Landfill Gas Investigations
At Former Landfills and Disposal Sites

CalRecycle

California Department of Resources Recycling and Recovery

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Executive Summary

Former landfills and disposal sites (herein referred to as disposal sites), particularly in developed areas, can pose a threat to public health and safety from the migration of landfill gas into surrounding soils and nearby structures and cause an explosion hazard. California Code of Regulations (CCR) 27 section 20919), requires that Solid Waste Local Enforcement Agencies (LEA) ensure that landfill gas is controlled if "there is sufficient relevant information" that indicates that landfill gas is a hazard or nuisance. Further, 27 CCR section 20919 requires the LEA to ensure that the site has an approved monitoring program in place to check for "the presence and movement of landfill gas." The regulations for landfill gas monitoring networks can be found in 27 CCR section 20925.

The Closed, Illegal and Abandoned (CIA) Site Program was established in October 2000 by the California Integrated Waste Management Board (now CalRecycle) to assist LEAs with the inspection, investigation, and enforcement of state minimum standards for pre-regulation disposal sites. The Solid Waste Information System (SWIS) database contains more than 2,500 CIA sites with more than 1,500 inspected by LEAs statewide. Many of these sites are located in urbanized areas of California such as Los Angeles, San Diego, Orange County, Riverside, San Bernardino, the San Francisco Bay Area, Silicon Valley (Santa Clara), and Central Valley (Sacramento, Stockton, Modesto).

To date, the CIA program has performed landfill gas investigations at 17 former landfills and disposal sites. The investigations included designing and constructing a landfill gas monitoring network and performing monthly monitoring of the network for an initial 12-month period. The data from these investigations support LEAs in enforcing LFG monitoring and control requirements at former landfills and disposal sites to protect public health and safety.

Investigation of landfill gas migration at former landfills and disposal sites can be challenging for a number of reasons: 1) the horizontal and vertical extents for the disposal site may not be well defined, 2) there may be multiple property owners due to subdivision of the former disposal site, 3) development of the site that includes structures, utilities, hardscape, etc., which can create pathways for landfill gas migration and 4) complex environmental setting, e.g. gas monitoring wells difficult to install due to geology, e.g. bedrock, shallow water table, etc.

This guidance document provides a compilation of experience and lessons learned from conducting landfill gas investigations at various locations in California (but primarily in developed, populated urban areas). The perspective of this guidance is from state and local regulators and consultants, who have applied California landfill gas monitoring and control regulations at pre-regulation former landfills and disposal sites and are providing practical knowledge and experience from conducting these investigations. The purpose of this guidance document is to assist regulators, consultants, property owners, developers, and legal firms (and responsible parties) in planning, implementing, and estimating costs for landfill gas investigations at former landfills and disposal sites.

Introduction

Figure 1: Constructing and monitoring landfill gas monitoring wells

Former landfills and disposal sites (collectively referred to as waste disposal sites), particularly in developed areas, can pose a threat to public health, safety, and the environment from the generation and migration of landfill gas into surrounding soils and structures (see Figure 1). This can result in methane concentrations between the upper and lower explosive limit of 5 percent and 15 percent, which may cause explosion hazards or oxygen-deficient conditions. Title 27 of the California Code of Regulations (CCR) (27 CCR section 20919) requires that LEAs ensure that landfill gas is controlled if "there is sufficient relevant information" indicating that landfill gas is a hazard or nuisance. Furthermore, 27 CCR section 20919 requires that LEAs ensure that sites have an approved monitoring program in place to check for "the presence and movement of landfill gas." The regulations for landfill gas monitoring can be found in 27 CCR sections 20923 and 20925. In determining compliance with 20919, the LEA may reference 20925 as criteria for a compliant landfill gas monitoring network for a disposal site.

In January 2009, CalRecycle staff in conjunction with several LEAs and environmental consultants developed best management practices (BMPs) to provide operators of waste disposal sites guidance for the design and construction of LFG probes constructed or modified during the interim prior to modifications to 27 CCR section 20925. CalRecycle staff developed the BMPs based on recommendations adopted by the previous California Integrated Waste Management Board (CIWMB) that were taken from the landfill gas monitoring well functionality at 20 California landfills. In general, the following BMPs were developed:

- Probes should be constructed with maximized screened segments.
- Probes should be assembled using materials that provide an adequate seal and do not interfere with sampling trace constituents (PVC threaded assemblies).
- The design should limit the number of probe pipe connections by using longer PVC pipe sections.

- Probes should be constructed using a non-specialized valve assembly (e.g., lab cock or similar valve that is easily opened and closed).
- Wells and probes should be properly labeled and identified.
- Probes should be constructed of ¾-inch PVC to allow access by a bore monitor (e.g., down-hole camera).
- The depth of the probe in relation to the water table should be a design consideration.
- Probes should be preferentially located as far from surface vegetation as possible in order to avoid root intrusion into shallow probes.
- A Certified Engineering Geologist/Registered Civil Engineer or experienced and qualified persons under their direct supervision must "field design" the screened interval for the probes and certify installation/completion of wells/probes in the as-built required by the regulations.
- Probes should be based on subsurface conditions (i.e., lithology, contacts, groundwater, etc.) and should monitor zones that are the most likely pathways for soil gas migration.

The Closed, Illegal and Abandoned (CIA) Site Program was established in 2000 by the California Integrated Waste Management Board (now CalRecycle) to assist LEAs in the inspection, investigation, and enforcement of state minimum standards for pre-regulation waste disposal sites. The Solid Waste Information System (SWIS) database contains more than 2,500 closed, illegal, and abandoned waste disposal sites with more than 1,500 sites inspected by LEAs statewide. Many of these sites are located in urbanized areas of California such as Los Angeles, San Diego, Orange County, Riverside, San Bernardino, the San Francisco Bay Area, Silicon Valley (Santa Clara), and Central Valley (Sacramento, Stockton, Modesto). To date, the CIA program has performed landfill gas investigations at 17 waste disposal sites, which included the design and construction of landfill gas monitoring networks and the performing of monthly and quarterly monitoring of the network.

The investigation of landfill gas migration at former waste disposal sites can be challenging for a number of reasons, including the following:

- The horizontal and vertical extent of wastes may not be well defined.
- There may be multiple property owners due to subdivision of the land corresponding to the former disposal site.
- The site may have been developed to include structures, utilities, hardscape, etc., which can create pathways for landfill gas migration.
- There may be complex environmental and geologic setting or conditions (e.g., landfill gas monitoring wells are difficult to install in areas with hard bedrock, a shallow water table, etc.).

The purpose of this guidance document is to provide information to LEAs to assist in planning landfill gas investigations at former waste disposal sites.

Federal and State Regulations

Federal and state regulations require that landfills and disposal sites be monitored for landfill gas migration to prevent explosion hazards that may occur due to the accumulation of explosive gas within structures or utilities near the site (see Figure 2). In California, 27 California Code of Regulations (CCR), section 20921 requires local enforcement agencies to ensure that landfill gas concentrations do not exceed 5 percent methane by volume at the designated facility boundary or 1.25 percent in on-site structures. In addition, 27 CCR section 20919 requires that LEAs ensure that landfill gas is controlled if “there is sufficient relevant information” that indicates that landfill gas is a hazard or nuisance. Furthermore, 27 CCR section 20919 requires that LEAs ensure that sites have approved monitoring programs in place to check for “the presence and movement of landfill gas.” The regulations for landfill gas monitoring networks can be found in 27 CCR section 20925.

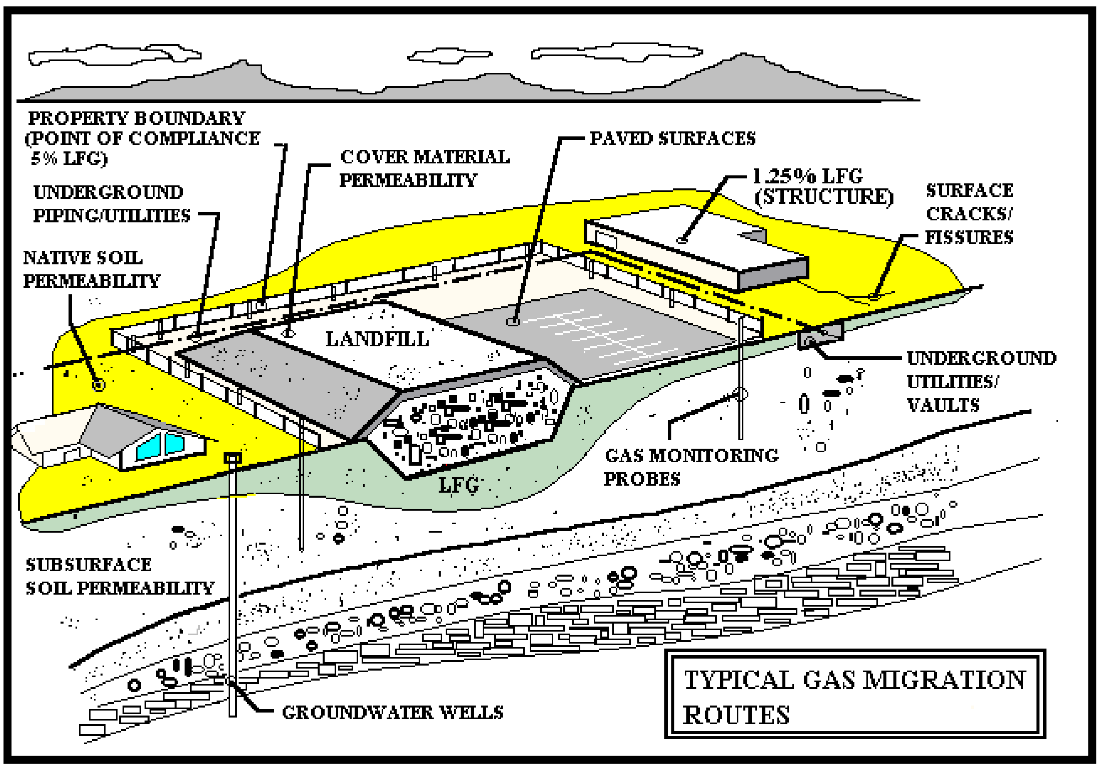


Figure 2: Diagram depicting potential landfill gas migration routes

The design and construction of landfill gas monitoring networks must be done in a manner that allows for the collection of representative data for regulators, owners, and operators to assess and control, if necessary, landfill gas migration that could potentially pose threats to public health and safety. California’s varying climates, topography, and geologic settings (e.g. coast, valley, mountains, etc.) present challenges in the application of regulations to the design and construction of landfill gas monitoring networks for landfills and disposal sites. For California Central Valley sites, alluvial plains and deposits provide relatively predictable inter-bedded subsurface conditions in which to design and locate landfill gas monitoring wells. Mountains, foothills, and coastal locations, on the other hand, can present geologic conditions that make locating and constructing wells difficult or infeasible. Other inherent problems in design and construction of LFG monitoring networks may include shallow or perched ground water conditions, tidally influenced locations, and landfills located in watershed areas (placed in ravines, canyons, and former waterways). Still another problem that can complicate the design and construction of a monitoring network is a lack of data and other information on the horizontal and vertical extents of the landfill, which must be determined prior to locating and designing landfill gas monitoring wells (See Figure 3).

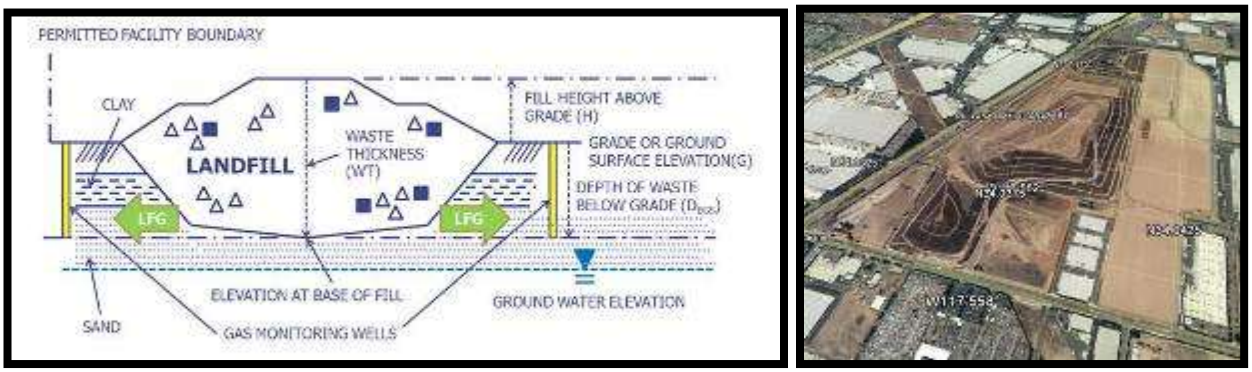


Figure 3: Diagram depicting landfill gas monitoring network parameters; Milliken Sanitary Landfill in San Bernardino County was placed in an excavation and filled above grade.

This guidance document will address the design and construction challenges for LFG monitoring networks, specifically as they relate to varying geologic settings in California and present case studies of various landfills and disposal sites where landfill gas monitoring networks or alternative monitoring programs were approved and constructed.

Preparation of a Landfill Gas Investigation Work Plan

Planning and coordinating a landfill gas investigation begins with the preparation of a LFG Investigation Work Plan that provides background information, defines the project objectives, describes the proposed scope of work and rationale, and describes how the investigation will be conducted based on available information and applicable regulatory requirements. A work plan should include results of a previous Phase I office investigation, or if such an investigation has not been conducted, it should be conducted as part of preparing the work plan. In general, a work plan should include the following sections:

- Introduction
- Project objectives
- Description of the site location
- Ownership and operators information
- A background section (information is used as a basis for well locations and depths) that includes the following information:
    - Chronological history of the site based on historical aerial photographs and topographic maps to evaluate the history of the waste disposal site, lateral extents, years of operation, land uses, etc.
    - Information from the CalRecycle SWIS database
    - Information in previously prepared background reports and documents from CalRecycle, LEAs, regional boards, previous consultants, and other regulatory databases
    - Interviews of persons knowledgeable about the site
- Descriptions of the site and regional topography, geology, and ground water
- Descriptions of the scope of work (SOW) and methodologies and rationale for why the specific SOW was selected
- Descriptions of pre-field work activities to be conducted that may include the following:
    - Boring/LFG well permits
    - Encroachment permits
    - Traffic control plans
    - Notification process
    - Site access/right-of-entry agreements
    - Reference to and description of the site-specific health and safety plan
    - LFG well locations and utility clearance (e.g., site visit to mark out proposed landfill gas well locations, contact Underground Service Alert, etc.)
    - Subsurface utility clearance by a private geophysical company, as applicable
    - Subsurface survey to confirm or assist with delineating the extent of wastes, as applicable
- Description of the investigation, methodologies, and rationale, including but not limited to the following:

- Proposed locations of LFG monitoring wells and rationale
- LFG monitoring well construction (proposed drilling and sampling methodology based on anticipated subsurface conditions, proposed LFG well design (e.g., single, dual, triple probes, well screen intervals); according to 27 CCR regulations, LFG monitoring wells must be placed outside the waste in native soils and must be constructed to a depth equivalent to the deepest portion of the wastes)
- LFG monitoring well construction methods
- Air and/or personal monitoring
- Equipment decontamination procedures
- Documentation
- Proposed sampling methods of subsurface materials
- Methodologies for preparing LFG well boring logs
- Procedures to document the fieldwork including preparation of daily field reports, photographs, etc.

- Proposed analytical testing program and rationale (soils, wastes, and LFG)
- Quality assurance/quality control
- Procedures to restore the site
- Management of investigative derived wastes
- Proposed LFG monitoring program and reporting requirements, schedule
- Figures:
    - Site location map
    - Site topographic and/or historical aerial map(s)
    - Site plan indicating site and estimated extent of wastes, based on available information (this may include overlays using historical aerial photographs and topographic maps onto current site conditions)
    - Site plan and proposed LFG well locations
    - LFG well schematic(s) indicating proposed number of probes, screened intervals, construction materials and specifications
- Tables:
    - Proposed LFG well locations
    - Proposed analytical testing program(s)
- Appendices:
    - Relevant background data (e.g., previous documents, reports, inspections, boring and/or trench logs, information on the history of the site and waste boundaries (horizontal and vertical extents)
    - Historical aerial photographs (chronologically identified)

Typically, a draft landfill gas investigation work plan is completed and submitted to regulatory agencies for review, comment, and approval. Following completion of final edits and revisions, the work plan is finalized and scheduling of the fieldwork can be coordinated between the regulatory agencies, consultant, property owner(s), drilling subcontractors, analytical testing laboratory, and others as appropriate. The CIA program also uses the LFG investigation work plan as the basis for a cost estimate for the investigation, which will include construction of the

LFG monitoring network, collection of LFG monitoring data and any other field work necessary to support the investigation (e.g., land surveying, topographic map development, geophysical survey and clearance, permits, etc.).

The LFG investigation work plan is also used to provide the proposed scope of work in sufficient detail so that regulating/permitting agencies have the necessary information to issue/approve the necessary permits or waivers and/or to obtain access to the waste disposal site and/or adjacent properties for the investigation. Permit fees may be included or waived, depending on the nature of the investigation; generally, if the investigation is for a public health and safety issue, most local government agencies will waive permit fees.

Landfill or Disposal Site Conditions and Developing a Conceptual Site Model

The Conceptual Site Model (CSM) is an understanding of the dynamics of the waste disposal site environmental conditions. The CSM is used to understand potential sources of contamination, migration pathways, and human and ecological receptors that, based on the results of the investigation, may need to be addressed. In designing a monitoring network to meet the intent of California Regulations (27 CCR section 20925), a well thought-out and researched conceptual site model (CSM) must be developed. The CSM should include, but not be limited to, as complete an understanding as possible of the following:

- Anticipated subsurface conditions (e.g., lithology, fill, formation, structures, etc.)
- Hydrogeological setting (depth to groundwater, groundwater flow direction, depth(s) of wastes with respect to the depth to groundwater (see Figures 9 and 10)
- Method/type of waste disposal site, (e.g., canyon fill, trench and fill operation, waste disposal onto former land surfaces, waste disposal into water bodies including rivers, bay, ocean, etc.) (see Figures 5-11)
- Types of wastes (municipal solid waste, inert debris, burned wastes, liquid wastes, unknown wastes, etc.)
- The lateral and vertical extent of wastes (e.g., waste footprint)
- Consideration of previous investigations and analytical data to identify constituents of potential concern (COPCs)

The lateral extent of the wastes (waste footprint) does not necessarily correlate with the property boundaries of the waste disposal site. The lateral waste extent must be established to ensure that perimeter LFG monitoring well probes are placed outside, but in close proximity to the limits of waste disposal area(s) (see Figure 4). The number of probes in a LFG well and the screened intervals are based on the depth of the wastes and subsurface conditions. Subsurface conditions are often not known in enough detail until the LFG well is drilled and sampled. Therefore it is necessary to have personnel experienced in the design and construction of LFG wells in the field while drilling and constructing the LFG wells.

Generally LFG wells are designed with single or multiple probes, with one probe constructed to a depth corresponding to the deepest portion of the disposal site. Construction of LFG probes to depths corresponding to the maximum depth of wastes will need to be modified at sites where wastes were placed in a former, steeply sloping canyon (see Figure 11). In the latter case, typically probes are constructed to depths corresponding to the depth of wastes in the area of the planned LFG well.

An understanding of the site geology and hydrogeology is critical to designing the probe depths and screened intervals and selecting the appropriate drilling equipment. The lengths and depths of screened intervals of probes constructed in the landfill gas boring should be designed based on subsurface conditions (i.e., lithology, contacts, groundwater, etc.) and should consider zones that are the most likely pathways for landfill gas migration (See Figures 4-11). Correlating the geology to the screen length and depth is essential for the effective monitoring for LFG and is considered part of the design of the monitoring network that must be certified by a registered civil engineer or certified engineering geologist. The as-built LFG well description should include the rationale for the design and placement of single and multiple LFG probes based on subsurface conditions and depth of the wastes.

Designing and installing a landfill gas monitoring network may be an iterative process if new site information is discovered during the installation of the monitoring network: For example, borings may indicate geology that is discontinuous or disturbed (fill) or that contains perched groundwater. In order to reduce the iterations required to install a compliant monitoring network, a well-designed investigation should be performed to collect the necessary field data and information that will allow a good conceptual site model to be developed. For landfills and disposal sites with on-site or adjacent development, an understanding of the location of residential or commercial buildings, structures, utilities, and other improvements is necessary to ensure that the LFG monitoring networks detect lateral migration in areas that may directly impact public health and safety.

A certified engineering geologist/registered civil engineer or a person working directly under such a registered professional must "field design" the screened interval(s) for the probe(s) and certify installation/completion of wells/probes in the "as-built" final construction drawing required by the regulations. The LFG regulations (Title 27, California Code of Regulations, Sections 20923 and 20925) require that 1) the monitoring network is designed by a registered civil engineer or certified engineering geologist; 2) monitoring wells are drilled by a licensed drilling contractor or a drilling crew under the supervision of a design engineer or engineering geologist; 3) wells are logged during drilling by a geologist or geotechnical engineer; 4) the specified depths of monitoring probes within the wellbore are adjusted based on geologic data obtained during drilling, and probes are placed adjacent to soils that are most conducive to gas flow; and 5) as-built construction drawing for each monitoring well are to be maintained by the operator and submitted to the Enforcement Agency (EA) upon request.

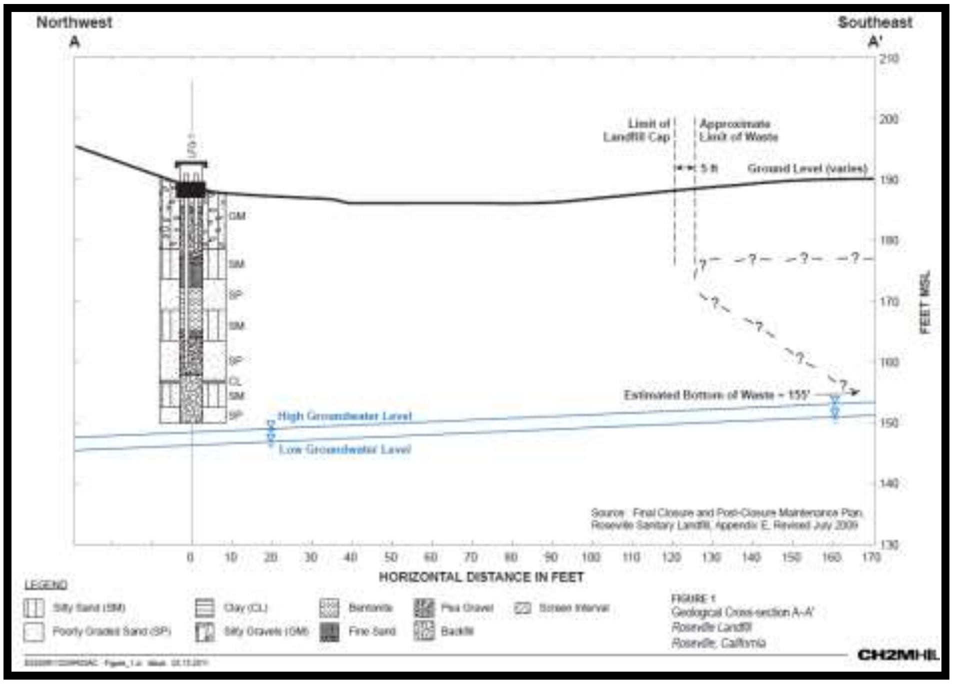


Figure 4: Cross-section showing landfill gas monitoring well with respect to landfill limits

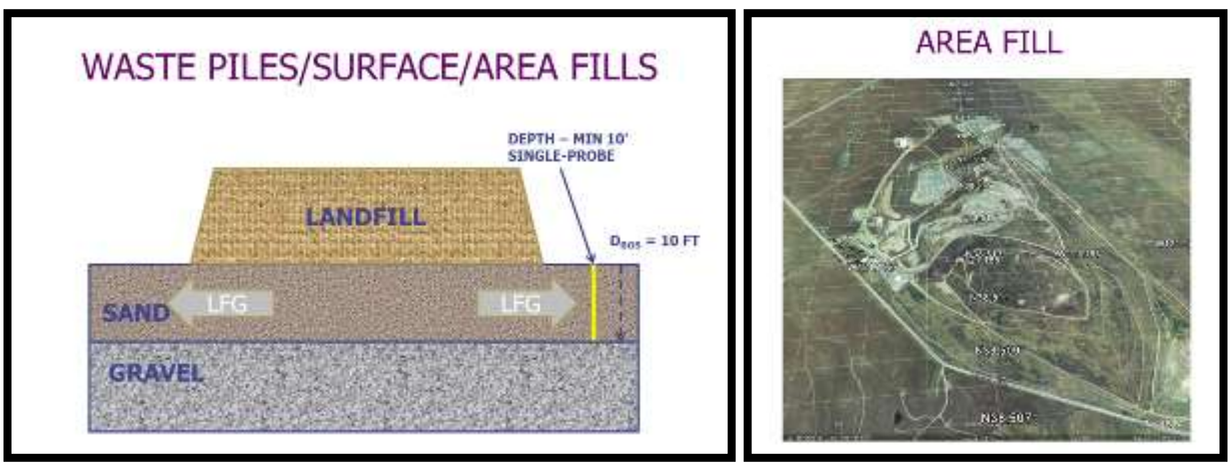


Figure 5: Example of waste pile/surface area fill - Kiefer Landfill Sacramento (Area Fill)

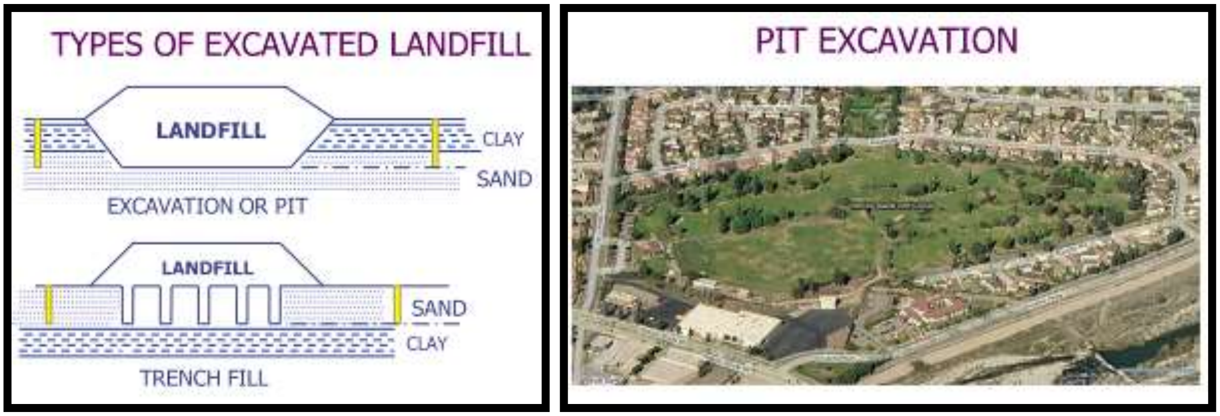


Figure 6: Southern California - Landfilled mining pit excavation, Duarte Golf Course, Los Angeles County

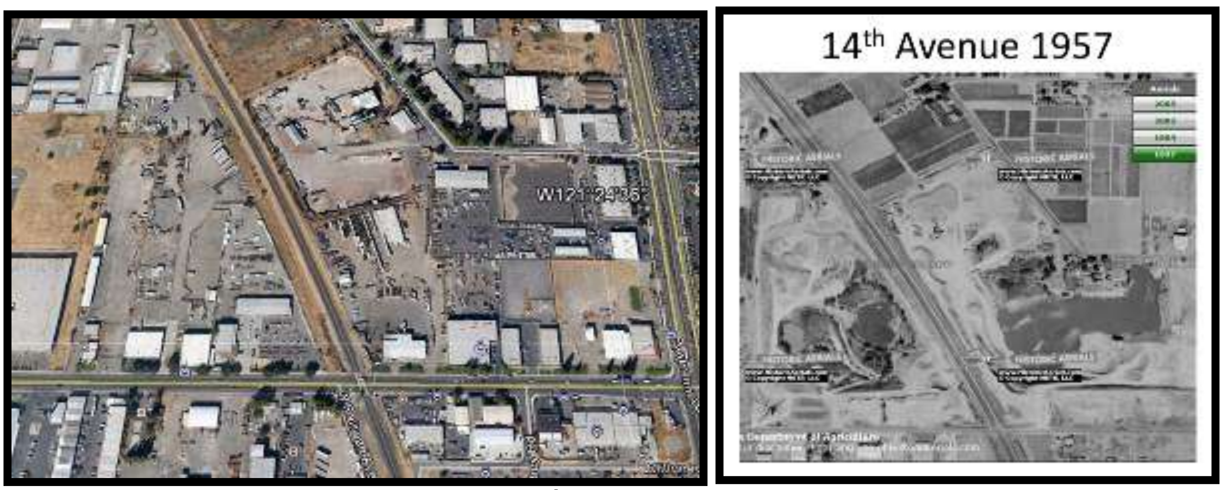


Figure 7: Northern California, Sacramento – 14^{th} Avenue Landfill – Landfilled mining pits

