Landfills 101 Part 2: Conceptual Design

Lecture Objective

Provide a general introduction to landfills for an engineer who may not have had formal training.

Try to touch on all aspects and lay foundation for more advanced material.

Presentation Outline

- Overview of design process
  - Soils and groundwater
  - Infrastructure and surroundings

- Conceptual design of liners and covers

- Site Operations
  - Fill plan, covers, water management

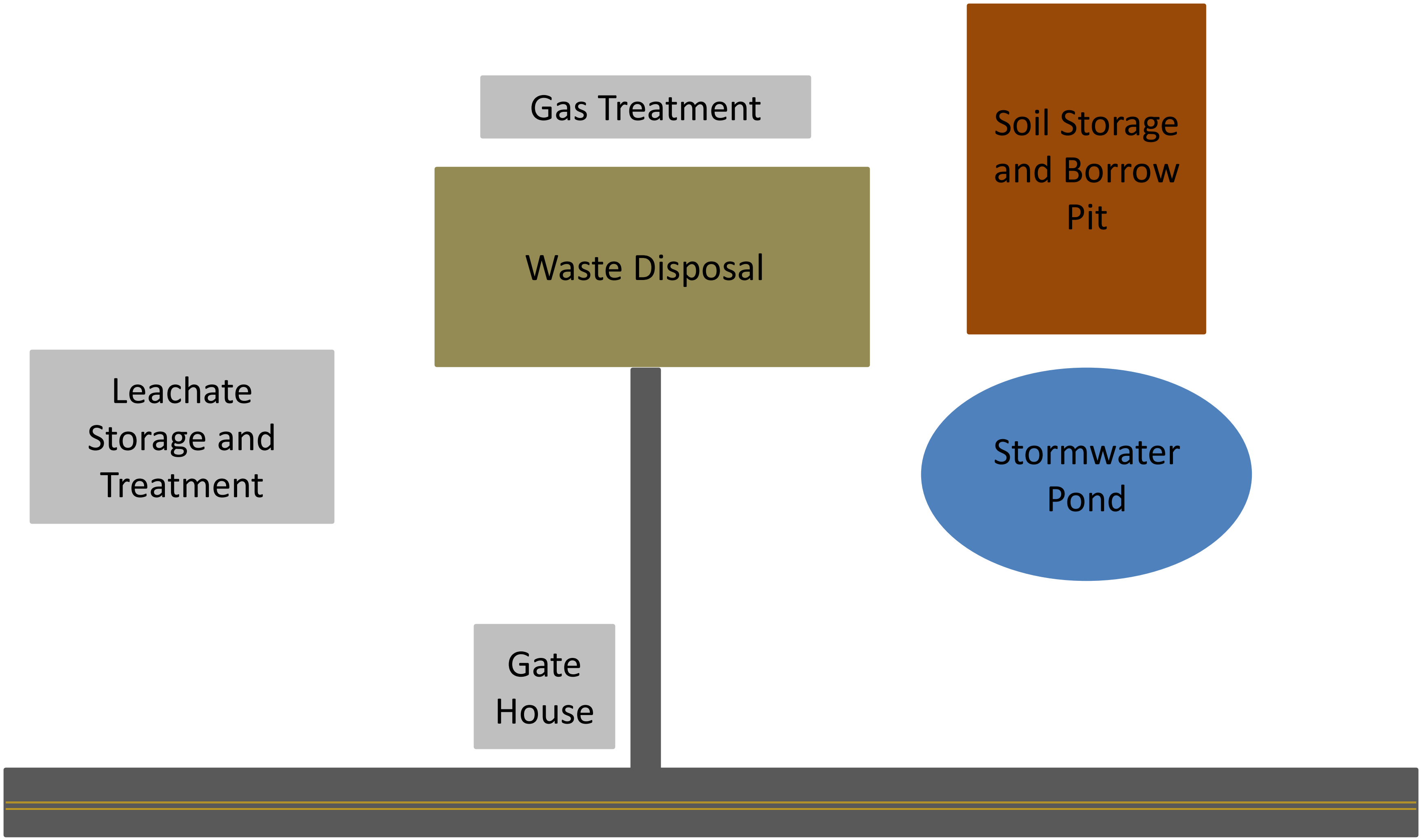
- Waste decomposition and landfill gas generation

- Leachate Quality

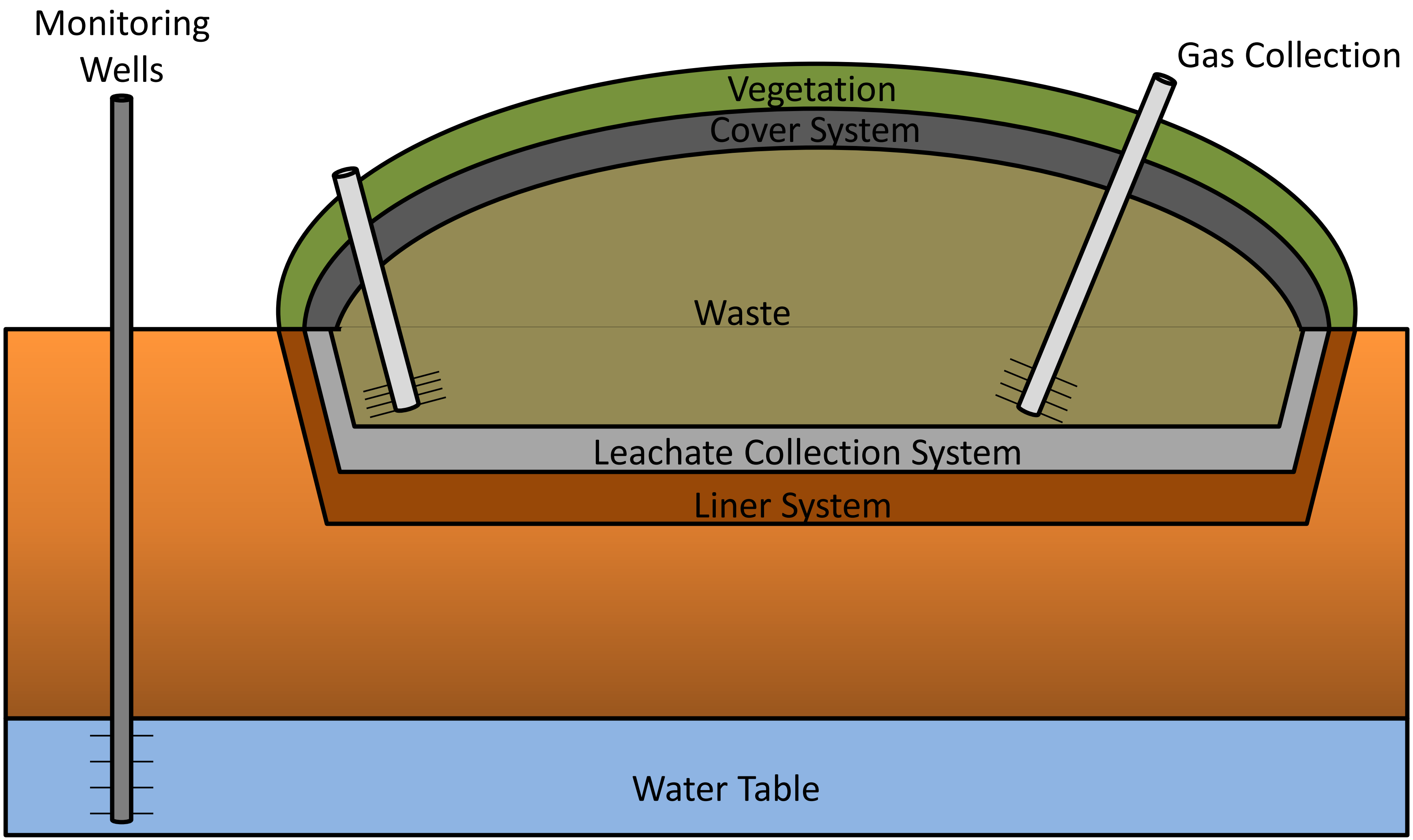
Design and Operation of Landfills

- Soils and hydrogeology
- Site layout and landfill operations
- Containment systems: liners and covers
- Water management
- Gas Production
- Leachate quality
- Groundwater
- Post-Closure monitoring
- Regulation

Landfill Site Plan (simplified)



Landfill Cross Section (simplified)



Design and Operation of Landfills

- Something for everyone
  - Geotechnical
  - Hydrology
  - Hydrogeology
  - Chemistry
  - Biology
  - Finance
  - Legal

The Design Process

1. Solid waste management planning

Public Sector

- Is a landfill needed?
  - Local or out of state?

Private Sector

- Is there a market for a landfll?
  - Where?

The Design Process

2. Identify permit and zoning conditions (state/local)
3. Site identification
   - Assess available land and eliminate unlikely candidates (wetlands, archaeology, floodplain, airport, politics)
   - Community interaction
   - Technical feasibility study - start spending money

The Design Process

4. Site design and preparation of permit application

    - Waste footprint
    - Layout of supporting facilities (storm water ponds, scale house, leachate storage and treatment)
        - Expansions
    - Airspace requirements
    - Soil balance
    - Leachate treatment alternatives
    - Utilities (roads, power)

The Design Process

5. Receipt of permit
6. Preparation of construction drawings and specifications

   Request for bids

7. Construction

   Certify construction QA/QC

8. Obtain operating permit
9. Operation

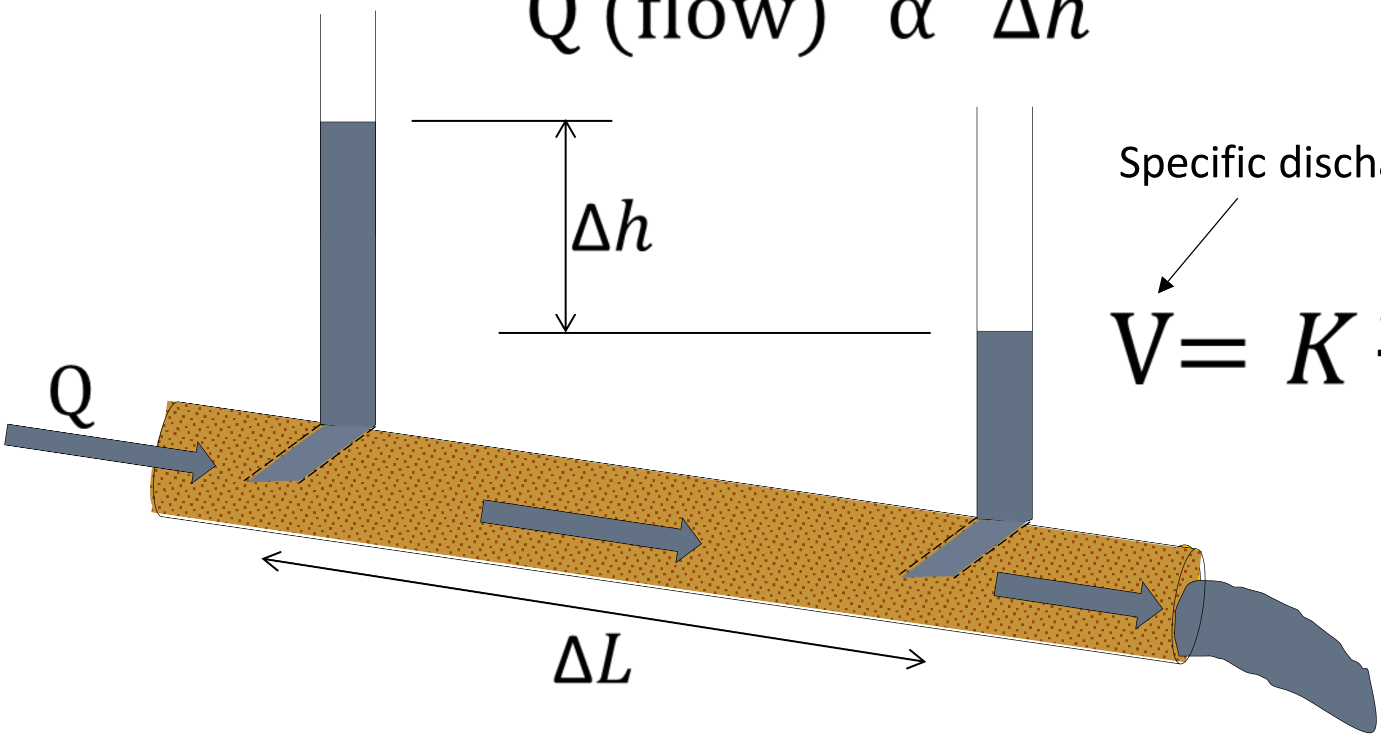
Groundwater and Soil Properties

- How water moves underground
  - must be able to understand potential impacts of a landfill on groundwater
  - direction of groundwater flow
  - changes in groundwater quality
- How are soils classified
- What soils are appropriate as liners, daily cover, drainage layers

