LANDFILL SELECTION CRITERIA WITH EMPHASIS IN ENGINEERING GEOLOGY AND ENVIRONMENT

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Abstract

A table which brings together all landfill selection criteria, is presented. For the compilation of the table international practice was taken into account but special consideration was given to Greek geological conditions. The table is composed of four columns which name the criteria and deal with their significance, some methods of investigation and the appropriate action to be taken during the selection proccess. 38 groups of criteria are included but the main subjects covered are: Hydrogeology - Hydrology, Engineering Geology - Neotectonics, Land Use, Climate and Planning. The aim of the paper is to lead landfill selection techniques towards environmental protection.

Site selection methodology

Landfill site selection process must involve teams of technical experts from the earth sciences, physical sciences and engineering. The "natural containment" aproach to waste management problems make engineering geology and hydrogeology very important aspects in the multidisciplinary study.

The tools available to the team of specialists are the usual for the heeds of a site investigation: Geological mapping, geotechnical mapping, aerial photographs satellite images, borehole logs, trial pits, laboratory and in situ tests, geophysical logging. Map overlays within G.I.S. (Geographycal Information Systems) and data bases can be used for better organisation of the collected information.

It must be emphasised that not all of the selection criteria will necessarily have to be considered for a specific site. The most important factors will become apparent in the first meeting with the planning authorities. The work of the competent scientist is to identify the important site specific parameters and design accordingly.

Selection and evaluation of a waste disposal site can be done using fuzzy set analysis (Horsak & Damico, 1985). This way a quantitative representation of the community opinion and the order of importance of all selection criteria can be obtained.

Detailed site investigation is necessary after the desk study stage. The procedure involves several stages. In Canada (Cooper, 1991) 20 sites were initially selected and then were reduced to 8. Site investigation and 5 boreholes to each site were used to select 1 site, after ranking the outcomes. At the final site, detailed field investigations were conducted including 12 additional boreholes which were then used as a guide for more than 100 boreholes to assess geotechnical, geochemical and hydrogeological parameters at the design stage.

The criteria used in the table can be grouped into 5 categories:

1-9 .... Hydrogeology - Hydrology
10-18........... Engineering Geology Neotectonics
19-24........... Land Use
25-28........... Climatte
29-38........... Others Planning

Conclusions

The table can be used as the basic decision making tool at the preliminary stages of landfill selection as it offers an essential checklist of all landfill selection criteria. Evaluation and ranking of selection criteria to assess different alternatives according to local geological, geotechnical and hydrogeological conditions are necessary during subsequent stages. The action to be taken in order to face any potential problem can also be of particular help during the selection procedure. Full containment philosophy which is behind the proposed actions will promote environmental protection.

