Prior Announcements

- Introduction of Course
- Schedule & Housekeeping Announcements
- Introduction of Sponsors, Speakers, & Attendees

LANDFILL GAS MONITORING
&
CONTROL STRATEGIES
at
DEVELOPED SITES

Sponsored by the:

CALIFORNIA INTEGRATED WASTE MANAGEMENT BOARD

Developed and Presented by:

SCS Engineers & GC Environmental, Inc.

California Environmental Protection Agency
Integrated Waste Management Board

SCS ENGINEERS

PURPOSE

To provide training on landfill gas (LFG) monitoring and control strategies at developed landfill sites to Local Enforcement Agency (LEA) and California Integrated Waste Management Board (CIWMB) Inspectors and to regulated parties.

OBJECTIVES

- Provide familiarity with LFG monitoring and control procedures at developed California landfills.

- Better standardize investigation and enforcement actions at sites in California.

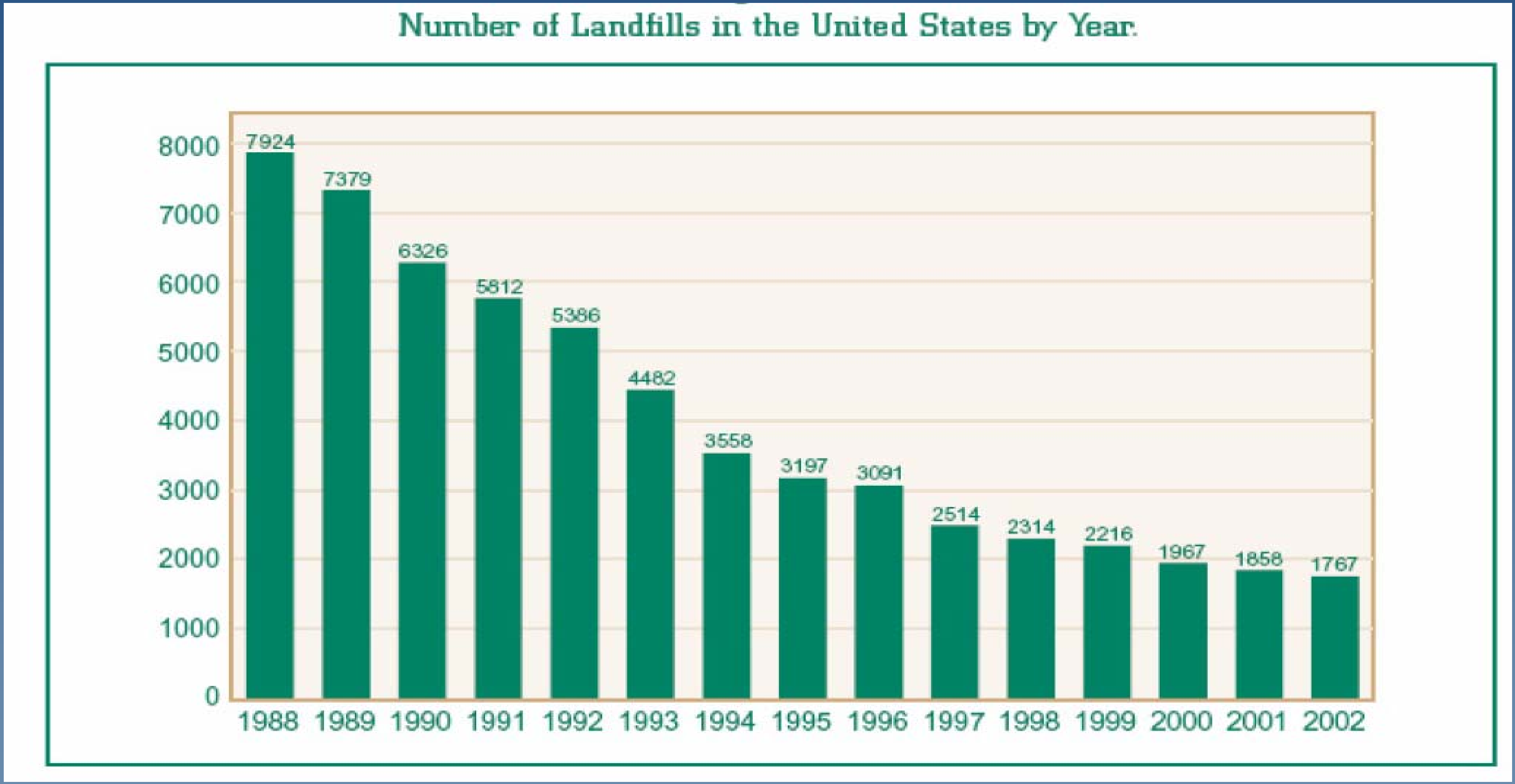
COURSE OUTLINE FOR DAY ONE

- Background & Introduction
- Landfill Gas Primer
- Regulatory Summary
- Gas Monitoring Summary
- Gas Control Summary
- Advanced Gas Monitoring & Control

COURSE OUTLINE FOR DAY TWO

- Case Studies:
  - LEA's Case Study
  - SCS Case Study
- CIWMB Tire Program Presentation
- CIWMB's Roles & Responsibilities
- Group Exercises
- Course Assessment/Evaluation

BACKGROUND & INTRODUCTION



Source www.epa.gov

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BACKGROUND & INTRODUCTION

- Development on and adjacent to closed/inactive urban landfills is on the increase:
  - Brownfields Revitalization Projects
  - Increased surrounding property value
- Older landfill sites historically have been under less regulatory oversight.
- This can, and does, create potential critical compliance situations.

BACKGROUND & INTRODUCTION

- There are approximately 2,500 Closed, Illegal, and/or Abandoned (CIA) sites identified in the CIWMB's Solid Waste Information System (SWIS) database.
- The SWIS database contains information on solid waste facilities, operations, and disposal sites throughout the State of California.

BACKGROUND & INTRODUCTION

- For each facility, the SWIS database contains information about location, owner, operator, facility type, regulatory and operational status, authorized waste types, local enforcement agency, and inspection and enforcement records.

- http://www.ciwmb.ca.gov/SWIS

BACKGROUND & INTRODUCTION

- Of these 2,500 sites, 2,122 are pre-regulations (or legacy) municipal solid waste disposal sites.
- About 506 of these 2,122 sites are burn dump sites.
- Of the total 2,500 sites, 206 are landfills closed with a permit, and 73 sites are illegal disposal sites.
- The CIWMB maintains a list of priority CIA sites being worked on by LEA and CIWMB staff.

BACKGROUND & INTRODUCTION

- 500 of these sites have some type of development (e.g. residential, commercial or industrial) on or close to them.
- At these sites the LEA has a responsibility to ensure compliance with the state minimum standards for gas monitoring and control as the primary public health and safety concern.
- Of these 500 sites, 200 sites have LFG issues that have been addressed by some type of gas control system.

BACKGROUND & INTRODUCTION

- The CIWMB, in coordination with LEA’s, has identified 50 to 60 CIA sites with suspected gas issues that do not have a gas control system.
- Further assessment of these sites is needed to determine the status and best corrective approach.

BACKGROUND & INTRODUCTION

- While the CIWMB has a good idea of the universe of CIA sites in California, there is a project underway to more accurately capture the number of CIA sites that are/have been developed, the issues at the identified sites, and ways to better address any issues.

BACKGROUND & INTRODUCTION

- CIA Definitions:
  - **Closed Site -** A disposal site that has ceased accepting waste and was closed in accordance with applicable statutes, regulations, and local ordinances in effect at the time.
  - **Clean Closed Site -** A disposal site where all waste has been physically removed as well as all contaminated materials from the site and from its underlying and surrounding environs, such that the site no longer poses a threat to public health, safety and the environment.

BACKGROUND & INTRODUCTION

- CIA Definitions:
  - **Abandoned Site -** A disposal site where there is no responsible party.
  - **Illegal Site -** A disposal site that is not permitted and not exempt from obtaining a permit and is not closed or excluded from the requirement to obtain a solid waste facilities permit. (Active un-permitted sites which an LEA intends to permit are not considered CIA sites).

LANDFILL GAS PRIMER

- LFG Generation
- LFG Characteristics
- How and why these characteristics vary
- How and why LFG moves
- Hazards associated with LFG

Landfill Gas Generation

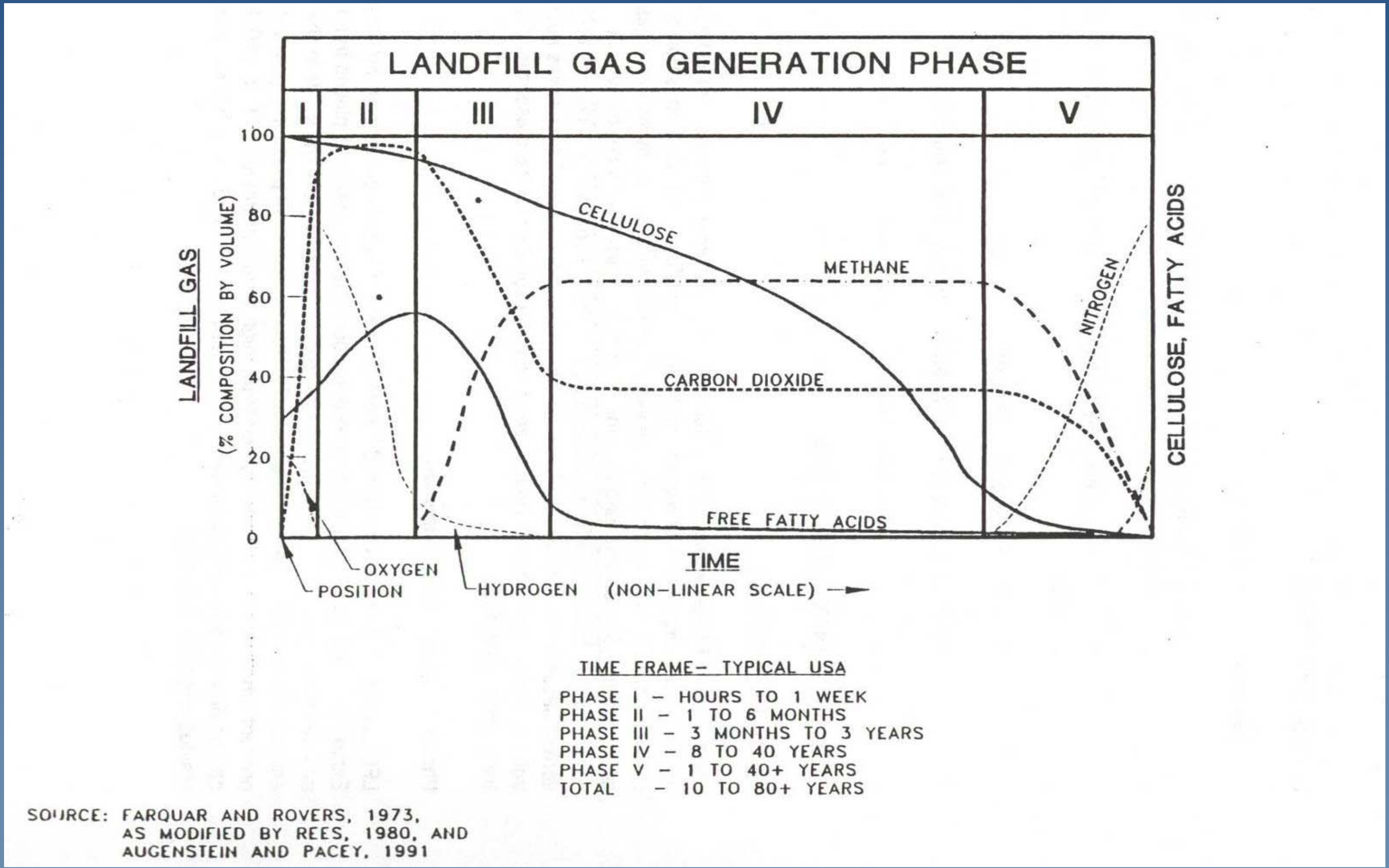
- Landfill gas is produced anaerobically. Anaerobically means without oxygen.

$$\underset{\text{(Waste)}}{C_NH_NO_N} \xrightarrow[\text{Microorganisms}]{\text{Anaerobic}} \underset{\text{(Methane)}}{CH_4} + \underset{\text{(Carbon Dioxide)}}{CO_2}$$

- The presence of oxygen will inhibit landfill gas production. Aerobic microorganisms take over when oxygen is present.

$$\underset{\text{(Waste)}}{C_NH_NO_N} \xrightarrow[\text{Microorganisms}]{\text{Aerobic}} \underset{\text{(Water)}}{H_2O} + \underset{\text{(Carbon Dioxide)}}{CO_2}$$

Landfill Gas Generation



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Landfill Gas Generation

- Amount of LFG production is governed by amount of waste.
- Rate of LFG production is governed by: age of waste; moisture content; temperature; pH; and other factors.
- These factors cannot be easily modified.

Landfill Gas Characteristics

- As-Produced:
  - Methane 55% to 60%
  - Carbon Dioxide 40% to 45%
- Immediate Additions:
  - Moisture
  - Volatile organic compounds (VOCs)
  - Hydrogen Sulfide (H_2S)
- Dilution:
  - Nitrogen
  - Oxygen

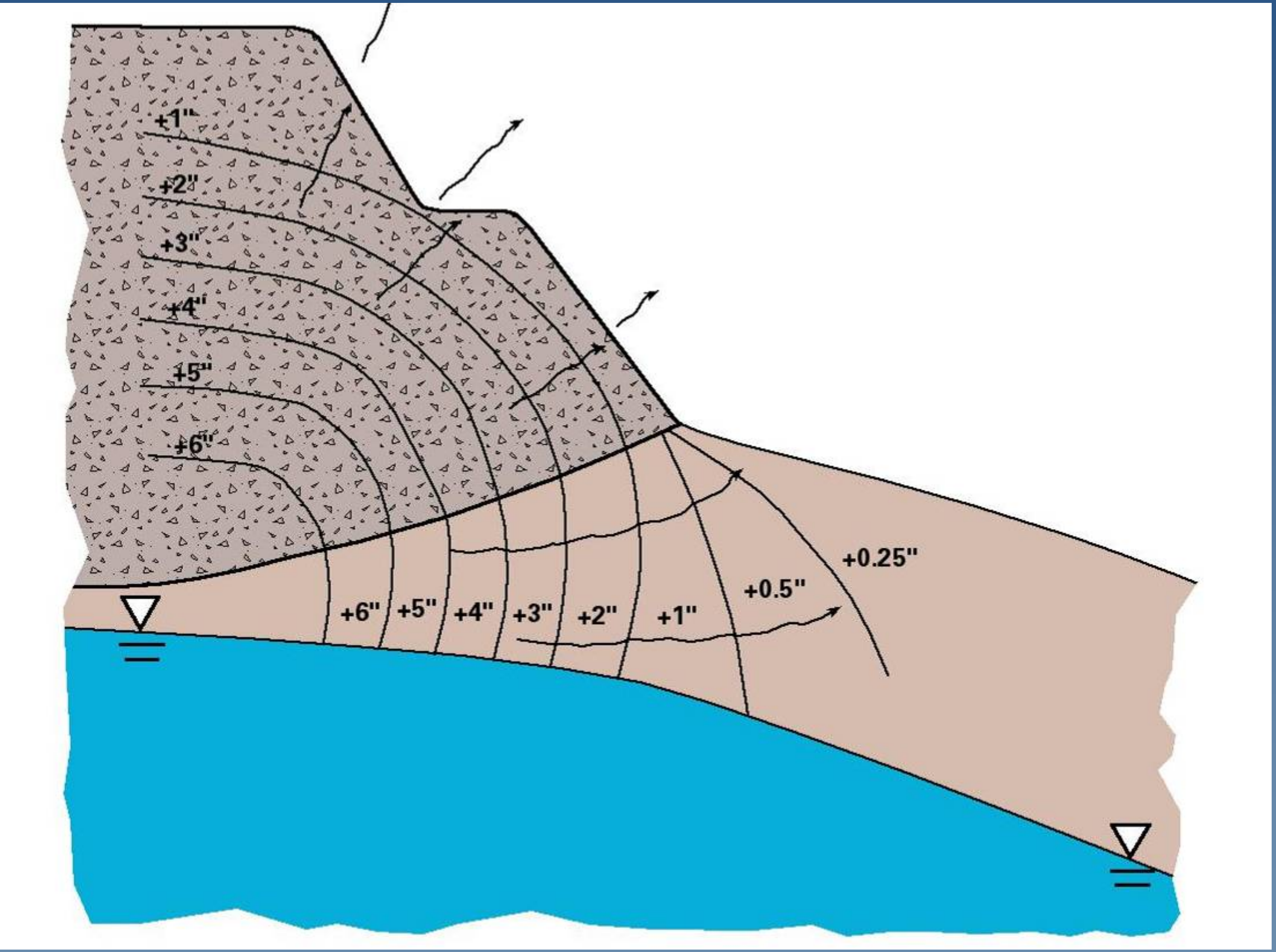
Landfill Gas Characteristics

- The maximum amount of moisture that a gas can hold is primarily a function of gas temperature.
- Volatile Organic Compounds (VOCs) are stripped from the waste by the LFG.
- H_2S is produced by microbial action on sulfur compounds. High H_2S is often associated with wallboard and sometimes native cover material.