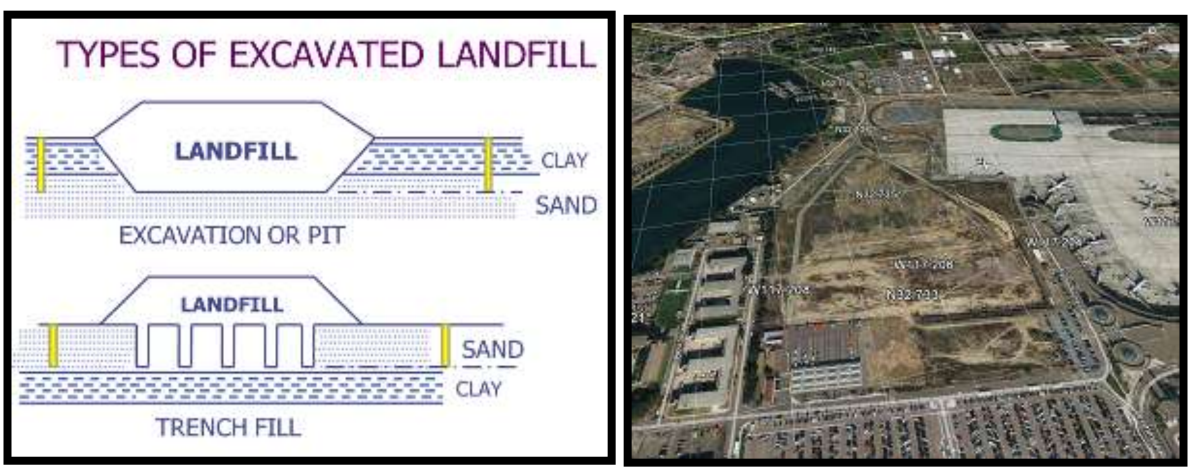


Figure 8: Example of trench fill – Naval Training Center Landfill (San Diego Port Authority)

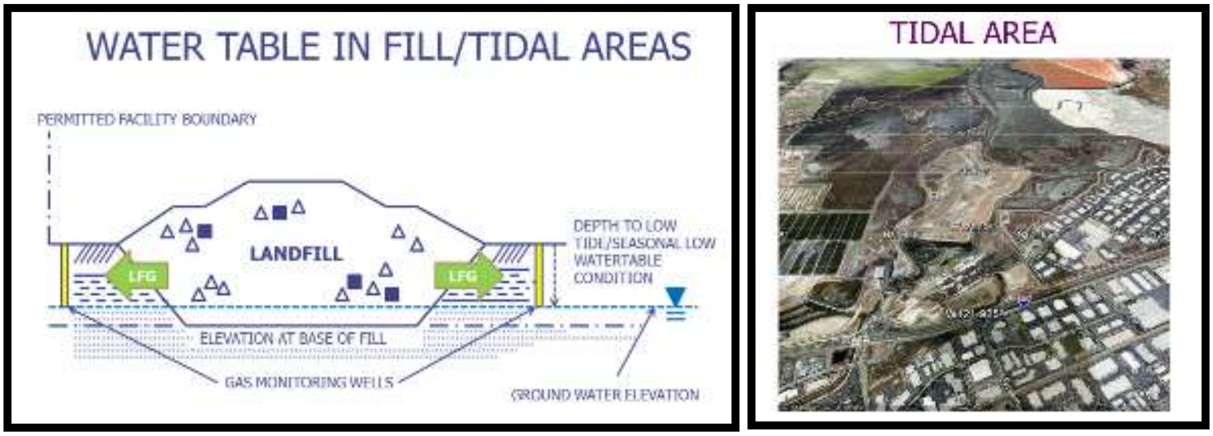


Figure 9: San Francisco Bay Area – Landfill in Tidal Areas – Tri-Cities Landfill

Figure 10: Sacramento Valley – Landfill Adjacent River – Sacramento City Landfill – American River

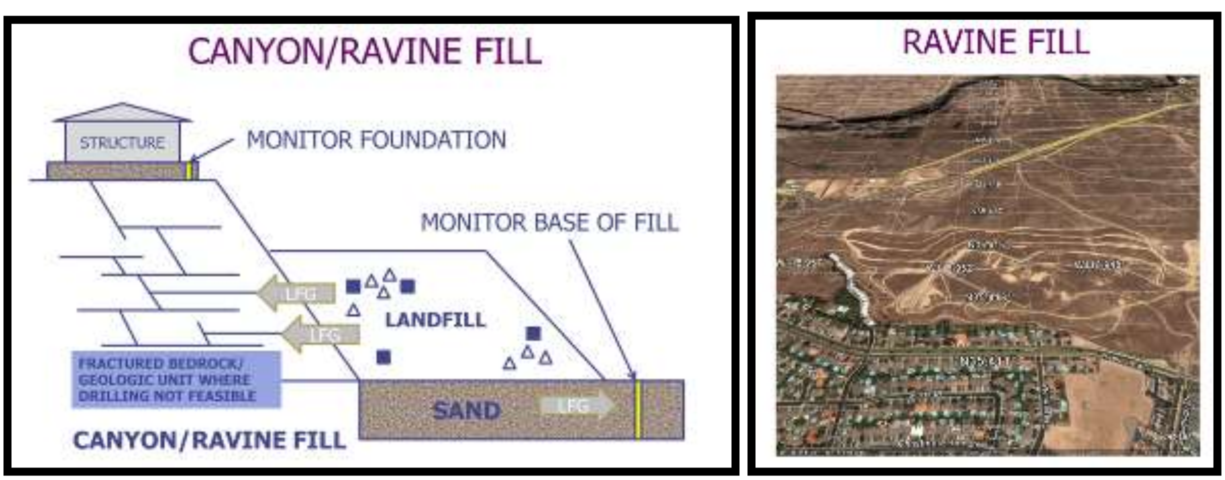


Figure 11: Canyon/ravine fill – Panorama Bluff/Burn Dump – Kern County

Landfill Gas Monitoring Well Locations

Waste Extents/Waste Disposal Site Boundary

Prior to designing a landfill gas monitoring network, the horizontal and vertical extent of wastes must be determined. In California, perimeter landfill gas monitoring wells are required to be located outside and in close proximity to the lateral waste limits (27 CCR section 20925). Also, the design depth(s) of landfill gas monitoring probes with a LFG well must correspond to the lowest elevation of the base of the wastes (27 CCR section 20925). The only condition under which this may change is if the depth of groundwater (seasonal low) is higher than the base elevation of the wastes (see Figures 9 and 10).

The extent of wastes is generally determined through a site investigation, which may include review and analysis of previous assessments of the site that delineated or partially delineated the extent of wastes, historical aerial photograph analysis, geophysical surveys, drilling, direct push, trenching and sampling, and interviews with knowledgeable persons (see "Former Landfill and Disposal Site Investigations" guidance). If an investigation has been performed and documented, the design of the landfill gas monitoring network should take into account information from waste disposal site topographic drawings and sections, trench logs, boring logs, etc. Even when previous field data and information is available pertaining to the extent of wastes, alternate well locations should be planned in case wastes are encountered at the planned location(s). This is because, in general, inferred boundaries from known exploratory locations may require updating based on new field information.

In previous cases in which CalRecycle has provided technical assistance with landfill gas monitoring programs to LEAs, monitoring wells installed by consultants/contractors have been placed within the wastes or in close proximity to the waste limits due to the lack of a buffer zone between the limits of wastes and the property boundary or because the property boundary traverses the waste area. In some cases where a disposal site has been subsequently subdivided, interior parcels located entirely within wastes may have monitoring wells at their property boundary; however, these wells are located within wastes and technically are not compliant with CCR Title 27. Landfill gas monitoring wells located within wastes, while helpful in assessing LFG generation within the waste disposal site, do not fulfill the purpose of monitoring off-site migration. Also, at sites where a landfill gas collection system is installed and wells are located within wastes, it is not possible to assess the effectiveness/compliance of the monitoring network (e.g., less than 5 percent methane gas) since the wells are not located just outlying the lateral extent of wastes. Figure 12 provides some basic considerations for LFG monitoring network design.

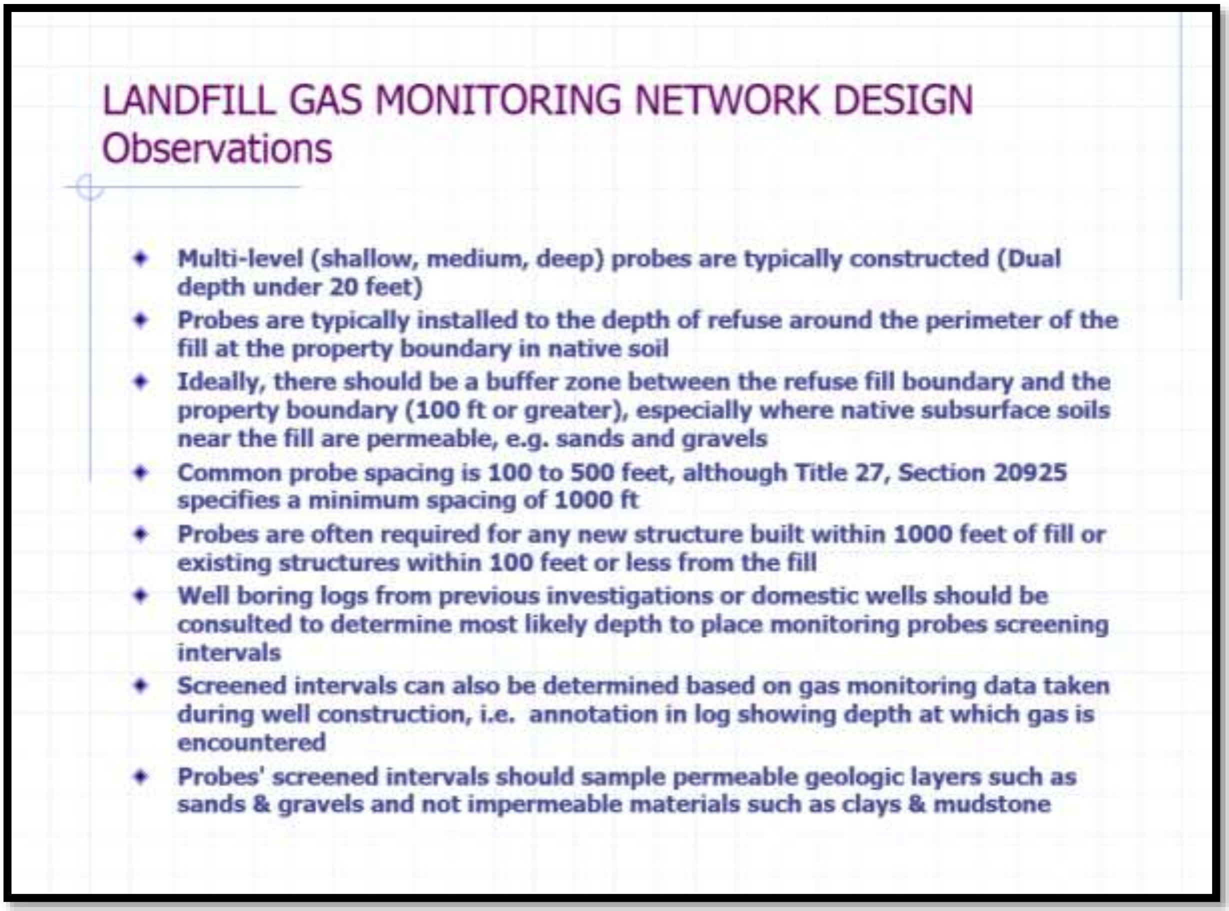


Figure 12: Landfill gas monitoring network design considerations (27 CCR section 20925)

Impacted Structures

The primary purpose of landfill gas monitoring wells is to determine whether lateral gas migration might have the potential to impact structures on or near the landfill. Landfill gas monitoring wells should be located between the landfill and any adjacent structures. At some developed sites in California (pre-regulation landfills), landfill properties were subdivided such that the landfill's boundaries coincided with the property boundary; in the case of a former landfill in Los Angeles California, the landfill boundary was the rear property line on a residential subdivision. In order to construct landfill gas monitoring wells without placing them in the backyards of the residences, access was obtained from the local government to locate wells in the street in front of the homes (see Figure 13). Although the site had been closed since the 1970s and developed in the 1980s, landfill gas was discovered at concentrations exceeding the upper explosive limit (15 percent) almost 20 years later (2006).

Figure 13: Landfill gas monitoring wells constructed in front of homes adjacent to landfill

<u>Well Spacing</u>

Landfill gas monitoring well spacing can be up to a maximum of 1,000 feet for perimeter monitoring wells (27 CCR section 20925). The maximum spacing is generally for sites that do not have adjacent land-uses or structures, e.g. open space land-use. The LEAs have the authority to decrease spacing (or increase the number of monitoring wells) for sites where landfill gas could impact structures, utilities, or other improvements (see Figure 17). Also in California, local air quality management districts (AQMDs) may permit landfill gas collection and treatment systems and require landfill gas monitoring networks that may have more stringent well spacing requirements (see: SCAQMD Rule 1150.1). For example, the South Coast Air Quality Management District requires a probe spacing of 650 feet for open space, 500 feet for sites with public access, and 100 feet for residential/commercial development.

Landfill Gas Monitoring Well Construction

Generally, landfill gas monitoring wells are developed using drilling equipment such as hollow-stem augers, air percussion, air rotary, or mud rotary rigs (see Figure 14). The type of geology and depth of wells generally will determine the type of equipment to be used. The borings for landfill gas monitoring wells are generally between 8 and 12 inches in diameter (depending on the number of monitoring intervals and number and diameter of machine-slotted plastic pipe). Machine-slotted threaded PVC plastic pipe, which comes in both 8- and 10- foot slotted and blank sections, are inserted into the well boring above the well bore seal (see Figure 23). California regulations (27 CCR section 20925) require that well bore seals be constructed using 5 feet of hydrated bentonite (see Figure 23). The annular space between the boring and plastic pipe is generally filled with a permeable material such as Monterey sand, aquarium sand, or washed pea gravel (see Figure 23). Wells under 30 feet may use a "dual-depth" design (see Figure 16). Wells deeper than 50 feet may use a "quadruple completion" with two intermediate zones. The number of completions within a boring will be limited by the boring diameter, number of probes, and probe casing diameter, e.g. number of probe casings that can fit within the boring diameter (generally a maximum of 12 inches). Figures 15 and 16 depict typical construction details for triple and dual completed landfill gas monitoring well installations.

Figure 14: Drilling methods – hollow stem auger, air percussion

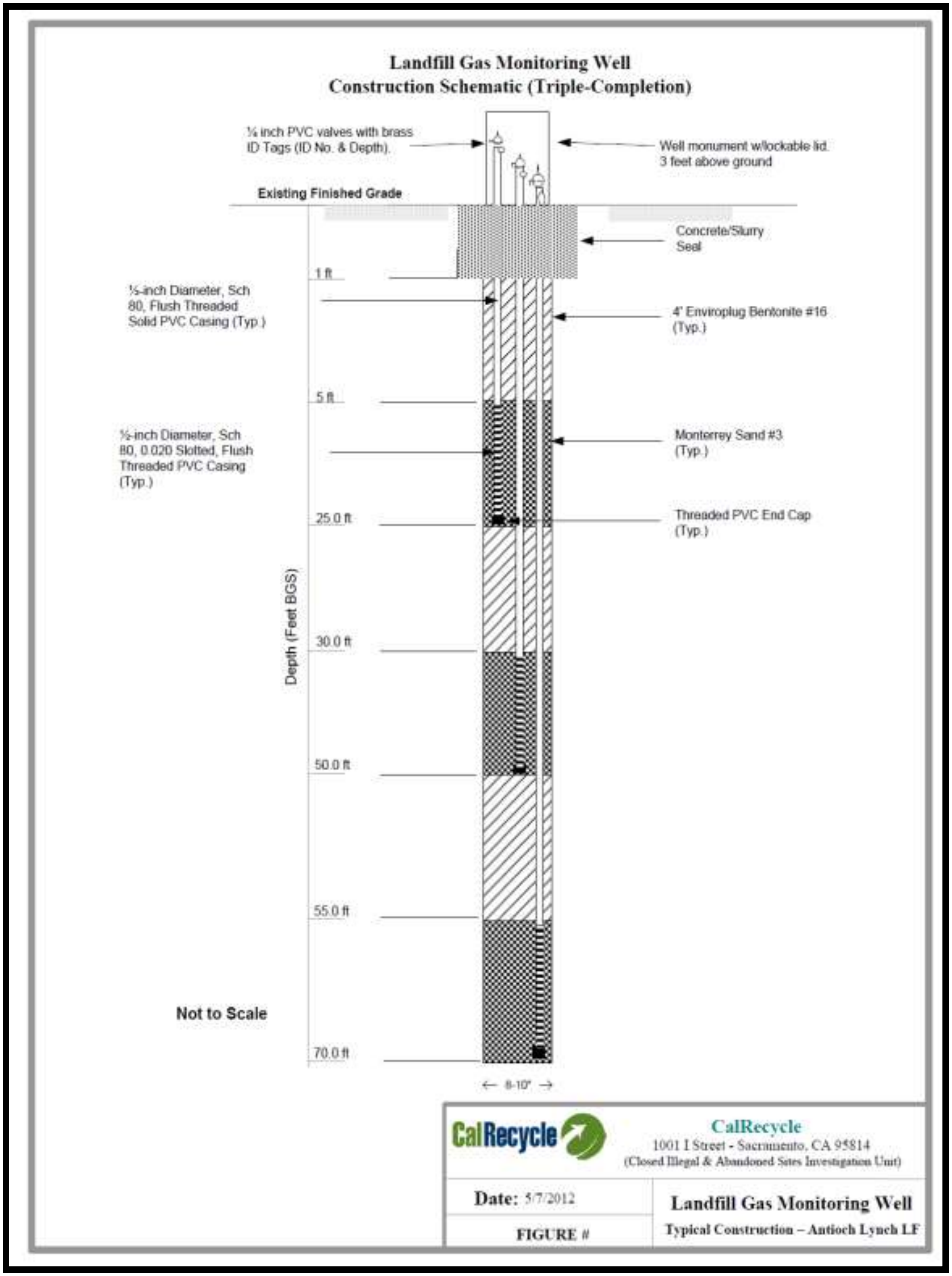


Figure 15: Drawing showing typical construction of a triple-depth landfill gas monitoring well

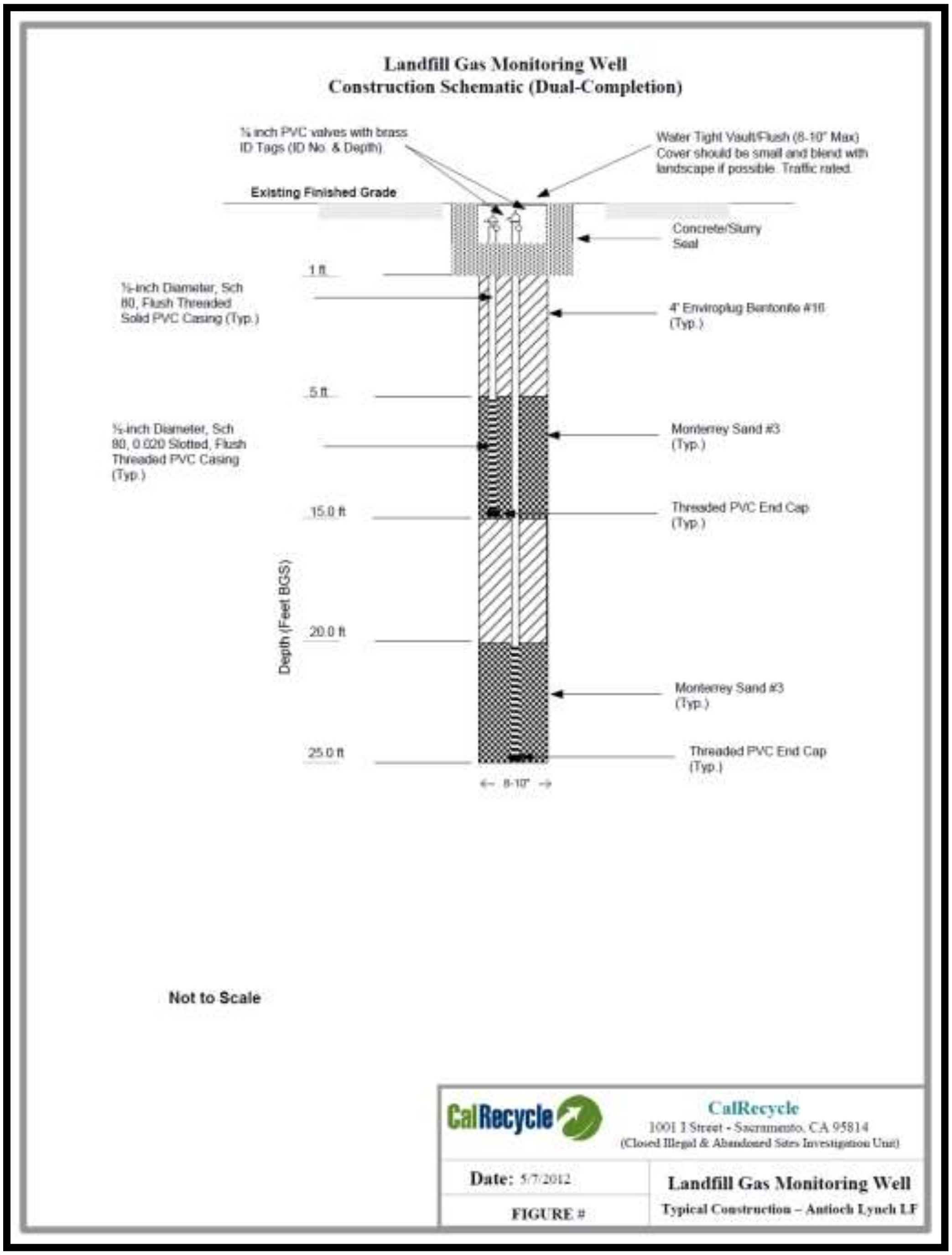


Figure 16: Drawing showing typical construction of a dual-depth landfill gas monitoring well

Boring Seals—Landfill gas monitoring wells require a 5-foot bentonite seal between each monitoring probe completion (and interval) within the well boring. Seals are constructed by pouring dry bentonite pellets into the annular space of the well (between the monitoring probe pipe and the well boring) and hydrating the bentonite pellets with water (see Figure 18). Careful measurement and logging of the depths of the well bore seal location and screened zone are critical in the LFG monitoring well as-built construction drawing and well log (Figure 18). Placement of boring seals using a tremie pipe and a bentonite slurry mix is another method; however, this is not a common practice in LFG monitoring well construction. Boring seals provide a gas barrier between monitored zones, which allows regulators to determine the approximate impacted zone in the subsurface where landfill gas may be laterally migrating from the site.

Figure 17: Avoiding damaging unforseen utilities – hand-augering the first 5 feet; geophysical survey of well location; Call USA

Figure 18: Drilling crew pouring bentonite pellets and constructing well-bore seal in annular space (following this process, water will be added to hydrate pellets); using tape to measure down-hole distance to start and finish of well-pack material (Monterey sand) for screened interval.

Well Head Vault—It is important to ensure that the wellhead is designed and constructed to last a minimum of 10 years (given a recurring maintenance inspection program to replace broken or non-functioning parts). Wellhead components should be manufactured from high-grade plastics or metals that will not degrade or corrode over time, e.g. Brass lab cock valves, Schedule 80 PVC or SDE 40 Pipe, etc. Probe labels should be on either brass tags or plastic tags (see Figure

24). Probe tags should be secured using zip-ties or plastic fasteners (figure 19). All components should be press-fit or threaded and fastened using Teflon tape. Plastic components should not be joined using cements that contain volatile organic compounds, e.g. benzene, toluene, acetone, etc. VOCs used in plastic solvents may cause “false positives” when performing landfill gas sampling and analysis. Probe labels should include the depth of the well in feet and show whether it is shallow (S), medium (M), or deep (D). Well vaults may be raised or flush; generally flush vaults (installed using traffic-rated vaults) can accommodate vehicle access but can be prone to flooding from surface water (see Figures 19 and 20). Raised vaults are easier to see and find (see Figure 21), but they may require barriers such as traffic bollards to protect them from vehicle traffic, and they may also be more susceptible to vandalism. All wellheads should come with a locking vault cover to secure the well from tampering (see Figure 21). Wells in unpaved areas should include a small 4-inch thick concrete pad around them to protect the wellhead (see Figure 20).


Figure 19: Flush-mounted LFG monitoring well with traffic-rated vault; dual completion well head with brass lab cock valve and brass identification tags (Probe ID & Depth)


Figure 20: Flush-mounted vault in concrete pad in undeveloped area; single probe with plastic lab cock valve

Figure 21: LFG monitoring well monument with locking well head cover – triple completion well with plastic lab cock valves

Figure 22: Flush-mounted LFG monitoring well with traffic-rated vault (LFG well in street)

Figure 23: Landfill gas monitoring well materials: 1) monitoring probe: schedule 80 PVC machine-slotted pipe in 8-foot threaded sections; 2) screen well pack: Monterey sand or equivalent, 3) well bore seal: bentonite (pellets)

Figure 24: Monitoring probe brass identification tags – well number and depth

Some landfill and disposal site owners' consultants have proposed the use of direct-push vapor wells or bored wells with flexible tubing in place of slotted/blank plastic pipe; however, the construction of these wells does not meet the requirements of 27 CCR section 20925. See Figure 26 for basic LFG monitoring network design considerations.

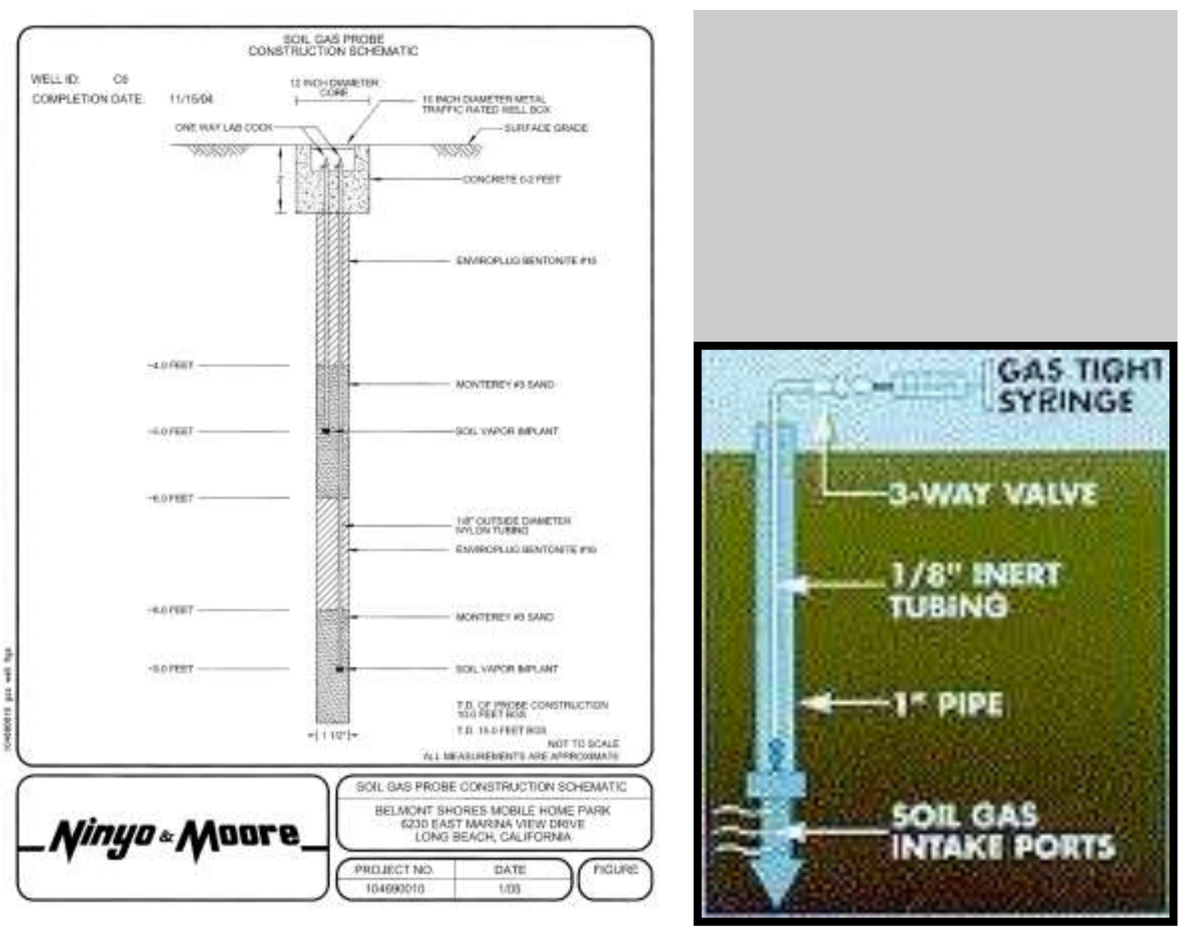


Figure 25: Direct push soil vapor probes – not compliant with 27 CCR section 20925 (use of tubing rather than slotted and blank pipe; use of metal fitting for sampling tip – fouling/blockage is a common problem).

