Landfill siting

Phases of investigation:

1. Analysis of existing geological information
2. New drilling campaign
3. Coring and sampling campaign
4. In-situ and laboratory campaign
5. Geophysical prospections (electrical, physical and seismic methods)
6. Analysis of fractures
7. Well inventory – well logging
8. Observation of water levels

Landfill siting

Critical factors assessing the necessity of increasing the frequency of drilling/sampling:

1. Fractures
2. Geological formation discontinuities
3. *Facies* transitions and expected permeability variations

Methods employed to determine site geology:

1. Direct methods
2. Geophysical Methods
3. Drive Methods

Landfill siting

Direct Methods:

Soil or rock sampling through the use of hand augers, trenches or boreholes

Geophysical Methods (reduce cost; useful for preliminary investigation)

Electrical/electromagnetic methods (measure resistivity and conductivity of fluid and surroundings rocks)

Nuclear methods (use natural or artificial source of radiation and detectors)

Acoustic/seismic methods (analyse elastic response of subsurface rock)

(and surface geophysical methods)

method	*general application*	*continuous measurements*	*depth of penetration*	*major limitations*
Radar	profiling and mapping; highest resolution of any method	yes	to 30 m (typically less than 10 m)	Penetration limited by soil conditions
EM (Frequency-domain)	profiling and mapping; very rapid measurements	yes (to 50 feet)	to 60 m	Affected by cultural features (metal fences, pipes, buildings, vehicles)
EM (time-domain)	soundings or profiling and mapping	no	to few hundred meters	Does not provide measurements shallower than 150 feet
Resistivity	soundings or profiling and mapping	no	No limit (commonly used to 100 to 300 m)	Requires good ground contact and long electrode arrays Integrates a large volume of subsurface Affected by cultural features (metal fences, pipes, buildings, vehicles)
Seismic refraction	profiling and mapping soil and rock	no	No limit (commonly used to 100 to 300 m)	Requires considerable energy for deeper surveys Sensitive to ground vibrations
Seismic reflection	profiling and mapping soil and rock	no	to few hundred meters	Shallow surveys, <100 feet are most critical Sensitive to ground vibrations
Micro gravity	profiling and mapping soil and rock	no	No limit (commonly used to 100 to 300 m)	Very slow, requires extensive data reduction Sensitive to ground vibrations
Magnetics	profiling and mapping soil and rock	yes	No limit (commonly used to 100 to 300 m)	Only applicable in certain rock environments Limited by cultural ferrous metal features

* Applications and comments should only be used as guidelines. In some applications, an alternate method may provide better results.

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Drive Methods:

Cone Penetrometry (measures resistance to penetration)

Direct push methods, such as Geoprobe (use percussion hammers and static vehicle weight combined with hydraulic cylinders to advance tools to depth)

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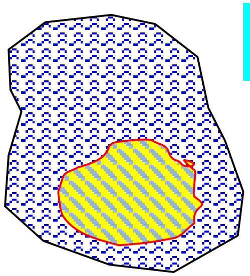
Methods to determine site hydrogeology:

1. Piezometers and Monitoring wells
2. In-situ hydraulic conductivity testing (packer tests, slug tests, pumping tests)
3. Drive Methods

Properties to be considered	Requirements
Porosity (primary and effective)	Low permeability (horizontal and vertical)
Plasticity index	High Plasticity Index
Carbonate content	Low Carbonate content

Landfill siting

Sample density:



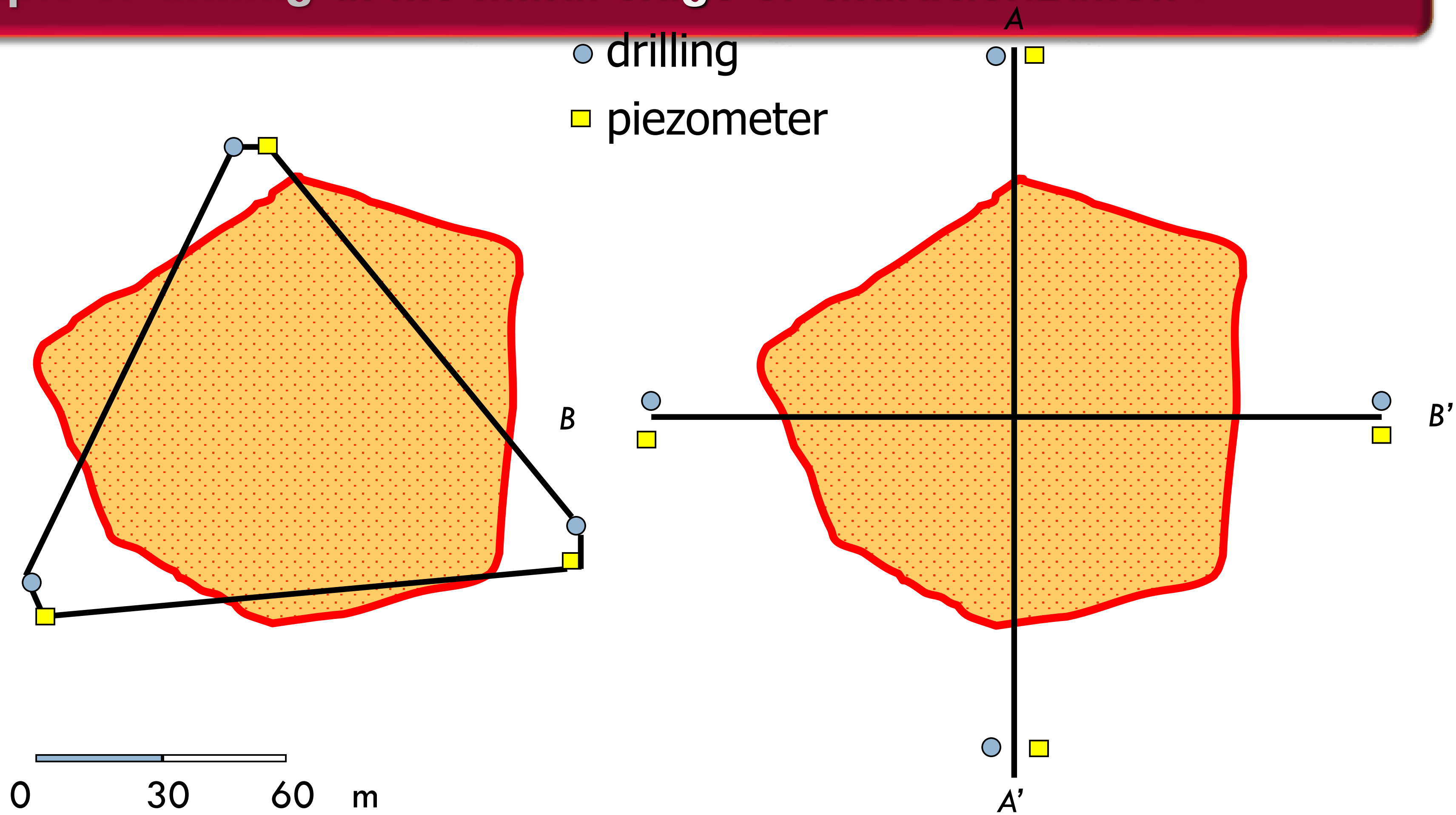
Area of Site = As

Area of target site= At

Probability of Detection	As/At = 10	As/At = 100	As/At = 1000
100	16	160	1600
98	13	130	1300
90	10	100	1000
75	8	80	800
50	5	50	500
40	4	40	400
30	3	30	300

Landfill siting

Example of drilling at the initial stage of characterization :



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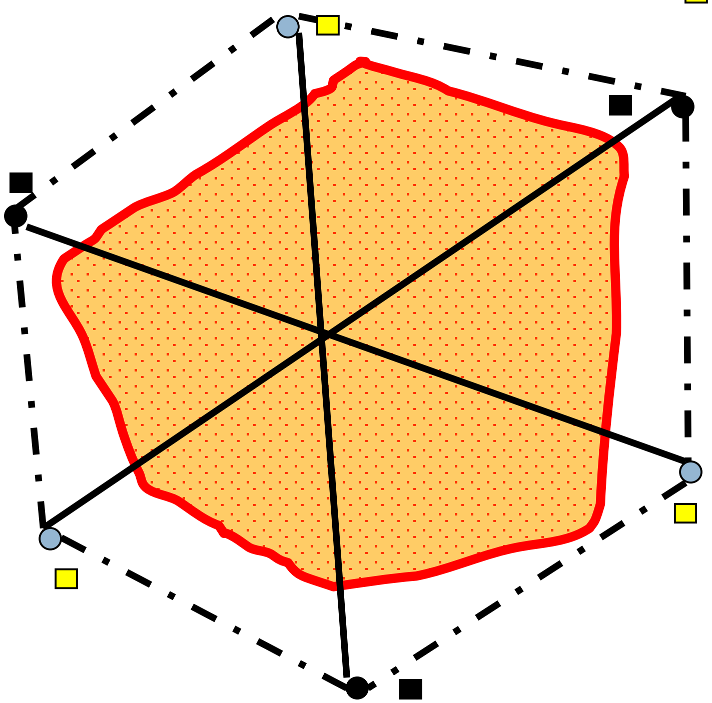
Example of drilling for further characterization :

- ○ drilling
- □ piezometer
- ● additional drilling
- ■ additional piezometer



Landfill siting

Example of drilling for further characterization :

