FULL SCALE LANDFILL BIOREACTOR PROJECT AT THE YOLO COUNTY CENTRAL LANDFILL

Final Report

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ABSTRACT

The Yolo County Department of Planning and Public Works is constructing a full-scale bioreactor landfill as a part of the Environmental Protection Agency's (EPA) Project XL program to develop innovative approaches while providing superior environmental protection. The overall objective is to manage landfill solid waste for rapid waste decomposition, maximum landfill gas generation and capture, and minimum long-term environmental consequences. Waste decomposition is accelerated by improving conditions for either the aerobic or anaerobic biological processes and involves circulating controlled quantities of liquid (leachate, groundwater, gray water, etc.), and, in the aerobic process, large volumes of air.

The first phase of the project entails the construction of a 12-acre module that contains a 6-acre anaerobic cell, a 3.5-acre anaerobic cell, and a 2.5-acre aerobic cell at the Yolo County Central Landfill near Davis, California. The cells are highly instrumented to monitor bioreactor performance. Construction is complete on the 3.5 acre anaerobic cell and liquid addition has commenced. Construction of the 2.5 acre aerobic cell is nearly complete with only the blower station and biofilter remaining. Waste placement and instrumentation installation is ongoing in the west-side 6-acre anaerobic cell. The current project status and preliminary monitoring results are summarized in this report.

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ACKNOWLEDGMENTS

The costs of the Yolo County Full-Scale Landfill Bioreactor Project are shared under repayable research contracts from the California Integrated Waste Management Board (CIWMB), National Energy Technology Laboratory (NETL), and the Western Regional Biomass Energy Program((WRBEP). The continued support provided by the CIWMB Contract Manager, Scott Walker is greatly appreciated.

The assistance of John Pacey and the Solid Waste Association of North America and Don Augenstein of the Institute for Environmental Management (IEM) in developing and co-sponsoring Yolo Counties application and subsequent selection for the EPA XL Program. Both Don and John also provided valuable technical guidance and advice during the design and planning phase of the project.

Each of the agencies and organization that assisted and signed the EPA XL agreement, including, the U.S, Environmental Protection Agency and in particular the Mark Samolis and his staff from Region 9, Yolo County, the California Regional Water Quality Control Board, The State Water Quality Control Board, the Yolo-Solano Air Quality Management District, the California Air Resources Board, the Solid Waste Association of North America, and the Institute for Environmental Management. Without the regulatory flexibility made possible by the EPA XL Program, this project would not have been possible.

The work of the consultants and contractors was invaluable. Scott Purdey and Todd Ramey of Vector Engineering and Rick Thiel of Theil Engineering for the expedited design of the aerobic base liner and anaerobic bioreactor surface liner. Richard L. Vogler and Sharon M. Kimizuka of ATEEM Electrical for the SCADA data acquisition and control system. Benjamin & Tim Geerts and the rest of the construction crew of B & D Geerts General Contractors for their assistance and patience in installing the various components of the monitoring and piping systems. John Glitch and Ed Parker of Colorado Lining for the installation of the anaerobic surface liner, gas collection system, and leachate injection system.

The ongoing support of the Yolo County Board of Supervisors has been essential to the success of the project.

The success of the Project to date is due, in large part, to the dedication, hard work, and creativity of all Yolo County staff members, from the scalehouse attendants who tracked the amount of waste to the Director who supported the concept of research into superior landfilling technologies.

Finally, I would like to thank everyone else who has contributed to this project and has not been mentioned above.

1 EXECUTIVE SUMMARY

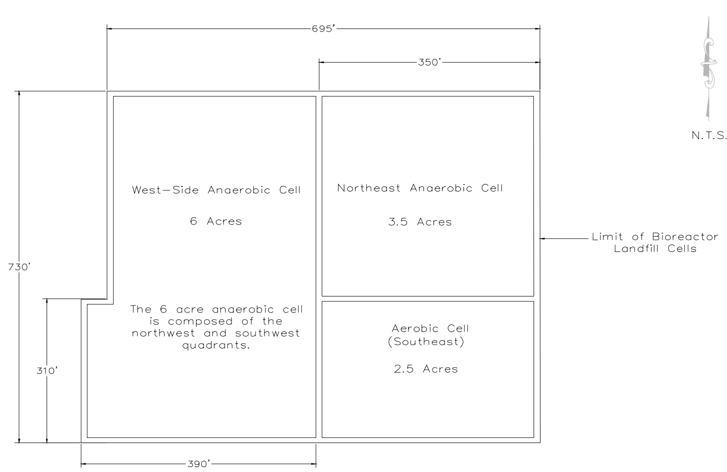
In 1996, Yolo County began operation of a pilot-scale project to evaluate the costs and benefits a relatively new concept in landfill operation, often termed “bioreactor” or “enhanced” landfilling. The basic concept of a bioreactor landfill is to increase the biological activity of the waste (through the addition of waster) to maximize the production of landfill gas, increase the amount of waste settlement, and create a stabilized environmentally benign end product. The results of this pilot project were favorable and, as a result, Yolo County requested and gained approval from state and federal regulatory agencies to conduct this full-scale demonstration of bioreactor landfilling.

This full-scale demonstration project will evaluate two different forms of enhanced landfilling techniques. The first is a direct extension of the previous pilot-scale project where conditions were optimized for anaerobic decomposition. A second, even newer, technology will be evaluated whereby conditions will be optimized for aerobic decomposition.

Because current Federal and California State regulations generally do not allow the addition (or recirculation) of leachate and other supplemental liquid to a lined landfill module, special regulatory flexibility was required to conduct this project. Yolo County applied for, and was granted the necessary flexibility through the Unites States Environmental Protection Agency XL Program which stands for "eXcellence and Leadership.” The XL program is allows state and local governments, businesses and federal facilities to develop with EPA innovative strategies to test better or more cost-effective ways of achieving environmental and public health protection.

1.1 SUMMARY OF CURRENT PROJECT STATUS

The configuration of the project bioreactor cells separates the northeast quadrant from the northwest and southwest quadrants, resulting in 3 separate landfill cells, two cells will be operated anaerobically and one aerobically (Detail 1). We have designated the three bioreactor cells as the west-side anaerobic cell, the northeast anaerobic cell, and the aerobic cell. This configuration allows the northeast anaerobic cell to be constructed and operation of the bioreactor to begin prior to completion of the west-side anaerobic cell. By separating the anaerobic bioreactor into two separate cells, experiences gained from construction of the northeast cell will be incorporated into the west-side anaerobic cell.



Detail 1. Overview of Module D Bioreactor Cells

The northeast anaerobic cell and the southeast aerobic cell have been filled with waste and the instrumentation, leachate injection, and gas collection systems have been installed. A total of 65,104 tons of waste were placed in the northeast anaerobic module and 11,942 tons of waste were placed in the southeast aerobic module. The west-side anaerobic cell is still in the process of being filled with waste and is anticipated to be completely filled by June 2002.

The installation of a surface reinforced polypropylene (RPP) membrane cover over the northeast anaerobic cell was completed in November 2001 and will allow precise quantification of the amount of landfill gas produced. The aerobic cell received a cover of 12-inches of soil covered by 12-inches of greenwaste alternative daily cover (ADC). The planned surface membrane cover for the west-side anaerobic module will be similar to the northeast module, with the exception that 40-mil linear low density polyethylene (LLDPE) will be used instead of RPP.

A Supervisory Control and Data Acquisition (SCADA) system has been installed and will monitor and control the operation of the bioreactor cells. By incorporating a SCADA system, real time data monitoring and analysis is possible.

1.2 LESSONS LEARNED AND PRELIMINARY RESULTS

With the majority of the construction phase complete, and liquid addition just beginning, the majority of knowledge gained related to the design and initial contraction of a bioreactor landfill. As the operating phase begins, significant data will be accumulated on the response of waste to enhanced, full-scale, aerobic and anaerobic decomposition. A summary of our current knowledge and preliminary results are as follows.

- With close coordination with the waste placement contractor, the monitoring, landfill gas collection, and liquid injection systems were successfully installed concurrent with waste placement. In addition, the methods utilized to protect the various instruments and piping from construction equipment and subsequent waste placement (chipped or shredded greenwaste was utilized as bedding and shredded tires were used as cover) were successful.

- The effects of having a saturated waste mass on the overall stability of the landfill module were evaluated. The result of this analysis indicated that waste filling and bioreactor operation was possible with up to 2 to 1 (horizontal to vertical) side-slopes. This analysis was specifically performed for the YCCL site and the specific material utilized in construction of Module 6D, Phase 1. We would recommend any landfill operator perform a site specific stability analysis prior to considering bioreactor operation.

- A total of 76,164 tons of waste and greenwaste ADC placed in the northeast anaerobic cell. Landfill gas collection began in mid-December 2001 and through the end of March 2002 a total of 2.16×10^6 scf of landfill gas has been collected (with an average methane concentration around 40 percent). With the average age of the waste only about one year old, it is clear that significant amounts of landfill gas can be collected in a relatively short amount of time provided sufficient collection infrastructure exists.

- The installation of an exposed surface membrane cover as part of the bioreactor project ensures that accurate and complete data collection is possible regarding liquid addition volumes (by eliminating rainwater infiltration) and landfill gas collection. However, the installation of this surface liner accounted for a major portion of the costs of constructing the northeast anaerobic bioreactor. In addition, the sandbag ballast system designed to restrain the cover sustained significant damage from the resident seagull population (they enjoyed picking holes in the sandbags). For the next module, we intend to use discarded tires as the ballast material.

- Shredded tires can be beneficially used in both the operations layer and gas collection system. As demonstrated by this and previous projects at Yolo County, the market should continue to develop for the beneficial use of discarded tires. Approximately 1.5 million tires were utilized during the course of this project.

- Under certain circumstances it was necessary to stockpile shredded tires for subsequent use in construction of the landfill gas collection lines. While the use of shredded tires is still economically more advantageous than gravel, reduced costs could be achieved if the shredded tires could be directly placed in the area of construction.

- The use of alternative daily cover in the form of greenwaste or tarps was successfully during the waste filling phase of this project. By limiting the amount of soil placed in the landfill we hope to increase waste permeability which will allow for more uniform liquid distribution throughout the waste.

- The incorporation of a Supervisory Control and Data Acquisition (SCADA) system will significantly reduce the labor requirements for the long term monitoring and operation of this project. However, significant knowledge in the programming and installation of this system are necessary to attain the maximum benefit.

- Because this bioreactor project was designed mainly as a research project to collect and analyze large volumes of data, it is assumed that the amount and frequency of monitoring could be significantly reduced once this technology is widely understood and accepted by the regulatory community.

- Preliminary results indicate no fugitive landfill gas emissions from a covered bioreactor with an active gas collection system.

- Although the construction phase of the aerobic bioreactor has not been completed, it is apparent that there are significant capitol and operations costs associated with this form of landfilling. One of the more significant operational costs of aerobic operation is the purchase of electricity necessary to operate the blowers that will inject or pull the air through the waste for aeration and heat dissipation.

- Initial cost estimates are marginal for enhanced aerobic bioreactor operation. While requiring an initial investment of $5.11 per ton of waste, a return of $6.40 per ton of waste is possible, resulting in a benefit cost ratio of 1.25. Refer to Section 8 of this report for a more detailed analysis.

- Initial cost estimates are favorable for enhanced anaerobic bioreactor operation. While requiring an initial investment of $2.27 per ton of waste, a return of $5.57 per ton of waste is possible, resulting in a benefit cost ratio of 2.45. Refer to Section 8 of this report for a more detailed analysis.

1.3 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY

With the initial construction phase of the project complete for the northeast anaerobic cell and nearly complete for the southeast aerobic cell Yolo County has gained valuable knowledge about the design and operation of bioreactor landfills. The following sections provide a summary of recommendations for future bioreactor operation and areas that require additional research.

- Based on the stability analysis performed for the YCCL, it is likely that other landfills could construct and operate a bioreactor module with an acceptable factor of safety. We would recommend any landfill operator perform a site specific stability analysis prior to considering bioreactor operation.

- Early recovery of the landfill gas being generated by the northeast cell is only possible because the landfill gas collection system (horizontal gas collection lines) were installed during waste placement and subsequently connected to the site gas collection system shortly after completion of waste placement. In addition, the placement of the synthetic surface liner has ensured near complete capture of the landfill gas that is being generated.

- Early installation of a landfill gas collection system and subsequent gas collection could significantly reduce fugitive emissions in addition to increasing the opportunity for power generation.

- Because the early installation of a membrane cover represents a significant capitol outlay, an area for future research should involve the trial operation of a bioreactor module that is without a synthetic cover. The purpose of this research would be to determine if surface emissions can be controlled with an active gas collection system without the presence of a synthetic cover. A possible alternative that would require demonstration would be the inclusion of a relatively thick layer of greenwaste or compost over the entire module that could act as a natural biofilter for possible fugitive emissions.

- The capitol necessary to purchase the blowers and subsequent electricity costs may be the achilles heel of aerobic bioreactors. Further research is required to demonstrate whether the advantages of aerobic bioreactors (rapid settlement and the elimination of methane generation) can outweigh the significant costs.

- One option that requires further study would be mining and sorting of the waste following aerobic and/or anaerobic decomposition. The reclaiming landfill space could improve the overall economics of aerobic operation by creating a sustainable operation.

2 INTRODUCTION

Sanitary landfilling is the dominant method of solid waste disposal in the United States, accounting for about 217 million tons of waste annually (U.S. EPA, 1997). The annual production of municipal solid waste in the United States has more than doubled since 1960. In spite of increasing rates of reuse and recycling, population and economic growth will continue to render landfilling as an important and necessary component of solid waste management.

In a Bioreactor Landfill, controlled quantities of liquid (leachate, groundwater, grey-water, etc.) are added to increase the moisture content of the waste. Leachate is then recirculated as necessary to maintain the moisture content of the waste at or near it's moisture holding capacity. This process significantly increases the biodegradation rate of waste and thus decreases the waste stabilization and composting time (5 to 10 years) relative to what would occur within a conventional landfill (30 to 50 years or more). If the waste decomposes (i. e., is composted) in the absence of oxygen (anaerobically), it produces landfill gas (biogas). Biogas is primarily a mixture of methane, a potent greenhouse gas, carbon dioxide, and small amounts of Volatile Organic Compounds(VOC's). This by-product of anaerobic landfill waste composting can be a substantial renewable energy resource that can be recovered for electricity or other uses. Other benefits of a bioreactor landfill composting operation include increased landfill waste settlement and a resulting increase in landfill capacity and life, improved opportunities for treatment of leachate liquid that may drain from fractions of the waste, possible reduction of landfill post-closure management time and activities, landfill mining, and abatement of greenhouse gases through highly efficient methane capture over a much shorter period of time than is typical of waste management through conventional landfilling.

2.1 DESCRIPTION OF THE PROJECT AND ITS PURPOSE

The County of Yolo Planning and Public Works Department (Yolo County) is operating its next 20-acre landfill module near Davis, California as a controlled bioreactor landfill to attain a number of superior environmental and cost savings benefits. In the first phase of this 20-acre project, a 12-acre module will be constructed. This 12-acre module contains a 6-acre cell and a 3.5-acre cell, which will be operated anaerobically, and a 2.5-acre cell, which will be operated aerobically. The County will construct the second phase of Module 6D in two years and depending on the results of the first phase of Module 6D, Yolo County may operate the second phase either anaerobically or aerobically.

Co-sponsors of the project with Yolo County are the Solid Waste Association of North America (SWANA) and Institute for Environmental Management (IEM, Inc.). As part of the EPA Project XL, Yolo County requested that U.S. EPA grant site-specific regulatory flexibility from the prohibition in 40 CFR 258.28 Liquid Restrictions, which may preclude addition of useful bulk or non-containerized liquid amendments. The County intends to use leachate and groundwater first but if not enough liquid is available then other supplemental liquids such as gray-water from a waste water treatment plant, septic waste, and food-processing wastes will be used. Liquid wastes such as these, that normally have no beneficial use, may instead beneficially enhance the biodegradation of solid waste.

Yolo County also requested similar flexibility on liquid amendments from California and local regulatory entities. Several sections of the California Code of Regulations (CCR), Title 27, Environmental Protection, address the recirculation of liquids in lined municipal solid waste landfills. While the regulations do not specifically endorse bioreactors, regulatory flexibility is provided by the State of California Title 27, Chapter 3, Subchapter 2, Article 2, section 20200, Part (d)(3), *Management of liquids at Landfills and Waste Piles*. For additional information on this regulatory flexibility, see Section IV A of the FPA.

2.2 DESCRIPTION OF THE FACILITY AND THE OPERATIONS / GEOGRAPHIC AREA

The Yolo County Central Landfill (YCCL) is an existing Class III non-hazardous municipal solid waste landfill. The site encompasses a total of 722 acres and is comprised of 17 distinct Class III solid waste management units and two Class II leachate surface impoundments. The YCCL is located at the intersection of Road 104 and Road 28H, 2 miles northeast of the City of Davis. The YCCL was opened in 1975 for the disposal of non-hazardous solid waste, construction debris, and non-hazardous liquid waste. Existing on-site operations include a thirteen-year-old landfill methane gas recovery and energy generation facility, a drop-off area for recyclables, a metal recovery facility, a wood and yard waste recovery and processing area, and a concrete recycling area.

There are approximately 28 residences scattered within a 2-mile radius of the landfill. The closest residence is located several hundred feet south of the landfill, on the south side of Road 29 south of the Willow Slough By-pass.

Groundwater levels at the facility fluctuate 8 to 10 feet during the year, rising from lowest in the Fall to highest in the Spring. Water level data indicate that the water table level is typically 4 to 10 feet below ground surface during winter and spring months. During summer and fall months, the water table is typically 5 to 15 feet below ground surface. In January 1989, the County of Yolo constructed a soil/bentonite slurry cutoff wall to retard groundwater flow to the landfill site from the north. The cutoff wall was constructed along portions of the northern and western boundaries of the site to a maximum depth of 44 feet. The cutoff wall has a total length of 3,680 feet, 2,880 feet along the north side and 800 feet along the west. In the fall of 1990, irrigation practices to the north of the landfill site were altered to minimize the infiltration of water.

Additionally, sixteen groundwater extraction wells were installed south of the cutoff wall in order to lower the water table south and east of the wall, to provide vertical separation between the base of the landfill and groundwater.

Prior to placement of the slurry wall and dewatering system, the groundwater flow direction was generally to the southeast. Under current dewatering conditions, the apparent groundwater flow paths are towards the extraction wells located along the western portion of the northern site boundary. In essence, a capture zone is created by the cone of depression created by the ground water extraction system, minimizing the possibility of off-site migration of contamination.

3 NORTHEAST ANAEROBIC CELL

The northeast anaerobic cell occupies approximately 3.5 acres in the northeast quadrant of Phase 1, Module 6D.

3.1 EXPERIMENTAL

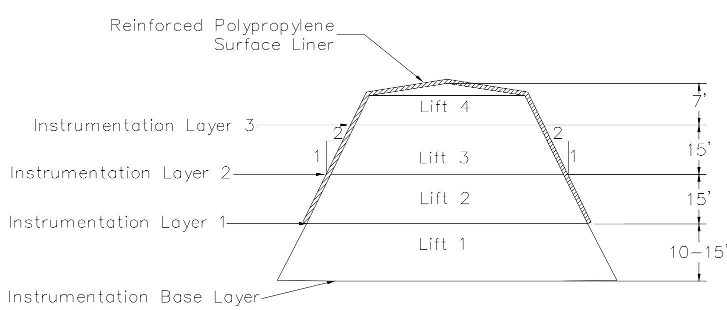
The experimental methods utilized are grouped into three categories: construction, monitoring, and operation. Each of these categories is discussed below.

3.1.1 Construction

Construction of the northeast anaerobic cell can be generally broken down into four major tasks: waste placement, liquid addition, gas collection, and surface liner installation. Each of these four tasks is discussed below. A summary of current monitoring data for the northeast anaerobic cell is provided in Appendix A, Table 2.

3.1.1.1 Waste Placement

Waste placement began on January 13, 2001 and was completed on August 3, 2001. Waste was placed in four separate lifts with an average thickness of 15 feet (Detail 2). In general, all waste received at the landfill was deposited in the northeast cell with the exception of self-haul waste. Because of the difficulties handling large volumes of self-haul vehicles in the limited area of the upper lifts, self-haul waste was not placed in lifts 3 and 4. The use of daily cover soil during waste filling was minimized to aid in the overall permeability of the waste. Whenever possible, greenwaste or tarps were used as alternative daily cover (ADC) and, in the event soil was placed (for example, access roads or tipping pad), the soil was removed prior to placing the next lift of waste. All side slopes were constructed at approximately 2.5 to 1 (horizontal to vertical) and received at least one foot of soil cover. Instrumentation Layers 1, 2, and 3 were placed between lifts, and base layer instrumentation was installed on the Module 6D base liner. A summary of sensors installed on each layer is provided in Appendix A, Table 3.



Detail 2. Northeast Anaerobic Cell Cross Section

3.1.1.2 Liquid Addition

Horizontal liquid injection lines were installed in each lift of waste (Image 1). Injection lines within the waste (between lifts 1 and 2, 2 and 3, 3 and 4) were placed at approximately 40-foot spacing. Injection lines installed on top of lift 4 were installed at approximately 25-foot spacing with an additional injection line following the perimeter of the top deck. Each injection line consists of a 1.25-inch-diameter high-density polyethylene (HDPE) pipe placed horizontally (north to south), which extends completely through the waste. Each injection line was perforated by drilling a $^{3}/_{32}$-inch hole every 20 feet. A total of 8,130 feet of injection piping was installed with a total of 342 injection holes.

Each of the injection laterals will be connected to a 4-inch-diameter HDPE injection header. Flow rate and pressure will be monitored at each injection lateral. Leachate injection for each lateral will be monitored and controlled by individual solenoid valves connected to the SCADA system. A second, redundant flow meter will monitor the total volume and injection flow rate for the entire northeast anaerobic cell.

Image 1: Horizontal LFG and leachate injection lines installed and being coverd by shredded tires.

3.1.1.3 Gas Collection

Horizontal landfill gas (LFG) collection lines were installed between each lift of waste (Image 1) and directly under the reinforced polypropylene (RPP) geomembrane cover. LFG collection lines consist of various combinations of alternating 4 and 6-inch–diameter, schedule 80 polyvinyl chloride (PVC) pipe (Image 2) as well as several variations using corrugated HDPE pipe. A summary of gas collection lines for the northeast anaerobic cell is provided in Appendix A, Table 4. At each line, shredded tires were used as the permeable media. The gas collection lines between layers are spaced approximately 40 feet apart and the lines directly under the RPP membrane are spaced at 25 feet. A total of sixteen LFG collection lines were installed.

Each LFG collection line is connected to a 6-inch-diameter LFG collection header that will convey the gas to the on-site LFG-to-energy facility. Each LFG collection line will incorporate a pre-manufactured wellhead capable of controlling flow and monitoring flow rate, temperature and pressure.

Image 2: Horizontal LFG collection line installation

3.1.1.4 Surface Liner

The County retained the services of Vector Engineering (Vector) to design the surface membrane covers for each of the bioreactor cells (Image 3). Their scope of work included the following subtasks:

- Research the different commercially available membrane materials, including high and low density polyethylene, polyvinyl chloride, and reinforced polypropylene;
- Design of a biofilter to treat the off-gas from the aerobic cell;
- Prepare plans and specification for the installation of the surface liners; and
- Provide on-site construction quality assurance for the installation of the surface membrane.

Vector's scope of work was modified to include preparation of plans and specifications for the tie-in of the leachate injection and landfill gas collection piping.

Image 3: Northeast anaerobic surface liner

Based on Vector and County staff research, it was determined that a 36-mil reinforced polypropylene geomembrane (RPP) would be the preferred choice for an exposed geomembrane cover[1]. Reinforced polypropylene offered distinct advantages over the other potential materials including long service life (a 20-year warrantee was obtained), superior strength due to the nylon reinforcement, and low thermal expansion and contraction.

To expedite construction and reduce the overall cost of the project, the County decided to directly purchase the necessary membrane material and provide it to the contractor for installation. On June 29, 2001, the County issued a request for quotes for 350,000 square feet of 36-mil RPP. Quotes were received on July 9, 2001 with the lowest priced quote received from Colorado Linings International (Colorado).

The plans and specifications for the installation of the RPP surface liner were issued for bid on June 15, 2001. Later that month, Addendum Number 1 was issued to include a majority of the leachate injection and gas collection piping. Bids were due on July 13, 2001; however, no bids were received. The County inquired to each of the plan holders and generally found that bids were not submitted because the liner companies could not locate a subcontractor to perform the earthwork.

The County reissued the plans and specifications on July 23, 2001 and allowed three separate bid options. Option A was the entire project. Option B was only the installation of the liner, and Option C was only the earthwork. Bids were received on August 6, 2001 with the selected contractor being Colorado Linings International. Because Colorado's winning bid was significantly higher than the engineer's estimate and the potential difficulties with excessive pressure buildup under the aerobic liner, the covering of the aerobic cell was eliminated (for further discussion refer to Section 5.1).

The installation of surface liner and associated piping was completed in November 2001.

3.1.2 Monitoring

Temperature, moisture, leachate quantity and quality, and LFG pressure and composition are monitored through an array of sensors placed within the waste and in the leachate collection and recovery system (LCRS). Each sensor location on the base layer received a temperature sensor (thermistor), a linear low-density polyethylene (LLDPE) tube, and selected locations received a PVC moisture sensor. Each sensor location within the waste received a temperature sensor (thermistor), a linear low-density polyethylene (LLDPE) tube, and a moisture sensor (a PVC moisture sensor and in some cases a gypsum block). For protection, each wire and tube was encased in either a 1.25-inch HDPE pipe or run inside the LFG collection piping. Refer to Appendix B, Details 7 through 10 for sensor location diagrams.

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[1] Vector Engineering, "Design Report for the Surface Liners of the Module D Phase 1 Bioreactors at the Yolo County Central Landfill", October 2001.

Image 4: Moisture, temperature , and tube installation

Sensors on instrumentation Layers 1, 2, and 3 were placed on either a bedding of greenwaste (shredded yard waste), wood chips (chipped wood waste), bin fines (fine pieces of greenwaste), or pea gravel to protect against damage from the underlying waste. Sensors installed on the primary liner (prior to any waste placement) were placed on geocomposite and covered with pea gravel prior to the placement of the chipped tire operations layer.

3.1.2.1 Temperature

Temperature is monitored with thermistors manufactured by Quality Thermistor, Inc. Thermistors with a temperature range of 0°C to 100°C were chosen to accommodate the temperature ranges expected in both the anaerobic and aerobic cells. To prevent corrosion, each thermistor was encased in epoxy and set in a stainless steel sleeve. All field wiring connections were made by first soldering the connection, then covering each solder joint with adhesive lined heat shrink tubing, and then encasing the joint in electrical epoxy. Changes in temperature are measured by the change in thermistor resistivity (ohms). As temperature increases, thermistor resistance decreases.

3.1.2.2 Moisture

Moisture levels are measured with polyvinyl chloride (PVC) moisture sensors and gypsum blocks. Both the PVC moisture sensors and gypsum blocks are read utilizing the same meter. The PVC sensors are perforated 2-inch-diameter PVC pipes with two stainless steel screws spaced 8 inches apart and attached to wires to form a circuit that includes the gravel filled pipe. The PVC sensors were designed by Yolo County and used successfully during the pilot scale project[2]. The PVC moisture sensor can provide a general, qualitative assessment of the waste's moisture content. A reading of 0 to 40 equates to no free liquid, 40 to 80 equates to some free liquid, and 80 to 100 means completely saturated conditions.

[2] Yazdani, R., Moore, R. Dahl. K. and D. Augenstein 1998 Yolo County Controlled Landfill Bioreactor Project. Yolo County Public Works and I E M, Inc. Yolo County Public Works and I E M, Inc. report to the Urban Consortium Energy Foundation (UUCETF) and the Western Regional Biomass Energy Program, USDOE.

The gypsum blocks are manufactured by Electronics Unlimited and are typically used for soil moisture determinations in agricultural applications. Gypsum blocks establish equilibrium with the media in which they are placed and are, therefore, reliable at tracking increases in the soil's moisture content. However, the gypsum block can take considerable time to dry and therefore may not reflect the drying of the surrounding environment.

3.1.2.3 Leachate Quantity and Quality

Leachate that is generated from the northeast anaerobic cell drains to the eastside Module D leachate collection sump (Image 5). A dedicated pump is then used to remove the leachate and pump it to one of the on-site leachate storage ponds. A flow meter measures rate and total volume pumped from the sump.

Leachate is monitored for the following field parameters: pH, electrical conductivity, dissolved oxygen, oxidation-reduction potential, and temperature. When leachate is generated in sufficient quantities, the following parameters will be analyzed by a laboratory: dissolved solids, biochemical oxygen demand, chemical oxygen demand, organic carbon, nutrients (NH_3, TKN, TP), common ions, heavy metals and organic priority pollutants. For the first year, monitoring will be conducted monthly during the first six months and quarterly for the following six months. After the first year, monitoring will be conducted semi-annually (pH, conductivity, and flow rate will continue to be monitored on a monthly basis as required by the State of California's Waste Discharge Requirements in Order 5-00-134).

3.1.2.4 Pressure

Pressure within the northeast anaerobic cell is monitored with ¼-inch inner diameter and $^{3}/_{8}$-inch outer diameter LLDPE sampling tubes. Each tube can be attached to a pressure gage and supplemental air source. By first purging the tube with the air source (to remove any liquid blockages), and then reading the pressure, an accurate gas and/or water pressure can be measured at each sensor location.

3.1.2.5 Landfill Gas Composition

Gas composition is measured utilizing a GEM-500 combustible gas meter, manufactured by LANDTEC. The GEM-500 is capable of measuring methane (either as a percent by volume or percent of the lower explosive limit), carbon dioxide, and oxygen. A reading for "balance" gas is also provided, which is assumed to be nitrogen. Currently, gas composition is analyzed from the same sampling tubes used to measure pressure.

Image 5: Gravel drainage layer and leachate collection sump

3.1.3 Operation

Operation of the northeast anaerobic cell as a bioreactor will begin once the surface liner, LFG collection system, leachate recirculation systems, and SCADA control systems are complete. Landfill gas collection began on December 13, 2001 and leachate addition began on March 27, 2002.

3.1.3.1 Leachate Recirculation

Leachate addition to the northeast cell began on March 27, 2002 (Image 6). Our initial plan calls for testing each of the horizontal liquid injection lines by pumping approximately 1000 gallons into the line to confirm operation and measure flow versus pressure for each injection lateral. Through the end of March 2002, a total of 1,610 gallons of liquid (leachate) was added to the northeast anaerobic cell.

Image 6: Leachate injection header and laterals

Once the initial testing phase is complete, large volumes of liquid will be added to bring the waste to field capacity. Once field capacity has been reached, only enough liquid to maintain field capacity will be added.

3.1.3.2 Landfill Gas Collection

Landfill gas collection began December 13, 2001 once the necessary piping was installed at the end of November 2001. Gas collection prior to leachate addition is necessary to prevent “billowing” or excess gas pressure under the surface liner.

3.2 RESULTS AND DISCUSSION

Sensor names are represented numerically by the instrumentation layer in which the sensor is located, followed by the assigned sensor number. The base layer is represented by a 0, Layer 1 is represented by a 1, and so forth. The complete name of the sensor is denoted by the layer number – the sensor number. For example, the second sensor on Layer 1 is named 1-02.

3.2.1 Temperature

Temperature is monitored with thermistors manufactured by Quality Thermistor, Inc. Thermistors with a temperature range of 0°C to 100°C were chosen so they would be able to accommodate the temperature ranges expected in both the anaerobic and aerobic cells. Resistance was measured by the SCADA system located in the instrumentation shed starting in March 2002. Resistance was previously measured manually by connecting the sensor wires to a 26 III Multimeter manufactured by Fluke Corporation.

Base Layer - The northeast base layer temperatures have steadily increased and are converging between 20^{o}C and 26^{o}C (68^{o}F and 77^{o}F) as presented in Appendix C, Figure 1.

Layer 1 - The majority of sensors within Layer 1 are recording temperatures ranging between approximately 40^{o}C to 50^{o}C (104^{o}F to 122^{o}F) as presented in Appendix C, Figure 2. Lower temperature readings from sensors 1-17 and 1-18 are most likely due to their proximity to the surface of the module. Temperature recorded by sensor 1-9 (59 ^{o}C) are approaching those measure in Layer 2.

Layer 2 - The elevated temperatures, between approximately 58^{o}C and 65^{o}C (136^{o}F and 149^{o}F), in Layer 2 appear to correspond to the beginning of the use of “bin fines” as the media surrounding the sensors and daily cover material (Appendix C, Figure 3). Wood chips were used on Layer 1 to cover the sensors, however, due to the low supply of this material, bin fines were used to cover the sensors on Layer 2. Bin fines seem to be a more readily biodegradable material than wood chips, as evidenced by the higher temperatures. During the month of March 2002, temperatures appeared to began converging towards approximately 60 ^{o}C.

Layer 3 - Temperature readings for Layer 3 generally range between 38^{o}C and 73^{o}C (100^{o}F and 163^{o}F) as presented in Appendix C, Figure 4. Lower temperatures are being measured by sensors close to the surface (3-1, 3-3, 3-6, 3-8, 3-11, 3-13) with the remaining sensors recording higher temperatures.

3.2.2 Moisture

The SCADA system started electronically measuring moisture in March 2002. Due to a slight variation between how the SCADA system measures moisture compared to the manual meter, moisture readings generally increased a small fraction relative to their previous manually recorded readings. Because moisture data are unitless numbers that give a qualitative assessment rather than a quantitative measure, we feel that this slight change is not significant. Moisture was previously measured manually with a Model MM 4 moisture meter manufactured by Electronics Unlimited. During the pilot scale project, Yolo County conducted laboratory tests with the PVC sensors to determine the relationship between the multimeter readings and the presence of free liquid in the PVC sensor. It was determined that a meter reading of less than 40 corresponded to an absence of free liquid. A reading between 40 and 80 corresponds to the presence of free liquid in the PVC pipe but less than saturated conditions. Readings of greater than 80 indicate saturated conditions; i.e. the PVC sensor is full of liquid.

Base Layer - PVC moisture levels for the base layer are presented in Appendix C, Figure 5. Moisture levels generally range from approximately 10 to 20, which equates to the no-free-liquid zone.

Layer 1 - PVC moisture levels for Layer 1 are presented in Appendix C, Figure 6. The moisture levels for this layer generally range between 0 and 30 in the no-free-liquid zone. Sensors 1-05 and 1-16 indicate higher moisture levels that equate to the some-free-liquid zone.

Layer 2 - PVC moisture readings generally lie in the no-free-liquid zone ranging between 30 and 38 (Appendix C, Figure 7). PVC moisture sensor 2-12 initially indicated some free liquid was present, however, it has since dropped to the no fee liquid zone. The elevated moisture levels initially recorded by PVC moisture sensor 2-12 were supported by gypsum in plaster sensor 2-12 (Appendix C, Figure 8); however, the gypsum sensor has remained in the some free liquid zone. High moisture readings from gypsum in plaster sensors 2-06, 2-08, 2-10, 2-11 and 2-15 do not correspond to PVC moisture sensor readings in the no-free-liquid zone. Gypsum in plaster sensors 2-04 and 2-10 exhibited high initial moisture readings, due to the plaster encasing the gypsum block not being fully dry prior to installation. High initial moisture readings from gypsum in plaster sensors 2-06, 2-11, and 2-12 are most likely a result of being wetted shortly after installation. Readings from gypsum in soil sensor 2-06 corresponds to the high readings from gypsum in plaster sensor 2-06 (Figure 9). However, the readings from gypsum in soil sensors do not reflect the high readings from gypsum in plaster sensors 2-11 and 2-12.

Layer 3 - With the exception of sensors 3-04 and 3-05, Layer 3 moisture readings generally remain steady in the no-free-liquid zone. Sensor 3-04 moisture readings declined from the some-free-liquid zone to the no free liquid zone while sensor 3-05 moisture readings remained in the completely saturated zone (Appendix C, Figure 10).

3.2.3 Leachate Quantity And Quality

Prior to mid-February 2001, leachate data reflects rainfall rather than actual leachate generation because the cells were only partially filled, and portions of the leachate collection and removal system were exposed to rainfall. Between February 2001 and March 2002, approximately 315,600 gallons of leachate was generated from the northeast anaerobic cell and southeast quadrant anaerobic base layer and collected in the east sump (Appendix C, Figure 11), with the vast majority of this flow attributed to rainfall runoff into exposed sections of the LCRS.

Leachate was sampled in February 2002 for analytical testing. Analytical results are presented in Appendix D. Field chemistry results are presented below in Table 3-1. Prior leachate chemistry and analytical results are not reported because samples taken during the wet season were rainfall rather than leachate and low leachate levels following the rainy season did not allow collection of fresh leachate samples.

Table 3-1. Field Chemistry and Selected Laboratory Chemistry for Leachate Sampled from Northeast Anaerobic Cell on February 14, 2002

Parameter	Units	Northeast Anaerobic Cell
Field Chemistry:		
PH		7.13
Electrical Conductivity	μmoh/cm	6,583
Oxidation Reduction Potential	mV	-119
Temperature	^{o}C	19.9
Dissolved Oxygen	mV	1
Total Dissolved Solids	mg/L	5,244
Laboratory Chemistry:		
Ammonia as N	mg/L	30
Bicarbonate	mg/L	1,740
BOD	mg/L	20
Chemical Oxygen Demand	mg/OL	633
Chloride	mg/L	1,070
Nitrate/Nitrite as N	mg/L	<0.03
Sulfate	mg/L	322
Total (Non-Volatile) Organic Carbon	mg/L	2.2
Total Alkalinity as CO_3	mg/L	1,740
Total Dissolved Solids @ 180 ^{o}C	mg/L	4,440
Total Kjeldahl Nitrogen	mg/L	53.1
Total Sulfide	mg/L	1.9
Dissolved Magnesium	mg/L	323
Dissolved Potassium	mg/L	152
Dissolved Iron	mg/L	1.1

3.2.4 Pressure

Pressure measurements are taken from sampling tubes with a DWYER Instruments, Inc., “Magnehelic” pressure gage. Pressure measurements can be either positive or negative, with positive pressures resulting from both the generation of landfill gas and saturated liquid conditions.

Base Layer - Pressure readings from the northeast base layer pressure tubes are currently positive and below 0.25 centimeters of water (0.1 inches of water) as presented in Appendix C, Figure 12.

Layer 1 - Pressure readings in Layer 1 are positive and remain below 3.05 centimeters of water (1.2 inches of water) as presented in Appendix C, Figure 13.

Layer 2 - Pressure readings in Layer 2 are positive and remain below 0.15 centimeters of water (0.06 inches of water) as presented in Appendix C, Figure 14.

Layer 3 - Pressure readings in Layer 3 are positive and remain below 0.10 centimeters of water (0.04 inches of water) as presented in Appendix C, Figure 15.

3.2.5 Landfill Gas Compositions

Gas composition is measured from sampling tubes on each layer of the cells with the GEM-500. Because liquid will damage the GEM, pressurized air is first forced through the tubes to remove any liquid, then the tube lines are purged with a vacuum pump and hooked up to the GEM to analyze the gas composition.

Base Layer - Gas compositions measured from sampling tubes, indicate high methane and carbon dioxide levels and depleted oxygen levels (Appendix C, Table 11). Any oxygen measured in the base layer is most likely the result of air intrusion into the permeable shredded tire operations layer (which was not completely covered by waste until recently) that covers the entire bottom of Module 6D.

Layer 1 - Gas compositions measured from sampling tubes indicate Layer 1 is in the anaerobic phase as presented in Appendix C, Table 12. Methane and carbon dioxide levels are steady and oxygen has been depleted.

Layer 2 - Gas compositions measured from sampling tubes indicate Layer 2 is in the anaerobic phase as presented in Appendix C, Table 13. Methane and carbon dioxide levels are steady and oxygen has been depleted.

Layer 3 - Gas compositions from sampling tubes on Layer 3 indicate depleted oxygen levels and steady methane and carbon dioxide levels as presented in Appendix C, Table 14. Higher methane concentrations have been recorded at location 3-1 compared to other locations monitored, this is most likely due to it's placement farther away from landfill gas collection lines relative to the other tube locations.

3.2.6 Landfill Gas Collection System

Gas composition is measured from the wellheads located on top of the northeast anaerobic cell with the GEM-500. Gas flow is measured by differential pressures at the well heads with a DWYER Instruments, Inc., "Magnehelic" pressure gage. A thermal mass flow meter installed in the main header pipeline near the instrumentation shed records flow rate and total for all of the northeast cell. The meter is equipped with two separate calibration curves (for different gas constituent concentrations) and automatically corrects for temperature and pressure and records in standard cubic feet.

Gas collection lines are represented numerically by the layer the line is located, followed by a "G" and the number which denotes the line on a specific layer. For example, the first gas collection line on layer 3 is denoted 3-G1.

Methane concentrations from the wellheads are variable. Methane concentrations for Layer 1 gas collection lines currently range between 23 and 28 percent while collection lines on Layer 2 and Layer 3 range between 40 and 47 percent (Appendix C, Figure 16). Methane concentrations from the header line range between 34 and 45 percent, carbon dioxide concentrations between 38 and 45 percent, balance concentrations between 8 and 26 percent, and oxygen concentrations near zero percent (Appendix C, Figure 17). Flow rates from each of the gas collection lines are variable and currently below 5 standard cubic feet per minute (scfm) as presented in Appendix C, Figure 18. In January 2002, valves to gas collection lines 1-G3 and 3-G1 were closed due to liquid build-up in the lines. In February 2002, these lines were reopened as shown by their rise in flow rates. Approximately 2.16 x 10^6 scf of methane has been collected from the northeast anaerobic cell between December 18, 2002 and March 29, 2002 (Appendix C, Figure 19).