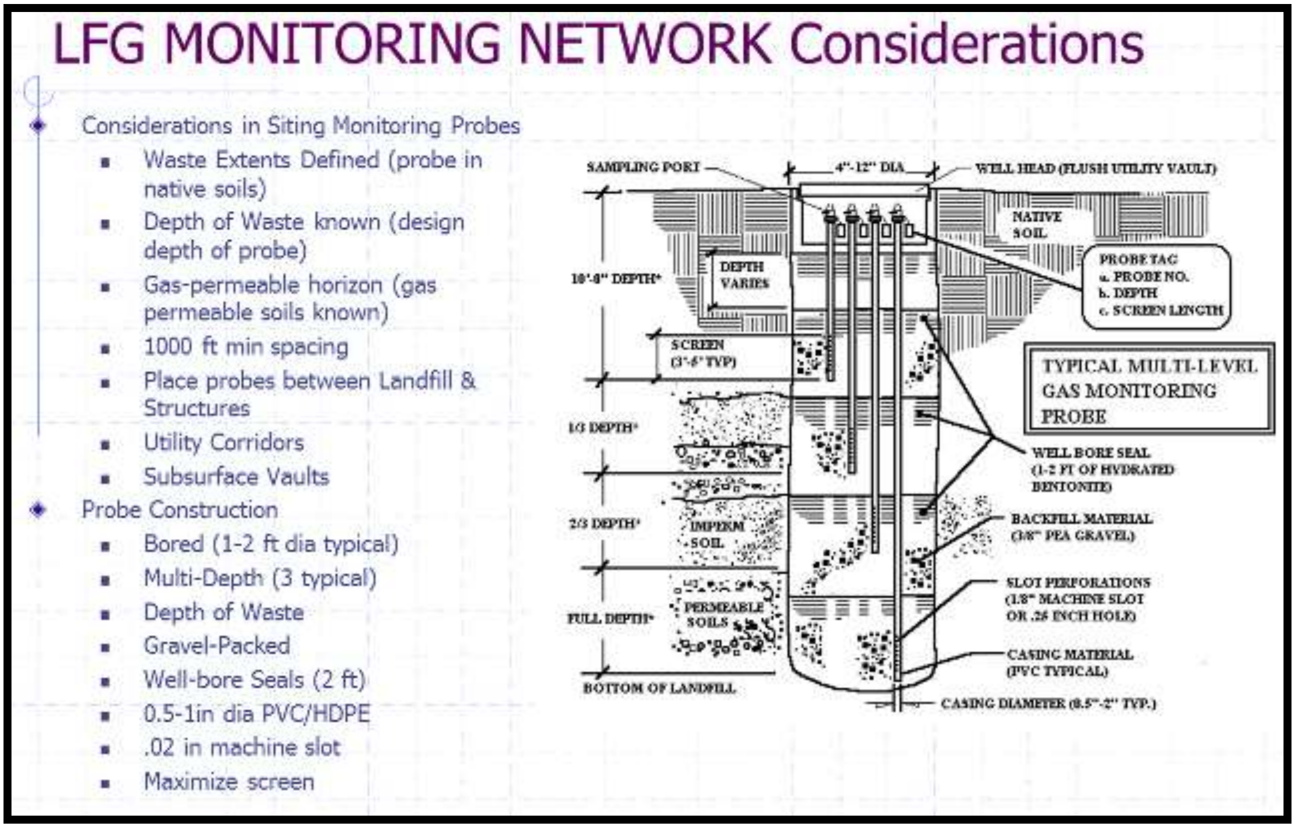


Figure 26: Landfill gas monitoring network design/construction considerations

Landfill Gas Monitoring Program

Solid waste disposal facilities are required, pursuant to 27 CCR section 20919 et seq., to prepare and implement a landfill gas monitoring plan as part of the facility operational plan. The goal is to ensure detection of methane from LFG that maybe migrating in the subsurface off-site and/or into on-site structures. In accordance with 27 CCR section 20921, methane from LFG should not exceed:

- The lower explosive limit (LEL), which is equivalent to 5 percent (by volume) at the facility's permitted property boundary, or
- 25 percent of the LEL, which is equivalent to 1.25 percent (by volume) in on-site structures.

If methane from LFG concentration exceeds these regulatory limits, steps must be taken to ensure the protection of public health and a remediation plan must be implemented in accordance with 27 CCR sections 20937 and 20939. The monitoring plan for a facility should be reviewed and updated as necessary. The LFG monitoring plan should include at least the following elements to accurately describe how the facility will comply with the aforementioned regulations.

Brief Description of the Facility

At a minimum, the monitoring program should briefly discuss the facility geographical location, weather settings, land use, design and operational history. Also, the facility's geology, soils, hydrogeology and their effects on LFG subsurface movement should be discussed. Further, a facility map (see Figure 27) should be included showing location of waste units, permitted facility boundary, on-site structures constructed on waste, on-site structures constructed on native soils, perimeter monitoring probe network, and all off-site structures located within 1,000 feet of the facility's permitted boundary.

Figure 27: Gas monitoring network location map

<u>**Description of Monitoring Points at the Facility Boundary**</u>
Methane from LFG at a facility's permitted boundary is typically monitored using soil gas probes to ensure compliance with the limit in 27 CCR section 20921(a) (2). While the depth and locations of these probes may vary, based on site specific features, they all must meet the criteria in 27 CCR sections 20923 and 20925. For example, probes should have a maximum lateral spacing of 1,000 feet, depending on the geology and soils of the facility, the adjacent land use, and proximity of potential receptors. Generally, if an off-site structure is located near the facility permitted boundary, a probe should be placed between that structure and the waste unit to ensure protection of public health and safety. Further, adherence to CalRecycle's *Best Management Practices for Landfill Gas Monitoring well/Probe Construction* (http://www.calrecycle.ca.gov/SWFacilities/Landfills/Gas/monitoring/BMPWellConst.htm) is also recommended.

The LFG monitoring plan should also include boring logs and construction diagrams (i.e. As-Built) for all of the soil gas probes at the facility. See Figures 28a and 28b.

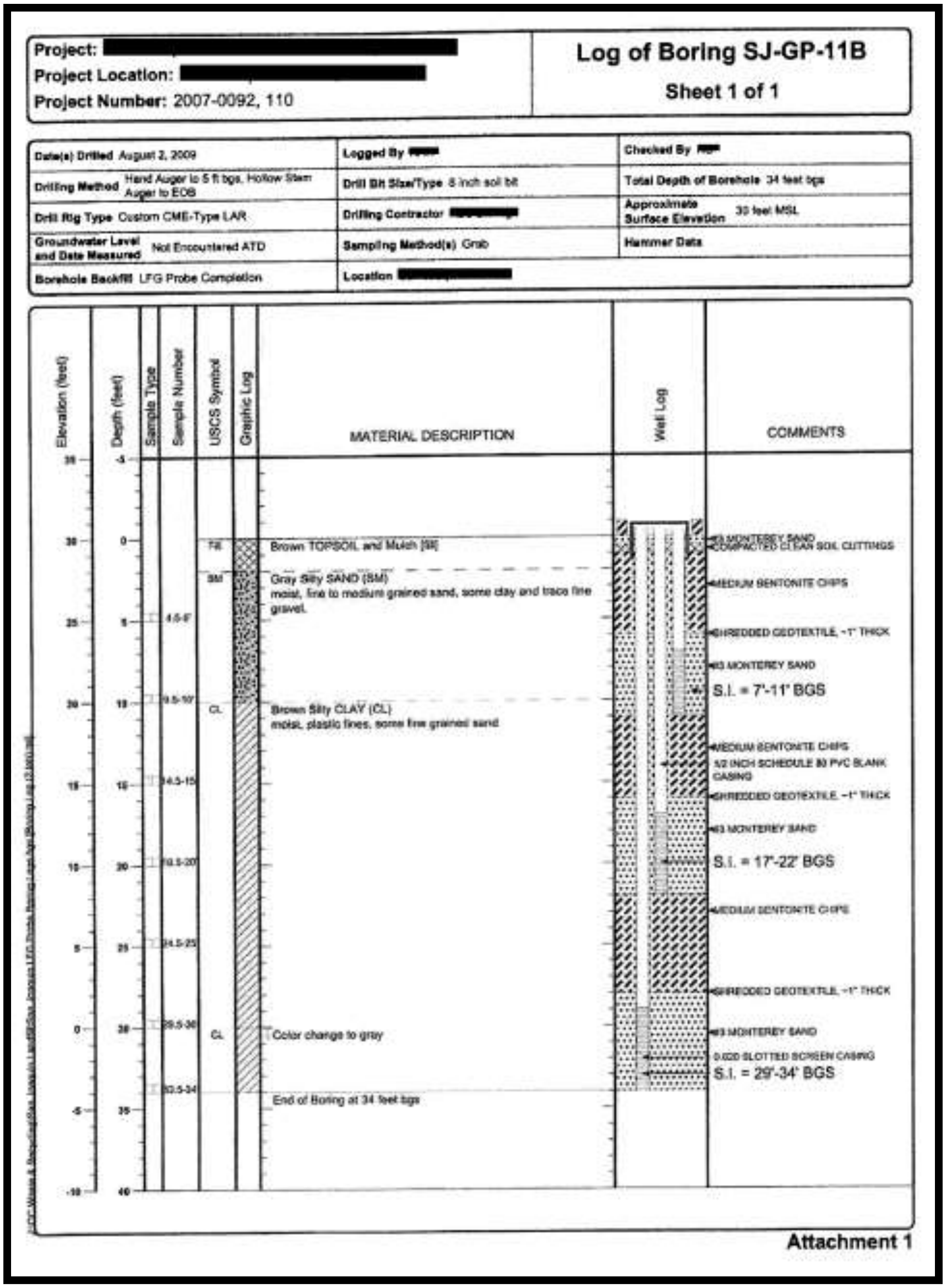
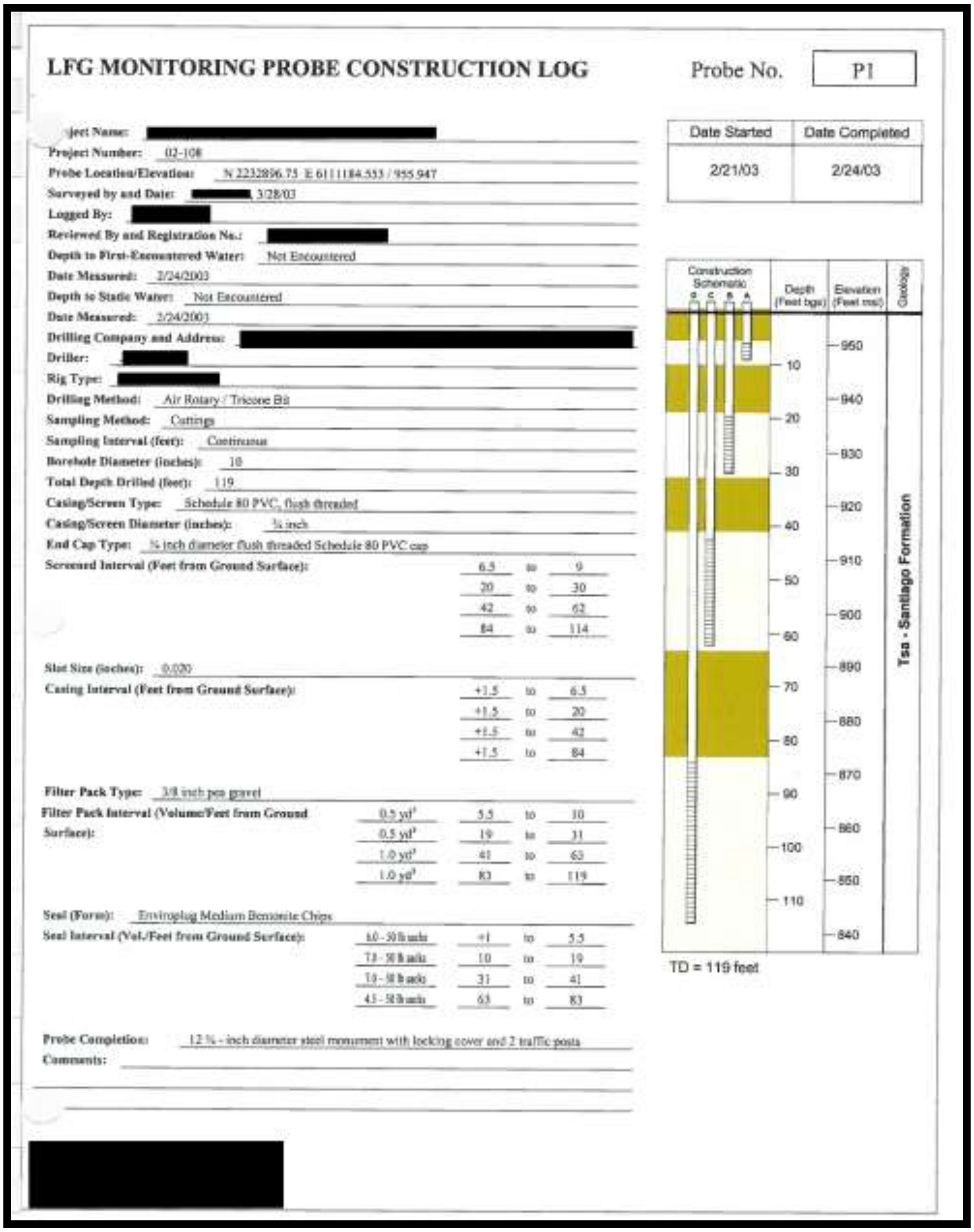


Figure 28a: Sample boring log



LFG MONITORING PROBE CONSTRUCTION LOG

Probe No. P1

Date Started	Date Completed
2/21/03	2/24/03

Project Name: [redacted]
Project Number: 02-108
Probe Location/Elevation: N 2232896.75 E 6111184.553 / 955.947
Surveyed by and Date: [redacted] 3/28/03
Logged By: [redacted]
Reviewed By and Registration No.: [redacted]
Depth to First-Encountered Water: Not Encountered
Date Measured: 2/24/2003
Depth to Static Water: Not Encountered
Date Measured: 2/24/2003
Drilling Company and Address: [redacted]
Driller: [redacted]
Rig Type: [redacted]
Drilling Method: Air Rotary / Tricone Bit
Sampling Method: Cuttings
Sampling Interval (feet): Continuous
Borehole Diameter (inches): 10
Total Depth Drilled (feet): 119
Casing/Screen Type: Schedule 80 PVC, flush threaded
Casing/Screen Diameter (inches): ¾ inch
End Cap Type: ¾ inch diameter flush threaded Schedule 80 PVC cap

Screened Interval (Feet from Ground Surface): 6.5 to 9; 20 to 30; 42 to 62; 84 to 114

Slot Size (inches): 0.020

Casing Interval (Feet from Ground Surface): +1.5 to 6.5; +1.5 to 20; +1.5 to 42; +1.5 to 84

Filter Pack Type: 3/8 inch pea gravel

Filter Pack Interval (Volume/Feet from Ground Surface): 0.5 yd³ 5.5 to 10; 0.5 yd³ 19 to 31; 1.0 yd³ 41 to 63; 1.0 yd³ 83 to 119

Seal (Form): Enviroplug Medium Bentonite Chips

Seal Interval (Vol./Feet from Ground Surface): 6.0 - 50 lb sacks +1 to 5.5; 7.0 - 50 lb sacks 10 to 19; 7.0 - 50 lb sacks 31 to 41; 4.5 - 50 lb sacks 63 to 83

Probe Completion: 12 ¾ - inch diameter steel monument with locking cover and 2 traffic posts
Comments:

[redacted]

Figure 28b: Sample boring log

Description of On-Site Structures Monitoring

All on-site structures (e.g. office buildings, crawlspaces, subsurface vaults, etc.) must be monitored for methane from LFG to ensure compliance with the limit in 27 CCR section 20921(a)(1).

i) Structures constructed on top of waste disposal areas must be equipped with continuous methane monitoring systems, pursuant to 27 CCR section 20931(c). See CalRecycle's webpage titled "Continuous Landfill Gas Monitoring for Structures Located Near Landfills and Disposal Sites (Part 1)."

ii) Structures constructed within the facility on native soils are monitored for methane pursuant to 27 CCR section 20931.

Figure 29: Landfill gas monitoring equipment; note that 2 different instruments are used to verify field measurements (GEM-2000, RKI Eagle and GMI 442) for field quality assurance/control.

<u>Probe Monitoring Procedure</u>

Description of the standard monitoring procedure for methane, including:

i) Type of instruments typically used in barometric pressure measurement, probe static pressure measurement, and probe LFG monitoring along with their detection ranges (see Figure 29)
ii) Instrument calibration procedures
iii) List of physical and chemical parameters monitored and recorded by the field instruments
iv) Operating field instrument and connecting to probe casing
v) Criteria for probe purging and sampling (i.e. instrument readings recorded after one casing volume is purged vs. continued purging until instrument readings stabilize at which time the readings are recorded)
vi) Recording of stabilized readings along with any other relevant information (e.g. initial spikes in concentrations and any issues with probe condition). See attached sample of probe monitoring field data sheet (see Figure 31)
vii) Collection of gas samples for lab analysis, if any
viii) List of analytical lab methods, if any (e.g. EPA TO -15 – see Figure 34)

Gas Data Review from Monitoring Wells

(Highest Concentration Wells at the Landfill)

		Methane Concentration* (% vol.)												
Well Name	**Location**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
A3BD	Laurelwood Property				24	26	25	12			3	7		2
D2V	Delta Equipment		30	41	38	38	34	24	20		18	17.5		
E9BS	14th Ave. Associates	21	22.5	32	31	40	27.5	28		40	22	22		
F1SD	Sacramento Ford Property				21	19	18	14			16	10		
G4BS	DRA Property				60	60	37	20			18	15		
L6FD	Lukenbill Property				28	21	21				15	2		
P3BS	Pacific Coast				44	40	40	24			21			
W14BD	Wil's Materials	50	48	40	38	40	55			27	15	17.5		
Y6BD	Curtis Roofing					12	8	6			8	8	6	5
Z1BD	Cozz European Property				40	39	35	31	26	26	20	17	16	

* Highest concentration measured within the specific year

Reference: Gas Monitoring Reports from 1985 to 1997.

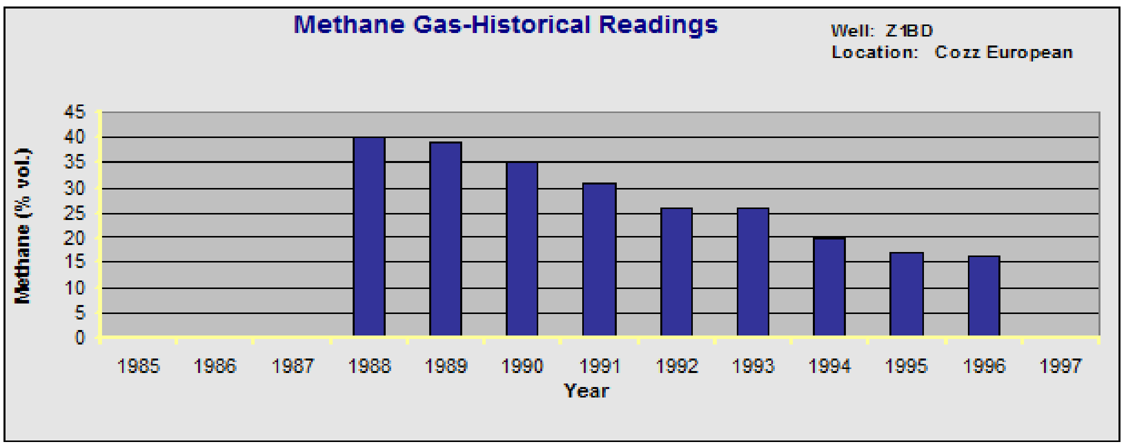


Figure 30: Annual LFG monitoring data table for site; annual landfill gas monitoring data by well

(Landfill/Disposal Site name) **Page 1 of**

Landfill Gas Probe Monitoring

Field Data Sheet

Date: **Instrument Used in LFG Monitoring:**

Weather Conditionas: **Calibration Date:**

Barometric Pressure (in Hg): **Instrument Used in Probe Pressure Measurement:**

Barometric Pressure Trend: ___ Increasing ____Decreasing **Staff:**

Probe ID	Casing Depth (ft)	Time	Static Pressure (in WC)	Purge Time (sec)	CH_4 (% v/v)	CO_2 (% v/v)	O_2 (% v/v)	Balance (% v/v)	Observations/Comments

Figure 31: Sample landfill gas monitoring data log

Figure 32: Landfill gas sampling – using Summa canisters and Tedlar bags

Note, some field instruments can measure methane in the LEL scale (i.e. 0 to 5 percent by volume) only, while others do not work in low-oxygen environments, making them less useful for probes with greater depths. Recommended field instruments are those that can accurately measure methane from 0 to 100 percent by volume independent of oxygen levels.

It is also important to note here that how LFG is collected by field instruments is very important especially when the probe is located in close proximity to buried waste – a common situation in former disposal sites surrounded by fully developed communities with very little native ground buffer zone. The monitoring goal is always to detect methane form LFG plume(s) that may be migrating through the area where the probe is located due to pressure differential between landfill interior in native soils and diffusion – not to “actively pull” LFG from buried waste to the probe casing. Therefore, when a probe is located in close proximity to waste, the amount of vacuum applied by the field instrument to purge the probe casing and collect/analyze gas sample, and the duration of this induced vacuum, becomes critical. Some field instruments have powerful built-in vacuum pumps (e.g. GEM 2000 produces 80 inches of water column-worth of vacuum) that can easily convert a monitoring probe into an active extraction well, if probe purging and sampling last long enough. For such a scenario, probe monitoring data may show elevated methane levels (i.e. exceeding LEL) that, under steady-state conditions when the probe is not being monitored, may show methane levels at or below LEL. In conclusion, an adequate amount of vacuum and an adequate time duration are needed to purge one volume-worth of a casing and collect a gas sample for field instrument or lab analysis when a probe is located in close proximity to buried waste.

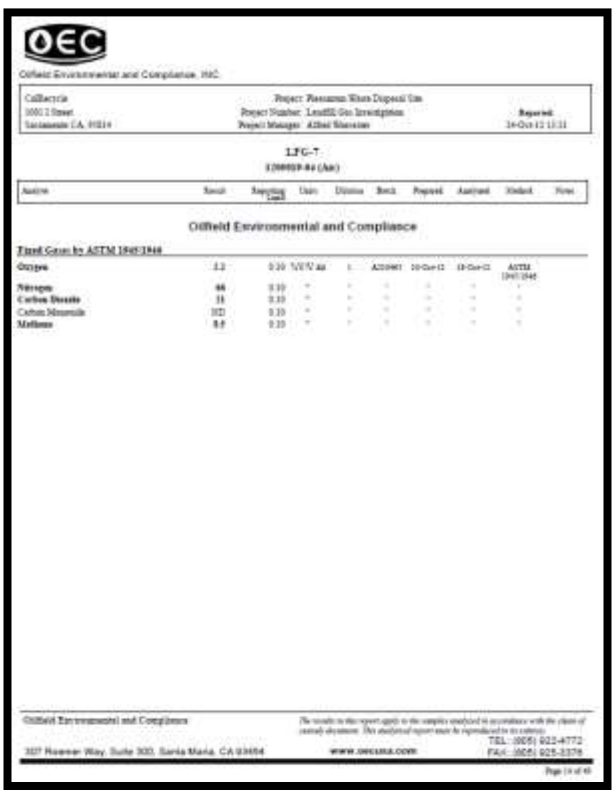
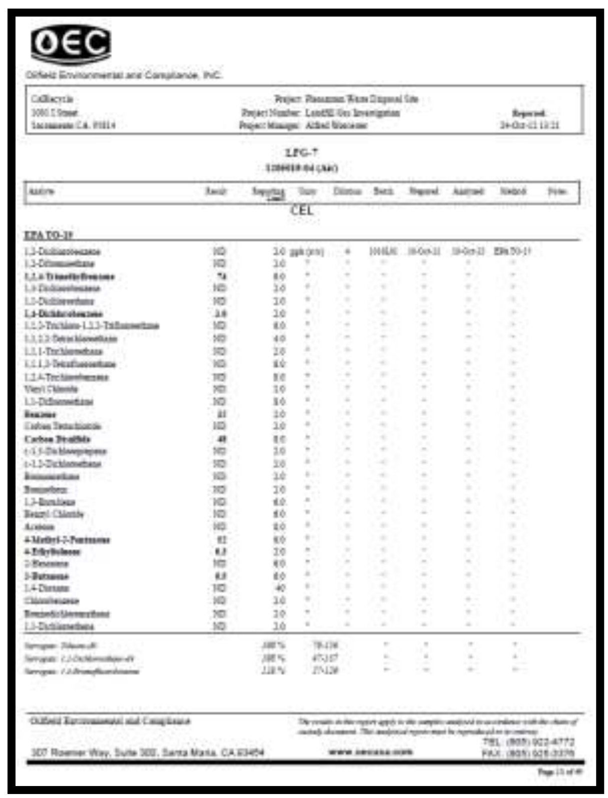



Figure 33: ASTM 1946 fixed gases and EPA T.O.-15 (VOCs) laboratory analysis results; landfill investigation final report

On-Site Structure Monitoring Procedure

i) Structures constructed on top of waste: Sensors, typically equipped with audible alarms that are triggered at pre-set levels, are wall-mounted near the floor. They are located throughout the structure, especially in poorly ventilated areas and wherever the floor is penetrated by a utility (e.g. sewer drain, electrical conduit, etc.). To ensure proper operation of the continuous methane-monitoring system, it is essential to implement manufacturer's maintenance instructions (e.g. frequency of sensor calibration) by a contractor well-versed in this field.

ii) Structures constructed on native soils: Periodic monitoring (floor survey/sweep) for methane utilizing field instruments. The focus should be on preferential pathways for LFG migration such as subsurface utility lines, trenches, and confined spaces. Utility corridors should be carefully identified and located accurately on a site map.

Frequency of Monitoring

Pursuant to 27 CCR section 20933(a), the minimum frequency of monitoring both probes and on-site structures at landfills quarterly. However, the LEA can require more frequent monitoring (e.g. monthly basis) for:

i) larger facilities which produce more LFG,
ii) facilities located in or near developed areas with close proximity to potential receptors, and
iii) Facilities with a history violating the limits in 27 CCR section 20921(a).

The LFG monitoring plan should describe the frequency of routine monitoring and any follow-up monitoring in case methane from LFG is detected at levels exceeding the limits in 27 CCR section 20921(a). Note, monitoring frequency in the LFG monitoring program should be reevaluated when there is a change in the land use of adjacent properties. For example, if a disposal site is surrounded by open space, quarterly monitoring of perimeter probes maybe adequate. If, however, there are definitive plans in the near future to change some or all of the adjacent open space into any type of development involving enclosed habitable structures (e.g. residential, commercial, industrial, etc.), the LEA should re-evaluate the layout and monitoring frequency of the perimeter probe network. Consequently, the number of probes as well as their monitoring frequency may have to be increased.

Regulatory Reporting

Pursuant to 27 CCR section 20934(a), if probe and on-site structure monitoring results do not show methane levels exceeding the limits in 27 CCR section 20921(a), the landfill operator must submit these results to the LEA within a time period typically specified by the LEA, but no more than 90 days from the monitoring event. At a minimum, submitted monitoring data shall include:

- Methane concentration measured at each probe and within each on-site structure
- Concentrations of specified trace gases, if required by the LEA
- Date and time of the monitoring event
- Barometric pressure (typically measured as in or mm Hg or millibars), atmospheric temperatures, and general weather conditions

- Probe static pressure recorded prior to probe purging and sampling, typically measured as inches of water column (positive number if probe casing is under pressure, negative number if probe casing is under vacuum)
- Names of field staff
- Name and model of monitoring instrument(s) and other relevant data (e.g. last calibration date)
- Site plan showing all perimeter probes (along with their identification numbers), and on-site structures

The LFG monitoring program should clearly identify measures to be implemented by the landfill operator to protect public health and safety immediately upon detecting methane concentration from LFG in a probe or on-site structure exceeding the applicable limits in 27 CCR section 20921(a). The landfill operator should also notify the LEA via phone or email immediately. This is especially important if habitable structures are located adjacent to the disposal site. To ensure implementation of public health and safety protection measures in a timely and organized manner, it is recommended that the landfill operator coordinate such contingency efforts with the local city, county, and/or fire authority having jurisdiction in advance.

Pursuant to 27 CCR section 20937(a)(2), the LFG monitoring program should describe how the landfill operator will investigate excessive LFG subsurface migration within seven days of first detecting methane exceeding the limits in 27 CCR section 20921(a), or on an alternative schedule approved by the LEA and CalRecycle. The LFG monitoring program should also state that the landfill operator will report again to the LEA the findings of its investigations, including:

i. Detected methane and trace gas (if any is required) concentrations
ii. Description of the nature and extent of the problem based on field data collected up to that point
iii. Measures implemented by the landfill operator to protect public health and safety and the environment
iv. Description of any additional interim measures the landfill operator plans to undertake for protection of public health and safety and the environment prior to implementing a remedial plan

Landfill Gas Monitoring

This section discusses methods to monitor for landfill gas. The data collected during monitoring serve two important purposes: 1) to meet regulatory requirements and provide environmental regulators with information about the performance of landfill gas collection systems, and 2) to determine whether migration of landfill gas might pose a hazard to public health and safety and the environment.

Purpose of Monitoring

Landfill gas compliance probes, also called monitoring probes, are designed and constructed in accordance with 27 CCR and are used to measure the concentrations of landfill gas in the soils immediately surrounding the probes. There are a number of different monitoring measurements (emission, ambient, and indoor, to name a few); however, here we only discuss monitoring from landfill compliance probes.

Scope of Monitoring

Screening monitoring is routine expedient field monitoring to determine the status of landfill gas migration and whether a violation exists that might require supplemental enhanced monitoring. This monitoring is conducted whether or not an on-site monitoring system is in place. A monitoring system usually consists of a series of in-ground landfill gas probes installed around the permitted facility boundary at a spacing determined by the regulations governing the landfill. The probes should not be connected to or be impacted by any negative pressure (vacuum) source such as gas extraction wells are installed as part of a landfill gas control and collection system. It is suggested that to adequately understand screening monitoring, the following subjects should be reviewed to gain a better understanding of landfill gas generation.