Darcy's Law

- Defines the flow of fluids through porous media (soil)

$$Q\ (\text{flow})\ \alpha\ \Delta h$$



$$V = K\frac{\Delta h}{\Delta L}$$

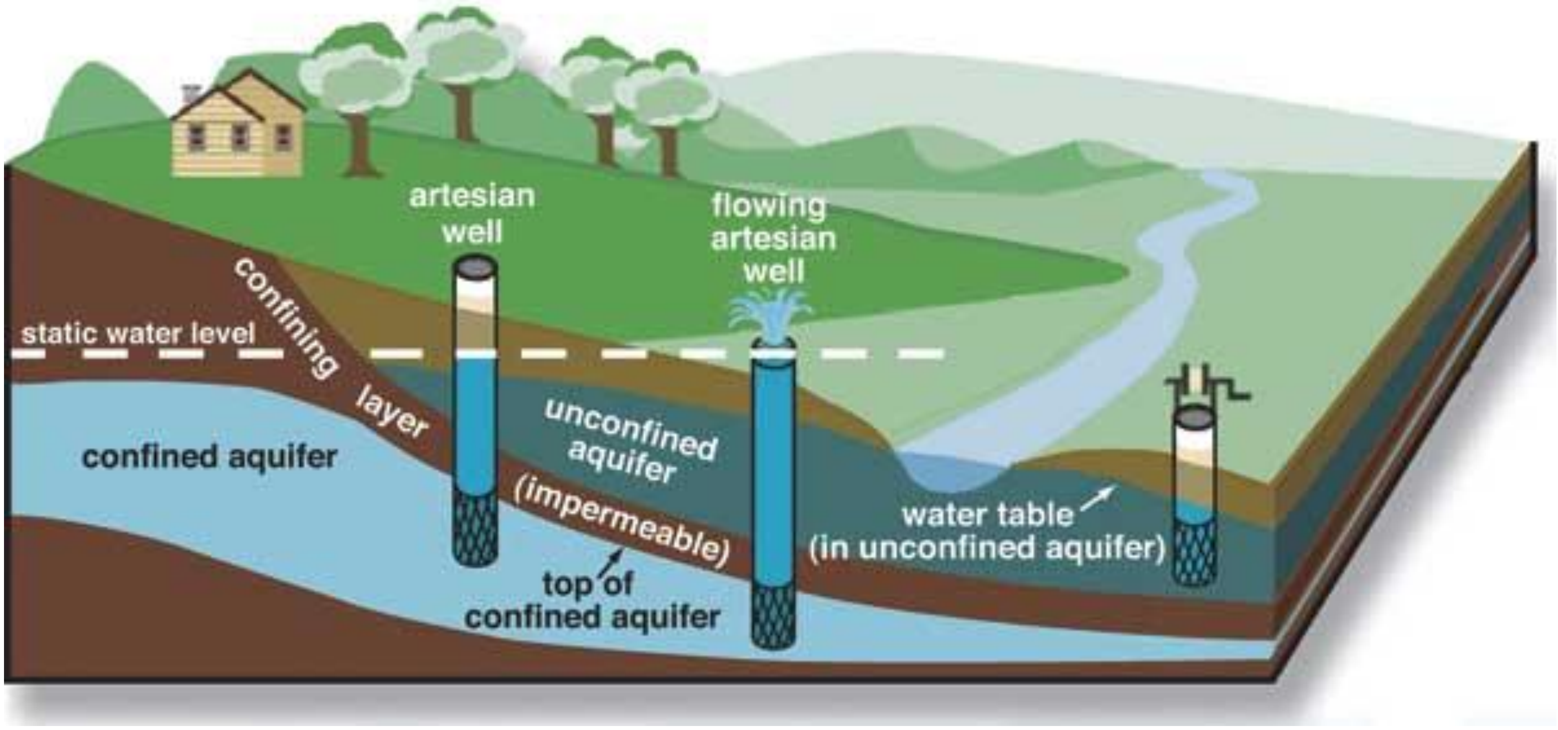
Typical Values of Hydraulic Conductivity

Gravel	$1 - 10^{-2}$ cm/sec
-Stone (#57)	1
-Pea gravel	10^{-1}
Sand	$10^{-2} - 10^{-4}$
- clean coarse sand	10^{-2}
- well graded	10^{-4}
Silt	$10^{-5} - 10^{-6}$
Clay	$< 10^{-6}$
Refuse	$10^{-3} - 10^{-6}$ (????)

Groundwater Flow in Aquifers

- Aquifer
  - transmits significant quantities of water under normal hydraulic gradients
- Confined Aquifer
  - an aquifer between 2 low conductivity layers
- Unconfined Aquifer
  - water table forms the upper boundary

Groundwater Flow in Aquifers



http://www.kgs.ku.edu/Publications/PIC/pic23.html

Site Assessment - Soils

- In order to evaluate the feasibility of a site, the available soils and underlying groundwater must be characterized
  - What types of soil are present on site?
  - Permeability of on-site soils:
    - Use for liner, drainage layer, cover material
  - Is there enough?
  - Availability of off-site soils
  - Depth to bedrock

Site assessment - Soils

- Perform soil borings and characterize soils visually and by lab analysis
- Borings per acre:
  - Suitability – 1/acre
  - Detailed design – 10/acre

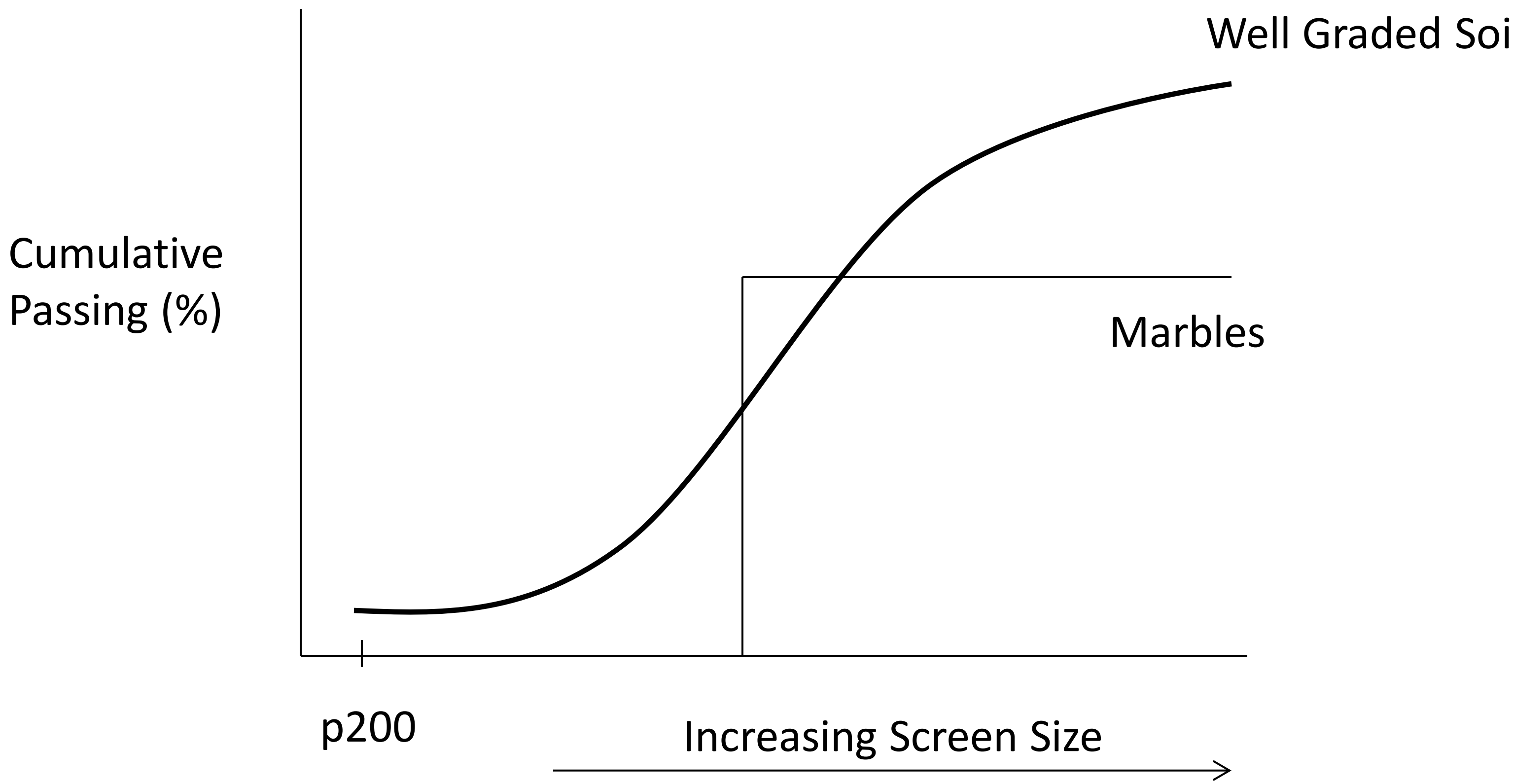
Major Divisions

- Gravel
  - Rounded pebbles, no cohesion
- Sand
  - Granular loose grains, easily visible, no cohesion, settles rapidly
- Silt
  - Barely visible grains, no cohesion, will settle in water in 30-60 minutes
- Clay
  - Invisible cohesive particles, will remain suspended in water for a minimum of several hours

Clays

- The fines fraction is frequently referred to as the p200 fraction - the fraction passing a 200 screen
  - A small decrease in p200 can result in a large increase in conductivity due to changes in grain size distribution
- Slippery when wet
- Difficult to work with or drive on
- Absorb large quantities of water and swell, then shrink as they dry, developing large cracks
  - Freeze/thaw

Grain Size Analysis



Can we make clay?

- <u>Bentonite soil amendment</u>
  - 2 - 8% bentonite will achieve 10^{-8} cm/sec
  - ~30 \$/yd^3 to mix bentonite into native soil and compact

Boring Log

LOG OF BORING NO. LG-9

CLIENT
PROJECT NAME
PROJECT LOCATION
BORING LOCATION Sta 126 + 34 Offset 1' lt
FOREMAN
INSPECTOR

JOB NO.
DATE 12/5-6-10/85
BORING METHOD HSA
ROCK CORE DIA. NX IN
SHELBY TUBE DIA. ___ IN
CASING DIA. ___ IN.

SURFACE ELEVATION 250.8

MATERIAL DESCRIPTION	STRATUM DEPTH, FT.	DEPTH, FT.	Sample No. (Core Run #)	BLOWS/6 IN. THREE 6 IN. INCREMENTS	RECOVERY In.	Casing Blows	BORING AND SAMPLING NOTES
Red brown, moist, very stiff, Silty CLAY, some medium to fine Sand (MH)			S-1	3 8/10	16		PP on S-1; qu = 2.0 tsf
Red brown, moist, very stiff, Silty CLAY and medium to fine Sand (MH)	5.5	5	S-2	6 9/12	18		PP on S-2; qu = 2.3 tsf
Tan to brown to black, moist, medium dense, coarse to fine SAND, trace Silt (SW)	8.0		S-3	6 8/8	16		
Tan, moist, very dense, coarse to fine SAND, some Silt, little fine gravel rock fragments (decomposed Gneiss) (SM)		10	S-4, S-5	80/2"	2		Spoon refusal at 8.5' attempted to core- broke thru hard seam of decomposed rock at 9.0'
Orange, tan, moist, very dense, coarse to fine SAND, trace Silt, trace fine gravel rock fragments, (decomposed Gneiss) (SW)		15	S-6	100/5"	3		15.5' to 16.0' drill thru hard seam
	16.5		S-7	100/1"	0		
C-1, Gneiss, white to orange moderately hard, unweathered			C-1*		2		*Core barel malfunct- ion
C-2 same C-1	20.0	20	C-2		30		Only 2" of recovery Barrel must be re- placed
Bottom of boring 20.0'							RQD = 23/30"

WATER LEVEL OBSERVATIONS
NOTED ON RODS ____ FT.
AT COMPLETION 9'8" FT.
AFTER ____ HRS ____ FT.