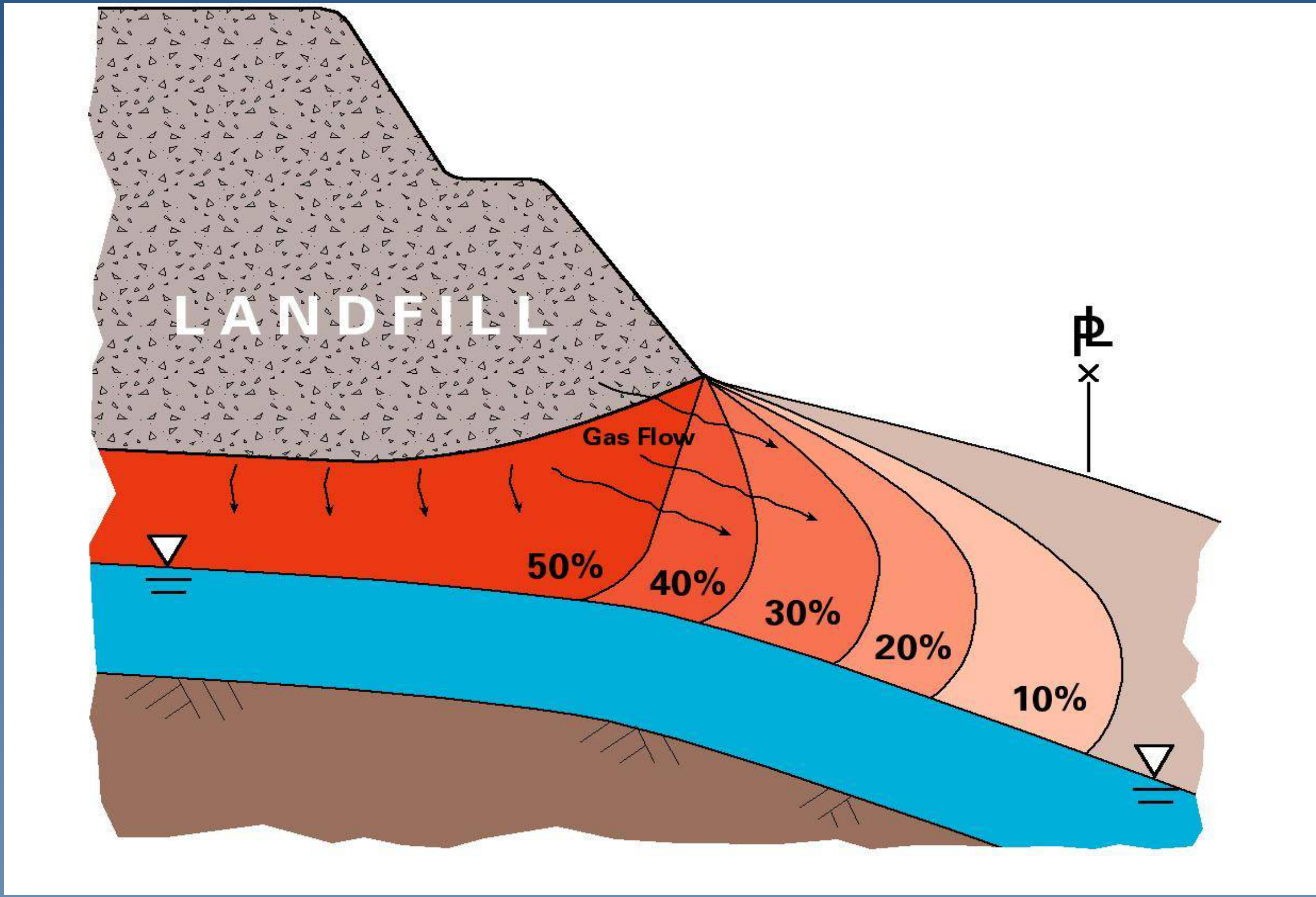
Landfill Gas Movement

- Driven by Pressure and Concentration Differential:
  - LFG migrates from areas of high pressure to areas of low pressure (i.e., interior of the refuse mass to the atmosphere and soil). Process is known as convection.
  - LFG is driven from areas of high concentration to low concentration. Process is known as diffusion.

Landfill Gas Movement – Pressure Impact



Landfill Gas Movement – Concentration Impact



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INTEGRATED WASTE MANAGEMENT BOARD

Landfill Gas Movement

- Convection generally governs in LFG applications. But when pressure does not govern (i.e., in old landfills), diffusion will cause LFG movement.

- Liners block underground migration, but are not always 100% effective. Unlike water, LFG will move toward defects in any direction and LFG exploits small defects.

- Ground & surface water is a no flow barrier to convection, but not diffusion.

Landfill Gas Hazards - Flammable/Explosive

- LFG is explosive when methane is between 5% and 15% by volume, in air.
- These limits are known as lower explosive limit (LEL) and upper explosive limit (UEL).
- Do not assume that 15%+ is safe. The LFG can easily be diluted to 15% or be explosive at air-to-LFG interface point.
- Enclosed or partially enclosed spaces, where LFG can accumulate (vaults, manholes, underground conduit, crawl spaces, basements, etc.,) are areas of great risk.

Landfill Gas Hazards - Suffocation

- Humans are extremely sensitive to oxygen deficiency. Ambient air is about 21% oxygen.
- The legal definition of oxygen deficiency varies, but 19.5% is considered to be a safe minimum limit.
- Confined space entry procedures must be established and followed.
- Oxygen deficiency and explosive conditions can occur in "semi-confined" spaces such as trenches.

Landfill Gas Hazards – Trace Compounds

- LFG contains trace quantities of many other compounds.
- Hydrogen sulfide is generally in the 20 ppmv to 60 ppmv range, but it can be much higher.
- Hydrogen sulfide is very odorous, but the nose can become insensitive to the odor surprisingly quickly.
- LFG contains trace quantities of benzene, carbon tetrachloride, methylene chloride and other volatile organic compounds.

Landfill Gas Hazards – Environmental Impacts

- Odors
- Groundwater Contamination
- Vegetation Damage
- Local Air Pollution
- Global Climate Change

REGULATORY SUMMARY

- Resource Conservation & Recovery Act (RCRA), Subtitle D
- California Code of Regulations (CCR), Title 27
- Local Regulations
  - South Coast Air Quality Management District (SCAQMD) Rule 1150.1

REGULATORY SUMMARY-RCRA

- **Resource Conservation and Recovery Act (RCRA) Subtitle D** - focuses on state and local governments as the primary planning, regulating, and implementing entities for the management of non-hazardous solid waste, such as household garbage and non-hazardous industrial solid waste.

REGULATORY SUMMARY-RCRA

- **Code of Federal Regulations (CFR)**

  Title 40: Protection of Environment

  Part 258-Criteria for MSW Landfills

  Subpart C-Operating Criteria

  § 258.23 Explosive gases control

REGULATORY SUMMARY-CCR

- **CCR Title 27 Division 2, Solid Waste**

  Chapter 3, Subchapter 4

  Article 6 - Gas Monitoring and Control at Active and Closed Disposal Sites
  Sections 20918 - 20937

REGULATORY SUMMARY-CCR

- **20919.5. CIWMB - Explosive Gases Control.**
  - (a) Owners or operators of all MSWLF units must ensure that:
    - (1) The concentration of methane gas generated by the facility does not exceed 25 percent of the lower explosive limit for methane in facility structures (excluding gas control or recovery system components); and
    - (2) The concentration of methane gas does not exceed the lower explosive limit for methane at the facility property boundary.

REGULATORY SUMMARY-CCR

- (b) Owners or operators of all MSWLF units must implement a routine methane monitoring program to ensure that the standards of (a) are met.
  - (1) The type and frequency of monitoring must be determined based on the following factors:
    - (i) soil conditions;
    - (ii) the hydrogeologic conditions surrounding the facility;
    - (iii) the hydraulic conditions surrounding the facility; and
    - (iv) the location of facility structures and property boundaries. Except as provided in (f).
  - (2) the minimum frequency of monitoring shall be quarterly.

REGULATORY SUMMARY-CCR

- (c) If methane gas levels exceeding the limits specified in (a) are detected, the owner or operator must:
  - (1) immediately take all necessary steps to ensure protection of human health and notify the EA;
  - (2) within seven days of detection, place in the operating record the methane gas levels detected and a description of the steps taken to protect human health;

REGULATORY SUMMARY-CCR

- (3) within 60 days of detection, implement a remediation plan for the methane gas releases, place a copy of the plan in the operating record, and notify the EA that the plan has been implemented. The plan shall describe the nature and extent of the problem and the proposed remedy; and
- (4) The EA with concurrence by the CIWMB pursuant to 40 CFR 258.23(c)(4) may establish alternative schedules for demonstrating compliance with (c)(2) and (c)(3).

REGULATORY SUMMARY-CCR

- **20925. CIWMB - CIWMB - Perimeter Monitoring Network.**
  - (a) Location
    - (1) Perimeter subsurface monitoring wells shall be installed around the waste deposit perimeter but not within refuse. The entire perimeter of the disposal site may not warrant the installation of monitoring wells. In this case, the operator shall demonstrate to the satisfaction of the EA that gas migration could not occur due to geologic barriers and that no inhabitable structure or other property such as agricultural lands within 1,000 feet of the property boundary are threatened by gas migration.

REGULATORY SUMMARY-CCR

- (2) Perimeter monitoring wells shall be located at or near the disposal site property boundary. The operator may establish an alternate boundary closer to the waste deposit area based on a knowledge of the site factors in section 20923(a)(2). When compliance levels are exceeded at the alternate boundary, the operator shall install additional monitoring wells closer to the property boundary, pursuant to section 20937.

REGULATORY SUMMARY-CCR

- (b) Spacing
  - (1) The lateral spacing between adjacent monitoring wells shall not exceed 1,000 feet, unless it can be established to the satisfaction of the EA, in section 20923(a)(2).

REGULATORY SUMMARY-CCR

- (2) The spacing of monitoring wells shall be determined based upon, but not limited to: the nature of the structure to be protected and its proximity to the refuse. Wells shall be spaced to align with gas permeable structural or stratigraphic features, such as dry sand or gravel, off site or on site structures, and areas of dead or stressed vegetation that might be due to gas migration.
- (3) Probe spacing shall be reduced as necessary to protect persons and structures threatened by landfill gas migration.

REGULATORY SUMMARY-CCR

- (c) Depth
  - (1) The depth of the wellbore shall equal the maximum depth of waste as measured within 1,000 feet of the monitoring point. The number and depths of monitoring probes within the wellbore shall be installed in accordance with the following criteria, except as specified in (c)(2).

REGULATORY SUMMARY-CCR

- (A) a shallow probe shall be installed 5 to 10 feet below the surface;
- (B) an intermediate probe shall be installed at or near half the depth of the waste;
- (C) a deep probe shall be set at or near the depth of the waste;
- (D) the specified depths of monitoring probes within the wellbore shall be adjusted, based on geologic data obtained during drilling, and probes shall be placed adjacent to soils which are most conductive to gas flow;

REGULATORY SUMMARY-CCR

- (E) All probes shall be installed above the permanent low seasonal water table, above and below perched groundwater, and above bedrock; and
- (F) When the depth of the waste does not exceed 30 feet, the operator may reduce the number of probes to two, with one probe located in the shallow zone as indicated above, and the other located adjacent to permeable soils at or near the depth of the waste.

REGULATORY SUMMARY-CCR

- (2) Exclusions or modifications to (c)(1) may be requested for certain disposal sites (i.e., filled pits, cut and trench, and canyon fills). When conditions limit the practicality or do not warrant the installation depth criteria, the operator shall propose an alternate system of equivalent probe depths. The proposal must demonstrate to the satisfaction of the EA, that probes located at these depths are sufficient to detect migrating landfill gas and provide protection to public health and safety and the environment.

REGULATORY SUMMARY-CCR

- (3) The EA may require an increase in the number of monitoring probes, the depth of the wellbore, or modify the depths of monitoring probes within a wellbore to ensure compliance with section 20921(a). The operator is not precluded from utilizing existing gas monitoring probes of an alternate design, when the operator demonstrates to the satisfaction of the EA, that such probes have been installed in a manner that ensures the detection of landfill gas migrating from the disposal site.

REGULATORY SUMMARY-CCR

- (d) Monitoring Well Construction
  - (1) Monitoring wells shall be drilled by a licensed drilling contractor, or where in-house drilling capability exists, by a drilling crew under the supervision of the design engineer or engineering geologist. Wells shall be logged during drilling by a geologist or geotechnical engineer. Soils shall be described using the ASTM Designation: D2488 84 method for visual classification, Standard Practice for Description and Identification of Soils (Visual Manual Procedure), which is incorporated by reference. Rock units shall be described in a manner appropriate for geologic investigation.

REGULATORY SUMMARY-CCR

- (2) A record of each monitoring well shall be maintained by the operator and submitted to the EA upon request. The record shall include:
  - (A) a facility map drawn to a scale proposed by the design engineer or engineering geologist, sufficient to show the location of all monitoring wells. The well must be identified with a number that corresponds to the well log. Surface elevations at the wellheads shall be denoted on the map;
  - (B) well logs, including the names of the person(s) logging the hole; and

REGULATORY SUMMARY-CCR

- (C) an as-built description, including a well detail which indicates probe material and depth, extent and type of filter pack, thickness and material used for seals, extent and material used for backfill, size and interval of perforations, and a description of any shutoff valves or covers.

- (3) To isolate monitored zones within the wellbore, and prevent contamination of perched groundwater and permanent groundwater, the operator shall provide a minimum seal of five (5) feet of bentonite at the surface and between the monitored zones.

REGULATORY SUMMARY-CCR

- **Section 20931. CIWMB - Structure Monitoring.**
  - (a) To ensure that the requirements of section 20923(a)(1) are met, the monitoring network design shall include provisions for monitoring on-site structures, including but not limited to buildings, subsurface vaults, utilities or any other areas where potential gas buildup would be of concern. The proposal shall address on-site structures, both adjacent to and on top of the waste deposit area.

REGULATORY SUMMARY-CCR

- (b) Methods for monitoring on-site structures may include, but are not limited to: periodic monitoring, utilizing either permanently installed monitoring probes or gas surveys; and continuous monitoring systems.

REGULATORY SUMMARY-CCR

- (c) Structures located on top of the waste disposal area shall be monitored on a continuous basis. When practical, structures shall be monitored after they have been closed overnight or for the weekend to allow for an accurate assessment of gas accumulation. Areas of the structure where gas may accumulate shall be monitored and may include, but are not limited to areas in, under, beneath and around basements, crawl spaces, floor seams or cracks, and subsurface utility connections.

REGULATORY SUMMARY-CCR

- **Section 20933. CIWMB - Monitoring Frequency.**
  - (a) At a minimum, quarterly monitoring is required. The EA may require more frequent monitoring based upon site specific factors in section 20923(a)(2). When more frequent monitoring is necessary, the requiring agency shall notify the operator.

REGULATORY SUMMARY-CCR

- (b) More frequent monitoring may also be required at those locations where results of monitoring indicate that landfill gas migration is occurring or is accumulating in structures.
- (c) The operator shall increase the monitoring frequency, as is necessary, to detect migrating gas and ensure compliance with section 20921.

REGULATORY SUMMARY-CCR

- **Section 20937. CIWMB - Control.**
  - (a) When the results of gas monitoring indicate concentrations of methane in excess of the compliance levels required by section 20921(a), the operator shall:
    - (1) Take all immediate steps necessary to protect public health and safety, and the environment.
    - (2) Notify the EA in writing within five (5) working days of learning that compliance levels have been exceeded, and indicate what has been done or is planning to be done to resolve the problem.

REGULATORY SUMMARY-CCR

- (3) Verify accuracy of results by reviewing the following:
  - (A) probe readings;
  - (B) possible liquid interference;
  - (C) control well influence; and
  - (D) barometric pressure effects.
- (4) Within ten (10) working days, submit to the EA a letter which describes the nature and extent of the problem, and any immediate corrective actions that need to be taken to protect public health and safety, and the environment.

REGULATORY SUMMARY-CCR

- (5) Construct a gas control system, designed by a registered civil or mechanical engineer, within a period of time specified by the EA. Installation of the system shall be in accordance with a design and in a manner approved for construction by the EA in coordination, if applicable, with the RWQCB.

REGULATORY SUMMARY-CCR

- (b) A gas control system shall be designed to:
  - (1) Prevent methane accumulation in on-site structures.
  - (2) Reduce methane concentrations at monitored property boundaries to below compliance levels.
  - (3) Reduce trace gas concentrations.

REGULATORY SUMMARY-CCR

- (4) Provide for the collection and treatment and/or disposal of landfill gas condensate produced at the surface. Condensate generated from gas control systems shall not be recirculated into the landfill unless analysis of the condensate demonstrates to the satisfaction of the EA, that it is acceptable to allow recirculation into landfills which have a liner and an operating leachate collection systems and the RWQCB approve such discharge pursuant to Section 20200(d).

REGULATORY SUMMARY-CCR

- (c) Subsurface gas control systems may include, but are not limited to, one or more of the following:
  - (1) Active perimeter or interior control systems which are designed to accommodate the maximum expected flow rate from the disposal site, and provide access for system monitoring and flow rate adjustment. The control system shall be operated to ensure that gas is controlled at a sufficient rate without overpulling, to maximize control and not production, and to ensure adequate control for compliance with Section 20923(a).

REGULATORY SUMMARY-CCR

- (2) Perimeter air injection systems which shall be installed in native soil between the refuse and the area to be protected. Injection wells shall not be located in the refuse. The system shall be designed and operated to prevent air infiltration into the landfill but maintain methane concentrations to compliance levels.
- (3) Passive systems, including cutoff trenches, slurry walls, and vent trenches, when used shall be constructed with an impermeable geomembrane liner. The passive systems shall be installed to the depth of permanent low seasonal groundwater or keyed into a low permeability layer below the limit of migration.

REGULATORY SUMMARY-CCR

- (d) When the results of monitoring in on-site structures indicate levels in excess of those specified in Section 20923(a), the operator shall take appropriate action to mitigate the effects of landfill gas accumulation in on-site structures. Gas control measures to protect structures, and public health and safety, shall include one or more of the following:
  - (1) Flexible membrane liners;
  - (2) Active collection systems;
  - (3) Passive collection systems designed to be upgraded to an active system;

REGULATORY SUMMARY-CCR

- (4) Alarms;
- (5) Ignition source control;
- (6) Utility collars installed within structures and outside in trenches; and
- (7) Ventilation.

- (e) To ensure that the gas control system is operating at optimum efficiency to control landfill gas, the operator shall provide for system monitoring and adjustment.

REGULATORY SUMMARY-CCR

- (f) To provide for the safe, efficient operation of the gas control system, the operator shall implement a maintenance program in accordance with the following requirements:
  - (1) A site specific operations and maintenance manual shall be maintained and kept current to reflect any expansion or modifications to the gas control system.
  - (2) An operations and maintenance manual shall provide for periodic inspections and servicing of gas control equipment.
  - (3) Operations and maintenance shall be recorded and the records shall be retained by the operator.

REGULATORY SUMMARY-CCR

- (g) Construction Quality Assurance/Quality Control
  - (1) The operator shall be responsible for providing inspections, as needed, to ensure the integrity of the system.
  - (2) Prior to construction, the designer shall obtain and review all applicable test reports, shop drawings, and manufacturer’s certificates to verify that all equipment used in the gas control system has been manufactured in accordance with industry standards.

REGULATORY SUMMARY-Local

- SCAQMD 1150.1. - CONTROL OF GASEOUS EMISSIONS FROM MUNICIPAL SOLID WASTE LANDFILLS
  - Migration Control, Monitoring & Remediation Requirements
- Other Local Air Districts & the California Air Resources Board (CARB) also have LFG emission & migration monitoring & control requirements.
- It is not the LEA's responsibility to enforce air-related regulations.