Landfill Gas Generation

There are certain processes that form landfill gas, including bacterial decomposition, chemical reactions, and volatilization. During bacterial decomposition, organic waste (which includes food waste, green waste, paper products, and wood) is broken down by bacteria naturally present in the waste and in the soil that is used to cover the landfill. Bacteria decompose organic waste in five distinct phases, and gas composition changes during each phase. During chemical reactions, non-methane organic compounds (NMOCs) are created, and during volatilization, landfill gases can be created when certain wastes, particularly organic compounds, change from a liquid or a solid into a vapor.

Landfill Gas Composition

Landfill gas is composed of a mixture of hundreds of different gases. By volume, landfill gas typically contains 45 percent to 60 percent methane and 40 percent to 55 percent carbon dioxide. Landfill gas also includes small amounts of nitrogen, oxygen, ammonia, sulfides, hydrogen, carbon monoxide, and NMOCs such as trichloroethylene, benzene, and vinyl chloride.

LFG Generation Rate Factors

The rate and volume of landfill gas generated at a specific site depend on the characteristics of the waste (e.g., composition and age of the refuse) and a number of other environmental factors (e.g., the presence of oxygen in the landfill, moisture content, and temperature).

Landfill Gas Migration

Once gases are produced under the landfill surface, they generally move away from the landfill. Landfill gas moves through the limited pore spaces within the refuse and soils covering the landfill. The natural tendency of landfill gases that are lighter than air, such as methane, is to move upward, usually through the landfill surface. Upward movement of landfill gas can be inhibited by densely compacted waste or landfill cover material (e.g., by daily soil cover and caps). When upward movement is inhibited, the gas tends to migrate laterally to other areas within the landfill or to areas outside the landfill, where it can potentially continue its upward path. Basically, landfill gas follows the path of least resistance. Some gases, such as carbon dioxide, which is denser than air, would most likely collect in subsurface areas, such as utility corridors. Three main factors influence the migration of landfill gas: 1) diffusion (response to concentration gradient), 2) convection (response to pressure gradient), and 3) permeability (following the path of least resistance).

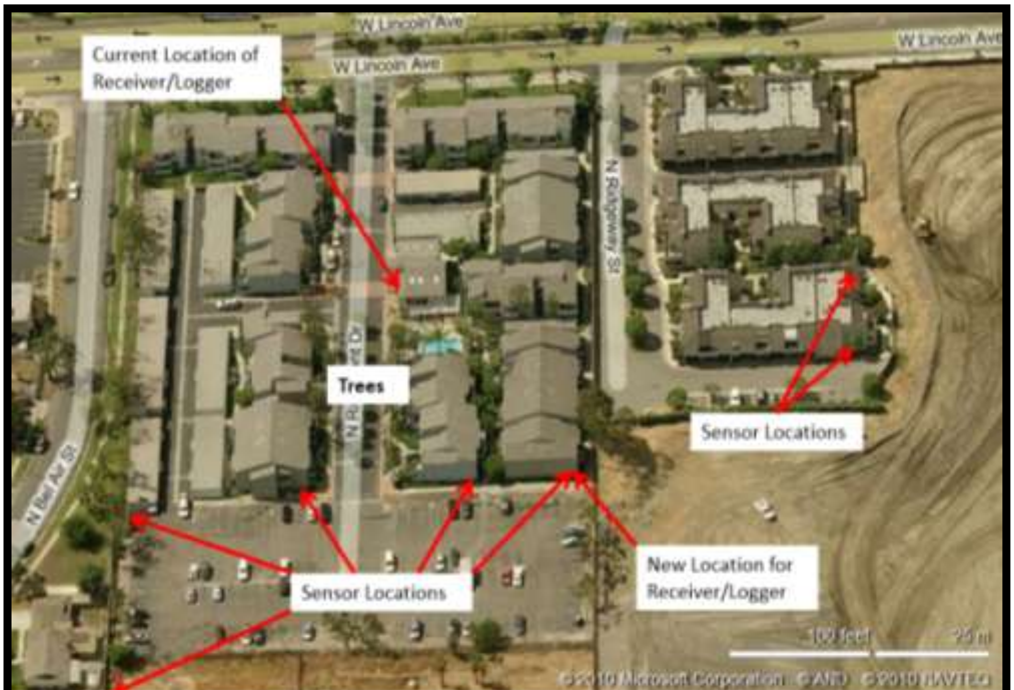
Performing Monitoring

Check probe condition and structural integrity and suitability for monitoring. Be sure each inspected probe is not subject to excessive negative pressure generated by nearby vacuum sources. A simple way to check for negative pressure is to hold a sheet of paper just above the opening of the probe and see if the paper is sucked to the opening. If the paper is sucked to the probe opening, the probe is more than likely influenced by negative pressure. A pressure gage, such as a magnehelix gage, if available, should be used to determine whether a probe is under the influence of excessive negative pressure. The magnehelix is a device that measures pressure in terms of inches of water. If the probe is influenced by negative pressure, then it should not be sampled because attempting to overcome the negative pressure could damage the instrument, and it may not detect gas at the correct concentration. Probes should also be checked for presence of water prior to monitoring. Since water vapor can damage the instrument, if water is observed in any of the compliance probes, water traps should be used to prevent water from entering the instrument. Probes that are damaged or under negative pressure are inadequate for use.

Use a gas monitoring instrument that is not damaged and is properly calibrated. Open the petcock or otherwise ready the probe for sampling, and connect the flexible intake tube assembly to the probe, making sure that there is a tight seal. Understanding how to use the instrument for landfill gas monitoring is very important to collecting reliable data.

Monitoring of On-Site Structures/Continuous Monitoring Systems

To determine the potential for landfill gas (methane) to accumulate near structures surrounding a former disposal site/landfill and to provide a quantitative assessment of gas concentration in ambient air, the use of continuous gas monitoring systems sometimes is necessary to comply with gas monitoring and control regulations (see 27 CCR 20931). Additional information can be found on CalRecycle's LFG Continuous Monitoring Systems webpage. Continuous gas monitoring systems have the advantage of being able to detect both short-term degassing events that occur in time periods lasting minutes to hours as well as long-term changes that occur over days to months. These systems are tailored to monitor landfill gas (methane) on a continuous basis. Data is collected by sensors installed at specific areas within a structure and then data is sent to a controller unit located on-site for data processing and storage. Data stored can then be accessed directly from the system or remotely depending on the capabilities of the system (via a phone line or the Internet). Finally, data can be processed and analyzed to determine whether methane gas is migrating and collecting in spaces within onsite structures (see Figure 34).



Sparks-Rains Landfill Continuous Monitoring System

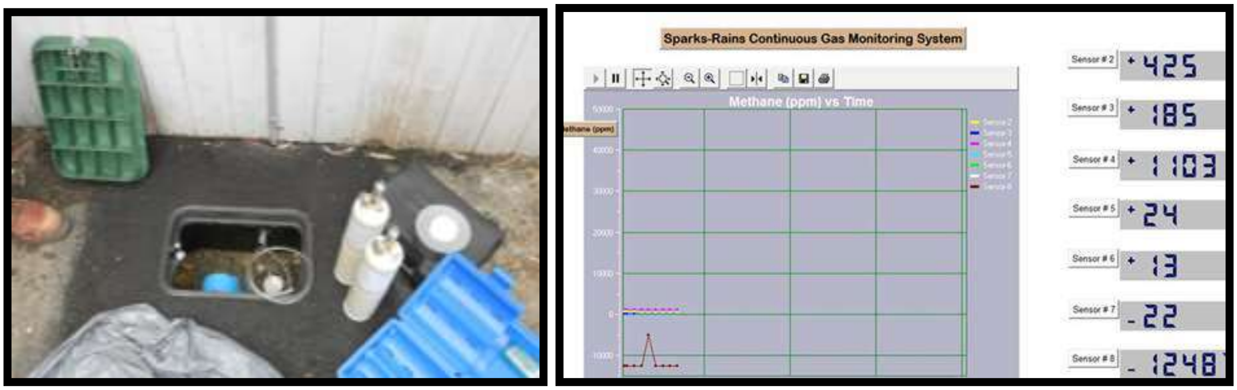


Figure 34: Landfill gas continuous monitoring system installed near apartments adjacent to a former Orange County Landfill

Sensing Technology

The most widely available sensing technology suitable for this application is the infrared method, which is commonly used to detect combustible substances in concentrations reaching explosive limits. However, another technology available is the catalytic method or sensor. Continuous monitoring systems are composed of field-installed 4-20 mA transmitters (gas sensors) and data receiver/controller, and a data logger. Transmission of information between the field sensors and the receiver is normally accomplished via hardwire or wireless methods. An example of the wireless technology is described here and in Figure 34.

Wireless communication between the field sensors and the receiver is accomplished via a radio transmitter, which will convert 4-20 mA signals from the field sensors (16-bit, high-resolution A/D conversion) into wireless data and will send the data packets to a radio receiver. This receiver converts the wireless data back to discrete 4-20 mA analog outputs for direct connection to a data logger. The Mil-Ram® wireless system like the one shown in Figure 35 simply and reliably replaces the wire that traditionally interconnects the 4-20 mA transmitter (sensor) and the receiver/controller.

The radio transmitter/receiver utilizes advanced data recognition technology to ensure data reliability and integrity. The radio transmitter/receiver has LCD displays for easy configuration.

Figure 35: Wireless radio transmitter and wireless radio receiver (by MilRam)

Data Logging

The Hyperlogger® is a data-logging instrument that is normally fixed-mounted onsite to control the data logging process. This system collects data from the field sensors installed onsite. Collected data is mathematically processed by the Hyperlogger and stored in its internal memory while it simultaneously performs basic onsite control functions.

The collected data can then be downloaded into a computer with a phone line modem or by Internet access, depending on the logger capabilities. Housed in a lockable, weather-proof enclosure, the system is designed for onsite mounting and long-term outdoor remote data-collection applications. A large wiring compartment is provided for input/output wiring routing to connections. Wiring access holes are provided in the base with tight fittings. See Figure 36.

Figure 36: The Hyperlogger is a data-logging system (by Logic Beach)

Installation Details

This section briefly describes the procedures for the installation and operation of a typical continuous gas monitoring system for onsite structures.

At the receiver end are the following components and installation needs:

- Radio receiver/controller
- Data logger (Hyperlogger)
- Telephone line/Internet line

Select an area for mounting the equipment considering that enough room needs to be available to work around it during installation. There should also be enough room to open the housing doors of each of the instruments.

Position components 1 and 2 from left to right on a vertical surface at eye level (4½ to 5 feet from the floor). The components should be mounted using screws through the slots on the housing of the equipment.

Components 1 and 2 should be independently connected to an outlet or power source (120 VAC). Power should be connected only after all interconnections between the receiver and the data logger have been completed.

Wireless Receiver

Connect the wireless receiver with 8 analog outputs (4-20 mA) to the data logger. Connections should be done using wire #22 or #20 AWG 3-conductor shielded cable. Use the terminal strips at each one of the instruments (3-wire, 4-20 mA terminals). See details in Figure 39 as well as in additional literature provided. To provide for the best possible reception, an omni-directional antenna for outdoor installation is provided with this equipment (7.2 dBi 23” Omni Antenna). The antenna could be located on the roof of a building where cable should be guided to the receiver for connection (30 feet of -4.3 dBi cable is provided).

Telephone or Internet Line

Finally, a telephone line should be guided to the data logger for modem connection or an Internet connection, depending of the capabilities of the logger.

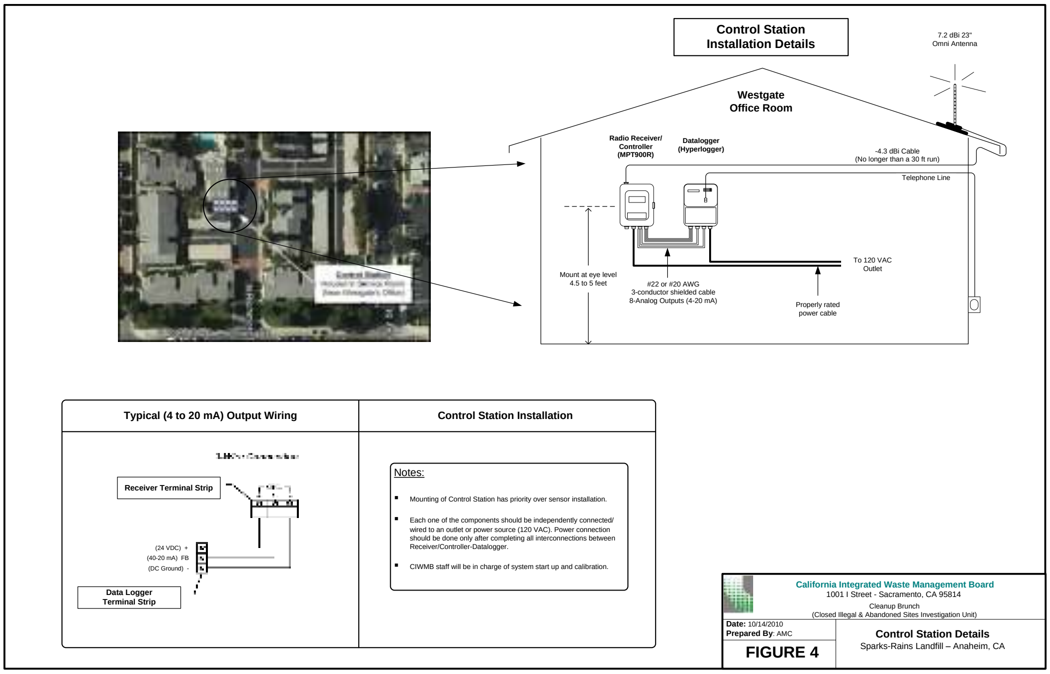


Figure 37: Sensor installation details

This section describes the procedure for mounting the gas methane gas sensors and the wireless transmitters.

- The transmitter should be mounted in such a way that a clear line of sight is achieved with the antenna of the receiver.
- The transmitter should be mounted in the highest spot available in order to clear any obstacles. A clear line of sight for optimal reception should be accomplished by eliminating any obstacles between the two antennae (receiver and transmitter) if possible.
- Gas sensors should be installed at designated locations (inside buildings, near buildings, in underground utility vault enclosures, etc.). See Figure 38.
- The transmitter and the sensor have ¼- inch diameter slots that must be screw-mounted.
- The sensors should be connected to the transmitter using wire #22 or #20 AWG 3-conductor shielded cable.
- A 24 VDC transformer is included with the system to power the transmitter unit. Connect the step-down transformer to the transmitter with an appropriately rated power cable. Guide the AC power cord from the transformer into the most readily available outlet or power source (120 VAC).

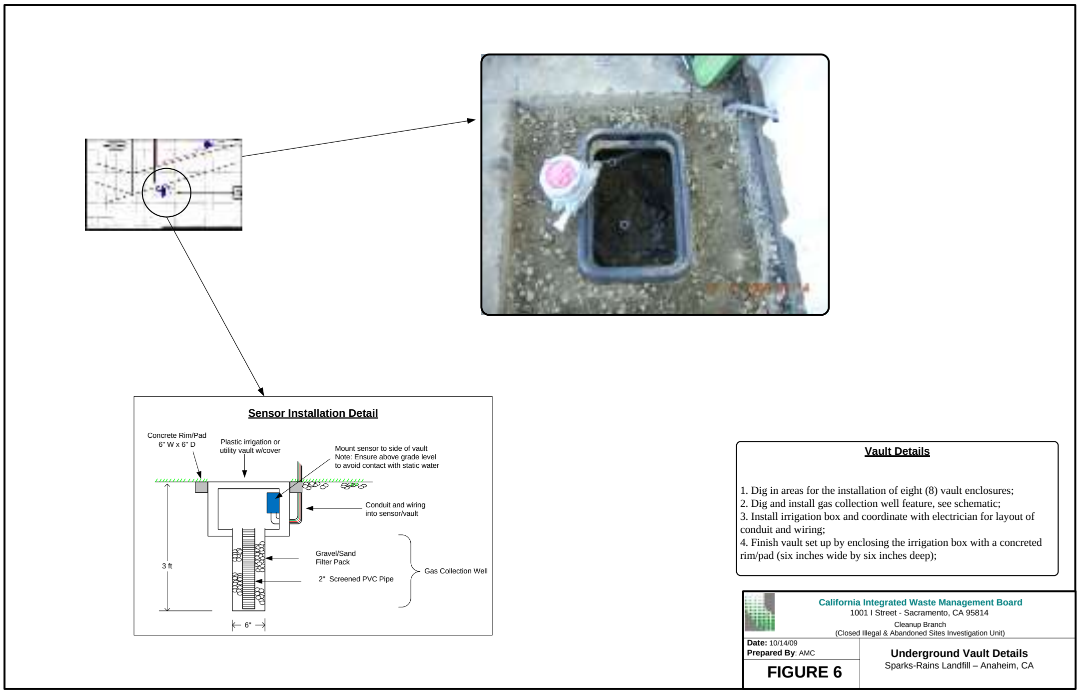


Figure 38: Combustible gas sensor vault installed in the ground adjacent to structures

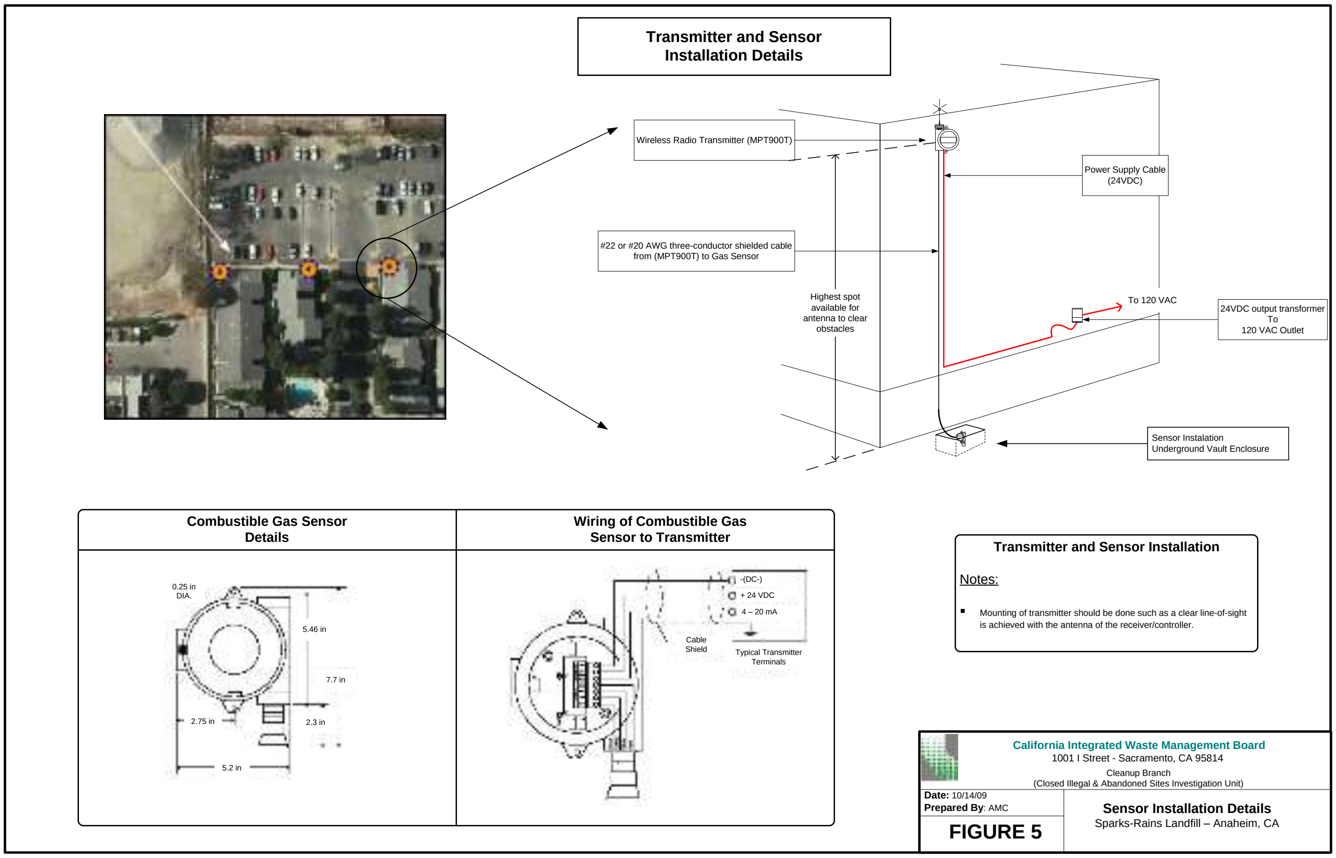


Figure 39: Combustible gas sensor installation details

Landfill Gas Analytical Data Assessment for Identification of Methane Sources

Background

Identification of methane sources in some cases is necessary to determine whether the detected methane is from a landfill. This could affect the scope of regulatory oversight of a landfill or former disposal site.

For very specific scenarios and settings throughout California, landfill locations and their gas releases may comingle with or be mistaken for gas releases from other sources as identified below. Under such circumstances, owners of landfills as responsible parties have used various tools including (fingerprinting of landfill gas) to trace the sources of methane and to compare the landfill gas to the detected gas occurrence. Determining the source of methane gas is not an easy task given that there are several potential sources to include: Natural gas (pipeline gas), naturally occurring methane gas (oil field), landfill gas, and other biogases (swamp gas). However, methane has two primary origins: thermogenic and biogenic. The following are the most widely accepted theories, well established by several geochemical studies (Jones, 1999).

Thermogenic methane—This is formed from organic matter through increasing depth of burial and temperature. It is formed in three main stages requiring peak temperatures of (150-200^{o} F). Along with methane, other gases are also generated: ethane (C_2), propane (C_3), butane (C_4), and pentane (C_5). The quantity of gaseous hydrocarbons C_2-C_5 formed varies with the type of organic source material, which can be broadly classified as marine and terrestrial. However, it has been reported that more C_2-C_5 hydrocarbons are generated from marine sources (McKenna and Kallio, 1965). During the thermogenic formation of hydrocarbons (including methane), other elements such as sulfur and aromatic hydrocarbons (i.e., benzene, toluene, and xylene [BTEX]) may also be produced in relatively small quantities.

Biogenic methane—This is formed at shallow depths and low temperatures by anaerobic bacterial decomposition of sedimentary organic matter. This gas is very dry, meaning that it consists almost entirely of methane. There is no evidence suggesting that C_2-C_5 hydrocarbons can be formed biogenically (Jones et al., 1999). During the biogenic process, hydrogen sulfide, carbon dioxide, organic acids, alcohols, ketones, and other compounds are formed by the fermentation and enzymatic action of bacteria.

Methane Sources

Landfill gas—This is a biogenic gas of which major components are methane and carbon dioxide. The carbon 14 isotope (^{14}C) in this gas is significantly enriched. Some of the best tracers for this gas are the chlorinated hydrocarbons. The concentrations of non-methane straight chain of hydrocarbons (C_2-C_5) are very low, normally in the ppm range. This gas is also characterized for low oxygen concentrations.

Other biogases (swamp gas, or sewer gas)—These are characterized by low concentrations of straight-chain hydrocarbons, mostly CO_2 and methane with some H_2S. Swamp gas could be mistaken for landfill gas; however, this gas does not contain chlorinated hydrocarbons. Sewer gas is a mixture of gases including N_2, H_2S, NH_3, CH_4, CO_2, SO_2, and NOx. Similar to swamp gas, sewer gas typically contains no chlorinated hydrocarbons.

Pipeline gas—This is a thermogenic gas that contains CH_4, other straight-chain hydrocarbons C_2-C_5, and tracers (i.e., helium or mercaptans). This gas has low sulfur content (3.5 ppm of H_2S maximum). It is also characterized for containing straight-chain hydrocarbons and no chlorinated hydrocarbons and contains no ^{14}C.

Naturally occurring gas—This is thermogenic gas that may have elevated quantities of CH_4, other straight-chain hydrocarbons C_2-C_5, and possibly elevated sulfur content as H_2S. This gas contains no oxygen, ^{14}C, or chlorinated hydrocarbons.

Analytical Methods

A variety of geochemical methods for identification of methane sources can be applied; these methods are designed to search for specific characteristics in each sample supplied for analysis. Gas geochemistry can be used to distinguish landfill gas from other types of gases (thermogenic and biogenic) as proposed by Prosser (1999). The techniques that can be used for the forensic characterization of methane gas occurrences include the following:

- Identification of certain chemical constituents
- Carbon dioxide (CO_2)
- Aromatic hydrocarbons (BTEX)
- Volatile organic compounds (VOCs)
- Pipeline tracers
- Hydrogen sulfide (H_2S)
- Identification of light hydrocarbon gases C_2-C_5
- Determination of stable isotope ratios of carbon $^{13}C/^{12}C$ and hydrogen ($^{2}H/H$) in methane
- Radiocarbon measurement ^{14}C in methane (carbon dating)
- Tritium measurement ^{3}H in methane (radiogenic isotope of hydrogen)

Identification of Certain Chemical Constituents

Once methane is detected, identifying its chemical compounds can help determine the source of the gas.

Carbon dioxide—The presence of this compound will help determine methane sources, as carbon dioxide is particularly concentrated in landfill gas. The biogenic process is dominated by the productions of CH_4 and CO_2 in about equal proportions. However, low concentrations of carbon dioxide does not confirm that the source of methane is thermogenic, since carbon dioxide can undergo physical and chemical processes within subsurface soils and can be removed from a gas from a biogenic source (e.g. dissolution in groundwater).

Aromatic hydrocarbons (benzene, toluene, and xylene)—During the thermogenic formation of hydrocarbons (including methane), other elements such as aromatic hydrocarbons such as benzene, toluene, and xylene may also be present in relatively small quantities. Furthermore, some landfills may contain small quantities of these hydrocarbons.

Volatile organic compounds—Probably one of the best tracers for landfill gas are the chlorinated hydrocarbons, these are synthetic compounds found in household and other commercial and industrial waste that would clearly identify a landfill as the source of methane occurrences (Prosser, 1998). However, just like other compounds, the lack of VOCs is not conclusive to rule out landfill gas as the source of methane, since VOCs can undergo physical and chemical processes within the soils in the subsurface where they can be removed from the gas.

Pipeline tracers— Thiopane and T-butyl mercaptans are pipeline gas tracers used by gas utility companies. The presence of one of these compounds practically indicates pipeline gas as one potential source of detected methane.

Hydrogen sulfide—Although an important test, this has to be considered cautiously, since it is not a clear indicator of the origins of a gas for the following reasons:

- A variety of discrete sources for the formation of H_2S in the petroleum industry have been identified (i.e., bacterial reduction of sulfate, thermal decomposition of sulfides, and thermochemical reduction of sulfate). These processes will typically raise the H_2S concentration of a gas up to 10 percent by volume (Oiltracers LLC, 2004).
- Many former landfills accepted large quantities of construction and demolition (C&D) debris in addition to municipal solid waste. Gypsum wallboard in C&D debris can result in the generation of hydrogen sulfide gas (H_2S). C&D debris may include substantial percentages of gypsum ($CaSO_4.2H_2O$) in discarded wallboard materials. Under anaerobic landfill conditions, sulfate-reducing bacteria produce H_2S from the sulfate (SO_4) in gypsum and the organic carbon in waste material as follows:

  $$SO_4 + 2CH_2O = 2HCO_3 + H_2S$$

Sulfate-reducing bacteria tend to out-compete methane-producing bacteria (Bogner et al., 2000). Even though historical values of H_2S in landfill gas have been reported to be less than 100 ppmv, several landfills in different parts of the United States are installing gas-processing equipment to treat H_2S concentrations in excess of 3 percent to 5 percent (30,000-50,000 ppmv). The use of gypsum in the United States began at the end of the 19^{th} century (Harley, 1973).

Other sources that can contribute to the presence of H_2S include sewage sludge, local soils used as cover materials, landfills developed in high-sulfate geologic materials, and high-sulfate groundwater.

Consequently, due to the variety of sources of H_2S, the forensic characterization and determination of the potential source of methane gas based solely on the presence of H_2S tends to be difficult. Therefore, the presence of H_2S should not be considered a determining factor when attempting to identify the source of methane gas.

However, H_2S analysis should be considered when planning landfill gas extraction and control system, since increasing concentrations of H_2S can have several detrimental effects: (1) the onset of odor problems, (2) acid gas corrosion of gas recovery hardware, (3) increased SOx emissions from flaring or other combustion processes, and (4) possible health consequences for workers and people living near the landfill.

Identification of Light Hydrocarbon Gases in the C_2-C_5 Range

The identification and testing of occurrences of ethane through pentane in gas samples is of fundamental importance for the purpose of identification of methane sources, since these gases are prospective indicators of buried natural gas and petroleum deposits. Typical composition of

$C_2H_6 – C_5H_{12}$ (C_2-C_5) in oil and gas fields varies from 0 to 20 percent by volume. Solid proof exists that only methane and ethylene are produced by bacteria in a landfill environment atmosphere (McKenna and Kallio, 1965). The results of studies by Jazenic (1979) and Coleman (1979) strongly suggest that C_2-C_5 hydrocarbons are not generated biogenically. Even assuming that small quantities of C_2-C_5 gases are generated in biological environments (i.e., landfills), a methane to ethane ratio greater than 350 appears sufficient to delineate anaerobic gas production from thermogenic gases, since such ratios do not occur in petrogenic natural deposits.