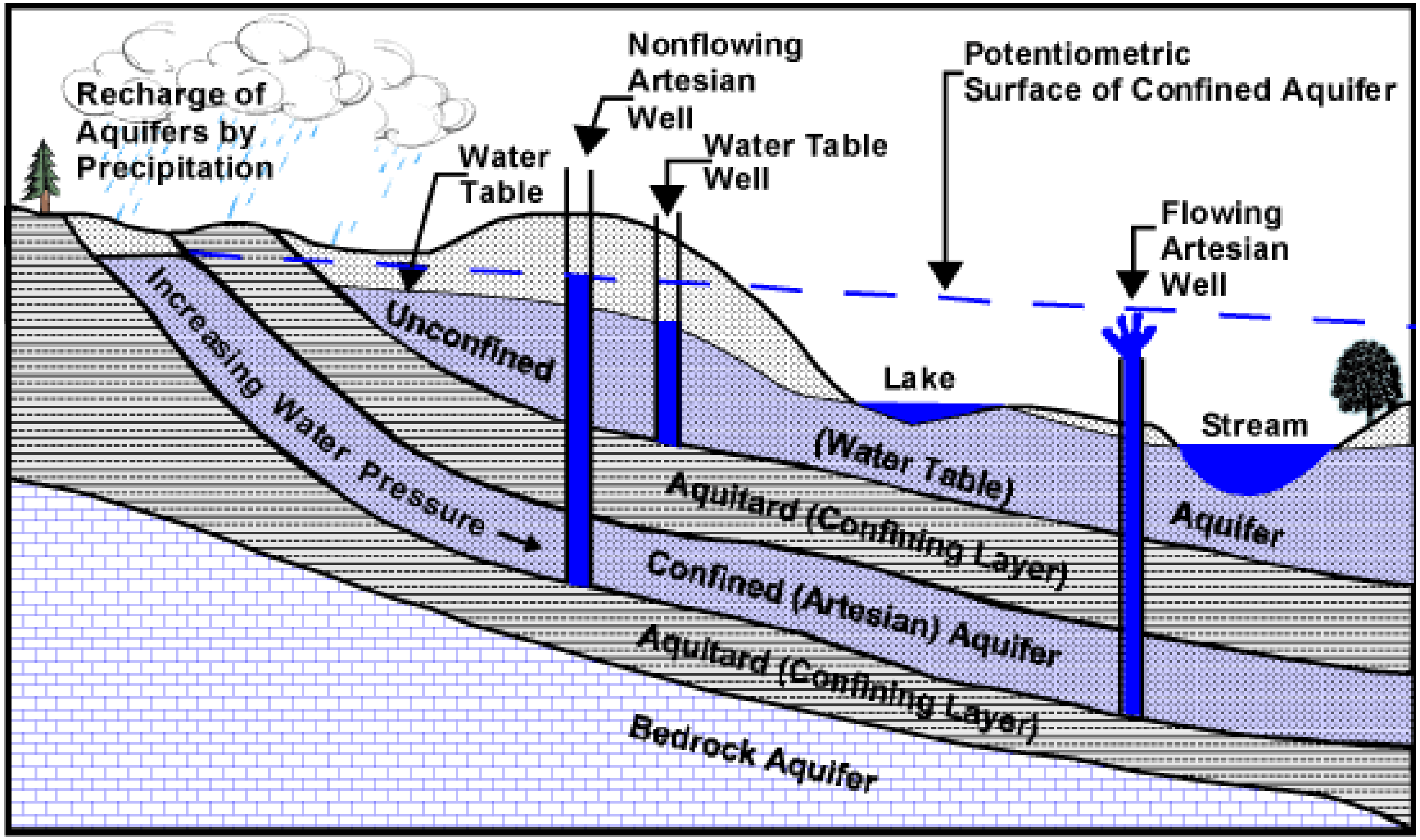
BORING METHOD
HSA — HOLLOW STEM AUGER
CFA — CONTINUOUS FLIGHT AUGER
DC — DRIVEN CASING
MD — MUD DRILLING
RC — ROCK CORING
CA — CASING ADVANCER

SAMPLE TYPE
S- Splitspoon
U- Undisturbed
C- Core Run

Groundwater

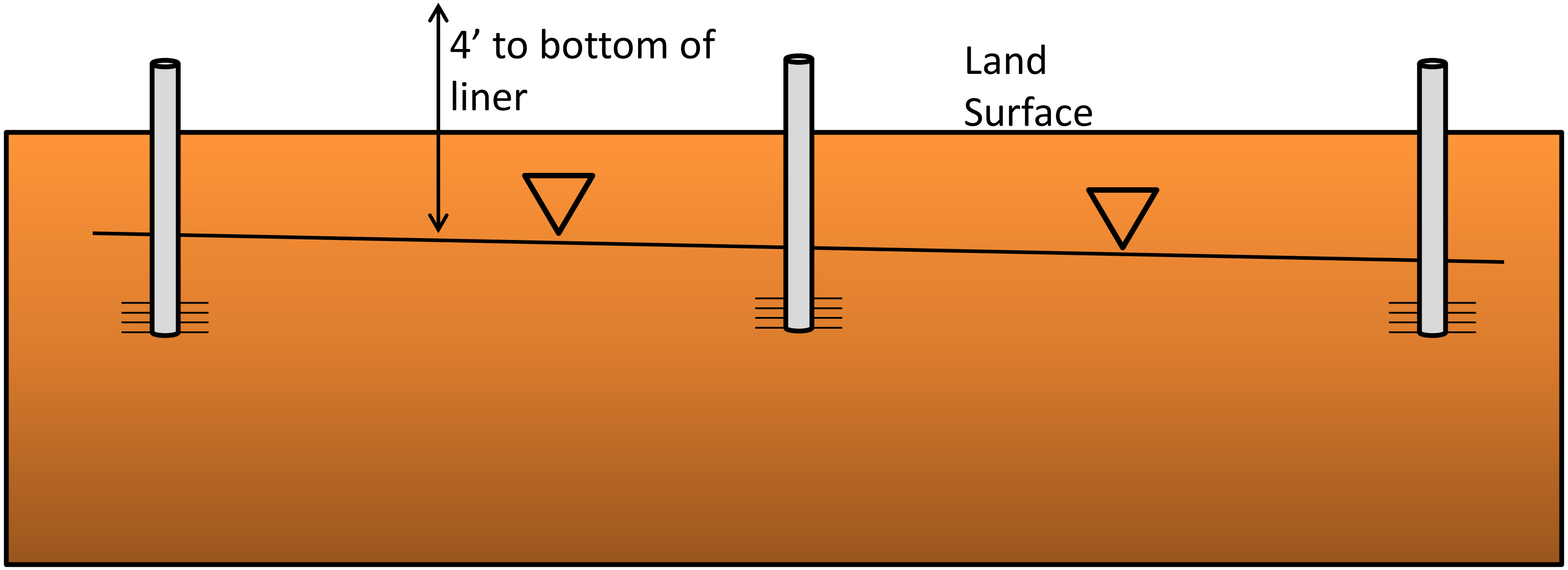
- Seasonal high water table
  - Bottom elevation of liner must be at least 4 feet above water table
- Present and potential uses
  - (Well inventory)
- Groundwater quality
- Map of potentiometric surface

Potentiometric Surface

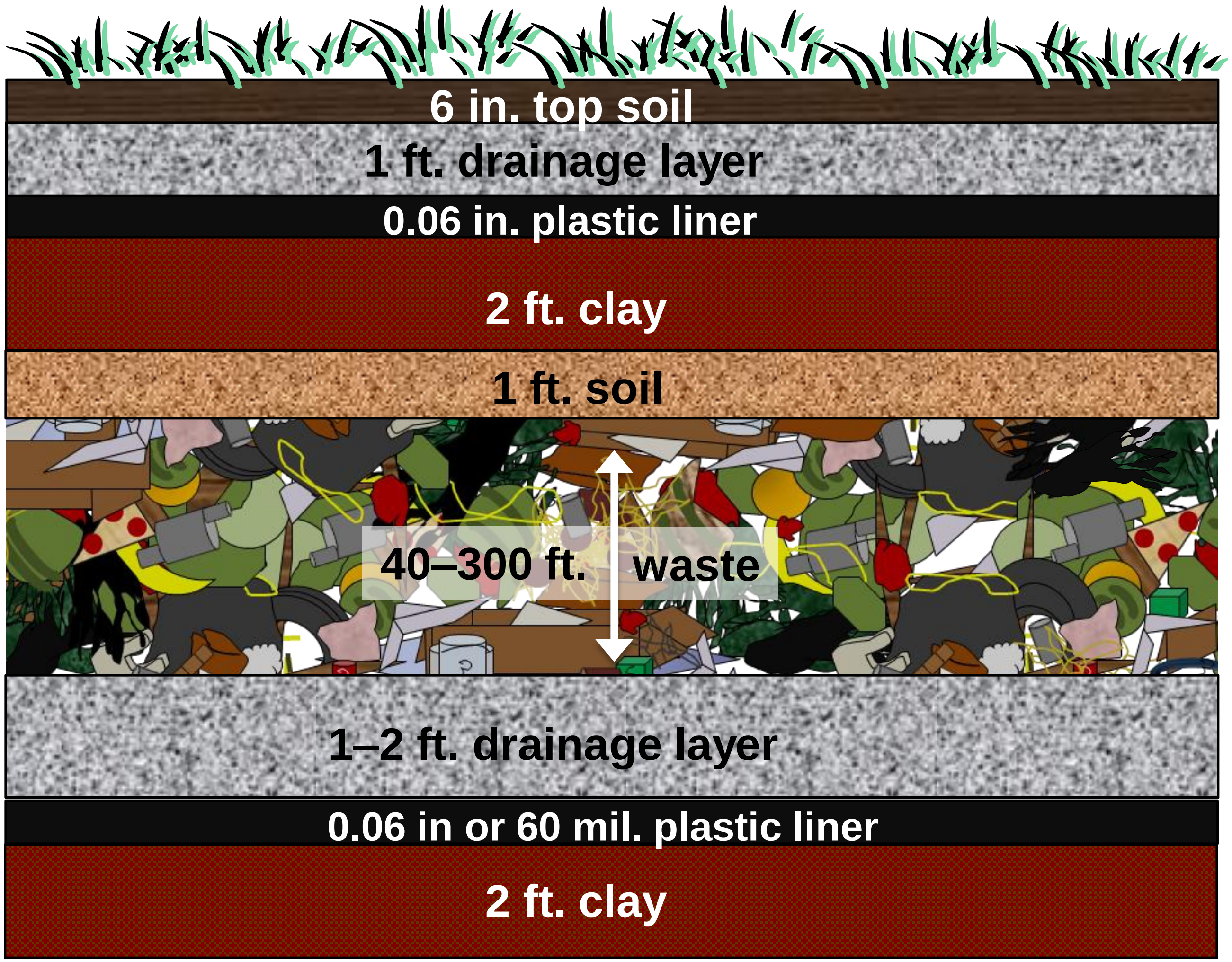


http://www.in.gov/dnr/water/7258.htm

Potentiometric Surface



Conceptual Landfill Liner System



Landfill Liner and Cover Systems: Design Guidelines

- A liner suggests a single layer, a liner system suggests a series of layers working together
- Leakage from liner systems can be very low with proper engineering and construction
- Design principles versus regulations

Geosynthetics

- Synthetic polymers
  - Polyethylene and polypropylene most common
- Geotextiles (relatively permeable)

  - Separation and Filtration
    - Retain soil particles
    - Let water pass
    - Do not clog over time ??
  - Typically used to protect a leachate collection system from clogging

Geosynthetics

- Geonets
  - Substitute for sand or gravel
  - Very high transmissivity, low storage

Geosynthetics

- Geomembrane (low permeability)
  - Vapor and liquid barrier
  - Diffusion may control
- Sheets 23 - 35' wide, 60 - 80 mil thick
- Smooth vs. textured

Geocomposites

- A combination of any of the above
- Geobentonite composites:
  - Include a layer of bentonite between two layers of geotextile
  - Geosynthetics may save airspace

Typical Design Guidelines

- Sub-base
  - 6 - 12" thick
  - Compact to 95% of maximum density
  - K $<$ 10^{-5} cm/sec
  - Slope: 2 - 25% or 1V:4H
  - Soil must be rock free
    - $<$3/4” if geomembrane in contact
    - $<$1.5” if clay contact

Secondary Liner
Final Protection Between Waste and Environment

- Clay @ $<10^{-7}$ cm/sec compacted in 6” lifts
- Overlain by a geomembrane
- Possibly a geobentonite instead
- Must present and follow a QC/QA program
    - Quality Assurance - 3rd party inspector

Leachate Detection Zone

- Must rapidly detect, collect and transmit liquid to a collection system
- Function without clogging
- 12" thick
- K $>$ 10^{-2} cm/sec (gravel or geonet)
- Contain a perforated piping system at least 4" diameter, sch 80
  - Wrapped in a geotextile
- Slope $\geq$ 2%
- Distance for flow $\leq$ 100' (200' on centers)

Primary Liner System

- Prevent leachate migration and force water into overlying leachate collection system

Options:

1. Compacted clay + geomembrane

   Clay: 2' - 3' compacted in 6" lifts

   geomembrane - 60 mil

2. Geobentonite + geomembrane

Must follow a rigorous QC/QA program

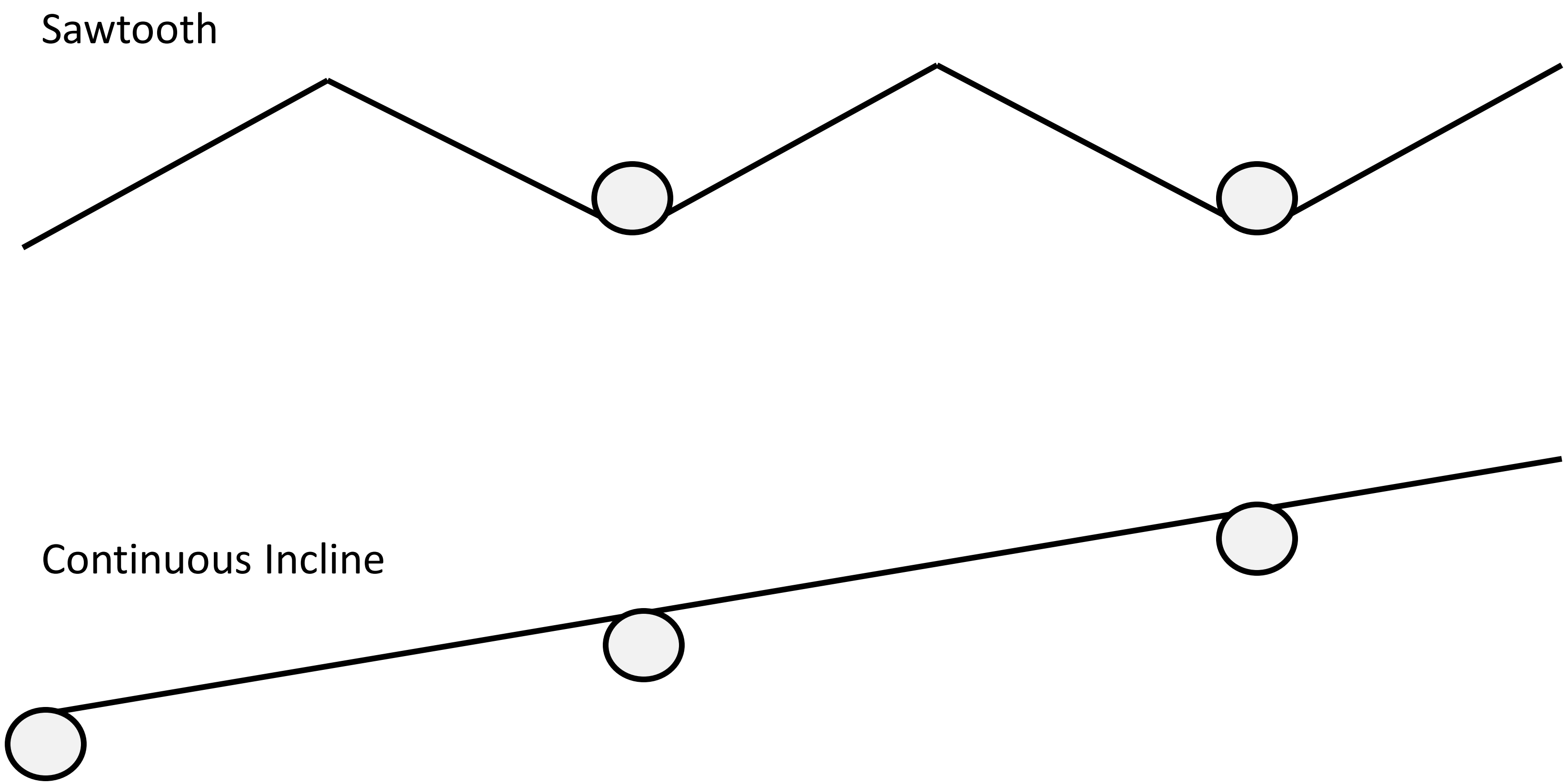
Leachate Collection and Removal

- Must cover bottom and sides of landfill
- Function without clogging (biological, chemical, physical)
- Keep head on liner $\leq$ 12"
- 12 - 18" thick
  - 24” between liner and waste
- K $\geq 10^{-2}$ cm/sec (move towards stone)
- Contain a perforated piping system typically 6" diameter, sch 80 surrounded by non-carbonate stone, wrapped in a geotextile (??)

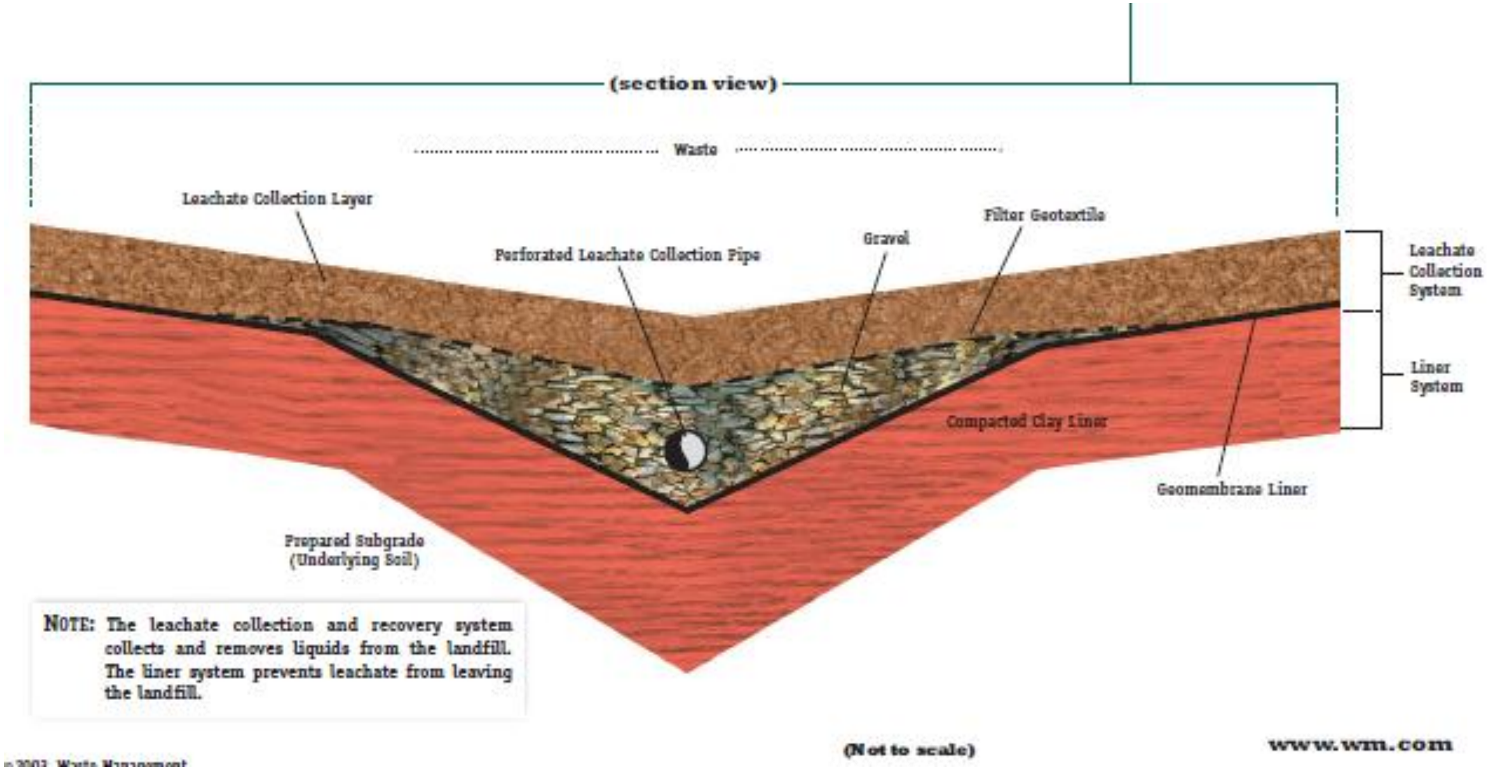
Leachate Collection and Removal

- No stone > 0.25”
- Slope ≥ 2%
  - 8” Headers typically at 1% - 2%, provide cleanouts
- Distance for flow ≤ 100’ (200' on center)
- Some protection above the leachate collection system is needed
- Options include:
  - Baled refuse
  - Additional soil
  - Tire chips
  - Layer of uncompacted <u>select</u> refuse

Leachate Collection Systems

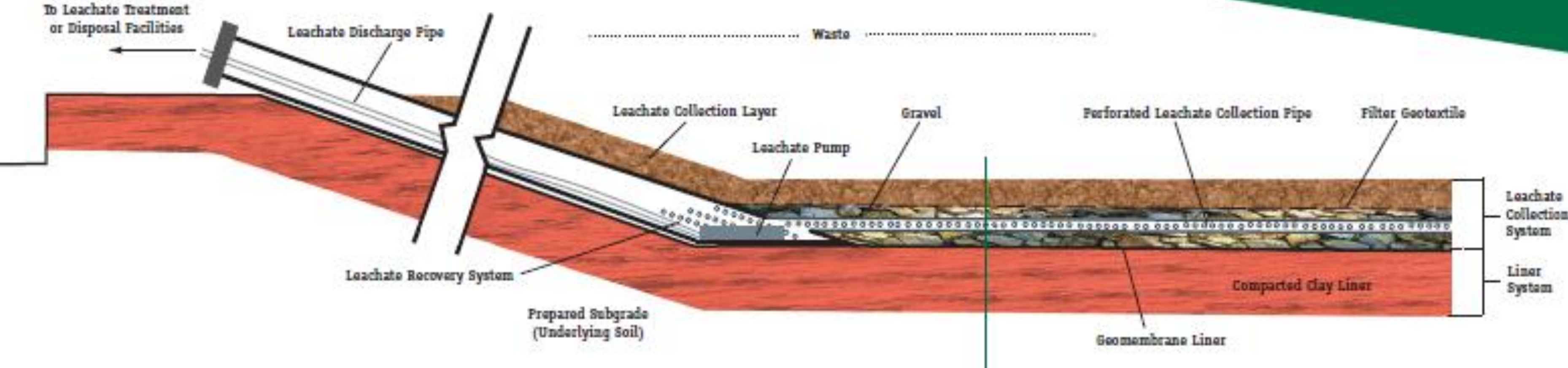


Leachate Collection Systems



Slide Courtesy of Waste Management

Leachate Collection Systems



Slide Courtesy of Waste Management


P2C3

Liner Slopes

- Maximum slope is 3(h):1(v) both above and below grade
- Excavations
  - Sand 2:1
  - Clay 0.5:1
  - Other 1:1

Final Cover

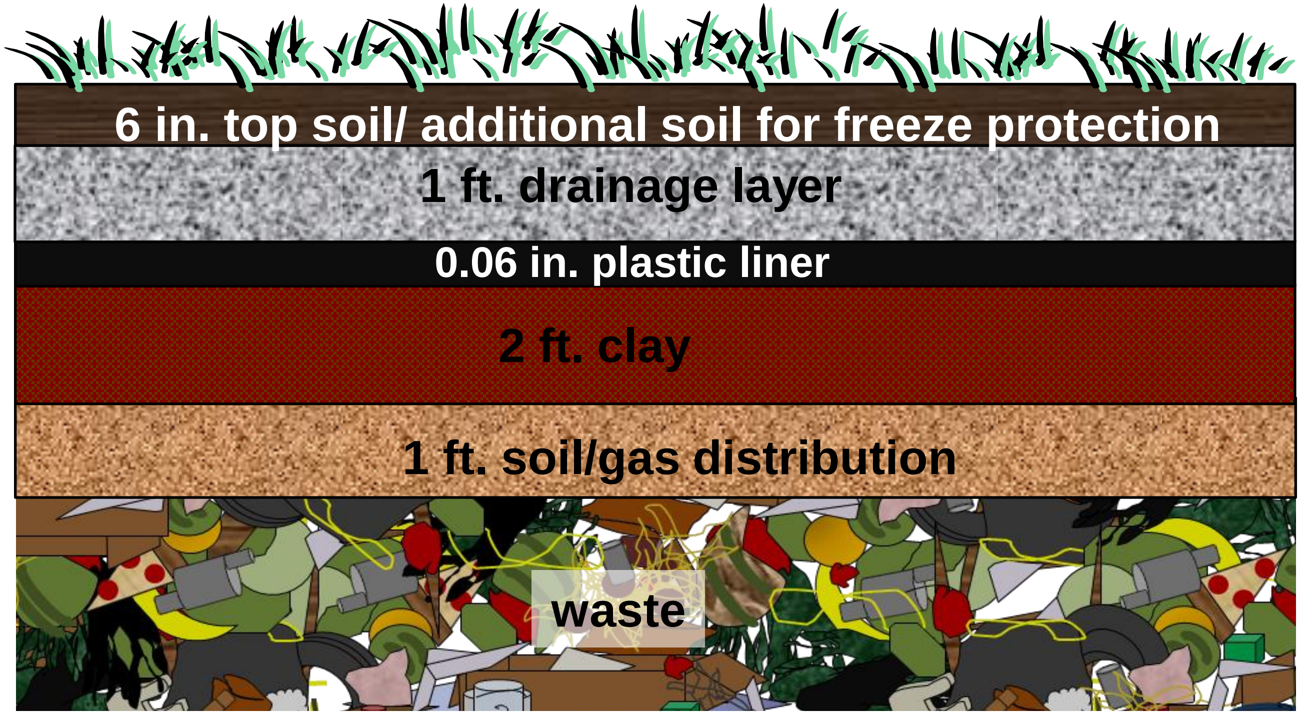
Functions:

- keep water out
- control runoff
- separate the waste from plants and animals
- gas collection/odor control

Complicating Factors:

- plant root penetration
- freeze/thaw
- vehicle haul roads
- differential settlement

Cover Cross Section



Clays

- Hard to compact over sand or refuse
- Desiccate and shrink from both top and bottom
- Thin layers (even 18") of cover do not prevent desiccation
- Final grade > 3% on top, slopes @ 3:1

Vegetation

- Objectives
  - Stabilize soil
  - Minimize erosion
  - Promote evapotranspiration
- Next possible planting season
- > 70% ground cover
- No deep rooted plants or shrubs

Additional Considerations

- Practice is to place final cover once site (or cell) is full
- Differential settlement will cause cracks in clay, geomembranes are more resistant and recommended
- Ideal - use an intermediate cover until settlement is complete
  - Financial implications
    - Recover airspace
    - Less maintenance
  - low permeability desirable for gas collection

Final Use

- Decide during design phase
- Can expect settling of 5 - 15%, more for bioreactors
- Open space / conservancy
- Park - requires more maintenance and cover soil
- Gravel parking lot
- Golf course

Summary

- Liners vs. Liner Systems
- Landfills are built in increments – cells that hold 2-5 years of waste

Landfill Layout and Operation

- Scalehouse
- Truck washing area
- Drop-off areas
  - recyclables, HHW, white goods, tires, oil, car batteries
  - yard waste - possibly composting
- Construction and demolition debris
  - unlined section??