GAS MONITORING & CONTROL SUMMARY

- The purpose of an LFG monitoring or migration control system is to do all of the following:
  - Protect human health and safety
  - Protect the environment
  - Achieve compliance with applicable regulations

GAS MONITORING & CONTROL SUMMARY

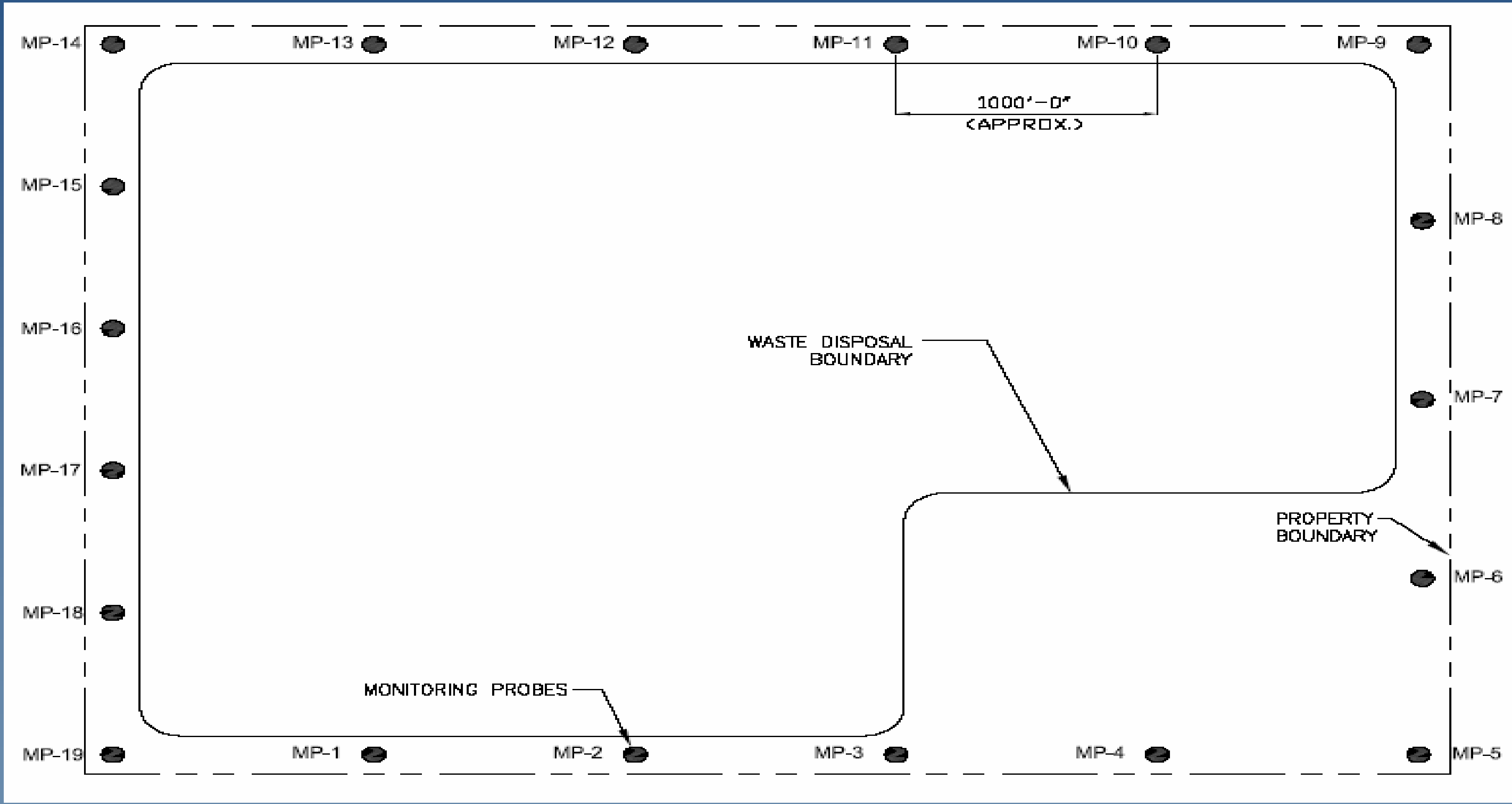
- The properly designed monitoring system accomplishes its goal by detecting an LFG migration problem if it exists and by providing a warning back-up system for a LFG control system.

- The properly designed migration control system prevents LFG from migrating subsurface off-site, or into on-site structures.

GAS MONITORING SUMMARY

- Probes
  - Placement
  - Construction
- Building Sweeps
- Continuous Monitoring Systems
  - Uses
  - Placement

GAS MONITORING SUMMARY – PROBES



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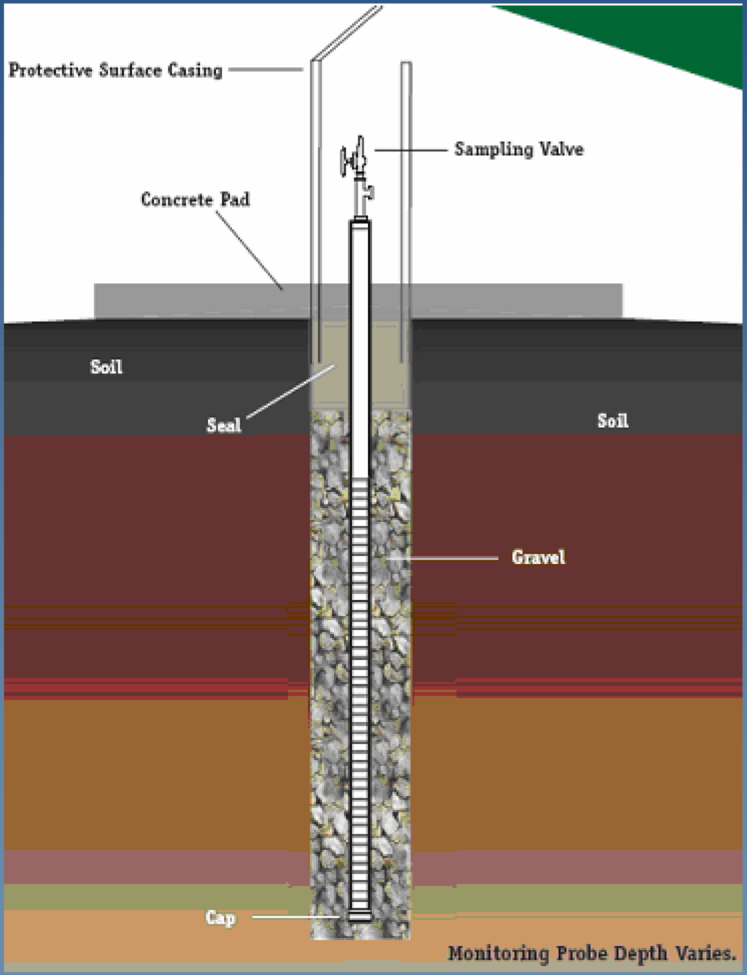
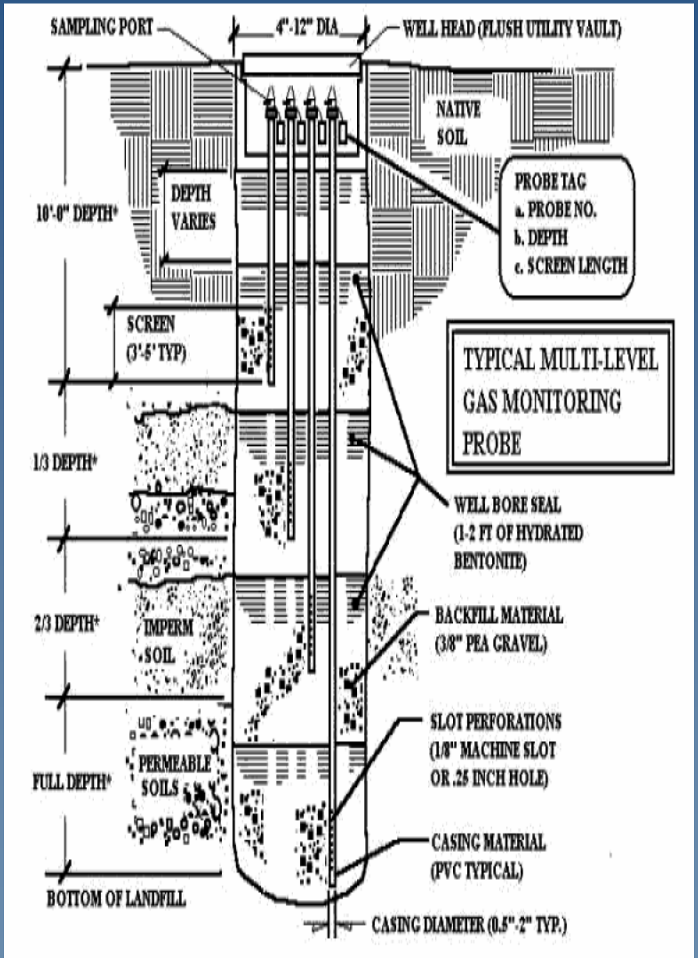
GAS MONITORING SUMMARY – PROBES - CONSTRUCTION





GAS MONITORING SUMMARY
BUILDING SWEEPS

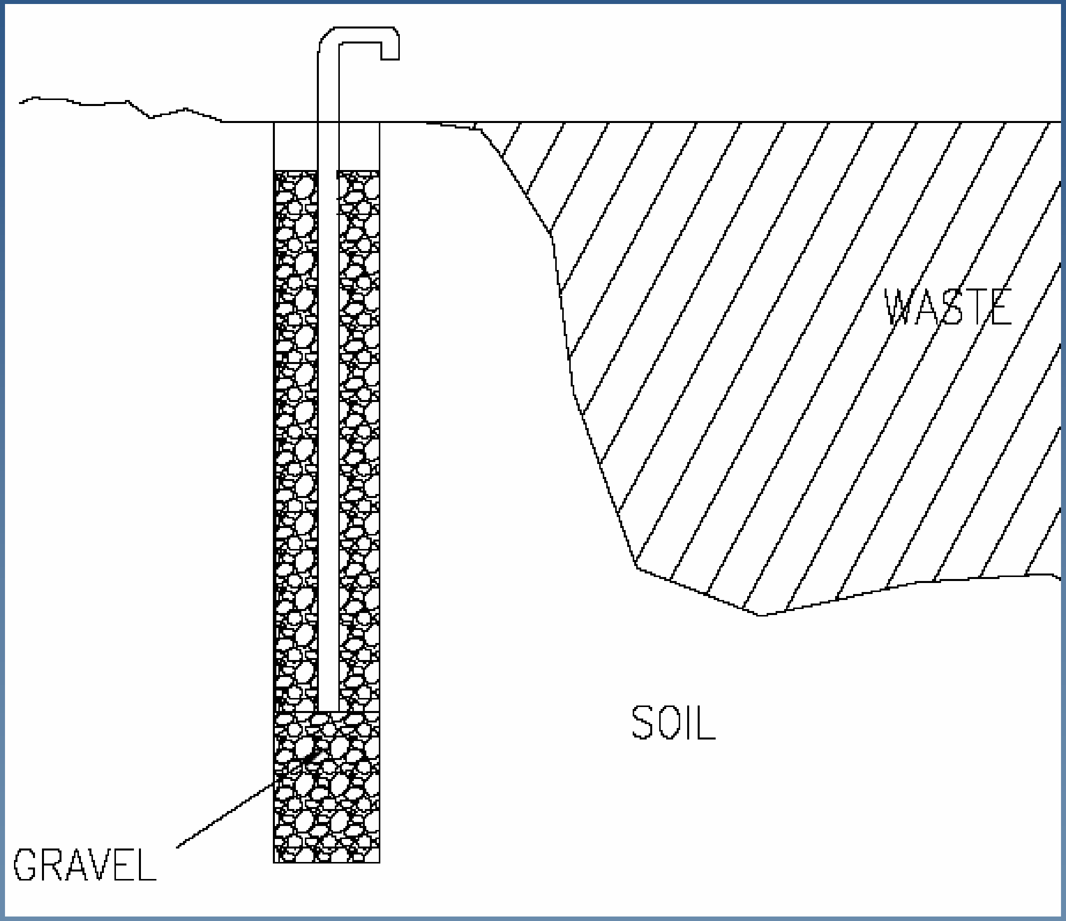
GEM-500™

GAS MONITORING SUMMARY – PROBES – CONTINUOUS MONITOR

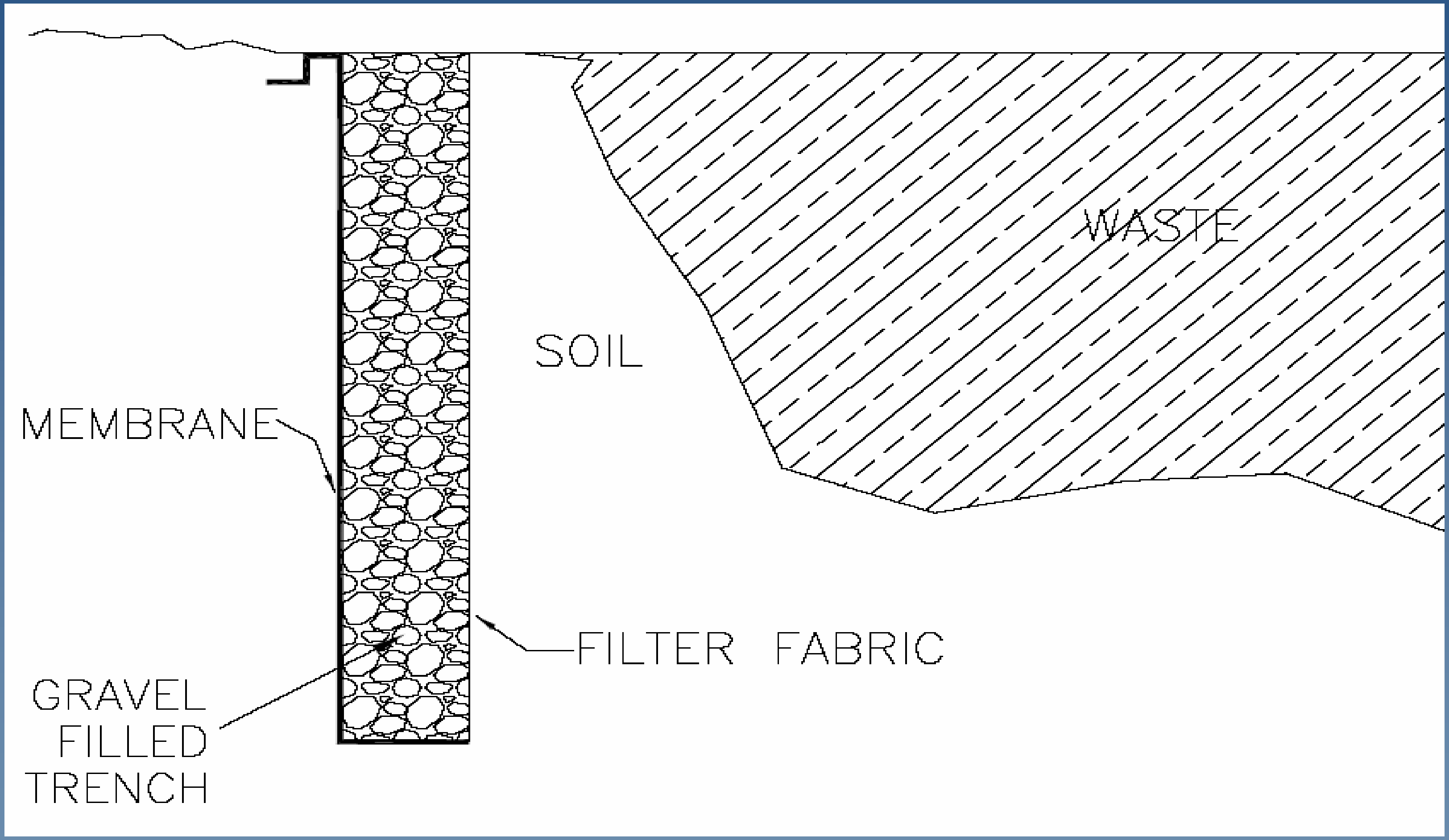
GAS CONTROL SUMMARY

- Passive Systems
  - Vents
  - Barriers
    - Trenches
    - Liners
- Active Systems
  - Negative pressure
  - Positive pressure
- Combination Systems