Ratios reported by Jones et al. (1999) are a clear aid in defining the transition between thermogenic and biogenic gases. As can be seen from Table 1, ratios of C_1/C_2, C_1/C_3, C_1/C_4 and C_1/C_5 were reported from more than 200 sample points at oil and gas fields. Basically, their data suggest that the following upper limits would clearly indicate biogas (i.e., landfill) as the source of the methane occurrences. Table 1 is an example of the use of lighter hydrocarbons and their ratios to determine methane sources.

Hydrocarbon Ratio	Biogenic Origin (i.e., Landfill) <u>If Above</u>
C_1/C_2	350
C_1/C_3	900
C_1/C_4	1,500
C_1/C_5	4,500

Table 1: Ratios of Light Hydrocarbons with Respect to Methane

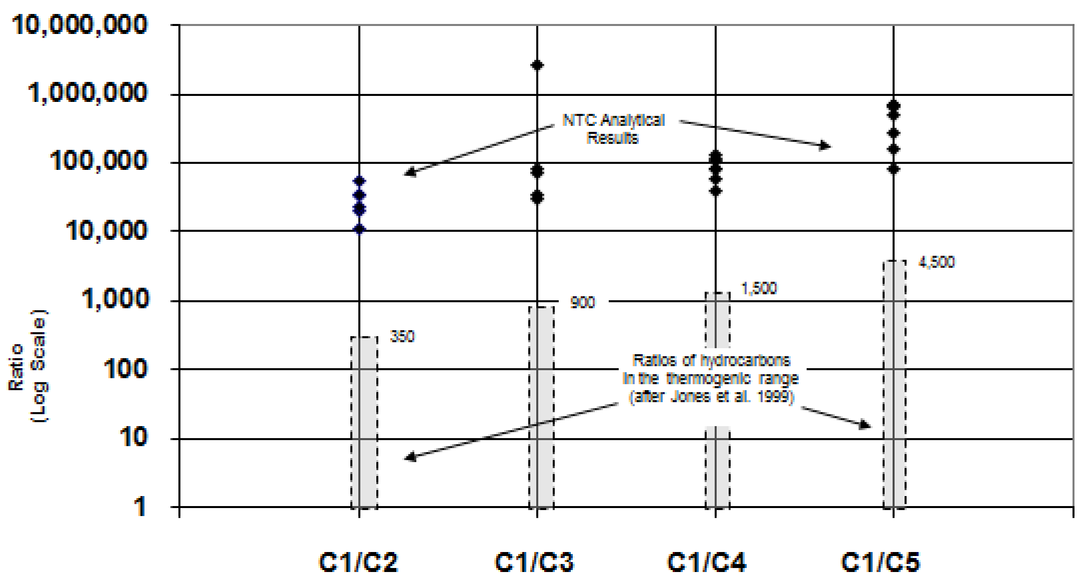


Figure 40: Determination of the stable isotope ratios of carbon and hydrogen in methane

There are a variety of naturally occurring isotopes of carbon (atoms of carbon with different atomic weight). Abundance of carbon isotopes:

^{12}C	98.89%	(Stable)
^{13}C	1.115%	(Stable)
^{14}C	$1x10^{-10}$%	(Radioactive)

The measurement of the stable isotope ratios of carbon ($^{13}C/^{12}C$) is an effective method for differentiating sources of methane. The principle of employing stable isotopes is that the distribution of these isotopes in organic matter is a function of the original photosynthetic fixation of CO_2. Subsequent decomposition of organic matter follows a kinetic pathway by which the light isotopes (^{12}C) are preferentially selected over the heavy isotopes (i.e., methanogenesis). Hence, different decomposition products have different stable isotope distribution (Jones et al., 1999). Based on international standards, the isotope ratios are expressed as delta values ($\delta^{13}C$) given in per mill ($^{o}/_{oo}$) units. Isotope ratio values are negative if the ($^{13}C/^{12}C$) ratio is lower than the standard (arbitrarily assigned a 0 $^{o}/_{oo}$) and positive if the ($^{13}C/^{12}C$) ratio is greater than the standard value. Following these principals, studies have reported carbon ratios for different carbon-containing matter that can be used to differentiate methane sources. The stable carbon isotope ratio for biogenic gases (i.e., landfill generated) have been reported to fall in the $\delta^{13}C$ range of -45 to -100$^{o}/_{oo}$, whereas thermogenic gases cover a $\delta\,^{13}C$ range of -15 to -50$^{o}/_{oo}$ (Jeffrey et al., 2003), see Figure 41.

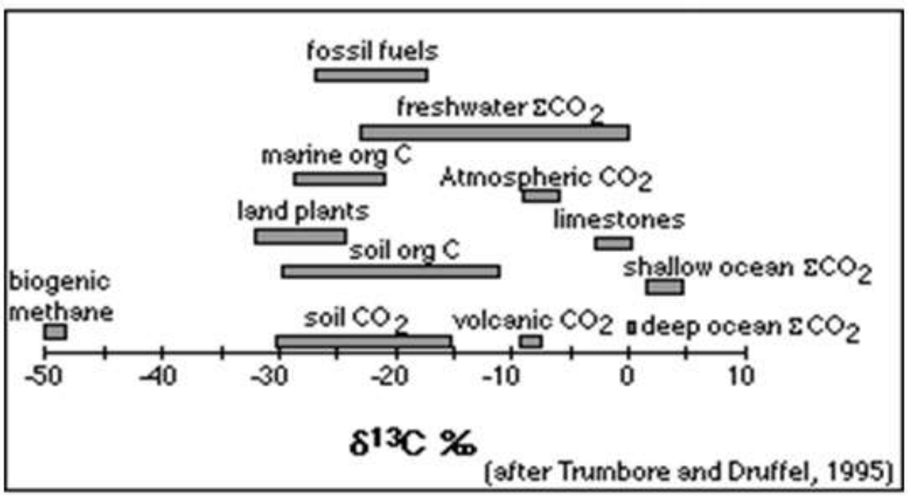


Figure 41: Different pools of methane

At the same time, hydrogen also has two stable isotopes—H (hydrogen) and ^{2}H (deuterium or D)—and the isotopic ratio of hydrogen ($^{2}H/H$) can be used to differentiate sources of methane. The fraction of hydrogen isotopes associated with the thermogenic and biogenic processes is different, resulting in methane with isotopic compositions that are fairly distinct. For example, the hydrogen isotopic composition of methane produced by a thermogenic process typically ranges from -125 to -250 $^{0}/_{00}$ (Schoell, 1980), while the isotopic composition of hydrogen by a biogenic process ranges from -270 to -350 $^{0}/_{00}$. (Coleman at al., 1995). When plotted on a graph (Figure 41) showing the isotope ratios of hydrogen versus carbon, a distinction can be made of the general regions for methane generation by fermentation vs carbon dioxide reductions, vs thermogenic methane (Bogner at al., 1996).

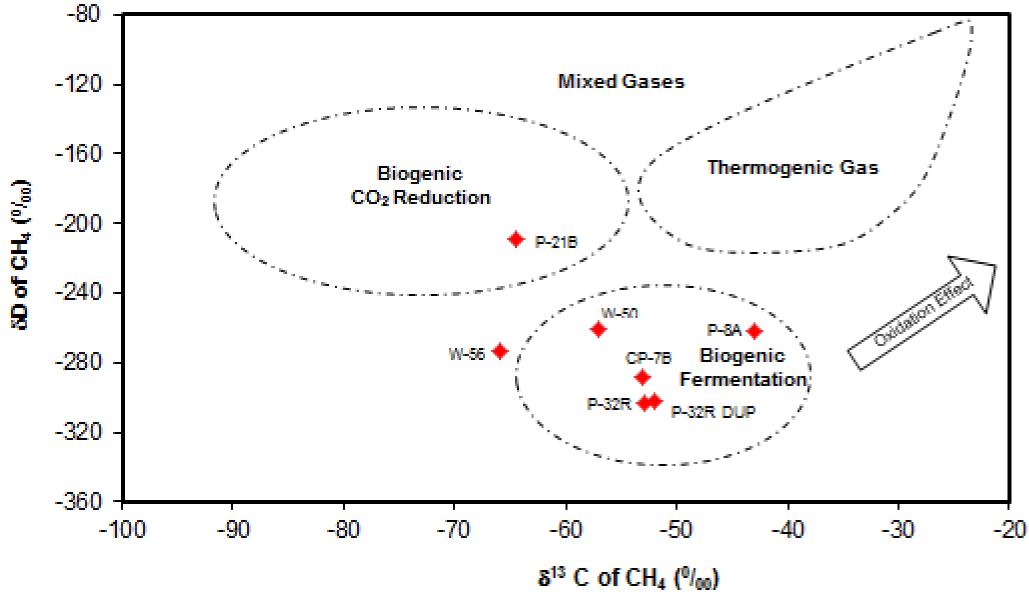


Figure 42: Stable isotope ratios for methane ($\delta^{13}C$ vs δD) – case study

Radiocarbon Measurement ^{14}C in Methane

Measurement of the radiocarbon isotope ^{14}C is a very effective and straightforward method for differentiating sources of methane. Basically if carbon 14 shows up in analysis, the gas must have been generated within the last 70,000 years (e.g. landfill). It has to be of recent origin because thermogenic gases (i.e., oil and gas fields) were generated millions of years ago, therefore, they will contain no carbon 14 (Oiltracers LLC, 2004). Content of ^{14}C in methane will be reported as percent Modern Carbon (pMC) with respect to an international standard. Therefore, biogenic methane formed in landfills contains carbon from organic matter that was part of living organisms until recently and so contains ^{14}C with values in the order of 120 to 150 pMC. Thermogenic methane, in contrast, contains carbon from organisms that died millions of years ago, in which all the ^{14}C has radioactively decayed giving a value of 0 pMC (Jeffrey et al., 2003). See Figure 43.

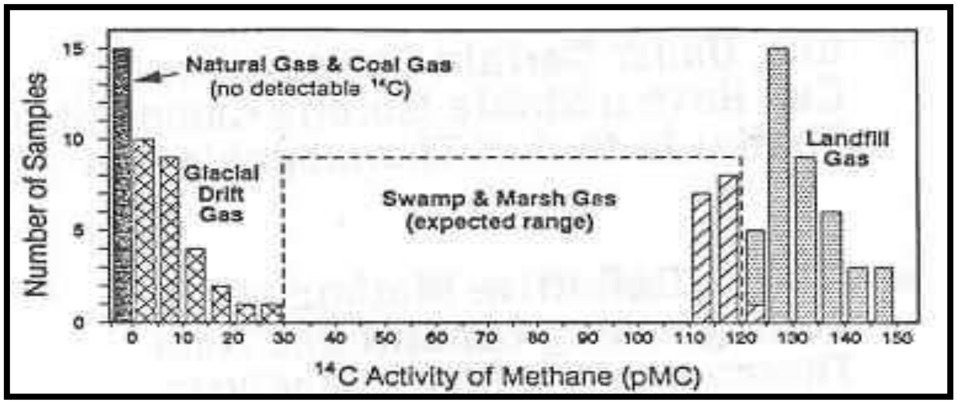


Figure 43: Concentration of ^{14}C in Methane from Various Sources (After Coleman at al., 1995)

Tritium Measurement ^{3}H

Analysis of tritium, a radioactive hydrogen isotope, is another method to determine the source of methane when there is a question concerning its origin (Hackley et al., 1999). At present there have been very few published tritium analyses of landfill derived methane. Currently the published values range from 160 TU to approximately 2800 TU (Coleman et al. 1995). Since a significant portion of the hydrogen in microbial methane originates from the surrounding aqueous media during methanogenesis (Whiticar et al., 1986), it can be reasonably assumed that methane from landfills will have relatively high concentrations of tritium, since most landfill leachates analyzed thus far contain elevated tritium levels (Rank et al., 1992).

Determination of LFG Fraction from Commingled Methane Sources

As discussed previously, in some circumstances CH_4 in a probe can be from comingling of several sources. Therefore, it is important from a regulatory point of view to determine LFG contribution to the mixture whenever CH_4 is detected exceeding 5% (v/v) in a probe. If CH_4 from LFG in the mixture exceeds 5% (v/v), the level is in violation of 27 CCR 20921(a)(2). There are several methods to determine LFG fraction in a probe where a mixture of CH_4 sources is suspected.

CH_4/CO_2 Ratio for Thermogenic/LFG Mixture

The two major components of LFG are CH_4 (approximately 55 percent v/v) and CO_2 (approximately 45 percent v/v). Therefore, landfill gas typically has CH_4/CO_2 ratio of 1-1. Meanwhile, thermogenic gas typically has a much higher CH_4/CO_2 ratio range. Therefore, concentration of biogenic CH_4 in a sample collected from a probe:

$$\text{Biogenic } CH_4 \text{ (\% v/v)} = f_B \times CH_{4\,sample}$$

$$f_B = (R_{C\,Sample} - R_{C\,T}) \div (R_{C\,B} - R_{C\,T})$$

where

$CH_{4\,sample}$ = concentration of CH_4 in the probe's sample (% v/v)

f_B = fraction of CH_4 from biogenic (landfill gas) source in a probe sample

$R_{C\,B}$ = CH_4/CO_2 ratio of landfill gas

$R_{C\,sample}$ = CH_4/CO_2 ratio in the probe's sample

$R_{C\,T}$ = CH_4/CO_2 ratio of thermogenic gas

However, this tool is considered preliminary for two reasons: a) Oxidation of CH_4 in the subsurface can skew the CH_4/CO_2 ratio lower, and b) dissolution of CO_2 in groundwater would result in higher CH_4/CO_2 ratio. Therefore, additional analytical testing as discussed above is needed to further delineate the sources of detected methane.

C_2H_6/CH_4 Ratio for Thermogenic/LFG Mixture

As discussed above, ethane (C_2H_6) can be present in significant quantities in thermogenic gas (typically in the % range). Meanwhile, C_2H_6 levels in landfill gas are very low (typically in the ppm range) resulting in negligible value for C_2H_6/CH_4 ratio. Therefore, concentration of biogenic CH_4 in a sample collected from a probe:

$$\text{Biogenic } CH_4 \text{ (\% v/v)} = f_B \times CH_{4\,sample}$$
$$f_B = 1 - (R_{E\ Sample} \div R_{E\ T})$$

where
$CH_{4\,sample}$ = concentration of CH_4 in the probe's sample (% v/v)
f_B = fraction of CH_4 from biogenic (landfill gas) source in a probe sample
$R_{E\ Sample}$ = C_2H_6/CH_4 ratio in the probe's sample
$R_{E\ T}$ = C_2H_6/CH_4 ratio of thermogenic gas

Isotope Data for Thermogenic/LFG Mixture

Methane from landfill gas typically has radioactive isotope of carbon (^{14}C) levels exceeding 100 pMC [Coleman et al. 1990], while thermogenic methane typically contains negligible levels of ^{14}C. Therefore, concentration of biogenic CH_4 in a sample collected from a probe:

$$\text{Biogenic } CH_4 \text{ (\% v/v)} = (^{14}C_{Sample} \div {}^{14}C_B) \times CH_{4\,sample}$$

where
$CH_{4\,sample}$ = concentration of CH_4 in the probe's sample (% v/v)
$^{14}C_B$ = ^{14}C level of biogenic landfill gas
$^{14}C_{Sample}$ = ^{14}C level in the probe's sample (pMC)

Freon-12 Data for LFG/Other Biogenic Methane Source Mixture

Landfill gas typically has much higher concentration of VOCs from near-surface fermentation of decomposing organic materials (e.g. vegetation) than other biogenic CH_4 sources. VOCs, however, can undergo degradation in the subsurface as well as sorption to soil particles. One particular VOC that is typically present in LFG and not generally detected in other biogenic methane from fermentation of vegetation sources is Dichlorodifluoromethane (R-12), commonly known as Freon-12. Resistant to subsurface degradation and not significantly affected by sorption, Freon-12 data can be used to determine concentration of CH_4 from LFG in a sample collected from a probe:

$$\text{Biogenic } CH_4 \text{ (\% v/v)} = (\%CH_4 \div \text{Freon-12})_{LFG\ Std} \times \text{Freon-12}_{sample}$$

Where
$(\%CH_4 \div \text{Freon-12})_{LFG\ Std}$ = CH4/Freon-12 ratio (% / ppbv) in LFG based on composition data from samples from the LFG collection system
Freon-12_{sample} = Concentration of Freon-12 (in ppbv) in the probe's sample

Field Sampling and Testing Procedures

Figure 44: Landfill gas sampling and screening using Summa canisters and a GEM 2000

The following gas sampling plan is only an example and is intended to help those planning to conduct sampling events to collect gas samples for gas characterization to identify sources of methane. The protocols found herein should aid in documenting the procedural and analytical requirements needed to carry out an assessment of methane gas occurrences for identification of methane sources.

Protocol

Containers—Gas samples should be collected using Summa canisters (see Figure 44), with the exception of the samples collected for H_2S analysis; these will be contained using one-liter Tedlar bags. All sampling equipment and containers should be previously decontaminated by the certified laboratory.

Screening—All sampling locations should be screened using portable gas detection equipment (GEM-2000) and/or (RKI-Eagle) for fixed gases and methane before obtaining samples. Screening results should be logged in a field data sheet.

Parameters—If during gas screening the instrument reads concentrations of methane gas above 1% v/v, a Summa Canister should be used to collect a gas sample for laboratory analysis after the probe has been adequately purged (until stable gas reading is obtained). Purging is highly recommended, especially when testing for gaseous hydrocarbons, stable isotopes, and radiocarbon, to avoid any cross-contamination of the subsurface gases in the probe with ambient air. If no gas is detected with a GEM-2000 or similar instrument, the gas probe should be screened using RKI-Eagle or similar instrument to detect methane concentrations equal to or lower than 1,000 ppm. If the RKI instrument reads less than 500 ppm of combustible gas as methane, the sampling should be discarded, since not enough methane is be present to run the required laboratory analyses.

Logging—Field staff should log sampling location points and field measurements in a field log-sheet.

Chain of custody—After each sample is collected, it should be labeled, logged on a chain-of-custody form, and packed for shipment to an accredited laboratory.

Collection of soil vapor samples—Soil vapor samples will be collected in accordance with the procedures and methodology described in the following section.

<u>Collection and Analysis of Gaseous Hydrocarbons</u>

Before collecting a sample using a Summa canister, the probe being sampled should be screened for concentrations of methane using a GEM-2000 or similar infrared instrument. The GEM-2000 should be allowed to run for purging of the probe (until a steady gas reading is obtained) at a rate of 300 cc/min. As stated previously, the use of an RKI instrument maybe warranted if gas concentrations are lower than 1,000 ppm. Following purging of the probe, a Summa canister should be connected to the sampling port of the probe to allow the vacuum in the canister to withdraw a soil vapor sample from the subsurface. The canister should then be removed, sealed, labeled and shipped to an accredited laboratory for analysis. From this sample the following analyses should be performed:

Parameter	Test Method
Light Hydrocarbons Gases (C_2-C_5)	ASTM D2820 (10 ppm Detection Limit)
VOCs (Includes BTEX)	TO-15 (0.5 ppm Detection Limit)
Fixed Gases + CH_4	ASTM D 1946 (10 ppm Detection Limit)
Gas Tracers	GC Thiopane & T-Butyl Mercaptan (0.5 ppm DL)

<u>Collection and Analysis of Stable Isotopes and Radioactive Isotopes</u>

From the previous sampling step and at the same probe, a second Summa canister should be connected to the sampling port to allow the vacuum in the canister to withdraw a soil vapor sample from the subsurface. The canister should then be removed, sealed, labeled, and shipped to the appropriate laboratory for analysis. From this sample, the following analyses should be performed:

Parameter	Test Method
Radiocarbon Measurement	AMS Detection (^{14}C)
Tritium Measurement	CG-P-IRMS (^{3}H)

Stable Isotope Ratio Measurement of CH_4	Continuous Flow IRMS Detection ($^{13}C/^{12}C$)
Stable Isotope Ratio Measurement of CH_4	Continuous Flow IRMS Detection ($^{2}H/H$)

Collection and Analysis of Hydrogen Sulfide

Sampling the probe for H_2S should be done at the end of the sampling journey to avoid any cross contamination of sampling materials. First, to be able to have real-time information of the hydrogen sulfide concentrations at the probe, a field instrument should be used for screening (i.e., RKI-Eagle) or similar. A Tedlar bag should be used for sample collection only if the instrument shows H_2S readings above 10 ppm. A very short Tygon tube should be used to draw a sample from the probe into the container (no longer than a few inches). When using the Tedlar bag, a sample train should be assembled using a peristaltic pump able to withdraw a sample at a rate not greater than 250 cc/min to limit stripping, prevent ambient air from diluting the soil sample, and to reduce the variability of purging rates. From this sample the following analysis should be performed:

Parameter	Test Method
Hydrogen Sulfide Measurement	EPA 15/16

Former Landfill and Disposal Site LFG Investigation Case Studies

Case Study: Cannery Street Landfill, Orange County

Figure 45: Installation of landfill gas monitoring wells at the Cannery Street Landfill in Orange County

Site Setting and Background

- The Cannery Street Landfill site is located at NW Magnolia Street and Hamilton Avenue in Huntington Beach.
- The Cannery Street Landfill is approximately 20 acres in size and contains an estimated volume of 900,000 cubic yards of miscellaneous debris which, was accepted at the landfill from 1957 to 1969 while being operated by Orange County.
- The site is currently a city park operated by the City of Huntington Beach and is surrounded primarily by residential structures that were potentially impacted by subsurface landfill gas migration.
- An assessment was implemented to determine gas migration levels from the former landfill into the surrounding structures, particularly the elementary school located 300 feet northwest of the site.
- The assessment consisted of the installation of perimeter gas monitoring wells and a methane gas assessment to determine the source of gas occurrences at the elementary school.

Landfill Gas Investigation

At the request of the Orange County Solid Waste LEA, CalRecycle prepared a work plan and performed an investigation in June 2005 at the Cannery Street Landfill (SWIS # 30-CR-0096). The assessment was implemented to determine gas off-site migration levels from the waste deposits in the landfill and the impact on the surrounding neighborhood and the elementary school located northwest of the site. Of particular interest was the determination of sources for gas being detected on school property 300 feet away from the landfill. The City of Huntington Beach, which owns the site, and the LEA needed to determine the sources of these gases, as the school district was claiming that they originating and migrating from the landfill. Because the Cannery Street Landfill site was located near the West Newport Oil Field, where approximately 452 oil wells were located within a 1-mile radius, there was concern that methane from that site might be present at the Cannery Street Landfill. Furthermore, there was evidence that two oil exploratory wells were drilled immediately northeast of the disposal site, which raised concerns as to whether gases were seeping from those abandoned wells and impacting the school grounds as opposed to methane gas migrating from the landfill.

Identification of methane sources was necessary to assign regulatory responsibility for the control of gases migrating off-site from the landfill, or in turn, to change the scope of regulatory oversight and address the control of gas occurrences in the school grounds through other mechanisms. Under such circumstances, fingerprinting of landfill gas was used to trace the sources of methane and to compare the landfill gas to the gas detected in the school grounds.

A sampling program was established for the assessment of gas occurrences in monitoring wells located in the landfill and in the school grounds in a two-phased approach: Phase I included the installation of additional landfill gas monitoring wells according to Title 27, California Code of Regulation. Six additional landfill gas wells were installed on April 29 and 30, 2005. Phase II called for sampling of monitoring wells based on a schedule to include the newly installed wells and existing monitoring wells. Gas samples were collected using Summa canisters for most of the analyses performed; Tedlar bags were used for hydrogen sulfide analysis samples. The below table summarizes the total number of samples taken for laboratory analyses:

Table 2: Summary of Samples

Kettler Elementary School & Cannery Street Landfill			
Total Samples	**Containers**	**Laboratory Used**	**Analysis**
Eight (8)	8 Summa canisters	University of California Irvine Radiocarbon Laboratory Earth System Science Dept.	- Hydrogen Isotope Ratio* - Carbon Isotope Ratio - Radiocarbon
Eight (8)	8 Summa canisters	ExcelChem Environmental Labs Roseville, CA	- VOCs - Fixed Gases - Methane - C2 – C5
Eight (8)	8 Tedlar bags	ATL Air Labs City of Industry, CA	- Hydrogen Sulfide - t-Butyl Mercaptan - Tetrahydrothiophene
Note: * Analysis of the hydrogen isotope ratio of the methane was not considered in the work plan, but was important for this assessment as an additional isotopic signature.			

Case Summary

- The landfill gas investigation conducted by CalRecycle included the installation of a landfill gas monitoring network to assess the potential for landfill gas off-site migration to ensure the protection of public health and safety and the environment.
- The laboratory results and the various methods and analyses were examined and used to compare the signature of the methane gases showing up in the school with signatures of other potential sources of methane: natural gas (e.g., pipeline gas), naturally occurring methane (e.g., oil fields), and landfill gas.
- Evidence was found that the resulting off-site gas migration into adjacent soils and affecting the school grounds had the signature of a landfill gas source.
- With these results, it was determined that the source of methane showing up in the school originated from the Cannery Street Landfill.
- The LEA issued a recommendation to the owner of the site (City of Huntington Beach) to provide plans for the immediate mitigation of the gas generation rates and control of gas off-site migration.
- The immediate mitigation measures executed by the city included a new park irrigation schedule to reduce the amount of water percolation into waste, which in turn reduced the gas generation rates.
- A long-term mitigation measure included the construction of an active collection trench system consisting of gravel-filled trenches and a perforated PVC pipe going through the middle of the main trench and connected to a blower station for gas extraction.
- The active collection trenches were constructed in those areas where there had been historical concerns with potential landfill gas migration (west and north areas surrounding the landfill).

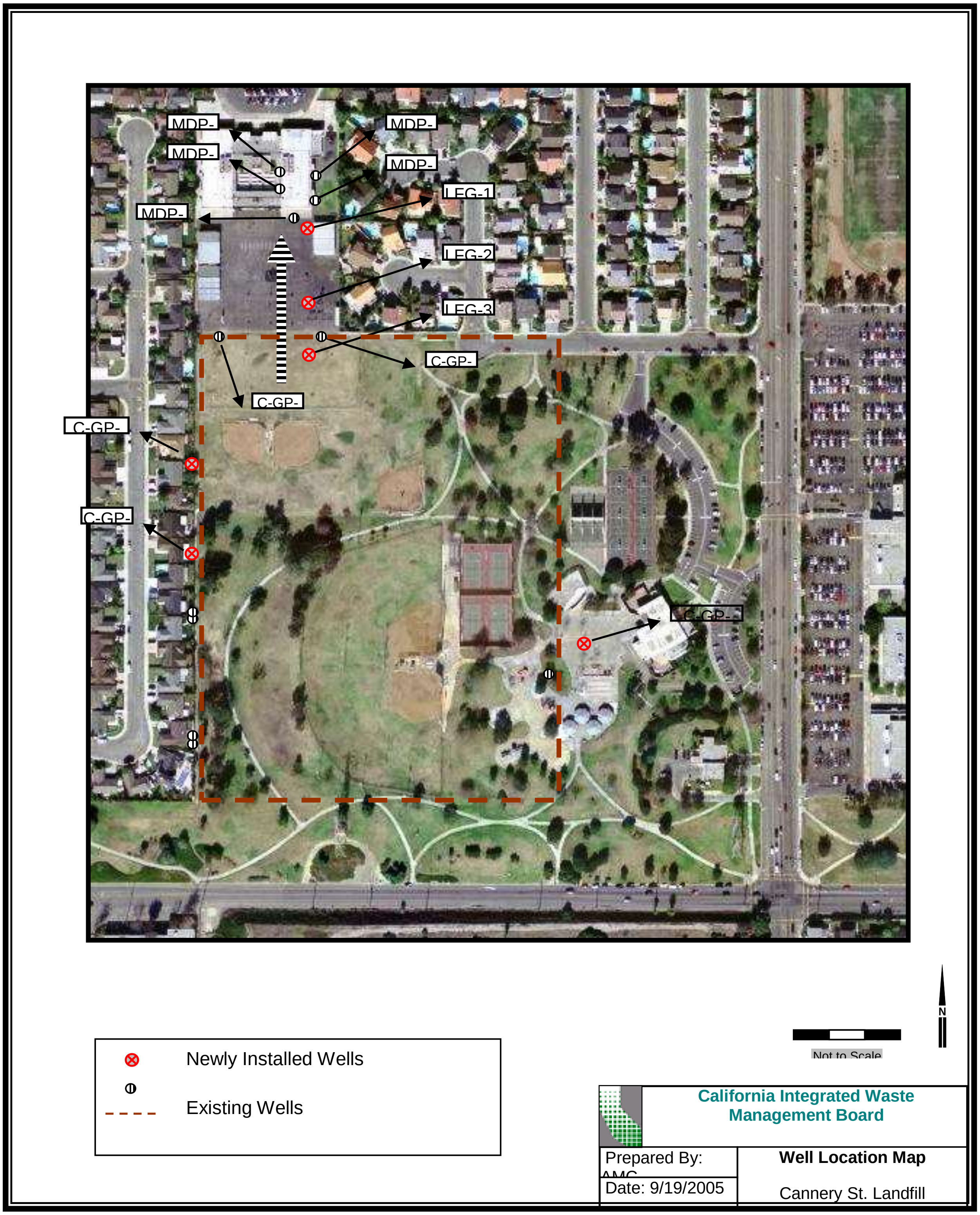


Figure 46: Site location – Cannery Street Landfill

Case Study: 14th Avenue Landfill, Sacramento County

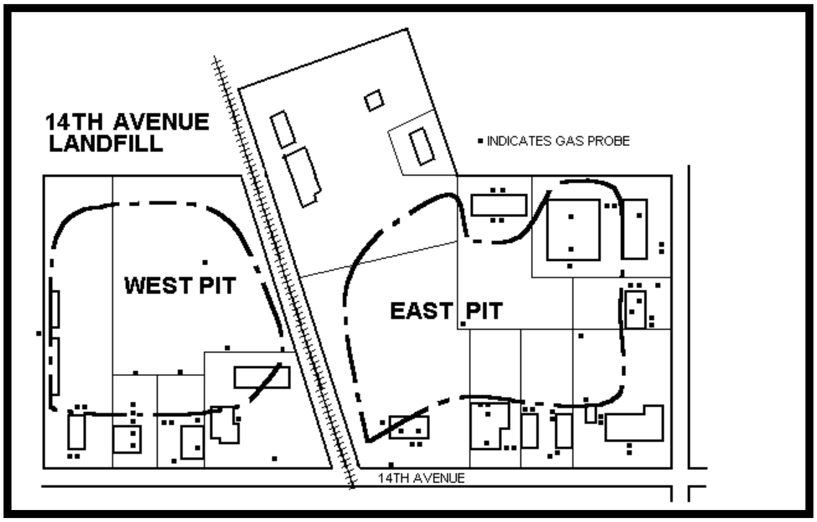


Figure 47: 14th Avenue Landfill, Sacramento – Commercial development; installing a landfill gas well

Site Setting and Background

- Waste disposal corresponded to two former gravel mining pits.
- The property corresponding to the landfill was subsequently subdivided and developed with commercial and industrial businesses. It is owned by 16 separate parties, making it difficult to enforce LFG monitoring requirements.
- Some properties are located entirely overlying the wastes, and perimeter LFG monitoring in accordance with CCR Title 27 requirements could not be conducted.
- LFG concentrations exceeded 5 percent methane gas at the landfill perimeter and 1.25 percent at on-site structures.
- Groundwater encountered in the well boreholes prevented construction of deep probes in each LFG well, corresponding to the maximum depth of wastes.
- Lengths of screened intervals of each probe was maximized and corresponded to locations of lithology most conducive to the migration of LFG, if present (e.g., sands and gravels).
- The site exhibits extreme surface settlement at some locations.
- LFG is being controlled by passive vent wells.