Fill Plan

- Daily cell - typically the amount of refuse received in one day and covered
  - Not to be confused with a larger cell
  - 4’-20’ high, 8’-12’ typical
  - Minimize size to control odors but also have to get trucks in and out
- Orient working face to minimize wind
  - Placement of temporary litter control fence

Fill Plan

- Size working face to minimize at-site time to extent practical
  - ~20’ per vehicle
- Normal vs. wet vs. windy weather disposal areas

Daily Cover

- Protects Against:
  - wind blown debris
  - odor
  - animals
- Minimize the amount of cover needed
  - historically soil at a ratio of:
    - 4 yd^3 refuse/ 1 yd^3 soil
  - now 9:1 is more typical, includes scraping some off in the morning
- Stockpile cover for wet and freezing periods
  - excavate in areas of southern exposure

Alternative Daily Cover

- Foams which are sprayed on and last overnight
  - Posi-shell
- Compost
  - Mixed waste residual from a MRF
  - Yard waste
- Plastic sheet
  - one use
  - multiple use
- C&D fines (without wallboard)

Alternative Daily Cover

- Revenue generating material
  - contaminated soil
  - foundry sand
  - ash
  - auto shredder fluff
  - C&D fines
- Use soil as a fire break weekly

Plastic Sheets Pulled Over Refuse

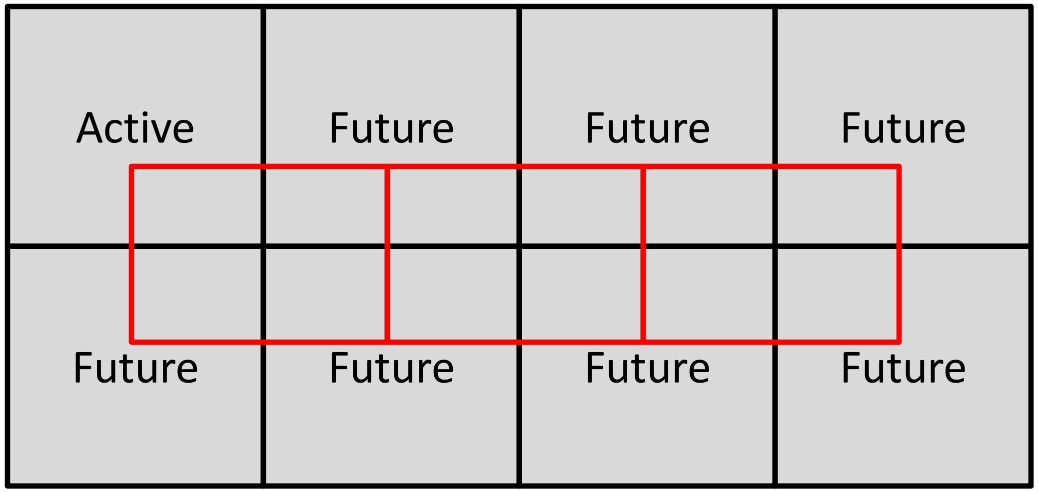
- Lifecycle - 30 applications per panel
- Must be held in place with soil, sandbags, tires
- One time use:
  - 4 mil film, punch holes in morning

Plastic Sheets Pulled Over Refuse

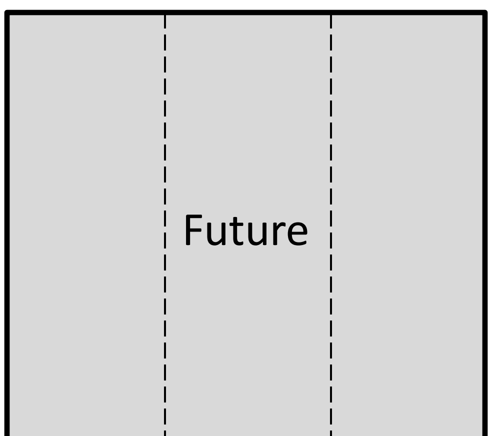
Site Hydrology

- Run-on must be minimized through the use of diversion ditches
- Design for 25 year storm
- Manage water so minimum amount is contaminated
  - Temporary berms
- Phased construction to avoid stormwater accumulation
- Valving/berm to segregate clean and contaminated water
- Sediment ponds to treat clean runoff
- Test impounded water before release

Site Hydrology



Detailed cell



Temporary berms to separate storm water from leachate

Personnel

- scale attendant /record keeper
- equipment operators
  - compact refuse
  - Push refuse
  - haul cover ?
- litter control
- traffic control
- manager
- mechanic/handyman
- site engineer - monitor fill plan
- miscellaneous

Personnel

2500 TPD Site:

- 1-traffic control
- 2-compactors
- 2-laborers
- 1-gate attendant

Refuse Density

- AUF – airspace utilization factor
- Allow 1200 - 1500 lb/yd^3 initially
- This values allows for:
  - cover soil
- AUF increases with settlement

Landfill Fires

Causes

- hot loads
- lightening
- cigarette butts
- hot equipment
- aeration due to wind
  - spontaneous combustion?

Landfill Fires

- Most occur on windward side slopes
- Spreading from burning grass
- Practices to minimize potential for fire:
  - good compaction
  - soil cover daily
  - load screening

Biological Transformations of Refuse

- <u>Aerobic decomposition</u>
  - Organic matter + O_2 → CO_2 + H_2O + NH_3 + Heat
  - NH_3 + O_2 → NO_3
  - This is composting - air is supplied to refuse
- <u>Anaerobic decomposition</u>
  - Organic matter ---> CO_2 + CH_4 + NH_3 + H_2S
  - This occurs in landfills
  - Methane is only produced in the absence of oxygen

Methane Production From Landfills

- Landfill gas = $CH_4 + CO_2$
- Methane production rate = CH_4
- Must specify temperature and pressure

Methane Production From Landfills

- Composition under steady methane production

CH_4	50 - 70%
CO_2	30 - 50
N_2	2 - 5
O_2	0.1- 1 indicates over pumping
H_2	0- 0.2
CO	0 - 0.02
Trace*	0.01 - 0.6

* petroleum hydrocarbons, chlorinated aliphatics, alkanes, ketones, aldehydes, alcohols, terpenes, siloxanes, H_2S

- Pumping scenario will influence oxygen and nitrogen content significantly

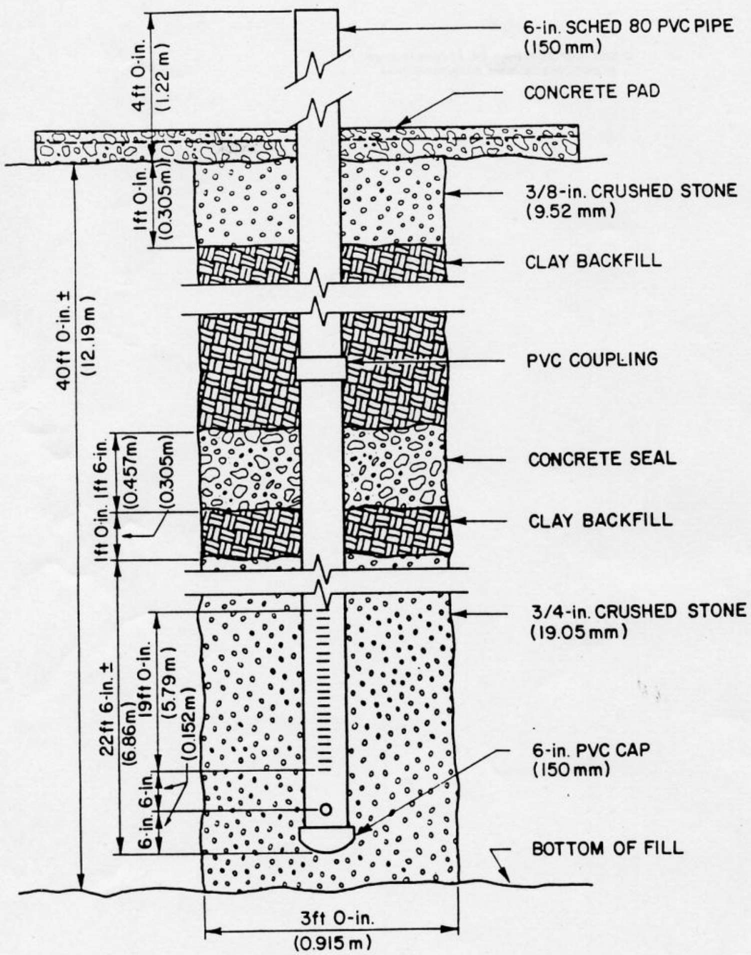


Figure 4-2. 36" Well Installation (2 Required)

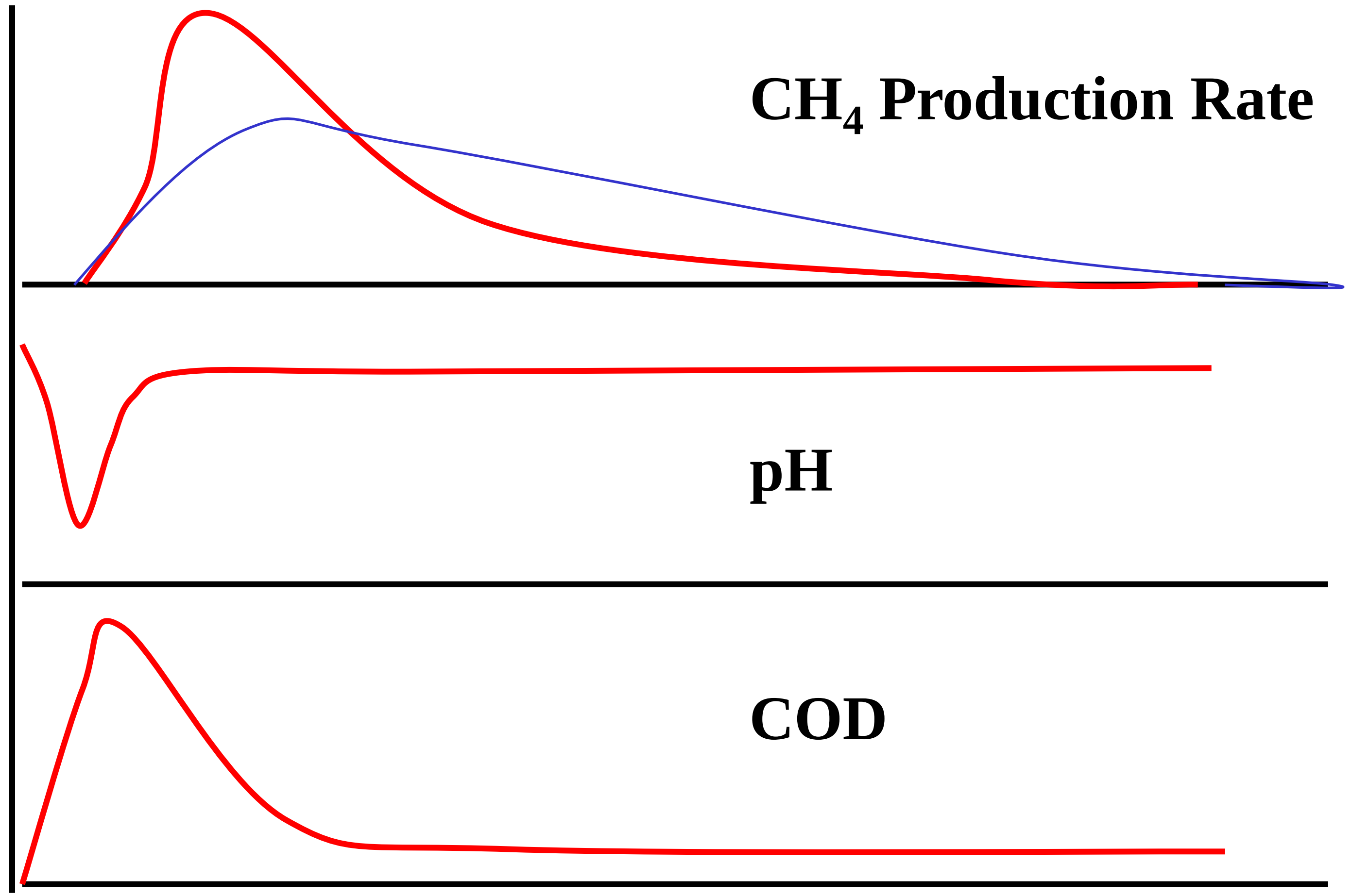
Biodegradable Substrates

- Paper, yard waste and food waste are comprised of cellulose and hemicellulose
- These compounds are converted to CH_4 and CO_2 by bacteria under anaerobic conditions
- Several groups of bacteria are involved