Landfill gas from the northeast cell was sampled in February 2002 for and sent to an independent laboratory for analytical testing. Analytical results are presented in Appendix E.

4 WEST-SIDE ANAEROBIC CELL

The west-side anaerobic cell is located on the western 6 acres of Phase 1, Module D. Filling in the west-side anaerobic cell is continuing with instrumentation, leachate injection and gas collection equipment being installed as filling proceeds.

4.1 EXPERIMENTAL

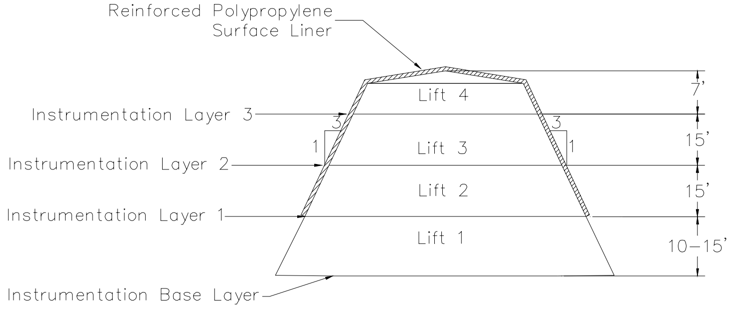
The experimental methods utilized are grouped into three categories: construction, monitoring, and operation. Each of these categories is discussed below.

4.1.1 Construction

Construction of the west-side anaerobic cell can be generally broken down into four major tasks: waste placement, liquid addition, gas collection, and surface liner installation. Each of these four tasks is discussed below.

4.1.1.1 Waste Placement

In the west-side anaerobic cell, waste will be placed in four lifts of approximately 15-foot thickness with 2.5:1 side slopes on interior slopes and 3:1 on exterior slopes (Detail 3, Image 7). Waste placement for lifts 1and 2 is complete. Waste is currently being placed in lift 3 and is approximately two-thirds complete.. A summary of sensors installed on the base layer is shown in Appendix A, Table 3.



Detail 3. Cross Section of West-Side Anaerobic

Image 7: Waste placement in the west-side cell

4.1.1.2 Liquid Addition

Liquid addition piping is currently being installed in the west-side anaerobic cell. Leachate injection piping will be installed between lifts 2 and 3 and on top of lift 4.

4.1.1.3 Gas Collection

Gas collection piping is currently being installed in the west-side anaerobic cell. Gas collection piping will be installed between lifts 2 and 3 and on top of lift 4.

4.1.1.4 Surface Liner

A consultant was retained to provide design, plans and specifications for the surface lining systems. The west-side anaerobic cell is scheduled to be covered during the summer of 2002.

4.1.2 Monitoring

Temperature, moisture, leachate quantity and quality, and LFG pressure and composition are monitored through an array of sensors placed within the waste and in the leachate collection and recovery system (LCRS). Each sensor location on the base layer received a temperature sensor (thermistor), a linear low-density polyethylene (LLDPE) tube, and selected locations received a PVC moisture sensor. For protection, each wire and tube was encased in a PVC pipe. Refer to Appendix B, Detail 7 for a diagram of base layer sensor locations.

Sensors installed on the primary liner (prior to any waste placement) were placed on geocomposite and covered with pea gravel prior to the placement of the chipped tire operations layer.

4.1.2.1 Temperature

Temperature is monitored with thermistors manufactured by Quality Thermistor, Inc. Thermistors with a temperature range of 0°C to 100°C were chosen to accommodate the temperature ranges expected in both the anaerobic and aerobic cells. To prevent corrosion, each thermistor was encased in epoxy and set in a stainless steel sleeve. All field wiring connections were made by first soldering the connection, then covering each solder joint with adhesive-lined heat shrink tubing, and then encasing the joint in electrical epoxy. Changes in temperature are measured by the change in thermistor resistivity (ohms). As temperature increases, thermistor resistance decreases.

4.1.2.2 Moisture

Moisture levels are measured with polyvinyl chloride (PVC) moisture sensors and gypsum blocks. Both the PVC moisture sensors and gypsum blocks are read utilizing the same meter. The PVC sensors are perforated 2-inch-diameter PVC pipes with two stainless steel screws spaced 8 inches apart and attached to wires to form a circuit that includes the gravel filled pipe. The PVC sensors were designed by Yolo County and used successfully during the pilot scale project. The PVC moisture sensor can provide a general, qualitative assessment of the waste's moisture content. A reading of 0 to 40 equates to no free liquid, 40 to 80 equates to some free liquid, and 80 to 100 means completely saturated conditions.

4.1.2.3 Leachate Quantity and Quality

Leachate that is generated from the west-side anaerobic cell drains to the west-side Module D leachate collection sump. A dedicated pump is then used to remove the leachate and pump it to one of the on-site leachate storage ponds. A flow meter measures rate and total volume pumped from the sump.

Leachate is monitored for the following field parameters: pH, electrical conductivity, dissolved oxygen, oxidation-reduction potential, and temperature. When leachate is generated in sufficient quantities, the following parameters will be analyzed by a laboratory: dissolved solids, biochemical oxygen demand, chemical oxygen demand, organic carbon, nutrients (NH_3, TKN, TP), common ions, heavy metals and organic priority pollutants. For the first year, monitoring will be conducted monthly for the first six months and quarterly for the following six months. After the first year, monitoring will be conducted semi-annually (pH, conductivity, and flow rate will continue to be monitored on a monthly basis as required by the State of California's Waste Discharge Requirements in Order 5-00-134).

4.1.2.4 Pressure

Pressure within the northeast anaerobic cell is monitored with ¼-inch inner diameter and $^3/_8$-inch outer diameter LLDPE sampling tubes. Each tube can be attached to a pressure gage and supplemental air source. By first purging the tube with the air source (to remove any liquid blockages) and then reading the pressure, an accurate gas and/or water pressure can be measured at each sensor location.

4.1.2.5 Landfill Gas Composition

Gas composition is measured utilizing a GEM-500 combustible gas meter manufactured by LANDTEC. The GEM-500 is capable of measuring methane (either as a percent by volume or percent of the lower explosive limit), carbon dioxide, and oxygen. A reading for "balance" gas is also provided, which is assumed to be nitrogen. Currently, gas composition is analyzed from the same sampling tubes used to measure pressure.

4.1.3 Operation

Operation of the west-side anaerobic cell will begin once waste placement, sensor installation, landfill gas (LFG) collection system, leachate recirculation systems, and SCADA control systems are complete.

4.1.3.1 Leachate Recirculation

Initially, large volumes of liquid will be added to bring the waste to field capacity. Once field capacity has been reached, only enough liquid to maintain field capacity will be added.

4.1.3.2 Landfill Gas Collection

Landfill gas collection will begin as soon as waste placement is completed and the necessary piping installed.

4.2 Results And Discussion

Sensor names are represented numerically by the instrumentation layer in which the sensor is located and by the assigned sensor number for that layer. The base layer is represented by a 0, Layer 1 is represented by a 1, and so forth. The complete name of the sensor is denoted by the layer number – the sensor number. For example, the second sensor on Layer 1 is named 1-02.

4.2.1 Temperature

Temperature is monitored with thermistors manufactured by Quality Thermistor, Inc. Thermistors with a temperature range of 0°C to 100°C were chosen so they would be able to accommodate the temperature ranges expected in both the anaerobic and aerobic cells. Resistance was measured by the SCADA system located in the instrumentation shed starting in March 2002. Resistance was previously measured manually by connecting the sensor wires to a 26 III Multimeter manufactured by Fluke Corporation.

Base Layer - Southwest base layer temperatures are converging and range between approximately 24^{o}C and 35^{o}C (75^{o}F and 95^{o}F) as presented in Appendix C, Figure 20. Northwest base layer temperatures are converging and range between approximately 22^{o}C and 33^{o}C (71^{o}F and 91^{o}F) as presented in Appendix C, Figure 21.

4.2.2 Moisture

The SCADA system started electronically measuring moisture in March 2002. Due to a slight variation between how the SCADA system measures moisture compared to the manual meter, moisture readings generally increased a small fraction relative to their previous manually recorded readings. Because moisture data are unitless numbers that give a qualitative assessment rather than a quantitative measure, we feel that this slight change is not significant. Moisture was previously measured manually with a Model MM 4 moisture meter manufactured by Electronics Unlimited. During the pilot scale project, Yolo County conducted laboratory tests with the PVC sensors to determine the relationship between the multimeter readings and the presence of free liquid in the PVC sensor. It was determined that a meter reading of less than 40 corresponded to an absence of free liquid. A reading between 40 and 80 corresponds to the presence of free liquid in the PVC pipe but less than saturated conditions. Readings of greater than 80 indicate saturated conditions; i.e. the PVC sensor is full of liquid.

Base Layer - PVC moisture levels for the base layer are presented in Appendix C, Figure 22. Moisture levels range from approximately 0 to 7 indicating no free liquid.

4.2.3 Leachate Quantity And Quality

Prior to October 2001, leachate data reflects rainfall rather than actual leachate generation because the cells were only partially filled, and portions of the leachate collection and removal system were exposed to rainfall. Between October 2001 and March 2002, approximately 70,500 gallons of leachate was generated from the west-side cell (Appendix C, Figure 11).

Leachate was sampled in February 2002 for analytical testing. Analytical results are presented in Appendix D. Field chemistry results are presented below in Table 4-1. Prior leachate chemistry and analytical results are not reported because samples taken during the wet season were rainfall rather than leachate and low leachate levels following the rainy season did not allow collection of fresh leachate samples.

Table 4-1. Field Chemistry and Selected Laboratory Chemistry for Leachate Sampled from West-Side Anaerobic Cell on February 14, 2002

Parameter	**Units**	**West-Side Anaerobic Cell**
Field Chemistry:		
PH		6.74
Electrical Conductivity	μmoh/cm	3,530
Oxidation Reduction Potential	mV	-62
Temperature	^{o}C	24.9
Dissolved Oxygen	mV	3.15
Total Dissolved Solids	mg/L	2,617
Laboratory Chemistry:		
Ammonia as N	mg/L	20.3
Bicarbonate	mg/L	1,700
BOD	mg/L	28
Chemical Oxygen Demand	mg/OL	350
Chloride	mg/L	187
Nitrate/Nitrite as N	mg/L	0.016 (trace)
Sulfate	mg/L	1.7 (trace)
Total (Non-Volatile) Organic Carbon	mg/L	112
Total Alkalinity as CO_3	mg/L	1,700
Total Dissolved Solids @ 180 ^{o}C	mg/L	2,220
Total Kjeldahl Nitrogen	mg/L	32.6
Total Sulfide	mg/L	0.13
Dissolved Magnesium	mg/L	195
Dissolved Potassium	mg/L	55.2
Dissolved Iron	mg/L	0.4

4.2.4 Pressure

Pressure measurements are taken from sampling tubes with a DWYER Instruments, Inc., "Magnehelic" pressure gage. Pressure measurements can be either positive or negative, although a vacuum has not yet been applied to the gas extraction lines, so negative pressures are not expected at this time. Positive pressures can result from both the generation of landfill gas and saturated liquid conditions.

Base Layer - Pressure readings from the west-side anaerobic cell are currently positive and remain below 4.06 centimeters of water (1.6 inches of water) as presented in Appendix C, Figures 23 and 24

4.2.5 Landfill Gas Composition

Gas composition is measured from sampling tubes on each layer of the cells with the GEM-500. Because liquid will damage the GEM, pressurized air is first forced through the tubes and liquid is pushed out, then the tube lines are purged with a vacuum pump and hooked up to the GEM to analyze the gas composition.

Base Layer

Data from sampling tubes presented in Appendix C, Table 15 indicates increasing methane levels and depleted oxygen levels. Oxygen measured in the base layer is most likely the result of air intrusion into the permeable shredded tire operations layer (which was not completely covered by waste) that covers the entire bottom of Module 6D.

5 AEROBIC CELL

The aerobic cell occupies approximately 2.5 acres in the southeast quadrant of Phase 1, Module 6D.

5.1 EXPERIMENTAL

The experimental methods utilized are grouped into three categories: construction, monitoring, and operation. Each of these categories is discussed below.

5.1.1 Construction

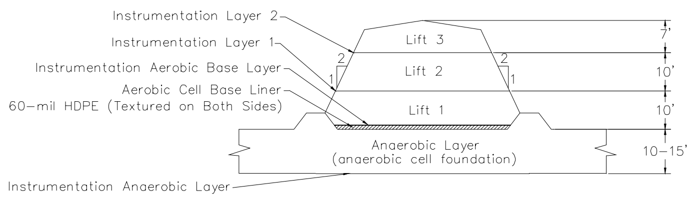
Construction of the aerobic cell can be generally broken down into five major tasks: waste placement, liquid addition, gas collection, air injection and surface liner installation. Each of the five tasks is discussed below. Refer to Appendix A, Table 5 for a summary of current monitoring data for the northeast anaerobic cell.

5.1.1.1 Waste Placement

Waste placement first began November 14, 2000 with an approximate 10-foot lift of waste placed on the Module 6D liner. This first lift of waste will act as a buffer between the Module 6D primary liner and the future aerobic cell. The waste was graded to promote drainage and a 60-mil HDPE geomembrane (Image 8) was installed to capture all leachate being generated by the aerobic cell. A sixteen-ounce geotextile was then placed on the membrane to act as a cushion for a shredded tire operations layer.

Image 8: Aerobic liner ready for shredded tire operations layer and waste placement

Waste placement in the aerobic cell occurred between August 8, 2001 and September 26, 2001. Waste was placed in three 10-foot lifts with 2:1 side slopes on the north, east and west (internal side slopes), and a 3:1 side slope on the south (external side slope) as presented in Detail 4. Because of the limited tipping area of the aerobic cell, self-haul waste was excluded. The use of daily cover soil during waste filling was also minimized to aid in the overall permeability of the waste. Whenever possible, greenwaste or tarps were used as alternative daily cover (ADC) and, in the event soil was placed (for example, access roads or tipping pad), the soil was removed prior to placing the next lift of waste. To further aid permeability of the waste, compaction was restricted to only 1to 2 passes with a Caterpillar 826 compactor. Based on waste tonnage records and as-built topography, the in-place refuse density is approximately 800 pounds per cubic yard. Instrumentation Layers 1 and 2 were placed between lifts, and base layer instrumentation was installed on the aerobic cell base liner. A summary of sensors installed on each layer is provided in Appendix A, Table 6.



Detail 4. Aerobic Cell Cross Section

5.1.1.2 Liquid Addition

Horizontal liquid injection lines were installed in each lift of waste. Injection lines within the waste (between lifts 1 and 2, 2 and 3) were placed horizontally (north to south) at approximately 20-foot spacing. Injection lines on top of lift 3 were placed east to west every 20 feet. Various combinations of 1¼-inch-diameter chlorinated polyvinyl chloride (CPVC) and 1¼-inch-diameter HDPE pipe were installed and perforated with $^{3}/_{32}$–inch-diameter holes spaced every 10 feet (Image 9). Because of the elevated temperatures expected in the aerobic cell, CPVC was

Image 9: Leachate injection laterals in trench

installed a selected locations as a redundancy in the event the HDPE piping fails (CPVC is rated for service at temperatures up to 200^{o}F, however is approximately 4 times as expensive). A total of 4,780 feet of injection piping was installed with a total of 326 injection holes.

Each of the injection laterals will be connected to a 4-inch-diameter HDPE injection header. Flow rate and pressure will be monitored at each injection lateral. Leachate injection for each lateral will be monitored and controlled by individual solenoid valves connected to the SCADA system. A second redundant flow meter will monitor the total volume and flow rate being injected in the aerobic cell.

5.1.1.3 Air Collection

Horizontal air collection lines were installed between each lift of waste. Air collection lines consist of various combinations of alternating 4 and 6–inch-diameter CPVC pipe and 6 and 8–inch-diameter corrugated metal pipe. Each air collection line utilizes shredded tires as the permeable media. The air collection lines between layers are spaced approximately 40 feet apart. A total of 1660 feet of horizontal air collection lines were installed. A summary of the air collection lines for the aerobic cell is shown in Appendix A, Table 7.

Image 10: Horizontal air collection line

Each air collection line will be connected to a 12-inch-diameter air collection header that will convey the gas to and on-site blower and biofilter. Each air collection line will incorporate a pre-manufactured wellhead capable of controlling flow and monitoring flow rate, temperature and pressure.

5.1.1.4 Surface Liner

Vector was retained to provide design, plans and specifications for a surface lining system, including a biofilter for the treatment of the aerobic off-gas.

Since the operation of an aerobic bioreactor at the Yolo County Central Landfill was first considered, two methods of air management for oxygen delivery have been discussed. One method is to push air into the landfill and the other is to apply a vacuum and draw air through the landfill. Both methods have advantages and disadvantages. However, Yolo County has decided that the best alternative is to leave the aerobic cell covered with soil and greenwaste (shredded yard waste), but without an impermeable geomembrane, so that air could be drawn through the waste by applying a vacuum. In this way, air will enter through the cell surface and migrate to horizontal pipelines to which a vacuum is applied. Alternate operations plans could include using some of the installed pipelines as vents and others for vacuum.

Yolo County had intended to cover the aerobic cell with an exposed geomembrane with a biofilter at the top of the cell to provide some treatment of the off-gas. However, the weight of the geomembrane that would have been placed on the aerobic cell along with the weight of a sandbag surface ballast system would result in a pressure equivalent to only 0.17 inches of water. Calculations indicate that the required pressure present in the cell to force the air through the waste, to the top of the cell, and through the biofilter would result in a great deal of ballooning of the surface liner. Additionally, the expected high settlement rate would create a great deal of maintenance difficulties for the geomembrane surface liner.

Yolo County developed a design for a geomembrane surface liner for the aerobic cell and advertised for bids on the construction. The bids received were very expensive and not within the budget of the project. As a result of both the technical and economic difficulties encountered, it was decided that leaving the aerobic cell without a geomembrane liner is the preferred approach.

5.1.2 Monitoring

Temperature, moisture, leachate quantity and quality, and air pressure and composition are monitored through an array of sensors placed within the waste (Image 11) and in the leachate collection and recovery system (LCRS). Each sensor location on the base layer

Image 11: Moisture, temperature, and tube installation

received a temperature sensor (thermistor), a linear low-density polyethylene (LLDPE) tube, and selected locations received a PVC moisture sensor. Each sensor location within the waste received a temperature sensor (thermistor), a moisture sensor (a PVC moisture sensor and in some cases a gypsum block) and a linear low-density polyethylene (LLDPE) tube. For protection, each wire and tube was encased in a 1.25-inch-diameter HDPE pipe. Refer to Appendix B, Detail 7 for a diagram of sensor locations.

Sensors on instrumentation Layers 0.5, 1, and 2 were placed on a bedding of greenwaste (shredded yard waste), or bin fines (fine pieces of greenwaste). Sensors installed on the primary liner (prior to any waste placement) were placed on the geotextile and covered with pea gravel prior to the placement of the shredded tire operations layer.

5.1.2.1 Temperature

Temperature is monitored with thermistors manufactured by Quality Thermistor, Inc. Thermistors with a temperature range of 0°C to 100°C were chosen to accommodate the temperature ranges expected in both the anaerobic and aerobic cells. To prevent corrosion, each thermistor was encased in epoxy and set in a stainless steel sleeve. All field wiring connections were made by first soldering the connection, then covering each solder joint with adhesive-lined heat shrink tubing, and then encasing the joint in electrical epoxy. Changes in temperature are measured by the change in thermistor resistivity (ohms). As temperature increases, thermistor resistance decreases.

5.1.2.2 Moisture

Moisture levels are measured with polyvinyl chloride (PVC) moisture sensors and gypsum blocks. Both the PVC moisture sensors and gypsum blocks are read utilizing the same meter. The PVC sensors are perforated 2-inch-diameter PVC pipes with two stainless steel screws spaced 8 inches apart and attached to wires to form a circuit that includes the gravel filled pipe. The PVC sensors were designed by Yolo County and used successfully during the pilot scale project. The PVC moisture sensor can provide a general, qualitative assessment of the waste's moisture content. A reading of 0 to 40 equates to no free liquid, 40 to 80 equates to some free liquid, and 80 to 100 means completely saturated conditions.

The gypsum blocks are manufactured by Electronics Unlimited and are typically used for soil moisture determinations in agricultural applications. Gypsum blocks establish equilibrium with the media in which they are placed and are, therefore, reliable at tracking increases in the soil's moisture content. However, the gypsum block can take considerable time to dry and therefore may not reflect the drying of the surrounding environment.

5.1.2.3 Leachate Quantity and Quality

Leachate that is generated from the aerobic cell will drain to a separate leachate sump installed on top of the eastside Module D leachate collection sump (Image 12). A dedicated pump is then used to remove the leachate and pump it to one of the on-site leachate storage ponds. A flow meter will measure rate and total volume pumped from the sump.

Image 12: Aerobic sump installed and ready for backfill

Leachate is monitored for the following field parameters: pH, electrical conductivity, dissolved oxygen, oxidation-reduction potential, and temperature. When leachate is generated in sufficient quantities, the following parameters will be analyzed by a laboratory: dissolved solids, biochemical oxygen demand, chemical oxygen demand, organic carbon, nutrients (NH_3, TKN, TP), common ions, heavy metals and organic priority pollutants. For the first year, monitoring will be conducted monthly for the first six months and quarterly for the following six months. After the first year, monitoring will be conducted semi-annually (pH, conductivity, and flow rate will continue to be monitored on a monthly basis as required by the State of California's amended Waste Discharge Requirements in Order 5-00-134).

5.1.2.4 Pressure

Pressure within the aerobic cell is monitored with ¼-inch inner diameter and $^3/_8$-inch outer diameter LLDPE sampling tubes. Each tube can be attached to a pressure gage and supplemental air source. By first purging the tube with the air source (to remove any liquid blockages), and then reading the pressure, an accurate gas and/or water pressure can be measured at each sensor location.

5.1.2.5 Landfill Gas Composition

Gas composition is measured utilizing a GEM-500 combustible gas meter manufactured by LANDTEC. The GEM-500 is capable of measuring methane (either as a percent by volume or percent of the lower explosive limit), carbon dioxide, and oxygen. A reading for "balance" gas is also provided (to make up 100 percent) and is assumed to be nitrogen. Currently, gas composition is analyzed from the same sampling tubes used to measure pressure.

5.1.3 Operation

Operation of the aerobic cell as a bioreactor will begin once the air collection system, leachate recirculation systems, and SCADA control systems are complete. At this time, we anticipate bioreactor operation to begin in early 2002.

5.1.3.1 Leachate Recirculation

Initially, large volumes of liquid will be added to bring the waste to field capacity (Image 13). Once field capacity has been reached, only enough liquid to maintain field capacity will be added. We anticipate that greater volumes of liquid (compared to the anaerobic cells) will be necessary to maintain field capacity due to the removal of liquid by the air collection system.

Image 13: Aerobic leachate injection header and lateral

5.1.3.2 Air Collection

Air collection will begin as soon as the necessary piping, blower, and biofilter is installed, which is anticipated to be in early 2002.

5.2 Results And Discussion

Sensor names are represented numerically by the instrumentation layer in which the sensor is located and by the assigned sensor number. The base layer is represented by a 0, Layer 1 is represented by a 1, and so forth. The complete name of the sensor is denoted by the layer number – the sensor number . For example, the second sensor on Layer 1 is named 1-02.

5.2.1 Temperature

Temperature is monitored with thermistors manufactured by Quality Thermistor, Inc. Thermistors with a temperature range of 0°C to 100°C were chosen so they would be able to accommodate the temperature ranges expected in both the anaerobic and aerobic cells. Resistance was measured by the SCADA system located in the instrumentation shed starting in March 2002. Resistance was previously measured manually by connecting the sensor wires to a 26 III Multimeter manufactured by Fluke Corporation.

Anaerobic Base Liner - The Module 6D base liner temperatures range between 19°C and 32°C (66°F and 89°F) as presented in Appendix C, Figure 25. Lower temperatures generally correspond to areas with less overlying waste and higher temperatures correspond to areas with greater overlying waste.

Aerobic Base Layer - Aerobic base layer temperatures range between 27°C and 60°C (80°F and 140°F) as presented in Appendix C, Figure 6. Lower temperatures generally correspond to areas with less overlying waste and higher temperatures correspond to areas with greater overlying waste.

Layer 0.5 - Temperatures from Layer 0.5 remain relatively steady and range from 56°C and 61°C (132°F to 141°F) as presented in Appendix C, Figure 27.

Layer 1 - Layer 1 temperatures generally remain steady and range between 38°C and 71°C (100°F to 160°F) as presented in Appendix C, Figure 28. Lower temperatures are recorded from sensors closer to the waste surface and higher temperatures from sensors buried deeper in the waste mass.

Layer 2 - Layer 2 temperatures are steady and range between 51°C and 60°C (124°C and 140°C), as presented in Appendix C, Figure 29. The spatial variations present within layers 0 and 1 are not present within layer 2. This is most likely due to the uniform thickness of waste overlying the Layer 2 sensors.

5.2.2 Moisture

The SCADA system started electronically measuring moisture in March 2002. Due to a slight variation between how the SCADA system measures moisture compared to the manual meter, moisture readings generally increased a small fraction relative to their previous manually recorded readings. Because moisture data are unitless numbers that give a qualitative assessment rather than a quantitative measure, we feel that this slight change is not significant. Moisture was previously measured manually with a Model MM 4 moisture meter manufactured by Electronics Unlimited. During the pilot scale project, Yolo County conducted laboratory tests with the PVC sensors to determine the relationship between the multimeter readings and the presence of free liquid in the PVC sensor. It was determined that a meter reading of less than 40 corresponded to an absence of free liquid. A reading between 40 and 80 corresponds to the presence of free liquid in the PVC pipe but less than saturated conditions. Readings of greater than 80 indicate saturated conditions; i.e. the PVC sensor is full of liquid.

Anaerobic Base Liner - PVC moisture levels for the base liner are presented in Appendix C, Figure 30. Moisture levels have slightly increased, ranging from approximately 8 to 7, indicating no free liquid.

Aerobic Base Layer - Aerobic base layer PVC moisture levels vary considerably from nearly 0 to 89 as presented in Appendix C, Figure 31. The increase in moisture readings generally corresponds to the onset of the wet weather/rainy season.

Layer 0.5 - Layer 0.5 PVC moisture levels currently range between 63 and 78 in the some-free-liquid zone as presented in Appendix C, Figure 32.

Layer 1 - Layer 1 PVC moisture levels vary considerably from nearly 0 to 77 as presented in Appendix C, Figure 33. Generally, sensors that began in the “some free liquid” zone have remained in that zone and sensors in the “no free liquid zone” have indicated a slight increase.

Layer 2 - Layer 2 PVC moisture levels generally range between 0 to 75 as presented in Appendix C, Figure 34. Sensor 2-20 shows a decline in moisture from the some free liquid zone to the no free liquid zone while sensor 2-19 remains steady in the some free liquid zone. Sensor 2-02 shows an increase in moisture to the some free liquid zone.

5.2.3 Leachate Quantity And Quality

Leachate was sampled in February 2002 for analytical testing. Analytical results are presented in Appendix D. Field chemistry results are presented below in Table 5-1. Prior leachate chemistry and analytical results are not reported because samples taken during the wet season were rainfall rather than leachate and low leachate levels following the rainy season did not allow collection of fresh leachate samples.

Table 5-1. Field Chemistry for Leachate Sampled from Aerobic Cell on February 26, 2002

Parameter	Units	Aerobic Cell
Field Chemistry:		
PH		7.75
Electrical Conductivity	μmoh/cm	7,026
Oxidation Reduction Potential	mV	195
Temperature	^{o}C	15.1
Dissolved Oxygen	mV	5.45
Total Dissolved Solids	mg/L	5,673
Laboratory Chemistry:		
Ammonia as N	mg/L	2.8
Bicarbonate	mg/L	1,120
BOD	mg/L	3.3
Chemical Oxygen Demand	mg/OL	595
Chloride	mg/L	1,670
Nitrate/Nitrite as N	mg/L	0.16
Sulfate	mg/L	290
Total (Non-Volatile) Organic Carbon	mg/L	766
Total Alkalinity as CO_3	mg/L	1,120
Total Dissolved Solids @ 180 ^{o}C	mg/L	4,810
Total Kjeldahl Nitrogen	mg/L	19.9
Total Sulfide	mg/L	0.51
Dissolved Magnesium	mg/L	273
Dissolved Potassium	mg/L	-
Dissolved Iron	mg/L	0.32

5.2.4 Pressure

Pressure measurements are taken from sampling tubes with a DWYER Instruments, Inc., “Magnehelic” pressure gage. Pressure measurements can be either positive or negative, although a vacuum has not yet been applied to the air extraction lines, so negative pressures are not expected at this time. Positive pressures can result from both the generation of landfill gas and saturated liquid conditions.

Anaerobic Base Liner - Pressure readings from the anaerobic base liner sampling tubes are currently positive and below 0.15 centimeters of water (0.06 inches of water) as presented in Appendix C, Figure 35.

Aerobic Base Layer - Pressure readings from the aerobic base layer remain positive and currently below 0.25 centimeters of water (0.10 inches of water) as presented in Appendix C, Figure 36.

Layer 1 - Pressure readings from Layer 1 remain positive and currently below 5.08 centimeters of water (2 inches of water) as presented in Appendix C, Figure 37. Only sampling tube 1-19 has measured an increase in pressure, however it is now decreasing.

Layer 2 - Pressure readings from Layer 2 remain positive and generally below 2.54 centimeters of water (1.0 inches of water) as presented in Appendix C, Figure 38. The high readings from 2-14 are not supported by moisture readings which suggests the tube may be clogged.

5.2.5 Landfill Gas Composition

Gas composition is measured from sampling tubes on each layer of the cells with the GEM-500. Because liquid will damage the GEM, pressurized air is first forced through the tubes to remove any liquid, then the tube lines are purged with a vacuum pump and hooked up to the GEM to analyze the gas composition.

Anaerobic Base Liner - Data presented in Appendix C, Table 16 indicates rising methane levels and depleted oxygen levels. Oxygen measured on the anaerobic base liner is most likely the result of air intrusion into the permeable shredded tire operations layer (which was not completely covered by waste) that covers the entire bottom of Module 6D.

Aerobic Base Layer - Gas compositions from the aerobic base layer indicate depleted oxygen levels and low methane concentrations as presented in Appendix C, Table 17. Indicating this layer is still generally in the aerobic phase.

Layer 1 - Gas compositions from the aerobic Layer 1 indicate depleted oxygen levels and low methane concentrations as presented in Appendix C, Table 18. Indicating this layer is still generally in the aerobic phase.

Layer 2 - Gas compositions from the aerobic Layer 2 indicate depleted oxygen levels and low methane concentrations as presented in Appendix C, Table 19. Indicating this layer is still generally in the aerobic phase.

6 MODULE 6D BASE LINER

The three bioreactor cells share a common composite liner system, designated the Module 6D primary liner. This composite liner system was constructed in 1999 and was designed to exceed the requirements of Title 27 of CCR and Subtitle D of the Federal guidelines.

6.1 EXPERIMENTAL

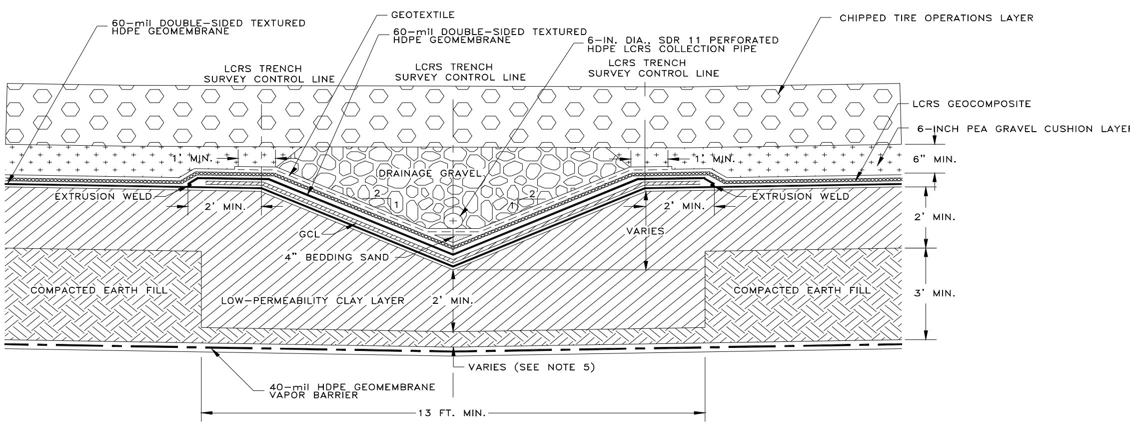
The experimental methods utilized are grouped into two categories: construction and monitoring. Each of these categories is discussed below.

6.1.1 Construction

Construction of the Module 6D primary liner system can generally be separated into two tasks: grading and base liner assembly.

6.1.1.1 Grading

The base layer of Module D was constructed in a ridge and swale configuration, enabling the west-side 6-acre anaerobic cell to be hydraulically separated from the northeast anaerobic cell and the aerobic cell in the southeast quadrant. The base layer slopes 2 percent inward to two central collection v-notch trenches located on the southeast and southwest side of Module D (Detail 5). Each of the trenches drain at 1 percent to their respective leachate collection sumps located at the south side of the module.



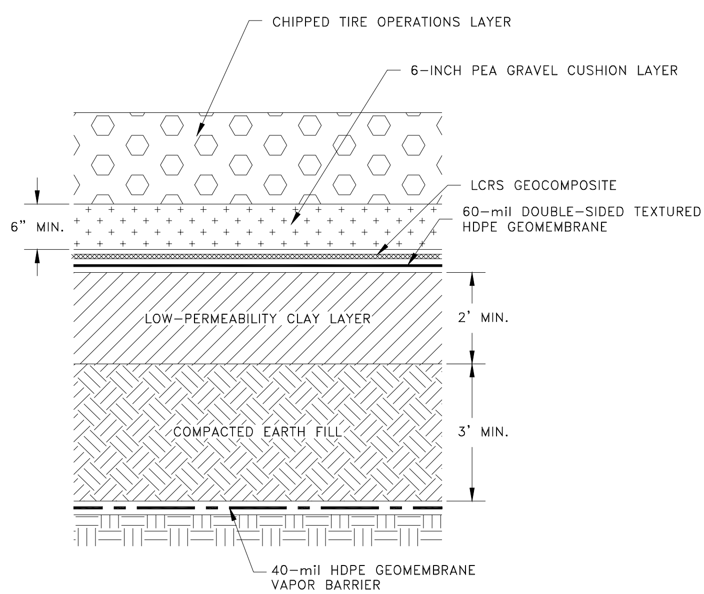
Detail 5. Module D Bottom Liner and Leachate Collection Trench Cross-Section

6.1.1.2 Base Liner Assembly

The liner is composed, from top to bottom, of the following materials: an operations/drainage layer consisting of 2 feet of chipped tires (permeability [k] > 1 centimeter per second [cm/s]) (Image 14), 6-inches of pea gravel, geocomposite drain net, a 60-mil high density polyethylene

Image 14: Shredded tire operations layer

(HDPE) geomembrane, a 2–foot-thick compacted clay liner ($k < 6 \times 10^{-9}$ cm/s), 3 feet of compacted earth fill ($k < 1 \times 10^{-8}$ cm/s), a 40-mil HDPE vapor barrier layer, and a clay subgrade with 90-percent (ASTM D1557) relative compaction[3] (Detail 6).



Detail 6. Module D Bottom Liner Cross-Section

[3] Golder Associates, "Final Report, Construction Quality Assurance, Yolo County Central Landfill, WMU 6, Module D, Phase 1 Expansion", December 1999.

6.1.2 Monitoring

As part of the requirements specified under Waste Discharge Requirements in Order 5-00-134, Yolo County is required to monitor liquid buildup on the liner. Under typical landfilling, liquid buildup on a Class III composite liner system must be maintained to less than 1 foot. In order to gain approval from the California Regional Water Quality Control Board to operate Module 6D as a bioreactor, Yolo County must maintain less than 4-inches of liquid buildup on the Module 6D primary liner[4]. Head over the liner is monitored through a series of pressure transducers and sampling tubes either in or next to the two leachate collection trenches. In addition, sampling tubes located on the Module 6D liner (designations 0-1 through 0-66) are utilized to monitor head over the liner. The sampling tubes are discussed in previous sections.

6.1.2.1 Leachate Collection Trenches

Three LLDPE sampling tubes were installed in each of the leachate collection trenches (Image 15). The tubes were installed inside a 2-inch-diameter PVC pipe for protection, and terminate at different points along the trenches. The sampling tubes can be hooked up to the same "Magnahelic" pressure gage, which reads directly in inches-of-water.

Pressure transducers were installed at three locations adjacent to each leachate collection trench. Additionally, tubes were installed that terminate adjacent to each of the pressure transducer locations (Appendix B. Detail 7). The pressure transducers provide an output current between 4 and 20 milliamps, which is directly proportional to pressure. The pressure transducers installed on the Module 6D liner are Model PTX 1830 manufactured by Druck, Inc. Their pressure range is 0 to 1 pounds per square inch (psi) and have an accuracy of ±1 percent of full scale.

Image 15: Pressure tubes installed in LCRS trench

[4] California Regional Water Quality Control Board, Central Valley Region, "Waste Discharge Requirements for the Yolo County Central Landfill, No. 5-00-134", June 16, 2000.

6.2 RESULTS AND DISCUSSION

Tubes located in the leachate collection trenches are referred to as trench liquid level (TLL) tubes. Pressure transducers and their accompanying tubes that are located adjacent to the leachate collection trenches are denoted as PT or PT-TUBE respectively.

6.2.1 Leachate Collection Trenches

Pressure transducers generally range between 0.13 and 1.02 centimeters of water (0.05 and 0.4 inches of water), and adjacent tubes range between 0 and 0.31 centimeters of water (0 and 0.15 inches of water) as presented in Appendix C, Figure 39. The difference between the pressure transducers and the adjacent tubes are within the range of measurement error and therefore tend to confirm each other.

Trench liquid levels range between 0 and 4.57 centimeters of water (0 and 1.8 inches of water). Because leachate generation and pumping data suggest very little leachate was present on the base liner it may be possible that some of the elevated readings may be due to partial collapse or failure of the tubes (Appendix C, Figure 40). Monitoring and evaluation of the trench liquid level tubes will continue.

7 SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEM (SCADA)

The Supervisory Control and Data Acquisition (SCADA) system will be used to monitor the various sensors and control the operation of the bioreactor. The field electronics will be linked by radio signal to a computer located in our Woodland office.

7.1 HARDWARE INSTALLATION

The data collection hardware has been installed in a shed located at the southern limit of Module 6D. All instrumentation installed in the northeast anaerobic, aerobic, and on the Module 6D composite liner have been connected to an Allen-Bradley central processor which will be radio linked to a computer located in our woodland office.

7.2 SOFTWARE PROGRAMMING

The SCADA programming using Wonderware software is currently being developed by a consultant, A-TEEM Electrical Engineering. The first phase of software development is complete and encompass data collection from the instrumentation installed on the Module 6D liner, northeast anaerobic, and southeast aerobic modules. Once the remaining instrumentation has been installed in the west-side anaerobic cell, it will be incorporated into the system.

8 PROJECTED ECONOMICS

This section discusses the project economics for both the anaerobic and aerobic bioreactor operations. Anaerobic bioreactor costs are estimated based on the current costs-to-date for the northeast and west-side cells and then extrapolated for a complete 12 acre module. Aerobic bioreactor costs are estimated based on the current costs-to-date for the southeast cell and then extrapolated for a complete 12 acre module (with a waste capacity of 359,400 tons). The economics of either bioreactor option are highly dependent on the chosen waste fill configuration, with a higher ratio of waste per unit of lined area (i.e. higher depth of fill) equating to more favorable economics.

8.1 ANAEROBIC BIOREACTOR

Anaerobic bioreactor costs are estimated based on the current costs-to-date for the northeast and west-side cells and then extrapolated for a complete 12 acre module.

8.1.1 Design, Capital, and Monitoring and Maintenance Costs

The design, capitol, and monitoring costs for an anaerobic bioreactor are presented in Table 8-1 below. The costs associated with both the northeast and west-side bioreactor have been combined and then extrapolated to estimate the cost of bioreactor operation. The estimated unit cost for anaerobic operation on a full-scale basis is $2.27/ton.