Landfill Gas Investigation

The 14th Avenue Landfill in Sacramento, California was formerly the location of two gravel mining pits that were filled with wastes from the early 1960s to the late 1970s. The two pits known as the East and West Pits were approximately 14 and 16 acres in size, respectively. Subsequent to waste disposal, the landfill was developed into a commercial subdivision and sold in the early 1980s to 16 separate owners. During construction of a pile foundation for a commercial warehouse located over a portion of the landfill, a worker was killed when he was overcome by methane gas while trying to retrieve a drill bit that had fallen into a piling hole.

Figure 48: Commercial warehouse at 14th Avenue (note ponding in parking lot due to settlement); landfill differential settlement damage to warehouse floor (portion of warehouse floor supported by grade beams tied to piles – rest of slab allowed to "float")

During the early 1980s, the Sacramento County Environmental Health Department required the individual property owners to install a landfill gas monitoring network to monitor for methane gas migration into on-site structures and at the perimeter. However, some of the property owner parcels were located entirely within wastes, and therefore monitoring at the waste perimeter in accordance with CCR Title 27 requirements was not possible. Landfill gas concentrations, exceeding the lower explosive limit of 5 percent were detected in several perimeter landfill gas monitoring wells. Some wells had concentrations exceeding 20 percent. The commercial warehouse that was built on pilings and located overlying the wastes was required to install a continuous LFG monitoring system within the warehouse to detect LFG gas within the structure (see Figure 49).

In the early 1990s, landfill gas concentrations in on-site monitoring wells and structures continued to exceed regulatory limits of 5 percent in perimeter wells and 1.25 percent in structures. In addition, differential settlement cracks began to form in a warehouse building foundation constructed over waste. State and county inspectors used combustible gas instruments to check the cracks within the warehouse and found landfill gas concentrations exceeding 25 percent.

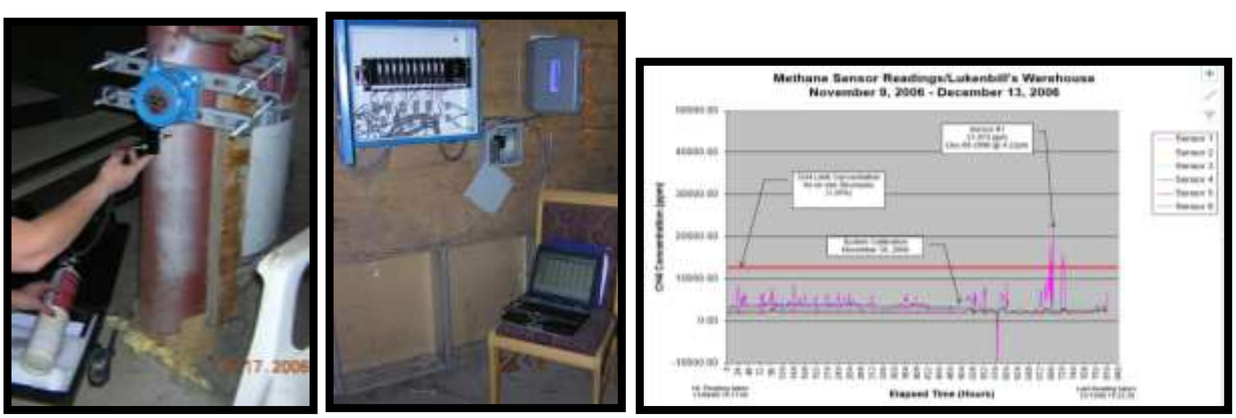


Figure 49: Calibration of combustible gas sensor (catalytic bead type); continuous monitoring system to include controller, logger, and PLC program; LFG concentration data versus time graph. Note the spike where concentration exceeded the regulatory limit of 1.25 percent.

In January 2002, the Sacramento County LEA requested assistance from the California Integrated Waste Management Board’s Closed, Illegal and Abandoned Sites program to review site conditions and previous investigations for landfill gas migration at the 14th Avenue Landfill and to perform a field investigation to obtain current data on LFG migration. In 2003, the CIA program obtained site access from the 16 property owners to install an updated LFG monitoring network that complied with state regulations (27 CCR 20925). The previous LFG monitoring network was constructed prior to state regulations and did not meet the requirements of 27 CCR 20925.

In July 2002, 10 LFG monitoring wells were installed, meeting 27 CCR 20925 requirements. The well boreholes were drilled to depths corresponding to the deepest portion of the landfill and were completed with either shallow, medium, and deep probes or shallow and deep probes that screened lithology consisting of inter-bedded clays, sands, silts, and gravels (alluvial deposits from the American River floodplain). Probes within the wells were constructed to maximize the screened intervals and designed to screen lithology most conducive to landfill gas migration (e.g., sands and gravels), if present.

One year of monthly landfill gas monitoring was performed, along with quarterly sampling and analytical testing. Monthly gas monitoring consisted of obtaining readings for fixed gases to include methane, carbon dioxide, oxygen, and nitrogen using a GEM 2000. Sampling and analysis consisted of obtaining landfill gas samples using Summa canisters and having laboratory analysis conducted on the samples using ASTM 1946 Fixed Gas Test (methane, carbon dioxide, oxygen, and nitrogen) and EPA T.O.-15 for volatile organic compounds. The results of testing over the one-year period indicated that five of the 10 wells had LFG concentrations exceeding the 5 percent methane gas rule. The LEA used the monitoring results to issue an enforcement order to the 16 property owners stating the necessity to control the migration of LFG at the site in accordance with 27 CCR Section 20919. The property owners hired an environmental consultant to propose a remediation system to control the LFG migration problem. Passive venting wells were installed near the monitoring wells that were exceeding the 5 percent methane gas rule to control the landfill gas. Concentrations at some perimeter and on-site wells continued to exceed regulatory levels.

In August 2013, CalRecycle assisted the LEA by drilling and constructing four additional LFG wells on specific properties located on the landfill to comply with a recent enforcement order. The wells were designed and constructed on specific properties at locations outlying the waste limits. The wells were constructed to evaluate the potential presence and composition of landfill gas and the potential for LFG migration, and to provide information as to whether LFG posed a threat to public health and the environment.

At each property, the wells were located at accessible areas for drilling and subsequent LFG monitoring, and in close proximity to and outlying the lateral extent of the former gravel pits interpreted to generally correspond to the extent of wastes. The wells were designed in the field based on review of previous well boring logs, topographic maps indicating the lateral and vertical extent of wastes, and specific subsurface lithology observed while drilling each LFG well boring. Groundwater encountered in the well boreholes prevented construction of deep probes in each well, corresponding to the maximum depth of wastes. Screened intervals of the probes corresponded to locations of lithology most conducive to the migration of LFG, if present (e.g., sands and gravels). The LEA continues to inspect, monitor, and take appropriate actions as necessary based on LFG monitoring data.

Case Summary

- The use of a property owner's association to manage landfill maintenance, monitoring, remediation and other regulatory requirements had mutual benefit to owners (use of a single legal representative and environmental consultant to address regulatory requirements for the entire landfill) and regulators (managing inspection, investigation, enforcement, and remediation of the landfill for 16 property owners).
- Development at the site required major capital repairs and modifications to structures, grading, pavements, utilities, etc. due to differential settlement of the landfill; gravity-fed storm water and sewer utilities located within the landfill were compromised due to changes in design slope caused by landfill settlement.
- A commercial warehouse located over waste (constructed on a pile-supported foundation) was damaged by differential settlement and had two major construction projects to repair the warehouse foundation, parking lot, and utilities before eventually being razed. See Figures 48 and 50.
- The use of automated landfill gas continuous monitoring systems allowed regulators and owners to check methane gas concentrations within structures located over the landfill and take appropriate measures (venting) when concentrations exceeded the regulatory limit of 1.25 percent. See Figure 49.
- Landfill gas monitoring and control systems are still being monitored and maintained, 35 years after the landfill property was commercially developed in 1979. Methane concentrations have decreased during this period, but concentrations above the lower explosive limit of 5 percent are detected both in monitoring wells and in passive vents during routine monitoring.


Figure 50: Commercial warehouse demolition in May 2011

Case Study: Canyon Park Dump, Los Angeles County

Figure 51: Landfill gas monitoring well construction in a residential area adjacent to the Canyon Park Landfill

Site Setting and Background

- The site is located at the intersection of Hacienda Drive and Las Lomas Road in the City of Duarte.
- The site was a former gravel quarry that operated from approximately 1938 to about 1961.
- The site is surrounded by residential and commercial buildings that were potentially impacted at the time by subsurface landfill gas migration.
- An assessment was implemented to determine gas migration levels from the former landfill into the surrounding structures.
- The assessment consisted of the installation of a perimeter gas monitoring network and gas monitoring program to determine gas migration levels.

Landfill Gas Investigation

The Los Angeles Solid Waste LEA requested technical assistance from CalRecycle (formerly the California Integrated Waste Management Board) in 2006 to investigate landfill gas migration issues at the Canyon Park Dump, also known as the Duarte Golf Course. The LEA had measured landfill gas concentrations as high as 50 percent within landfill gas extraction wells on the golf course, and measurements at several locations in the neighborhood surrounding the landfill (at water meters boxes in the ground) determined that methane concentrations exceeded the regulatory threshold of 1.25 percent by volume in air.

CalRecycle staff conducted an office and field investigations that included research on the site's history from City of Duarte records. The office investigation showed that the golf course was constructed over a gravel quarry that had been reclaimed and used as a landfill until the 1960s. The golf course and the adjacent residential neighborhood were developed by the City of Duarte Redevelopment Agency in 1979. In order to construct these dwellings, it was required that protective gas-impermeable membranes be installed for the residential units and a gas control system be installed at the landfill. A gas collection system had been installed in the 1980s that consisted of an interior and perimeter well field that collected gas for power generation. A gas migration study was performed by a landfill gas consultant (Lockman and Associates) of subsurface structures in the neighborhood north of the site in the mid-1980s. It was determined, based on the gas collection system plans, that no perimeter monitoring wells had been installed in the landfill boundary, and it was unknown if gas was migrating in the subsurface into adjacent areas.

CalRecycle staff prepared a work plan to install eight multi-depth gas monitoring wells meeting Title 27 California Code of Regulations (CCR) requirements around the golf course (see Figure 52). The landfill gas monitoring wells were installed using an air percussion drill rig, which was selected due to difficult drilling conditions presented by cobble and gravel formations. Two rounds of gas sampling conducted in May and June of 2002 at the wells installed indicated explosive levels (18 percent) of gas in the shallow probe of a well in the middle of the residential area north of the site. The LEA sent out a health advisory on July 3, 2006, to warn residents of the explosive gas hazards and recommended precautionary measures for residents to take.

Case Summary

- The site had a gas collection and control system, but it did not have a gas monitoring network to determine the efficacy of the control system and the site's compliance with gas migration control.
- The landfill gas investigation conducted by CalRecycle included the installation of a landfill gas monitoring network to assess the potential for landfill gas off-site migration to ensure the protection of public health and safety and the environment.
- The gas monitoring network installed consisted of eight monitoring wells located in residential streets adjacent to the landfill, as residential and commercial properties were located immediately adjacent to the landfill's waste boundary.
- Based on the boring logs and reviewed reports, it was concluded that the geology of the site consists of alluvial deposits, which are highly permeable and could transmit landfill gases rapidly.
- Evidence was found of off-site gas migration into adjacent soils and structures, particularly to areas located north and northeast of the former landfill, almost 30 years after development.
- CalRecycle recommended modifications to the current gas extraction and collection system to control landfill gas migration based on a compliance schedule established in coordination with the LEA.

Figure 52: Landfill gas monitoring network location – Canyon Park Dump

Case Study: Old Pleasanton Landfill, Alameda County

Figure 53: Landfill gas collection and perimeter monitoring plans overlaid on a Google Earth aerial image of the Old Pleasanton Landfill provide a 3-D perspective of the site and layout of the landfill gas collection system and perimeter monitoring network. Note: The drawing overlay on the right is the landfill gas migration system installed in the Delco Property development west of the landfill. Landfill gas migration was detected in off-site monitoring wells in the subdivision south of the site (located at top of figure).

Site Setting and Background

- The landfill is a canyon fill adjacent to residential properties to the south that were constructed on fill placed in the same canyon.
- As early as 1980, it was known that the landfill was generating landfill gas that was migrating off site, and as early as 1986, the landfill owner and developer of the residential property to the south entered into an agreement indicating the landfill owner must control LFG migration.
- The landfill includes an extensive landfill gas collection system; however, LFG continues to migrate off site.

- The environmental consultant to the landfill believes that methane gas in a landfill gas well approximately 15 feet from the southern property boundary does not appear to be related to the LFG migrating from the refuse mass, but may possibly be related to natural organic matter buried within the earth fill of the former drainage channel/canyon.
- The landfill prior to the August 2012 LFG investigation contained 18 LFG extraction wells, five perimeter migration extraction wells, and 12 LFG perimeter monitoring wells
- The August 2012 investigation consisted of constructing 8 on-site wells and 2 off-site wells. Additional wells were planned off site but could not be constructed at the time due to subsurface utility conflicts.
- In off-site monitoring wells located in the residential area to the adjacent south, the methane concentration exceeds 5 percent.
- The LEA is currently working with the owner of the Old Pleasanton Landfill and the City of Pleasanton to control landfill gas through modifications to the current LFG control system and requiring that they take appropriate measures to protect residents from LFG by monitoring the off-site wells regularly and by installing methane sensors in the homes adjacent to the LFG monitoring wells.

Landfill Gas Investigation

The Old Pleasanton Landfill, located on Vineyard Avenue in Pleasanton, is a 23-acre site with a waste footprint of approximately 13 acres. The landfill is a canyon fill that operated from 1950 until 1976 and was subsequently graded to form a series of flat terraces that step down from north to south. The site was closed in 1983 under a waste discharge requirement from the San Francisco Bay Area Regional Water Quality Control Board.

As early as May 1980, a letter states that during a site inspection, methane gas was found to be migrating off site at the southern property boundary at concentrations of up to 18 percent. A 1983 LFG migration assessment report indicated that methane gas monitoring indicated concentrations met or exceeded the regulatory limit at five locations explored. A migration assessment conducted in October 1984 for the planned residential development indicated methane at 5 percent in one boring, and the report concluded that a LFG control system should be installed. A 1986 report for the same development included five boring logs from October 1984; the logs indicated LFG concentrations in the borings ranged from zero to 45 percent.

In November 1986, the landfill owners entered into an agreement with the owners of the property adjacent to the south of the site stating that methane gas was migrating from the landfill onto the proposed residential property at levels requiring mitigation under the local, state, and federal guidelines at the time. The agreement stated that the landfill owner would prevent the methane gas generated at the site from migrating onto the proposed residential development by installation of a “boundary control system.” In May 2003, sampling was performed at LFG monitoring wells LFG-1 and LFG-4, located on the landfill property boundary adjacent to the proposed residential subdivision. LFG samples from LFG-4 indicated methane at concentrations of 12.7 percent, 22.6 percent, and 26.4 percent.

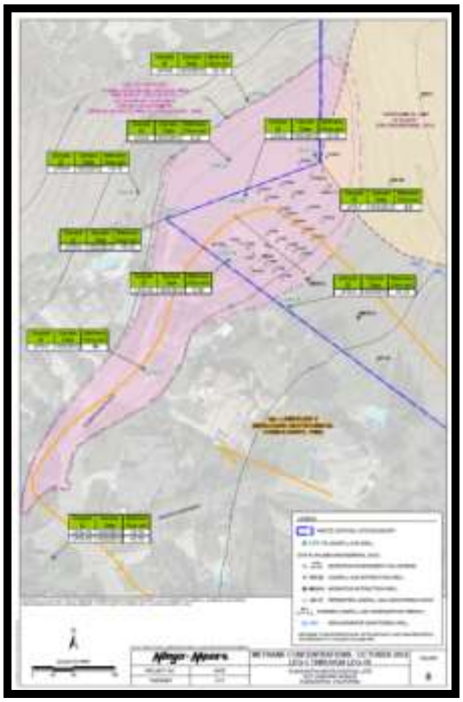


Figure 54: Investigation map showing CalRecycle gas monitoring well locations and landfill gas concentrations (note LFG-2 at 18 percent); EBA topographic map showing homes in Gray Fox Circle (LFG-2)

In October 2010, the Alameda County Environmental Health Department requested technical assistance from the CalRecycle CIA program in reviewing LFG monitoring data for the Old Pleasanton Landfill. The owner's consultant had indicated that a perimeter LFG well contained methane gas exceeding 5 percent. It was determined by CalRecycle staff that additional fieldwork was necessary to delineate the extent of waste at the southern property boundary of the landfill and the adjacent residential neighborhood and install additional LFG monitoring wells off site given the disposal site history (the residential area was constructed on fill that was placed in the same canyon that was filled with wastes at the landfill).

A landfill gas investigation work plan was coordinated and finalized in June 2012. Prior to the August 2012 investigation, the landfill contained 18 LFG extraction wells, five perimeter migration extraction wells, and 12 LFG perimeter monitoring wells. The field investigation included the installation of 10 LFG monitoring wells (see Figure 53): eight at the southern perimeter of the landfill and two in accessible public right-of-way areas at the residential property to the south-southwest. The investigation evaluated the potential presence and composition of landfill gas and whether it was migrating off site and at concentrations that would pose a threat to public health and the environment. The investigation also evaluated the presence, extent, and chemical and physical characteristics of the "lithological unit of primary interest/organic fill," identified by the landfill owner's consultant as consisting of a sandy silt, approximately 2 to 11 feet thick, and characterized by an abundance of organic materials consisting of straw, grass, roots, plant stems, and leaves. The wells were constructed in accordance with 27 CCR section 20925 to depths of 28 to 40 feet, coinciding with the maximum depth of wastes. The well screen intervals corresponded to depths of the "organic fill" as observed by the landfill owner's consultant during assessments and to the presence of minor (typically less than 1 percent) amounts of this material observed in LFG well borings drilled during the August 2012 investigation.

During monthly LFG monitoring, methane was detected at concentrations exceeding 5 percent in one off-site well in the residential area to the adjacent south of the landfill. The LEA is currently working with the owner of the Old Pleasanton Landfill and the City of Pleasanton to:

- control LFG through modifications to the current LFG control system, and
- take appropriate measures to ensure residents are protected from the migration of LFG through regular monitoring of the off-site wells and by installing methane sensors in the homes adjacent to the LFG monitoring wells.

Case Summary

- Historical aerial photographs obtained in preparing the LFG Investigation Work Plan provided information on pre-landfill topography and areas of the canyon filled as a result of development of adjacent residential areas. This information assisted in locating LFG monitoring wells.
- In assessing current landfill gas migration conditions at the site, a thorough review of previous investigation reports and studies was conducted to determine LFG migration patterns, concentrations, and characteristics.
- Concerns about methane sources and origins were addressed by collecting landfill gas samples from monitoring wells and the LFG control system and analyzing for ASTM 1946 fixed gases (methane, carbon dioxide, oxygen, and nitrogen) and T.O.-15 (volatile organic compound analysis). The presence of carbon dioxide in landfill gas sources is indicative of biogenic gas. The presence of trace volatile organic compounds, particularly chlorinated hydrocarbons (from industrial chemicals), is also typical of landfill gas.
- A 36-inch storm water drain that services the residential area south of the landfill intersects the landfill and runs north to Vineyard Avenue. These types of utility systems are often constructed in trench bedding materials (sands and gravels) that can be conducive to off-site landfill gas migration and would need to be sealed off or "influenced" by LFG extraction systems.
- It is critical to assess landfill gas migration conditions prior to allowing development to occur adjacent to landfills. Assessment, characterization, and remediation of landfill gas migration problems should be a condition of development.

Case Study: Antioch-Lynch Landfill, Contra Costa County

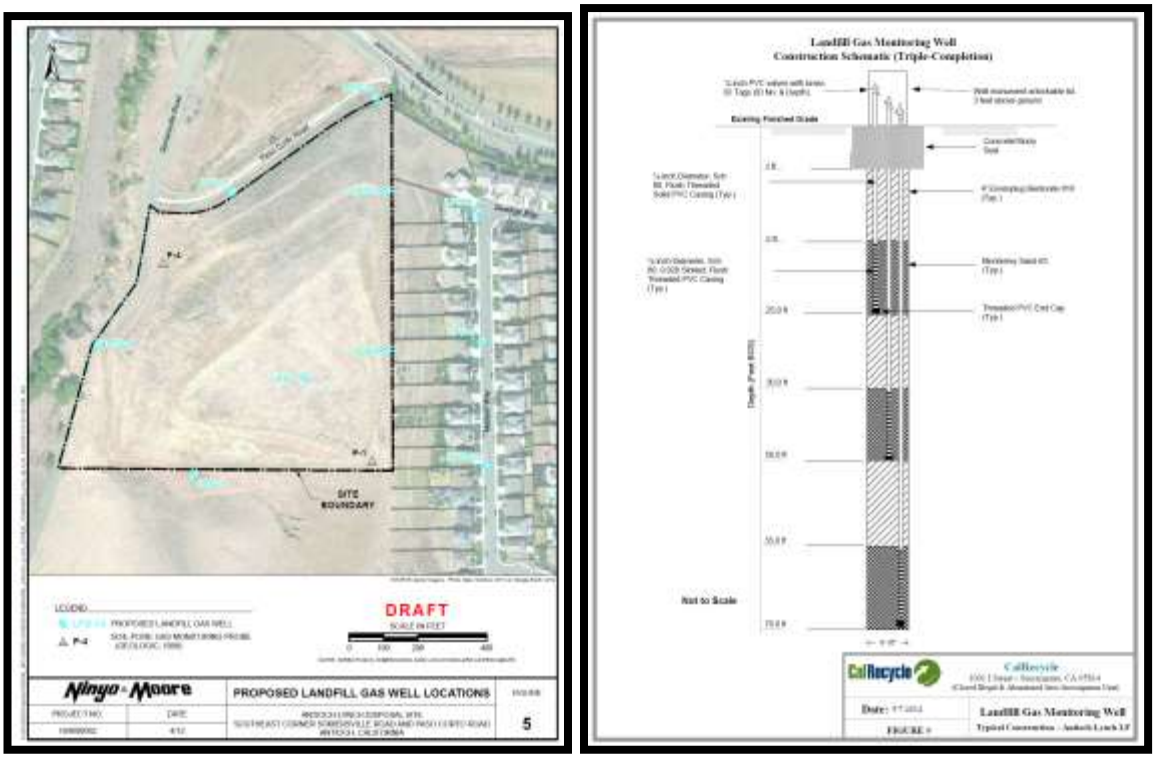


Figure 55: Landfill gas monitoring network proposed well location map – note that property line of residential parcels coincides with western boundary of the disposal area; second figure: 27 CCR 20925 compliant landfill gas monitoring well (bored, multi-level, depth of waste, multi-level, machine slotted pipe, gravel/sand-packed screen, bentonite-sealed)

Site Setting and Background

- The Antioch-Lynch Landfill is a 16-acre disposal site located in Antioch (Figure 55).
- The site was operated as a gravel mining operation from 1956 to 1964 and received waste from 1968 to 1975.
- After the site ceased operations in 1985, a developer purchased the property and began construction of a 40-home residential development.
- In 1998, the Contra Costa County Environmental Health Department requested that the developer conduct an investigation of the western perimeter of the landfill where homes were planned.
- The consultant for the developer performed a trenching investigation and was able to determine the western limits of the landfill. A proposal to install a subsurface wall at the western perimeter of the landfill was approved by the LEA; however, no landfill gas monitoring wells were installed.
- In 2004, residential homes were constructed on Mallard Way, with the back portions of the lots abutting the western perimeter of the landfill (the subsurface wall was constructed as a barrier between the landfill and the residential lots on Mallard Way).
- In 2006, the Contra Costa County LEA requested technical assistance to determine whether LFG migration was occurring.

Landfill Gas Investigation

In October 2011, a landfill gas investigation work plan was prepared and an investigation was conducted in July 2012. The investigation included the installation of six landfill gas monitoring wells around the perimeter of the disposal site (three on the east side of the landfill, one on the north side of the landfill, one on the western boundary, and one on the southern boundary), and one within the waste disposal area. Three wells were constructed outside the eastern perimeter, in the street (Mallard Way), as monitoring wells could not be installed between the homes and the perimeter of the landfill.   (Figure 55). Landfill gas monitoring was conducted monthly for a one-year period. Although low concentrations of landfill gas was detected in the monitoring well located within the waste area, perimeter monitoring wells had not detected any concentrations of LFG exceeding the 5 percent compliance threshold. A final investigation report was completed by CalRecycle in November 2012 and transmitted to the LEA in December 2012. Monthly gas monitoring has been conducted by the LEA since August 2013, and to date, none of the wells have exceeded the 5 percent rule. The well installed in the waste has concentrations of landfill gas in the 3 percent range. Gas samples have been collected and analyzed by the CalRecycle contracted laboratory, Oilfield Environmental, and the results have indicated the presence of trace volatile organic compounds. The site will continue to be inspected and monitored by the LEA on a quarterly basis to ensure that there are no threats to the residents from the landfill.

Figure 56: Photo 1: Landfill gas observation well located within the deepest portion of the waste – the bottom elevation of the boring was used to determine the design depth of perimeter monitoring wells; Landfill gas monitoring well installed in the street (Mallard Way) due to a lack of a buffer zone between homes and the boundary of the landfill.

Case Summary

- The geologic setting for the site—a mining pit excavation in a hill—made locating perimeter LFG monitoring wells difficult. Since homes were constructed on the east slope of the hill containing the landfill, wells were located in the street in front of the homes.
- The decision to locate the wells in the street were based on monitoring the permeable geologic formation that was exposed by the pit excavation.

- Although the residential lots were not placed on top of the landfill, no buffer zone had been planned into the development to allow for LFG monitoring wells between the landfill and adjacent residential lots.
- The first exploratory boring conducted in the investigation was in the deepest portion of the landfill to determine the landfill depth, which the other LFG monitoring wells would be constructed to; this initial boring was constructed as a single-completion well and is used to monitor LFG concentrations within the landfill.

<u>Case Study: City of Lodi Landfill, San Joaquin County</u>

Figure 57: Landfill gas monitoring located near the south boundary of the landfill east of the railroad tracks; monitoring wells being constructed in a residential subdivision west of the railroad tracks

<u>Site Setting and Background</u>

- The City of Lodi Landfill is a 3.7-acre landfill located on Awani Drive near the Mokelumne River and Southern Pacific railroad in Lodi.
- The site operated from the mid-1930s to the mid-1950s as a municipal disposal site and then for limited use by the city for disposal of landscape debris until the mid-1970s.
- The adjacent land was developed into residential homes in the early 1980s. Several environmental and geotechnical investigations were conducted in the 1980s to determine the extent of the landfill, characteristics of the wastes, and the feasibility of development of the site and adjacent areas for residential use.
- Geotechnical and environmental investigations (prior to residential development) indicated the presence of landfill gas.

<u>Landfill Gas Investigation</u>

In 2010, the City of Lodi submitted a plan to the LEA (San Joaquin Environmental Health Department) that proposed to develop the landfill into a kayak-access park. The LEA requested assistance from CalRecycle for the review of the City of Lodi's plans. After reviewing previous investigation reports for the site, CalRecycle recommended that an investigation be performed to determine the extent of wastes at the site (based on a review of historical aerial photographs) and that a landfill gas monitoring network be installed to evaluate whether LFG is being generated and impacting adjacent residential areas.