Refuse Decomposition

- Refuse decomposition is affected by:
  - Climate, surface hydrology, pH, temperature, operations
- Exerts an influence on:
  - Gas composition and volume
  - Leachate composition

Trends in Methane, COD, and pH



Landfill Gas Modeling

$$Q_n = k \cdot L_0 \cdot \sum_{i=0}^{n} \sum_{j=0.0}^{0.9} \frac{M_i}{10} \cdot e^{-k \cdot t_{i,j}}$$

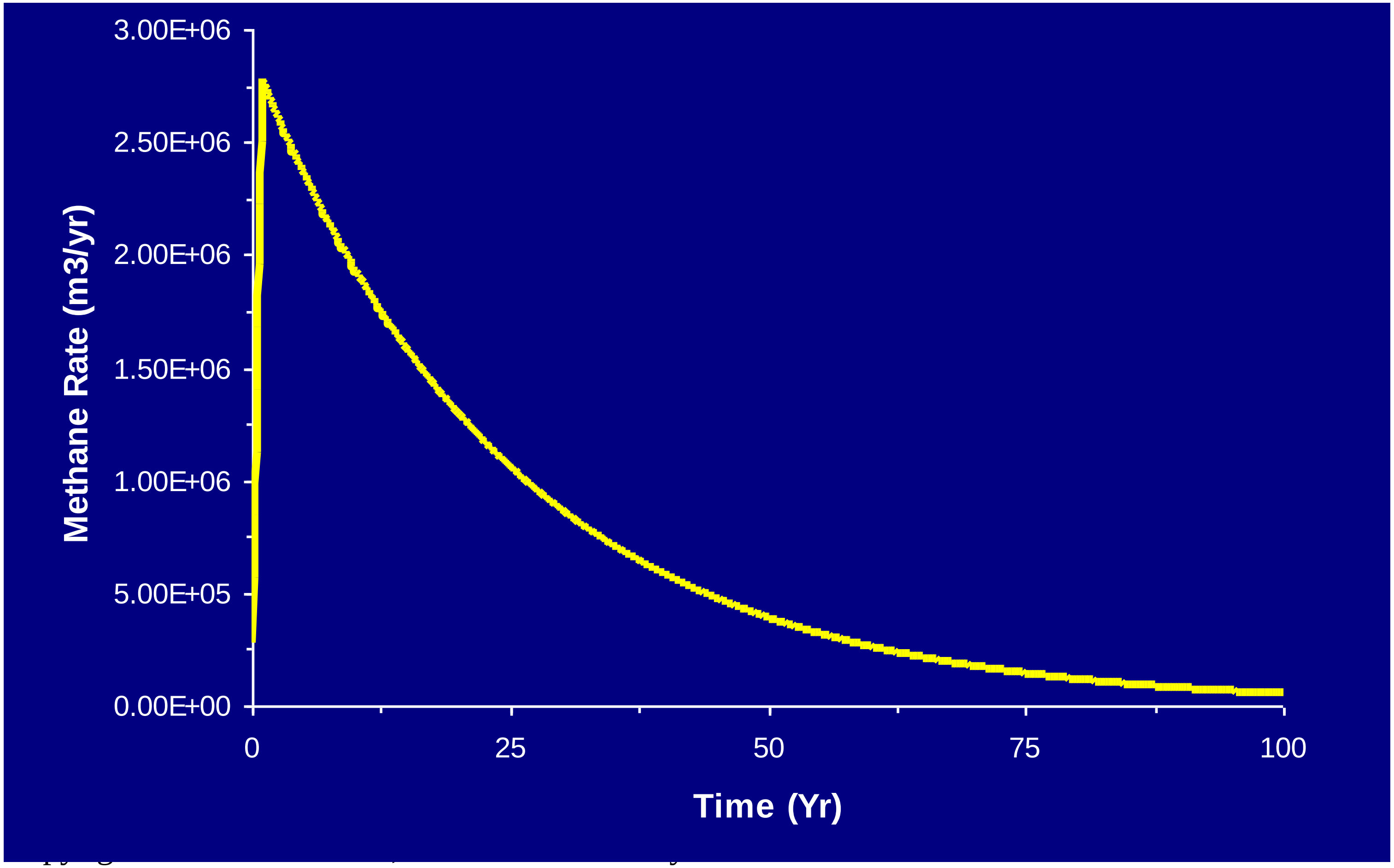
- **Q_n** is annual methane generation for a specific year t (m^3 CH_4/yr);
- **k** is first order decay rate constant (1/yr)
- **L_0** is total methane potential (m^3 CH_4/ton of waste);
- **M_i** is the annual burial rate (wet tons)
- **t** is time after initial waste placement (yr);
- **j** is the deci-year time increment

Landfill Gas Emissions Model (LandGem)
http://www.epa.gov/ttn/catc/products.html#software

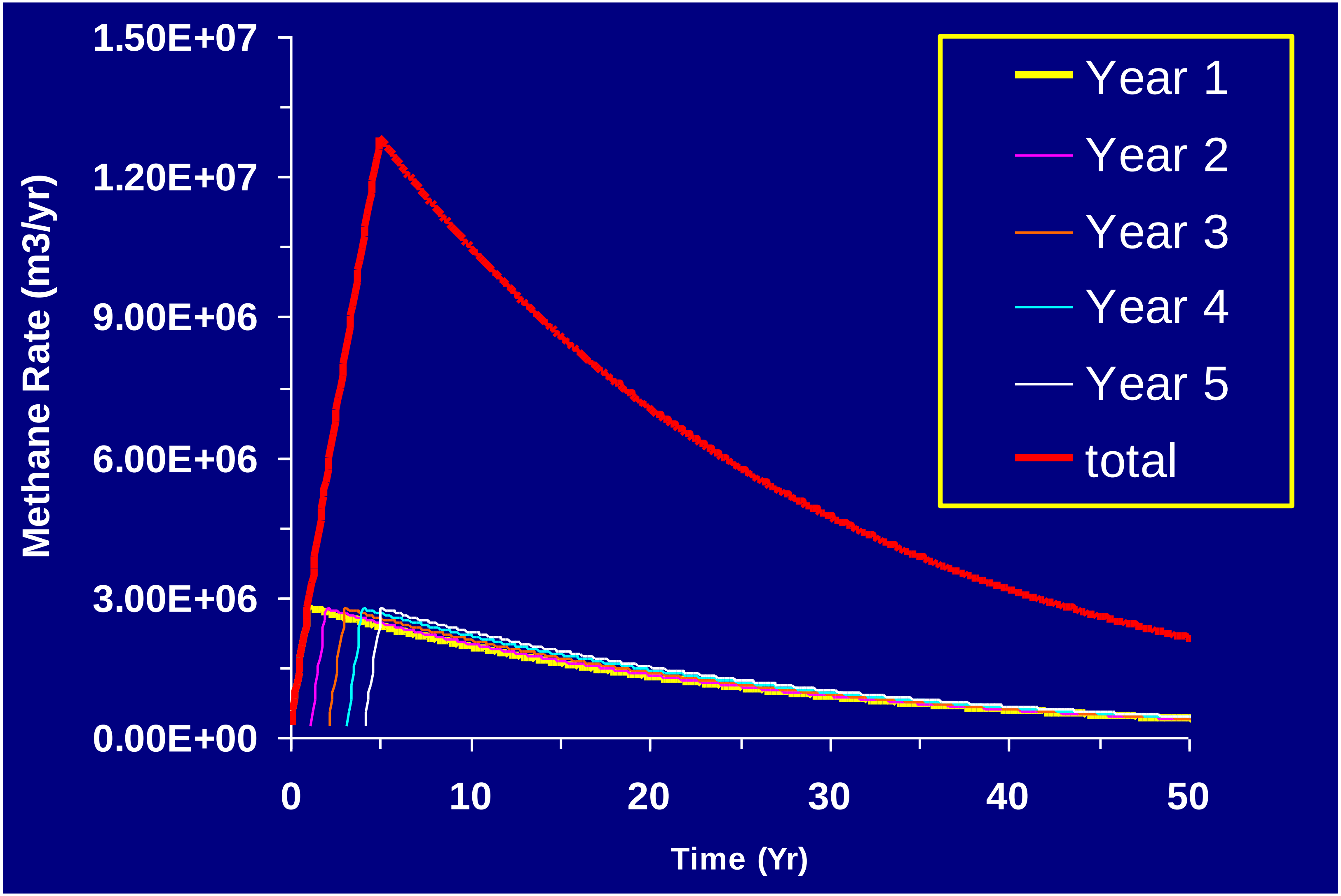
Landfill Gas Modeling

- Understand difference between production and collection
- Must assume a collection efficiency to apply over entire landfill life
- Decay rate will vary dependent upon climate and operating conditions

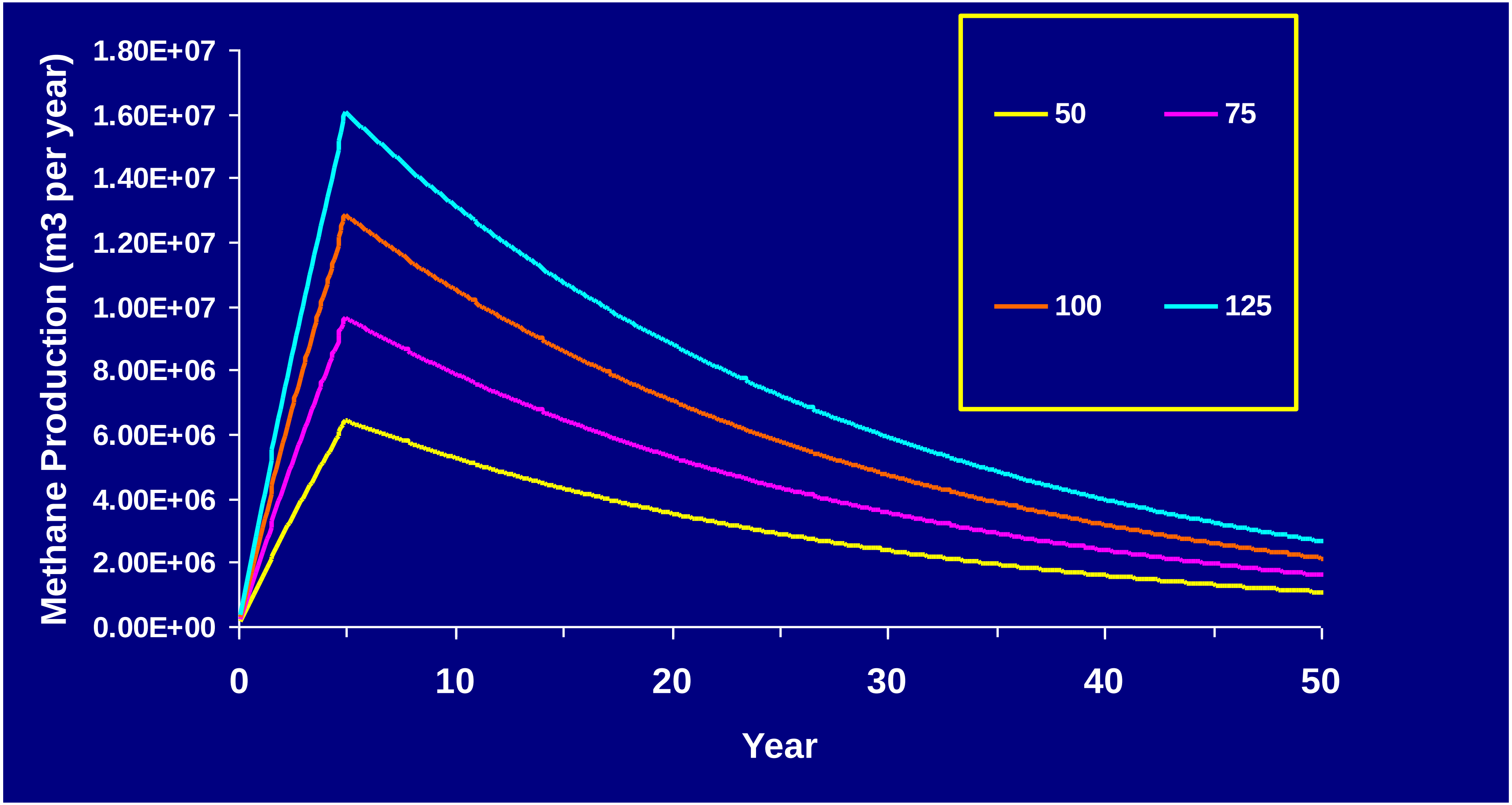
Methane Production Rate Curve for One Year of Waste