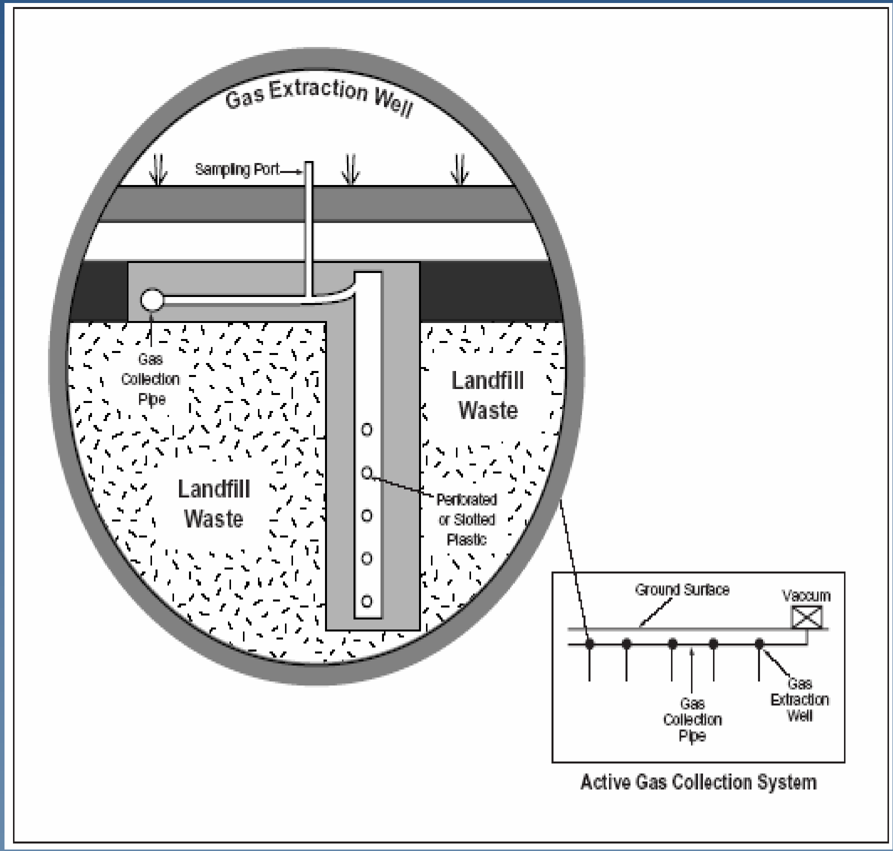
GAS CONTROL SUMMARY CONTROL SUMMARY – VENT SYSTEMS

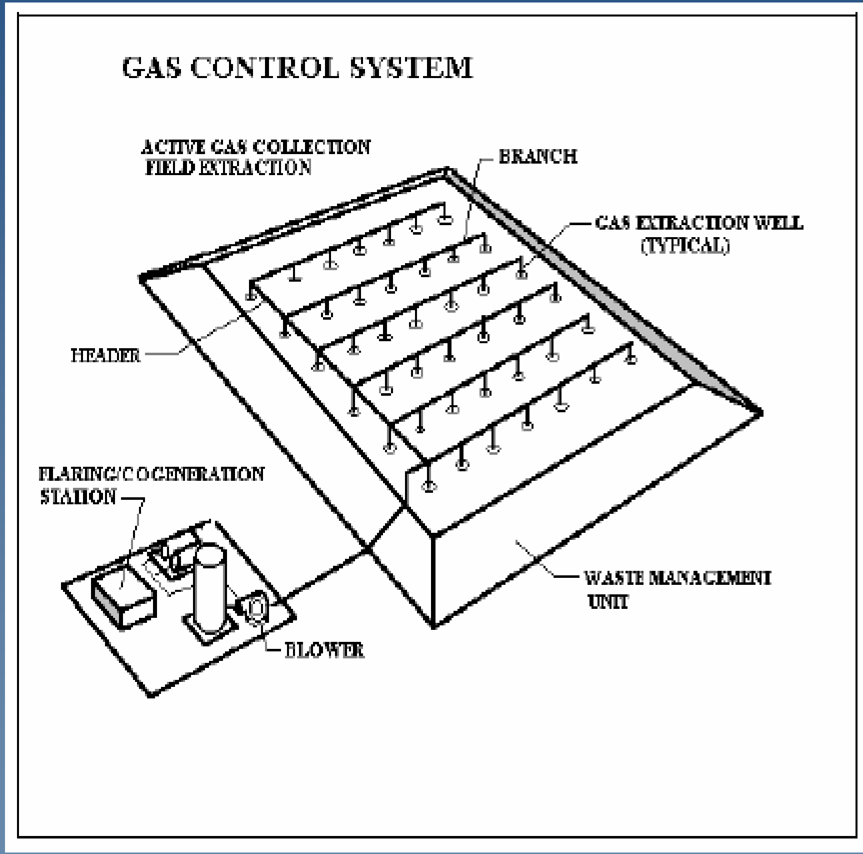


Gas Control Summary – Barrier Systems



Gas Control Summary – Active Systems





ADVANCED GAS MONITORING

- Best Practices for Determining Subsurface Gas Conditions
- Best Practices for Systems for Long-Term Monitoring of Subsurface Gas Conditions
- Best Practices for Systems for Long-Term Monitoring of Structures

ADVANCED GAS MONITORING

- Best Practices for Determining Subsurface Gas Conditions
  - Determine Source of Gas
  - Determine Waste Extent

Determine Gas Source

- Methane can be naturally occurring:
  - Natural gas
  - Swamp gas
- Methane can also come from:
  - Imported soils (clean & contaminated)
  - Pipeline leaks

Determine Gas Source

- Records
- Analyses
  - Carbon Chain
  - Isotopic
- Contaminant VOCs

Determine Waste Extent

- Records
- Cracks at Ground Surface
- Geophysical Methods
- Soil Gas Survey
- Probes
- Drilling & Pot-holing

Determine Waste Extent

- Lack of historic recordkeeping requirements (pre-1991)
  - Amount/type of waste accepted
  - Thickness/depth of waste
  - Cover material and thickness

- Multiple search locations for data
  - Different/multiple addresses (new street names, subdivision, etc.)
  - Surrounding properties

Determine Waste Extent

- Older landfill properties can be subdivided due to urban encroachment on once rural areas.
  - Logistical difficulties
    - Multiple owners
    - Multiple consultants
    - Multiple development potential

- Current property owner is usually not the former operator.
  - Current property owner may be held liable for investigation/cleanup costs under federal and state laws.

Determine Waste Extent

- Records
  - SWIS Database
  - RWQCB
  - City/County Health/Environmental Dept.
  - Aerial Photos
  - Environmental Databases
  - City/County Property Records

Determine Waste Extent

- Geophysical Methods
  - Electromagnetic Conductivity (EM)
  - Ground Penetrating Radar (GPR)
  - Ground Resistivity

Determine Waste Extent

- EM uses the principle of induction to measure the electrical conductivity of the subsurface.

- EM is used for delineating landfill boundaries.

Determine Waste Extent

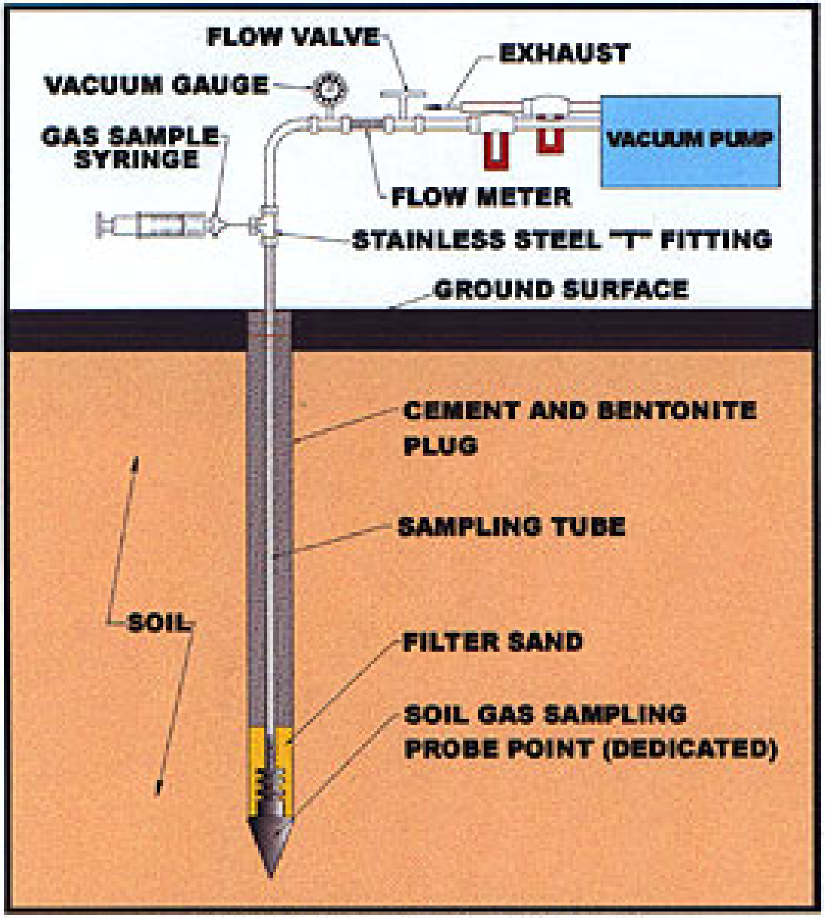
- GPR uses radar (microwaves) waves generated at the surface that are reflected from subsurface boundaries.
- GPR is used for delineating landfill boundaries.

Determine Waste Extent

- Ground resistivity uses direct current resistivity measurements from electrodes placed in the ground.
- Ground resistivity is used for delineating landfill bottom contours.

Determine Waste Extent

- Soil Gas Survey – Subsurface gas samples are collected and analyzed for methane in real time.



SOIL GAS SAMPLING SYSTEM

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Determine Waste Extent

- Bar-punch probes & spike probes
- Used to determine waste extent
- Not to be relied on for compliance purposes

Determine Waste Extent

- Bar-punch probes can be used to screen for subsurface methane concentrations, but are limited in depth and data reproducibility.

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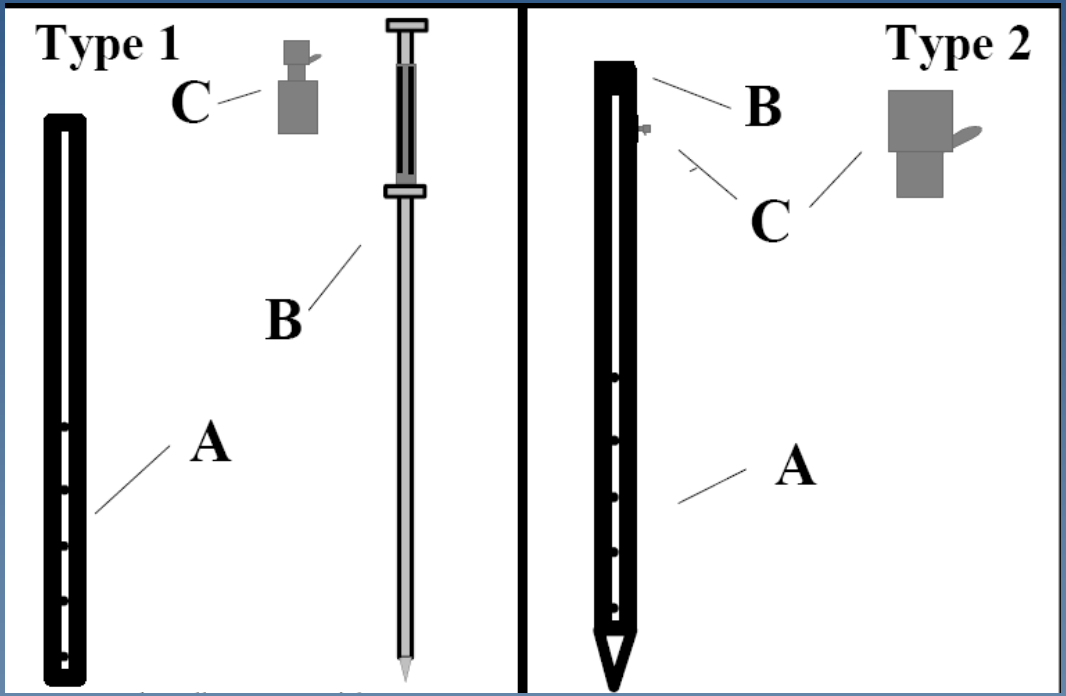
Determine Waste Extent

- Spike probes are also limited in depth (up to 10 ft.) but can be used to provide reproducible sampling data.



Determine Waste Extent

- Drilling & Pot-holing
  - Invasive, but often fastest way to confirm landfill boundary.

ADVANCED GAS MONITORING

- Best Practices for Systems for Long-Term Monitoring of Subsurface Gas Conditions
  - Probes
    - Detailed designs for differing site conditions
    - Why other systems may not be effective.
  - The importance of time-trend data
    - Surface development and diurnal variations in atmospheric pressure.

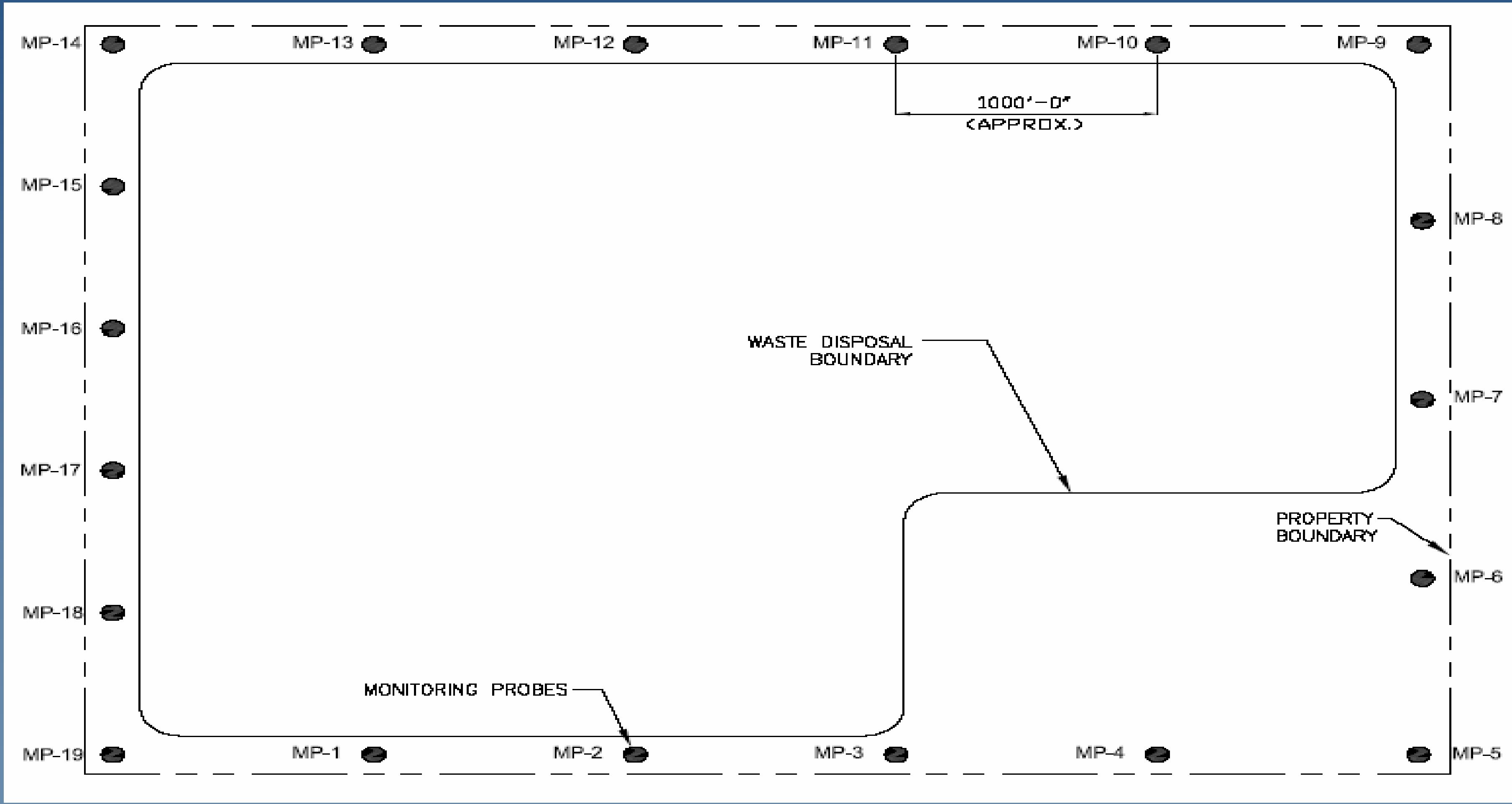
Long-Term Subsurface Monitoring

- Probes
  - Placement
  - Equipment
  - Design
  - Monitoring Procedures
  - Data Analysis

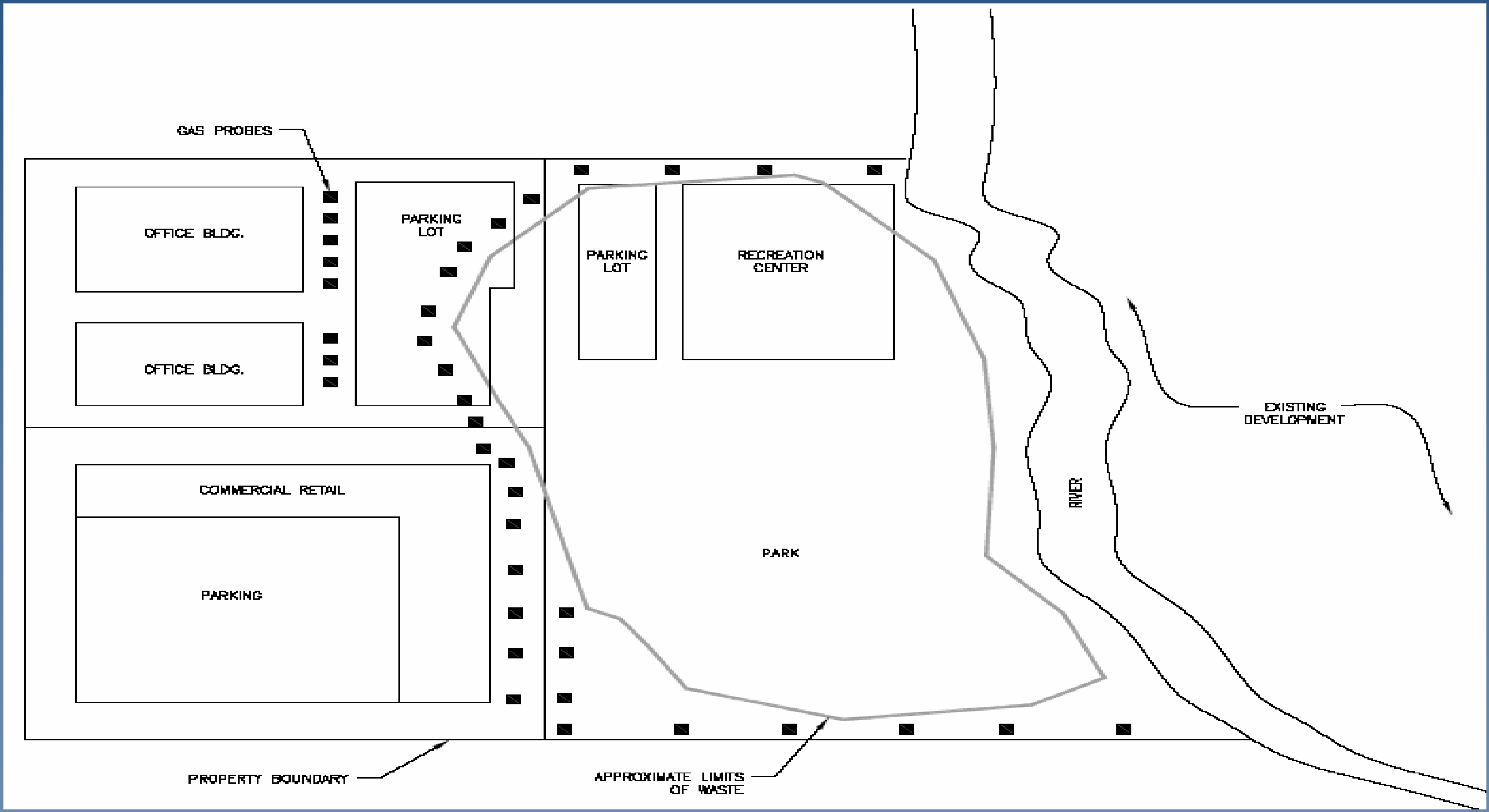
Long-Term Subsurface Monitoring - Probes