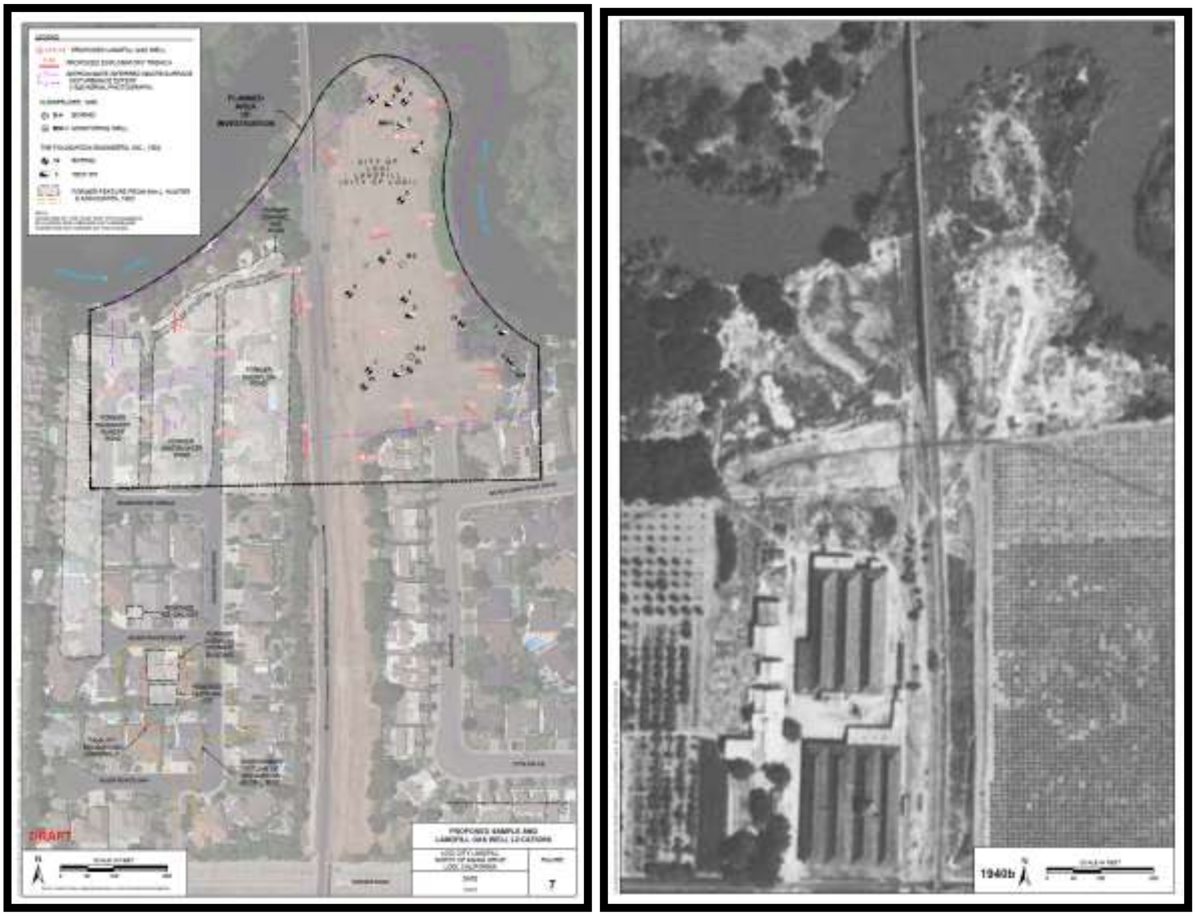


Figure 58: Landfill gas monitoring well, trench, and boring locations; 1940 historical aerial view showing the landfill west of the railroad and land disturbance east of the railroad (winery buildings are shown west of the railroad).

CalRecycle staff and consultant Ninyo & Moore initially conducted a Phase I office investigation that focused on obtaining background information pertaining to the extent of the wastes based on review of previous investigation reports and historical aerial photographs. They prepared and coordinated a field investigation work plan with the LEA, City of Lodi, and adjacent residents in February 2012.

In March 2012 a field investigation was conducted that accomplished the following:

- It evaluated the potential presence and composition of landfill gas and potential for LFG migration, and whether the site poses a threat to public health and the environment with respect to LFG.

- It evaluated waste types, locations, and thicknesses, and, to the extent possible based on site access, the potential presence of wastes at a portion of the private residential development west of the City of Lodi property.
- It provided an estimated in-place volume of wastes and evaluated the presence, characteristics, composition, and thicknesses of the landfill cover (cap) with respect to whether it meets state minimum standards for cover thickness, extent, slope, and grading/drainage.

Thirteen exploratory trenches were excavated on the City of Lodi property to obtain information about the depths, lateral extent, waste and cover thicknesses, and types of wastes at the site. Based on waste depth information, eight single completion landfill gas wells were designed and constructed on the City of Lodi property and at limited locations on residential property to the west to evaluate whether LFG is being generated, and to the extent possible, whether it is migrating off City of Lodi property. The wells were constructed in accordance with requirements of 27 CCR 20925 and as possible, were located at the waste perimeter. However, wastes extending beyond the City of Lodi property boundaries precluded the construction of some wells outside the waste perimeter.

Based on the investigation, the City of Lodi property was found to contain municipal solid wastes and burned wastes, the lateral extent generally corresponding to the entire property. Metal concentrations of burned wastes at some locations classify the materials as California and federal hazardous. However, the landfill is adequately covered and graded. The presence of 8 to 14.5 feet of wastes at the city's property boundaries indicated the likelihood that wastes extend off site and onto adjacent residential properties. Historical aerial photographs further suggest that wastes were disposed of at locations beyond the city property and the previously assumed lateral extent of the landfill.

In one year of monthly landfill gas field monitoring and quarterly sampling and analytical testing by LEA and CalRecycle staff, landfill gas concentrations exceeding 5 percent were not detected on the City of Lodi property, including locations where wells were constructed within wastes. However, elevated LFG concentrations exceeding 5 percent methane have been detected in a well in the residential subdivision to the west, on property known to have environmental contamination associated with previous site uses. The well containing greater than 5 percent methane gas was located within fill; however, wastes were not observed at that location.

Case Summary

- Extensive community outreach and coordination was conducted with adjacent property owners, as historical aerial photographs indicated that the disposal site boundaries encompassed several properties.
- Aerial photograph review suggest that wastes extended off site (City of Lodi property) and onto multiple adjacent residential properties.
- Aerial photographs indicate that wastes could also be located in the area west of the City of Lodi property, and former site uses in this area indicated previous environmental contamination other than the landfill.

- Geotechnical and environmental investigations conducted in the 1980s associated with developing the site and adjacent properties for residential use indicate that it was known prior to residential developments that the former landfill was generating landfill gas.
- The extent of wastes likely extends off site onto several residential properties but could not be delineated at the time due to limited site access.
- The depth and type of wastes were characterized, and waste depth information was used to design the landfill gas wells.
- Based on surface elevations and depth of wastes, the well probes for two offsite wells were modified so that the screened intervals would be as shallow as possible to correspond to the depth of the wastes.
- Because wastes extended off site, some LFG wells could not be located in compliance with CCR Title 27 requirements (e.g., just outlying the waste perimeter).
- Background environmental documents indicate that the residential area to the west of the City of Lodi property was the location of previous environmental contamination due to past site uses unrelated to the landfill. The types of remedial activities conducted in association with that contamination are questionable.
- VOCs in the LFG wells in the residential area west of the City of Lodi property could be attributed to the landfill and/or other contaminant sources unrelated to the landfill.

Case Study: La Veta Refuse Disposal Station, Orange County

Site Setting and Background

- La Veta Refuse Disposal Station site is located at the corner of Palmyra Avenue and S. Jennifer Lane in Orange.
- The landfill starts from the corner of La Veta Avenue and Tustin Street, extends eastward along the southeastern side of Santiago Creek, and continues beneath the Newport-Costa Mesa Freeway (California State Highway 55) into the entire area currently occupied by the YMCA of Orange facilities at the corner of Palmyra Avenue and Jennifer Lane.
- The County of Orange operated the site from 1946 to 1956. Prior to 1946, Consolidated Rock Products excavated sand and gravel from pits along the southeastern bank of Santiago Creek.
- The quantity of material that was accepted at this site was estimated to be several hundred thousand cubic yards.
- The objective of this investigation was to monitor onsite structures to determine potential methane gas intrusion through the installation of a continuous gas monitoring system.

Figure 59: Air percussion drill rig used to construct landfill gas monitoring wells; samples of waste from drilling

<u>Landfill Gas Investigation</u>

In October 2008, a work plan was prepared by CalRecycle and its consultants to address requirements to mitigate any potential human exposure to landfill gases and that concentrations of methane gas do not exceed 1.25 percent by volume in air within on-site structures. The lateral extent of waste had been confirmed through previous investigations and was found to be impacting two particular parcels: one owned by the YMCA of Orange, and a private residence at 334 S. Jennifer Lane. The work plan called for the installation of a continuous gas monitoring system to determine methane gas occurrences in onsite structures of the former La Veta Refuse Disposal Station. The investigation included the installation of methane sensors at both the YMCA of Orange located at 2241 E. Palmyra Ave. and the private residence at 334 S. Jennifer Lane.

Continuous gas monitoring systems have the advantage of being able to detect both short-term degassing events that occur in time periods lasting minutes to hours and long-term changes that occur over days to months (see Figure 60). The system installed at the La Veta site was tailored to monitor soil gases (methane) on a continuous basis. Data was collected from the sensors every few seconds and sent by radio frequency to a control station located on site. The control station in turn processed the gas data, which was then logged by a data logger. Through a dedicated telephone line, a central computer located at CalRecycle's headquarters in Sacramento was able to communicate with the control station on site to download data. The data was then analyzed and plotted to determine methane gas migration patterns within onsite structures.

The system consisted of eight methane gas sensors (catalytic technology) with a measuring range from 0 to 5 percent v/v. Sensors were installed at the two properties of concern as described in the table and figure below.

Figure 60: Infrared combustible gas sensor installed in the patio area of a residence; wireless transmitter and infrared sensor installed at the YMCA.

Continuous Gas Monitoring System (Former La Veta Refuse Disposal Station – Orange)			
Sensor ID	**Location**	**Facility**	**Contact Information**
Sensor # 1	Snack Bar	YMCA	Dolores Marikian, CEO
Sensor # 2	Kitchen	YMCA	Dolores Marikian, CEO
Sensor # 3	Main Office	YMCA	Dolores Marikian, CEO
Sensor # 4	Hall Room	YMCA	Dolores Marikian, CEO
Sensor # 5	Lower Room	YMCA	Dolores Marikian, CEO
Sensor # 6	Locker Room	YMCA	Dolores Marikian, CEO
Sensor # 7	Kitchen	334. S Jennifer Lane	Guillermo Benitez, Owner

Sensor # 8	Pool Enclosure Area	334. S Jennifer Lane	Guillermo Benitez, Owner
Location of Control Station and Data-logger			
Location #1	Phone Room/ Second Floor	YMCA	Dolores Marikian, COE

Table 2: System installation details

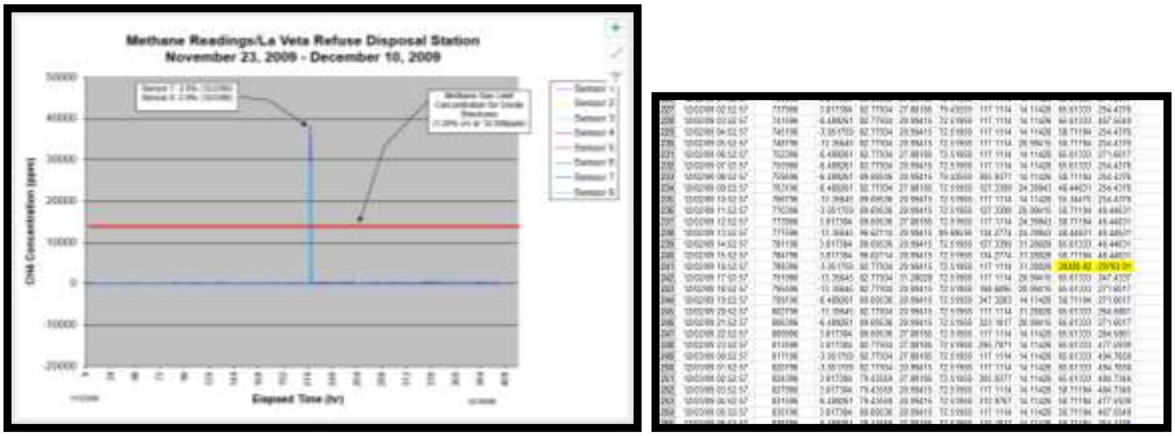


Figure 61: Landfill gas continuous monitoring data from sensors indicates an "event" (methane level exceeding 1.25 percent) in sensors 7 and 8 (344 S. Jennifer Lane) on Dec. 2, 2009, at 4:52 pm.

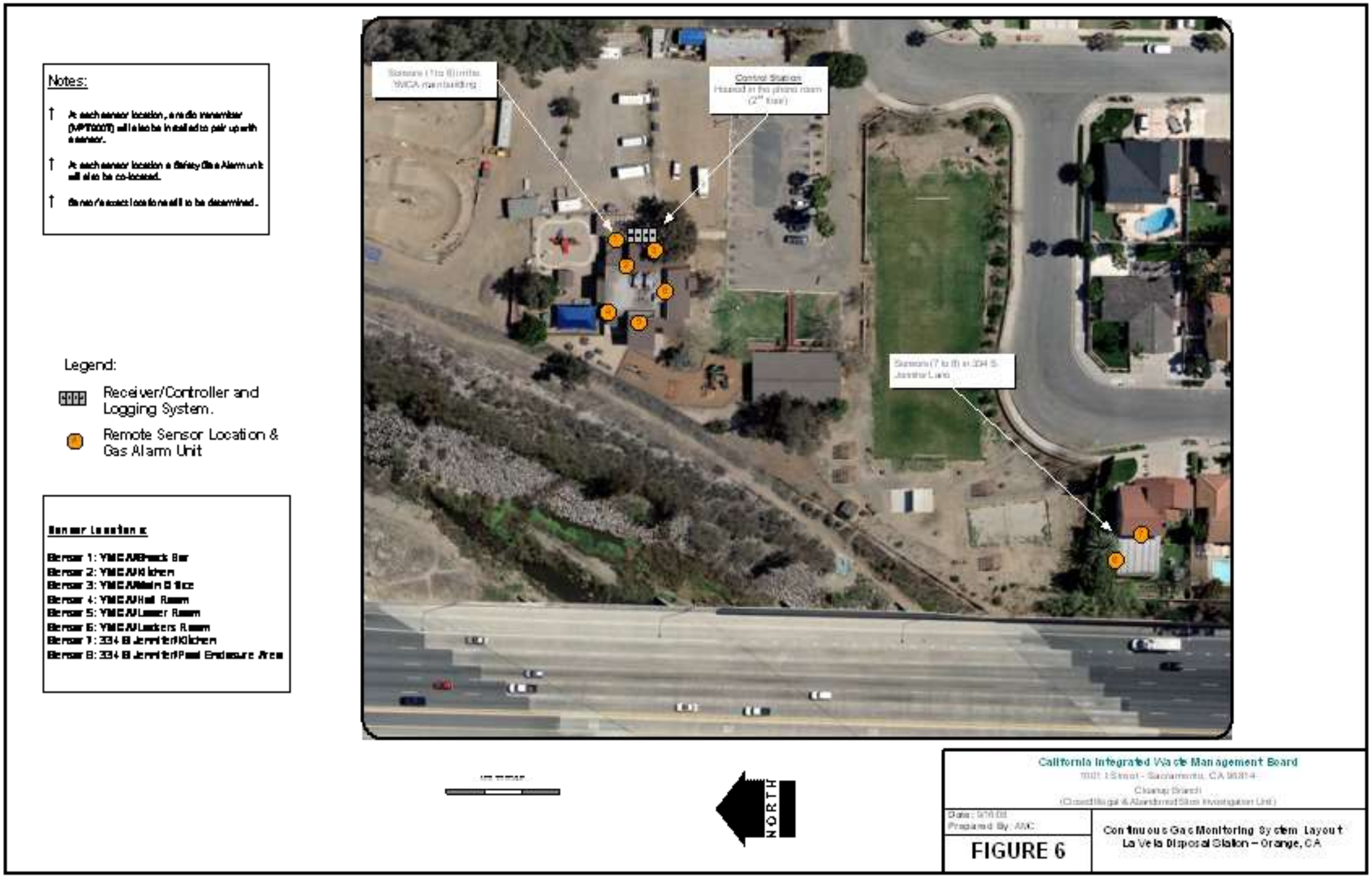


Figure 62: System Location Map

Case Summary

- The landfill gas investigation conducted by CalRecycle included the installation of a continuous gas monitoring system using combustible gas sensors, wireless transmitters and receivers, and a controller and data logger.
- The system data was downloaded by CalRecycle staff on a monthly basis, and reports were provided to the LEA and responsible parties or owners of the site.
- CalRecycle's commitment regarding operation of these systems was for one full year. At the end of 12 months, sufficient data was collected to make a determination regarding the potential for gas migration affecting on-site structures.
- After the completion of the one-year monitoring program, CalRecycle offered to loan the continuous gas monitoring system to the owners to operate and maintain. This was necessary to comply with LEA's requirements to monitor gas on-site structures.
- The owners of the site took over the operation of the system in the spring of 2010.
- During the year that CalRecycle operated the system, it was determined that a few sensors had detected high concentrations of methane gas (see Figure 60). It was then determined that the site had the potential to generate enough gas to affect on-site structures.
- Guidelines were established to respond to gas migration events and to continue with routine monitoring of onsite structures to protect public health and safety.

Case Study: Sparks-Rains Landfill, Orange County

Site Setting and Background

- Orange County Former Sparks-Rains Disposal Station No. 18 is located northeast of the intersection of Beach Boulevard and Lincoln Avenue in the City of Anaheim in Orange County.
- The site is less than 18 acres and consists of two contiguous properties: Sparks Pit (approximately 10.9 acres) and Rains Pit (approximately 6.9 acres).
- Beach Frontage and the former Anderson Pit disposal site are located west of the site.
- Lincoln Frontage is located southwest of the site. Apartment complexes are located south/southeast of the site.
- Immediately north of the site is the City of Buena Park.

The site's two pits were always owned separately. Currently, Westgate Investment Group (WIG) owns Rains Pit, while the City of Anaheim owns Sparks Pit. WIG also owns Westgate Village Apartment Complex, and the city owns Anderson Pit and Lincoln Frontage. The city is also the owner of some lots and is the long-term lessee of remainder lots along Beach Frontage.

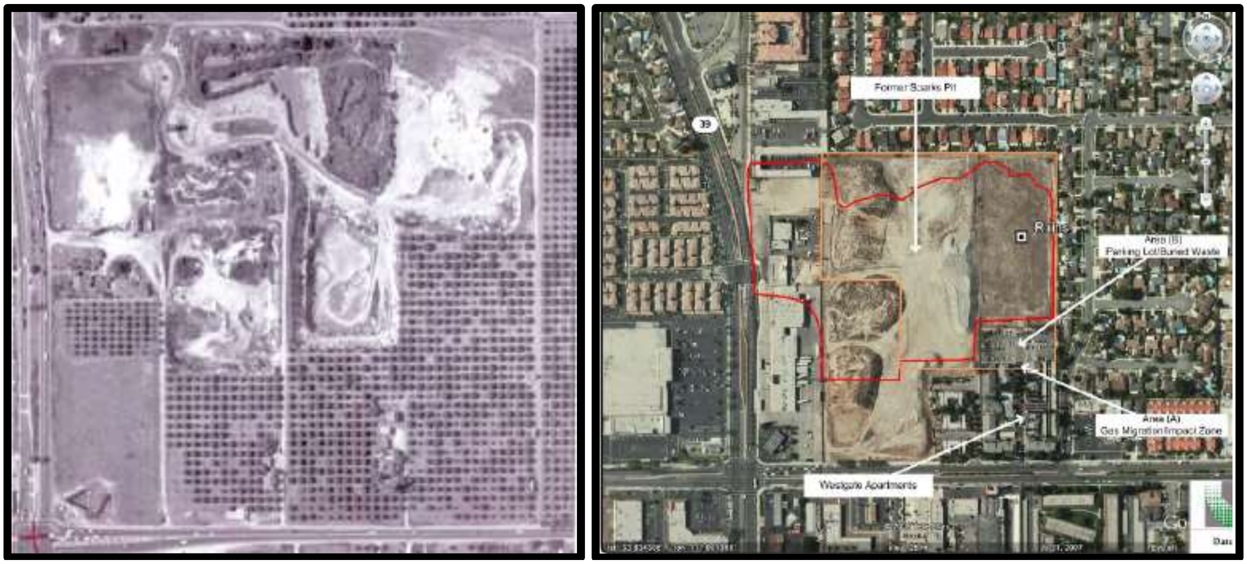


Figure 62: Sparks-Rains Landfill – 1955 historical aerial photo; current photo of site

Figure 63: Installation of landfill gas monitoring wells in Westgate Village Apartment Complex; geophysical survey of Rains Pit

Land Use
Until the mid-1950s, the site had an agricultural use (citrus orchard). Between the mid-1950s and 1958, it was mined for sand and gravel (see Figure 62). Between October 1958 and May 1960, the County of Orange leased and operated the site as one solid waste disposal station. Sparks Pit was developed into a mobile home park between 1968 and 1987. Meanwhile, all of Rains Pit was open space until 1978, when the southern portion was developed into the Richmont Apartments (currently known as Westgate Village Apartments).

As of 2014, all of Sparks Pit and the majority of Rains Pit are open space (see Figure 62). Lincoln Frontage, Westgate Village Apartments, and Lido Apartments are located immediately south of the site. There is very little clean fill/native soil buffer zone between the buildings and the edge of the waste. A small southern portion of Rains Pit is overlain by the parking lot of Westgate Village Apartment Complex. Single-family dwellings are located immediately north and east of the site. Beach Frontage, Lincoln Frontage, and the former Anderson Pit disposal site are all open space as of 2014.

For more than a decade, the city had plans to develop Sparks Pit, the former Anderson Pit disposal site, Lincoln Frontage, and Beach Frontage into a commercial retail shopping center as part of the overall West Anaheim Commercial Corridors Redevelopment Plan. Further, in 2013, WIG submitted an application to city's planning department for phased development of the open space portion of Rains Pit into a self-storage facility for shipping containers and RVs. As of 2014, however, the site remains open space, with the exception of Rains Pit's southern portion.

Disposal History
Between 1958 and 1960, the County of Orange leased the two pits from the Sparks and Rains families and operated them as one disposal facility. County records indicate approximately 500,000 cubic yards of municipal solid waste (MSW) and construction and demolition (C&D) waste was disposed of there. Filling operations began in the eastern portion of the site and progressed in a westerly direction.

According to county's 1958 disposal plan, the gravel pit bottoms were to be filled with inert waste up to elevation 60 feet above mean sea level. Above this elevation, the pits were filled with MSW. Waste thickness, based on historical records and field investigations, ranged from 15 to 30 feet below ground surface with a maximum of approximately 30 feet near the center of each pit. Final cover reportedly consisted of 3 feet of soil cover, bringing the final elevation to 86 feet above mean sea level.

The southern portion of Rains Pit, which had a minimal average of 4 feet of buried waste, was excavated in the 1970s to facilitate construction of the Richmont Apartments.

Lessons Learned

- Consistent with CalRecycle's point paper on enforcing state minimum standards (SMS) at pre-regulation subdivided landfills (CIA sites), all current site owner(s) of a former solid waste disposal are held jointly responsible for compliance with all pertinent state regulations, such as those pertaining to landfill gas.

- If there is evidence of off-site migration, one landfill gas migration control system should be constructed for the entire site when warranted, even if the site has been subdivided among multiple owners. Further, the monolithic LFG migration control system should be operated and maintained by one contractor retained by and agreed upon by all site owner(s). Such contractor should be well versed in the operation and maintenance of similar mechanical systems.
- Many factors can affect the outcome of development projects at former disposal sites, such as current economic or market conditions, community acceptance or opposition, regulatory requirements, etc. Such factors can cause significant delays or otherwise create conditions that can render a for-profit project such as a commercial or residential development infeasible. For such developments, the LEA should not agree to tie any aspects of pertinent SMS enforcement (e.g. site assessment for LFG migration, construction of LFG migration control system, etc.) to progress made or milestones achieved for the proposed development project. Compliance with SMS and progress in for-profit development projects at a former disposal site should be on two separate and independent tracks. The LEA, however, can be more flexible by including SMS enforcement as a condition of development if the proposed project is recreational or non-sensitive in nature (such as a community park), or if the former disposal site was privately owned and abandoned, resulting in very limited financial resources, if any, to fund remedial work.
- Several years may elapse between the time when development plans are initially approved by the LEA and other involved regulatory agencies and when the project is finally constructed. During this time, the scope (i.e. nature and extent) of the development may change. Therefore, it is important for the LEA to be involved throughout the process, as authorized by state statutes and regulations, to ensure the final version of the development project is in agreement with what was previously approved.
- When drafting an enforcement order, the LEA should seek the advice of its legal counsel and consult with CalRecycle. This is to ensure the reason(s) cited and directive(s) given in the enforcement order are justified. Further, should site owner(s) decide to appeal a well prepared enforcement order, it is more likely that the LEA would prevail.
- If the enforcement order is appealed by the responsible party, the LEA should adhere to established procedures in the PRC for handling appeals. The LEA should avoid extended and/or open-ended postponements of the appeal process, as such delays can have unintended negative consequences.
- If there is minimal native soil between buried waste and disposal site boundaries, it is more likely that methane from landfill gas exceeding the regulatory 5 percent limit will be detected in a perimeter probe and prove difficult to remediate. The LFG design consultant should always have contingency plans in advance for such a scenario. Also, it is advisable, under such a scenario, to limit the amount of vacuum applied by the field instrument when purging and collecting gas a sample from probe casing during a monitoring event. High vacuum by field instruments (e.g. GEM 2000), especially if applied for a prolonged period of time to a probe casings, may exacerbate elevated levels of methane detected.

- The LEA should not get involved in disagreements among owners of a subdivided former disposal site over financial responsibility for compliance with pertinent state minimum standards such as the costs of probe monitoring and regulatory reporting, construction of a new LFG remedial system, upgrade or expansion of an existing landfill gas remedial system, operation and maintenance of the system, etc.

Abbreviations and Acronyms

CCR – California Code of Regulations

LFG – Landfill Gas

PRC – Public Resources Code

T.O.-15 – Environmental Protection Agency (EPA) Gas Test for Volatile Organic Compounds

T.O.-3 – Environmental Protection Agency (EPA) Gas Test for Ethane, Butane, Propane, Pentane

ASTM 1945/1946 – American Society of Testing & Materials Method 1945/1946 for Fixed Gases to include Methane, Carbon Dioxide, Nitrogen and Oxygen

EPA – Environmental Protection Agency

LEA – Local Enforcement Agency

DRRR – Department of Resources Recovery and Recycling

CIA – Closed, Illegal and Abandoned Sites

SWIS – Solid Waste Information System

AQMD – Air Quality Management District

RWQCB – Regional Water Quality Control Board

DTSC – Department of Toxic Substances Control

CSM – Conceptual Site Model

COPC – Constituent of Potential Concern

SWAT – Solid Waste Assessment Testing (Water & Air)

PLC – Programmable Logic Control

IR – Infrared (Sensor)

LEL – Lower Explosive Limit

UEL - Upper Explosive Limit

CGI – Combustible Gas Indicator

FID – Flame Ionization Detector

PID – Photoionization Detector

PVC – Polyvinyl Chloride (Pipe)

HDPE – High Density Polyethylene (Pipe)

USA – Underground Service Alert

HSA – Hollow-Stem Auger

DP – Direct Push

SV- Soil Vapor

GP – Gas Probe

S – Shallow Well

M – Medium Depth Well

D – Deep Well

COC – Chain of Custody

QA/QC – Quality Assurance/Quality Control (Data, Sample)

VOC – Volatile Organic Compound

Glossary of Terms

27 California Code of Regulations (CCR) – State of California laws that pertain to the protection of public health and safety and the environment from the disposal of solid waste.

Air curtain – A landfill gas control remedial measure that injects pressurized air into permeable soil formations adjacent to landfill disposal areas to create a positive pressure zone that restricts the movement of landfill gas through the zone. For this measure to be effective, the entire zone must be under continuous pressure to prevent LFG migration through the zone.

Air rotary drill rig – A heavy, diesel-powered vehicle with a derrick that uses compressed air to push drilling spoils from the boring. The method uses an impact hammer that impacts the rotating drill bit and allows the drilling column to penetrate difficult geologic formations such as cobbles, mudstone, sandstone, etc.

Air solid waste assessment testing (SWAT) – A regulatory program implemented by the Air Resources Board in the late 1980s to determine gas emissions and migration characteristics of selected landfills and disposal sites in California. The testing included surface monitoring using an organic vapor analyzer or photoionization detector; integrated surface sampling using a composite air sampler; and installation and monitoring of probes to determine subsurface landfill gas concentrations. Air SWAT reports were prepared and kept on file by air quality management districts, local enforcement agencies, and CalRecycle.

Annulus space – The gap between the boring wall and probe casing. The annulus space is generally filled with permeable materials (Monterey sand or pea gravel) in screened zones and impermeable materials (bentonite) in sealed intervals between monitored compartments.

ASTM 1946 – American Society of Testing and Materials test method for analyzing fixed gas compounds such as methane, carbon dioxide, oxygen, and nitrogen.