Table 8-1
Costs Estimate for Anaerobic Bioreactor Operation[5]

Description	Anaerobic Bioreactor Cost per Ton for 9.5 Acres and 205,104 Tons of Waste[6]	Anaerobic Bioreactor Cost Per Ton for 12 Acres and 359,400 Tons of Waste[7]
Construction of composite liner and tire operations layer[8]	Not an additional cost for bioreactor operation	Not an additional cost for bioreactor operation
Construction of Waste Monitoring System	$0.889/ton	$0.634/ton
Construction Of Landfill Gas Collection And Removal System[9]	$0.337/ton	$0.238/ton
Construction Of Leachate Recirculation/Pumping System	$0.682/ton	$0.487/ton
Construction Of Synthetic Cover System[10]	Only used as part of this research project, assumed will not be necessary in commercial application	Only used as part of this research project, assumed will not be necessary in commercial application
SCADA Data Collection And Control System	$0.371/ton	$0.264/ton
Subtotal Of Capital Costs	**$2.279/ton**	**$1.623/ton**
Design Of All Systems	$0.321/ton	$0.321/ton
Initial Project Monitoring And Reporting	$0.200/ton	$0.143/ton
Ongoing Project O&M Costs For 5 Years	$0.417/ton	$0.417/ton
Subtotal Of Associated Costs	**$0.938/ton**	**$0.881/ton**
TOTAL PROJECTED COST	**$3.22/ton**	**$2.27/ton**

[5] Assumptions for this cost estimate are based on waste fill configurations specific to the Yolo County Central Landfill (YCCL). Currently, the maximum permitted waste depth at the YCCL is approximately 50 feet, If site conditions allow greater fill depths, unit costs for bioreactor operation should be significantly lower.
[6] The total tons of waste placed in the northeast cell was 65,104 tons, the estimated total tons of waste that will be placed in the west-side cell is 130,000 tons.
[7] The estimated capacity of Module 6D, Phase 1 is 359,400 tons assuming it was completely filled and had a maximum refuse depth of 50 feet.
[8] The total cost for the gravel and tire operations layer for all of Module 6D, Phase 1 was $321,000. The total cost of the Module 6D, Phase 1 composite liner system was $2,011,612. Because a composite liner and operations layer is required under normal landfill operations, no costs are attributed to the bioreactor
[9] Bioreactor landfill gas collection system costs are those above what are typically installed in conventional landfilling. Conventional landfill gas collection costs are assumed at $6000/ acre.
[10] Because a synthetic cover system would be required for final closure regardless of whether bioreactor operation is implemented, no costs are shown here

8.1.2 Applicability to Other Projects

Design, construction, and operation costs at the Yolo County Central Landfill can be used to estimate construction costs for other commercial scale projects. For the "as-constructed" anaerobic bioreactor, a total of 65,104 tons of waste were placed in the northeast anaerobic module and an estimated 140,000 tons will be placed in the west-side anaerobic module. If Module 6D, Phase 1 were completely filled, it would have an estimated refuse capacity of 359,400 tons.

For a comparison to traditional landfilling techniques, several of the tasks presented in Table 8-1 are not included in the bioreactor cost calculation. Capital and operating costs for application of enhanced landfill technology are only those incurred above and beyond the cost of conventional landfilling. For cost analysis purposes it is important to recognize that whatever containment design is used, *most* of the cost of landfilling is incurred as part of basic environmental protection and is independent of whether methane enhancement is practiced. For example, costs common to enhanced and conventional landfilling include:

- A base liner system and a leachate collection and removal system (although not necessarily with a layer of highly permeable shredded tires)
- Eventual waste coverage with a low permeability cover.
- The installation of a landfill gas recovery system.
- All normal operation and maintenance work will be incurred in any case.

If we subtract out the costs associated with a composite liner and operations layer, final cover system, and the portion of LFG collection and removal systems that would have been constructed under conventional landfilling, we end up with the true net additional cost for anaerobic bioreactor operation.

8.1.3 Estimated Benefit Based on Airspace Recovery

As settlement occurs in a landfill module, the difference between the original filled elevation and the settled elevation results in a recovery of available airspace. This recovered airspace is then available for additional waste placement. Based on the results of the previous pilot scale project[11] we anticipate airspace recovery rates on the order of 15 percent within 5 years of operation.

8.1.3.1 Full-Scale Bioreactor Operation

The estimated entire volume of Module 6D, Phase 1 is approximately 768,700 cubic yards. Assuming 15 percent airspace recovery within the first 5 years of operation, the recoverable airspace would be 115,305 cubic yards. Equating this to waste tonnage:

Tonnage = (115,305 cy)*(1100lb/cy)*(1ton/2000lb)(4/5) = 50,734 tons

Assumptions:

Refuse density = 1100 lb/cy
Refuse to soil ratio = 4:1

[11] Based on most recent topographic survey conducted by Yolo County, November 6, 2001

By placing additional waste in the same volume of airspace, landfilling costs such as liner construction, closure and corrective action fund contributions, and landfill replacement costs could be avoided or at least postponed. The portion of the current $36 tipping fee at the Yolo County Central Landfill that could be averted or postponed by bioreactor operation is $11.07/ton[12]. Thus, airspace recovery represents a potential benefit of $561,625.

8.1.4 Estimated Benefit Based on Landfill Gas Recovery

Landfill gas recovery and subsequent power generation can provide an additional source of revenue to a landfill. As an additional benefit (although not currently monetary) increased landfill gas recovery rates associated with bioreactor operation can significantly reduce the fugitive emissions of methane which has been shown as a potent greenhouse gas. Based on the results of the pilot scale project we anticipate methane gas recovery rates on the order of 1.5 cubic feet per dry pound of waste within 5 years of operation.

8.1.4.1 Full-Scale Bioreactor Operation

If Module 6D, Phase 1 were to be filled completely, the total estimated capacity of waste and greenwaste would be 413,300 tons (359,400 tons waste and 53,900 tons greenwaste ADC). Assuming the waste had an initial moisture content of 20 percent, the total dry tons of waste would be 330,640 tons. Equating this to an average cubic feet per hour over a 5 year period;

Cubic feet per hour = (330,640 tons)*(2000lb/ton)(1.5cf/lb)*(1/5years)(1/365 days)*(1/24hours) = 22,647 cubic feet per hour

The heat energy potential of the methane gas is estimated assuming 900 BTU per ft^3 of methane (Augenstein and Pacey, 1992). Electrical energy potential is estimated using a heat rate of 12,500 BTU per kWhr (Augenstein and Pacey, 1992). Therefore, the average flow rate of methane, converted to actual electrical generation would be;

BTU/hr = (22,647cf)*(900) = 20,382,300 BTU/hr

kWhr = (22,382,300 BTU/hr)/(12,500 BTU/kWhr) = 1,631 kWhr

Compare this to the Control Cell (no liquid addition) from the pilot project that, to-date, has generated approximately 0.6 cubic feet of methane per dry pound of waste (essentially a dry-tomb landfill with an excellent LFG recovery system);

Electricity generated (no liquid addition) = (1,631 kw-hr)*(0.6/1.5) = 652 kw-hr

Compare this to a dry-tomb landfill that has a poor LFG collection system. For estimation purposes, we have assumed approximately 0.3 cubic feet of methane per dry pound of waste will be produced over the first 5 years;

Electricity generated (no liquid addition) = (1631 kw-hr)*(0.3/1.5) = 326 kw-hr

An example calculation for the potential revenue from the sale of electricity (from the bioreactor cell, assuming $0.03/kw-hr over the course of 5 years) is;

[12] Tipping fee summary prepared by Yolo County personnel for Public Works Week display, May 2001

Revenue = (1631 kw-hr)*(24hr)*(365 days)*(5 years)*($0.03/kw-hr) = $2,143,134

A summary of benefits from increased landfill gas generation and recovery is provided in Table 8-2.

8.1.5 Estimated Benefit Based on Reduced Post-Closure Maintenance

One of the frequently discussed benefits of bioreactor operation is the potential for reduction of the post-closure maintenance requirements compared to traditional landfilling techniques. Basically, the argument presented is that by decomposing the waste quickly (5-10 years) and creating a stable waste mass, (potentially while the landfill is still operating) you will reduce the post-closure maintenance requirements. While we believe that significant reductions in post closure maintenance requirements are possible we feel it is unrealistic to assume no costs will be incurred within the currently mandated minimum 30-year post-closure period. For analysis purposes, we are assuming the waste will be stabilized and all post-closure maintenance activities will occur within 10 years, thus a two-thirds reduction in costs (from 30 to 10 years).

Currently, the estimated post-closure cost estimate for the composite lined modules at the Yolo County Central Landfill is $9,379,225[13] and the estimated airspace volume (less final cover) of these modules is 19,978,000 cubic yards. This equates to a post closure cost of $0.47 per cubic yard.

Table 8-2
Landfill Gas Generation and Recovery Benefit

Item	**Anaerobic Bioreactor Module**	**Dry-Tomb Landfill With Excellent LFG Recovery System[14]**	**Dry-Tomb Landfill With Poor LFG Recovery System**
Average flow rate (5 years)	22,647 cu-ft/hr	5,263 cu-ft/hr	2632 cu-ft/hr
Energy generation potential	1,631 kw-hr	652 kw-hr	326 kw-hr
Revenue potential from electricity sales (at $0.01 per kw-hr)	$714,378	$285,576	$142,788
Revenue potential from electricity sales (at $0.03 per kw-hr)	$2,143,134	$856,728	$428,364
Revenue potential from electricity sales (at $0.05 per kw-hr)	$3,571,890	$1,427,880	$713,940

[13] CH2M Hill, "Preliminary Closure and Post-Closure Maintenance Plan for Waste Management Units 6 and 7, Yolo County Central Landfill", June 1996.
[14] Based on data from the pilot-scale demonstration project and the assumption that excellent landfill gas recovery can be accomplished without the use of a synthetic cover by installation of additional gas collection wells.

8.1.5.1 Full-Scale Bioreactor Operation

The estimated volume of the completely filled Module 6D is 769,000 cubic yards. Thus, its share of the post closure cost is;

Typical post closure cost = (769,000 cubic yards)*($0.47) = $361,430

Assuming post closure maintenance costs are reduced by two-thirds (from 30 to 10 years), the bioreactor post closure cost estimate would be;

Bioreactor post closure cost = $62,040/3 = $120,477

8.1.6 Leachate Treatment Cost Savings

The recirculation of landfill leachate has been shown to result in a leachate with a reduced pollution load. This treatment benefit from recirculation can result in lower costs paid to a wastewater treatment facility or can preclude the necessity of a leachate pretreatment system prior to discharge to a wastewater treatment plant. Additionally, using the landfill for leachate storage can equalize leachate flows such that leachate is disposed of with a relatively constant flow-rate. This can reduce treatment costs and reduce the need to construct leachate storage facilities.

8.1.6.1 Full-Scale Bioreactor Operation

Based on the previous pilot-scale project conducted at the YCCL, the amount of liquid addition necessary to bring the waste to field capacity is approximately 30 to 50 gallons per ton of waste. With a estimated capacity of waste and ADC of 413,300 tons, the estimated volume of liquid required to increase the moisture content to field capacity (at 30 gallons per ton) is 12,399,000 gallons. Liquid will also be utilized in the anaerobic decomposition process. Utilizing a value of 0.0119 lb H2O/ft^3 of methane generated, and an average flow rate of 22,647 cf methane/ hour, the amount of water consumed over a 5 year period would be 11,804,069 lbs. Converting this to gallons, 1,414,975 gallons of leachate will be utilized. Based on a disposal cost of $0.035/ per gallon[15], the estimated benefit from averted leachate disposal cost is $483,489.

8.2 AEROBIC BIOREACTOR

8.2.1 Design, Capital, and Monitoring and Maintenance Costs

Because the southeast aerobic cell is just beginning operation, the majority of costs incurred thus far have been related to design, construction and startup of the system. To bring the system into full operation, the blower station and biofilter still require completion. We have estimated the costs to complete the blower station and biofilter and then extrapolated the cost and estimated the ultimate volume assuming the entire area (12 acres) of Module 6D, Phase 1 were operated as an aerobic bioreactor. The unit cost for aerobic bioreactor operation is $5.31/ton.

8.2.2 Applicability to Other Projects

Design, construction, and operation costs at the Yolo County Central Landfill can be used to estimate construction costs for other commercial scale projects. A total of 11,942 tons of waste were placed in the southeast aerobic module. . If Module 6D, Phase 1 were completely filled, it would have an estimated refuse capacity of 359,400 tons.

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[15] Cost estimate obtained form Sacramento County for the Kiefer landfill was $0.07/gal. For conservative estimation purposes, we have assumed one-half that value or $0.035/gal.

For a comparison to traditional landfilling techniques, several of the items presented in Table 8-3 are not included in the bioreactor cost calculation. Capital and operating costs for application of enhanced landfill technology are only those incurred above and beyond the cost of conventional landfilling. For cost analysis purposes it is important to recognize that whatever containment design is used, *most* of the cost of landfilling is incurred as part of basic environmental protection and is independent of whether methane enhancement is practiced. For example, costs common to enhanced and conventional landfilling include:

- A base liner system and a leachate collection and removal system (although not necessarily with a layer of highly permeable shredded tires)
- Eventual waste coverage with a low permeability cover.
- The installation of a landfill gas recovery system.
- All normal operation and maintenance work will be incurred in any case.

If we subtract out the costs associated with a composite liner and operations layer, aerobic liner and operations layer, and the portion of the air collection system that would have been constructed under conventional anaerobic landfilling (as a LFG collection system), we end up with the true net additional cost for anaerobic bioreactor operation.

Table 8-3
Costs Estimate for Aerobic Bioreactor Operation

Description	Aerobic Bioreactor Cost per Ton for 2.5 Acres and 11,942 Tons of Waste	Aerobic Bioreactor Cost Per Ton for 12 Acres and 359,400 Tons of Waste[16]
Construction of Module 6D composite liner and tire operations layer[17]	Not an additional cost for bioreactor operation	Not an additional cost for bioreactor operation
Construction secondary liner and tire operations layer[18]	Only was constructed as part of this research project	Only was constructed as part of this research project
Construction of Waste Monitoring System	$5.142/ton	$0.820/ton
Construction of Air Collection System, Including Piping, Blower and Biofilter[19]	$12.284/ton	$1.600/ton
Construction Of Leachate Recirculation/Pumping System	$6.741/ton	$1.075/ton
SCADA Data Collection And Control System	$4.689/ton	$0.748/ton
Subtotal Of Capital Costs	**$28.856/ton**	**$4.243/ton**
Design Of All Systems	$0.130/ton	$0.130/ton
Electricity for Blower	$1.532/ton	$0.254/ton
Initial Project Monitoring And Reporting	$1.993/ton	$0.317/ton
Ongoing Project O&M Costs For 1 Year	$2.512/ton	$0.167/ton
Subtotal Of Associated Costs	**$6.167/ton**	**$0.868/ton**
TOTAL PROJECTED COST	**$35.02/ton**	**$5.11/ton**

8.2.3 Estimated Benefit Based on Airspace Recovery

8.2.3.1 Full-Scale Aerobic Operation

The estimated volume of all of Module 6D, Phase 1 is 768,700. Assuming 30 percent airspace recovery within the first 1 year of operation, the recoverable airspace would be 230,610 cubic yards. Equating this to waste tonnage:

Tonnage = (230,610 cy)*(1100lb/cy)*(1ton/2000lb)(4/5) = 101,468 tons

Assumptions:

Refuse density = 1100 lb/cy
Refuse to soil ratio = 4:1

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[16] The estimated capacity of Module 6D, Phase 1 is 359,400 tons assuming it was completely filled and had a maximum refuse depth of 50 feet.

[17] The total cost for the gravel and tire operations layer for all of Module 6D, Phase 1 was $321,000. The total cost of the Module 6D, Phase 1 composite liner system was $2,011,612. Because a composite liner and operations layer is required under normal landfill operations, no costs are attributed to the bioreactor

[18] The total cost for the gravel and tire operations layer for all of Module 6D, Phase 1 was $321,000. The cost reported here is only for the portion of the gravel and tire operations layer below the Anaerobic modules. The total cost of the Module 6D, Phase 1 composite liner system was $2,011,612.

[19] Bioreactor air collection system costs are those above what are typically installed in conventional landfill gas collection system. Conventional landfill gas collection costs are assumed at $6000/ acre.

By placing additional waste in the same volume of airspace, landfilling costs such as liner construction, closure and corrective action fund contributions, and landfill replacement costs could be avoided or at least postponed. The portion of the current $36 tipping fee at the Yolo County Central Landfill that could be averted or postponed by bioreactor operation is $11.07/ton. Thus, airspace recovery represents a potential benefit of $1,123,251.

8.2.4 Estimated Benefit Based on Reduced Post-Closure Maintenance

One of the frequently discussed benefits of bioreactor operation is the potential for reduction of the post-closure maintenance requirements compared to traditional landfilling techniques. Basically, the argument presented is that by decomposing the waste quickly (5-10 years) and creating a stable waste mass, (potentially while the landfill is still operating) you will reduce the post-closure maintenance requirements. While we believe that significant reductions in post closure maintenance requirements are possible we feel it is unrealistic to assume no costs will be incurred within the currently mandated minimum 30-year post-closure period. For analysis purposes, we are assuming a reduction in post-closure time to 5 years (with a corresponding decrease in costs).

Currently, the estimated post-closure cost estimate for the composite lined modules at the Yolo County Central Landfill is $9,379,225 and the estimated airspace volume (less final cover) of these modules is 19,978,000 cubic yards. This equates to a post closure cost of $0.47 per cubic yard.

8.2.4.1 Full-Scale Aerobic Bioreactor Operation

The estimated total volume of all of Module 6D, Phase 1 is 768,700 cubic yards. Thus, its share of the post closure cost is;

Typical post closure cost = (768,700 cubic yards)*($0.47) = $361,289

Assuming post closure maintenance costs are reduced by five-sixths (from 30 to 5 years), the bioreactor post closure cost estimate would be;

Aerobic bioreactor post closure cost = $361,289/6 = $53,548

8.2.5 Leachate Treatment Cost Savings

The recirculation of landfill leachate has been shown to result in a leachate with a reduced pollution load. This treatment benefit from recirculation can result in lower costs paid to a wastewater treatment facility or can preclude the necessity of a leachate pretreatment system prior to discharge to a wastewater treatment plant. Additionally, using the landfill for leachate storage can equalize leachate flows such that leachate is disposed of with a relatively constant flow-rate. This can reduce treatment costs and reduce the need to construct leachate storage facilities.

8.2.5.1 Full-Scale Aerobic Bioreactor Operation

Based on the previous pilot-scale project conducted at the YCCL, the amount of liquid addition necessary to bring the waste to field capacity is approximately 30 to 50 gallons per ton of waste. With a estimated capacity of waste and ADC of 413,300 tons, the estimated volume of liquid required to increase the moisture content to field capacity (at 30 gallons per ton) is 12,399,000 gallons. Liquid will also be evaporated by the by the large volumes of air passing through the waste. For estimation purposes, we have assumed an equal volume (12,399,000) of liquid will be evaporated as was required to bring the waste to field capacity. Based on a disposal cost of \$0.035/ per gallon[20], the estimated benefit from averted leachate disposal cost is \$867,930.

8.3 CONCLUSION

Table 8-4 below summarizes the costs and benefits associated with bioreactor operation. As with any economic analysis, many assumptions must be made and as such a degree of uncertainty is involved. Particular attention should be paid to the aerobic bioreactor cost estimate. Because the blower station and biofilter have not been constructed yet it was necessary to assume many of the costs associated with these items. Additionally, because aerobic bioreactor technology is still relatively new, there is much uncertainty in the reaction of waste to the aerobic decomposition process (is 30 percent settlement realistic for a full scale operation?) and in the volume of air required to decompose the waste (which will have a dramatic effect on the number of blowers and power consumption requirements).

Overall, we are quite confident that anaerobic bioreactor operation is economically feasible. Indeed, if this analysis is confirmed by the eventual cost of this project, it is not only economically feasible, but economically beneficial. Further research is requires, however at this point, it is uncertain if aerobic bioreactor operation will be economically feasible.

Table 8-4
Aerobic and Anaerobic Bioreactor
Benefit/Cost Summary for a 12 Acre Module

Item	**Anaerobic Bioreactor**	**Aerobic Bioreactor**
Total Cost	**(\$2.27/ton)**	**(\$5.11/ton)**
Airspace Recovery Benefit	\$1.56/ton	\$3.13
Post-Closure Reduction Benefit	\$0.67/ton	\$0.86/ton
Electricity Benefit (at 0.01/kW-hr)	\$1.99/ton	\$0
Leachate Disposal Reduction Benefit	\$1.35/ton	\$2.41/ton
Total Benefit	**\$5.57/ton**	**\$6.40/ton**
Net (Cost)/Benefit	**\$3.30/ton**	**\$1.29/ton**
Benefit/Cost Ratio	**2.45**	**1.25**

9 CONCLUSION

With the initial construction phase of the project complete for the northeast anaerobic cell and nearly complete for the southeast aerobic cell Yolo County has gained valuable knowledge about the design and operation of bioreactor landfills. The following sections provide a summary of the knowledge we have learned to-date and recommendations for future bioreactor operation and areas that require additional research.

[20] Cost estimate obtained form Sacramento County for the Kiefer landfill was \$0.07/gal. For conservative estimation purposes, we have assumed one-half that value or \$0.035/gal.

9.1 INSTALLATION OF BIORACTOR SYSTEMS

Shredded tires can be beneficially used in both the operations layer and gas collection system. As demonstrated by this and previous projects at Yolo County, the market should continue to develop for the beneficial use of discarded tires. Approximately 1.5 million tires were utilized during the course of this project. Under certain circumstances it was necessary to stockpile shredded tires for subsequent use in construction of the landfill gas collection lines. While the use of shredded tires is still economically more advantageous than gravel, reduced costs could be achieved if the shredded tires could be directly placed in the area of construction.

The use of alternative daily cover in the form of greenwaste or tarps was successfully during the waste filling phase of this project. By limiting the amount of soil placed in the landfill we hope to increase waste permeability which will allow for more uniform liquid distribution throughout the waste.

With close coordination with the waste placement contractor, the monitoring, landfill gas collection, and liquid injection systems were successfully installed concurrent with waste placement. In addition, the methods utilized to protect the various instruments and piping from construction equipment and subsequent waste placement (chipped or shredded greenwaste was utilized as bedding and shredded tires were used as cover) were successful

9.2 BIOREATOR STABILITY

As part of the design and planed operation of a full-scale bioreactor landfill, we evaluated the effects of having a saturated waste mass on the overall stability of the landfill module. The County retained the services of Vector Engineering to perform laboratory tests on the materials used in constructing Module 6D (synthetic liner material, shredded tires, clay) and perform a stability analysis evaluating various fill configurations and different waste densities. The result of their analysis indicated that waste filling and bioreactor operation was possible with up to 2 to 1 (horizontal to vertical) side-slopes. A word of caution though, this analysis was specifically performed for the YCCL site and the specific material utilized in construction of Module 6D, Phase 1.

Based on the stability analysis performed for the YCCL, it is likely that other landfills could construct and operate a bioreactor module with an acceptable factor of safety. We would recommend any landfill operator perform a site specific stability analysis prior to considering bioreactor operation.

9.3 LANDFILL GAS RECOVERY

It is well established that by increasing the moisture content of waste undergoing anaerobic decomposition, increases in landfill gas generation will follow. As we have only just begun liquid addition, all of the landfill gas that has been generated to-date has occurred with the moisture content of the waste the same as the day it was placed. Through the end of March 2002 a total of 2.16×10^6 scf of landfill gas has been collected (with an average methane concentration around 40 percent). With the average age of the waste only about one year old, it is clear that significant amounts of landfill gas can be generated in a relatively short amount of time.

Early recovery of the landfill gas being generated by the northeast cell is only possible because the landfill gas collection system (horizontal gas collection lines) were installed during waste placement and subsequently connected to the site gas collection system shortly after completion of waste placement. In addition, the placement of the synthetic surface liner has ensured near complete capture of the landfill gas that is being generated.

It seems clear that the typical 3-5 years that elapses between waste placement and installation of landfill gas collection system components is resulting in an under utilization of a potential energy source and potentially allowing significant quantities of landfill gas to be emitted as fugitive emissions from the landfill surface.

9.4 EXPOSED SURFACE MEMBRANE COVER

The installation of an exposed surface membrane cover as part of the bioreactor project ensures that accurate and complete data collection is possible regarding liquid addition volumes (by eliminating rainwater infiltration) and landfill gas collection. However, the installation of this surface liner accounted for a major portion of the costs of constructing the northeast anaerobic bioreactor. As part of the regulatory flexibility granted for this project, the County agreed to install a synthetic cover prior to bioreactor operation.

Because the early installation of a membrane cover represents a significant capitol outlay, An area for future research should involve the trial operation of a bioreactor module that is absent a synthetic cover. The purpose of this research would be to determine if surface emissions can be controlled without the installation of a synthetic cover. A possible alternative that would require demonstration would be the inclusion of a relatively thick layer of greenwaste or compost over the entire module that could act as a natural biofilter.

9.5 AEROBIC BIOREACTOR OPERATION

Although the construction phase of the aerobic bioreactor has not been completed, it is apparent that there are significant capitol and operations costs associated with this form of landfilling.

The capitol necessary to purchase the blowers and subsequent electricity costs may be the achilles heel of aerobic bioreactors. Further research is required to demonstrate whether the advantages of aerobic bioreactors (rapid settlement and the elimination of methane generation) can outweigh the significant costs. One option that requires further study would be mining and sorting of the waste following aerobic decomposition. The reclaiming landfill space could improve the overall economics of aerobic operation by creating a sustainable operation.

10 REFERENCES

1. Vector Engineering, “Design Report for the Surface Liners of the Module D Phase 1 Bioreactors at the Yolo County Central Landfill”, October 2001.

2. Yazdani, R., Moore, R. Dahl. K. and D. Augenstein 1998 Yolo County Controlled Landfill Bioreactor Project. Yolo County Public Works and I E M, Inc. Yolo County Public Works and I E M, Inc. report to the Urban Consortium Energy Foundation (UUCETF) and the Western Regional Biomass Energy Program, USDOE.

3. Golder Associates, “Final Report, Construction Quality Assurance, Yolo County Central Landfill, WMU 6, Module D, Phase 1 Expansion”, December 1999.

4. California Regional Water Quality Control Board, Central Valley Region, “Waste Discharge Requirements for the Yolo County Central Landfill, No. 5-00-134”, June 16, 2000.

5. Yolo County, IEM, SWANA, EPA, Final Project Agreement for the Yolo County Accelerated Anaerobic and Aerobic Composting (Bioreactor) Project, September 14, 2000.

6. Tchobanoglous et al, “Integrated Solid Waste Management, Engineering Principles and management Issues”, McGraw-Hill, 1993.

APPENDIX A – EPA XL SCHEDULE AND SUMMARY OF MATERIALS INSTALLED

Table 1. Revised Project XL Delivery Schedule

Project Task	Delivery Date
• RWQCB approved the revised Waste Discharge Requirement Permit	June 22, 2000
• Final draft FPA circulated to stakeholders for comments	June 22, 2000
• Comments received for final FPA • Instrumentation installation began	July 3, 2000
• Finalize FPA and distribute for signature	July 21, 2000
• All parties sign FPA document	September, 2000
• Final Rule for Yolo County XL Project published in Federal Register	August 30, 2001
• First lift of waste completed in the southeast corner of Module 6D. This lift of waste is to be used as the foundation layer for the aerobic cell liner.	January 2001
• Waste placement begins in the northeast 3.5 acre anaerobic bioreactor	January 2001
• Begin monitoring temperature and moisture of waste	January 2001
• Begin waste placement in west 6-acre anaerobic cell (waste placement alternates between the west and northeast anaerobic bioreactors and the aerobic bioreactor to facilitate placement of instrumentation, piping, etc.)	March 2001
• Completed construction of aerobic cell liner and begin waste placement in aerobic cell	July, 2001
• Complete the following for the northeast anaerobic 3.5-acre cell: waste placement, instrumentation, leachate injection system, air injection system, and gas and leachate monitoring	September 2001
• Complete the following for the aerobic bioreactor: waste placement, instrumentation, data acquisition and control system, leachate injection system, air management system, gas and leachate monitoring	November 2001
• Begin liquid addition to the northeast 3.5-acre anaerobic cell	November 2001
• Begin liquid addition and air injection in aerobic bioreactor	December 2001
• Complete the following for the west anaerobic 6-acre cell: waste placement, instrumentation, data acquisition and control system, leachate injection system, air injection system, gas and leachate monitoring, and cover system	October 2002
• Begin liquid injection in the west side 6-acre anaerobic bioreactor	November 2002
• Data collection and reporting will continue	On-going until waste stabilization is complete, but dependent on sustained funding levels

Table 2. Summary of Data for the Northeast Anaerobic Cell

Description	Data
Footprint	3.4 acres
Average Waste Depth	35 feet
Construction of the Base Liner	1999
Waste Filling of Cells	1/13/2001 – 8/3/2001
Total # of Waste Lifts	4
Total Amount of Waste	65,104 tons
Total Amount of Greenwaste ADC[2]	11,060 tons
Volume of Soil[2] Within the Waste Mass	5,970 cubic yards
As-Placed Biodegradable Waste Tonnage[3,4] As-Placed Biodegradable Greenwaste ADC Tonnage[3,4]	29,600 tons 7,700 tons
Ratio of Waste to Greenwaste ADC	5.9 to 1
Ratio of Waste to Greenwaste ADC and Soil[3]	3.4 to 1
Average Density of Waste	1,162 pounds per cubic yard, lbs/cy (does not include soil or ADC)
Total # of Horizontal Gas Collection Lines[5] Layer 1 Layer 2 Layer 3 Layer 4	17 Spacing of approximately 6 40 feet on center 5 3 3
Total # of Liquid Addition Lines (HDPE Pipe)[6] Layer 1 Layer 2 Layer 3 Layer 4	25 Spacing of approximately 8 40 feet on center 7 5 5
Total Amount of Liquid Addition Piping Layer 1 Layer 2 Layer 3 Layer 4 (under construction)	34,997 feet 3080 feet 2,450 feet 1,500 feet to be determined
Total # of 3/32 inch Diameter Holes in Injection Line Layer 1 Layer 2 Layer 3 Layer 4 (under construction)	293 145 93 55 to be determined
Surface Liner	36-mil[7] Reinforced Polypropylene
Total # of Moisture Sensors PVC Gypsum	75 Spacing of 50 approximately 25 75 feet on center
Total # of Temperature Sensors	65

[1]Final Project Agreement, FPA
[2]ADC-Alternative Daily Cover
[3]This is an estimate
[4]Calculated using biodegradable fractions from Tchobanoglous et, al. (1993)
[5]Refer to Table 3 for a complete description of gas collection lines
[6]High Density Polyethylene, HDPE
[7]1-mil is equivalent to 0.001 inches and refers to the thickness of the liner

Table 3. Summary of Sensors for the Anaerobic Cells

Type of Instrumentation	FPA Proposed Location/Quantity/Spacing	Actual Location/Quantity/Spacing	Actual Location/Quantity/Spacing
Pressure Transducer	***Anaerobic Bioreactor***	***Northeast Bioreactor***	***West-Side Bioreactor***
	1. Eight over the primary liner near the LCRS trench at 200 spacing 2. Two over the primary liner within the leachate collection sump	1. 2 over the primary liner near the LCRS trench at 200 spacing 2. 1 over the primary liner within the leachate collection sump	1. 3 over the primary liner near the LCRS trench at 200 spacing 2. 1 over the primary liner within the leachate collection sump
Bubbler Gage for Liquid/Gas Pressure Measurement and Liquid/Gas Sampling	1. Top of primary bottom liner-66 gages at 75 feet spacing 2. Top of the first lift of waste- 55 gages 3. Top of the second lift of waste-40 gages 4. Top of the third lift of waste-30 gages 5. Top of the final lift of waste-20 gages TOTAL= 211 gages	1. Top of primary bottom liner-19 gages at 75 feet spacing 2. Top of the first lift of waste- 15 gages at 75 feet spacing 3. Top of the second lift of waste-13 gages at 75 feet spacing 4. Top of the third lift of waste- 13 gages at 75 feet spacing 5. Top of the final lift of waste- no gages TOTAL= 60 gages	1. Top of primary bottom liner-35 gages at 75 feet spacing 2. Still under construction 3. Still under construction 4. Still under construction 5. Still under construction TOTAL= Still under construction
Moisture and Temperature Sensors	1. Top of primary bottom liner-66 temperature sensors at 75 feet spacing and 12 moisture sensors 2. Top of the first lift of waste-55 temperature and moisture sensors 3. Top of the second lift of waste-40 temperature and moisture sensors 4. Top of the third lift of waste-30 temperature and moisture sensors 5. Top of the final lift of waste-20 temperature sensors TOTAL= 211 temperature sensors and 137 moisture sensors	1. Top of primary bottom liner-19 temperature sensors and 4 moisture sensors at 75 feet spacing 2. Top of the first lift of waste-18 temperature and 18 moisture sensors at 75 feet spacing 3. Top of the second lift of waste-15 temperature and 40 moisture sensors at 75 feet spacing 4. Top of the third lift of waste-13 temperature and 13 moisture sensors at 75 feet spacing 5. Top of the final lift of waste-20 temperature sensors TOTAL= 65 temperature sensors and 75 moisture sensors	1. Top of primary bottom liner-35 temperature sensors and 8 moisture sensors at 75 feet spacing 2. Top of the first lift of waste- 6 temperature sensors, and 6 moisture sensors. 3. Still under construction 4. Still under construction 5. Still under construction TOTAL= Still under construction

Table 4. Summary of Gas Collection Lines for the Northeast Anaerobic Cell

Gas Collection Line[1]	Description	Spacing
1-G1	Alternating 4 and 6 inch schedule 80 PVC[2].	50' from west toe
1-G2	Shredded tires with pipe at ends. The north end is 40 feet of schedule 40 PVC with a 10 foot section of 3 inch perforated schedule 80 PVC. The south end is 40 feet of 4 inch schedule 80 PVC, 5 feet of 3 inch schedule 80 PVC, and 10 feet of perforated HDPE.	40' from 1-G1-NE
1-G3	Alternating 4 and 6 inch schedule 80 PVC.	40' from 1-G2-NE
1-G4	Shredded tires with PVC pipe at ends. The south end is 40 feet of 4 inch schedule 80 PVC and 10 feet of 6 inch schedule 80 PVC. The north end is 40 feet of 4 inch schedule 40 PVC.	40' from 1-G3-NE
1-G5	Shredded tires with PVC pipes at ends. The south end is 40 feet of 4 inch schedule 80 PVC, 10 feet of 6 inch schedule 80 PVC, 20 feet of 4 inch schedule 80 PVC, and 5 feet of 24 inch corrugated HDPE. The north end is 40 feet of 4 inch schedule 40 PVC.	40' from 1-G4-NE
1-G6	Shredded tires with PVC pipes at ends. The south end is 40 feet of 4 inch schedule 80 PVC, 20 feet of 3 inch perforated schedule 80 PVC, 10 feet of 6 inch schedule 80, and 20 feet of 3 inch perforated schedule 80 PVC. The north end is 40 feet of 4 inch schedule 40 PVC.	40' from 1-G5-NE
2-G1	Shredded tires with PVC pipes at ends. The south end is 40 feet of 4 inch schedule 80, 10 feet of 6 inch schedule 80, and 10 feet of 4 inch schedule 80 PVC. The north end is 40 feet of 4 inch schedule 40 PVC.	30' from West toe
2-G2	Alternating 4 and 6 inch schedule 80 PVC pipe for the entire length with 40 feet of 4 inch at the north and south end.	40' from 2-G1-NE
2-G3	Shredded tires with PVC pipe at the ends. The north end is 40 feet of 4 inch schedule 40 PVC. The south end 40 feet of 4 inch schedule 80 PVC, 20 feet of 3 inch schedule 80 PVC, 10 feet of 6 inch schedule 80 PVC, and 20 feet 3 inch perforated schedule 80 PVC.	40' from 2-G2-NE
2-G4	Alternating 6 and 3 inch schedule 80 PVC pipe. The south end is 4 inch schedule 80 PVC and the north end is 4 inch schedule 40 PVC.	40' from 2-G3-NE
2-G5	Shredded tires with pipe at the ends. The north end is 40 feet of 4 inch schedule 40 PVC. The south end is 40 feet of 4 inch schedule 80 PVC, 20 feet of 3 inch schedule 80 PVC, 20 feet of 4 inch schedule 80 PVC, and 10 feet of 12 inch corrugated HDPE[3].	40' from 2-G4-NE
3-G1	Shredded tires with PVC pipe at the ends. The north end is 40 feet of 4 inch schedule 40 PVC. The south end is 40 feet 4 inch schedule 80 and 20 feet of 8 inch schedule 40.	45' from west toe
3-G2	Shredded tires with PVC pipe at the ends. The north end is 40 feet of 4 inch schedule 40 VC. The south end is 40 feet of 4 inch schedule 80 PVC, 20 feet of 8 inch HDPE, and 40 feet of 6 inch HDPE.	45' from 3-G1-NE
3-G3	Shredded tires with PVC pipe at the ends. The north end is 40 feet of 4 inch schedule 40 PVC. The south end is 40 feet of 4 inch schedule 80 PVC, 20 feet of 6 inch schedule 40 PVC, and 10 feet of 12 inch corrugated HDPE.	35' from 3-G2-NE

[1]Gas Collection Line Nomenclature: Layer # - G (for gas) and gas line #
[2]Polyvinyl chloride, PVC
[3]High Density Polyethylene, HDPE

Table 5. Summary of Data for the Aerobic Cell

Description	Data
Footprint	2.3 acres
Average Waste Depth	30 feet
Construction of the Base Liner	August 2001
Waste Filling of Cells	8/8/2001 – 9/26/2001
Total # of Waste Lifts	3
Total Amount of Waste	11,942 tons
Total Amount of Greenwaste ADC[2]	2,169 tons
Volume of Soil[2] Within the Waste Mass	347 cubic yards
Ratio of Waste to Greenwaste ADC	5.5 to 1
Ratio of Waste to Greenwaste ADC and Soil[3]	4.5 to 1
Average Density of Waste	pounds per cubic yard, lbs/cy (does not include soil or ADC)
Total # of Corrugated Metal Pipe Horizontal Air Collection Lines Layer 1 Layer 2	6 Spacings vary. 3 3
Total # of CPVC[4] Pipe Horizontal Air Collection Lines Layer 1 Layer 2	5 Spacings vary. 3 2
Total Amount of Air Collection Lines[5] Layer 1 Layer 2	1,660 feet 1,100 feet 560 feet
Total # of HDPE[6] Pipe Liquid Addition Lines Layer 1 Layer 2 Layer 3	21 Spacings approximately 10 40 feet on center to 8 alternate with CPVC pipe 3 for liquid addition lines.
Total # of CPVC [5] Pipe Liquid Addition Lines Layer 1 Layer 2	11 Spacings of approximately 6 40 feet on center to alternate 5 with HDPE pipe for liquid addition lines.
Total Amount of Liquid Addition Piping Layer 1 Layer 2 Layer 3	4,780 feet 2,870 feet 1,400 feet 510 feet
Total # of 3/32 inch Diameter Holes in Injection Lines Layer 1 Layer 2 Layer 3	326 186 97 43
Total # of Moisture Sensors	52 Spacings vary
Total # of Temperature Sensors	62

[1]Final Project Agreement, FPA
[2]ADC-Alternative Daily Cover
[3]This is an estimate
[4]Chlorinated Polyvinyl Chloride, CPVC
[5]Refer to table A for a complete description of air collection lines
[6]High Density Polyethylene, HDPE