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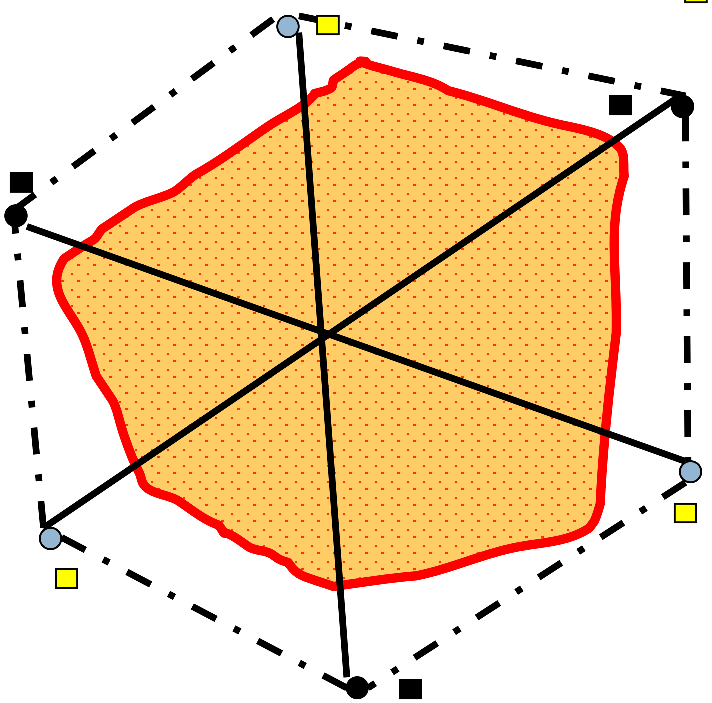