- Placement
  - Between Structures and Areas of Waste
  - Under Structures

GAS MONITORING SUMMARY – PROBES



Long-Term Subsurface Monitoring – Probes - Placement

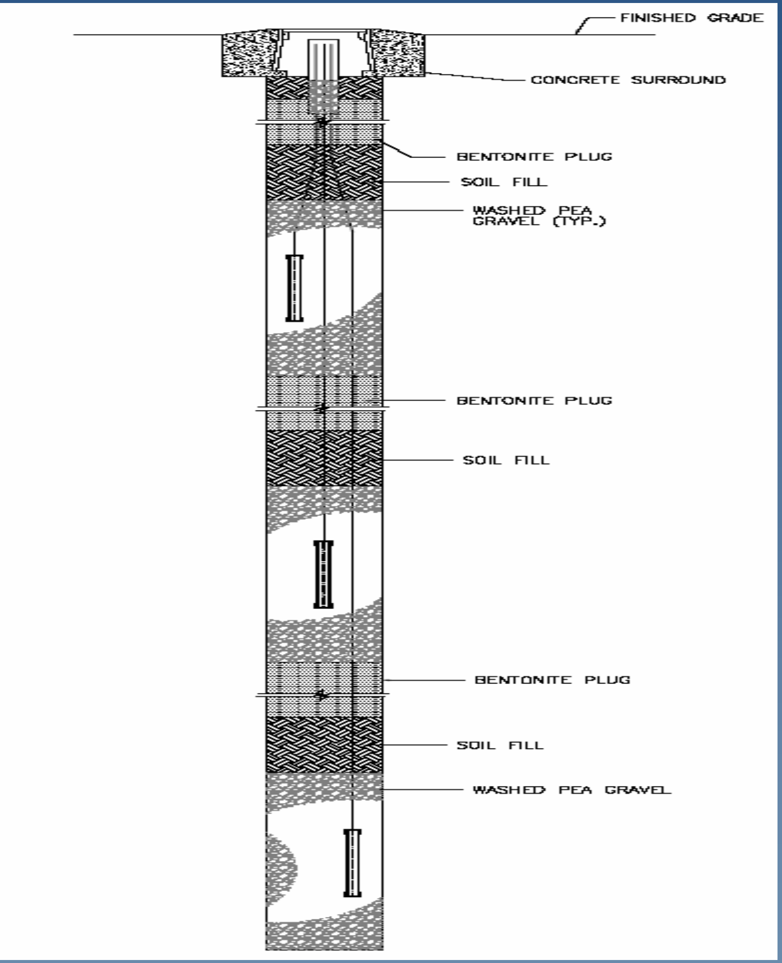


Long-Term Subsurface Monitoring - Probes

- Design
  - Depth
  - Single vs. Multi-Level
  - Protection
  - Identification

Long-Term Subsurface Monitoring - Probes

- Design
  - Shallow 5 to 10’ bgs.
  - Intermediate at ½ depth of waste within 1,000 feet.
  - Deep at/or maximum wastes depth of within 1,000 feet.
  - Located above seasonal LOW water table.
  - If waste is less than 30’ can eliminate intermediate probe.
- Protect & Identify



Long-Term Subsurface Monitoring – Probes – Equipment

- Combustible Gas Indicator
  - Must be able to detect methane gas at a concentration of 0.5 to 100.0 percent, by volume
  - Thermal conductivity/catalytic oxidation/infrared
  - Calibration

Long-Term Subsurface Monitoring – Probes

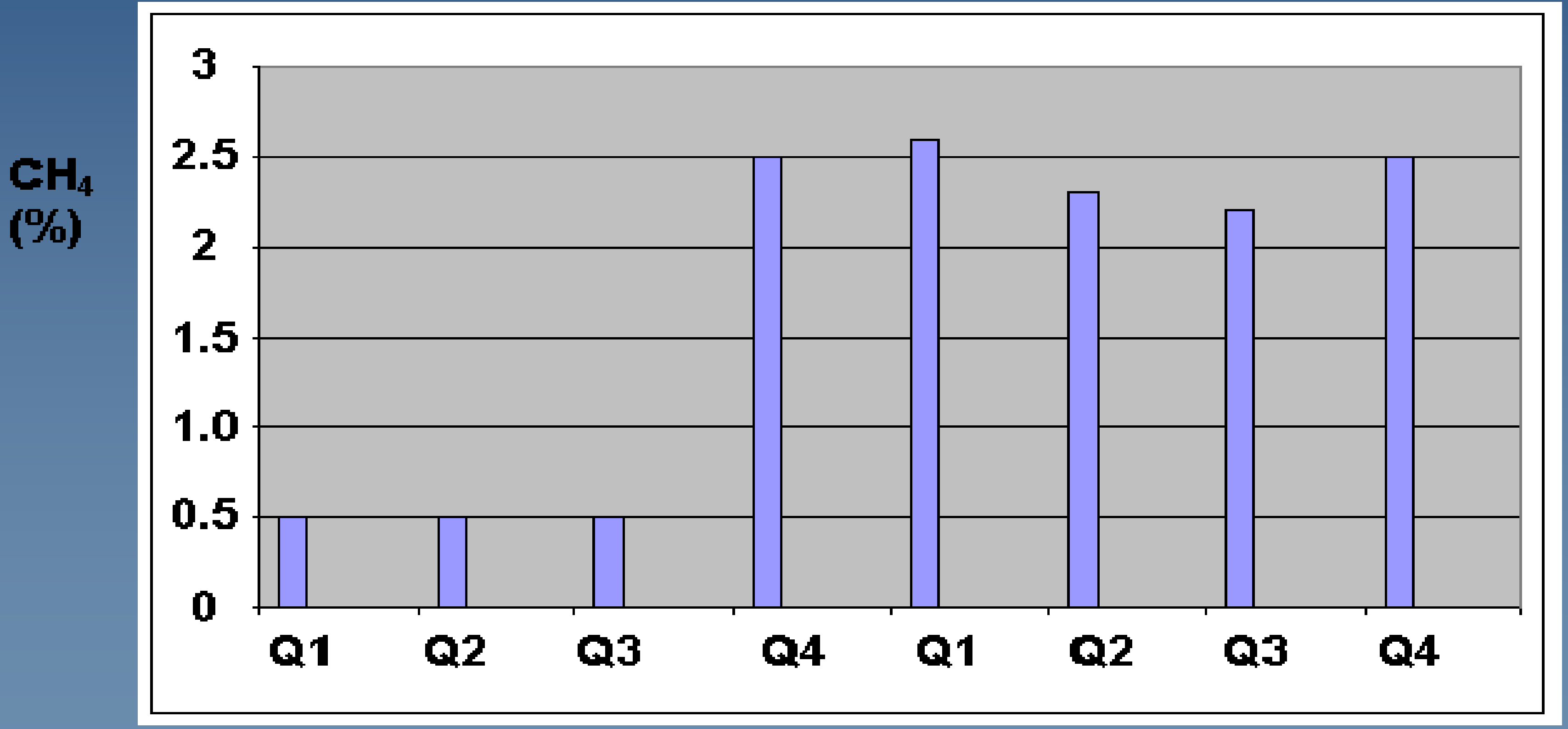
- Monitoring Procedures
  - Confirm probe identity
  - Inspect probe for functionality
    - Damage, water, dirt, etc.
  - No-purge

Long-Term Subsurface Monitoring - Probes

- Data Analysis
    - Time-Trend

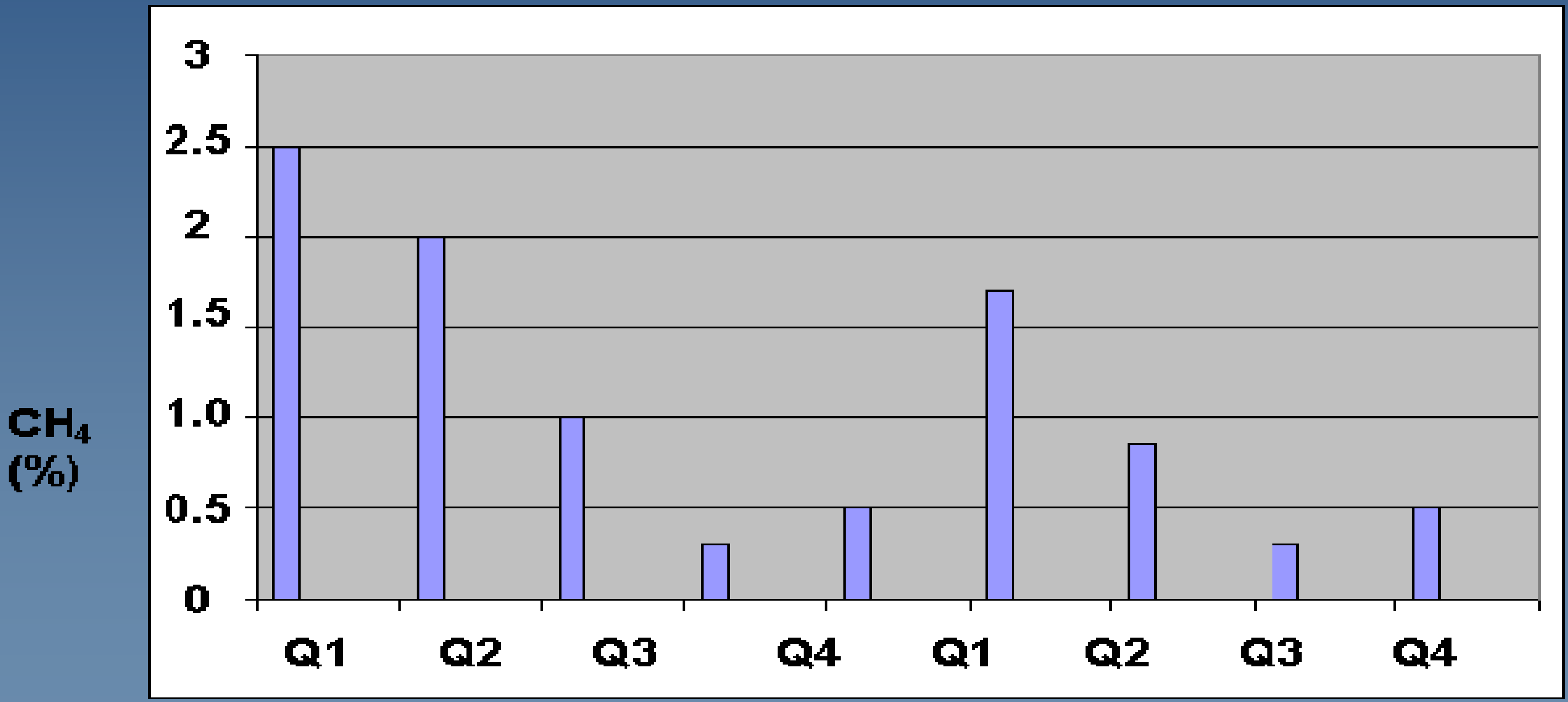
Long Term Subsurface Monitoring - Probes

- Data Analysis



Long Term Subsurface Monitoring - Probes

- Data Analysis



ADVANCED GAS MONITORING

- Long-Term Monitoring of Structures
  - 1.25 CH_4 (25% LEL) in on-site structures
  - In Los Angeles County – All structures within 1,000’ of a landfill.
  - Off-Site structures not CIWMB/LEA responsibility
    - Work with local departments
    - Comment on CEQA & CUP documents
  - Not required, but H_2S monitoring may also deserve consideration.

ADVANCED GAS MONITORING

- Best Practices for Systems for Long-Term Monitoring of Structures – Purposes & Differences Between
  - Probes
  - Building Sweeps
  - Designing and Implementing Continuous Gas Monitoring

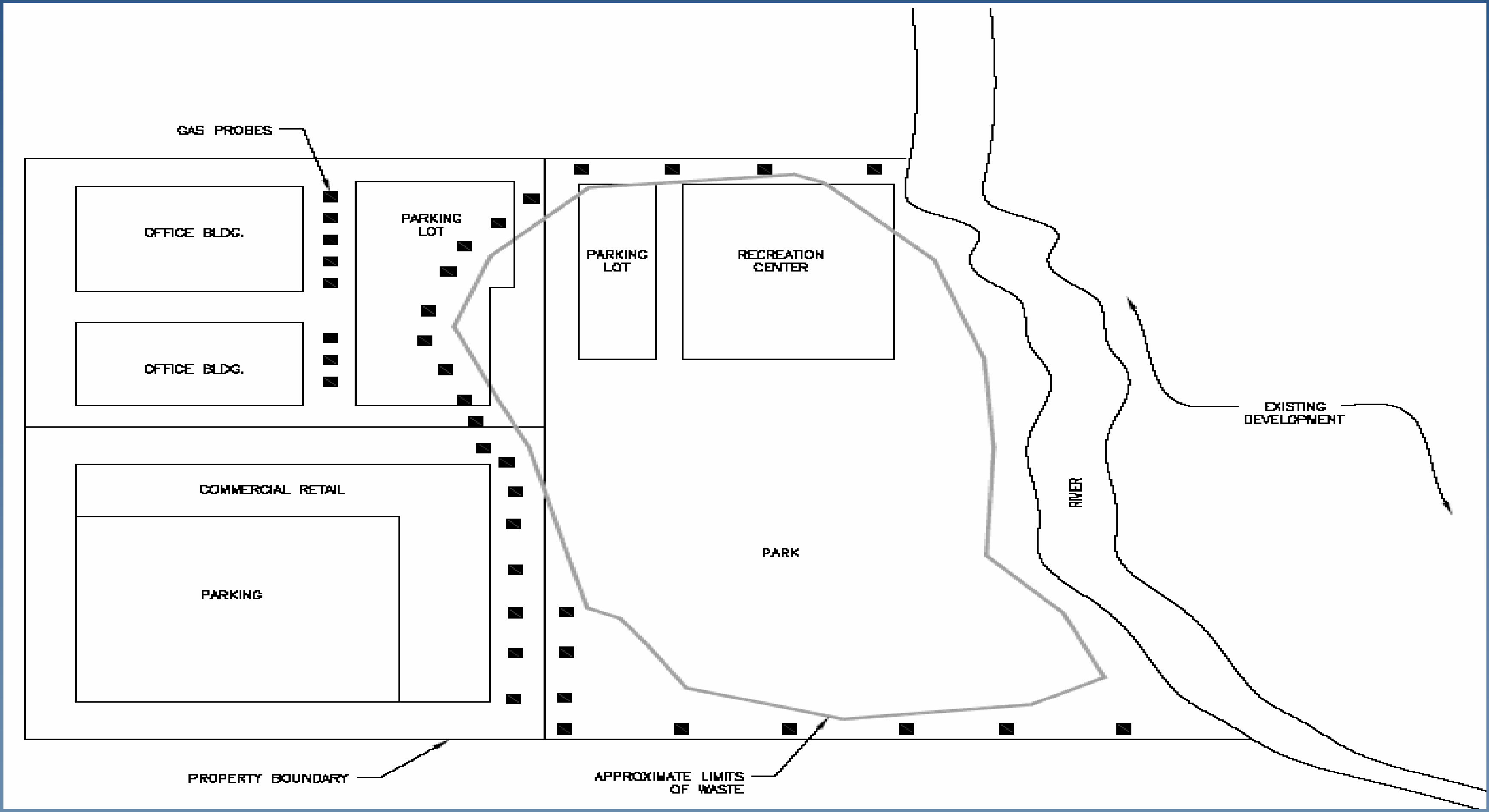
Long-Term Structure Monitoring - Probes

- Placement
- Design
- Monitoring Procedures

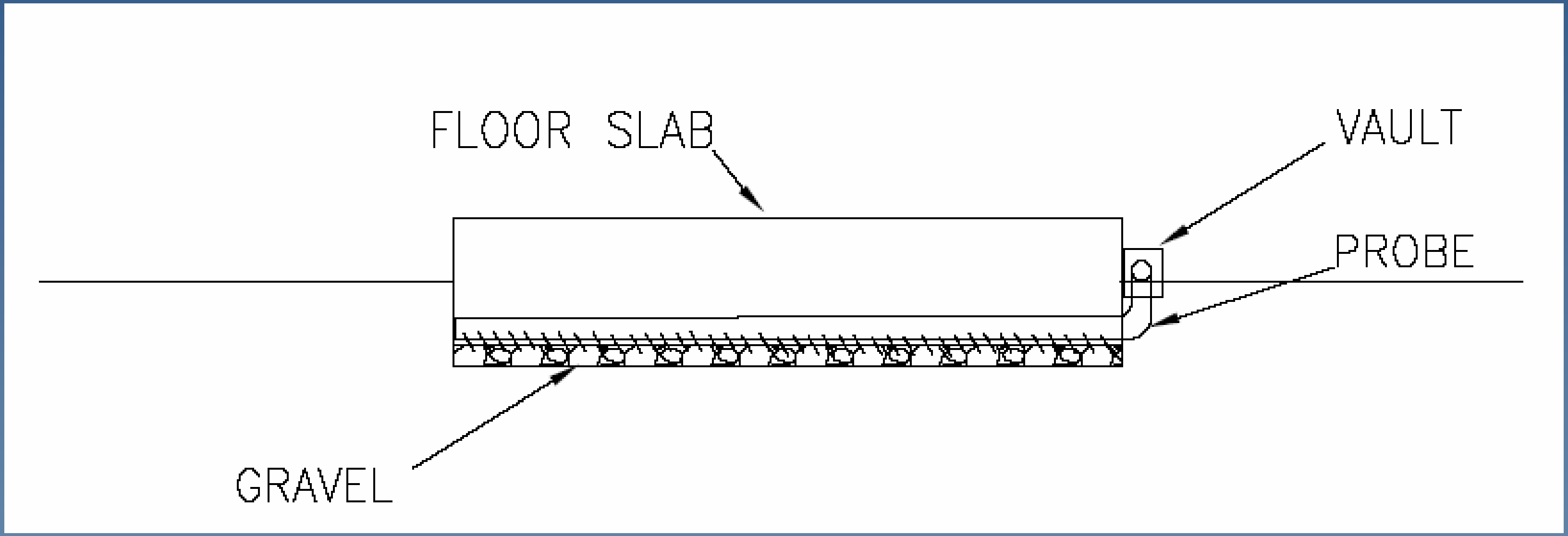
Long-Term Structure Monitoring - Probes

- Placement
  - Between Structures and Areas of Waste
  - Under Structures
  - Within Structures

Long-Term Structure Monitoring –
Probes - Placement



Long-Term Structure Monitoring – Probes - Placement



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Long-Term Structure Monitoring - Probes

- Monitoring Procedures
  - Equipment
  - Probe Functionality
  - No-Purge
  - Time-Trend Analysis