Table 6. Summary of Sensors for the Aerobic Cell

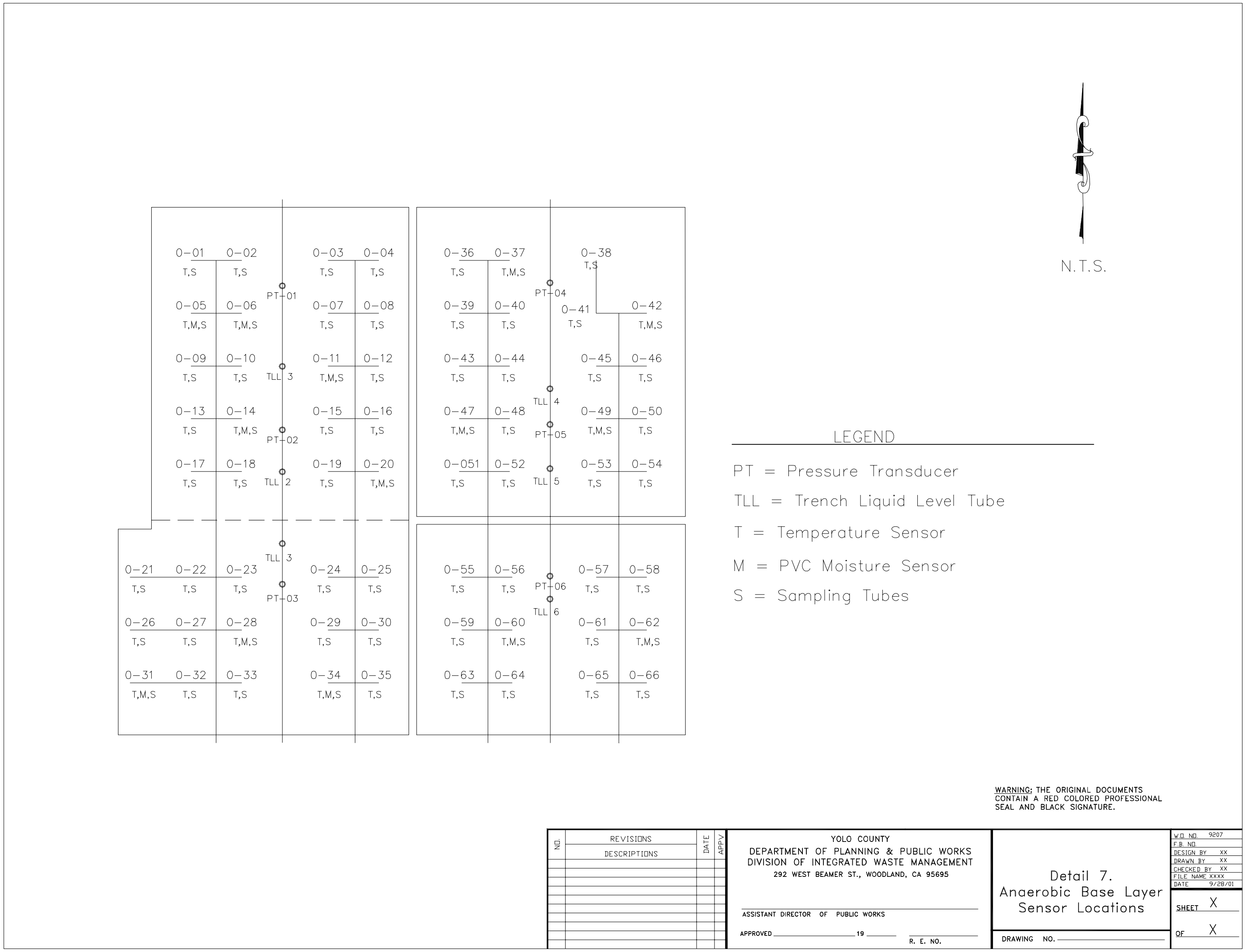
Type of Instrumentation	FPA Proposed Location/Quantity/Spacing	Actual Location/Quantity/Spacing
Pressure Transducer	1. 2 over the primary liner at 200 feet spacing 2. 1 within the leachate sump	1. 1 over the primary liner 2. 1 within the leachate sump
Bubbler Gage for Liquid/Gas Pressure Measurement and Liquid/Gas Sampling	1. Top of the aerobic bottom liner-48 gages at 50 feet spacing 2. Top of the first lift of waste-24 gages 3. Top of the seconf lift of waste-20gages 4. Top of the final lift of waste-20 gages TOTAL=112 gages	1. Top of the bottom liner-12 gages at 75 feet spacing 2. Top of the first lift of waste-26 gages 3. Top of the second lift of waste-16 gages 4. Top of the final lift of waste-no gages TOTAL=54 gages
Moisture and Temperature Sensors	1. Top of the aerobic bottom liner-48 temperature and 12 moisture sensors 2. Top of the first lift of waste-24 temperature and moisture sensors 3. Top of the second lift of waste-20 temperature and moisture sensors 4. Top of the final lift of waste-20 temperature and moisture sensors TOTAL=112 temperature sensors and 76 moisture sensors	1. Top of the aerobic bottom liner-15 temperature and 2 moisture sensors at 75 feet spacing 2. Top of the first lift of waste-29 temperature (3 in the middle of the waste) and 29 moisture sensors at various spacings (3 in the middle of the waste) 3. Top of the second lift of waste-18 temperature and 21 moisture sensors at various spacings 4. Top of the final lift of waste-no temperature or moisture sensors TOTAL=62 temperature sensors and 52 moisture sensors

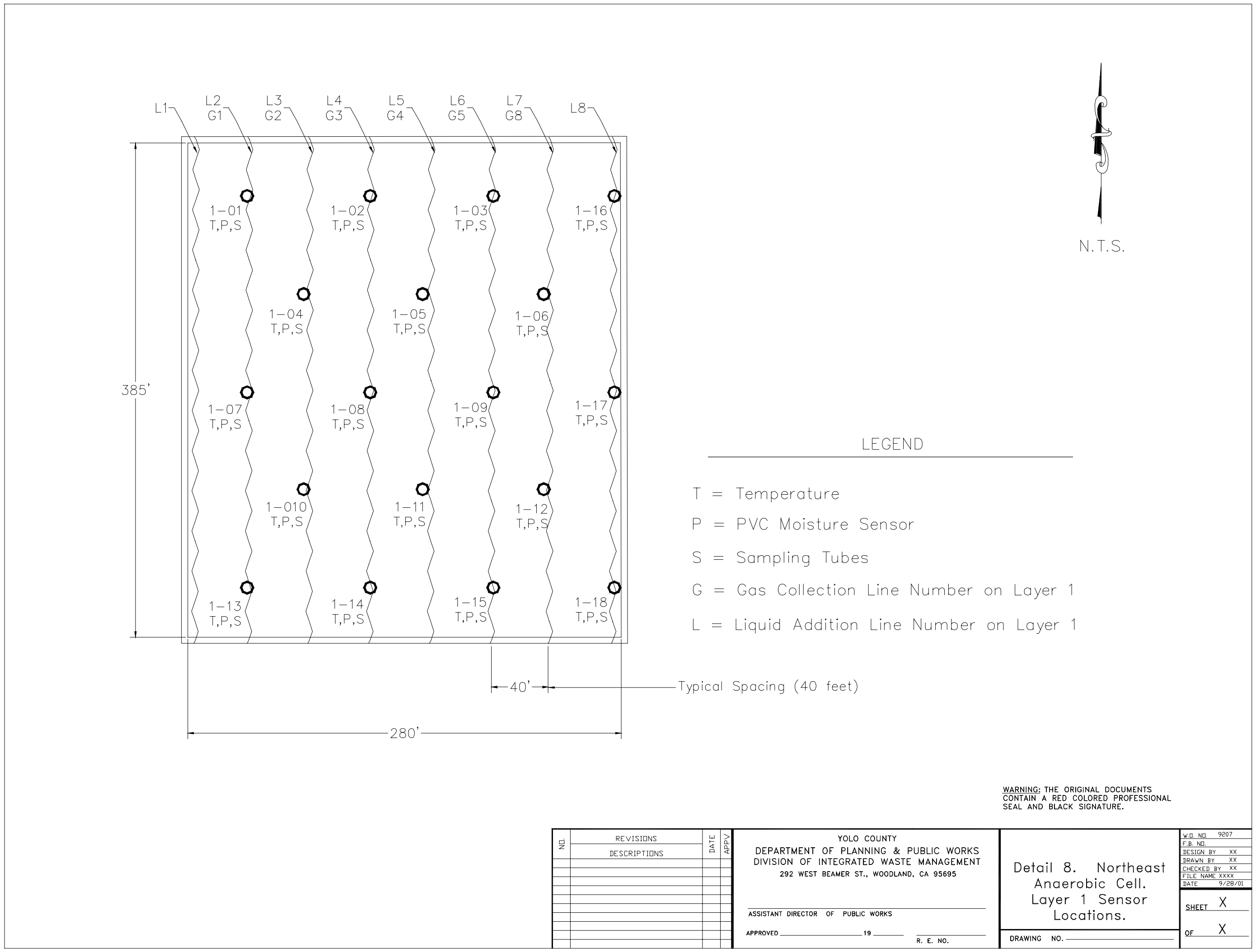
Table 7. Summary of Air Collection Lines for the Aerobic Cell

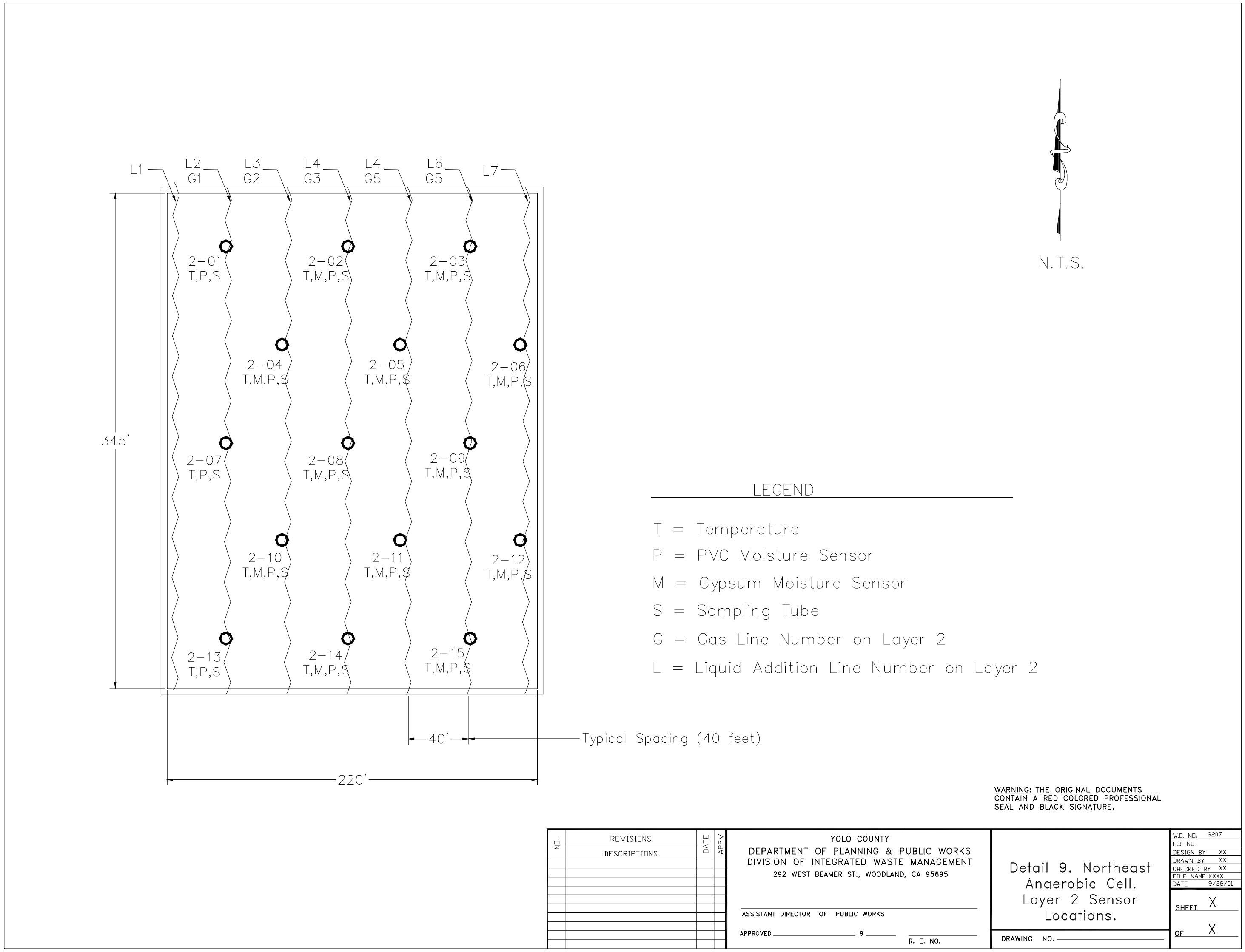
Air Collection Line[1]	Description	Spacing
1-A1	Alternating 10 foot lengths of 4 and 6 inch schedule 80 CPVC[2].	30’ from west toe
1-A2	Alternating 10 foot lengths of 6 and 8 inch corrugated metal pipe.	40’ from 1-A1-SE
1-A3	Alternating 10 foot lengths of 6 and 8 inch corrugated metal pipe.	40’ from 1-A2-SE
1-A4	Alternating 10 foot lengths of 4 and 6 inch schedule 80 CPVC.	40’ from 1-A3-SE
1-A5	Alternating 10 foot lengths of 6 and 8 inch corrugated metal pipe.	40’ from 1-A4-SE
1-A6	Alternating 10 foot lengths of 4 and 6 inch schedule 80 CPVC.	40’ from 1-A5-SE
2-A1	Alternating 10 foot lengths of 6 and 8 inch corrugated metal pipe.	25’ from west toe
2-A2	Alternating 10 foot lengths of 4 and 6 inch schedule 80 CPVC.	40’ from 2-A1-SE
2-A3	Alternating 10 foot lengths of 6 and 8 inch corrugated metal pipe.	40’ from 2-A2-SE
2-A4	Alternating 10 foot lengths of 4 and 6 inch schedule 80 CPVC.	40’ from 2-A3-SE
2-A5	Alternating 10 foot lengths of 6 and 8 inch corrugated metal pipe.	40’ from 2-A4-SE

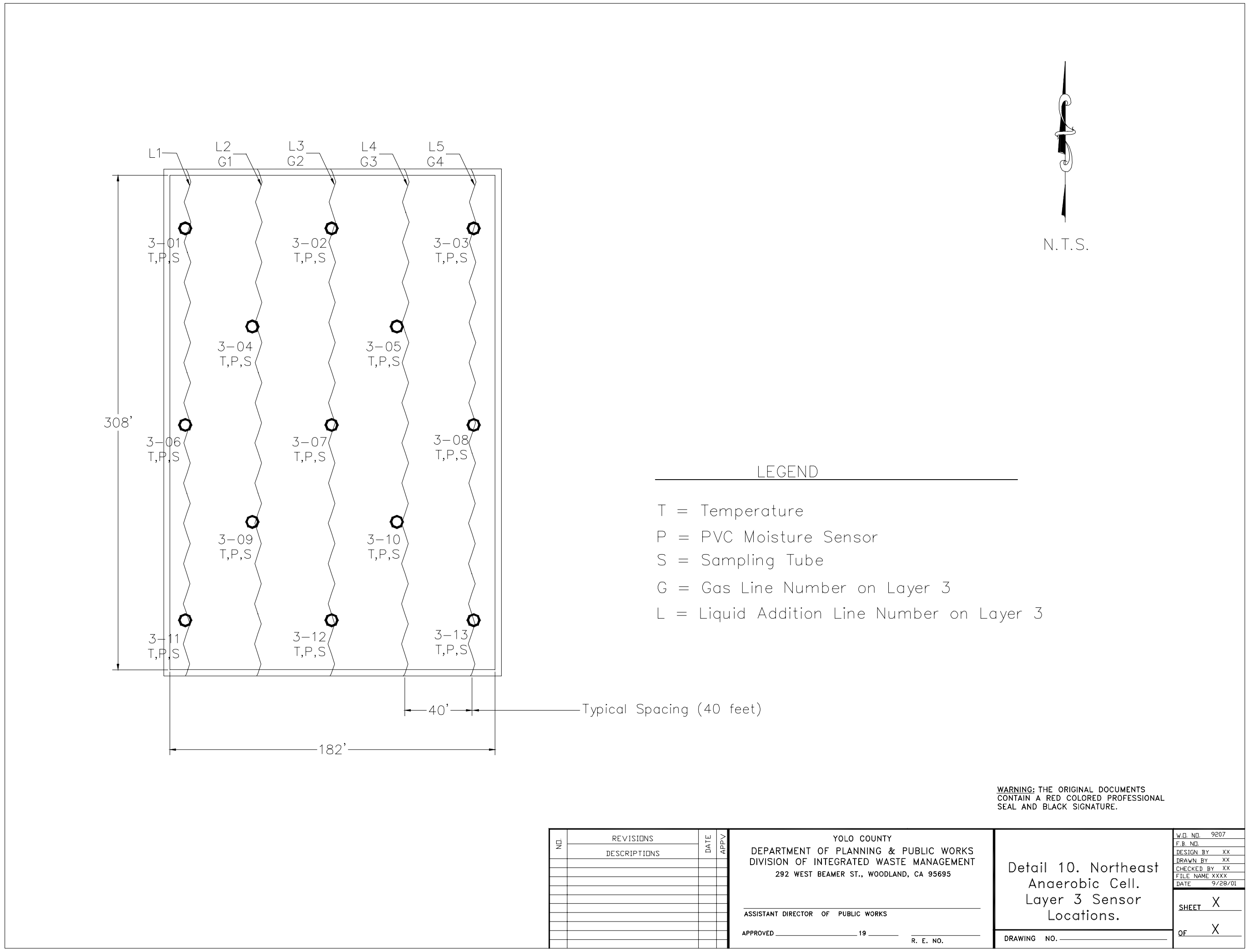
[1]Air Collection Line Nomenclature: Layer # - A (for air) and air collection line #
[2]Chlorinated Polyvinyl Chloride, PVC

APPENDIX B – PIPING AND INSTRUMENTATION PLAN


N.T.S.
LEGEND
PT = Pressure Transducer
TLL = Trench Liquid Level Tube
T = Temperature Sensor
M = PVC Moisture Sensor
S = Sampling Tubes
WARNING: THE ORIGINAL DOCUMENTS CONTAIN A RED COLORED PROFESSIONAL SEAL AND BLACK SIGNATURE.
YOLO COUNTY
DEPARTMENT OF PLANNING & PUBLIC WORKS
DIVISION OF INTEGRATED WASTE MANAGEMENT
292 WEST BEAMER ST., WOODLAND, CA 95695
Detail 7.
Anaerobic Base Layer
Sensor Locations
REVISIONS
DESCRIPTIONS
ASSISTANT DIRECTOR OF PUBLIC WORKS
APPROVED 19
R. E. NO.
DRAWING NO.
SHEET X
OF X


L1
L2 G1
L3 G2
L4 G3
L5 G4
L6 G5
L7 G8
L8
1-01 T,P,S
1-02 T,P,S
1-03 T,P,S
1-16 T,P,S
1-04 T,P,S
1-05 T,P,S
1-06 T,P,S
1-07 T,P,S
1-08 T,P,S
1-09 T,P,S
1-17 T,P,S
1-010 T,P,S
1-11 T,P,S
1-12 T,P,S
1-13 T,P,S
1-14 T,P,S
1-15 T,P,S
1-18 T,P,S
385'
40'
Typical Spacing (40 feet)
280'
N.T.S.
LEGEND
T = Temperature
P = PVC Moisture Sensor
S = Sampling Tubes
G = Gas Collection Line Number on Layer 1
L = Liquid Addition Line Number on Layer 1
WARNING: THE ORIGINAL DOCUMENTS CONTAIN A RED COLORED PROFESSIONAL SEAL AND BLACK SIGNATURE.
NO.
REVISIONS
DESCRIPTIONS
DATE
APPV
YOLO COUNTY
DEPARTMENT OF PLANNING & PUBLIC WORKS
DIVISION OF INTEGRATED WASTE MANAGEMENT
292 WEST BEAMER ST., WOODLAND, CA 95695
ASSISTANT DIRECTOR OF PUBLIC WORKS
APPROVED 19
R. E. NO.
Detail 8. Northeast Anaerobic Cell. Layer 1 Sensor Locations.
DRAWING NO.
W.O. NO. 9207
F.B. NO.
DESIGN BY XX
DRAWN BY XX
CHECKED BY XX
FILE NAME XXXX
DATE 9/28/01
SHEET X
OF X


L1
L2 G1
L3 G2
L4 G3
L4 G5
L6 G5
L7
N.T.S.
2-01 T,P,S
2-02 T,M,P,S
2-03 T,M,P,S
2-04 T,M,P,S
2-05 T,M,P,S
2-06 T,M,P,S
2-07 T,P,S
2-08 T,M,P,S
2-09 T,M,P,S
2-10 T,M,P,S
2-11 T,M,P,S
2-12 T,M,P,S
2-13 T,P,S
2-14 T,M,P,S
2-15 T,M,P,S
345'
40'
Typical Spacing (40 feet)
220'
LEGEND
T = Temperature
P = PVC Moisture Sensor
M = Gypsum Moisture Sensor
S = Sampling Tube
G = Gas Line Number on Layer 2
L = Liquid Addition Line Number on Layer 2
WARNING: THE ORIGINAL DOCUMENTS CONTAIN A RED COLORED PROFESSIONAL SEAL AND BLACK SIGNATURE.
NO.
REVISIONS
DESCRIPTIONS
DATE
APPV
YOLO COUNTY
DEPARTMENT OF PLANNING & PUBLIC WORKS
DIVISION OF INTEGRATED WASTE MANAGEMENT
292 WEST BEAMER ST., WOODLAND, CA 95695
ASSISTANT DIRECTOR OF PUBLIC WORKS
APPROVED 19
R. E. NO.
Detail 9. Northeast Anaerobic Cell. Layer 2 Sensor Locations.
DRAWING NO.
W.O. NO. 9207
F.B. NO.
DESIGN BY XX
DRAWN BY XX
CHECKED BY XX
FILE NAME XXXX
DATE 9/28/01
SHEET X
OF X


L1
L2
G1
L3
G2
L4
G3
L5
G4
3-01
T,P,S
3-02
T,P,S
3-03
T,P,S
3-04
T,P,S
3-05
T,P,S
3-06
T,P,S
3-07
T,P,S
3-08
T,P,S
3-09
T,P,S
3-10
T,P,S
3-11
T,P,S
3-12
T,P,S
3-13
T,P,S
308'
40'
182'
Typical Spacing (40 feet)
N.T.S.
LEGEND
T = Temperature
P = PVC Moisture Sensor
S = Sampling Tube
G = Gas Line Number on Layer 3
L = Liquid Addition Line Number on Layer 3
WARNING: THE ORIGINAL DOCUMENTS CONTAIN A RED COLORED PROFESSIONAL SEAL AND BLACK SIGNATURE.
NO.
REVISIONS
DESCRIPTIONS
DATE
APPV
YOLO COUNTY
DEPARTMENT OF PLANNING & PUBLIC WORKS
DIVISION OF INTEGRATED WASTE MANAGEMENT
292 WEST BEAMER ST., WOODLAND, CA 95695
ASSISTANT DIRECTOR OF PUBLIC WORKS
APPROVED 19
R. E. NO.
Detail 10. Northeast Anaerobic Cell. Layer 3 Sensor Locations.
DRAWING NO.
W.O. NO. 9207
F.B. NO.
DESIGN BY XX
DRAWN BY XX
CHECKED BY XX
FILE NAME XXXX
DATE 9/28/01
SHEET X
OF X

APPENDIX C – GRAPHS AND DATA TABLES

Figure 1. Northeast Anaerobic Cell Base Layer Temperature Readings

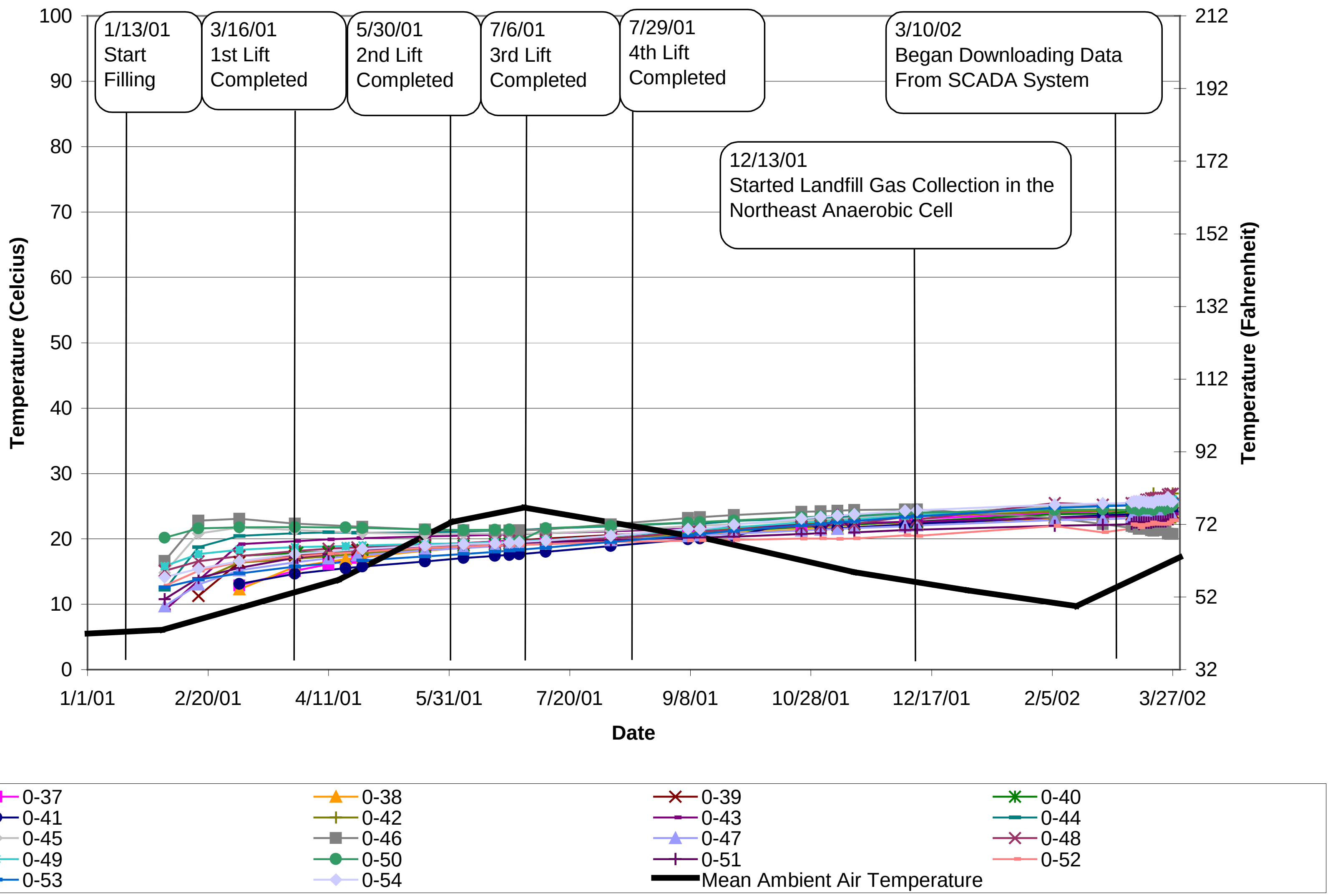


Figure 2. Northeast Anaerobic Cell Layer 1 Temperature Readings

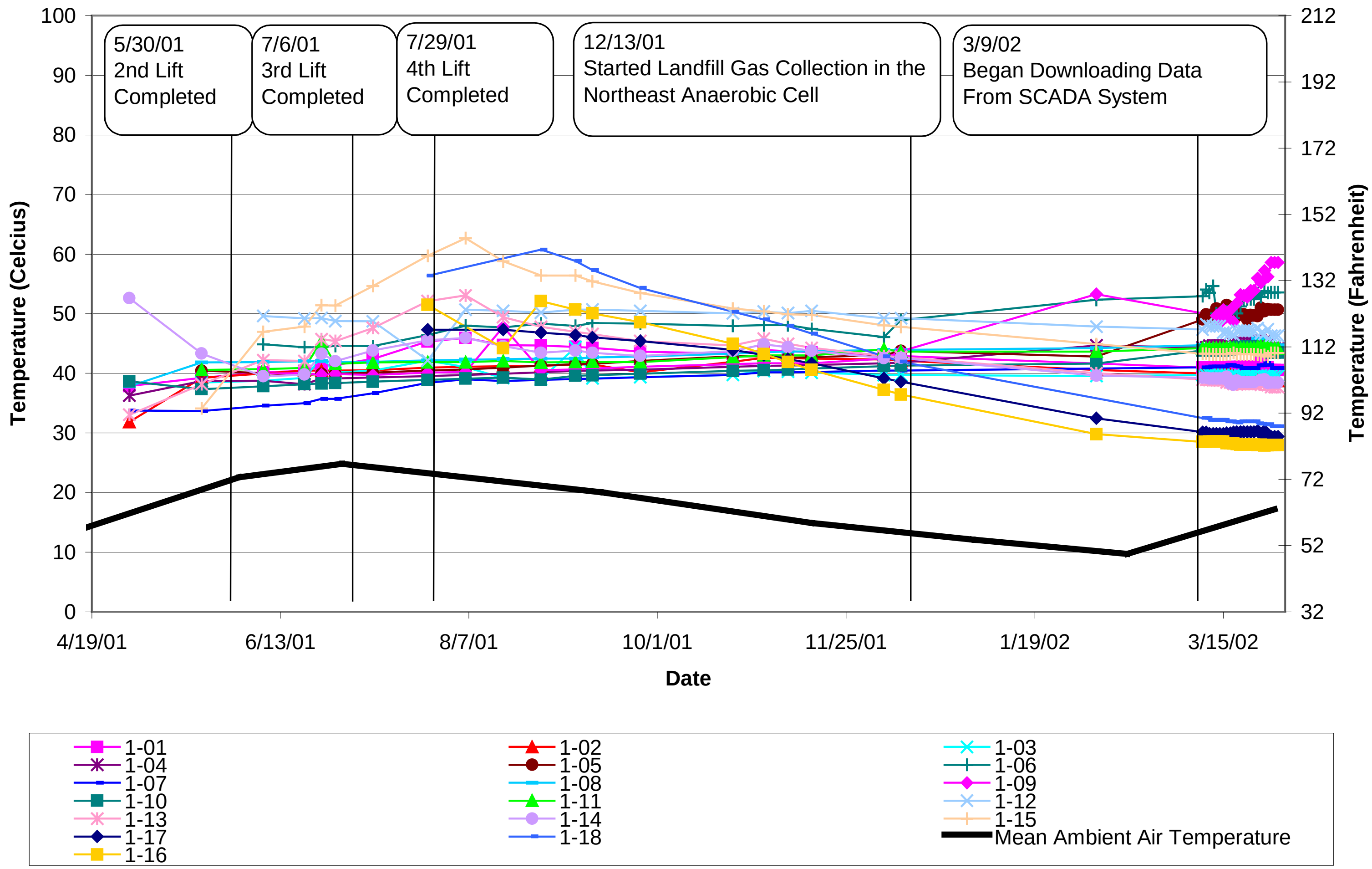


Figure 3. Northeast Anaerobic Cell Layer 2 Temperature Readings

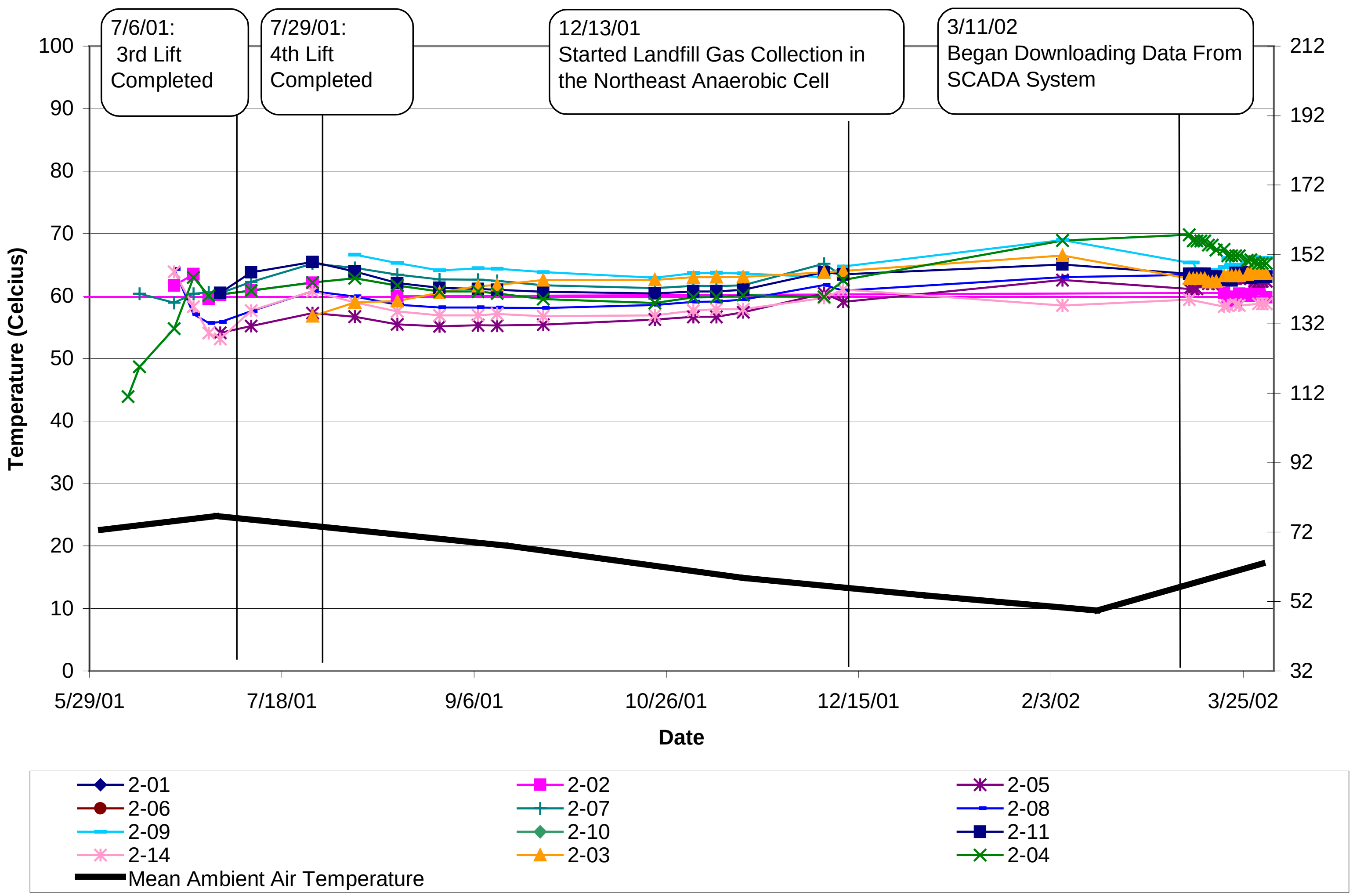


Figure 4. Northeast anaerobic Cell Layer 3 Temperature Readings

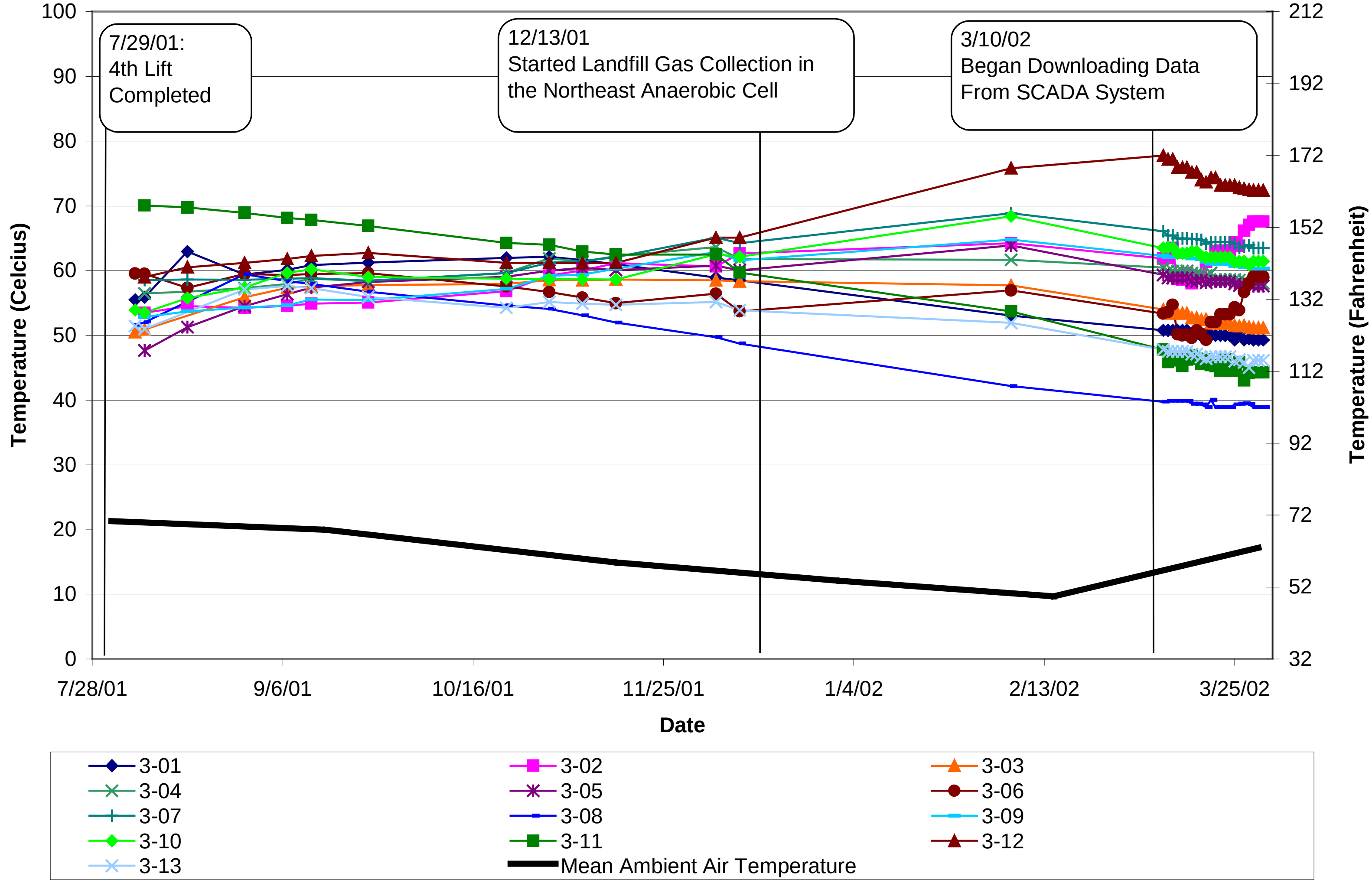


Figure 5. Northeast Anaerobic Cell Base Layer Moisture Readings (PVC Moisture Sensors)

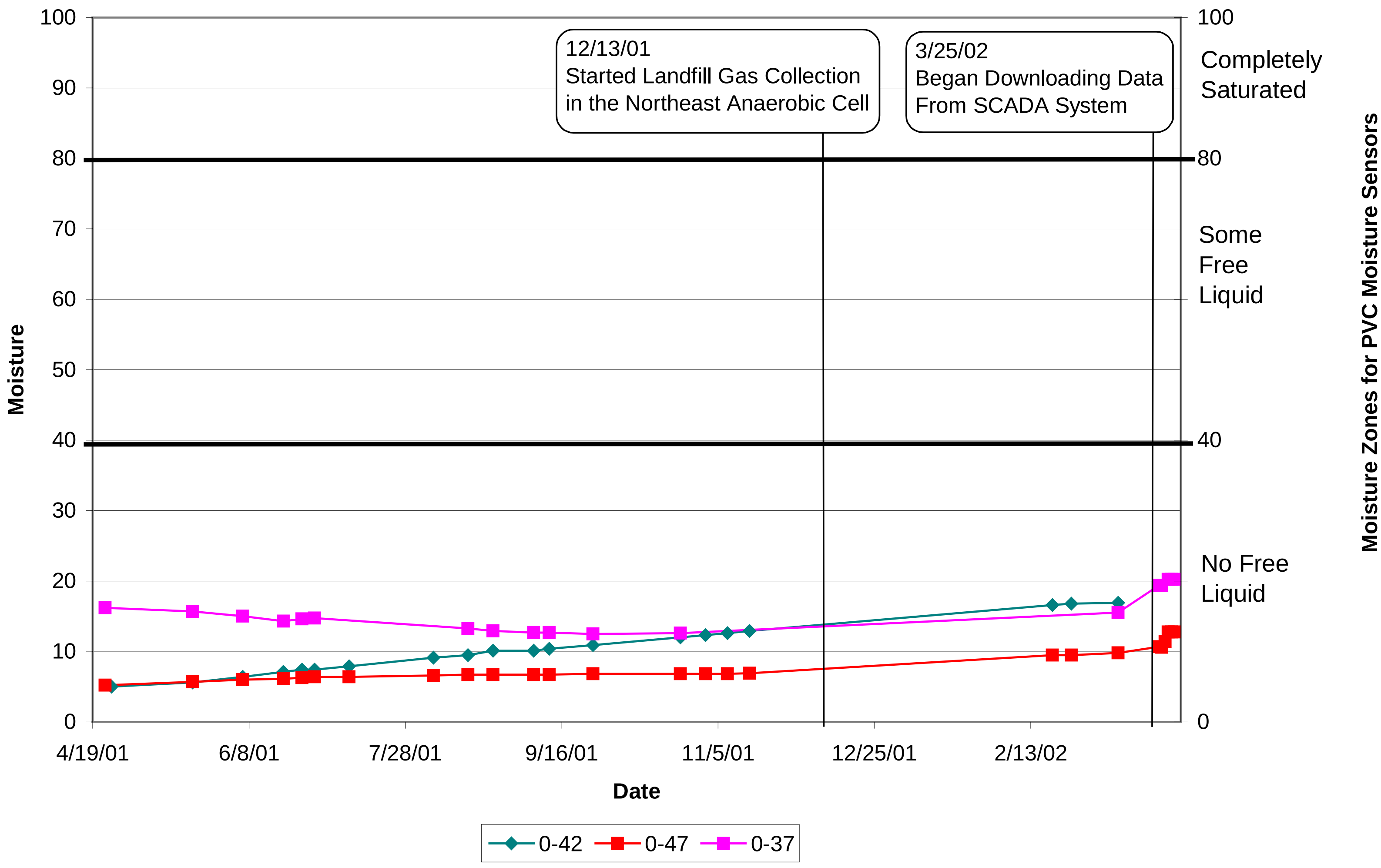


Figure 6. Northeast Anaerobic Cell Layer 1 Moisture Readings (PVC Moisture Sensors)