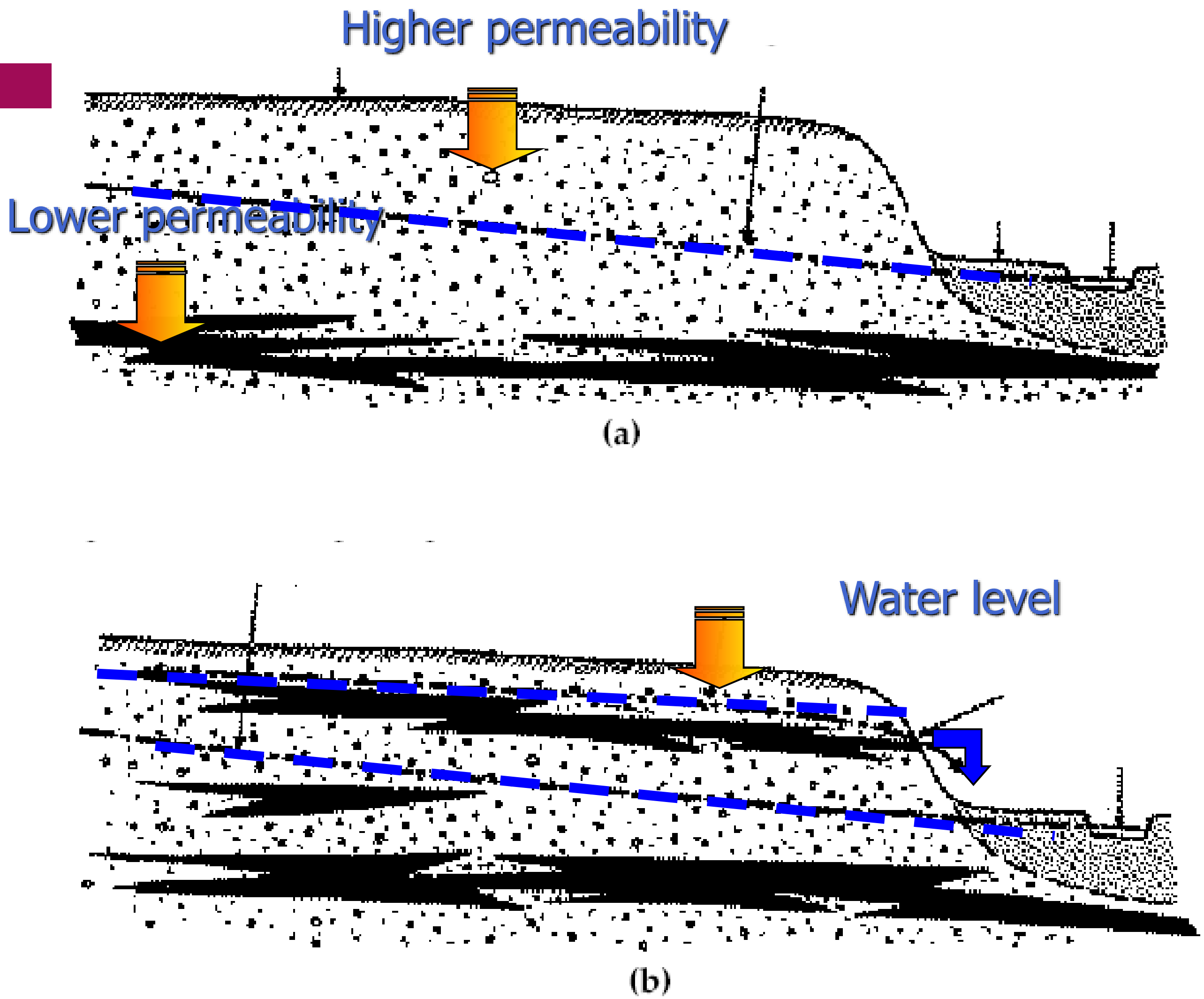
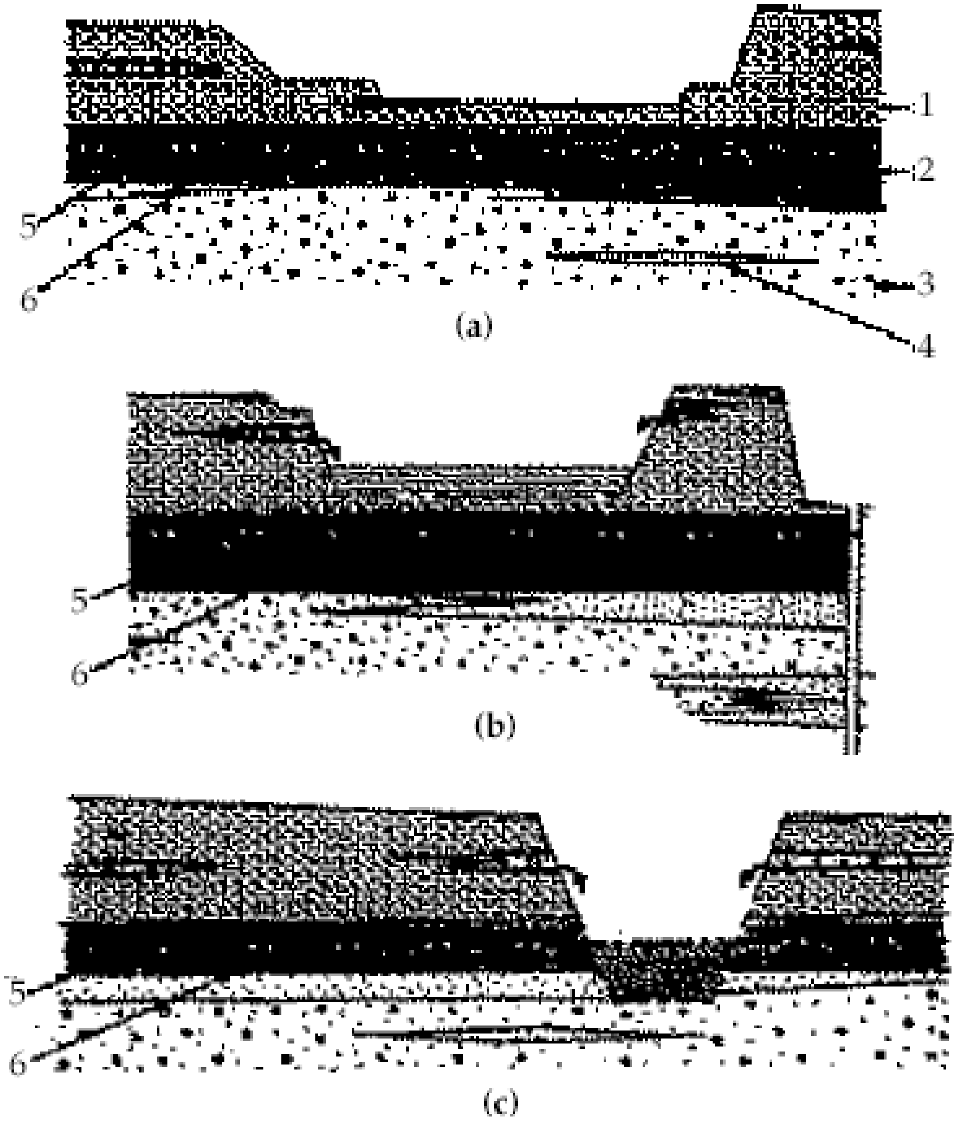


