, treatment may need to be only a storage/evaporation pond.

Leachate treatment in developing countries is typically accomplished through a series of lagoons. The lagoons are commonly designed to encourage a first phase of anaerobic decomposition, followed by facultative or aerobic decomposition. To the extent possible, full evaporation in a final storage lagoon is desirable so that no discharge of treated effluent is necessary. If full evaporation is not possible, recirculation of treated effluent back to the landfill (on the completed areas of fill), irrigation of the buffer zone of trees and bushes, discharge to a sewage treatment plant, or tanker haul to a sewage treatment plant is recommended. Discharge to a surface water is acceptable only if the effluent is treated and/or diluted to a level wherein there would be no significant adverse impact on the water quality requirements of the receiving water.

Gas Management. In addition to leachate management, landfill gas management is a critical component of sanitary landfill design. During peak periods of anaerobic decomposition, the landfill gas reaches methane concentrations of about 50%. Minimum requirements are that the landfill gases be properly ventilated to avoid build-up to potentially explosive levels and migration laterally from the site. For purposes of controlling green house gases, however, it is strongly recommended that landfills that will have a depth of over 10 meters be designed for gas recovery and use.

Emission reduction funds are available to cover the full costs of landfill gas recovery, through "carbon finance".

If there is no plan to flare or recover the gas, the gas ventilation may be designed as follows: (1) during site preparation the landfill side slopes are lined with impermeable clay to curtail lateral migration of the gases and then lined with coarse rock or gravel to allow gases to escape to the atmosphere; and (2) rock-filled, wire mesh wrapped, vertical wells of about 1 m diameter are created during landfill (about every 0.1 hectare).

If flaring or recovery are anticipated, gas vents may be implemented as follows: (1) during landfilling, using horizontally or vertically installed perforated plastic pipe (about 15 cm diameter) packed in gravel, with enclosure and capping of this pipe and gravel in a larger closed pipe from the point just below the ground surface; or (2) upon completion of a specific area of the landfill, by drilling a borehole and installing a perforated pipe within gravel packing.

Stability. Side slopes of the landfill should not be more than 2.5:1 (horizontal:vertical), otherwise erosion and loss of soil cover could occur. In seismically active areas or on poor soils, slopes of 5:1 or greater could be required. It is important that soil cover exist even on the side slopes of the landfill cells, as well as on the lateral surface. Without good soil cover, air will be able to enter freely. At the interface of the air with the underground landfill gas, underground fires, once started, could more readily persist. When there are underground fires, cavities within the solid waste will develop and the surface of the landfill may collapse. Serious accidents have been known to occur in such circumstances.

Composting. In cities where compost is a marketable product and the market is willing and able to cover the additional cost (i.e., above the cost of sanitary landfill) of producing compost, composting should be conducted at the sanitary landfill site. If composting shares the landfill site, the investment for access, fencing, gate control, water supply, electricity, and mobile equipment can be shared -- thus lowering the production cost of compost to potentially affordable levels. For example, the wheeled loader used for excavating soil cover for the landfill can be connected to a windrow turning machine to conduct the open air composting operation.

In most cities, only 10-30% of the incoming trucks to the sanitary landfill are from sources which have wastes of good quality for composting, such as wastes from purely residential neighborhoods, and wastes from special generators such as markets, restaurants, slaughterhouses, and food processing plants. If the compost operation shares the same facility as the sanitary landfill, the gate keeper could divert only the loads with appropriate quality of wastes to the composting operation. Rejects and residuals from the composting process could be readily discharged to the sanitary landfill. If the market for composting is only seasonal, the operation can be conducted on a seasonal basis. And, finally, if rainy season conditions inhibit the ease of composting, the operation can be conducted during dry seasons only. Location of composting at the sanitary landfill thus optimizes quality control of the product, flexibility for the operation, and cost minimization.

Construction Phasing. Construction of a sanitary landfill occurs in zones, over the life of the site. Typically each zone provides a capacity for about 3 years of solid waste. At the start of construction, the access road, entrance gate, weighbridge, fencing, water supply and Zone I refuse cell area are constructed. Refuse cell development always begin from the lowest elevation of each zone. Leachate treatment facilities to handle flows generated at the peak period over the life of the site are constructed from the onset, usually at the lowest elevation of the site so that leachates from all areas can flow to them by gravity. As the capacity of the Zone I refuse cell area nears its complete utilization, the Zone II refuse cell area needs to be prepared (i.e., with base grading and compaction, lining, leachate collection networks, gas ventilation systems, etc). And so on, over the life of the site, until each Zone of the landfill is completed.