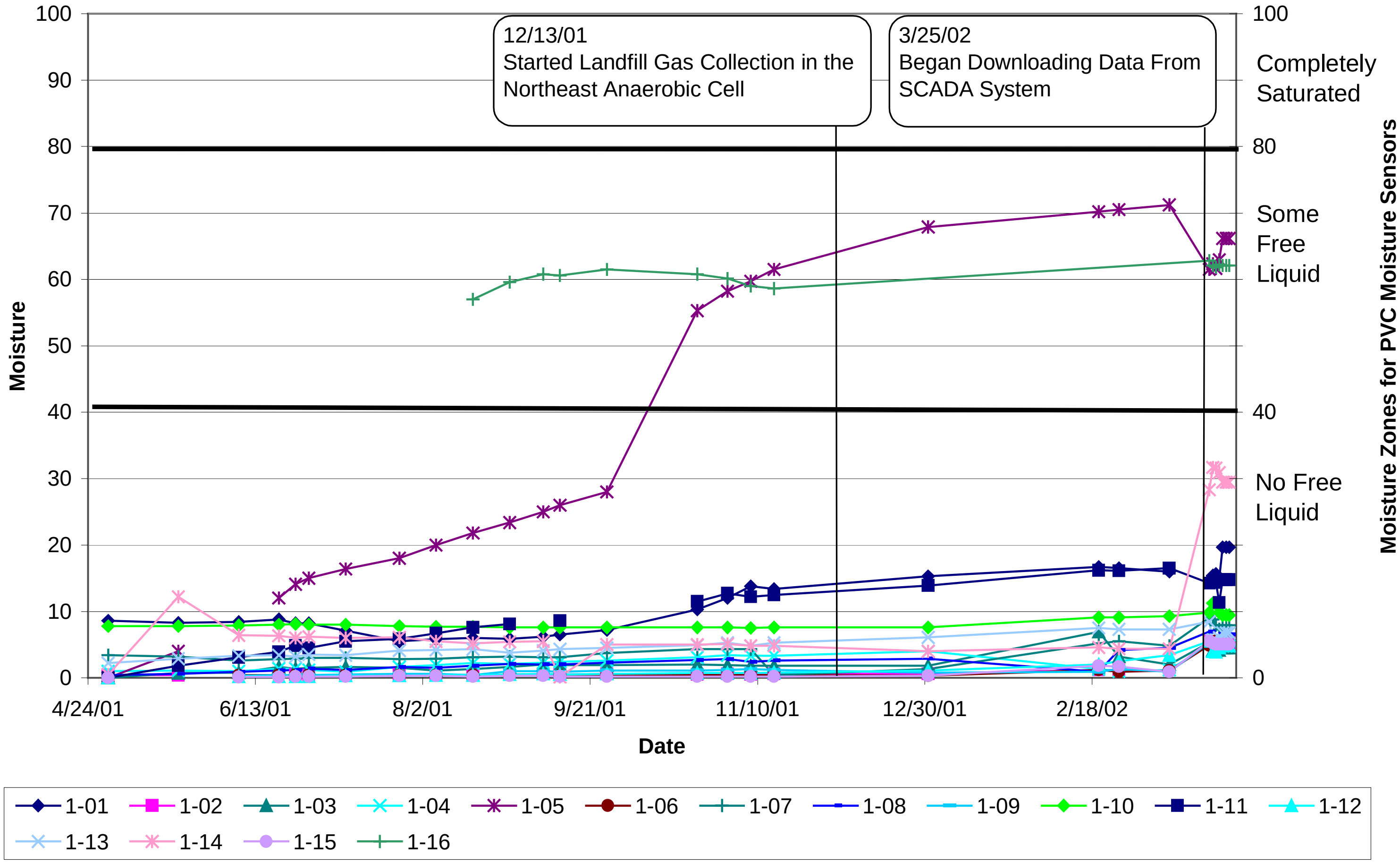


Figure 7. Northeast Anaerobic Cell Layer 2 Moisture Readings (PVC Moisture Sensors)

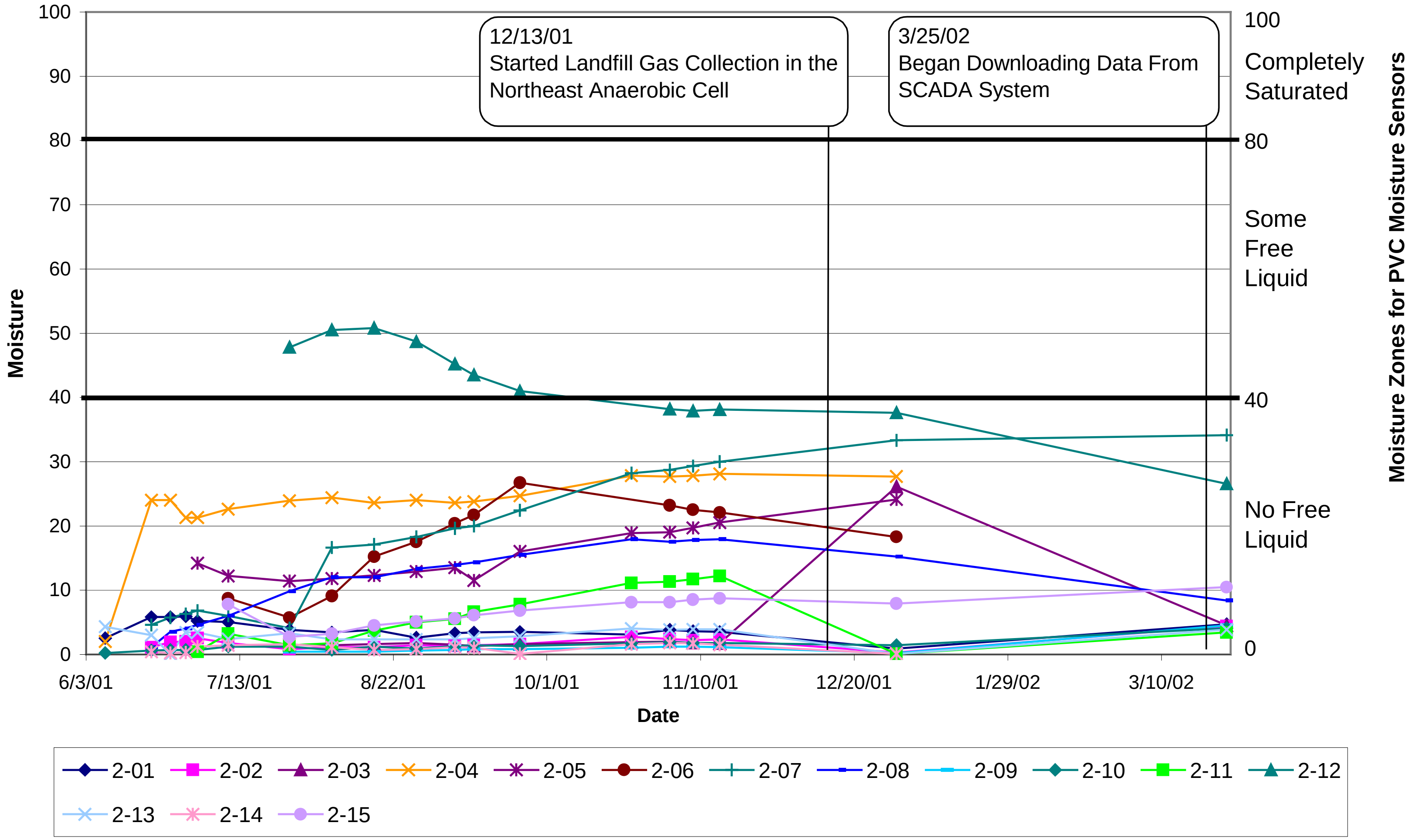


Figure 8. Northeast Anaerobic Cell Layer 2 Moisture Readings (Gypsum in Plaster Moisture Sensors)

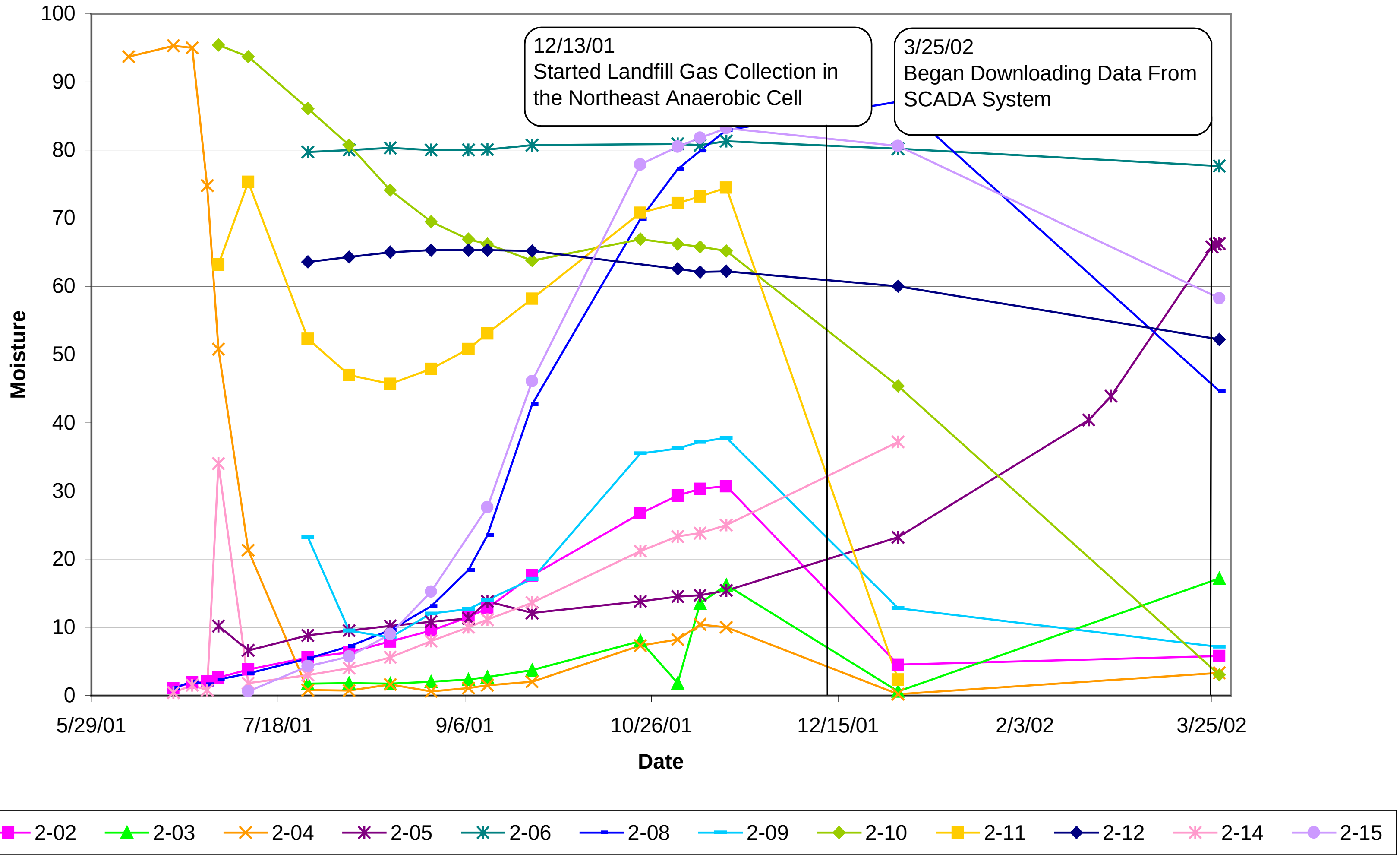


Figure 9. Northeast Anaerobic Cell Layer 2 Moisture Readings (Gypsum in Soil Moisture Sensors)

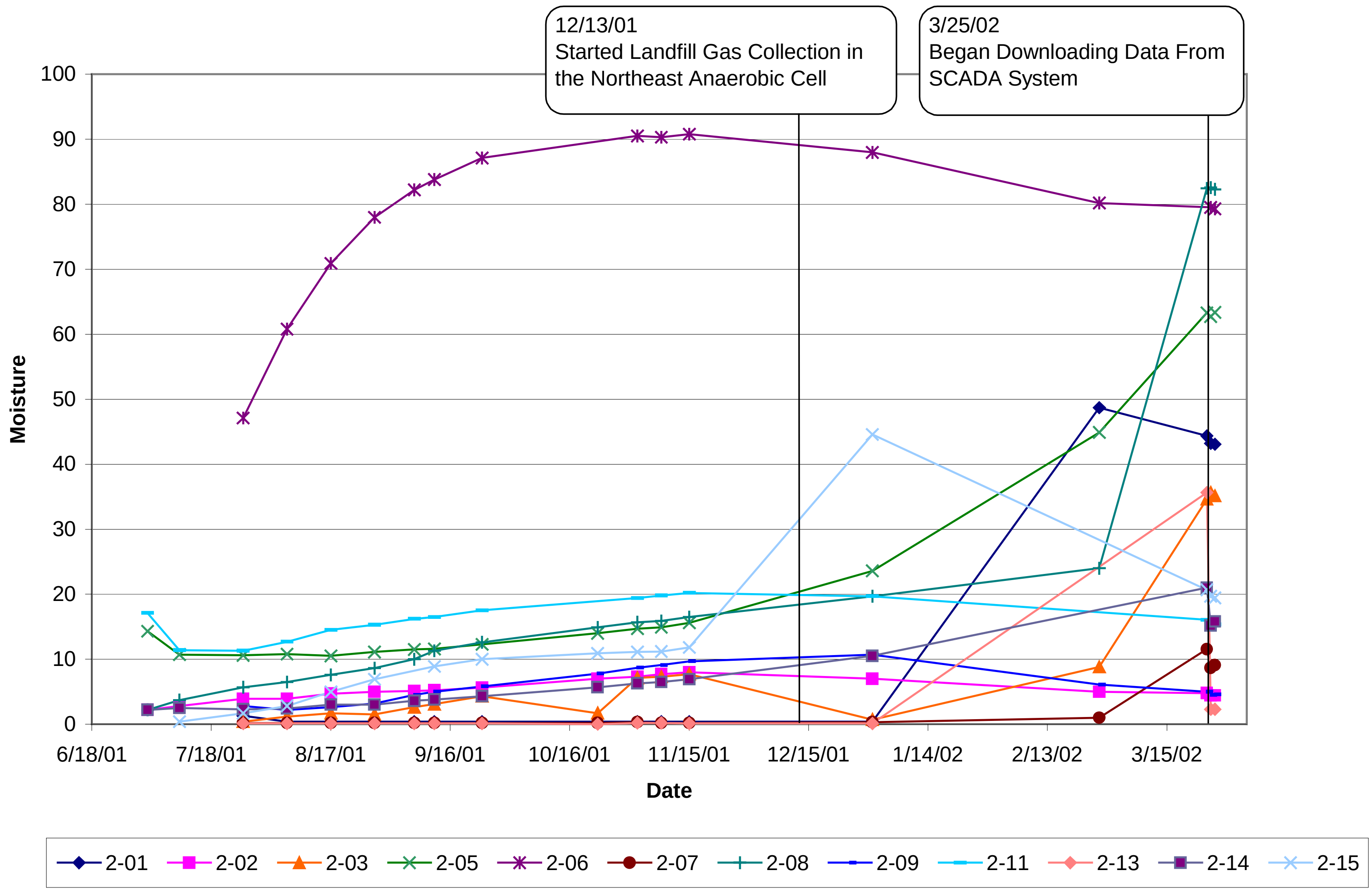


Figure 10. Northeast Anaerobic Cell Layer 3 Moisture Readings (PVC Moisture Sensors)

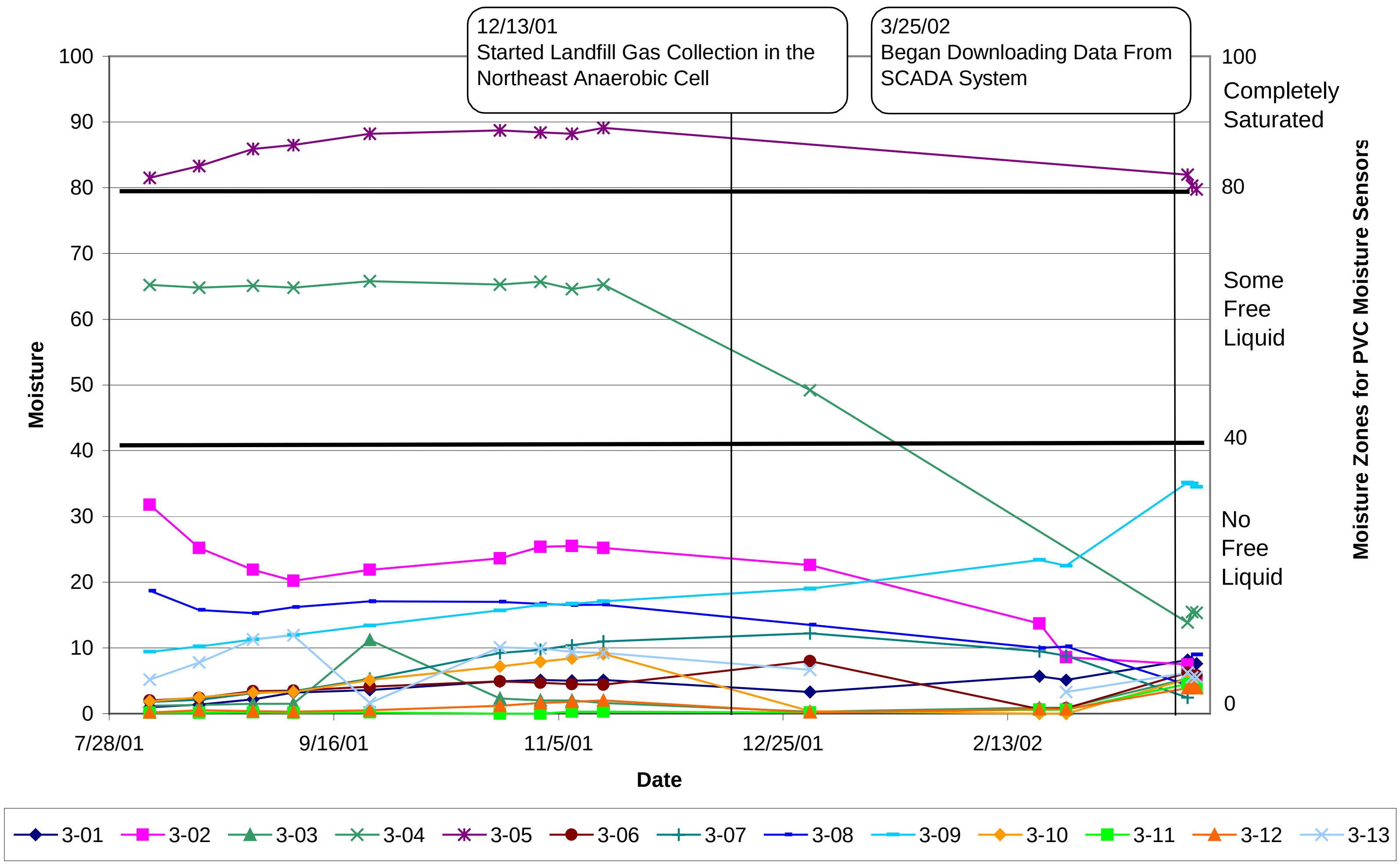


Figure 11. Module D Cumulative Leachate from the Leachate Collection and Removal System (LCRS)

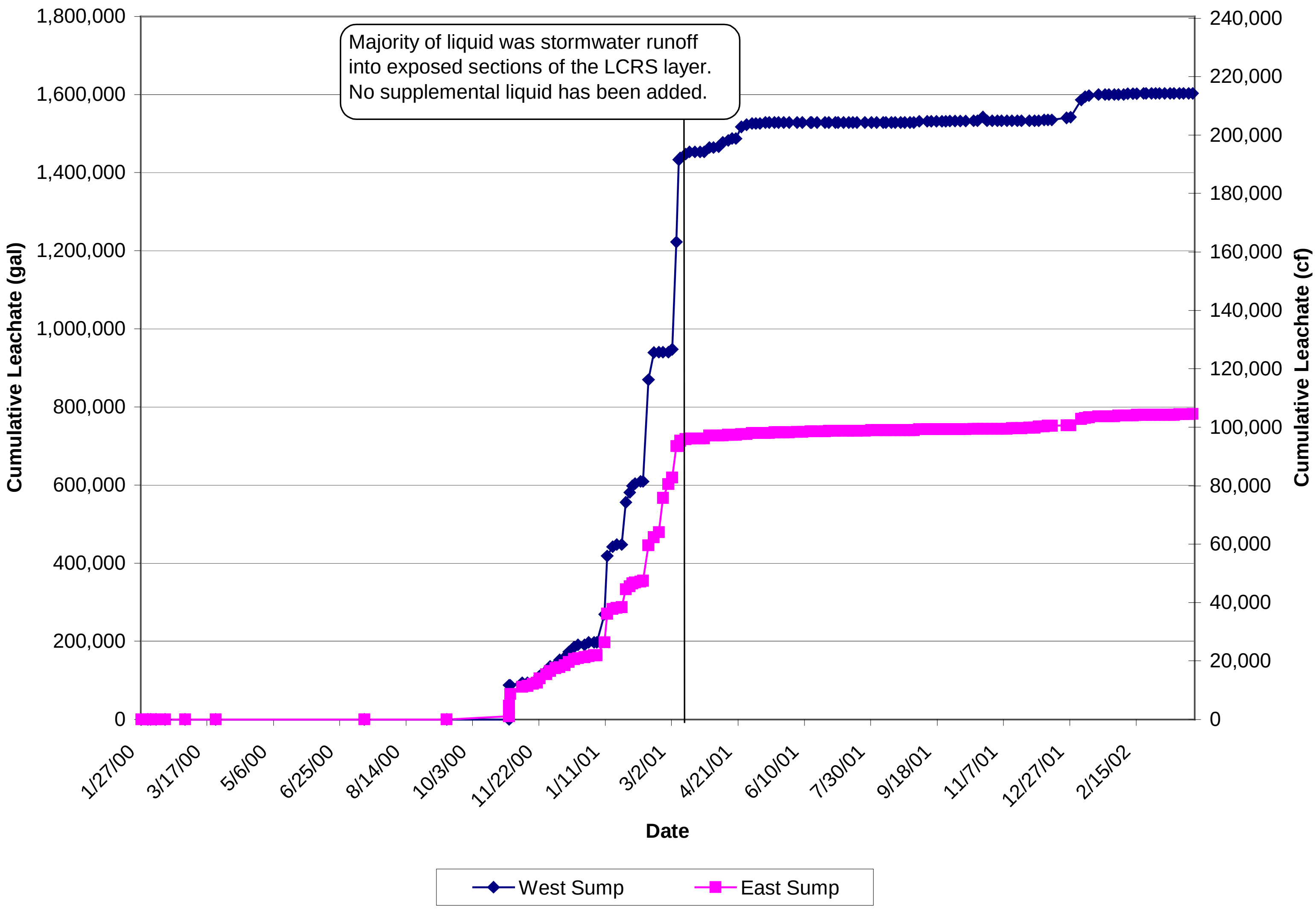


Figure 12. Northeast Anaerobic Cell Base Layer Pressure Readings from Sampling Tubes

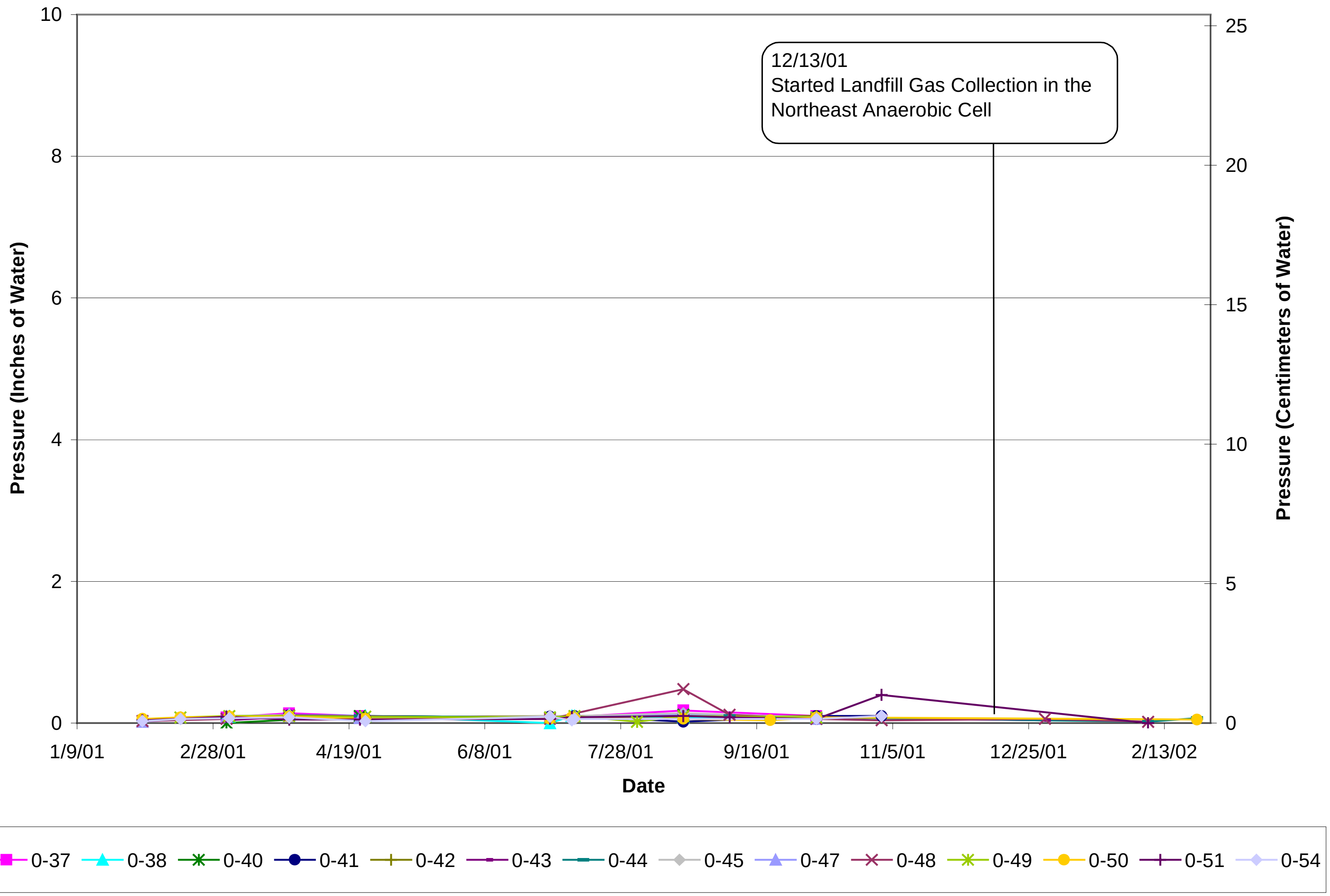


Figure 13. Northeast Anaerobic Cell Layer 1 Pressure Readings from Sampling Tubes

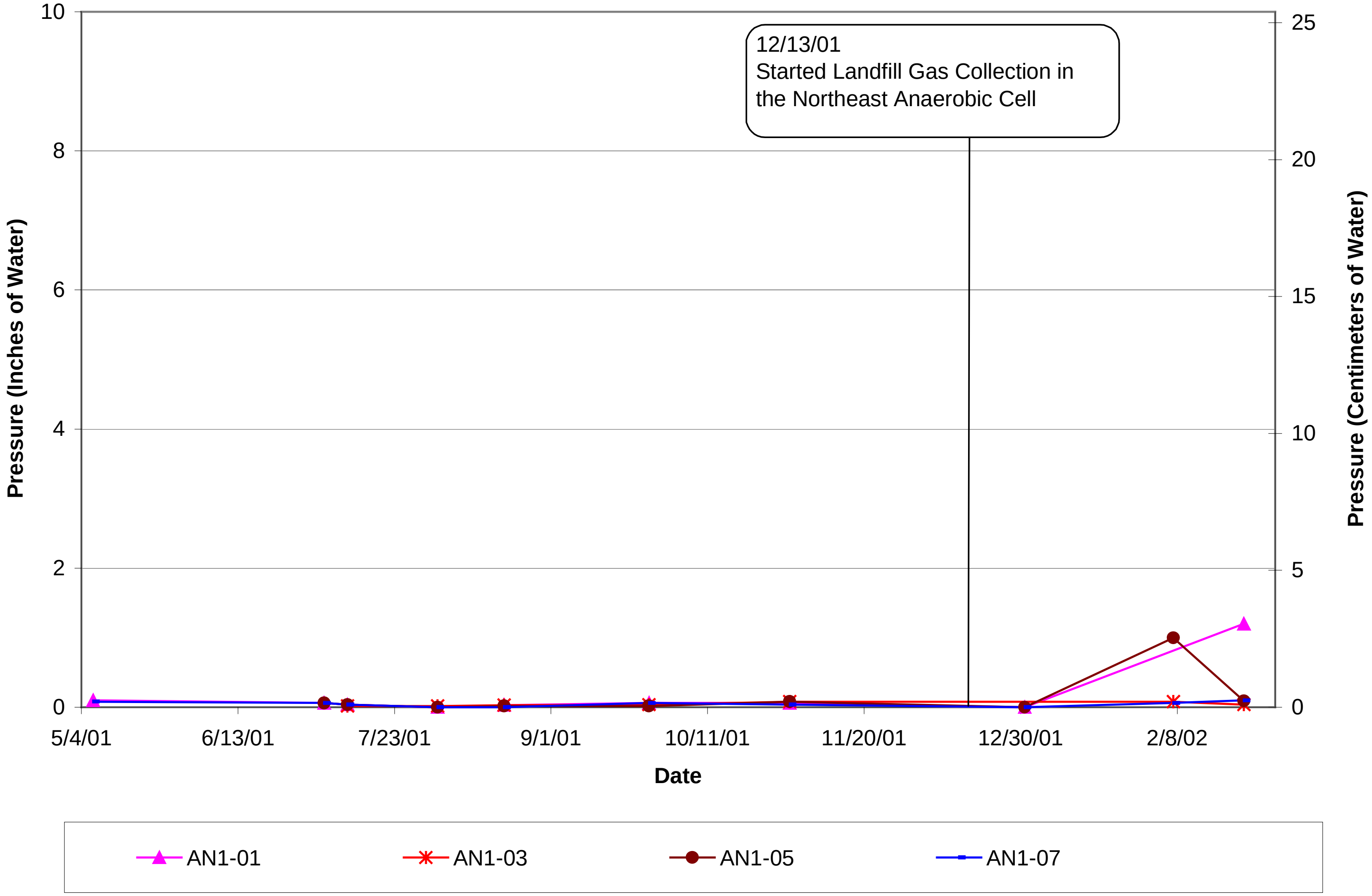


Figure 14. Northeast Anaerobic Cell Layer 2 Pressure Readings from Sampling Tubes

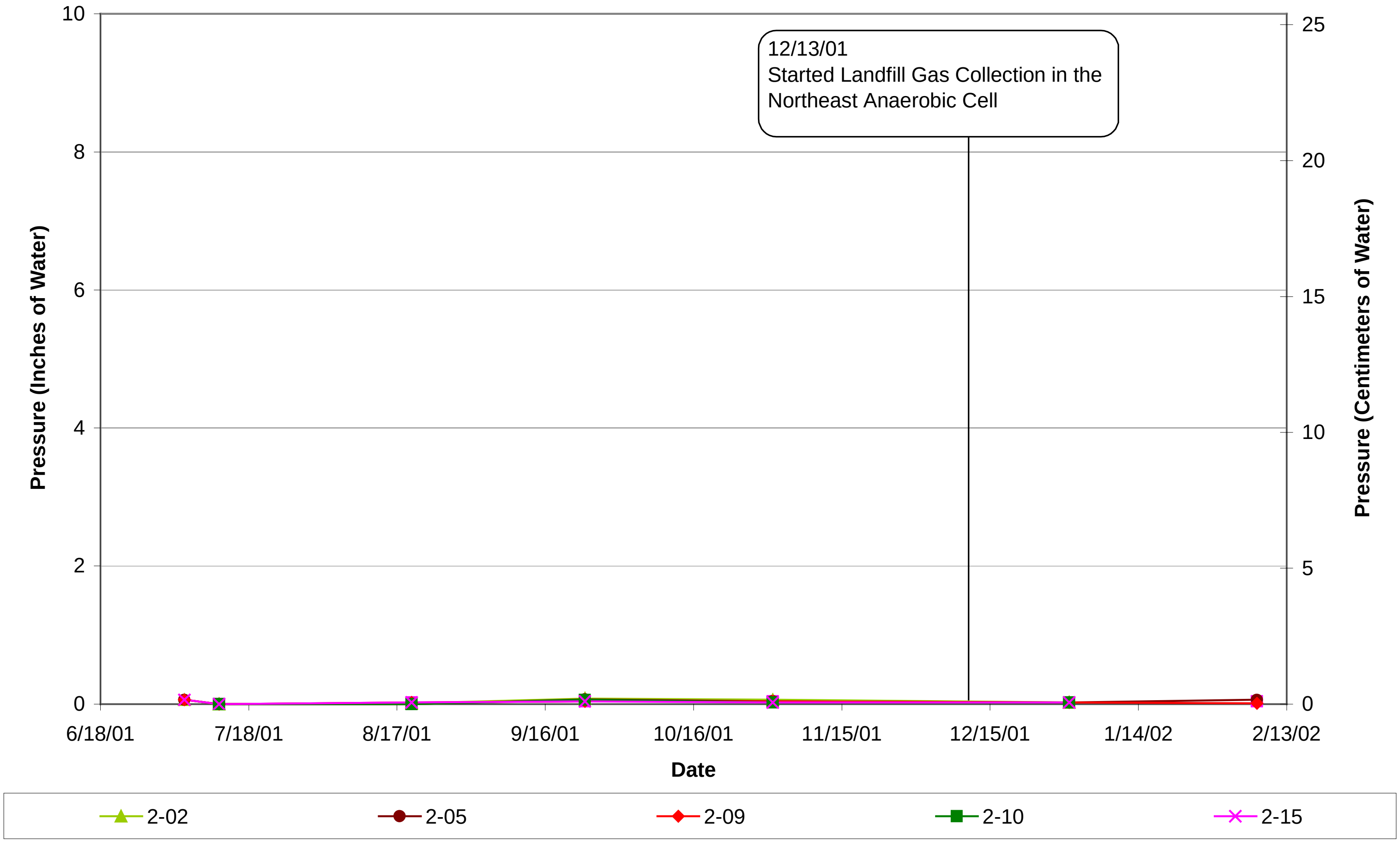


Figure 15. Northeast Anaerobic Cell Layer 3 Pressure Readings from Sampling Tubes

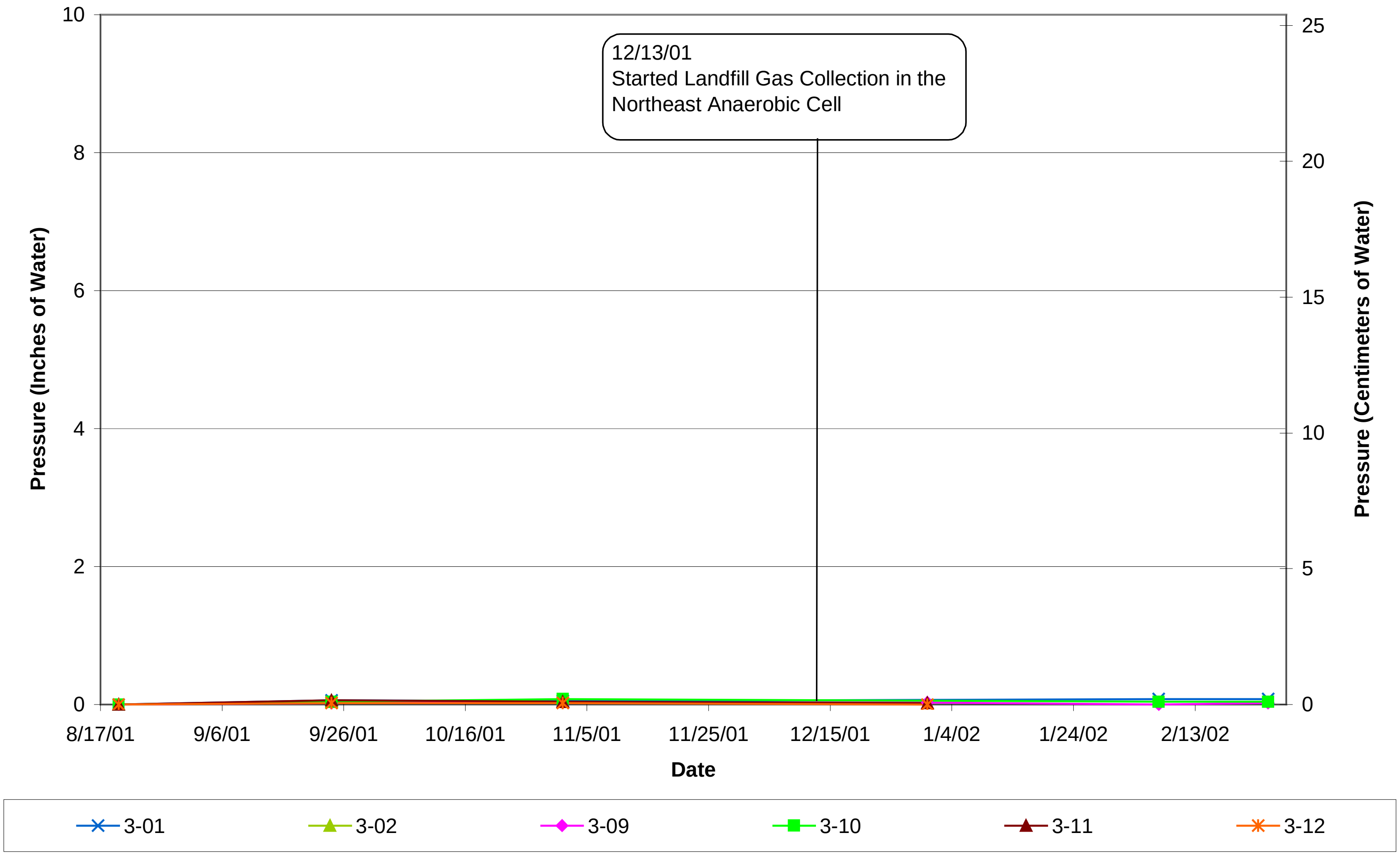


Table 11. Northeast Anaerobic Cell Base Layer Gas Compositions from Sampling Tubes

Sensor[1]	0-36				0-39				0-40				0-44			
Date Installed:	7/28/00				7/28/00				7/28/00				7/28/00			
Date Covered [2]:	2/16/01				2/16/01				2/16/01				2/2/01			
Date Monitored	% CH_4	% CO_2	% O_2	% Balance[3]	%CH_4	% CO_2	% O_2	% Balance	%CH_4	% CO_2	% O_2	% Balance	%CH_4	% CO_2	% O_2	% Balance
5/30/01					18.9	57.6	0.4	22.8	38.5	59.3	0	2.2				
7/3/01	21.6	55.6	0	22.4									28.8	57.9	0	12.9
7/10/01	45.3	54.6	0	0	40.4	59.7	0.1	0.7	46.5	53.4	0	0	31.7	59.1	0	9.4
7/11/01																
8/22/01					50.3	48.8	0	0					37.5	55.8	0	604
9/6/01					52.9	47.1	0	0					39.2	54.1	0	7.1
9/21/01	51.3	49.1	0	0									40.3	55.8	0	3.3
12/31/01					35.5	43.2	0.9	20.6					13.7	31	0	55.3
2/7/01					17.1	31.5	0	51.4					11	26	0	63
2/28/02					33.4	41.6	0	25					19.3	41.7	0	39

Sensor	0-48				0-51				0-52				0-54			
Date Installed:	7/28/00				7/28/00				7/28/00				7/28/00			
Date Covered:	2/2/01				2/2/01				2/2/01				2/2/01			
Date Monitored	%CH_4	% CO_2	% O_2	% Balance	%CH_4	% CO_2	% O_2	% Balance	%CH_4	% CO_2	% O_2	% Balance	%CH_4	% CO_2	% O_2	% Balance
5/30/01					18.4	54.9	0	26.7								
7/3/01					23.2	51.4	0	24.6	24	54.9	0	20.6				
7/10/01									27.8	55.2	0	17.5				
7/11/01													41.2	53.8	0.2	0.7
8/22/01	42.1	56.2	0	1.7	31.7	49	0	19.3					44.2	54.2	0	1.2
12/31/01	10.6	28.2	2.1	58.7												
2/7/01	6.1	24.9	0	69	19.2	32.9	3.1	44.5								
2/28/02	23	44	0	33	40	51	0	9								

[1]Sensor nomenclature: Instrumentation layer # the senor is located - Sensor # on that layer
[2]Date covered refers to the date waste was placed over the sensor
[3]Balance is assumed to be nitrogen
*Gas Compositions measured by the GEM-500 by Landtec

Table 12. Northeast Anaerobic Cell Layer 1 Gas Compositions from Sampling Tubes

Sensor[1]	1-01				1-07				1-13				1-04				1-10			
Date Installed:	4/9/01				4/13/01				4/13/01				4/19/01				4/19/01			
Date Covered[2]:	4/12/01				4/15/01				4/17/01				4/20/01				4/25/01			
Date:	% CH_4	% CO_2	% O_2	% Balance[3]	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance
5/8/01	24.7	55.4	0.2	19.7	25.4	67.8	0.1	6.7	23.6	63.2	0.1	13.1	11.5	50.6	2.8	35.1	27.7	61	0.2	11.1
5/30/01	28.6	54	0	17.4	31.1	60.7	0	8.2												
7/11/01	16.7	33.1	2.4	47.6									42.9	57.2	0	0	39.4	58.5	0	2.5
8/3/01													49.9	50.1	0	0				
9/26/01					44.2	55.3	0	0.6												
11/1/01					43.2	46.1	0	10.7												
11/28/01					45.8	50.8	0	3.5												
2/26/02					29	43.6	0	27.4												