As-built (drawing) – An engineering and construction document that graphically depicts the constructed work along with notes and specifications on how the “work” was constructed. For landfill gas monitoring wells, the as-built construction drawing is generally a drawing depicting the well diameter and depth, probe length, screen length and locations, bentonite seal length and locations, well head construction details, and notes and specifications for materials used. Generally, the drawing is stamped by a registered geologist or civil engineer and labeled or stamped “As-Built.”

Bentonite – A natural clay material that is manufactured into pellets that can be poured into a boring's annular space and hydrated with water to seal the well casing between monitoring compartments.

Blank casing – A 10-foot section of Schedule 80 PVC pipe that comes from the factory with no perforations in the pipe wall.

Boring log – The recorded field documentation of subsurface geologic, hydrologic, and fill conditions occurring during the drilling of monitoring wells; the logs generally include the classification of soils and rock, depths of formations and fill, and presence and depth of ground water. Logs may also note the presence of landfill gas or organic vapors taken by an instrument monitoring the boring opening.

Catalytic bead sensor – A bi-metallic, temperature-sensitive element used for detecting combustible gas. The element is used in a "Wheatstone bridge" circuit to detect changes in electrical resistance based on changes in temperature when the element is exposed to combustible gas.

Closed, Illegal and Abandoned Disposal Site (pre-regulation site) – Classification of pre-regulation disposal sites that are managed under the CalRecycle Closed, Illegal and Abandoned Sites program.

Combustible gas – A gas that when mixed with air exhibits explosive characteristics between a lower and upper explosive limit. For example, methane has an explosive range between 5 and 15 percent concentration by volume in air.

Combustible gas indicator (CGI) – An electronic handheld instrument used to detect concentrations of combustible gas, oxygen, carbon dioxide, and other specified gases, e.g. hydrogen sulfide, carbon monoxide, etc. A CGI is generally used for health and safety monitoring to determine whether an explosion hazard exists, e.g. concentration between 5 percent (low explosive limit or LEL) and 15 percent (upper explosive limit – UEL) for combustible gas.

Continuous monitoring for landfill gas – The measurement of gas concentrations at specified locations over a specified period of time using fixed gas detection equipment capable of collecting and logging gas concentration data from deployed combustible gas detection sensors.

Depth of waste – The elevation difference between the ground surface and the lowest elevation within the waste disposal area. Depth of waste should not be confused with the thickness of waste, which is measured from the highest waste elevation, e.g. top-deck, to the lowest waste elevation (bottom of waste elevation). See Figure A.

(Technical Illustration by Glenn K. Young)

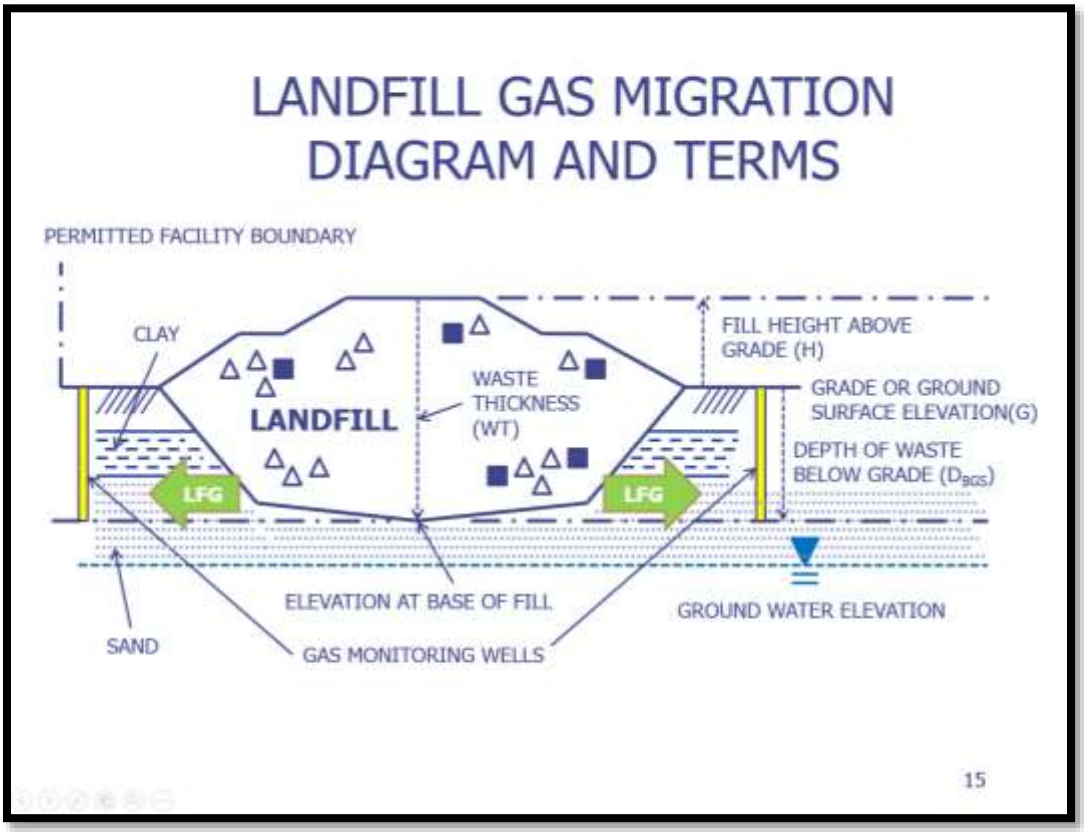


Figure A

Fixed gases – Atmospheric chemical compounds to include methane, carbon dioxide, nitrogen, and oxygen; American Standard for Testing and Materials (ASTM) Method 1946 provides procedures for analyzing gas samples for fixed gases.

Fixed gas detection system – Industrial electronic equipment (industrial instruments and controls) used to detect the concentration of toxic, flammable, or explosive gases in specified locations for a period of time, collect and log sensor data and trip audible alarms, and provide notification or actuate environmental control systems (ventilation, fire suppression, etc.). See Figure B.

(Technical Diagram by Glenn K. Young)

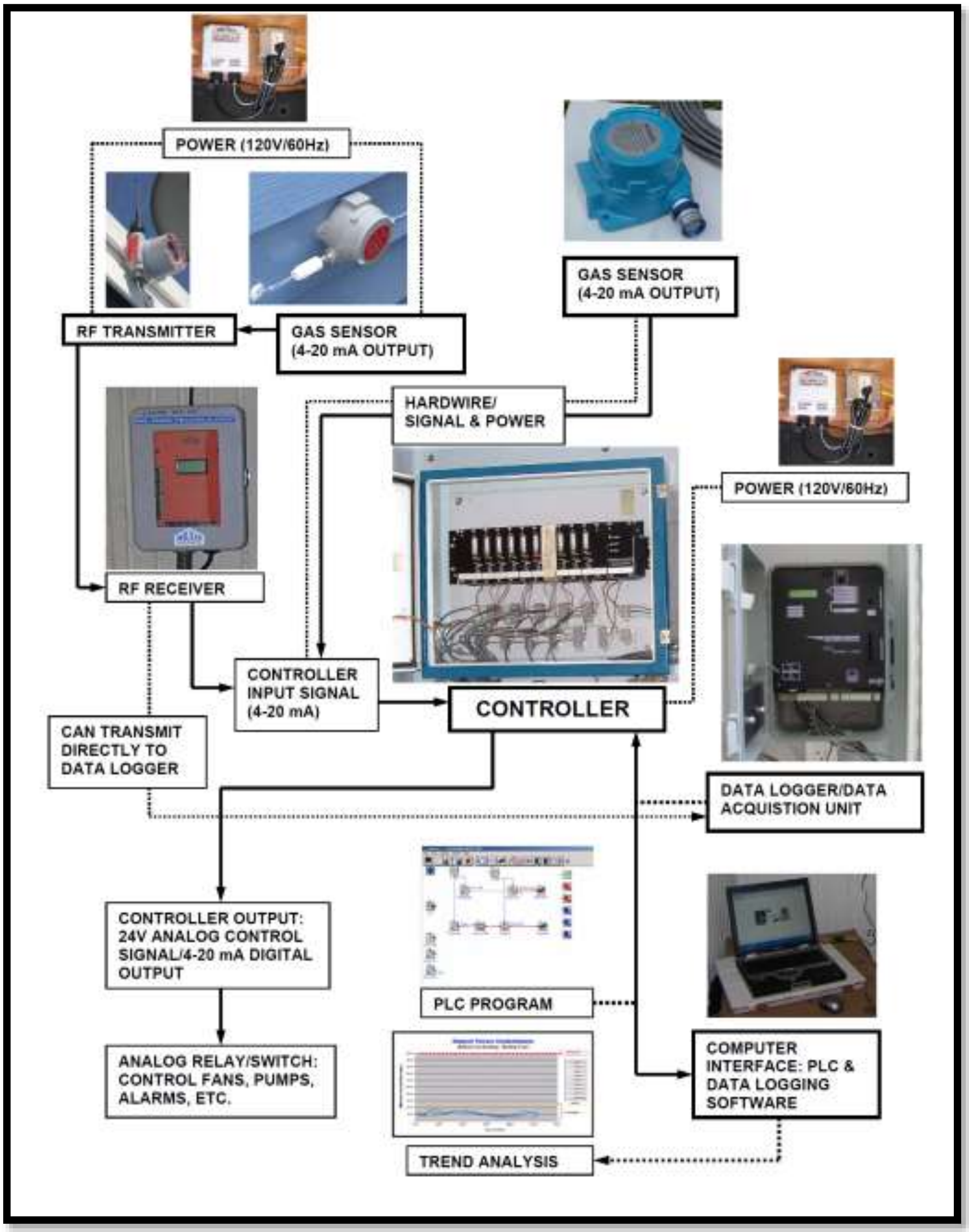


Figure B

Former landfill or disposal site (pre-regulation site) – Landfill or disposal site that was operated prior to the enactment of landfill permitting and closure regulations (1989).

Gas diffusion – The physical/chemical principle of gas movement due to molecular-level displacement that occurs when gas disperses from higher concentrations to lower concentrations, versus fluid movement governed by Darcy's Law.

Gas sampling train – A conveyance system (tubing or piping) with interconnected components, e.g. instruments (pressure gage) and valves, designed to allow gas characteristics to be monitored and sampled from landfill gas monitoring wells. See Figure C.

(Technical Diagram by Glenn K. Young)

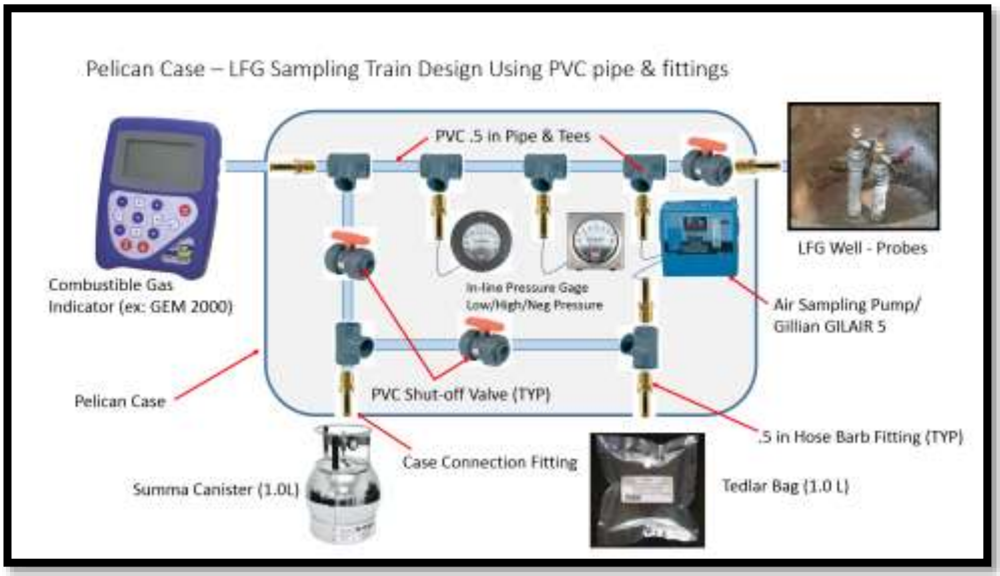


Figure C

Hollow-stem auger (HSA) drill rig – A heavy, diesel-powered vehicle with a derrick and hydraulic system that drives a rotating auger that is used to penetrate subsurface geologic formations for the purpose of obtaining geologic samples and installing monitoring wells. A hollow-stem auger is used when it is necessary to obtain undisturbed geologic/waste fill samples and install wells with casings. The use of an HSA rig depends on the soil types, geology, and depth of the boring, but it is generally the most commonly used drilling equipment in performing environmental field investigations.

Impacted structures – Any buildings, residences, subsurface vaults, basements, or utility corridors or other inhabitable confined spaces where migrating landfill gas may accumulate and cause explosive or oxygen-deficient conditions.

Infrared sensor – A physical method (optical/wavelength) for detecting combustible gas using known chemical and physical properties of the target gas to determine the composition and concentration of the gas.

Landfill gas – Gas generated by the decomposition of landfilled waste through methanogenesis (byproducts from the processing of organics in the waste by micro-organisms).

Landfill gas control/collection system – A mechanical system, consisting of a flare or carbon filters, blower, controls, piping network, condensate collection system, and extraction wells that is used to collect landfill gas to prevent off-site migration and minimize fugitive emissions through the cover. See Figure D.

(Technical Illustration by Glenn K. Young)

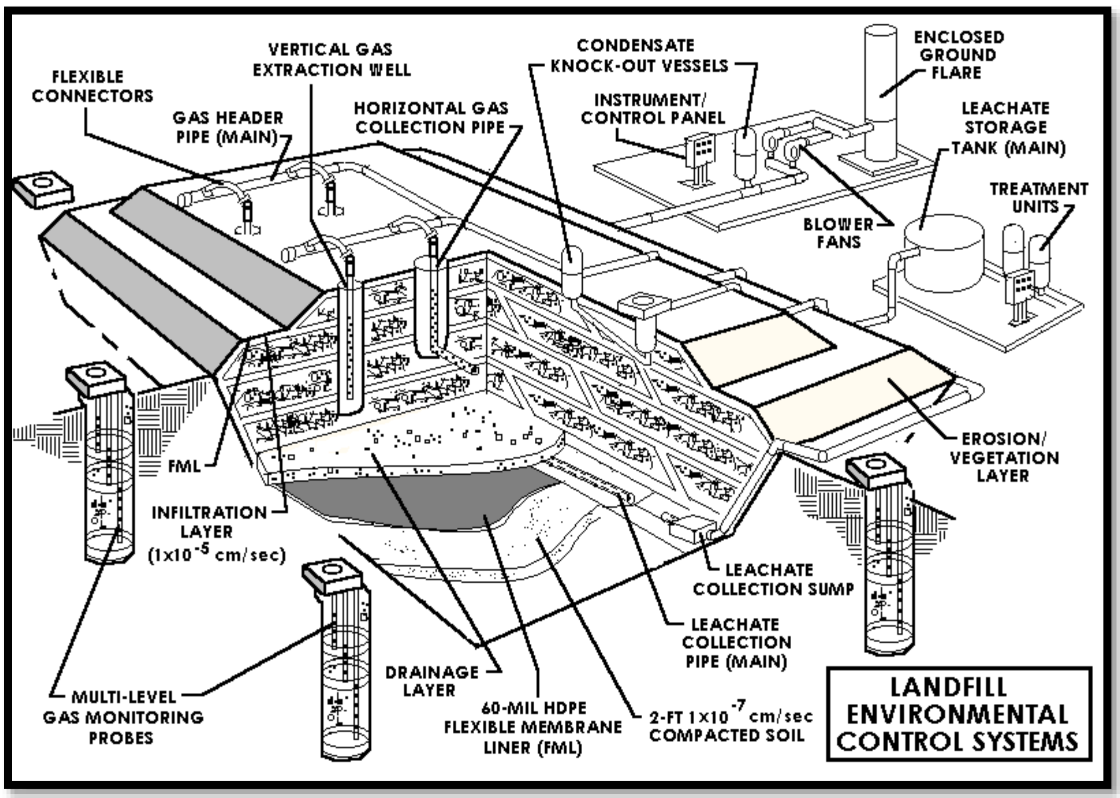


Figure D

Landfill gas extraction well – Either a horizontal well laid within a gravel-filled trench or a vertical well that is bored within the waste prism to two-thirds of the depth of the landfill and used to collect gas by applying a vacuum to the well and drawing gas into a blower and flare station for treatment and discharge. See Figure D.

Landfill gas migration – The movement of landfill decomposition gases through permeable geologic formations or man-made pathways due to pressure gradients or diffusion. See Figure E.

(Technical Illustration by Glenn K. Young)

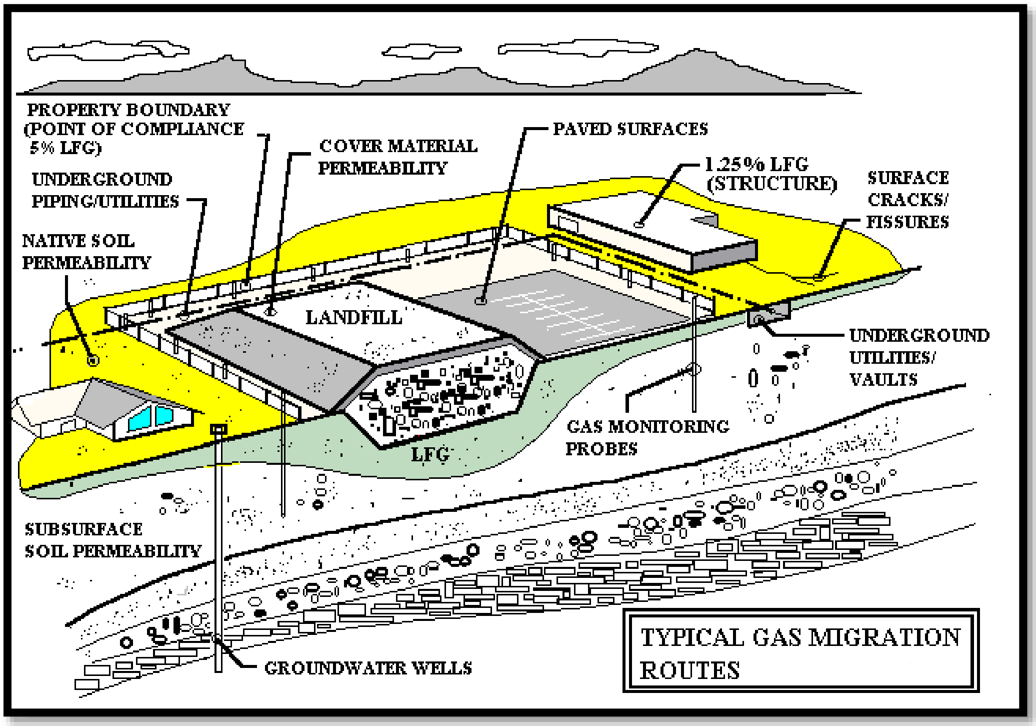


Figure E

Landfill gas monitoring – The electronic measurement of concentrations of landfill gas in monitoring wells, enclosed structures, utility corridors, or other locations near a landfill where accumulated landfill gas may pose an explosion or asphyxiation hazard.

Landfill gas monitoring probe – A machine-slotted (screen) plastic pipe (generally ½-inch diameter Schedule 80 PVC pipe) that is placed within a landfill gas monitoring well boring and filled in its annular space with pea gravel or Monterey sand and sealed with bentonite (annular space above and below screened interval) to prevent migration of landfill gas to adjacent monitoring compartments. See Figure F.

Landfill gas monitoring well – A constructed subsurface boring that is used to detect perimeter landfill gas migration. The well is constructed in native soils adjacent to a landfill; bored to the depth of landfilled waste; constructed with single or multiple probes depending on depth; screened in geologic formations that are permeable to landfill gas migration; sealed between screened intervals using bentonite; and completed with a well-head that consists of lab cock valves with hose-barb fittings and tags to allow instrument screening and sample collection. See Figure F.

(Technical Illustration by Glenn K. Young)

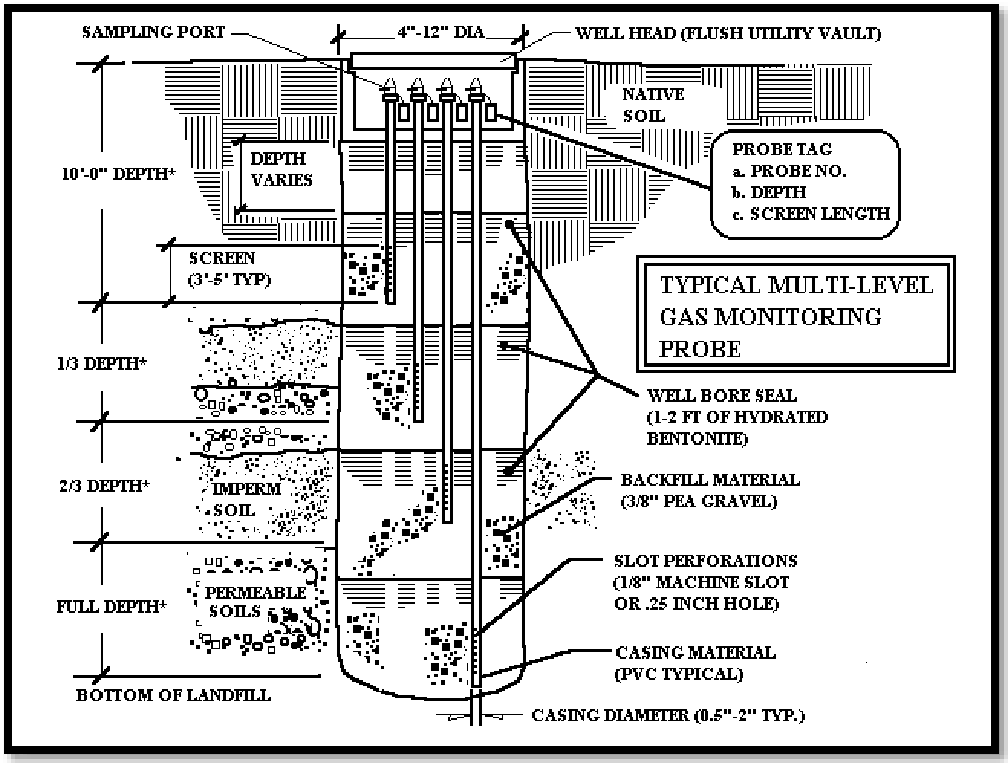


Figure F

Landfill gas monitoring well network – A series of equally spaced (1,000 feet minimum) constructed subsurface borings around a landfill perimeter designed to detect off-site migration of landfill gas in permeable geologic formations surrounding the landfill. See Figures D and F.

Landfill gas sampling – The collection of soil vapor gas or landfill gas from monitoring probes or other prescribed sampling points (structures, utilities, etc.) using gas sampling containers such as Tedlar bags or Summa canisters for the purpose of obtaining laboratory analysis, e.g. ASTM 1946 fixed gases, T.O.-15 (VOCs), T.O.-3.

Landfill gas source identification (fingerprinting) – Determination of methane gas origin using known chemical compositions of various sources of methane, e.g. landfills, swamps, bogs, pipelines, oil fields, etc. Generally, landfill gas contains trace volatile organic compounds (VOCs) associated with municipal waste; landfill gas also contains both methane and carbon dioxide. Analyzing for VOCs (T.O.-15) and fixed gases (ASTM 1946) can identify typical chemical properties of landfill gas.

LFG monitoring well construction as-built – A document providing a graphical representation and notes for a constructed landfill gas monitoring well.

Lithology/lithological – A description of physical characteristics of subsurface geologic formations and fill, e.g. rock unit (sandstone, shale, granite) or deposits (alluvium).

Lower explosive limit (LEL) – The minimum concentration of a combustible gas required to cause an explosion in the presence of an ignition source. For methane gas, this is 5 percent by volume in air.

Machine-slotted pipe – A 10-foot section of Schedule 80 PVC pipe that comes from the factory with a mechanically perforated pipe wall.

Magnahelic gage – A mechanical instrument used to measure pressure. The Magnahelic gage can measure high- and low-pressure ranges including positive and negative pressures (vacuum). Pressure units are generally in inches of water column or pounds per square inch.

Mud-rotary drill rig – A heavy, diesel-powered vehicle with a derrick that uses hollow drilling bits to penetrate into subsurface formations and pumps mud slurry (bentonite, barium, and drilling muds) into the bottom of the boring to cool the drill bit and push drilling spoils out of the boring cavity (through the annulus space).

Non-methane organic compound (NMOC) – A term used by the Air Resources Board to define organic chemical constituents other than methane present in landfill gas. Generally NMOCs refer to volatile organic compounds (or VOCs). They are also referred to as trace or toxic gases by CalRecycle regulations.

Off-site migration – The subsurface movement of landfill gas from the disposal site area onto adjacent properties (in subsurface geologic formations or manmade pathways). See Figure E.

Passive venting – A landfill gas control measure that allows methane to be vented directly to the atmosphere by establishing preferential pathways (vent piping into waste, gravel-filled perimeter trenches with vent pipe, permeable gravel layers in caps, foundations with vent pipes, etc.) from the disposal area to atmospheric conditions.

Perimeter migration – The movement of landfill gas at the boundary interface (through pressure gradient or diffusion mechanisms) of the landfill and adjacent geologic formations. See Figure E.

Perimeter migration control – A landfill gas control remedial measure that establishes a pressure zone of influence or subsurface barrier at the landfill boundary to prevent the migration of landfill gas into adjacent subsurface geologic formations and man-made pathways.

Petro-genic/bio-genic source of gas – The identification of methane sources based on laboratory analysis of gas samples for chemical composition and makeup and corresponding determination of similarities to other sources of methane. Methane can be produced from biogenic processes such as methanogenesis within a landfill or be commingled with petrogenic or naturally occurring gases such as ethane, propane, pentane, etc. Another potential source of methane is pipeline gas, which could be from a leaking natural gas line (generally these gases have a marker gas or mercaptans that allow them to be tracked by their odor).

Pressure gradient – The movement of gas between areas of high pressure to areas of low pressure. If landfill gas is being generated at pressure greater than surrounding geologic formation pressure or atmospheric pressure, then landfill gas will migrate laterally into areas of lower pressure or vent through the cover (provided the cover is permeable to gas).

Programmable logic control (PLC) – A computer program with graphical interface that is used to manipulate components of an industrial control system; PLC software allows a user to program an electro-mechanical control system to collect data from sensors and use the data to control system components, such as relays, pumps, and alarms. See Figure B.

Post-closure land-use development – Existing or proposed residential, commercial or industrial use of a landfill or disposal site.

Subsurface barrier – A landfill gas control remedial measure that uses a constructed perimeter barrier trench with a low-permeability geosynthetic plastic liner (60-80 mil high-density polyethylene) or bentonite slurry mix to create an impermeable zone that acts as a barrier to migrating landfill gas.

Screened interval/section – The location down-hole along the monitoring probe that contains perforations or openings in the pipe where landfill gas can migrate from surrounding soils into the well. See Figure F

Structure monitoring – The requirement (27 CCR 20931) to determine whether landfill gas is migrating into inhabitable enclosed spaces in concentrations that create an explosion hazard (>5% methane by volume) or asphyxiation hazard (<19% oxygen by volume) or other threat to public health and safety (toxic trace gases or volatile organic compounds).

Summa canister – A stainless steel pressure vessel that is placed under a vacuum (negative pressure) and is used to collect gas samples by connecting the canister to a sampling source and opening the canister valve to allow gases to flow from the sampling source into the canister. The canister is generally equipped with a pressure gage to indicate vacuum (or loss of vacuum) in the container. A rotameter or other flow measurement device in the sampling train connecting the sampling source to the canister can be used to determine the volume of sample collected. See Figure C.

Tedlar bag – A flexible, inflatable plastic sampling container with a valve used to collect gas samples under pressure; a pneumatic (air) or perastaltic pump is used to collect gas samples from a landfill gas monitoring well and fill a Tedlar sampling bag under pressure. "Tedlar" is a Dupont trade name for the specified plastic used to manufacture the bags. See Figure C.

Topographic map – A document that provides a graphic depiction of the Earth's surface at specified locations, which shows features including latitude and longitude, elevations, bodies of water, terrain patterns, buildings, and roads.

T.O.-15 – A USEPA testing method used to analyze gas samples collected in Summa canisters for concentrations of volatile organic compounds (also referred to as "trace gases" and non-methane organic compounds)**.**

Upper explosive limit (UEL) – The maximum concentration of combustible gas (in air) that will cause an explosion in the presence of an ignition source. Above the UEL, the combustible gas concentrations are considered "fuel-rich" and no longer in the explosive range. For methane, the upper explosive limit is 15 percent by volume in air.

Waste extents (horizontal and vertical extents of waste) – The areal (horizontal) location and depth of waste (vertical) of a waste disposal site, generally determined through a Phase I Office and Phase II Field investigation.

Well-bore seal – The placement of a non-permeable material (such as bentonite) in the annular space of a monitoring well boring and probe casing to prevent the migration of landfill gas between monitoring compartments within the well. See Figure F.

Wireless transmitter (4-20mA signal) – An electrical/radio frequency device that transmits 4-20 milliamp sensor measurements from a sensor, e.g. combustible gas sensor by radio frequency to a receiver that receives, processes, and stores the measurement data in electronic memory. See Figure B.

Zone of influence – The effective volume of space around a landfill gas extraction well where a specified (minimal) negative pressure is maintained to collect and control landfill gas.

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