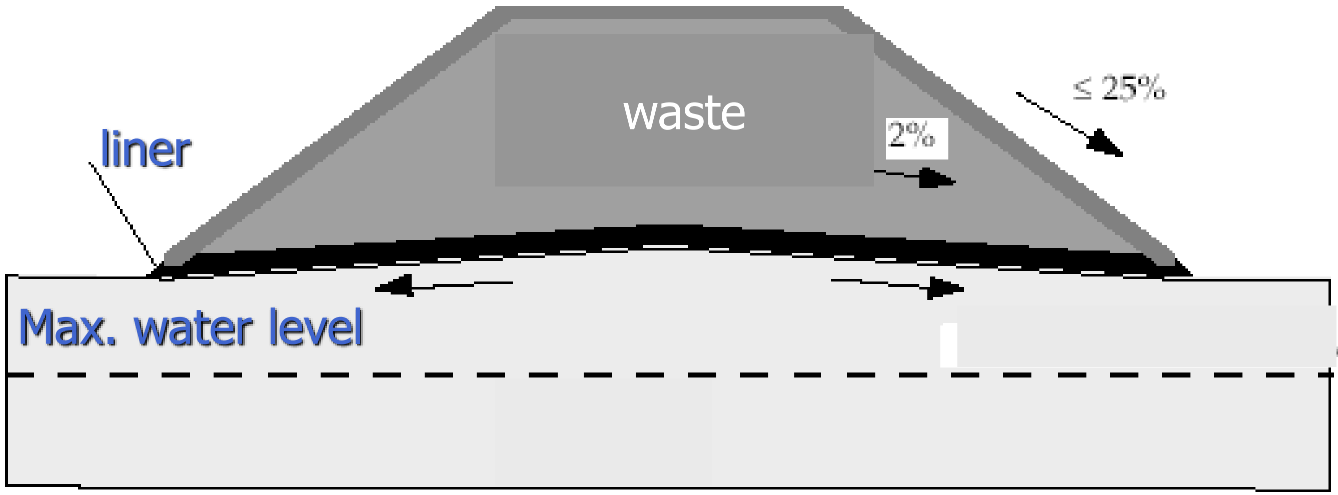
Landfill Siting - Critical examples



Landfill Siting - Critical examples



Landfill Siting - Critical examples



Issues to be considered:

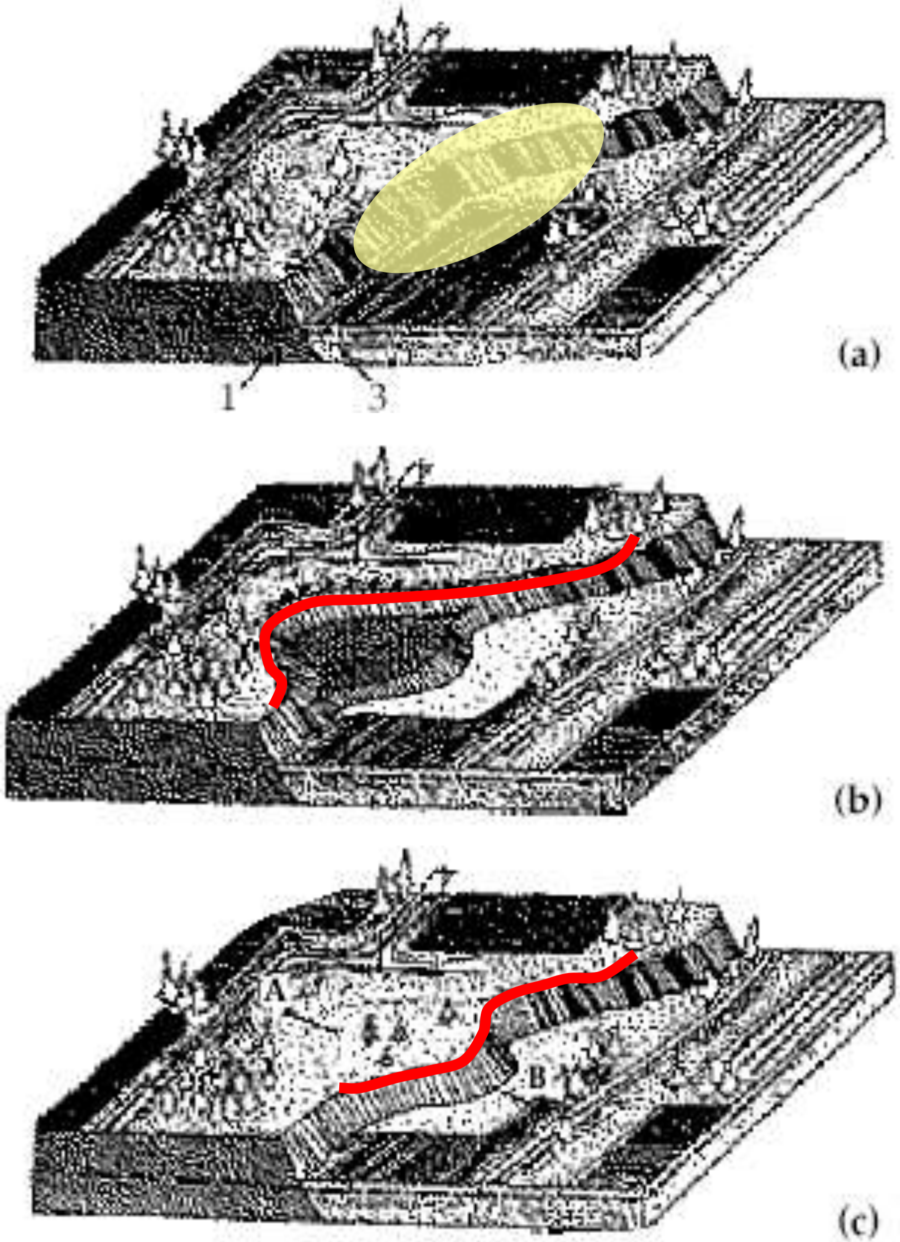
Impact on landscape

Waste can be visible during landfill operation

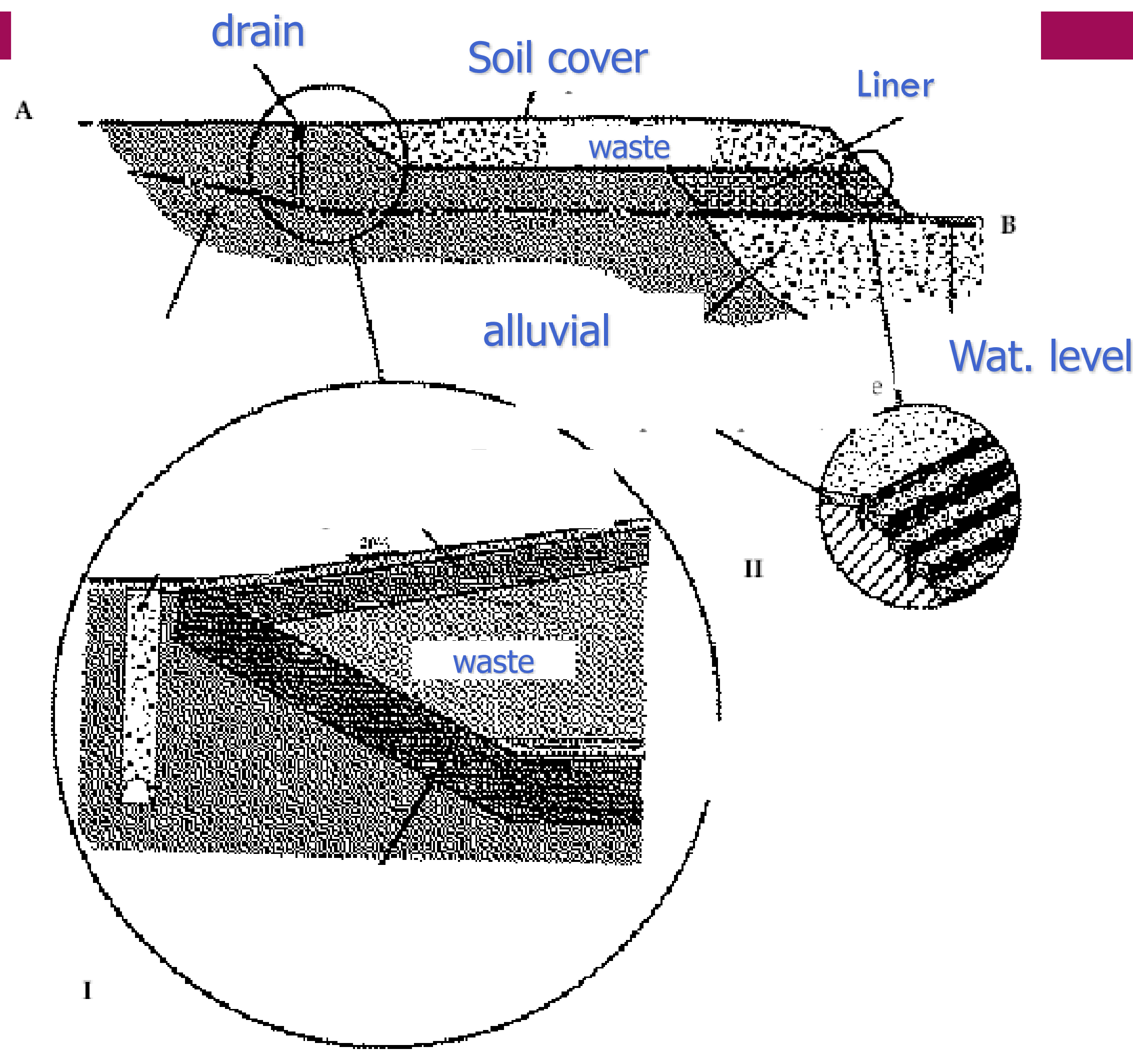
Daily cover material

Waste disposal can be more complex

Landfill Siting - Critical examples



Landfill Siting - Critical examples

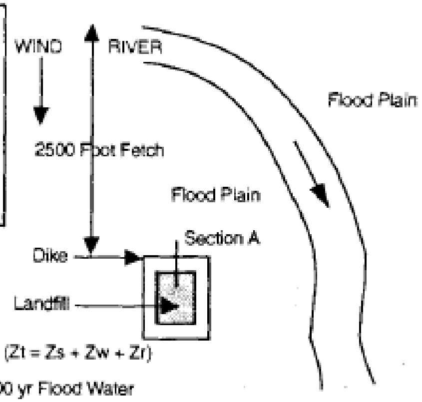


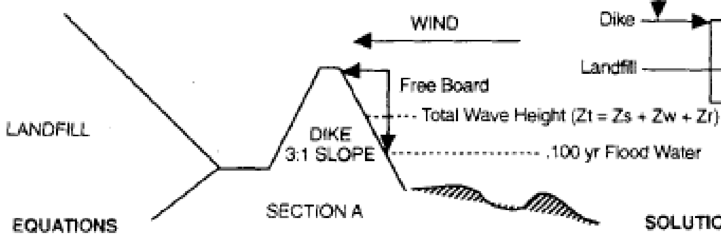
Landfill Siting - Critical examples

ASSUMPTIONS:
- FETCH = 2500 FT
- WIND SPEED = 50 MPH
- AVE. WATER DEPTH ALONG FETCH = 5 FT
- OVERBANK WATER VELOCITY = 0.25 FT/S

DEFINITIONS

Zs = Wave Setup (tilting of water surface upward at downwind end)
Zw = Capillary Waves Height (developed by wind over water surface)
Zr = Wave Run-up (water run-up along dike from wave impact)





SECTION A

EQUATIONS

$$Zr = Zw(Zr/Zw)$$

$$\lambda = 5.12 tw^2$$

$$tw = 0.46 Vw^{0.44} F^{0.28}$$

where:
Zr = Wave run-up along dike
Zr/Zw = Relative run-up ratio from chart below
λ = Wavelength
tw = Wave period
Vw = wind speed (mph)
F = fetch (miles)

$$Zw = 0.034 Vw^{1.06} F^{0.47}$$

where:
Zw = ave. height of heighest 1/3rd of waves (ft)
F = fetch (miles)

$$Zs = \frac{Vw^2 F}{1400 d}$$

where:
Zs = rise above still water level (ft)
Vw = wind speed (mph)
F = fetch (miles)
d = water depth along fetch (ft)

$$W = \frac{K\gamma H^3}{1000(0.016\gamma - 1)^3(\cos\alpha - \sin\alpha)^3}$$

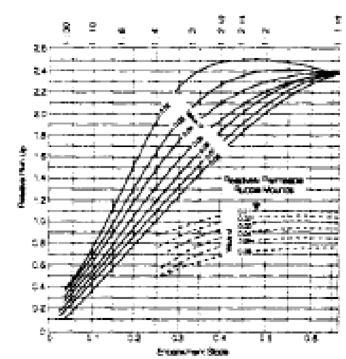