Long-Term Structure Monitoring - Building Sweeps

- Building Sweeps
  - Location(s) – Enclosed spaces, through-slab penetrations, ignition sources
  - Equipment
  - Reproducibility
  - Non-Continuous

Long-Term Structure Monitoring –
Continuous Monitoring Systems

- Designing and Implementing Continuous Gas Monitoring
  - Location(s)
  - Equipment
  - Calibration & Maintenance
  - Power Back-up?
  - Retro-fit vs. New Construction

Long-Term Structure Monitoring – Continuous Monitoring Systems

- Locations
  - Likely Entry Spots
  - Enclosed Spaces
  - Sources of Ignition

Long-Term Structure Monitoring –
Continuous Monitoring Systems

- Equipment
- System type
  - Individual sensor alarms
  - Networked systems
- Sensor type
  - Catalytic
  - Infrared
- Calibration & Maintenance

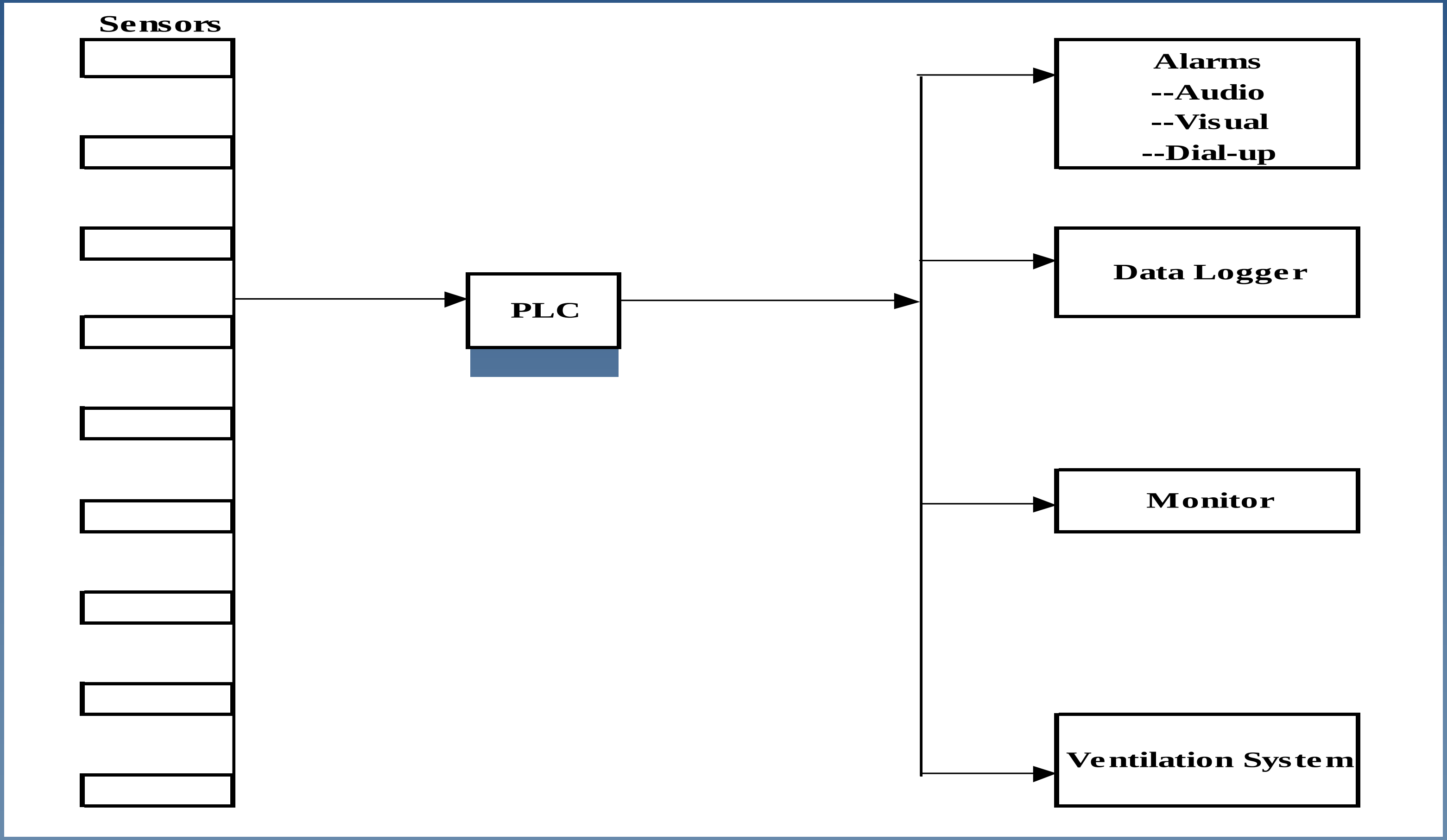
Long-Term Structure Monitoring – Continuous Monitoring Systems

- Equipment
  - Individual sensors
    - Most commonly used
    - Sensor placement
    - Provides visual or audio alarm at preset level

Long-Term Structure Monitoring – Continuous Monitoring Systems

- Equipment
  - Networked System
    - Sensor placement
    - Alarm
    - Controllers
    - Data Logger
    - Hard-wired vs. wireless

Long-Term Structure Monitoring – Continuous Monitoring Systems



ADVANCED GAS CONTROL

- Designing and implementing gas control remedies for maximum effectiveness.
  - Identify the goals for the project
  - Identify and evaluate potential remedies
  - Identify the design criteria
  - Select the appropriate technology(s)
    - Retrofit vs. new construction
  - Monitoring, operations and maintenance
    - How long should it take to mitigate a problem?
      - System balancing and optimization
      - Time to collect and control gas

Advanced Gas Control - Typical Goals

- Building/Structure Protection

- Regulatory Compliance
  - Gas Migration Control (Passive Systems)
  - Gas Migration/Emission/GW Protection/Odor/VOC (Active Systems)
  - Gas-to-energy systems
  - Combination goals

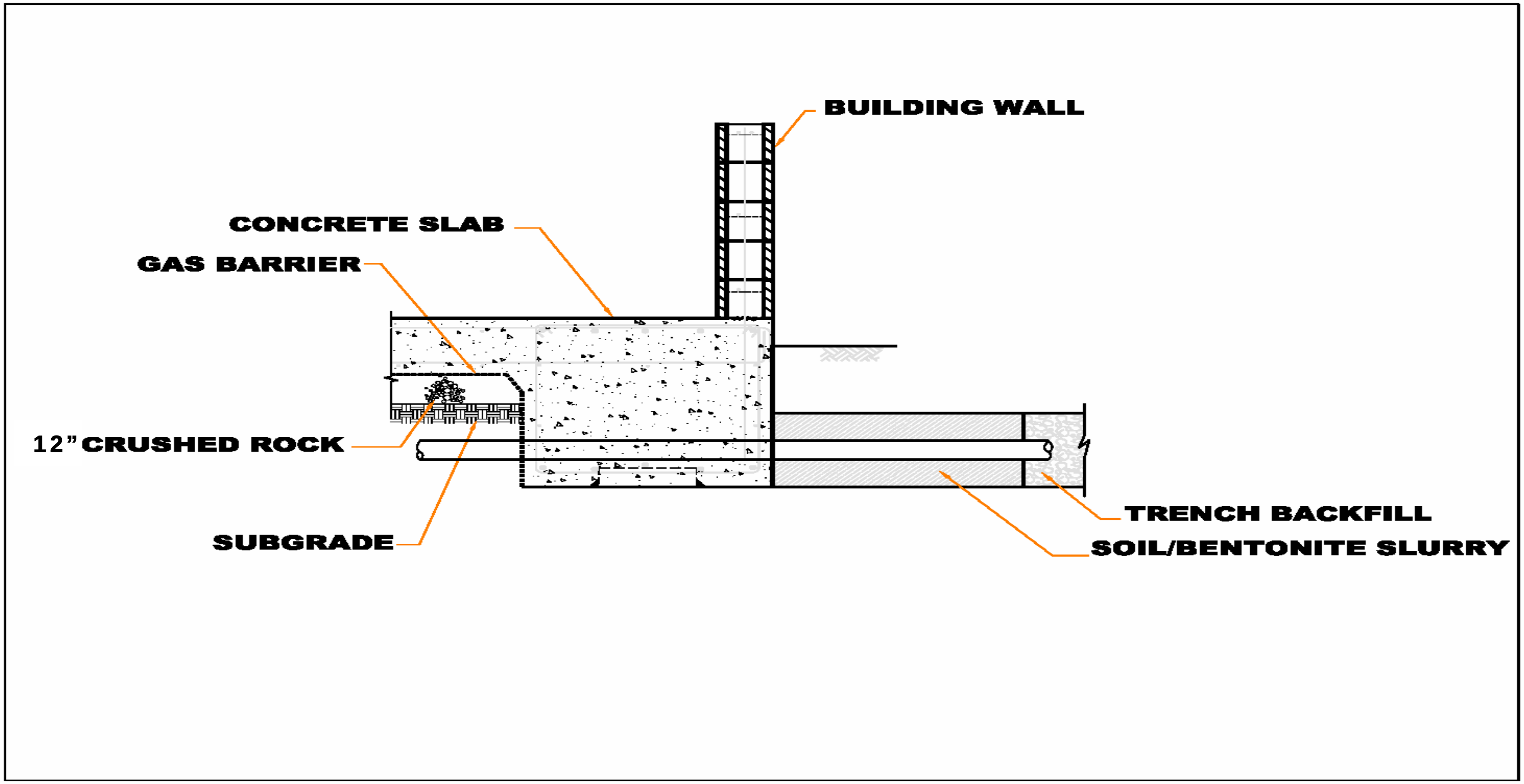
Advanced Gas Control – Building Protection

- Retrofit
  - Seal thru-slab penetrations
  - Utility trench dams & conduit seals
  - Expanded building ventilation
  - Install monitoring system
    - Single sensors
    - Continuous
  - Membrane barrier & interstitial venting?
    - (Have to raise floor deck)
  - Under slab venting (Difficult under existing slab).

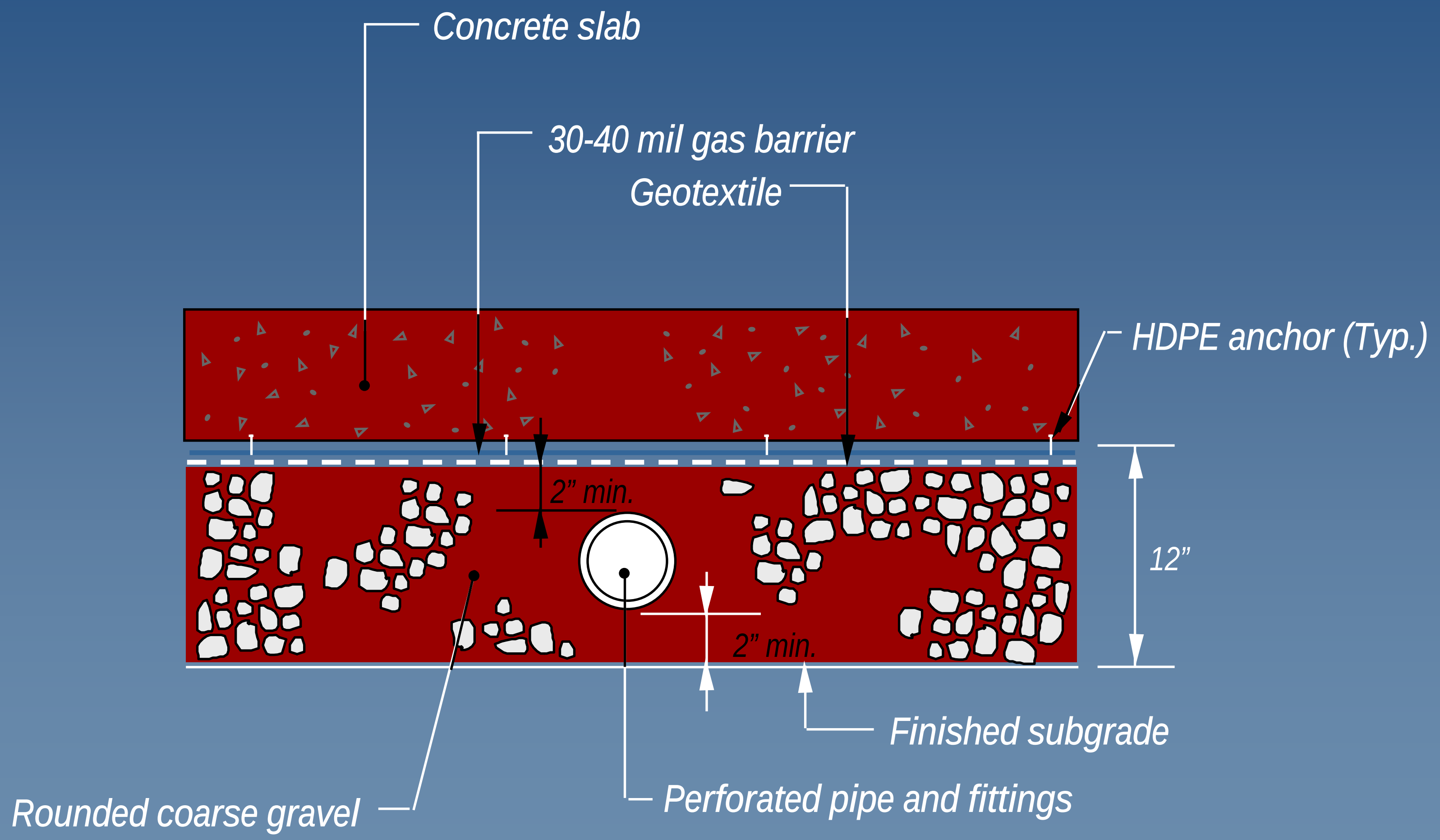
Advanced Gas Control – Building Protection

- New Construction
  - Under slab ventilation or air sweep
  - Minimize thru-slab penetrations
  - Utility trench dams
  - Conduit seals
  - Membrane barrier
  - Enhanced building ventilation
  - Monitoring System
    - Single sensors
    - Continuous

Advanced Gas Control – Building Protection



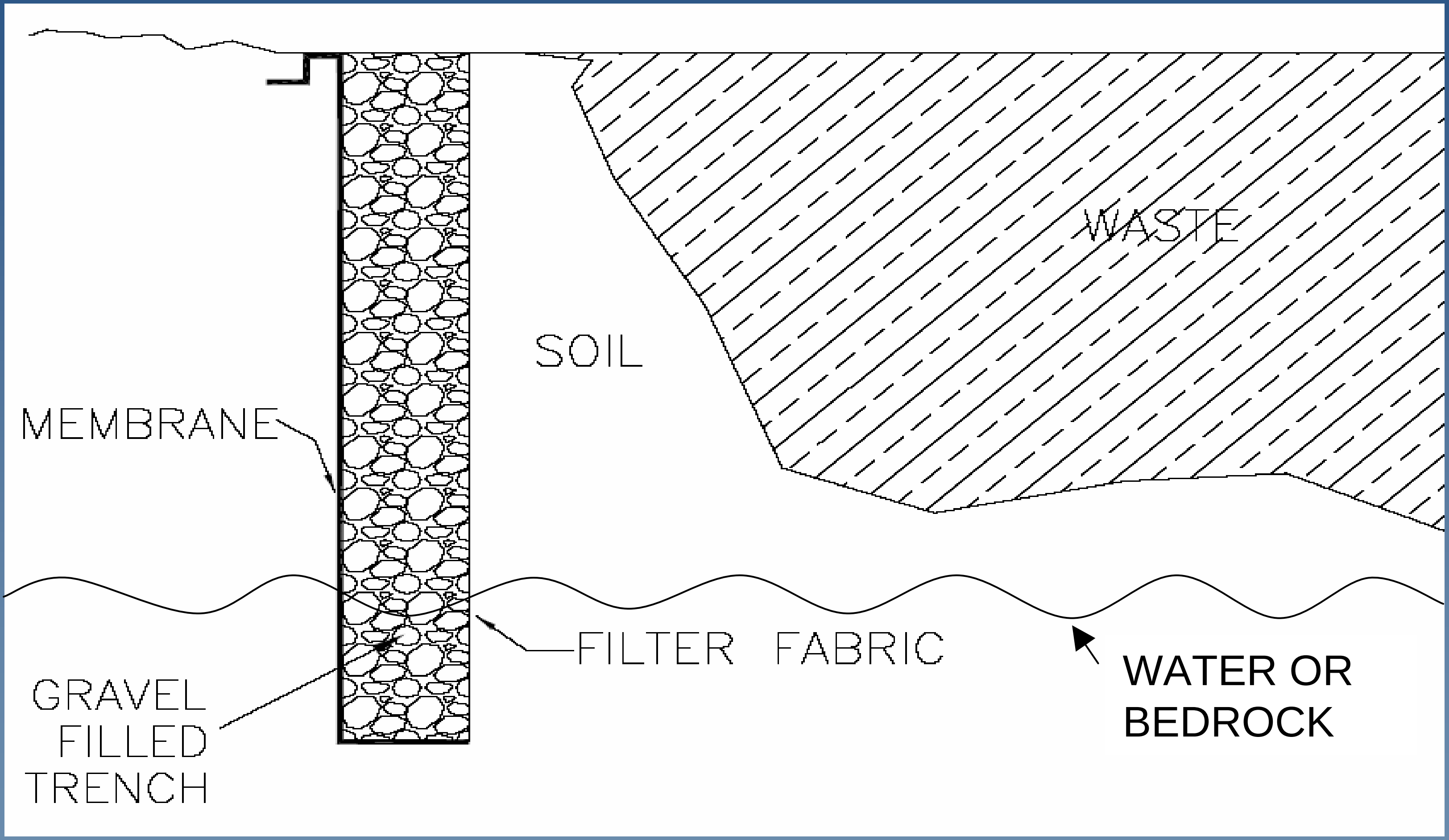
Advanced Gas Control – Building Protection



Advanced Gas Control – Passive Systems

- For Gas Migration Control
  - Passive barrier systems (may include venting)
  - Passive venting systems