Sensor	1-02				1-08				1-14				1-05				1-11			
Date Installed:	4/25/01				4/26/01				4/27/01				5/8/01				5/9/01			
Date Covered:	4/26/01				4/28/01				5/1/01				5/9/01				5/12/01			
Date:	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance
5/8/01	29.2	54.3	0.1	16.4	23.8	69.3	0.3	6.8	11.1	66.1	0.1	22.7								
5/30/01																	25.1	68.5	0	6.4
7/5/01	37.7	50.2	2.5	9.3																
7/11/01	45.4	52.7	0.3	2.1	40.5	59.5	0	0					51	47.3	1.9	0				
8/3/01																	24.7	52.3	0	22.9
8/22/01	49.7	50.3	0	0					21.1	42.2	0	37.2	50.2	49.8	0	0				
9/26/01	53.8	46.2	0	0													48.2	51.8	0	0
11/1/01	43.2	46.1	0	10.7																
11/28/01					47.6	47	0.7	4.3					54.6	45.4	0	0				
2/26/02													46.2	43.6	0	10.2				

Sensor	1-03				1-09				1-12				1-06			
Date Installed:	5/14/01				5/16/01				5/22/01				5/22/01			
Date Covered:	5/14/01				5/16/01				5/22/01				5/30/01			
Date:	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance
5/30/01					21.9	65.9	0	12.2								
7/5/01													28.2	48.4	0	22.9
7/11/01	3.8	10.7	12.6	72.6	25	56.9	1.9	15.8								
8/22/01	43.6	53.2	0	2.5									41.2	58.7	0	0
9/26/01					49.8	50.2	0	0								
11/1/01					51.8	48.2	0.1	0	50.4	49.6	0	0				
11/28/01	50.2	47.5	0	2.6												
2/26/02	45.2	41.7	0	13.1												

*Table Is Organized Based On Cover Dates
[1]Sensor nomenclature: Instrumentation layer # the senor is located - Sensor # on that layer
[2]Date covered refers to the date waste was placed over the sensor
[3]Balance is assumed to be nitrogen
*Gas Compositions measured by the GEM-500 by Landtec

Table 13. Northeast Anaerobic Cell Layer 2 Gas Compositions from Sampling Tubes

Sensor[1]	2-13				2-07				2-01				2-04				2-10			
Date Installed:	6/1/01				6/1/01				6/1/01				6/7/01				6/7/01			
Date Covered[2]:	6/1/01				6/5/01				6/6/01				6/8/01				6/8/01			
Date:	% CH_4	% CO_2	% O_2	% Balance[3]	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance
6/11/01	0	0.4	20.1	79.6	0.4	4.3	17	78.3	0.4	5.2	16.4	77.9								
7/2/01																	3.1	31.9	0	64.9
7/12/01	0	1.2	19.8	79	0.3	4	18.1	77.6	0.7	4.5	17.6	77	0.1	4.8	15.9	79.1	1.6	24.1	0	74.4
8/22/01													0.5	13.2	18.4	77.9				
9/26/01									22.8	37.1	1.8	38.7								
11/1/01									35.2	42.2	0.5	22.2	37	56.6	0	6.3				
11/28/01									39.5	46.6	0	13.9	21.2	31.2	7.8	39.8				
2/28/02					36.8	46.2	0.3	16.6	41.3	44.7	0	14								

Sensor	2-02				2-08				2-14				2-05			
Date Installed:	6/19/01				6/19/01				6/19/01				6/26/01			
Date Covered:	6/20/01				6/20/01				6/20/01				6/27/01			
Date:	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance
6/11/01																
7/2/01	6.8	41.6	0	57.7												
7/12/01	0.1	2.5	18.8	78.7	0.1	3.1	18.3	78.4	0	1.1	20.1	78.9	3.6	37.8	3.5	55.5
8/22/01	0.5	3.1	18.7	77.6												
9/26/01					16.6	46.7	2.3	34.1								
11/1/01																
11/28/01													30	52.6	0	17.4
2/28/02																

Sensor	2-11				2-03				2-09				2-15			
Date Installed:	6/26/01				7/5/01				7/5/01				7/5/01			
Date Covered:	6/27/01				7/6/01				7/6/01				7/6/01			
Date:	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance
6/11/01																
7/2/01																
7/12/01	0.7	6.7	17.1	75	1.6	21.3	9.9	67.5	0	3.5	18.8	77.6	0	1.1	20.6	78.3
8/22/01									0.4	5.4	18.1	76.3				
9/26/01									21	55.4	0.2	23.6				
11/1/01									24.3	44.9	0	31				
2/28/02									13.9	22.6	8.3	55.2				

*Table Is Organized Based On Cover Dates
[1]Sensor nomenclature: Instrumentation layer # the senor is located - Sensor # on that layer
[2]Date covered refers to the date waste was placed over the sensor
[3]Balance is assumed to be nitrogen
*Gas Compositions measured by the GEM-500 by Landtec

Table 14. Northeast Anaerobic Cell Layer 3 Gas Compositions from Sampling Tubes

Sensors[1]	3-01				3-09				3-02				3-10			
Date Installed:	7/13/01				7/17/01				7/20/01				7/27/01			
Date Covered[2]:	7/17/01				7/19/01				7/23/01				7/29/01			
Date:	%CH_4	%CO_2	%O_2	%Balance[3]	%CH_4	%CO_2	%O_2	%Balance	%CH_4	%CO_2	%O_2	%Balance	%CH_4	%CO_2	%O_2	%Balance
9/21/01	31.6	30.2	0	17.7	27.5	61.2	0	11.5	19.3	62.6	0	18.1				
9/26/01	28.7	48.6	0	13.2	26	57.8	0	16.1								
11/1/01	36.9	52	0	10	24.4	50.2	0	25.3					23.7	57	0	20.3
11/28/01	45.1	50.4	0	4.4					19.6	55.1	0	24.5	19.3	48	0	32.7
2/7/02	41.7	45.5	0	12.8												

*Table Is Organized Based On Cover Dates
[1]Sensor nomenclature: Instrumentation layer # the senor is located - Sensor # on that layer
[2]Date covered refers to the date waste was placed over the sensor
[3]Balance is assumed to be nitrogen
*Gas Compositions measured by the GEM-500 by Landtec

Figure 16. Northeast Anaerobic Cell Methane Concentrations from LFG Extraction Wellheads

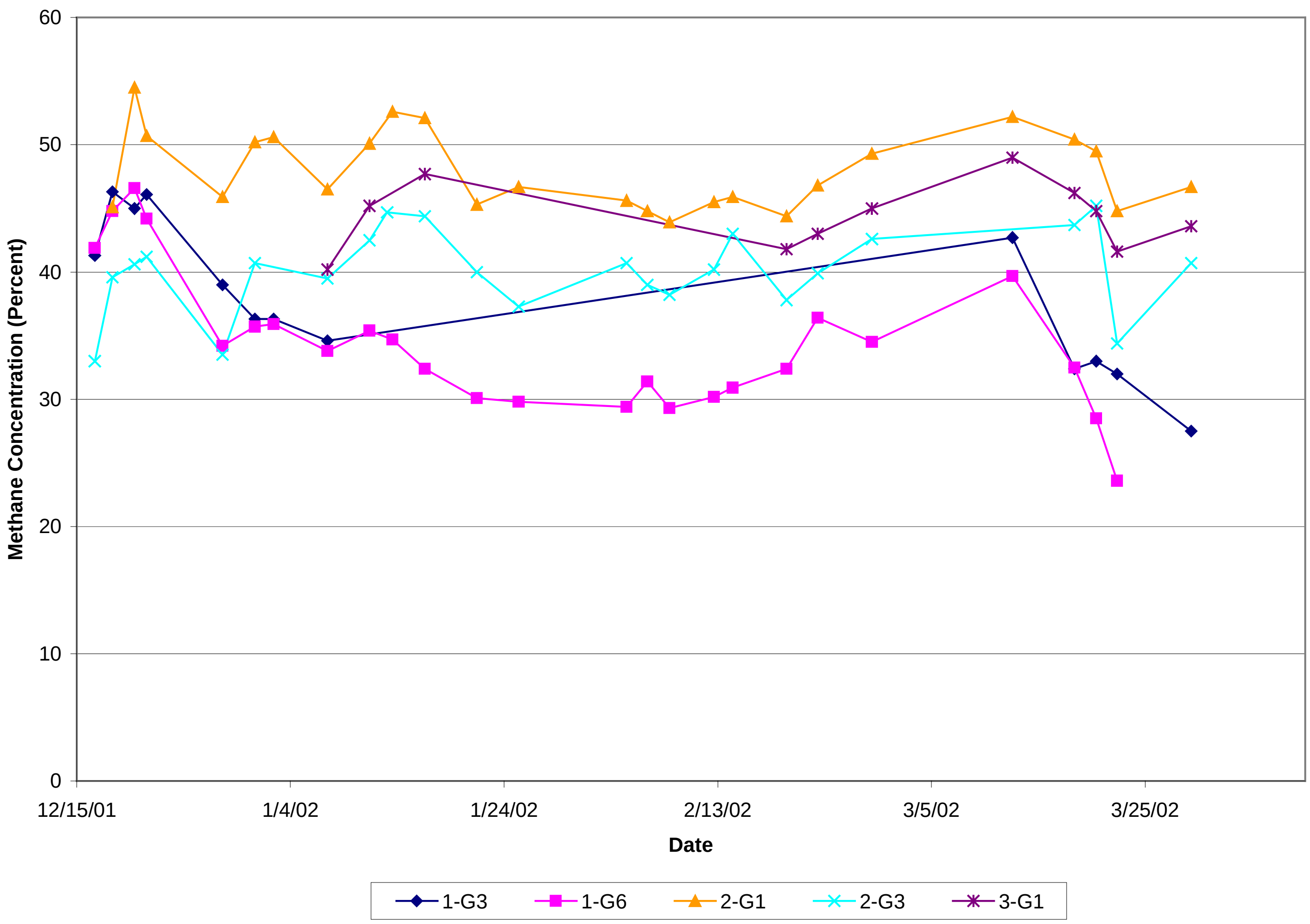


Figure 17. Northeast Anaerobic Cell Landfill Gas Concentrations from Header Line

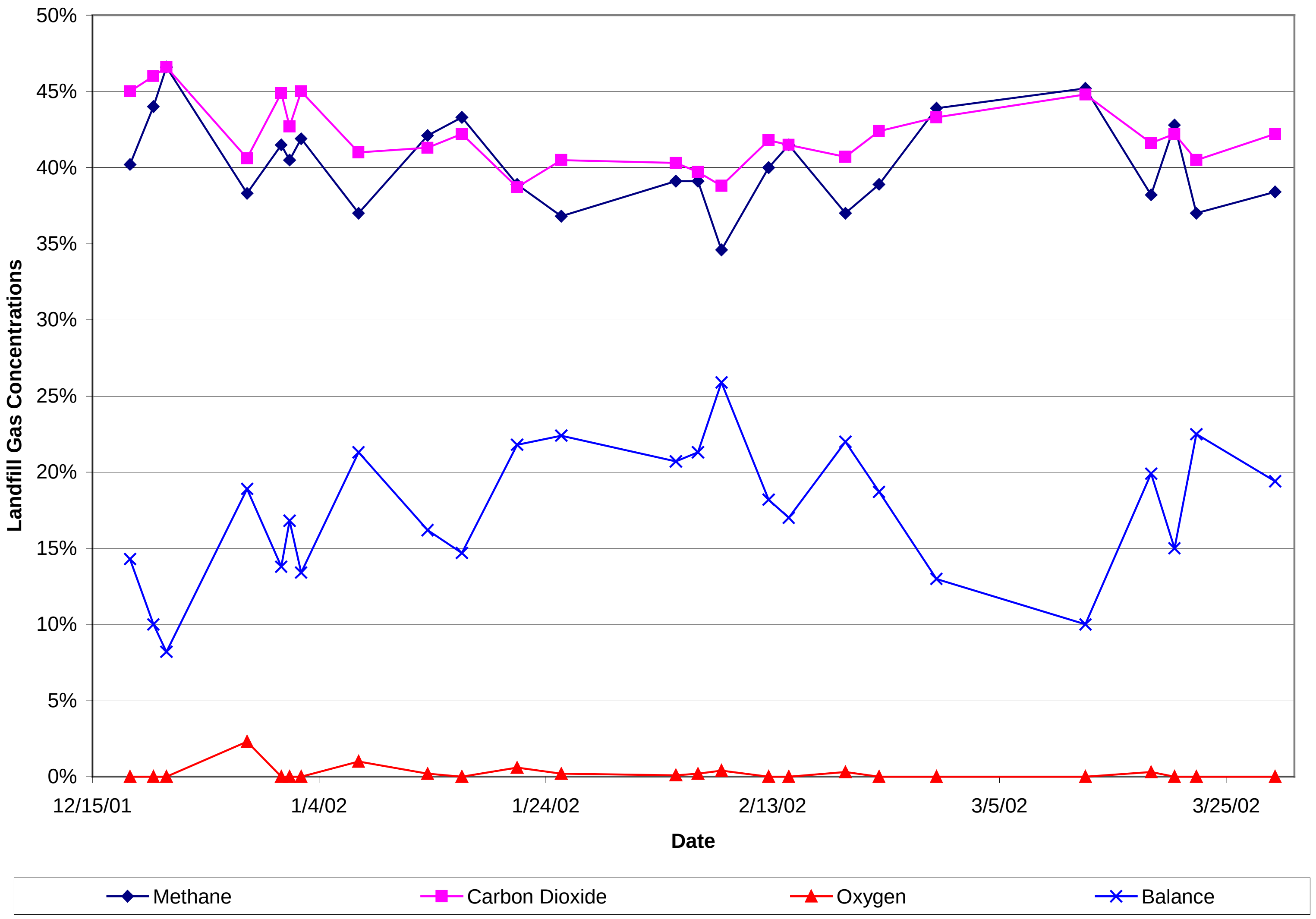


Figure 18. Northeast Anaerobic Cell Methane Flow Rates from Wellheads

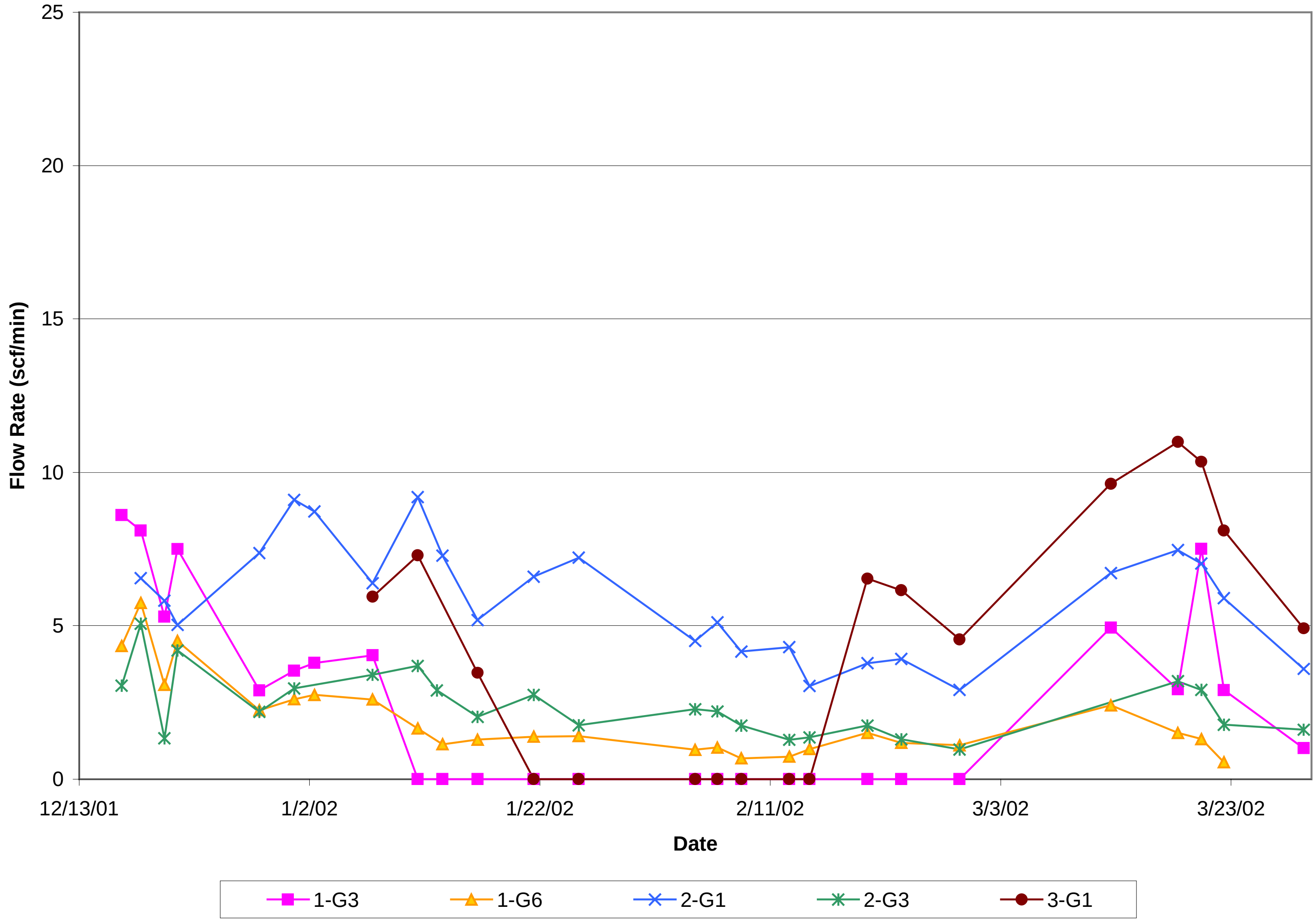


Figure 19. Northeast Anaerobic Cell Cumulative Methane

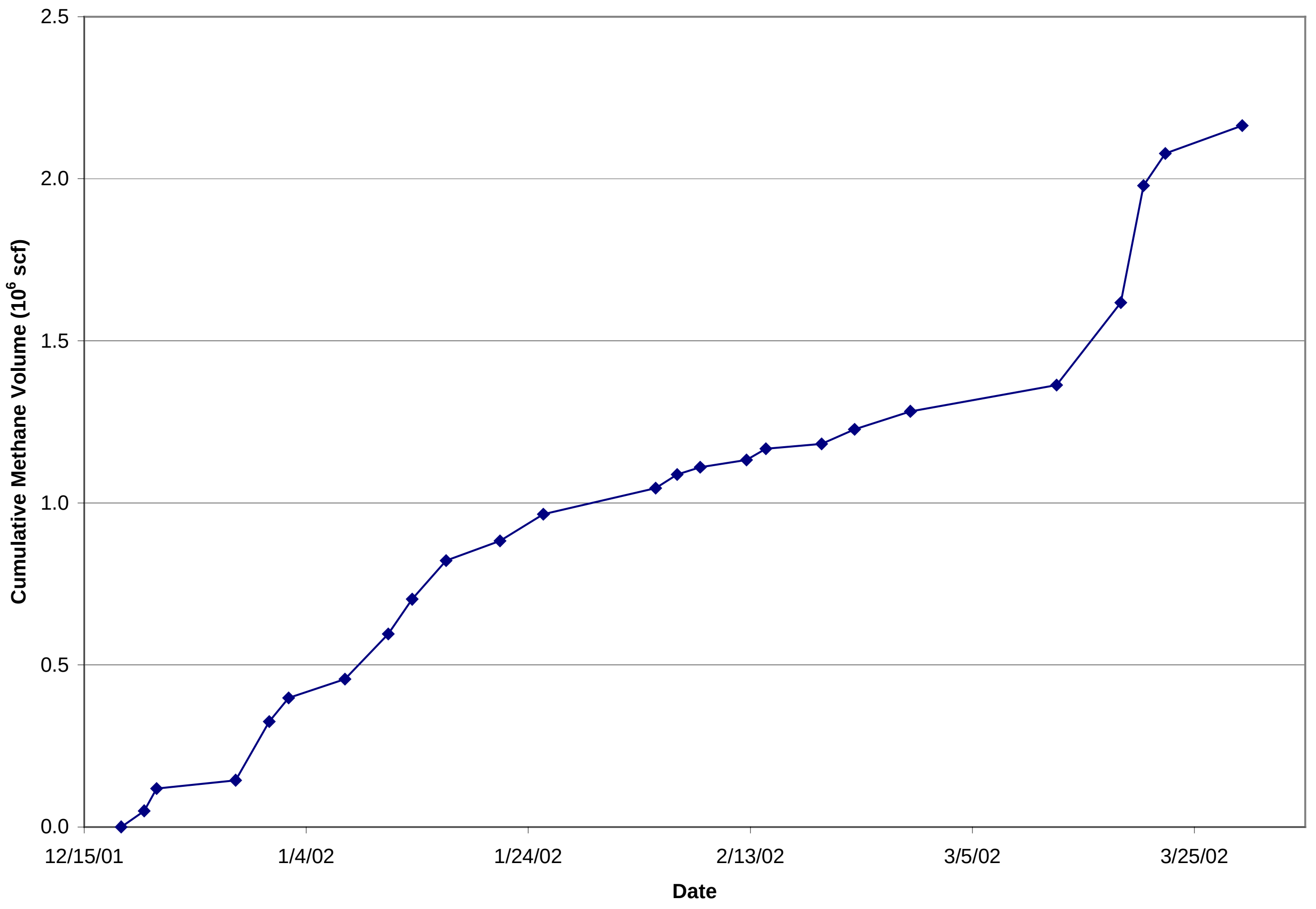


Figure 20. West-Side Anaerobic Cell (Southwest Quadrant) Base Layer Temperature Readings

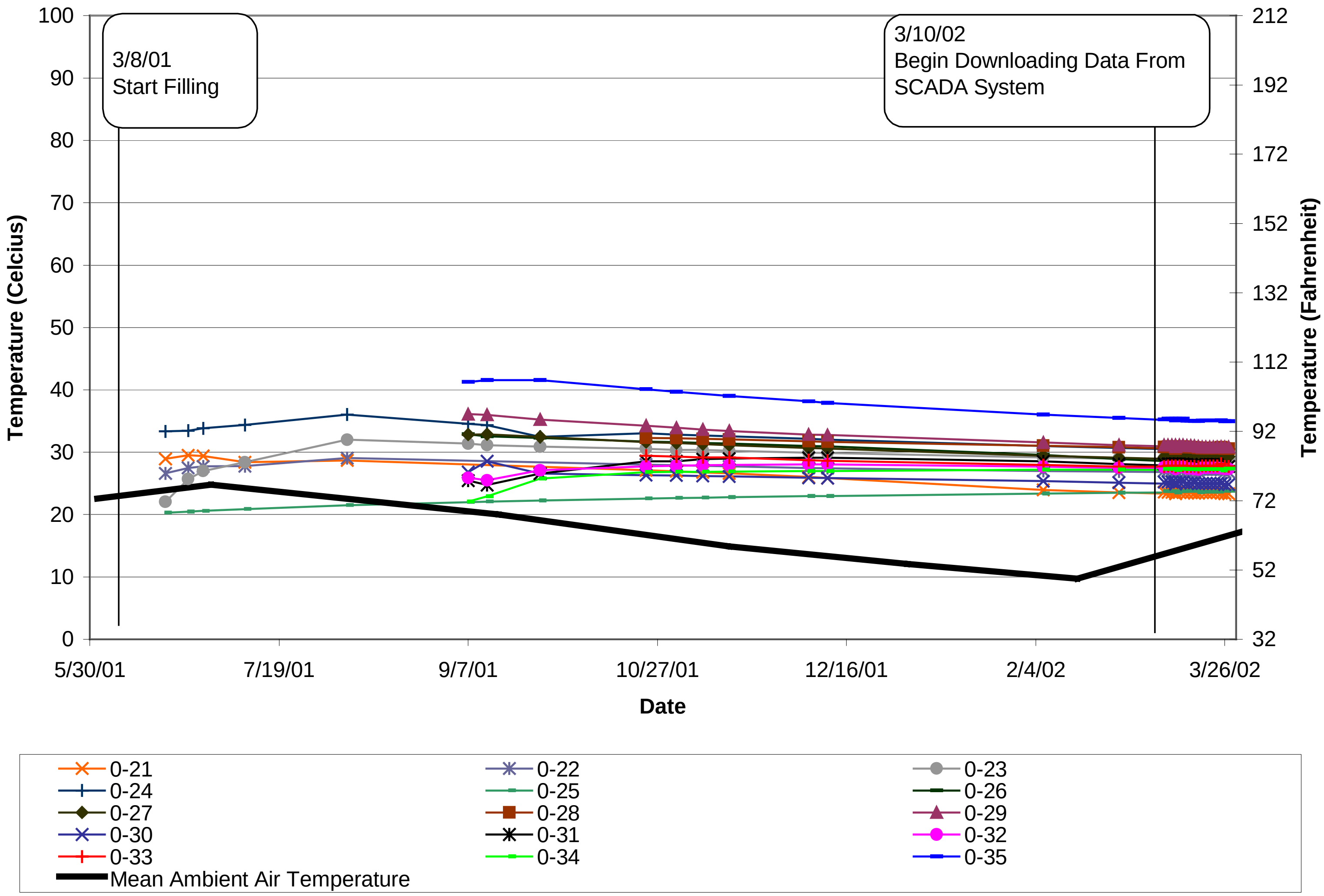


Figure 21. West-Side Anaerobic Cell (Northwest Quadrant) Base Layer Temperature Readings

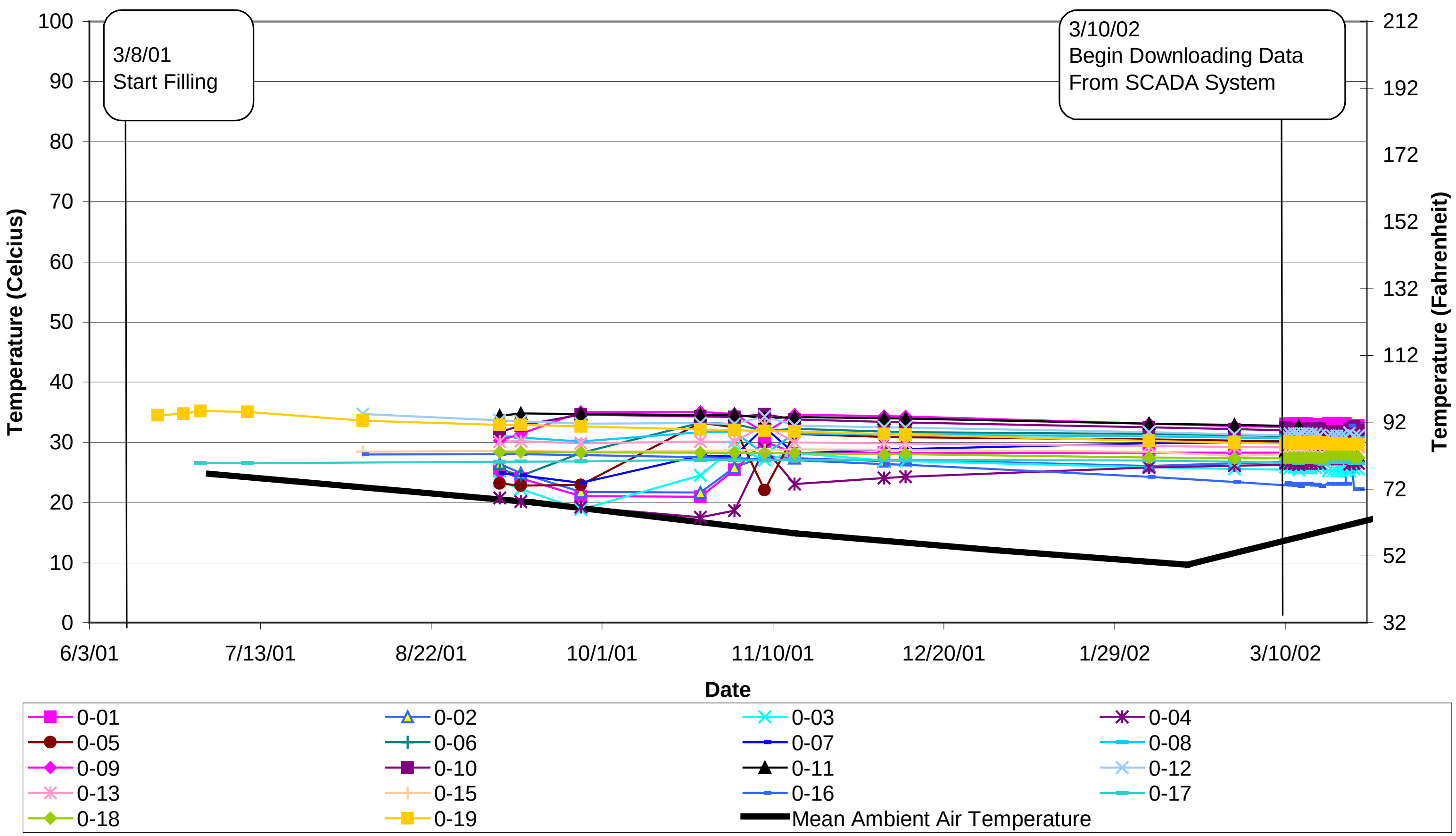


Figure 22. West-Side Anaerobic Cell Base Layer Moisture Readings (PVC Moisture Sensors)

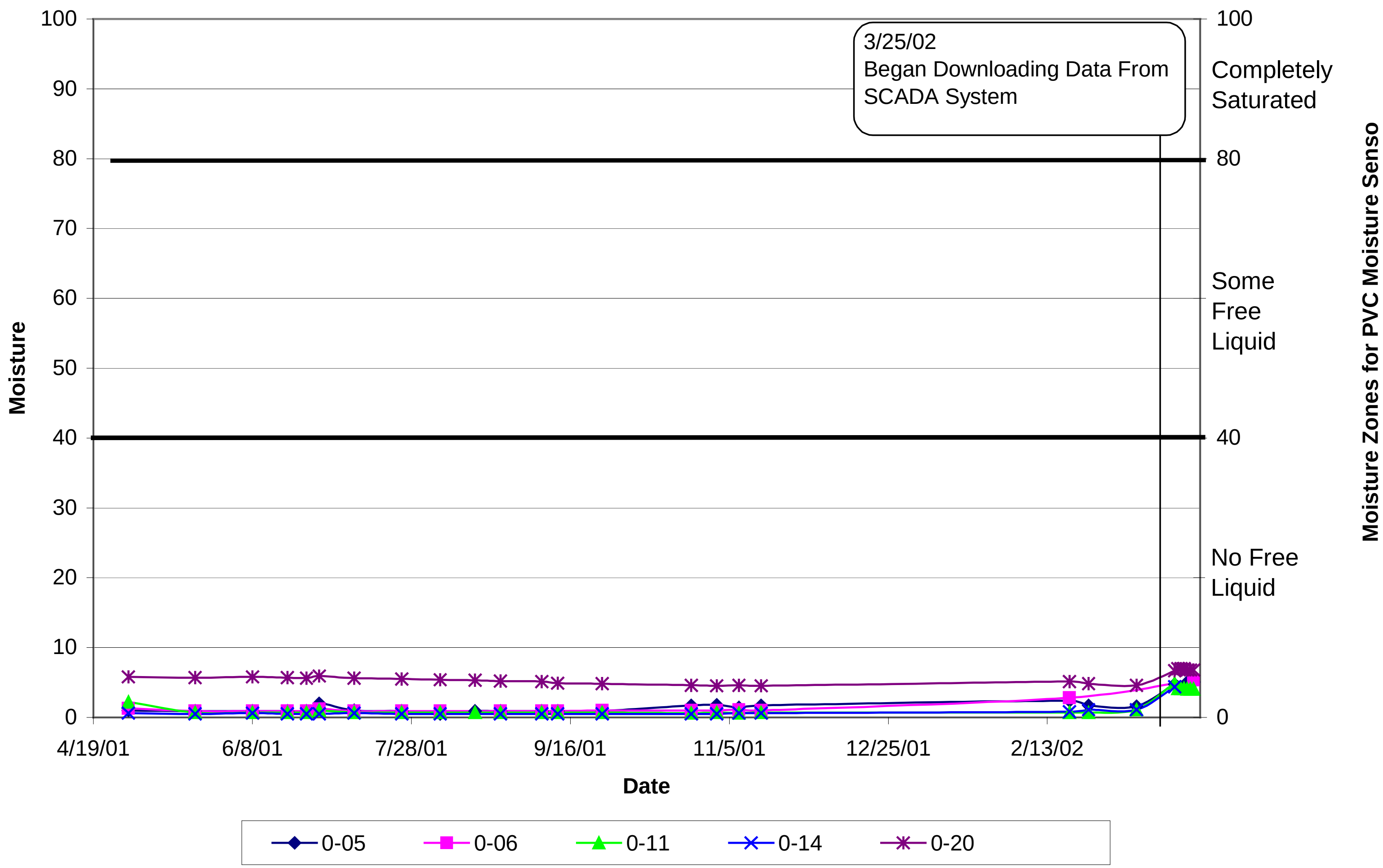


Figure 23. West-Side Anaerobic Cell (Southwest Quadrant) Base Layer Pressure Readings from Sampling

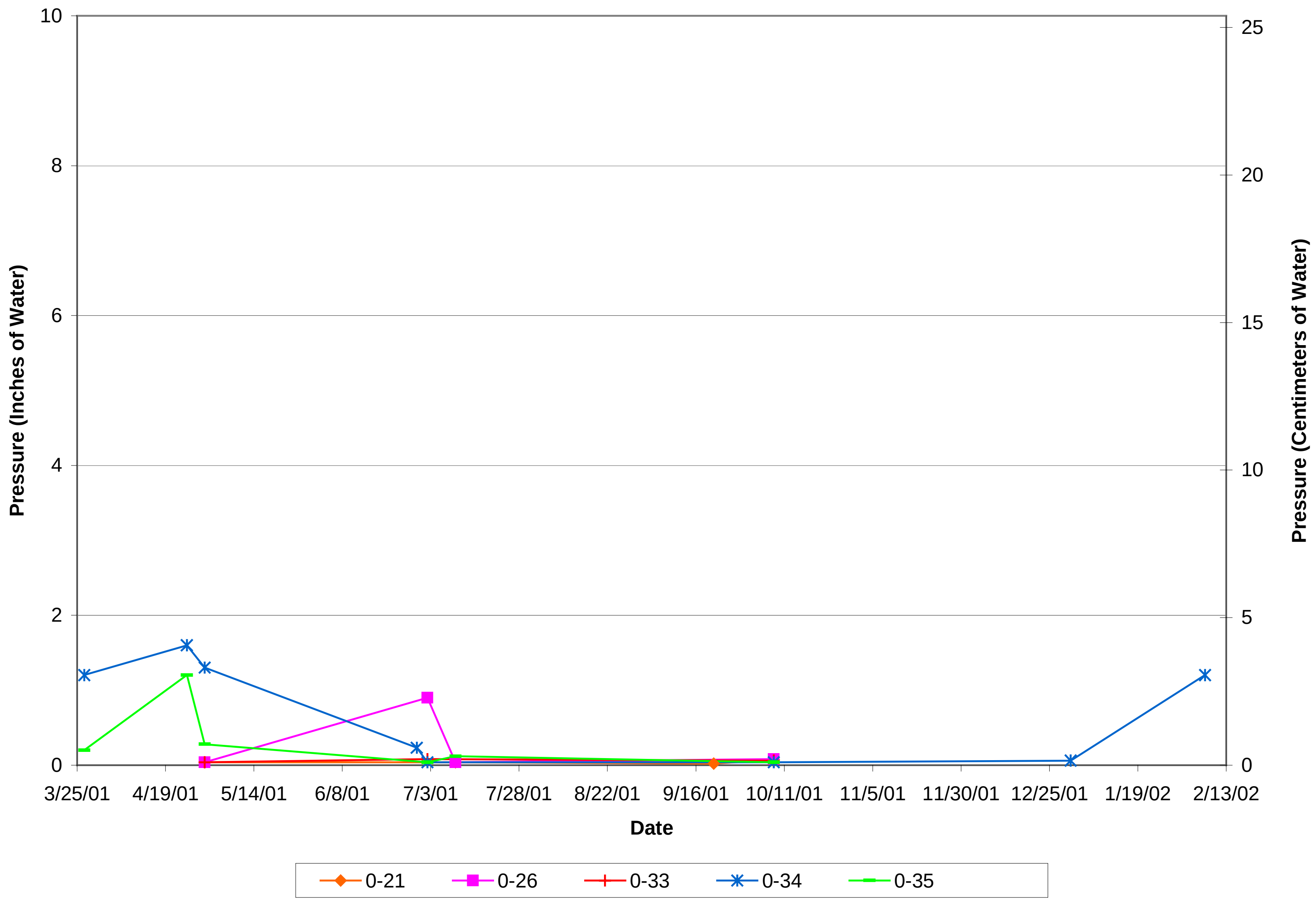


Figure 24. West-Side Anaerobic Cell (Northwest Quadrant) Pressure Readings from Sampling Tubes

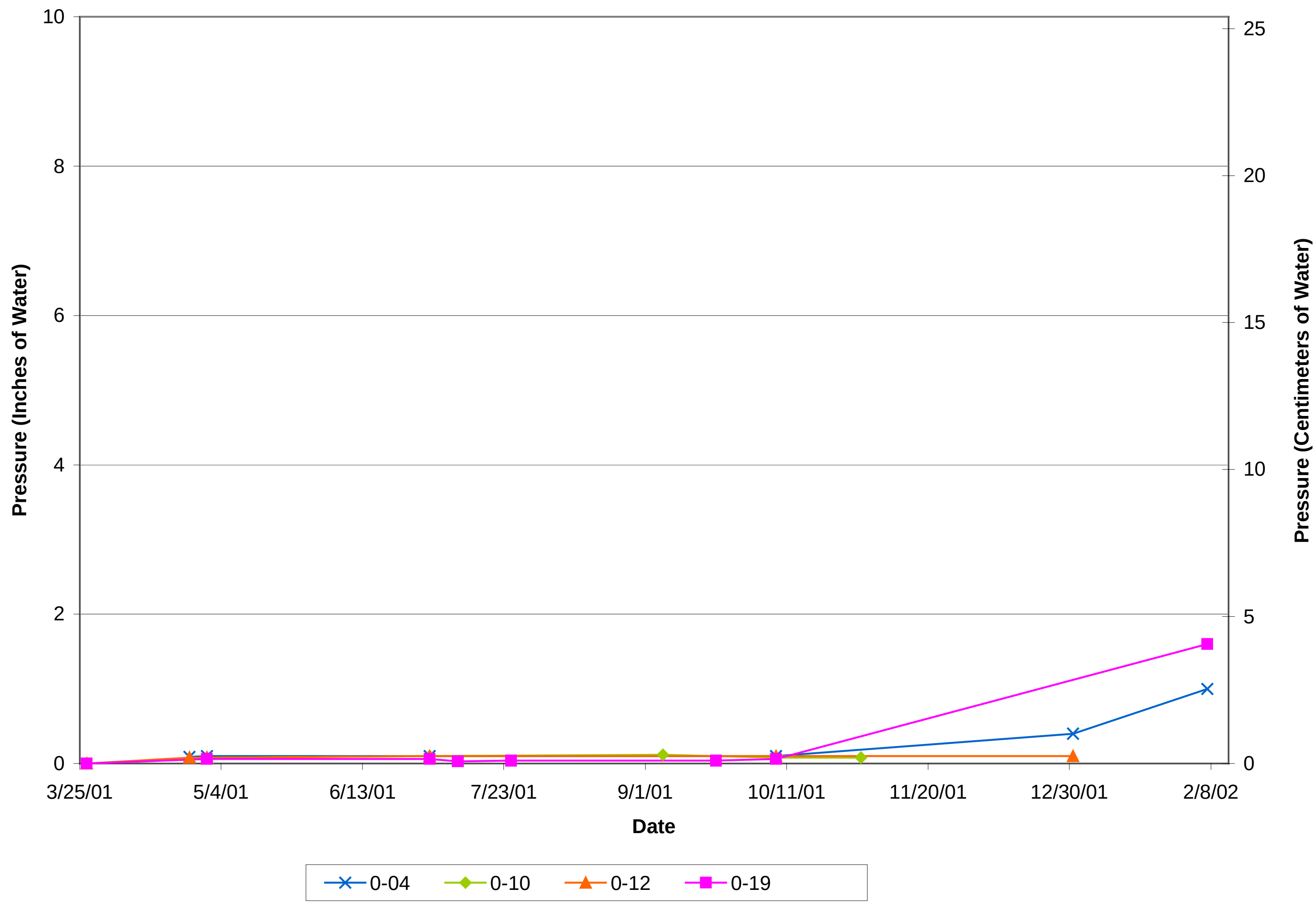


Table 15. West-Side Anaerobic Cell Base Layer Gas Compositions from Sampling Tubes

Sensor[1]	0-04				0-16				0-17				0-19			
Date Installed:	10/9/00				10/9/00				10/9/00				10/9/00			
Date Covered[2]:	11/1/01				6/21/01				6/18/01				6/18/01			
Date Monitored	% CH_4	% CO_2	% O_2	% Balance[3]	% CH_4	% CO_2	% O_2	% Balance[3]	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance
7/3/01					11.5	33.5	0	55.2								
7/10/01													7.1	22.6	9.9	60.2
8/21/01					19.3	36.3	0	44.4	7.2	34.7	0	58.1	25.1	40.5	0	34.3
9/6/01									5.4	30.7	0.1	63.8				
9/21/01													46.6	41.3	0	12.2
12/31/01	18.6	57	0.6	24												
2/7/02	38.5	57.1	0.6	3.8					23.7	58.7	0	17.6	27	57.1	0.2	15.7
2/28/02	40.9	59.1	0	0					33.3	58.1	0	0.6	31.3	58.7	0	10