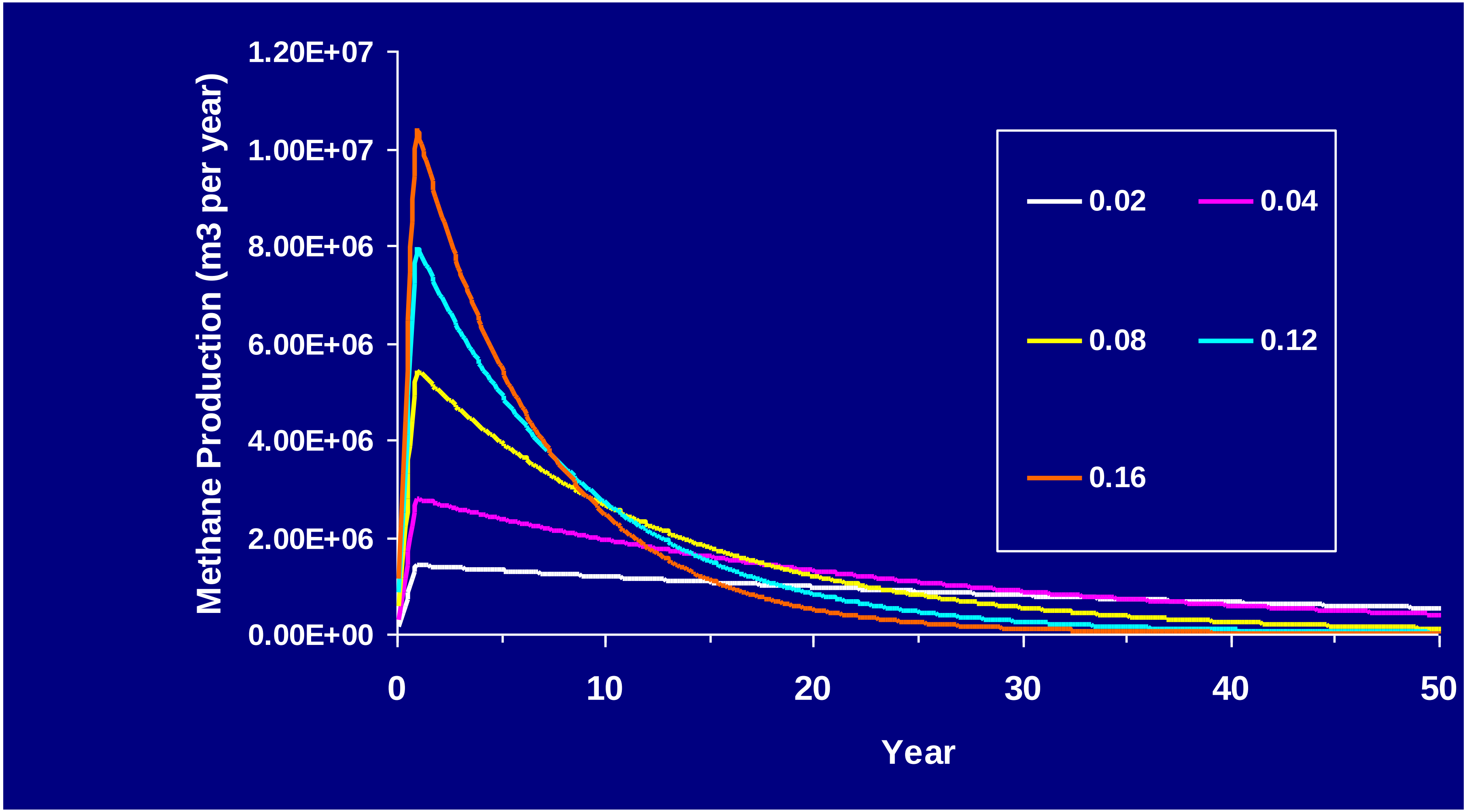
Methane Production Rate Curve for Five Years Waste



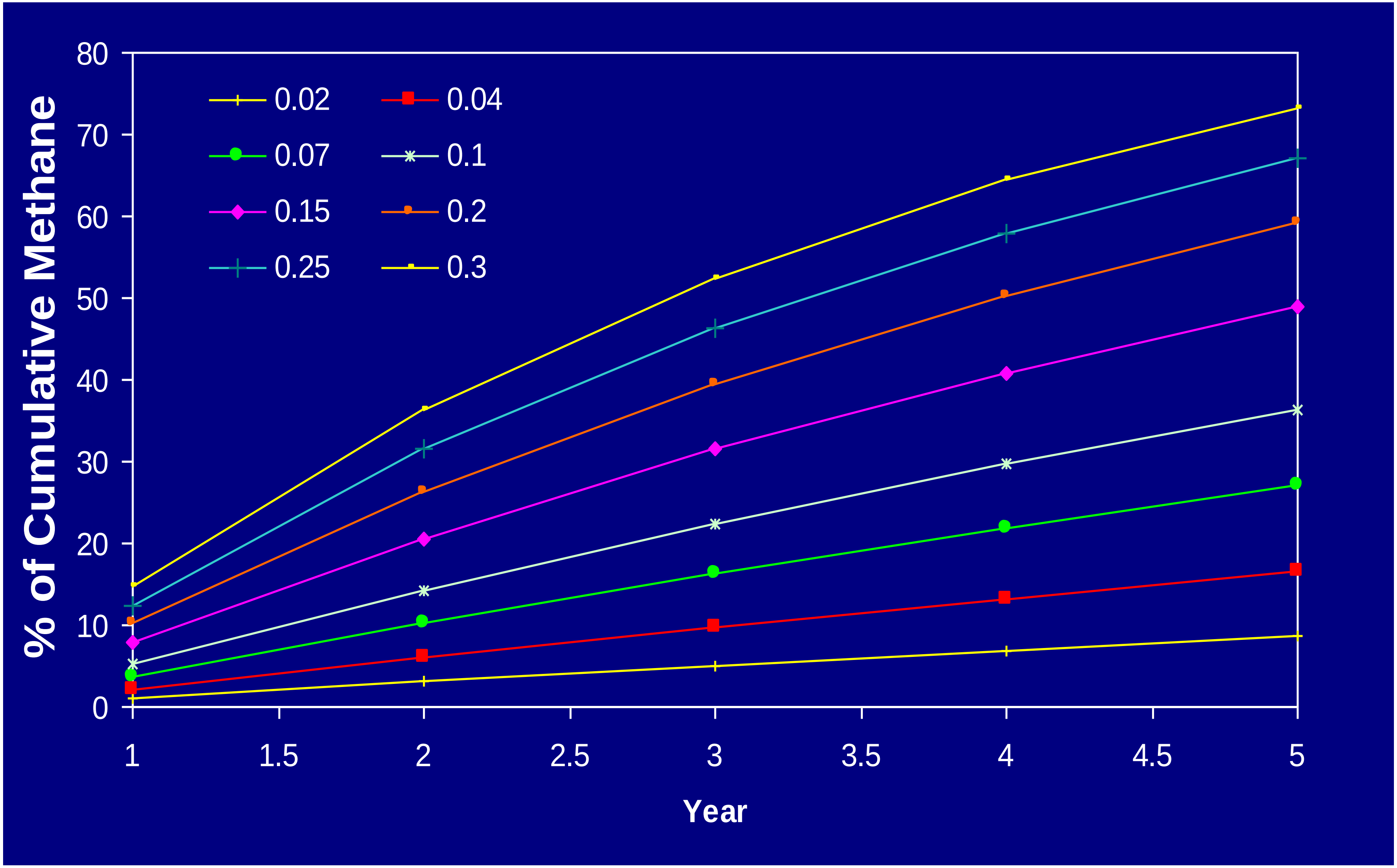
Effect of L_0 on Methane Production



Effect of Decay Rate (k) on Methane Production



Effect of Decay Rate (k) on Methane Production

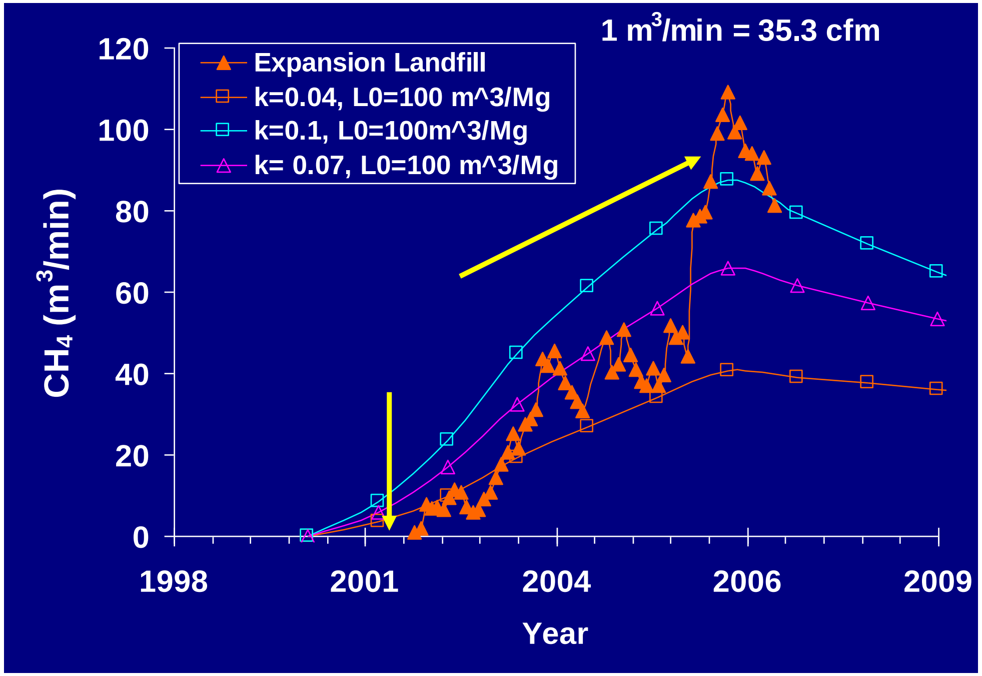


Landfill Gas Modeling

- Must be careful to use appropriate waste composition and quantity data
  - Mass of construction debris differs from a mass of food waste
  - Use multiple waste fractions
- Model results
  - Data should be presented as a range given uncertainty
  - Decreasing waste quantities will affect model predictions

Measured Yields

- Lab-scale data (ultimate versus actual)
- Assumptions to fit field data
    - mass of waste and time of burial
    - collection efficiency



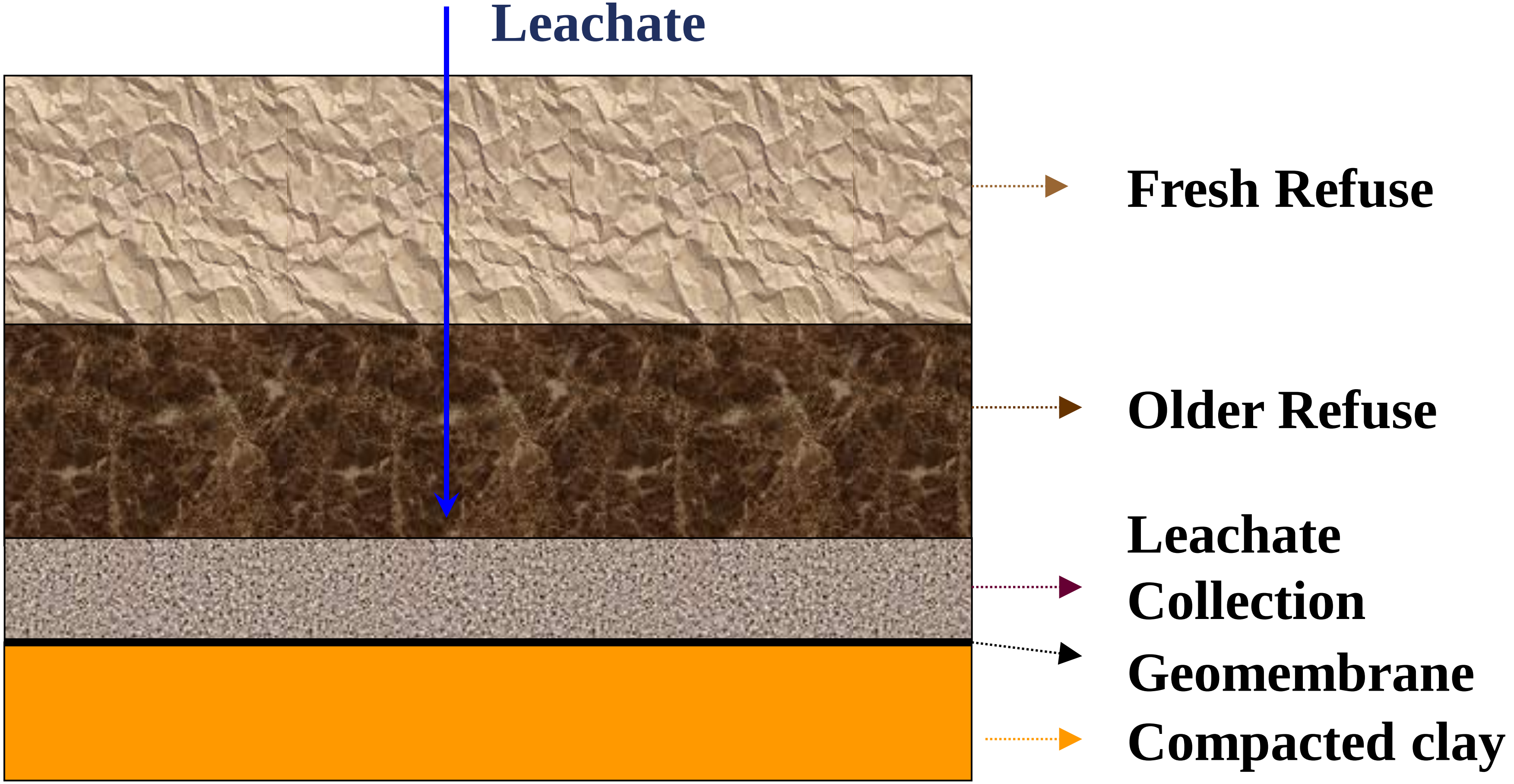
Leachate Treatment and Quality

- Leachate storage
- Leachate treatment alternatives
  - On-site with NPDES permit
  - On-site pretreatment
  - Truck or pipe to POTW
    - Will POTW accept leachate and for how long?
  - Evaporation
  - Recirculation