For landfill gas recovery (for purposes of energy production), the complete cover of the waste deposit would be necessary, so that gas does not escape and air does not enter and thus dilute the gas composition. Gas is recovered actively, through vacuum pumping to preserve the methane content.

Siting. Each sanitary landfill is uniquely designed to conform to the soil, geologic, topographic, and water resource conditions of the site. To minimize the costs of operating a sanitary landfill, the first and most critical step is proper siting in a location which enables economic operations and cost-effective environmental protection. Also, proper siting is essential to minimizing the cost of refuse collection. The following site selection criteria are provided as guidance.

A proposed landfill site can be selected even though it does not meet each of the screening criteria. Engineering design can mitigate inadequate site conditions -- but at a cost. When selecting a site which does not meet all of the screening criteria, possible engineering solutions which would bring the site into conformance with the intent of the unmet criteria shall be incorporated in the design.

World Bank Environmental Requirements. Solid waste components which involve new sanitary landfills are usually given an "A" ranking for environmental priority. With this ranking, the following activities are typically required to be accomplished prior to project appraisal: (1) documentation that site selection has been conducted to address the type of siting criteria listed below; (2) an environmental report to describe the site selected, outline potential environmental impacts of sanitary landfill at the site, and propose mitigative measures; (3) public education and local consultations with residents in the vicinity of the proposed sanitary landfill, including an open forum where all interested parties have an opportunity to express their opinions concerning site selection; (4) compensation and resettlement action plans for affected parties; and (5) conceptual design and budgetary costing of the sanitary landfill, including mitigative measures identified in the environmental report and responsive to the local consultations. If the proposed sanitary landfill is a substantial part of total project costs, the "A" ranking may also require that: (1) all design and tender document development be completed by the time of appraisal; and (2) the local environmental agency provide a letter of environmental permission allowing sanitary landfill construction to proceed.

Private Sector Involvement. Sanitary landfill is a public good, because benefits of environmentally sound disposal are derived collectively. Nevertheless, private sector involvement, if properly arranged, can increase the likelihood that landfill design and operation specifications will be followed. Ideally, the landfill would be designed, built, owned and operated by a private company under a 15-20 year concession agreement, with a guaranteed minimum of waste quantity delivered (or otherwise paid for) by its municipal clients, and carefully structured arrangements for closure and post-closure requirements. If government decides to build and own the facility, a private company could provide operation under a 5-8 year contract or, if tipping fees are well established, a franchise agreement.

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- Adequate land area and volume to provide sanitary landfill capacity to meet projected needs for at least 10 years, so that costly investments in access roads, drainage, fencing, and weighing stations are justifiable. For siting purposes, land area requirements shall be estimated based on the landfill cell area required (typically for a depth of 10-25 meters; a final solid waste density of 800-1,000 kg/cubic meter, and a minimum soil to refuse ratio of 1: 6), as well as about 2-4 hectares for the receiving area, 2-4 hectares for the leachate treatment and/or evaporation ponds, and additional 10% land for a landscaped buffer zone.
- Preferably, a site accessible within 30 minutes travel time (a function of road and traffic conditions) is to be sought, even if it means buying land, because of the need to avoid adversely affecting the productivity of collection vehicles. At distances greater than 30 minutes travel, for collection operations to be economic, investment in either large capacity collection vehicles (5 tonnes per load or greater) or transfer stations with large capacity vehicles (20 tonnes or greater) would be necessary.
- If transfer stations are required, the landfill should be accessible within 2 hours of travel time (one-way) by transfer trucks from the transfer station. Otherwise, for longer distances, transfer by rail or barge directly to the landfill site needs to be considered. Siting of rail or barge transfer sites within the refuse collection area may be difficult. Double handling by truck transfer and by rail or barge transfer units should be avoided because of costs.