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	CRITERION	SIGNIFICANCE	ASSESSMENT	ACTION
1	**Permeability**	Migration of contaminants. Pollution of surface & groundwater.	In situ (lysimeters, packer tests) and lab tests. Hydrogeological mapping. Aerial photos help in karst identification.	Low permeability strata is required (eg. clay with $K=10^{-9}$ m/sec). Leachate collection and treatment systems. Engineer the site (clay barriers, flexible membrane liners, slurry trench cutoff walls, diaphragm walls, sheet piling, grout curtains, hydraulic barriers).
2	**Run on - Run off**	Migration of contaminants. Pollution of surface and groundwater.	Surface and groundwater monitoring. Determination of flow (flow nets). Establishment of water balance.	Stream diversion. Peripheral ditch. Construction of culvert. Cover of landfill.
3	**Water levels**	Migration of contaminants in case of liner failure.	Hydrogeological investigation. Geophysical investigation. Piezometers - Monitoring.	Put landfill 6-9 m above shallowest aquifer and 2.5 m above highest seasonal level of water table.
4	**Proximity to wells & springs**	Pollution of surface and groung water. Water quality.	General use maps and records of planning authorities.	Standard in Greece is 300 away from wells. In America the standard is 800 m.
5	**Proximity to hydrological boundaries** (streams, lakes & sea)	Pollution of surface waters. Surface water quality.	General use maps.	Put the landfill away (300-3000 m) from hydrological boundaries. Travel time of the contaminant should be taken into account (400 day travel time is required in Britain)
6	**Proximity to aquifer. Proximity to recharge areas.**	Groundwater quality (all usable groundwater must be protected)	Hydrogeological investigation (thickness and depth of aquifers and aquicludes). determination of recharge areas.	Site the landfill where no impact on groundwater can be foreseen. Engineer the site.
7	**Aquifer yield, use & quality**	Influence to the magnitude of impact	Hydrogeological investigation (transmissivity, groundwater chemistry) Pumping tests.	Avoid aquifers that are used and, if possible, good quality and high yield aquifers.
8	**Groundwater flow. Hydraulic gradient.**	Impact to potential use if flow is towards it	Hydrogeological investigation. Establish the groundwater regime. Monitoring & piezometers (direction and rate of flow).	Select areas that flow is away from use and do not impact recharge areas.
9	**Flood prone areas**	Impacts operation of landfill & results to uncontrolled run off & leachate production. Can trigger landslides.	Identification of 100 years flood prone areas using records or geological criteria (permeability, flood deposits, elevation, proximity to streams etc). Amount and velocity of water need also to be assessed.	Avoid flood prone areas and torrents.
10	**Topography** (slopes, erosion)	Site development and operation (equipment mobility, installation of lining). Slope stability.	Topographical maps. Erodibility index. Evaluation of climatic conditions to slope erosion.	Grade the slopes to less than 33%. Compaction of the materials to resist erosion. Install special protection systems.
11	**Slope stability**	Safety. Potential failure of engineering works will lead to increased cost.	Site investigation (boreholes, geophysics, piezometers, laboratory and in situ strength tests). Identification of the potential slip surface. Calculation of the Factor of Safety.	Grade the slopes. Water abstraction. Toe weight. Reinforcement.
12	**Bedrock type**	Carbonate rocks are susceptible to solution, fractured rocks facilitates pollution migration.	Detailed geological survey (mapping, boreholes). Establishment of sequence of strata (vertically & laterally). Establishment of mass permeability (packer tests).	Sites with low permeability bedrock are preferable (eg. not fractured schists and flysch type deposits).

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13	**Discontinuities**	Migration of contaminants.	Tectonic analysis. Orientation, opening, filling material, length, block size, persistence.	Sites with minimum discontinuities are preferable.
14	**Weathering**	Development costs. Poor Geotechnical properties. Prone to landsliding. Increased permeability.	Geological and geotechnical investigation. Pedological survey.	Minimum thickness of weathering mantle is required.
15	**Distance from faults**	Increased permeability.	Geological survey including geological mapping and morphotectonic analysis. Aerial photos, satellite images.	Site the landfill away from faults. Construction of containment systems.
16	**Neotectonics. Seismicity.**	Presence of faults or fault zones. Earthquake endangers the integrity of the liner (soil or artificial).	Morphology, records of earthquakes, mapping, joint pattern. Earthquake probability and potential movement.	Avoid areas near active faults or engineer accordingly (eg. thick soil liners). Avoid highly seismic areas.
17	**Mechanical properties** Strength, settlement & rate of settlement, excavitability - diggability.	General behaviour of engineering work. Excavations costs. Landslides. Bearing capacity.	Geotechnical investigation [index tests, triaxial tests, shear box, oedometer, geophysics (seismic velocity, electrical resistivity, radar, etc)]	Change site or engineer accordingly (problems are not anticipated since load imposed by waste is low and soils are not as compressible as waste).
18	**Proximity to natural materials necessary for construction** (cover & lining). **Quality of materials.**	Cost. Time necessary for construction. Quality.	Geological maps, Geotechnical investigation including mapping and testing (estimation of permeability, PSD, strength and stability at placement).	Sites near material sources are preferable. Mixtures of materials (usually bentonite)or syntetic liner can be used.
19	**Land use** (agriculture, forest, scrubs, pasture, etc)	Cost. Security against fires. Environmental protection. Public reactions.	Land use maps	Put the landfill away from forests, if possible, or use them for screening
20	**Special Land uses** (airports, military bases)	Security of flights (landfills attract birds). Security against fires.	Land use maps	Put landfills away from airports and military bases.
21	**Distance from residential areas** or planned residential areas (including summer residences)	Nuisance, odour, litter, pests, increased traffic.	Land use maps. Planning authorities.	At least 250 m away from housing or proposed housing. Use of landfill gas abstraction and collection systems for safety and environmental protection
22	**Quarries - Mines**	Cost effective solution. Recreation of landscape. Non visible areas.	Land use maps. In situ geological, geotechnical and hydrogeological investigation.	Use of quarries or mines providing the fulfilment of environmental requirements.
23	**Sites of specific Scientific, architectural and archaeological interest**	Aesthetic impact. Impact on sites important to human heritage	Planning authorities	Avoid such sites. Planning authorities are responsible to give or not planning permission.