Sensor	0-20				0-21				0-25				0-34			
Date Installed:	10/9/00				10/25/00				10/11/00				10/11/00			
Date Covered:	6/18/01				5/24/01				6/26/01				9/20/01			
Date Monitored	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance	% CH_4	% CO_2	% O_2	% Balance
7/3/01																
7/10/01	12.6	32.7	6	48.5												
7/11/01					2.9	23	2	71.5	9.8	30.6	4.5	55.4				
8/21/01	42.2	40.3	0	34.3	5.3	30.2	0	64								
9/21/01									25.6	41.6	0.1	32.6				
12/31/01													16.2	53.9	0.3	29.3
2/7/02													22	60.2	0	17.8
2/28/02													22	60.2	0	17.8

[1]Sensor nomenclature: Instrumentation layer # the senor is located - Sensor # on that layer
[2]Date covered refers to the date waste was placed over the sensor
[3]Balance is assumed to be nitrogen
*Gas Compositions measured by the GEM-500 by Landtec

Figure 25. Southeast Quadrant Anaerobic Base Liner Temperature Readings

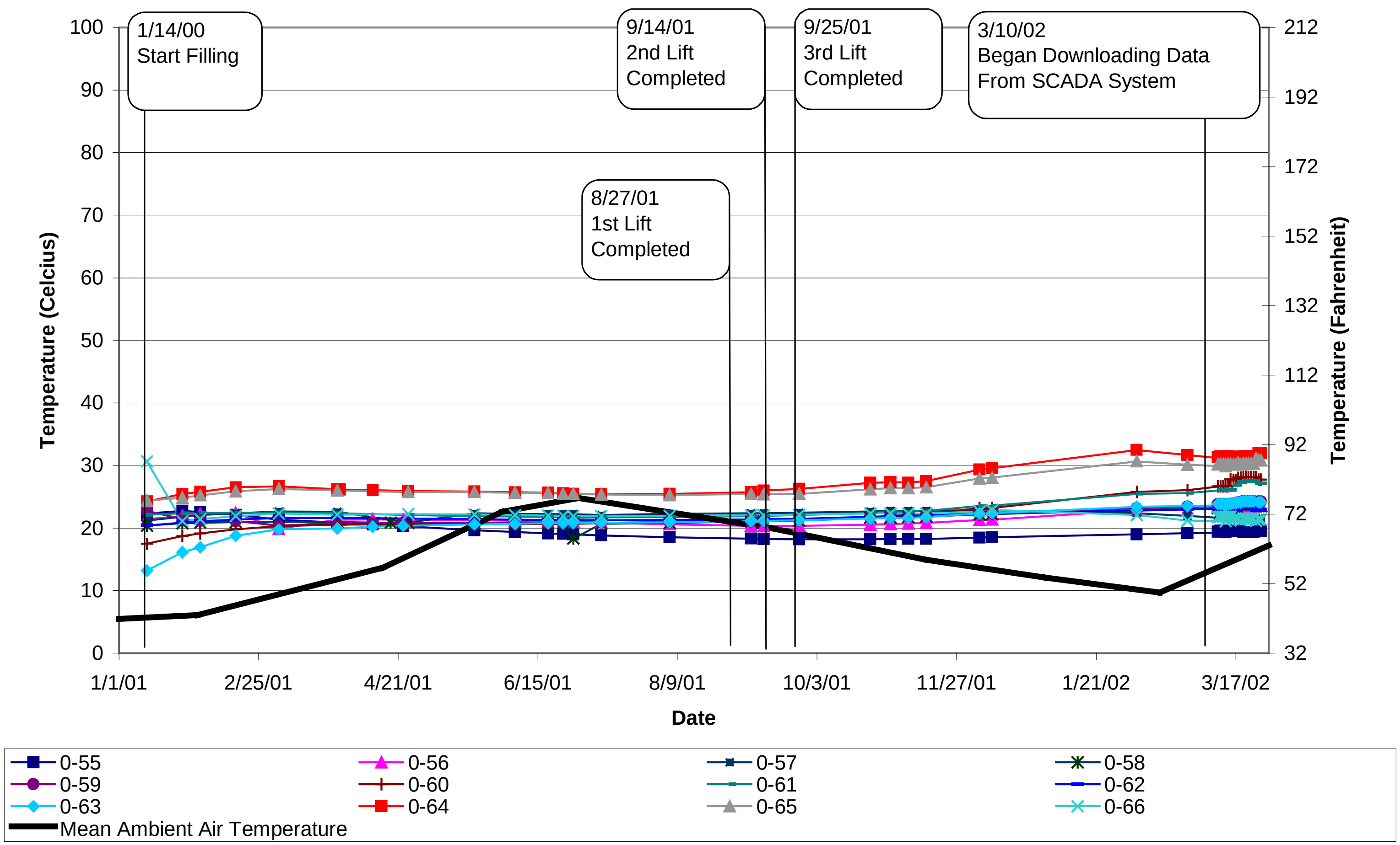


Figure 26. Aerobic Cell Base Layer Temperature Readings

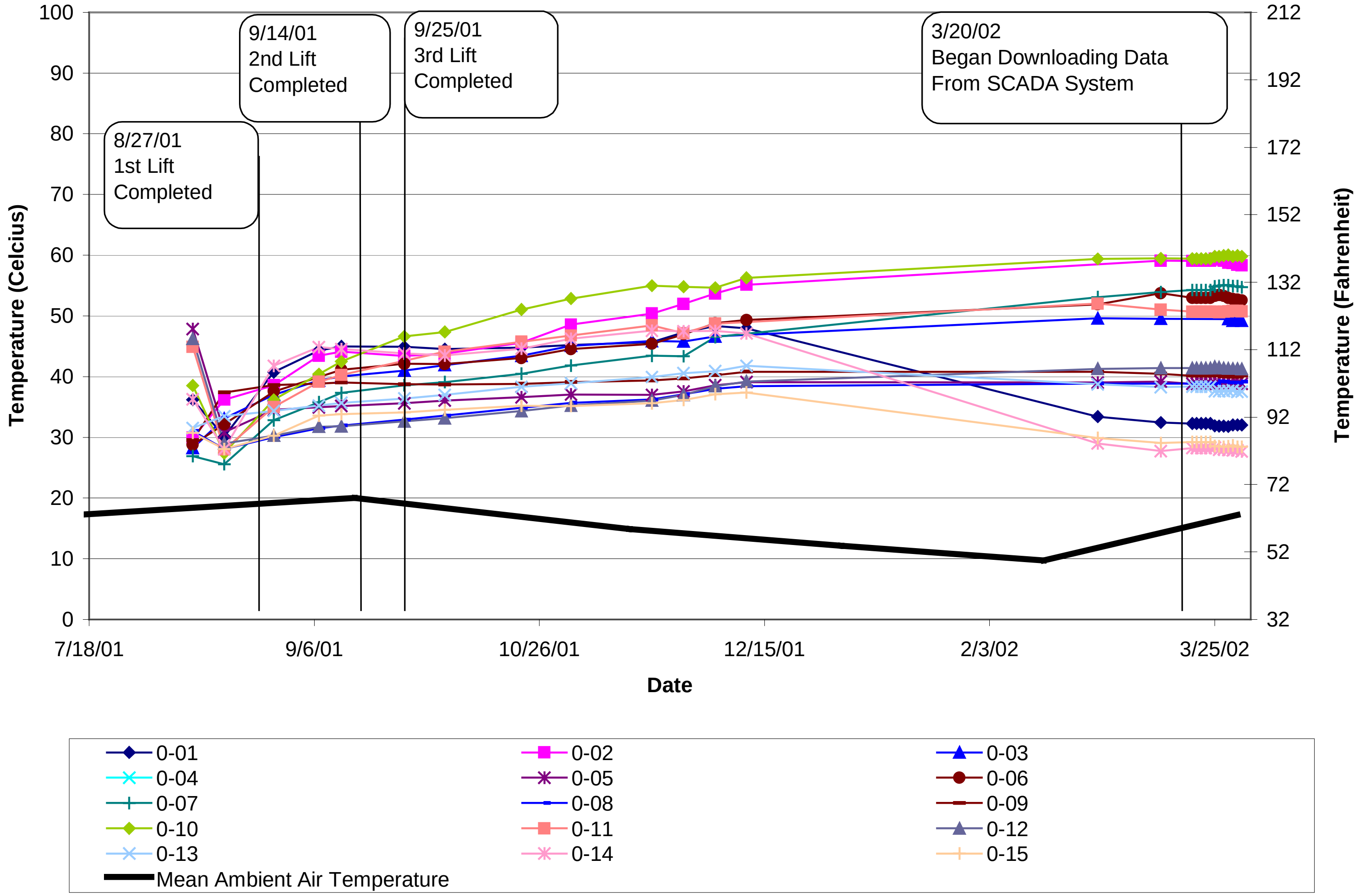


Figure 27. Aerobic Cell Layer 0.5 Temperature Readings

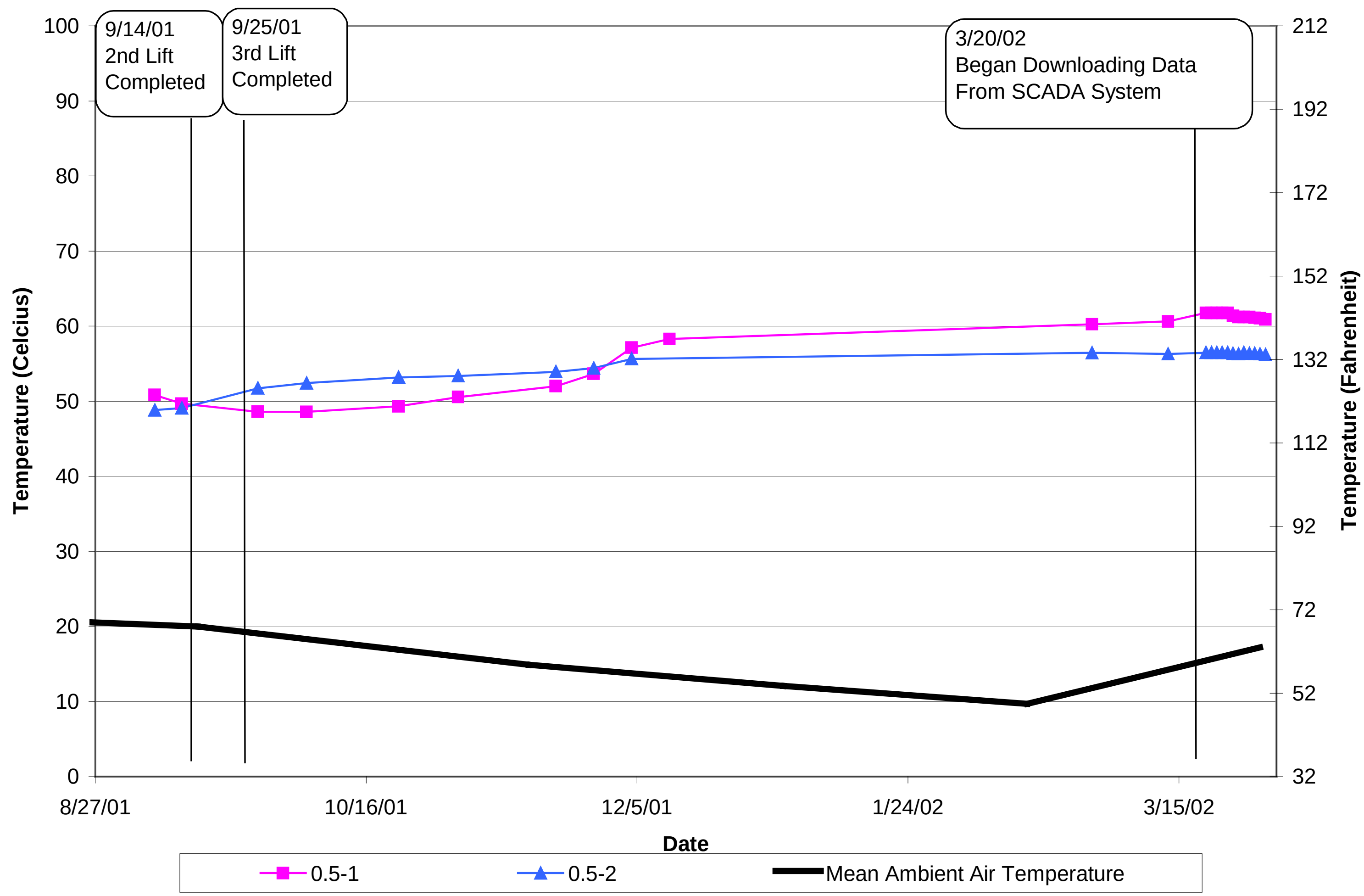


Figure 28. Aerobic Cell Layer 1 Temperature Readings

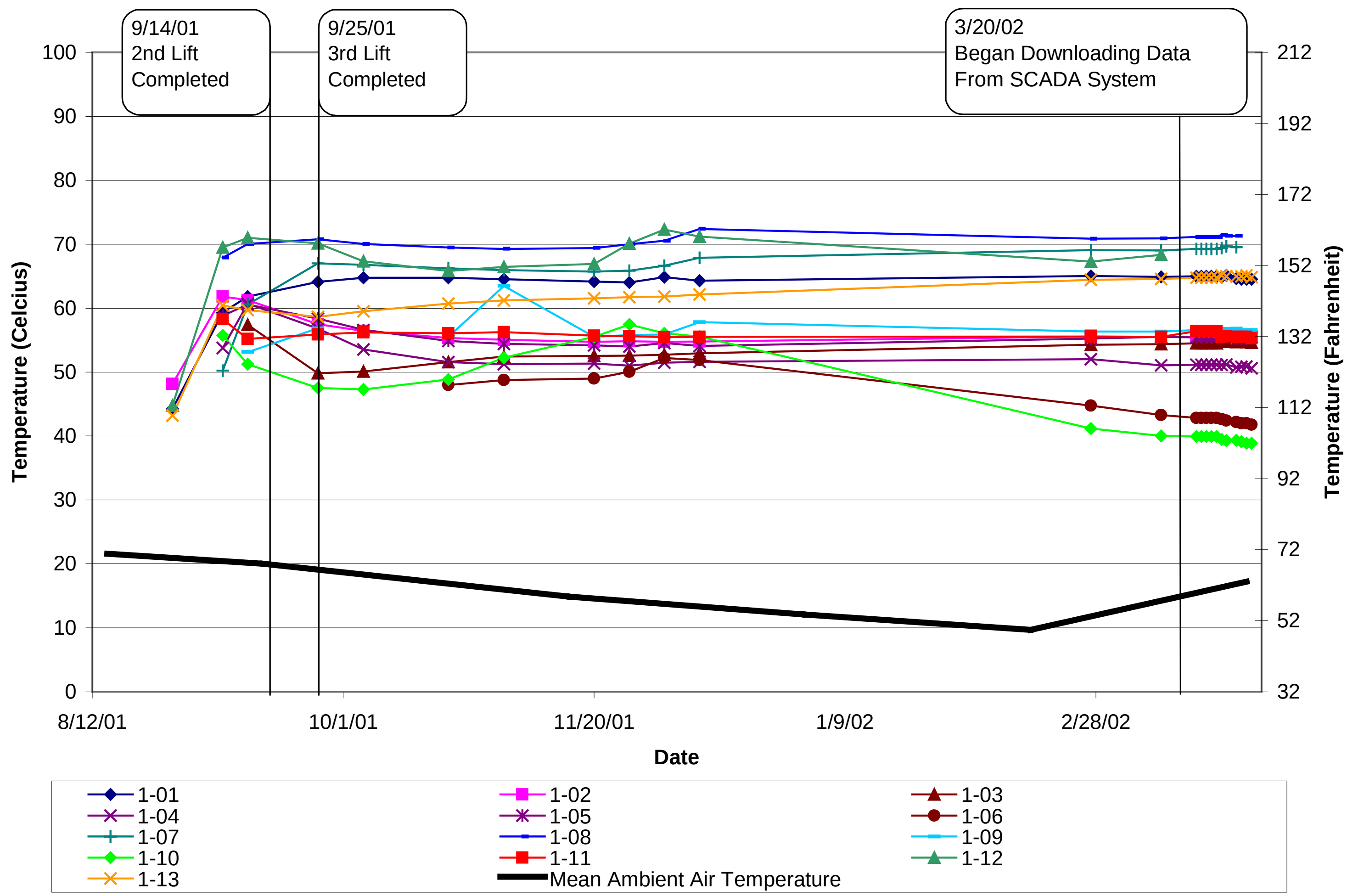


Figure 29. Aerobic Cell Layer 2 Temperature Readings

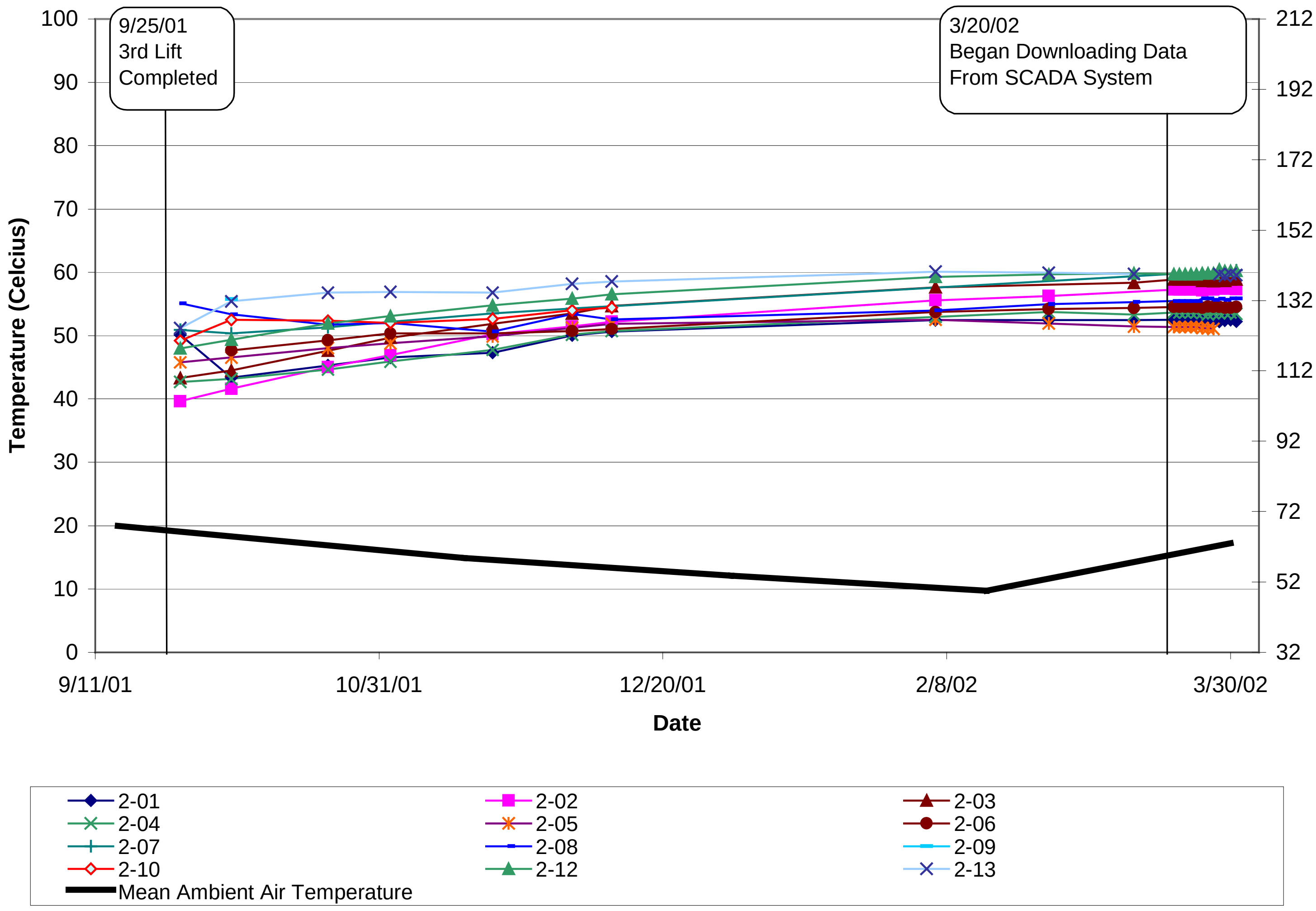


Figure 30. Southeast Quadrant Anaerobic Base Liner Moisture Readings (PVC Moisture Sensors)

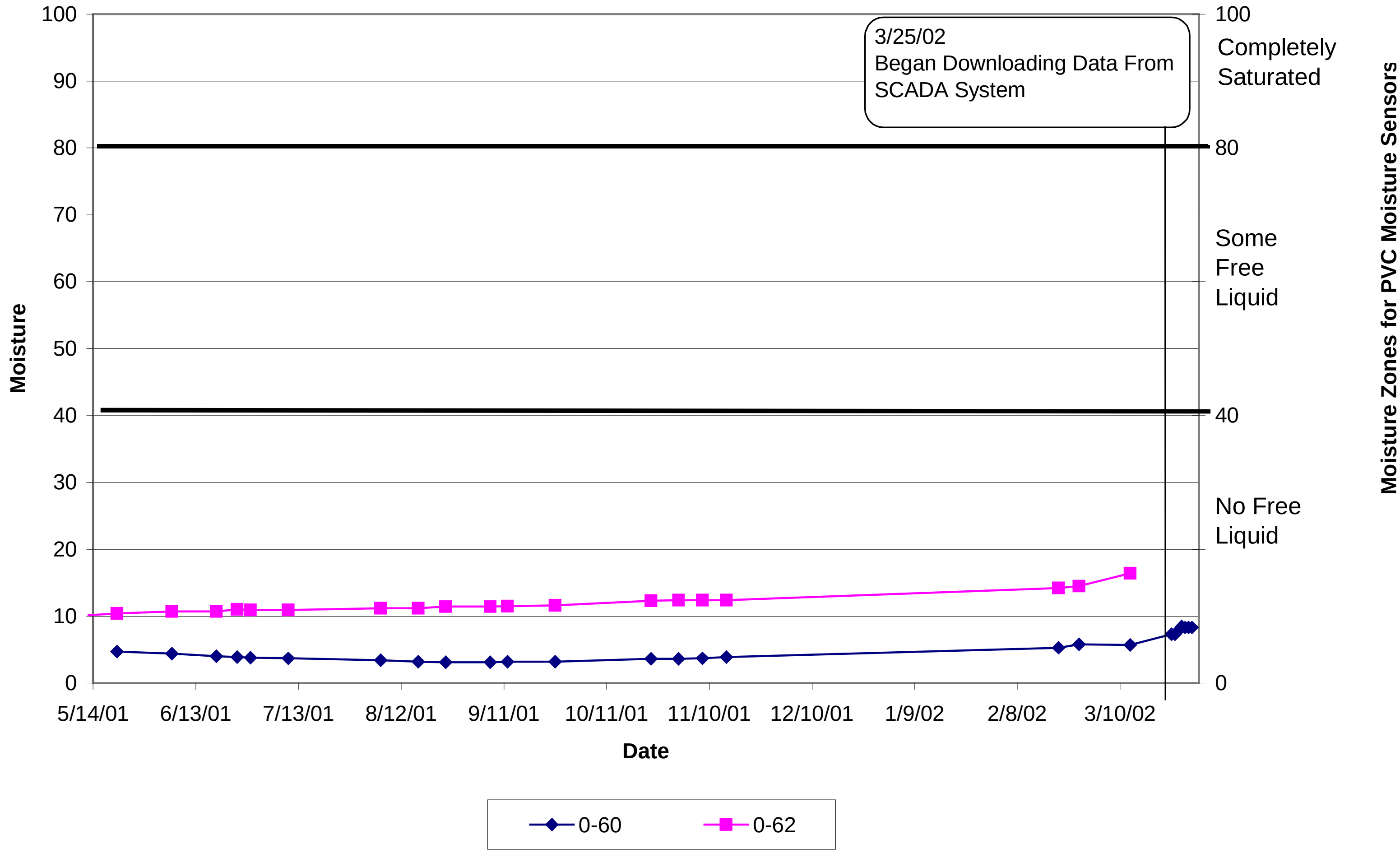


Figure 31. Aerobic Cell Base Layer Moisture Readings (PVC Moisture Sensors)

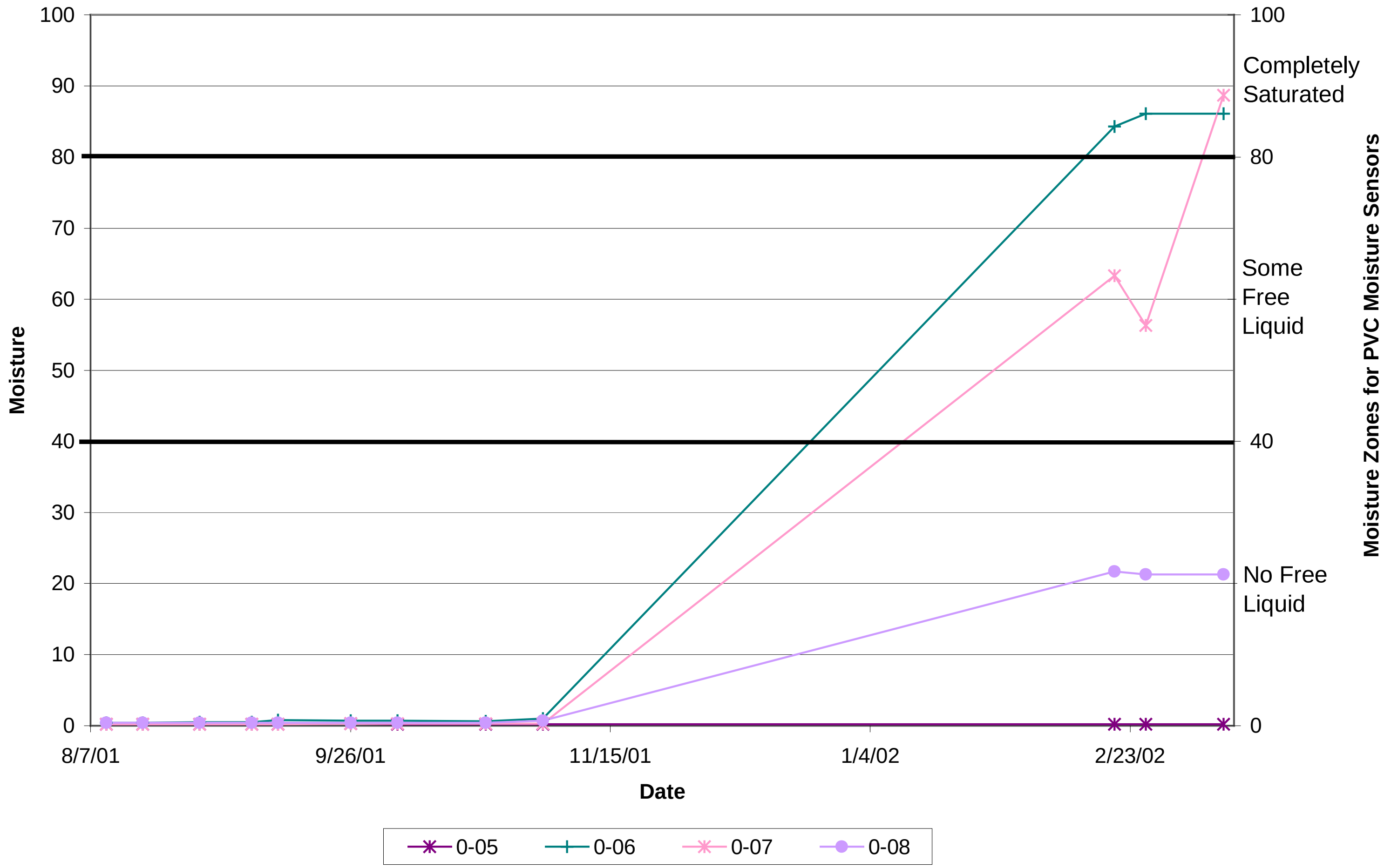


Figure 32. Aerobic Cell Layer 0.5 Moisture Readings (PVC Moisture Sensors)

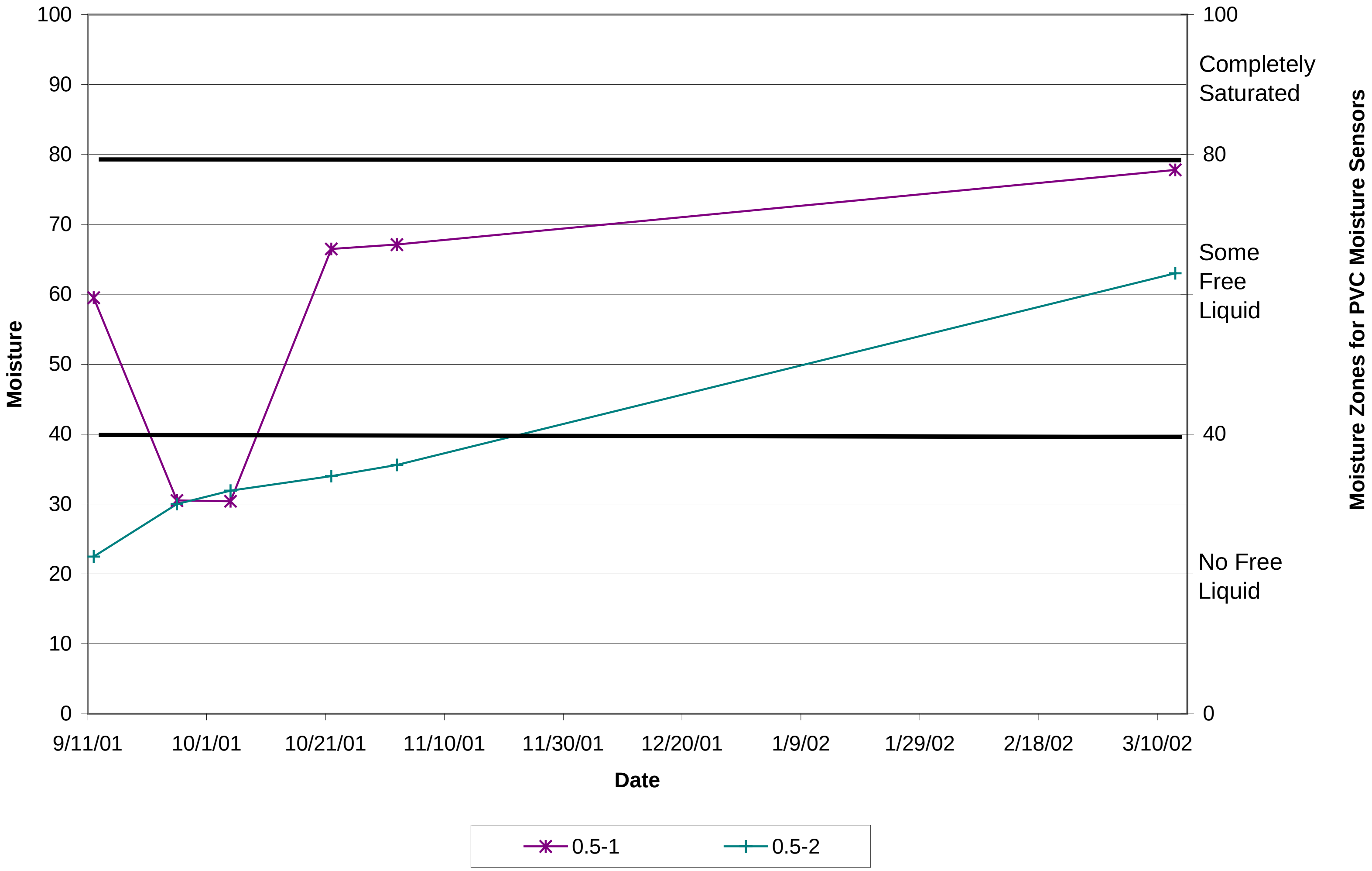


Figure 33. Aerobic Cell Layer 1 Moisture Readings (PVC Moisture Sensors)

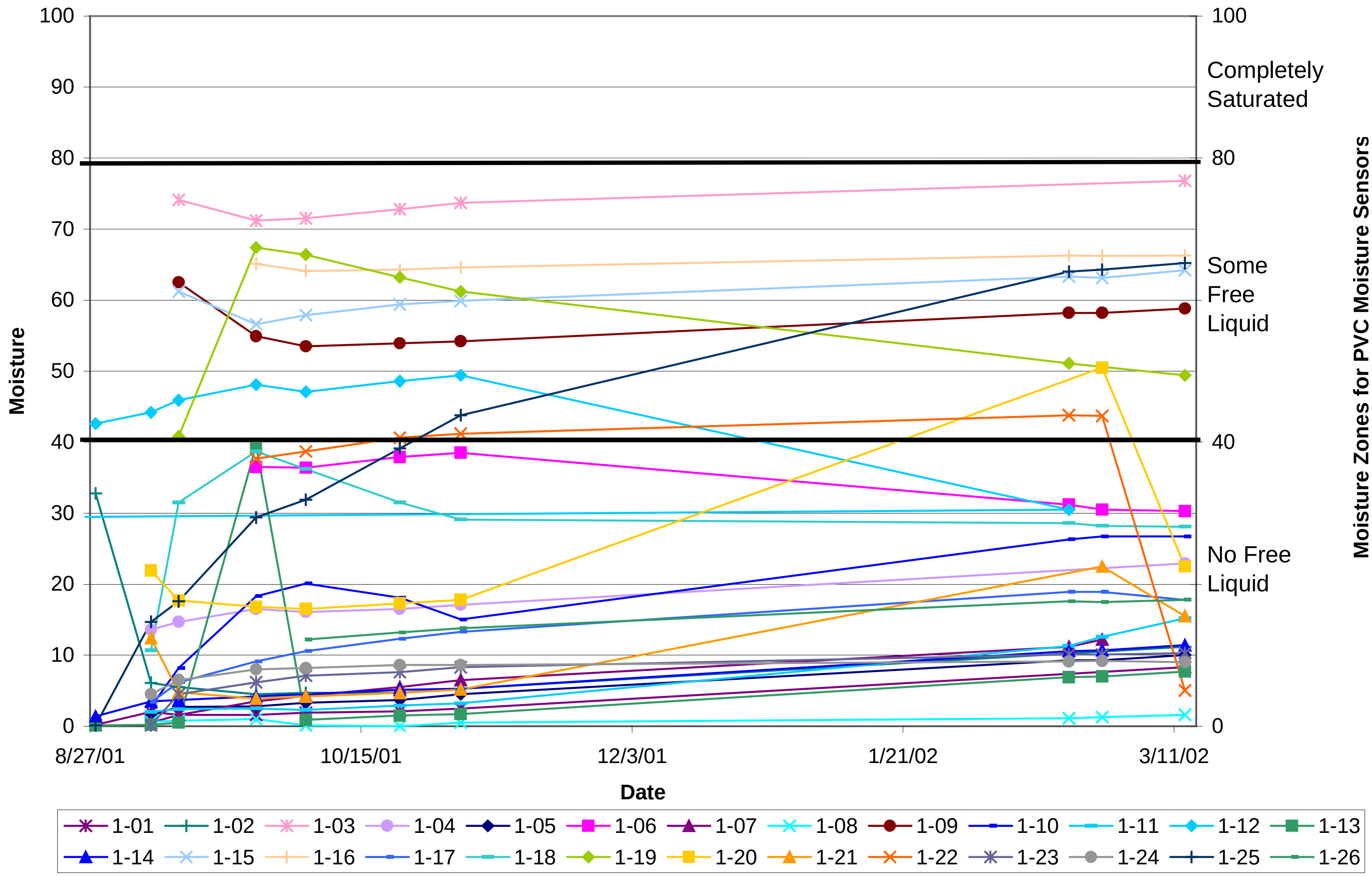


Figure 34. Aerobic Cell Layer 2 Moisture Readings (PVC Moisture Sensors)