$$d = \left(\frac{6W}{\pi\gamma}\right)^{1/3}$$

where:
W = Rip - Rap stone weight (lbs)
d = Rip - Rap stone diameter
K = Coefficient (30)
γ = Stone Density (lb/cf)
H = height of design wave (ft)
α = bank slope (degrees)

SOLUTIONS

From the data provided in the assumptions at the beginning of the example:
Zs = 0.18 ft., Zw = 1.55 ft., Zr = 2.40 ft
Zt Design Height = 4.13 ft
Base 100 yr flood level = 5 ft
for Factor of Safety of 1.5
Dike Height = (1.5) (4.13 + 5) = 13.7 ft

For the Rip - Rap design given:
K = 30, γ = 120, H = 1.55 ft., a = 18°
For the protective stone on Dike
d = 0.5 ft., W = 12 lbs./stone



Wave run-up ratios vs. wave steepness and embankment slopes

Reference for Equations: U.S. Department of Interior, Bureau of Land Reclamation (1974)
Reference for Wave Run-up Chart: Linsley and Franzini (1972)

FOODPLAIN

Criteria:
Excluded area located in a 100-year river floodplain

UNLESS

The unity is demonstrated to comply with flow-restrictions

Landfill Siting - Critical examples

FAULTS

New MSWLF units shall not be located within 60 m of a fault that has had displacement in Holocene unless it is demonstrated that the alternative setback distance of less than 60 m will prevent damage to the structural integrity of the MSWLF unit and do not pose environmental hazard

If a fault is situated within 3000 ft of the proposed unit, investigation should be conducted within 60 m:

Subsurface exploration, including drilling and trenching, to locate fault zones and evidence of faulting.
Trenching perpendicular to any faults or lineaments within 200 feet of the unit.
Determination of the age of any displacements
Examination of seismic epicenter information to look for indications of recent movement or activity along structures in a given area
Review of high altitude, high resolution aerial photographs with stereo-vision coverage

From US EPA

Landfill Siting - Critical examples

FAULTS

If an alternate setback is requested:

For zones with high probabilities of high accelerations (horizontal) within the moderate range of 0.1g to 0.75g, seismic designs should be developed

Seismic stability analysis of landfill slopes should be performed to guide selection of materials and gradients for slopes

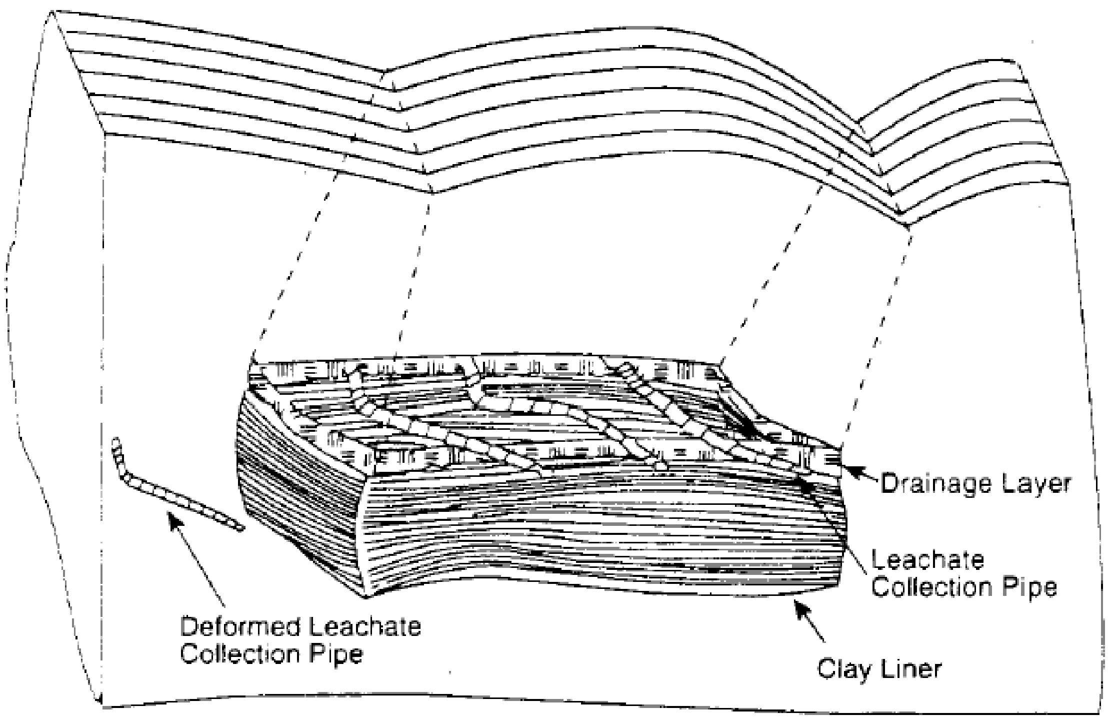
Where in-situ and laboratory tests indicate that a potential landfill site susceptible to liquefaction, ground improvement measures like grouting, dewatering, heavy tamping, and excavation should be implemented

From US EPA

Landfill Siting - Critical examples

FAULTS

Example of engineering solution: flexible pipes, secondary containment systems and ground improvement measures



A schematic diagram of a landfill showing potential deformation of the leachate collection and removal system by seismic stresses.

Source: US EPA, 1992

From US EPA

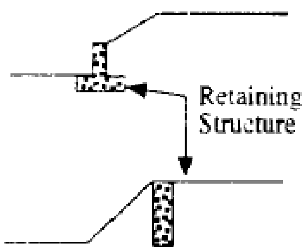
Landfill Siting - Stability

1. Reduce slope height by excavation at the top

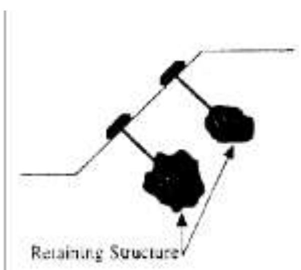
2. Flatten the slope angle
3. Excavate a bench in the upper part of slope

2. Earth Berm Fill

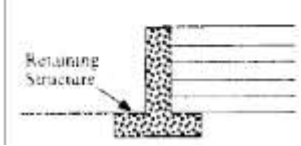
1. Compacted earth or rock berm placed at end beyond the toe. Drainage should be provided behind the berm



1. Retaining wall



1. Earth and rock angles



From US EPA