- Accessible from a competent paved public road which has an adequate width, slope, visibility and construction to accommodate the projected truck traffic. To minimize landfill development costs, the requirement for new access road construction generally should be less than 10 km for large landfills serving metropolitan areas and less than 3 km for small landfills serving secondary cities.
- A gently sloped topography, preferably amenable to development of sanitary landfill by the Cell (Bund) method), with slopes which minimize the need for earthmoving to obtain the correct leachate drainage slope of about 2%.
- Groundwater's seasonally high table level (i.e., 10 year high) is at least 1.5 meters below the proposed base of any excavation or site preparation to enable landfill cell development. A minimum depth of 1 meter of relatively impermeable soils above the groundwater's seasonable high level exists (preferably, less than 10^{-9} meters/second permeability when undisturbed). If these criteria is not met, use of impermeable clay and/or plastic liners may be required to protect groundwater quality.
- Availability on-site of suitable soil cover material to meet the needs for intermediate (minimum of 30 cm depth) and final cover (minimum of 60 cm depth), as well as bund construction (for the Cell method of landfill). Preferably, the site would have adequate soil to also meet daily cover needs (usually a minimum of 15 cm depth of soil). However, daily cover needs can be alternatively met by using removable tarps, other relatively inert materials (i.e., compost residuals), or by removing the previously laid daily soil cover at the start of each day for reuse at the end of the same day. For purposes of siting, assume that at least 1 cubic meter of daily, intermediate, and final compacted soil cover is needed for every 6 cubic meters of compacted refuse. In most developing countries with highly organic wastes and warm climates, compacted refuse (after one year of natural consolidation and decomposition within warm and wet climates) achieves a density of 800-1000 kg/cubic meter.
- None of the areas within the landfill boundaries are part of the 10-year groundwater recharge area for existing or pending water supply development.
- No private or public drinking, irrigation, or livestock water supply wells within 500 meters downgradient of the landfill boundaries, unless alternative water supply sources are readily and economically available and the owner(s) gives written consent to the potential risk of well abandonment.
- No environmentally significant wetlands of important biodiversity or reproductive value are present within the potential area of the landfill cell development.
- No known environmentally rare or endangered species breeding areas or protected living areas are present within the site boundaries. If this criteria is not met, alternative habitats of comparable quality for relocation of the species would need to be available.
- No significant protected forests are within 500 meters of the landfill cell development area.
- No open areas of high winds, otherwise windblown litter will not be readily manageable.
- No major lines of electrical transmission or other infrastructure (i.e., gas, sewer, water lines) are crossing the landfill cell development area, unless the landfill operation would clearly cause no concern or rerouting is economically feasible.
- No underlying limestone, carbonate, fissured or other porous rock formations which would be incompetent as barriers to leachate and gas migration, where the formations are more than 1.5 meter in thickness and present as the uppermost geologic unit above sensitive groundwaters.
- No underlying underground mines which could be adversely affected by surface activities of landfilling, or minable resources which could be rendered less accessible by landfilling, unless the owner(s) gives explicit consent.
- No residential development within 250 meters from the perimeter of the proposed landfill cell development.
- No visibility of the proposed landfill cell development area from residential neighborhoods within 1 km. If residents live within 1 km of the site, landscaping and protective berms would need to be incorporated into the design to minimize visibility of operations. Curving of the access road is recommended to avoid visibility of the active portions of the landfill from the main road.
- No perennial stream within 300 meters downgradient of the proposed landfill cell development, unless diversion, culverting or channeling is economically and environmentally feasible to protect the stream from potential contamination.

- No significant seismic risk within the region of the landfill which could cause destruction of berms, drains or other civil works, or require unnecessarily costly engineering measures, otherwise side slopes may need to be adjusted to be gentler than the maximum of 2.5:1.
- No fault lines or significantly fractured geologic structure within 500 meters of the perimeter of the proposed landfill cell development which would allow unpredictable movement of gas or leachate.
- No siting within 3 km of a turbojet airport and 1.6 km of a piston-type airport. For sites located more than 3 km and less than 8 km from the nearest turbojet airport (or more than 1.6 km and less than 8 km from the nearest piston-type airport), no consideration is to be given unless the aviation authority has provided written permission stating that it considers the location as not threatening to air safety.
- No siting within a floodplain subject to 10-year floods and, if within areas subject to a 100-year flood, must be amenable to an economic design which would eliminate the potential for washout.
- Avoid siting within 1 km of socio-politically sensitive sites where public acceptance might be unlikely (i.e., memorial sites, churches, schools) and avoid access roads which would pass by such culturally sensitive sites.