Passive Barrier Systems

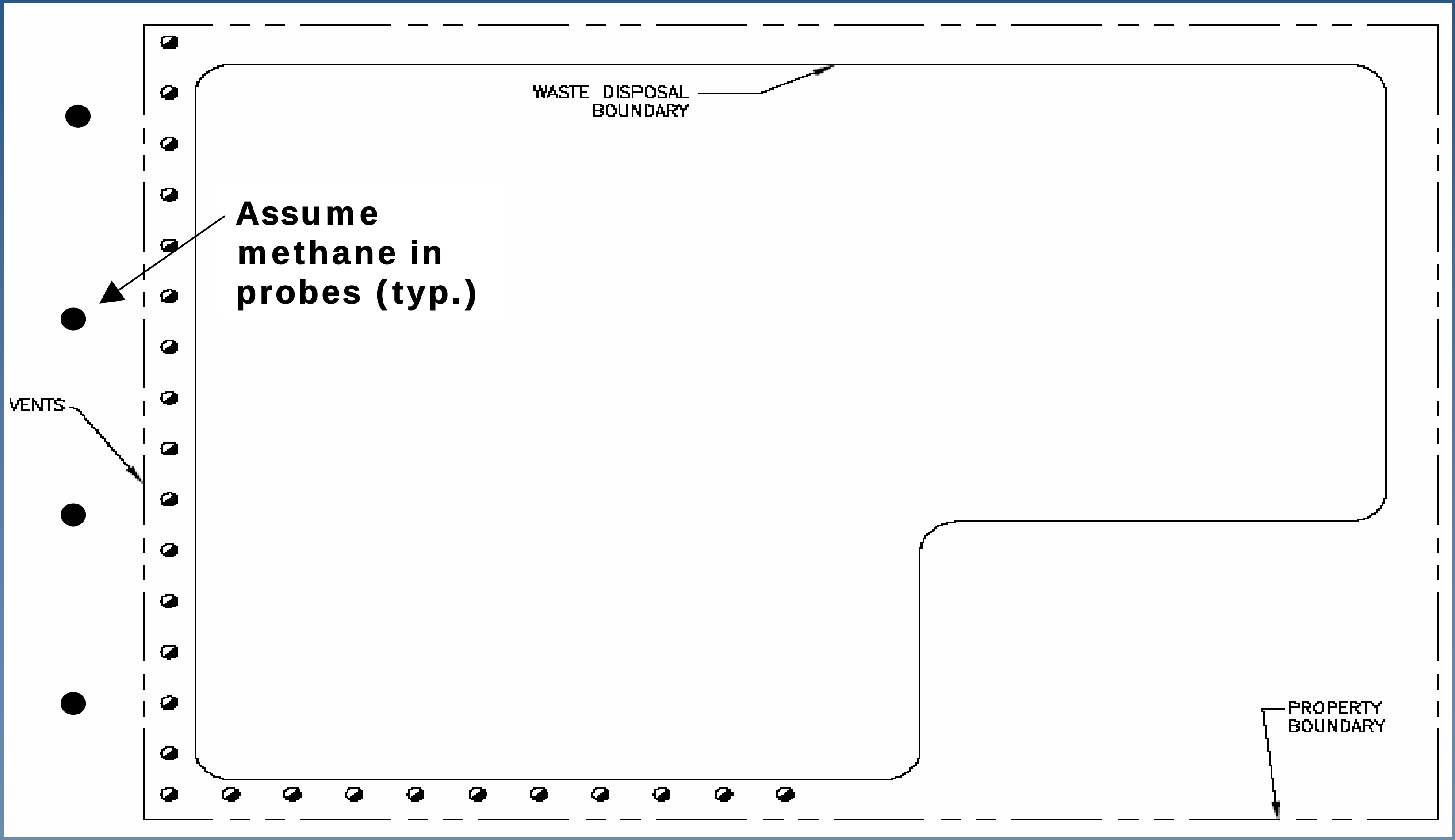


Advantages & Disadvantages of Passive Barrier Systems

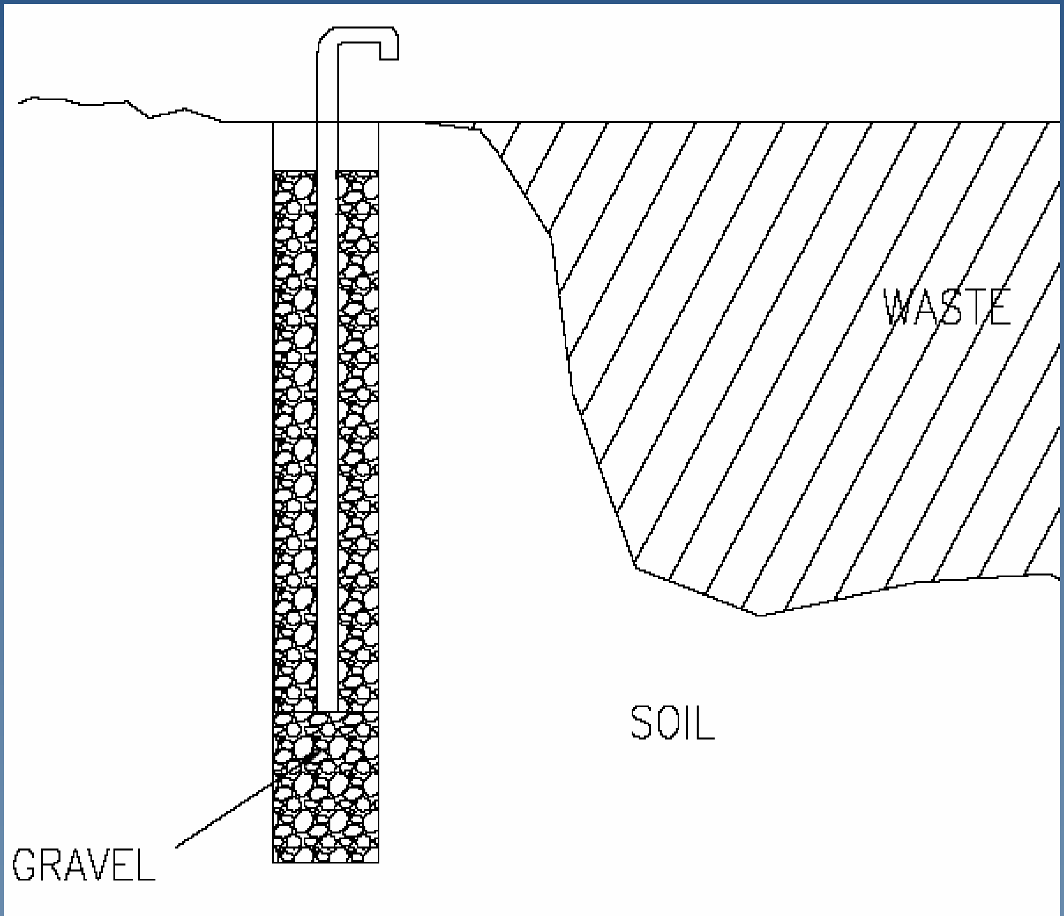
- Advantages
  - Easy to operate
  - Low cost of operation
  - Minimal training required

- Disadvantages
  - Difficult to mitigate offsite gas
  - Less control over air emissions
  - Can be expensive to construct
  - Needs a competent boundary at the bottom of the barrier

Passive Venting Systems



Passive Venting Systems



Advantages & Disadvantages of Passive Venting Systems

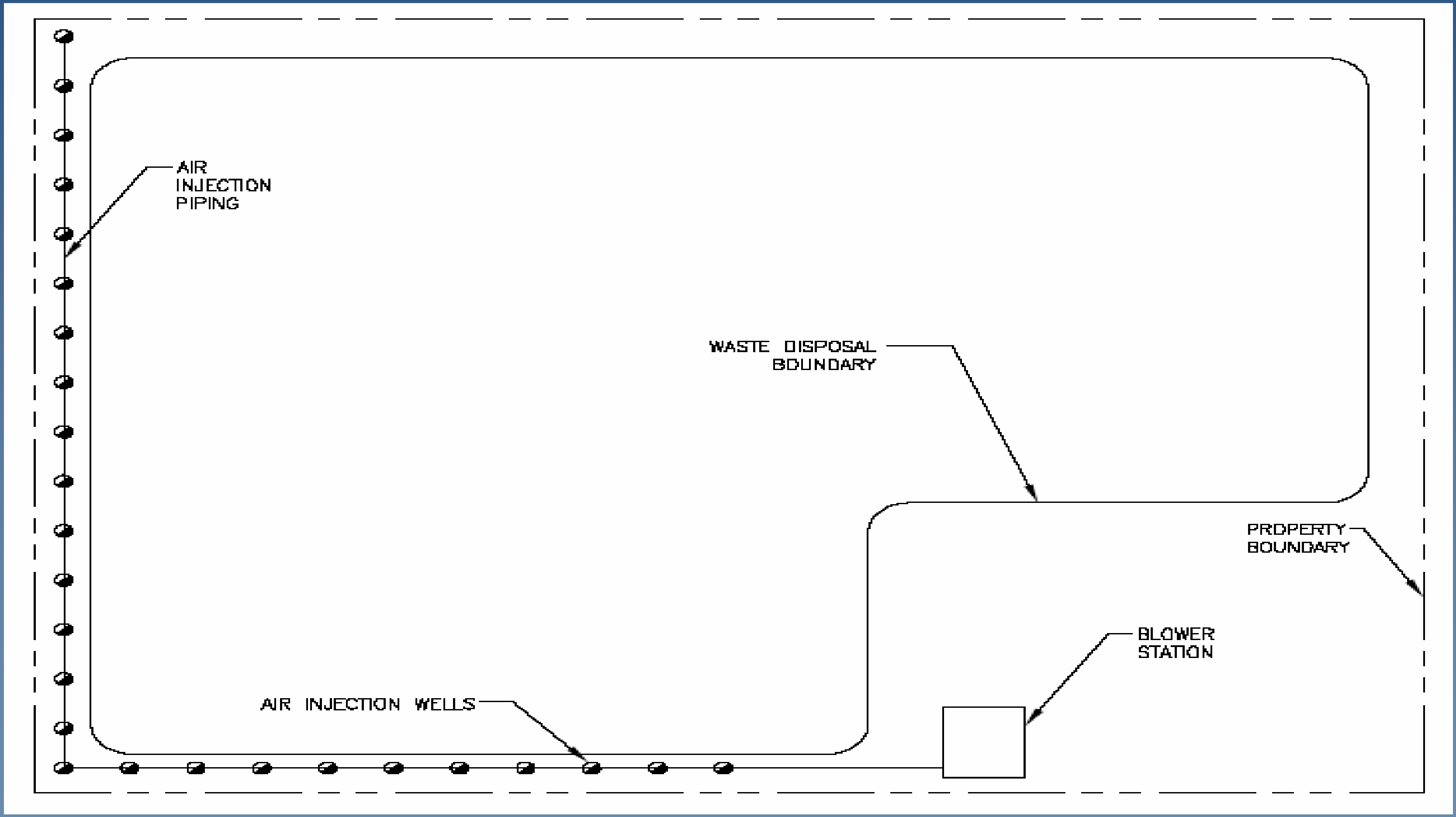
- Advantages
  - Easy to operate
  - Low cost of operation
  - Minimal training required

- Disadvantages
  - Difficult to mitigate offsite gas
  - Less control over air emissions
  - Will require more control points than an active system
  - Wells may not convert to active wells easily
  - Odors

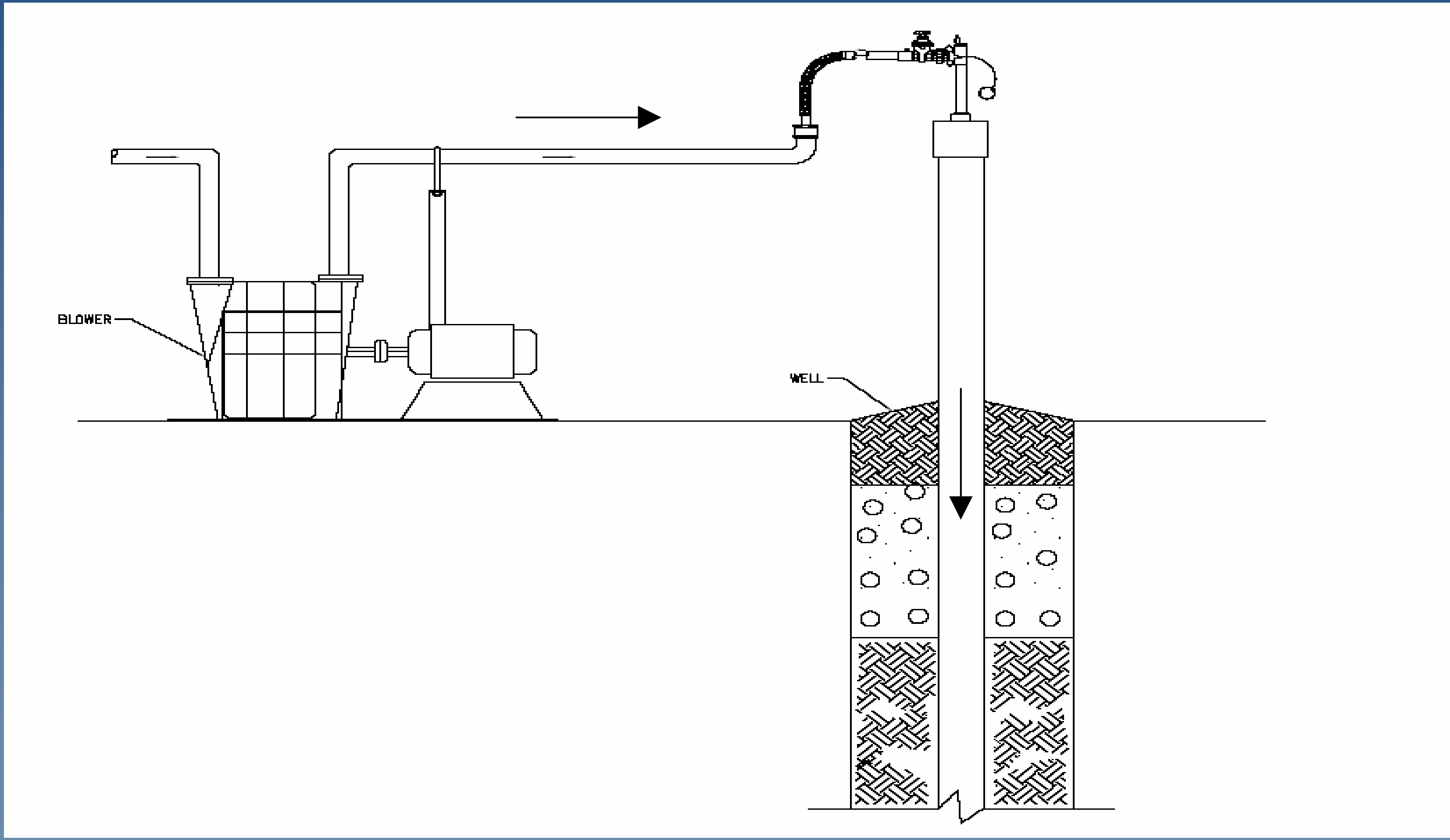
Advanced Gas Control - Active Systems

- For Gas Migration, Emissions, Odor & VOC Control; and Groundwater Protection
  - Positive Pressure Barrier Systems
  - Active Interior Wellfield Extraction
  - Active Perimeter Wellfield Extraction
  - Belt and Suspenders