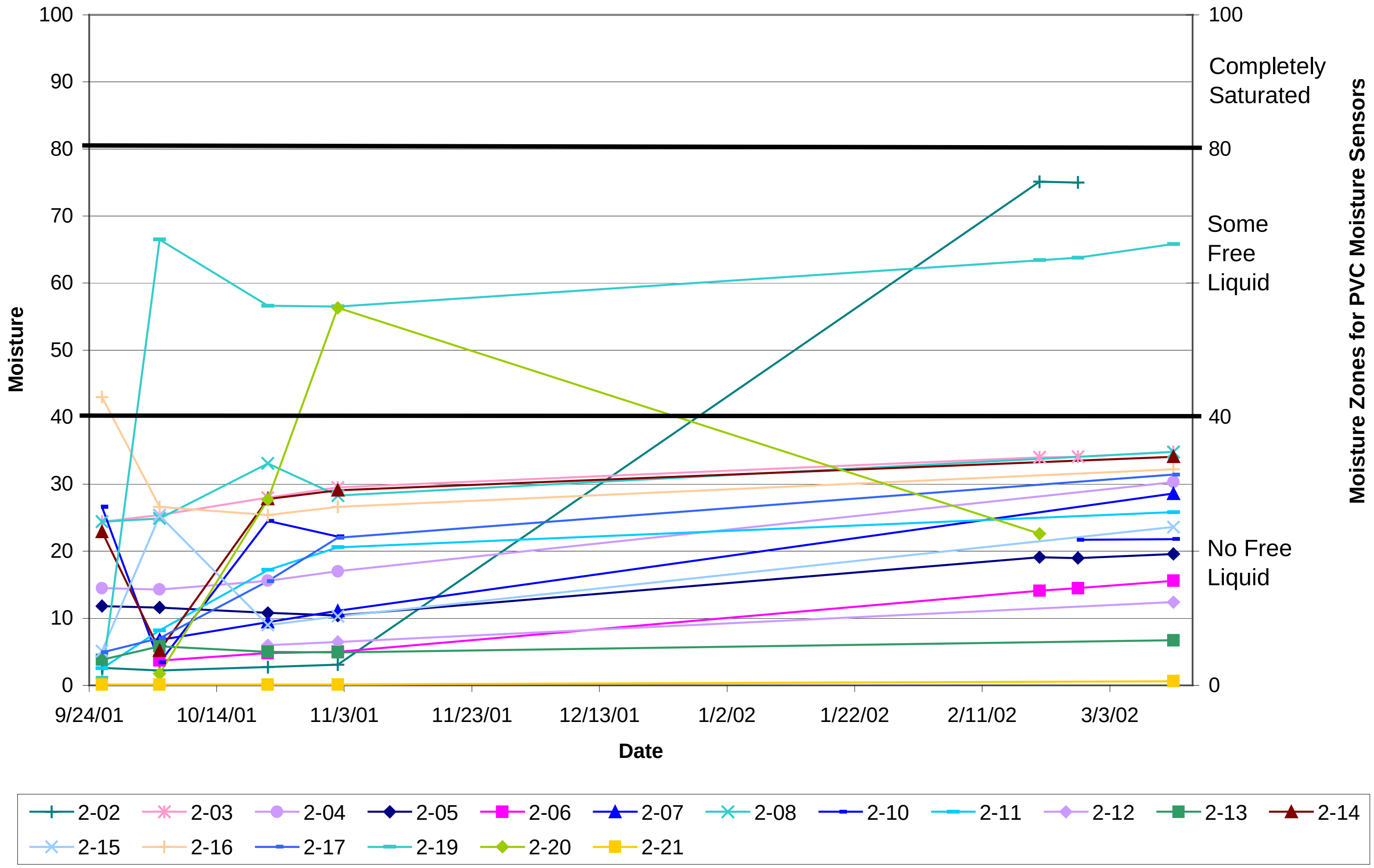


Figure 35. Southeast Quadrant Base Liner Pressure Readings from Sampling Tubes

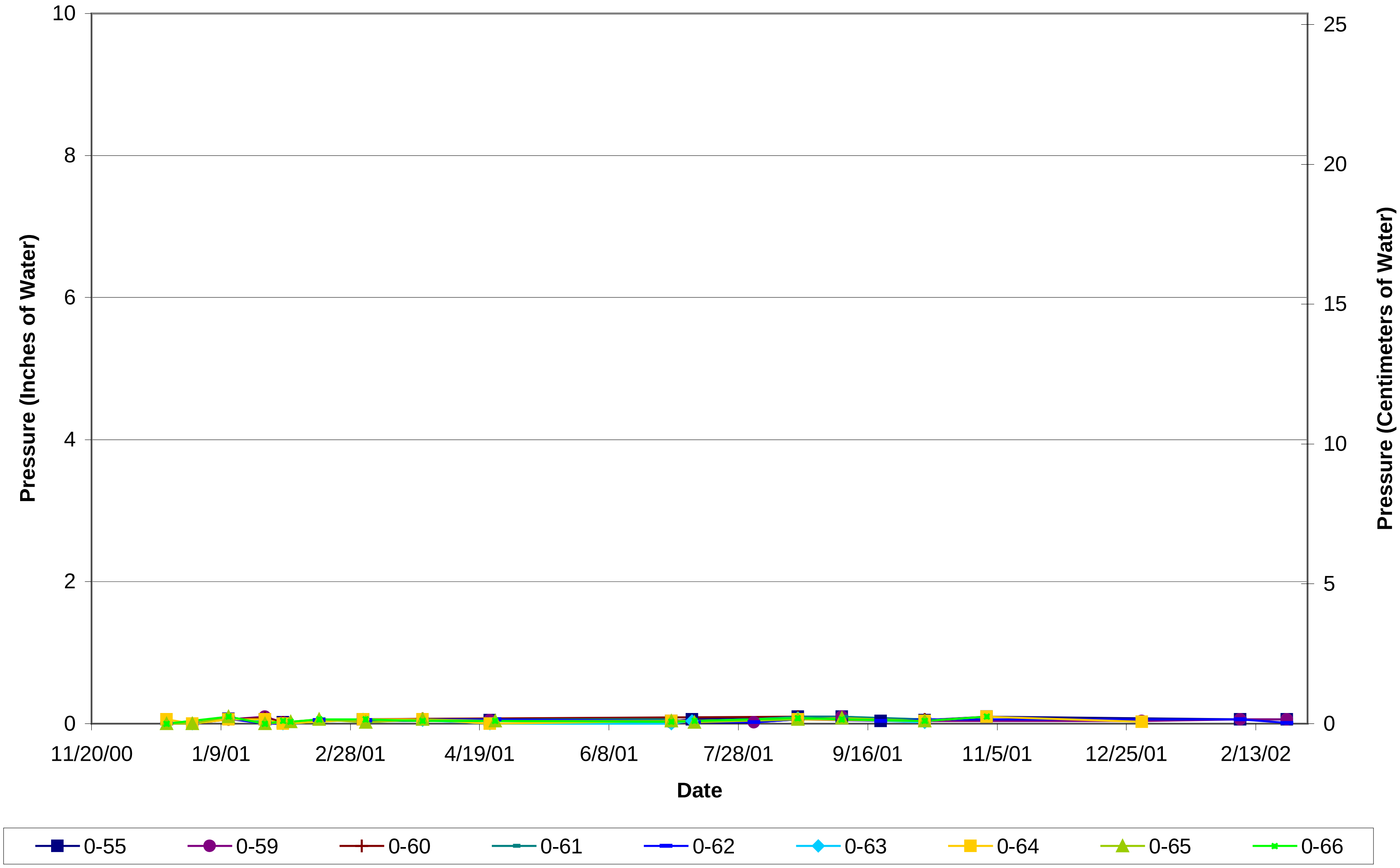


Figure 36. Aerobic Cell Base Layer Pressure Readings from Sampling Tubes

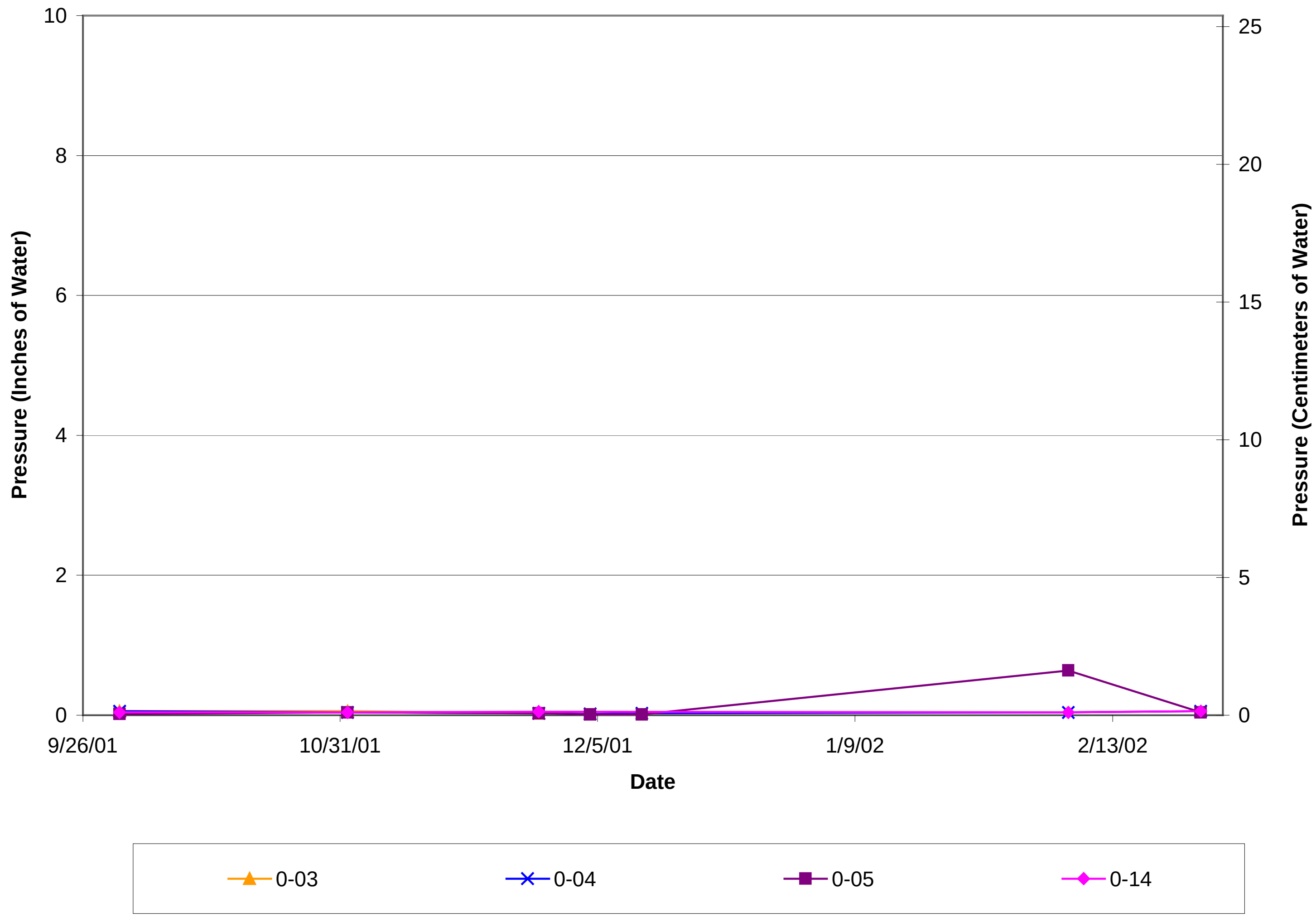


Figure 37. Aerobic Cell Layer 1 Pressure Readings from Sampling Tubes

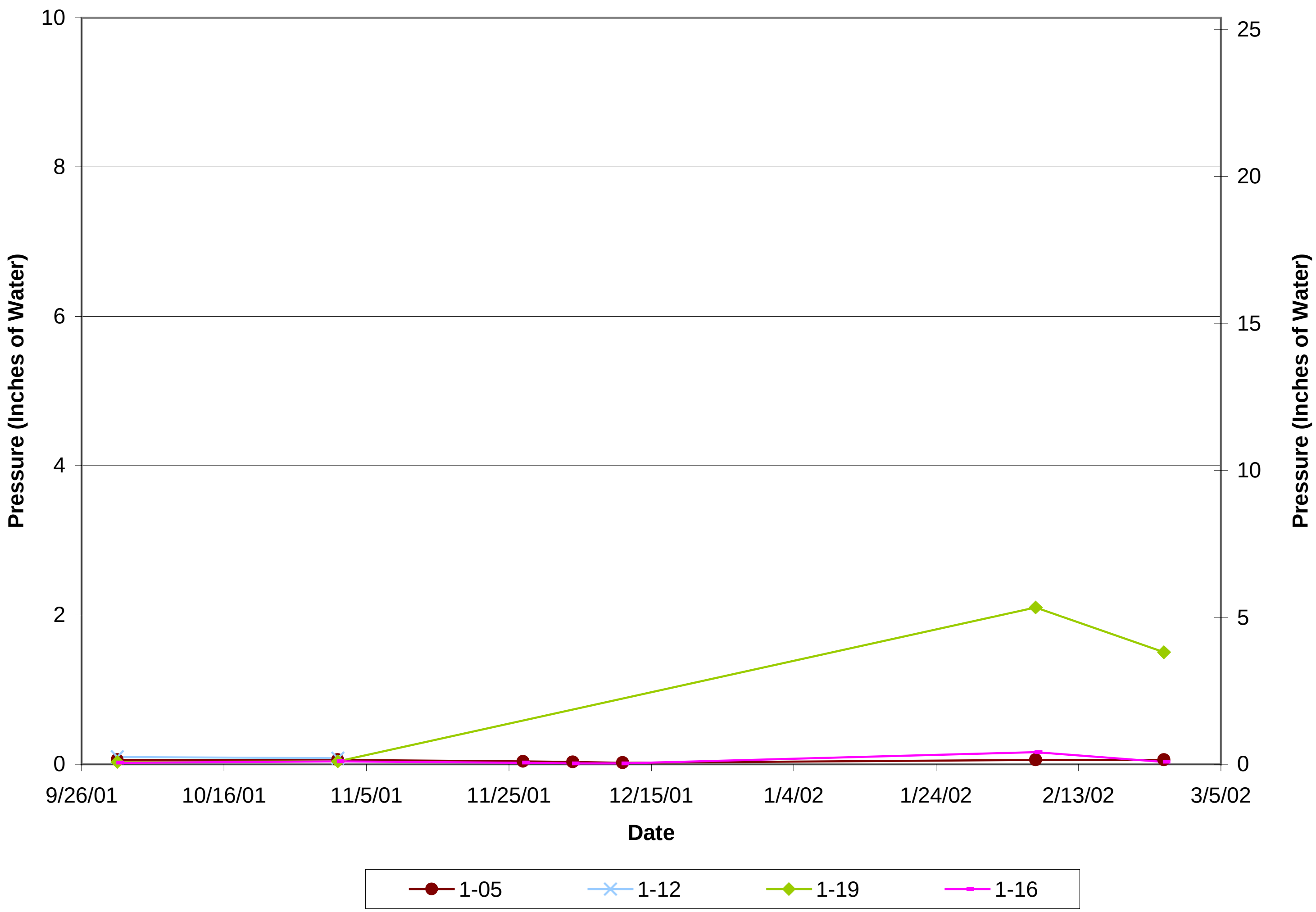


Figure 38. Aerobic Cell Layer 2 Pressure Readings from Sampling Tubes

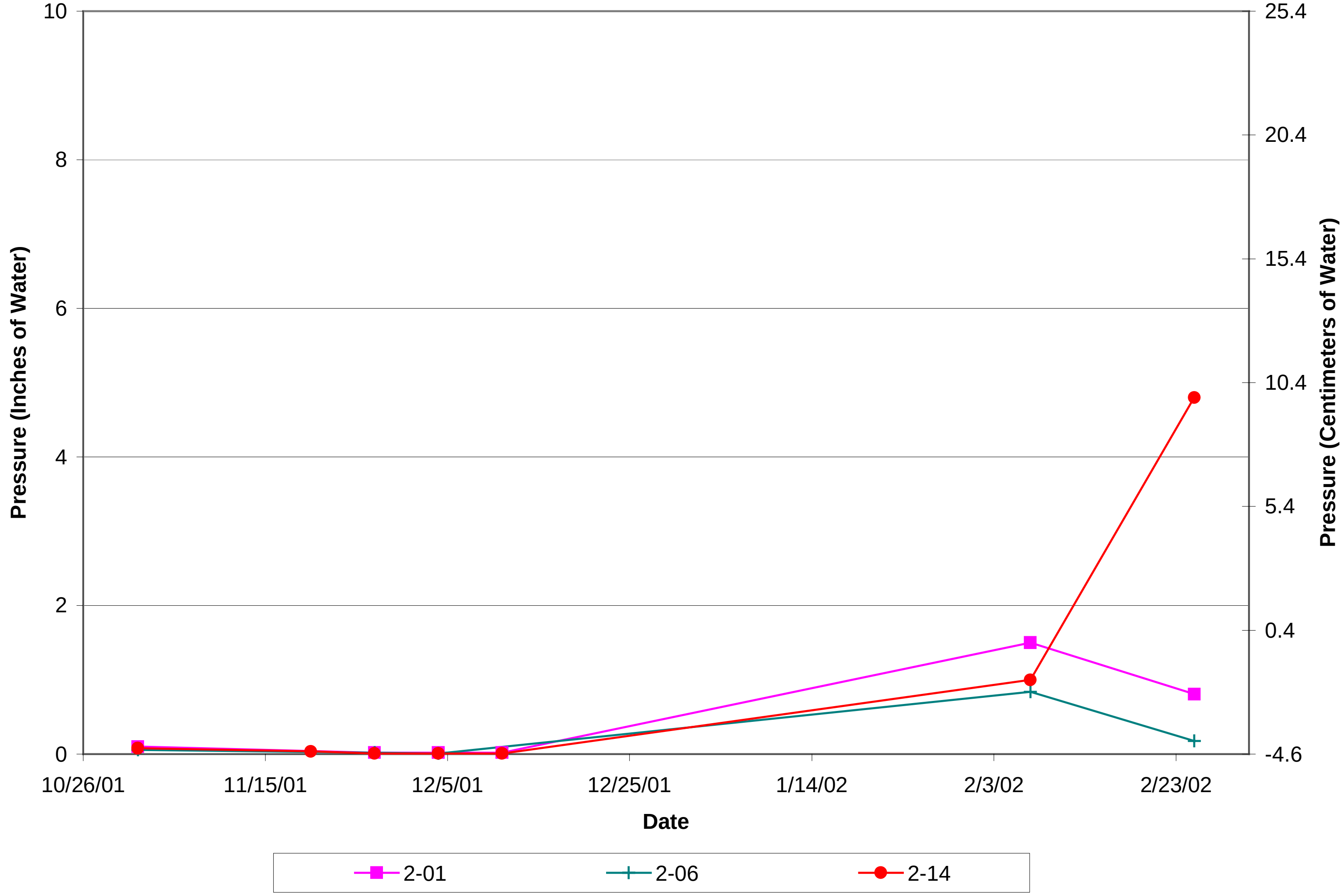


Table 16. Southeast Quadrant Anaerobic Base Liner Gas Compositions from Sampling Tubes

Sensor[1]	0-55				0-56				0-57				0-58			
Date Installed:	9/30/00				9/30/00				9/30/00				9/30/00			
Date Covered[2]:	1/12/01				12/29/00				12/29/00				12/29/00			
Date Monitored	%CH_4	% CO_2	% O_2	% Balance[3]	%CH_4	% CO_2	% O_2	% Balance	%CH_4	% CO_2	% O_2	% Balance	%CH_4	% CO_2	% O_2	% Balance
7/3/01					29	58.9	0	12.9								
7/10/01	20	46.8	1.1	31.9					32	58.2	0	9.9				
7/11/01									28.3	48.5	3.2	20	27.6	47.9	0	24.4
8/3/01													20.5	44.1	0	35.7
8/21/01					36.3	54.2	0	9.8								
9/6/01	36.2	48.5	1	14.7												
9/21/01	42.4	51.6	0.2	5.3												
12/31/01									23.5	43.7	0	32.6				
2/7/02	32.5	46.2	0	21.3												
2/28/02	43.6	53.3	0	3.1												

Sensor	0-59				0-62				0-65				0-66			
Date Installed:	9/30/00				9/30/00				9/30/00				9/30/00			
Date Covered:	1/12/01				12/29/00				12/29/00				12/29/00			
Date Monitored	%CH_4	% CO_2	% O_2	% Balance	%CH_4	% CO_2	% O_2	% Balance	%CH_4	% CO_2	% O_2	% Balance	CH_4	CO_2	O_2	Balance
7/3/01					9.6	37.5	0	52.7								
7/10/01	13.3	30.6	8.2	48												
7/11/01									28.4	57.2	0	14.4				
8/3/01	32.4	52.8	0	14.8	14	40.7	0	15.3								
8/21/01	30.6	53.5	0	8.1					33.4	56.5	0	10.5	16.8	40.5	0	42.5
9/6/01													19.9	40.7	0	39.4
9/21/01					14.3	39.7	0	46								
12/31/01	13.4	36.6	1.7	48.3												
2/7/02	19.5	41.7	0.3	38.5	17.1	41.2	0.4	41.1								
2/28/02	39.4	53.1	0	7.5	25.3	49.7	0	25								

[1]Sensor nomenclature: Instrumentation layer # the senor is located - Sensor # on that layer
[2]Date covered refers to the date waste was placed over the sensor
[3]Balance is assumed to be nitrogen
*Gas Compositions measured by the GEM-500 by Landtec

Table 17. Aerobic Cell Base Layer Gas Compositions from Sampling Tubes

Sensor[1]	0-04				0-05				0-07				0-14			
Date Installed:	8/1/01				8/1/01				8/1/01				8/1/01			
Date Covered:	8/6/01				8/6/01				8/6/01				8/6/01			
Date:	CH_4%	CO_2%	O_2%	% Balance[2]	CH_4%	CO_2%	O_2%	Balance %	CH_4%	CO_2%	O_2%	Balance %	CH_4%	CO_2%	O_2%	Balance %
8/20/01													0	0.9	20.5	78.7
10/2/01	1.8	23.3	4.3	70.4	2.3	29.9	0.9	66.8	4.4	38.3	5	51.6	3.6	32.5	0.6	63.3
11/1/01	4.3	23.9	0	71.8					4	26.4	0	69.6	1	14.7	3.8	80.1
11/20/01	4.4	25.8	0.2	69.7	4.7	25.3	1.1	68.7								
12/4/01	0.7	10.4	7.4	81.4	1.9	16.7	1.2	80								
2/26/02	1.8	22.3	0	75.9	6.4	25.6	0	68					2.7	26.3	0	71

[1]Sensor nomenclature: Instrumentation layer # the senor is located - Sensor # on that layer
[2]Balance is assumed to be nitrogen
*Gas Compositions measured by the GEM-500 by Landtec

Table 18. Aerobic Cell Layer 1 Gas Compositions from Sampling Tubes

Sensor[1]	1-02				1-05				1-07				1-15			
Date Installed:	8/24/01				8/29/01				8/28/01				9/12/01			
Date Covered:	8/24/01				8/29/01				8/28/01				9/12/01			
Date:	CH_4%	CO_2%	O_2%	% Balance[2]	CH_4%	CO_2%	O_2%	Balance %	CH_4%	CO_2%	O_2%	Balance %	CH_4%	CO_2%	O_2%	Balance %
10/2/01	10.7	58.4	0.4	30.8	7.9	41.1	0.4	50.7					12.1	63.9	0.1	23.6
11/1/01	13.4	47.8	0	39.9					5.4	22.5	0	72.3	16.2	59.4	0	24.2
11/27/01																
12/4/01					4.6	21.3	0	74.1								
12/11/01					5.3	22.1	0.1	72.3								
2/7/02					6.8	23.7	0	69.5								
2/28/02					8.5	22.9	0	68.9								

	1-16				1-18				1-19				1-22			
Date Installed:	9/13/01				8/31/01				9/11/01				9/13/01			
Date Covered:	9/13/01				8/31/01				9/11/01				9/13/01			
Date:	CH_4%	CO_2%	O_2%	Balance %	CH_4%	CO_2%	O_2%	Balance %	CH_4%	CO_2%	O_2%	Balance %	CH_4%	CO_2%	O_2%	Balance %
10/2/01	7	60	0	33					9.8	63.1	0.1	26	4.6	43.6	0.1	52.1
11/1/01	6.7	42.2	0	51.4												
11/27/01					4.5	15.5	1.2	78.7								
12/4/01	2.9	22.1	0	75	3.2	14.4	1.5	80.7								
12/11/01	3.2	21.7	0	75.1												
2/7/02	15.1	32.4	0	52.5					7.2	26	0	66.8				
2/28/02	12.9	33.1	0	54					6.3	24.2	0	69.5				

[1]Sensor nomenclature: Instrumentation layer # the senor is located - Sensor # on that layer
[2]Balance is assumed to be nitrogen
*Gas Compositions measured by the GEM-500 by Landtec

Table 19. Aerobic Cell Layer 2 Gas Compositions from Sampling Tubes

Sensor [1]	2-01				2-05				2-06				2-07				2-11			
Date Installed:	9/24/01				9/17/01				9/19/01				9/19/01				9/24/01			
Date Covered:	9/24/01				9/17/01				9/19/01				9/19/01				9/24/01			
Date:	CH_4%	CO_2%	O_2%	Balance %[2]	CH_4%	CO_2%	O_2%	Balance %	CH_4%	CO_2%	O_2%	Balance %	CH_4%	CO_2%	O_2%	Balance %	CH_4%	CO_2%	O_2%	Balance %
10/2/01	5.2	61.4	0.2	33.5	5.6	50.1	0	44.2	6.8	37.2	0.6	55.1	5.5	43	2.2	49.2				
11/1/01					10.8	48.6	0	40.7									8.2	52.4	0	39.6
11/27/01	8.3	34.6	0.1	56.7					4.6	27.9	0.2	67.3	4	22.5	0.2	73.2				
12/4/01	7.3	30	0	62.7					4.3	22.2	0.1	73.4	2.8	20.9	0.1	76.2				
12/11/01	6.3	26.6	0	67.1																
2/28/02	8.1	31	0	60.9					4.6	22.7	0	72.7								

Sensor	2-13				2-14			
Date Installed:	9/19/01				9/17/01			
Date Covered:	9/19/01				9/17/01			
Date:	CH_4%	CO_2%	O_2%	Balance %	CH_4%	CO_2%	O_2%	Balance %
10/2/01					4.6	59.2	0.5	35.5
11/1/01	13	45.3	0	41.6				
11/27/01					9.7	38	0.3	51
12/4/01					5.2	20.9	0.1	76.2
12/11/01					6.7	26.5	0.2	66.6
2/28/02					13.6	37.2	0	49.2

[1]Sensor nomenclature: Instrumentation layer # the senor is located - Sensor # on that layer
[2]Balance is assumed to be nitrogen
*Gas Compositions measured by the GEM-500 by Landtec

Figure 39. Pressure Transducers and Adjacent Sampling Tube Readings

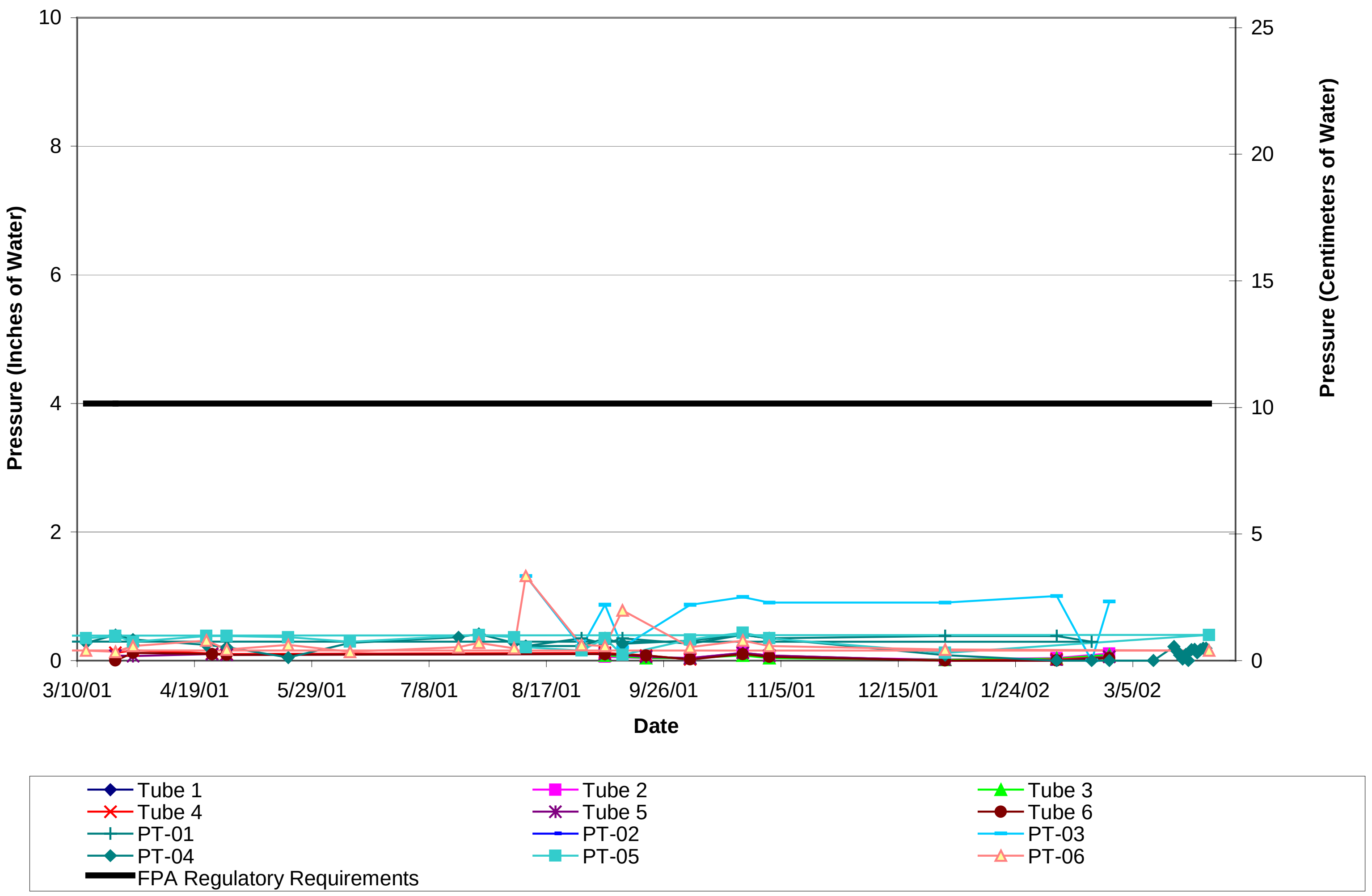
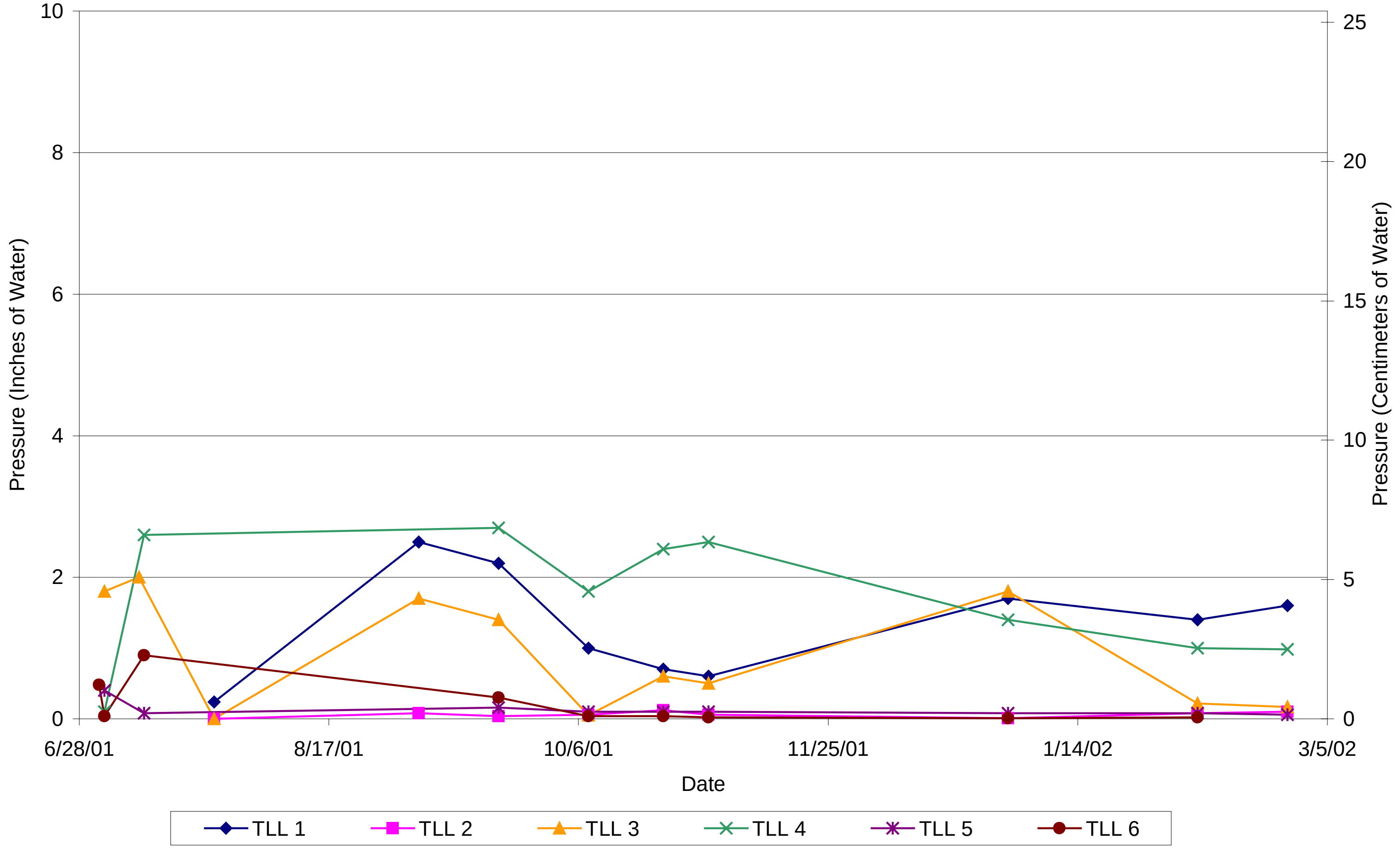


Figure 40. Trench Liquid Level Readings from Sampling Tubes



APPENDIX D – LEACHATE LABORATORY CHEMISTRY

Analytical Results from Leachate Removed from Module D Sumps				
		Northeast Anaerobic Cell	**West-Side Anaerobic Cell**	**Aerobic Cell**
Chemical Analysis Parameters	**Units**	(East Sump)	(West Sump)	(Aerobic Manhole)
General Chemistry:				
Ammonia as N	mg/L	30	20.3	2.8
Bicarbonate	mg/L	1740	1700	1120
BOD	mg O/L	20	28	3.3
Carbonate	mg/L	<5.0	<5.0	NA
Chemical Oxygen Demand	mg O/L	633	350	595
Chloride	mg/L	1070	187	1610
Hydroxide	mg/L	<5.0	<5.0	<5.0
Nitrate/Nitrite as N	mg/L	<0.030	0.016(tr)	0.16
Sulfate	mg/L	322	1.7(tr)	290
Total (Non-Volatile) Organic Carbon	mg/L	2.2	112	766
Total Alkalinity as CO_3	mg/L	1740	1700	1120
Total Dissolved Solids @ 180 C	mg/L	4440	2220	4810
Total Kjeldahl Nitrogen	mg/L	53.1	32.6	19.9
Total Phosphorus	mg/L	1.9	0.13	0.51
Total Sulfide	mg/L	1.3	0.033(tr)	<0.014
Metals:				
Dissolved Aluminum	mg/L	0.14	0.13(tr)	<0.043
Dissolved Antimony	mg/L	0.0022	0.0013(tr)	0.002
Dissolved Arsenic	mg/L	0.029	0.27	0.012
Dissolved Barium	mg/L	0.84	1.8	0.43
Dissolved Beryllium	mg/L	<0.000078	<0.000078	<0.000078
Dissolved Boron	mg/L	7.9	3.2	NA
Dissolved Cadmium	mg/L	<0.000074	<0.000074	0.00013(tr)
Dissolved Calcium	mg/L	183	241	NA
Dissolved Chromium	mg/L	0.036	0.0088	0.01
Dissolved Cobalt	mg/L	0.007	0.0038	0.0095
Dissolved Copper	mg/L	0.0054	0.0018(tr)	0.016
Dissolved Iron	mg/L	1.1	0.4	0.32
Dissolved Lead	mg/L	0.00046(tr)	0.00024 (tr)	0.00026(tr)
Dissolved Magnesium	mg/L	323	198	273
Dissolved Maganese	mg/L	4.1	24.6	1.1
Dissolved Mercury	mg/L	<0.000049	<0.000049	<0.000049
Dissolved Molybdenum	mg/L	0.012(tr)	<0.0046	0.026(tr)

Dissolved Nickel	mg/L	0.13	0.042	0.14
Dissolved Potassium	mg/L	152	55.2	NA
Dissolved Phosphorus	mg/L	1.9	0.28(tr)	NA
Dissolved Selenium	mg/L	<0.00034	<0.0017	<0.0085
Dissolved Silver	mg/L		<0.00003	<0.00003
Dissolved Sodium	mg/L	875	260	NA
Dissolved Thallium	mg/L		<0.00034	<0.00034
Dissolved Tin	mg/L	<0.022	<0.022	<0.022
Dissolved Vanadium	mg/L	0.059	0.0056(tr)	0.023(tr)
Dissolved Zinc	mg/L	0.032	0.068	0.027*
Volatile Organic Compounds:				
Acetone	µg/L	16	<50	12
Acrylonitrile	µg/L	<10	<500	<10
Benzene	µg/L	<0.13	<6.5	0.43(tr)*
Bromobenzene	µg/L	<0.18	<9.0	<0.18
Bromochloromethane	µg/L	<0.31	<16	<0.31
Bromodichloromethane	µg/L	<0.14	<7.0	<0.14
Bromoform	µg/L	<0.10	<5.0	<0.10
Bromomethane	µg/L	<0.08	<4.0	<0.08
2-Butananone (MEK)	µg/L	<1.0	<50	2.5
Carbon Disulfide	µg/L	<1.0	<50	<1.0
Carbon Tetrachloride	µg/L	<0.15	<7.5	<0.15
Chlorobenzene	µg/L	<0.12	<6.0	2
Chloroethane	µg/L	<0.34	<17	<0.34
Chloroform	µg/L	<0.12	<6.0	<0.12
Chloromethane	µg/L	<0.25	<12	<0.25
cis-1,2-Dichloroethene	µg/L	0.58(tr)	<5.0	0.38(tr)
cis-1,3-Dichloropropene	µg/L	<0.22	<11	0.38(tr)
Dibromochloromethane	µg/L	<0.40	<20	<0.40
Dibromomethane	µg/L		<10	<0.21
Dichlorodifluoromethane	µg/L	<0.16	<8.0	0.27(tr)
Ethyl Benzene	µg/L	<0.27	<14	<0.27
Hexachlorobutadiene	µg/L	<0.22	<11	<0.22
Iodimethane	µg/L	<1.0	<50	<1.0
Isopropylbenzene	µg/L	<0.12	<6.0	<0.12
Methylene Chloride	µg/L	1.5	<18	0.35(tr)
Methyl-tert-butyl ether (MTBE)	µg/L	14	<50	3
Naphthalene	µg/L	<0.15	<7.5	<0.15
n-Butylbenzene	µg/L	<0.12	<6.0	<0.12
n-Propylbenzene	µg/L	<0.15	<7.5	<0.15
p-Isoprpyltoluene	µg/L	<0.13	<6.5	<0.13
sec-Butylbenzene	µg/L	<0.12	<6.0	<0.12
Styrene	µg/L	<0.15	<7.5	<0.15
tert-Butylbenzene	µg/L	<0.14	<7.0	<0.14
Tetrachloroethene	µg/L	<0.38	<19	0.67(tr)

Toluene	µg/L	1.3	150	0.35(tr)
Total Xylenes	µg/L	<0.10	<5.0	0.34(tr)
trans-1,2-Dichloroethene	µg/L	<0.11	<5.5	<0.11
trans-1,3-Dichloropropene	µg/L	<0.30	<15	<0.30
trans-1,4-Dichloro-2-butene	µg/L	<1.0	<50	<1.0
Trichloroethene	µg/L	0.33(tr)	<16	1.6
Trichlorofluoromethane	µg/L	<0.23	<12	<0.23
Vinyl Chloride	µg/L	<0.12	<6.0	<0.12
Vinyl Acetate	µg/L	<1.0	<50	<1.0
1,1-Dichloroethane	µg/L	<0.77(tr)	<5.0	0.32(tr)
1,1-Dichloroethene	µg/L	<0.36	<18	<0.36
1,1-Dichloropropene	µg/L	<0.15	<7.0	<0.14
1,2-Dibromo-3-chloropropane	µg/L	<0.22	<48	<0.95
1,2-Dibromoethane	µg/L	<0.22	<11	<0.22
1,2-Dichlorobenzene	µg/L	<0.14	<7.0	<0.14
1,2-Dichloroethane	µg/L	<0.36	<11	<0.22
1,2-Dichloropropane	µg/L	<0.20	<7.5	<0.15
1,3-Dichlorobenzene	µg/L	<0.11	<5.5	<0.11
1,3-Dichloropropane	µg/L	NA	<10	<0.20
1,4-Dichlorobenzene	µg/L	<0.13	<6.5	<0.13
1,1,1-Trichloroethane	µg/L	<0.41	<20	<0.41
1,1,2-Trichloroethane	µg/L	<0.31	<16	<0.31
1,2,3-Trichlorobenzene	µg/L	<0.14	<7.0	<0.14
1,2,3-Trichloropropane	µg/L	<0.30	<7.0	<0.30
1,2,4-Trichlorobenzene	µg/L	<0.23	<12	<0.23
1,2,4-Trimethylbenzene	µg/L	<0.12	<6.0	<0.12
1,3,5-Trimethylbenzene	µg/L	<0.14	<7.0	<0.14
1,1,1,2-Tetrachloroethane	µg/L	<0.10	<5.0	<0.10
1,1,2,2-Tetrachloroethane	µg/L	<0.37	<18	<0.37
2-Chlorotoluene	µg/L	<0.26	<13	<0.26
4-Chlorotoluene	µg/L	<0.10	<5.0	<0.10
2,2 Dichloropropane	µg/L	NA	<6.5	<0.13
2-Hexanone	µg/L	<0.13	<50	<1.0
4-Methyl-2-pentanone (MIBK)	µg/L	2	<50	3.8
Surrogates:				
1,2-Dichloroethane-d4 (Surrogate)	%	112	88	128
Toluene-d8 (Surrogate)	%	104	96	110
4-Bromofluorobenzene (Surrogate)	%	102	89	113
Footnotes:				
NA = Not Analyzed				
MDL = Method Detection Limit				
PQL = Practical				

Quantification Limit				
< = less than the MDL				
tr = trace: the amount was above the MDL but below the PQL. Estimated result is provided by laboratory.				
* = this parameter was alo detected in the method blank				

APPENDIX E – GAS LABORATORY CHEMISTRY

Gas Analytical Results from the Northeast Anaerobic Cell

Gas Analysis Parameters	Units	Results
Method CFR60 EPA 25C Mod:		
Methane	ppm	280,000
Total Non-Methane Hydocarbons as Methane	ppm	10,000
Method CFR60A EPA 15/16:		
Dimethyl Sulfide	ppm	18
Hydrogen Sulfide	ppm	ND
Carbonyl Sulfide	ppm	ND
Methyl Mercaptan	ppm	ND
Ethyl Mercaptan	ppm	ND
Carbon Disulfide	ppm	0.64
Dimethyl Disulfide	ppm	0.52
Method CFR60 EPA 3C:		
Carbon Dioxide	%	41
Carbon Monoxide	%	ND
Methane	%	28
Nitrogen	%	26
Oxygen	%	0.83
Method EPA-21 to-14A		
Dichlorodifluormethane	ppb	7,900
Chloromethane	ppb	ND
1,2-Dichloro-1,1,2,2-tetrafluoroethane	ppb	ND
Vinyl Chloride	ppb	ND
Bromomethane	ppb	ND
Chloroethane	ppb	1,100
Trichlorofluoromethane	ppb	620
1,1-Dichlorethane	ppb	ND
Carbon Disulfaide	ppb	ND
1,1,2-Trichloro-1,2,2-trifluoroethane	ppb	ND
Acetone	ppb	54,000
Methylene Chloride	ppb	14,000
trans-1,2-Dichloroethene	ppb	ND
1,1-Dichloroethane	ppb	1,600
Vinyl Acetate	ppb	ND
cis-1,2-Dichloroethane	ppb	ND

2-Butanone (MEK)	ppb	38,000
Chloroform	ppb	ND
1,1,1-Trichloroethane	ppb	ND
Carbon Tetrachloride	ppb	ND
Benzene	ppb	1,700
1,2-Dichloroethane	ppb	ND
Trichloroethene	ppb	1,700
1,2-Dichloropropane	ppb	ND
Bromoodichloromethane	ppb	ND
cis-1,3-Dichloropropene	ppb	ND
4-Methyl-2-Pentanone (MIBK)	ppb	10,000
Toluene	ppb	31,000
trans-1,3-Dichloropropene	ppb	ND
1,1,2-Trichloroethane	ppb	ND
Tetrachloroethene	ppb	2,300
2-Hexanone	ppb	ND
Dibromochloromethane	ppb	ND
1,2-Dibromoethane (EDB)	ppb	ND
Chlorobenzene	ppb	ND
Ethylbenzene	ppb	2,800
Total Xylenes	ppb	9,400
Styrene	ppb	700
Bromoform	ppb	ND
1,1,2,2-Tetrachloroethane	ppb	ND
Benzyl Chloride	ppb	ND
4-Ethyltoluene	ppb	ND
1,3,5-Trimethylbenzene	ppb	ND
1,2,4-Trimethylbenzene	ppb	ND
1,3-Dichlorobenzene	ppb	ND
1,4-Dichlorobenzene	ppb	ND
1,2-Dichlorobenzene	ppb	ND
1,2,4-Trichlorobenzene	ppb	ND
Hexachlorobutadiene	ppb	ND