Leachate Treatment and Quality

- Leachate composition represents a composite
  - Water filtering through multiple layers of refuse
  - Short-circuiting
- Typical ranges are very broad
  - Dilution with stormwater

Leachate Quality Interpretation



Leachate Composition

- Organics
  - BOD = biochemical oxygen demand
  - COD = chemical oxygen demand
- The BOD is always lower than the COD
- In fresh waste, the BOD/COD could be ~0.7 – 0.9
- In well decomposed waste is will be <~0.15

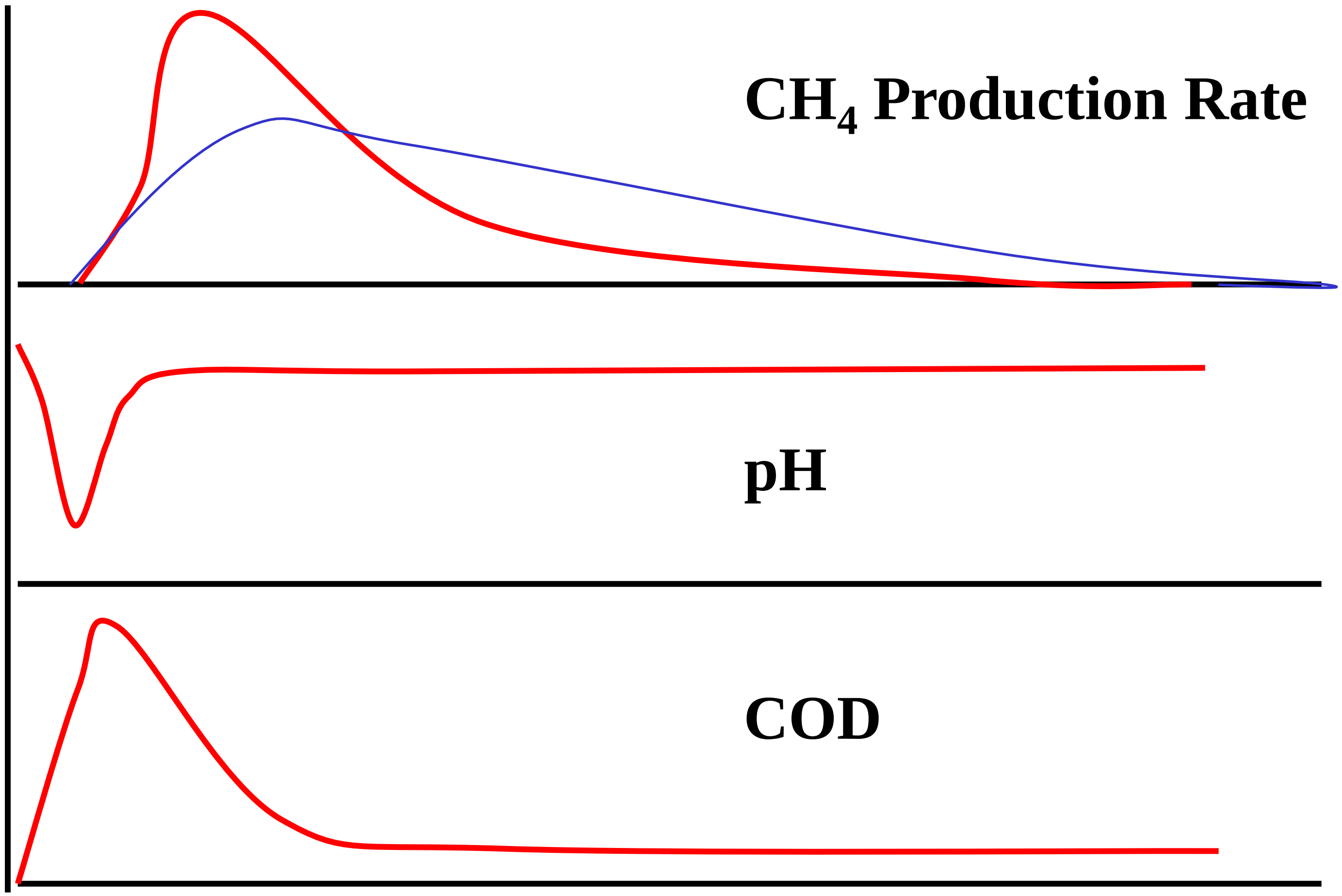
$$\text{Organic matter} + O_2 \rightarrow CO_2 + H_2O$$

Organic matter = intermediates of waste decomposition such as carboxylic acids and alcohols, humic matter

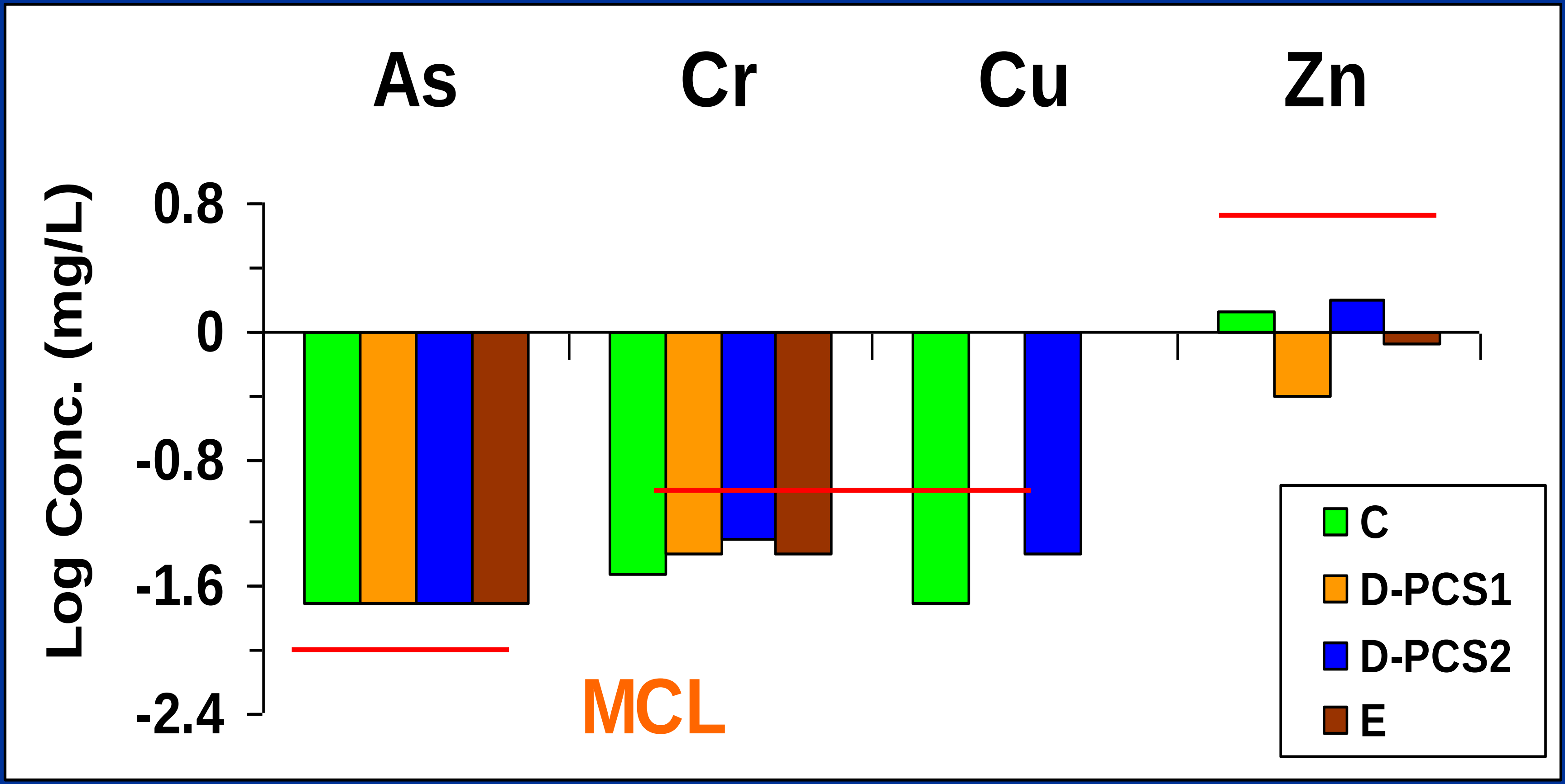
Leachate Composition

- Metals
  - Generally quite low though occasionally a problem with one or more metals (Se, As)
- Ammonia
  - Always elevated (~500 – 1000 mg/L)

Trends in Methane, COD, and pH are Predictable

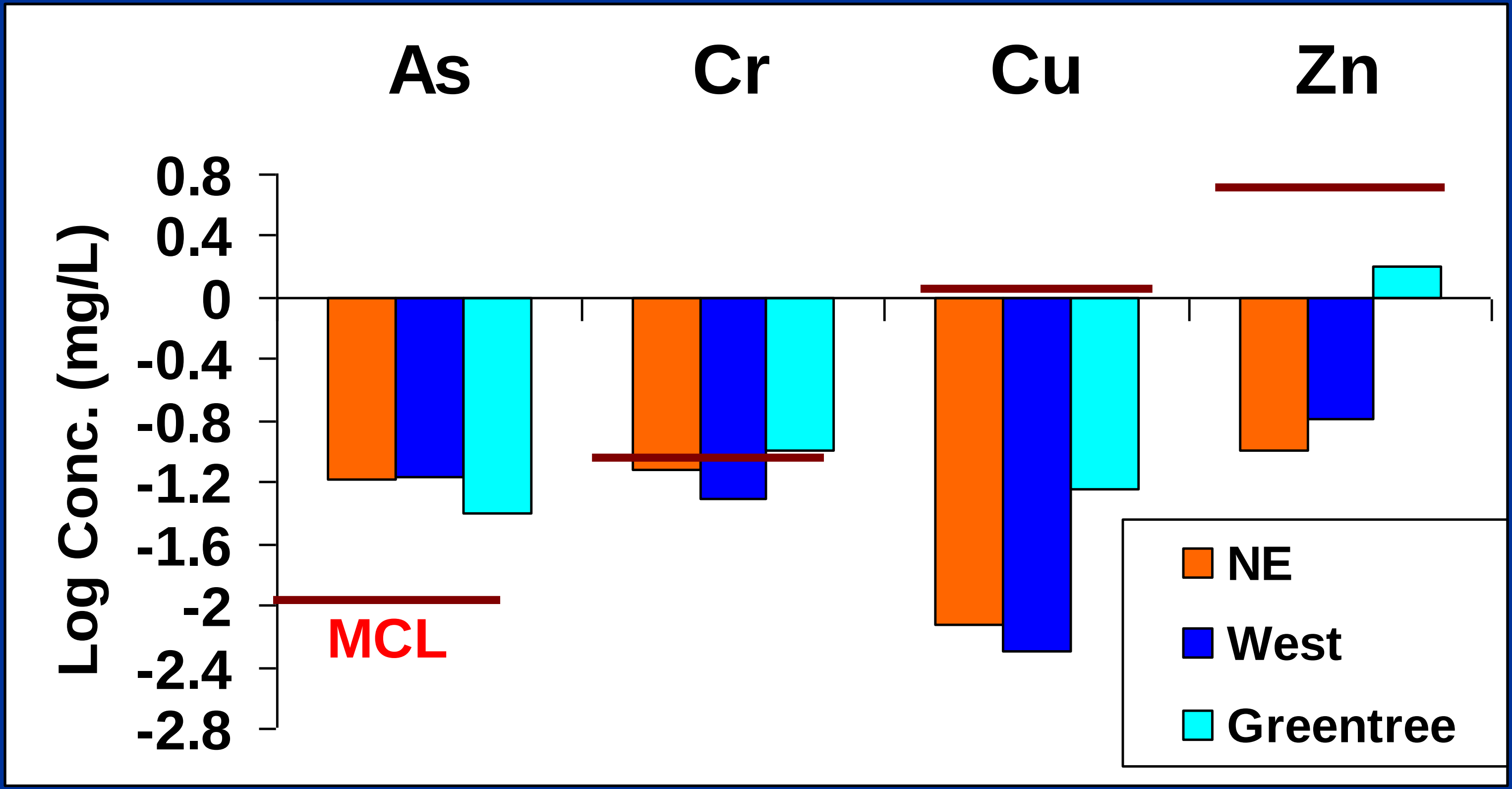


Metals Concentrations in DSWA Leachate



MCL – Maximum Contaminant Level

Metals Concentrations in Yolo and Greentree Leachate



Summary

- Landfills are complex engineered facilities that require expertise in many areas
  - Solids and geotechnical engineering
  - Hydrology, chemistry and biology
  - Legal and finance
- Communication amongst interdisciplinary design teams is crucial for success