Positive Pressure Barrier Systems



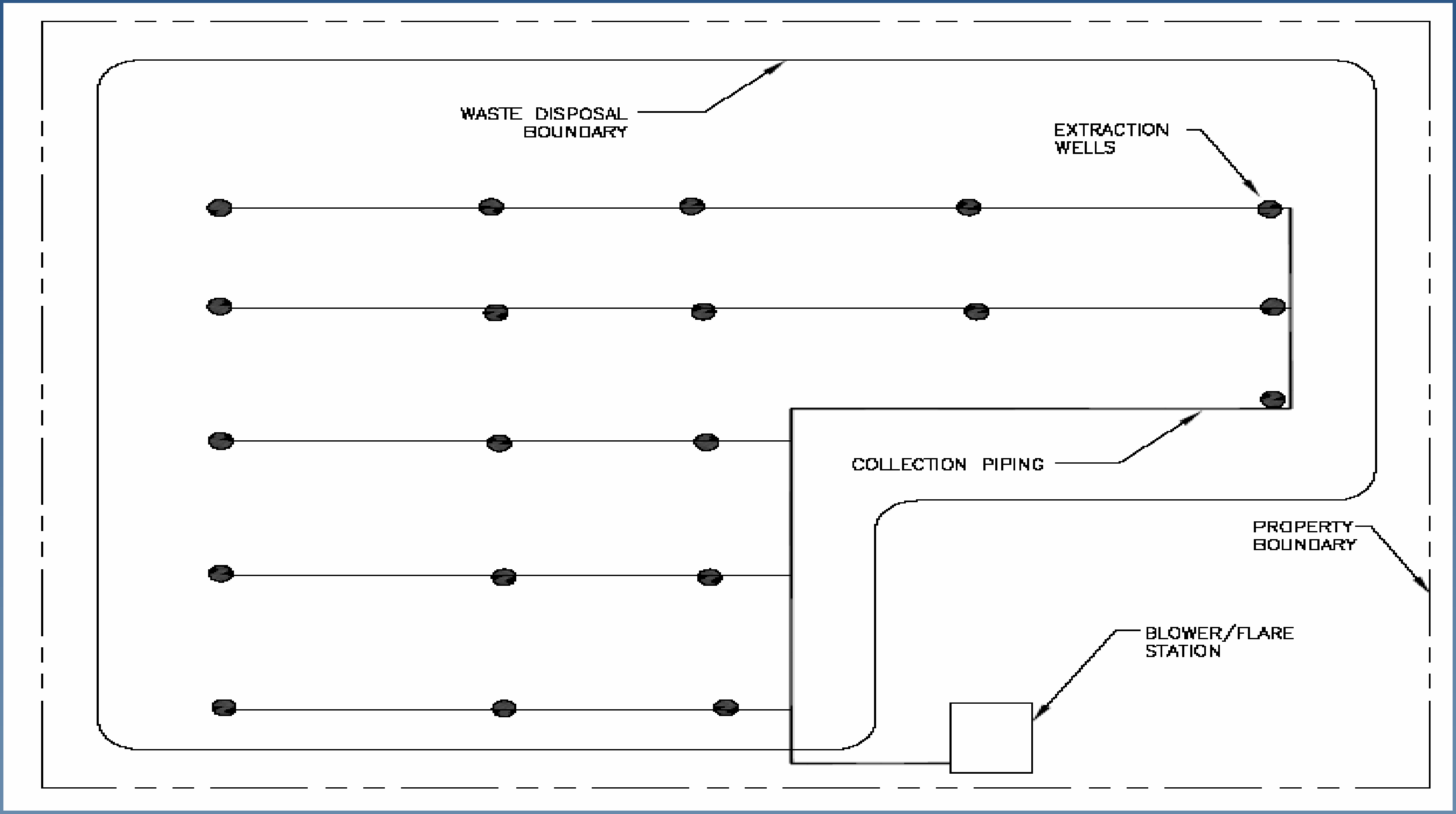
Positive Pressure Barrier Systems



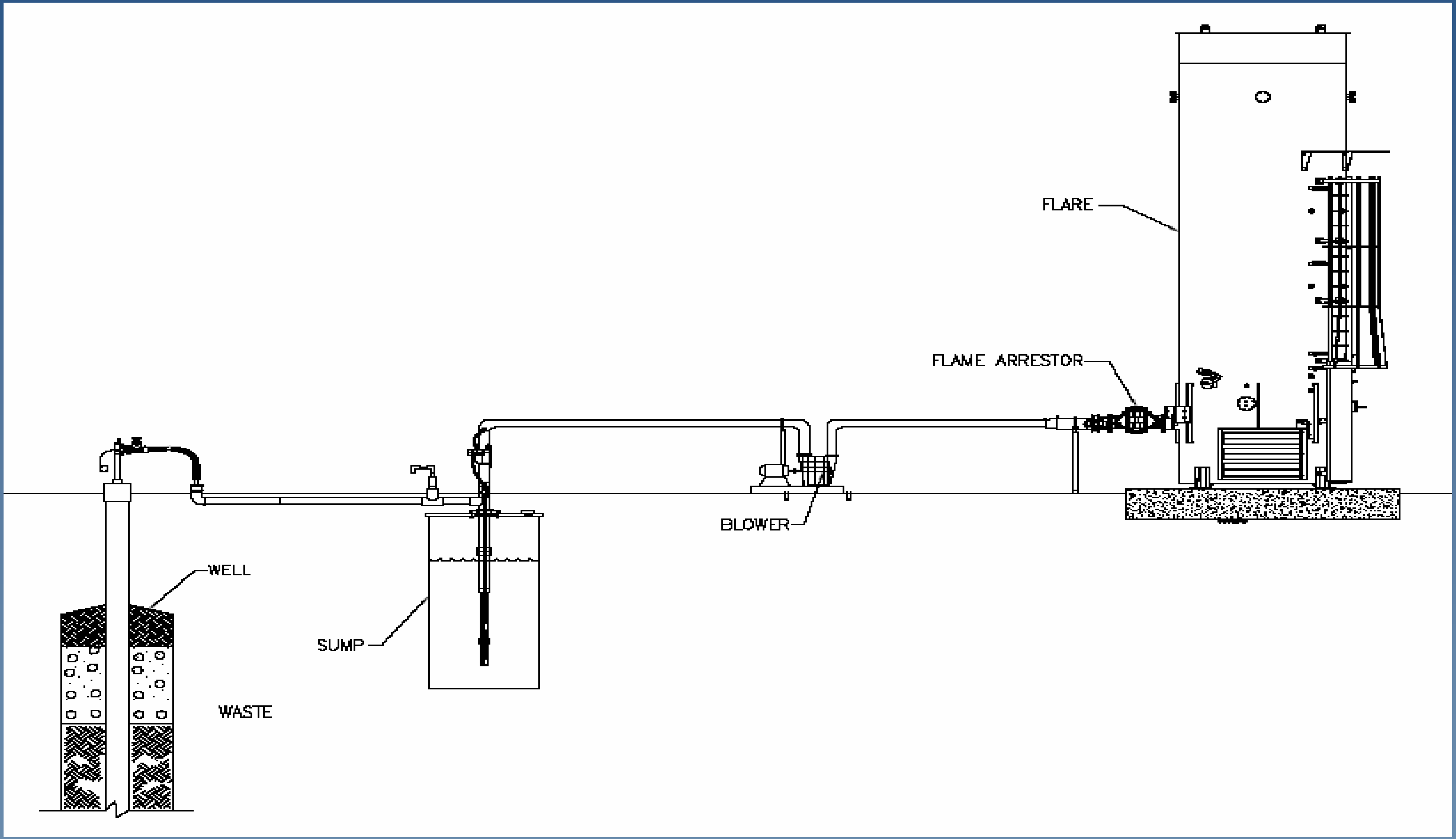
Advantages & Disadvantages of Positive Pressure Barrier Systems

- Advantages
  - Air injection is easy to implement
  - Pressure curtain
  - Aerobic attenuation
  - Good for very tight and/or fractured geology
- Disadvantages
  - Risk of fires in the refuse
  - Existing LFG in soil may be pushed from the landfill causing uncontrolled methane release
  - Does not collect LFG

Active Interior Wellfield Extraction



Active Interior Wellfield Extraction



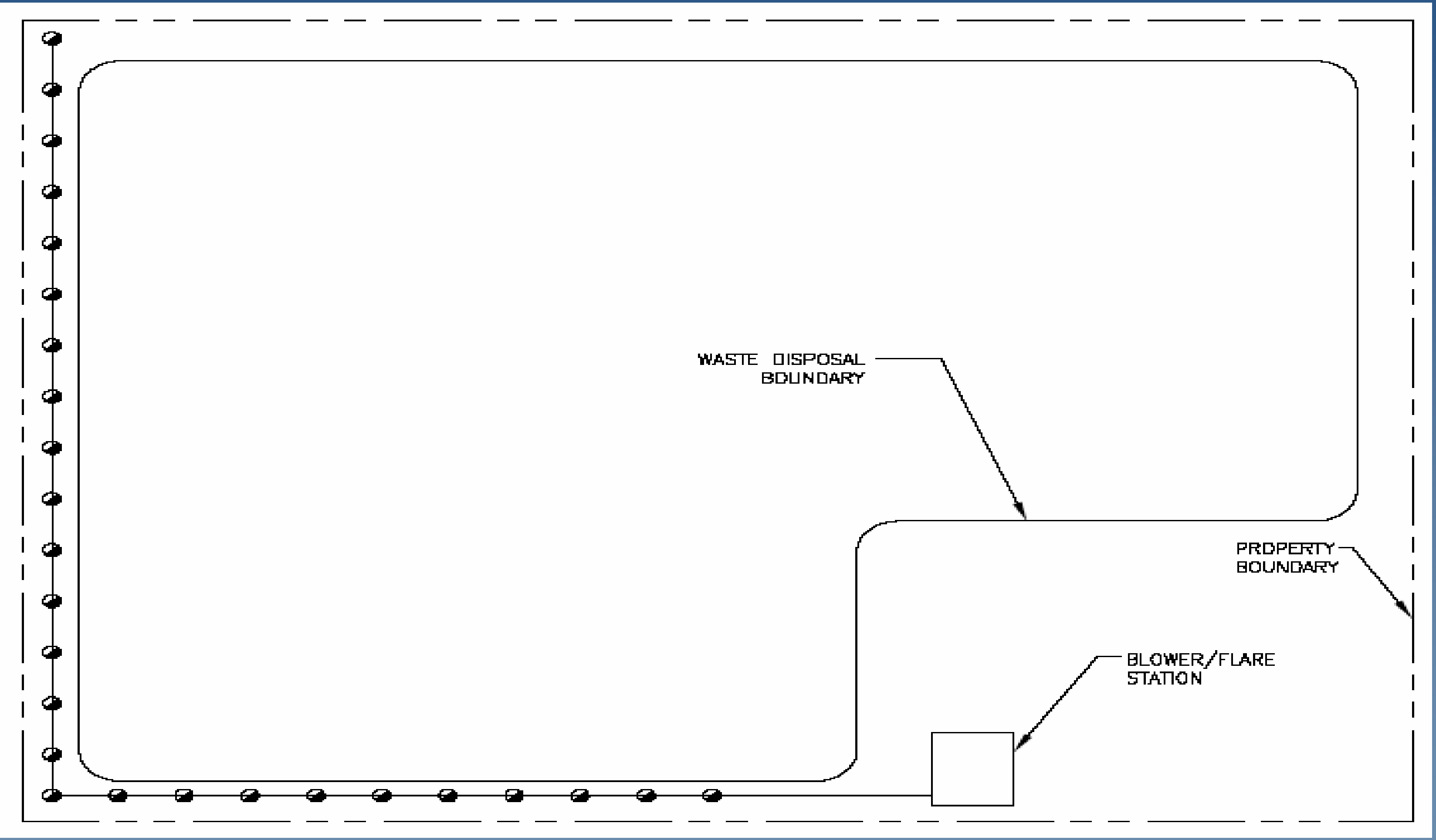
Advantages & Disadvantages of Active Interior Wellfield Extraction

- Advantages
  - Most commonly used LFG collection approach
  - Controls LFG within the waste mass
  - Can remove LFG from surrounding soil or groundwater
  - Allows beneficial use of the LFG

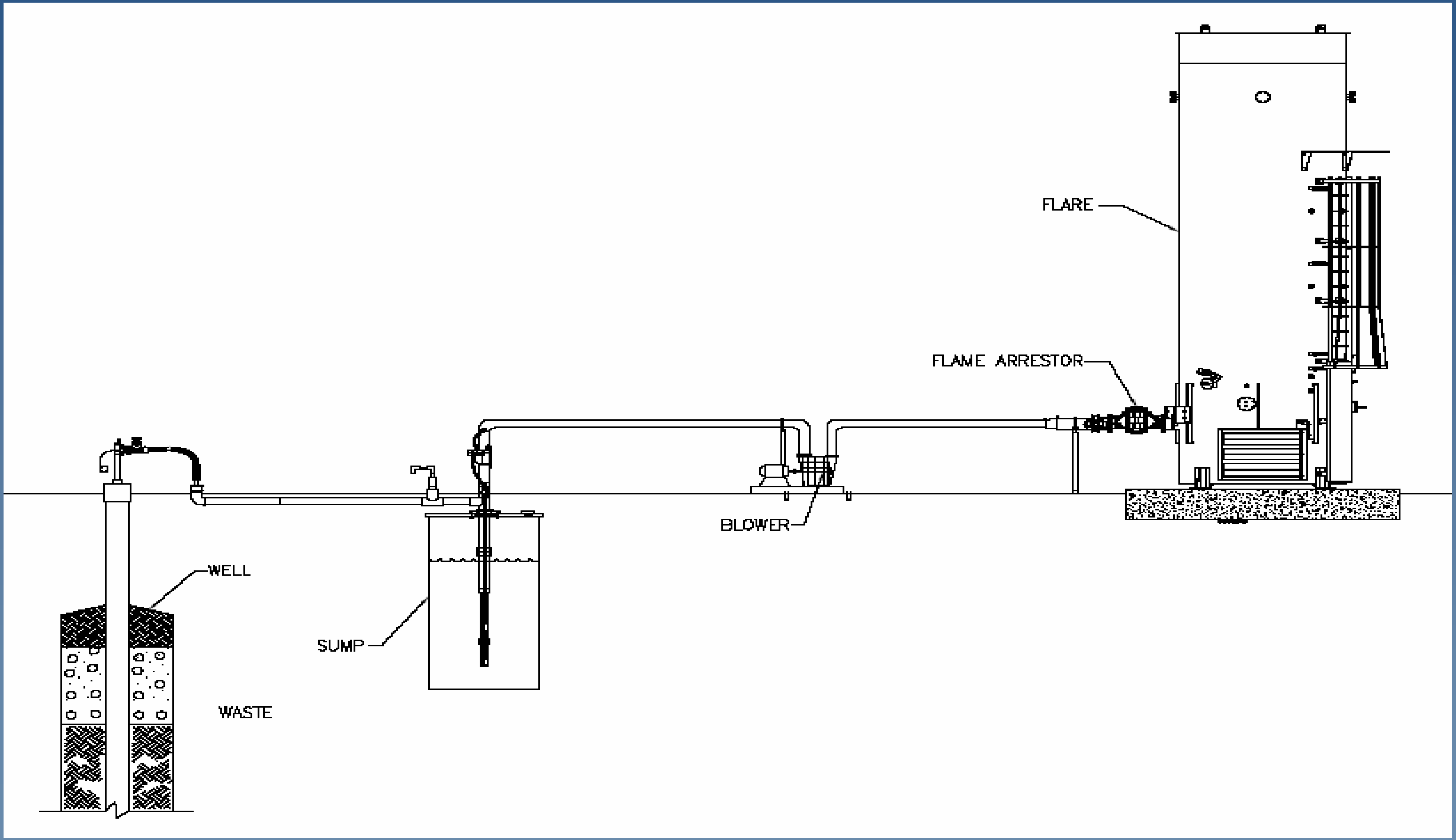
Advantages & Disadvantages of Active Interior Wellfield Extraction

- Disadvantages
  - Wet landfills can cause wells to flood
  - LF settlement can cause wells to pinch or break
  - Interference with landfill operations

Active Perimeter Wellfield Extraction



Active Perimeter Wellfield Extraction



Advantages & Disadvantages of Active Perimeter Wellfield Extraction

- Advantages
  - Provides LFG control when interior wells don't work
  - Can be used to pull LFG back to a landfill
  - Little limit on vacuum applied due to reduced risk of LF fires
  - No interference with active LF operations

Advantages & Disadvantages of Active Perimeter Wellfield Extraction

- Disadvantages
  - Increases the area of contamination by pulling LFG out of the landfill.
  - Methane content in collected gas can be low, making combustion more difficult.

Advantages & Disadvantages of Belt and Suspenders

- Advantages
  - Provides redundant and/or back-up systems
  - Improves control at critical sites
  - More rapid methane gas control
- Disadvantages
  - Increased costs for construction and O&M
  - More systems to maintain

Horizontal Wells vs. Vertical Wells

- Reduced interference with LF operations
- Early LFG Collection
- Wells can be installed when landfill is active

- Well ROI isn't as good vertically as horizontally
- Horizontal bored wells are costly to build

- Better vacuum spread throughout the landfill
- Can be installed after filling is complete

- Must protect wells when placing trash over or around wells

Barometric Pressure Consideration

- Approaches
  - Implement at the wellhead
  - Implement at branch headers
  - Implement at the point of collection (i.e. the blower)
  - Shut some systems off during periods of increasing pressure
  - Works best on low vacuum systems at arid landfills

Advanced Gas Well Control

- Automatic gas well monitoring and flow control

- Consider void volume in the landfill before making adjustments

ADVANCED GAS CONTROL

- Troubleshooting & correcting/upgrading existing gas control systems

- Designing and implementing Automatic ventilation control

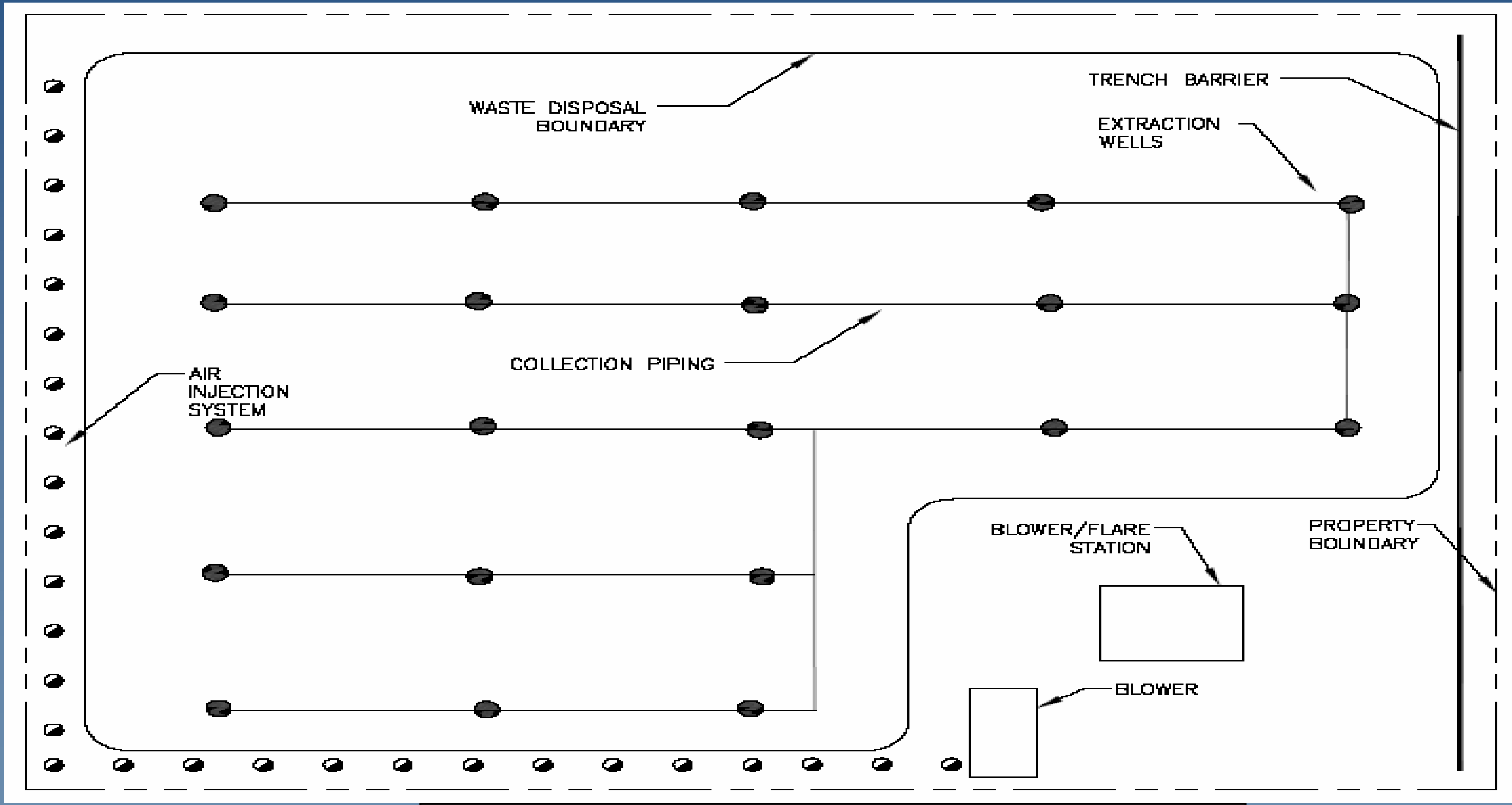
Just Enough Gas To Be A Nuisance

- (What to do when the landfill starts to run out of LFG)
  - Change the location of thermocouples
  - Remove gas burners, add partition walls to flares
  - Timed LFG collection system operation
  - Barometric pressure control (see above)
  - Change LFG disposal method (i.e. change from flare to alternate disposal systems)

Landfill Gas-To-Energy

- End Uses
    - Power Generation
    - Direct Use
    - Pipeline Quality Gas
    - Vehicle Fuel
- Not feasible at most older developed landfills
- May be a good choice for most recently closed landfills
- Energy production often not compatible with other gas management goals

Combination Systems



SCHOOL (or other sensitive receptor)