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24	**Sites of outstanding natural beauty - Protected sites**	Concervation of flora and fauna	Environmental impact assessemen	Site the landfill away from such areas.
25	**Prevailing wind direction speed and duration**	Odour. Health and safety. Air quality.	Meteorological office	Increase buffer around residential areas at the prevailing wind direction. Use fences and compacted intermediate cover.
26	**Rainfall** (amount, intensity, duration, days with rainfall per year)	Influences generation of leachate	Meteorological office. Rainfall contour maps.	Avoid high precipitation areas
27	**Temperature**	Influences decomposition of waste (pest breeding, odours)	Isothermal maps	High temperatures help decomposition but favour pest breeding.
28	**Ice.** **Snow.**	Influences landfill operation.	Climatic and meteorological data. Isothermal maps.	Avoid snow covered or frozen areas. Use of soil covers. Use of pesticides, deodourisers or lime.
29	**Chemical properties** (pH, cation exchange capacity). **Pollution baselevels.**	Characterises tendency of soils to absorb heavy metals. Baselevels are necessary for environmental impact assessement.	Chemical investigation. pH measurement. Clay mineralogy. Activity.	Clays with high pH and cation exchange capacity are preferable.
30	**Access.** **Distance from A-roads.** **Distance from B-roads.** **Distance from city.** **Transportation time.**	Cost of transportation, speed of operation, increased traffic, noise.	Detailed traffic surveys. Road network maps. Calculations of increased traffic, bearing capacity of roads.	Construction diversion roads. Transportation of waste using railroads (economical hauling distance is 16-24 km).
31	**Visual influence**	Aesthetic impact. Nuisance.	Topographical maps.	Check that no parks, hospitals stadiums or other special land uses are visible from the landfill. Use fences trees or earthworks to sreen operations.
32	**Ecology.** **Landscape.**	Impact on ecosystems and wild life (vegetation and animals)	Habitat survey	Creative conservation or avoid areas with significant ecological value.
33	**Economic criteria.** **Expropriation costs.**	Avoid opposition. Maintain property values.	Economic survey.	Dialogue. Give exchanges.
34	**Volume and area needed**	Secure long operational life (usually 20-30 years)	Density of waste (max 1.2 ton/m^3). Waste per person per day (0.6-1.2 kg/day).	Reject all sites that are not big enough.
35	**Presence of natural depressions**	Cost. Not visible areas.	Topographic maps.	Site the landfill in natural depressions given that all anvironmental criteria are fulfilled
36	**Restoration.** **Recreation.**	Cost. Health and safety. Restore to vegetation, social amenities, dry slope skiing, etc.	Special restoration plan.	Easy restoration is preferable. Need for special restoration must be taken into account for the selection

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37	**Ease of installation of public service networks** (telephone, electricity, potable water). **Ease of vehicles manouver-ability**	Cost. Health and safety of personnel	Consult planning or other responsible authorities	Reject sites that are uneconomical
38	**Opposition of people.** **Social criteria.**	Locals tend to object to landfill development ("not in my back yard"). Delay of works.	Fuzzy set analysis.	Avoid sites that face strong opposition. Give exchanges to local communities (new roads, employ locals). Establish dialogue.