FINAL REPORT

METHANE ENHANCEMENT BY ACCELERATED ANAEROBIC COMPOSTING AT THE YOLO COUNTY CENTRAL LANDFILL

Initial Test Cell Design, Engineering, Construction and Startup

California Energy Commission
Energy Technologies Advancement Program
1516 Ninth Street
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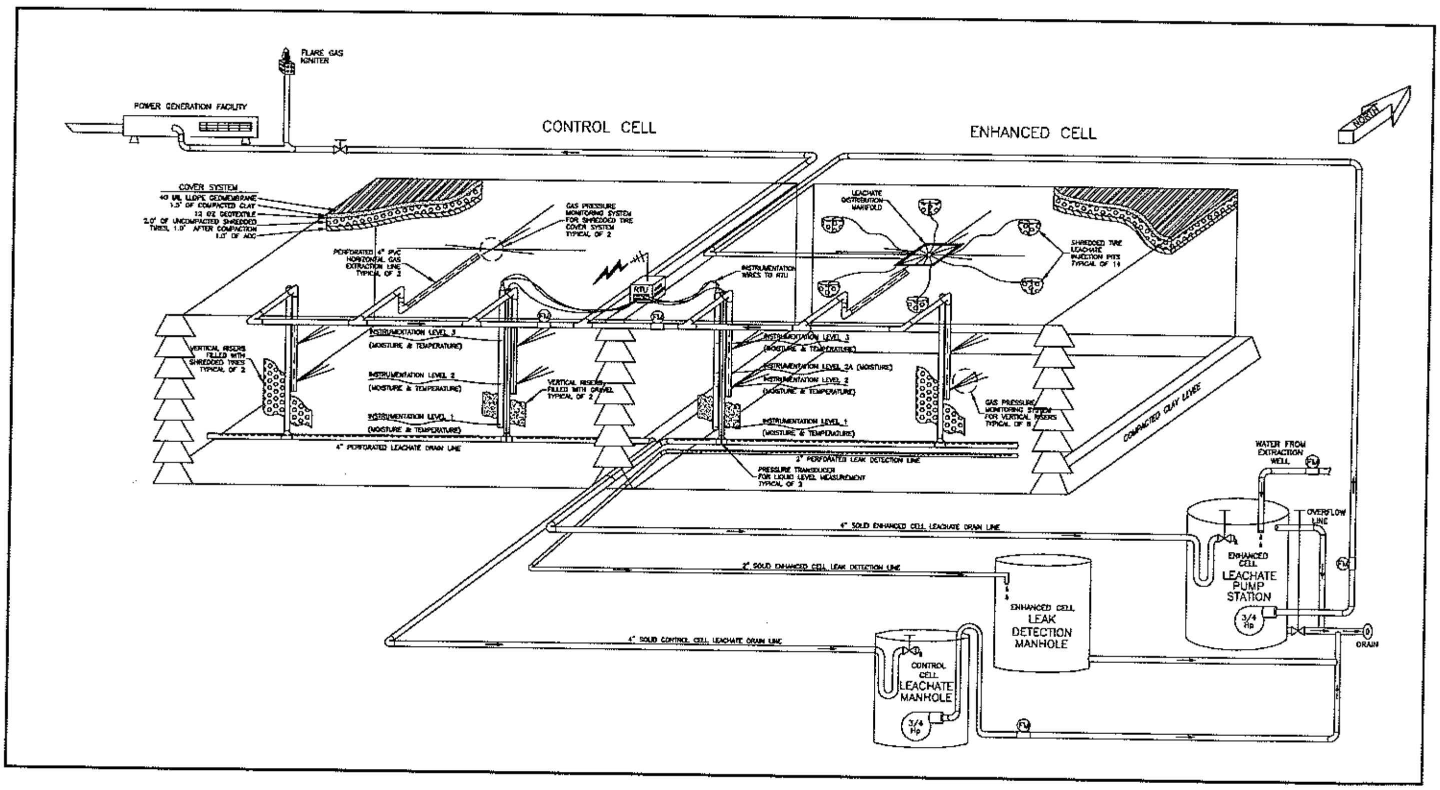

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ABSTRACT

The Yolo County Department of Public Works, at its Central Landfill outside Davis, California, is demonstrating new enhanced landfilling technology to manage solid waste landfills for rapid completion of total gas generation and maximum gas capture. Methane generation is accelerated by improving conditions for biological processes in the landfill through moisture management while gas capture is maximized through cell containment with clay side walls and bottom and top composite liner system. Compared to conventional operation, enhanced landfilling can more than double recovery of landfill gas for electricity generation or other energy applications. Enhanced landfilling also minimizes undesirable gas emissions over many years, including methane, which has been implicated in climate change.

The two demonstration cells incorporate the following features:

- Each cell contains approximately 9,000 tons of waste.
- Biological reactions are facilitated by optimized additions of water and leachate.
- Cells are covered with gas-impermeable membranes to contain methane.
- Permeable layers serve to conduct gas to collection points.
- The cells are instrumented to determine performance.

Gas generation, waste volume reduction, and a range of other parameters will be monitored for several years, until methane generation is complete. This enhanced landfilling technology is expected to offer an important advance in landfill operation, enabling low-cost mitigation of methane emissions, maximization of beneficial energy capture, reduction of landfill volume, and reduction of long term waste management costs. Larger full-scale applications are expected to follow the demonstration.

An economic analysis is presented for enhanced landfilling applied at the Yolo County Central Landfill. There is considerable uncertainty involved in this analysis; economic projections 30-50 years into the future can only be considered to be very approximate. However, given the assumptions used in this analysis, enhanced landfilling can be accomplished with a benefit to cost ratio equal to one at a selling price for electricity of 3.5 - 4.5 cents per kWh if a double composite liner system is not required. Requiring the use of a double liner system would render enhanced landfilling uneconomical.

ACKNOWLEDGMENTS

The costs of the Yolo County Demonstration Project are shared under a repayable research contract from the California Energy Commission (CEC), Yolo County, Sacramento County, and the California Integrated Waste Management Board. The continued support provided by the CEC Contract Manager, Dara Salour is greatly appreciated.

Several consultants and contractors have also given much support. The efforts of Don Augenstein of the Institute for Environmental Management (IEM) of Palo Alto are acknowledged. Mr. Augenstein, while at EMCON, gave considerable time and effort in the preparation of the Yolo County Proposal to the California Energy Commission, which led to the realization of this project. He initially developed a major part of the basic project plan. He has assisted in areas including design, operation, engineering and environmental impact analysis, and final draft report preparation. His continuous technical support and enthusiasm has been a tremendous benefit to the project.
The technical guidance and advice of John Pacey of FHC Corporation during the design and planning phase of the project is appreciated.

Richard L. Vogler and Sharon M. Kimizuka of ATEEM Electrical Engineers of Sacramento were instrumental to the success of the data acquisition and programming system. Benjamin & Tim Geerts and the construction crew of B & D Geerts General Contractors contributed in the successful construction of the levees, the gas collection and leachate recirculation system, and the placement of waste in the test cells.

The on-going financial and staff support of Sacramento County have been instrumental to the success of this project during the design and construction phases, and deserves special mention here.

George Yazdani of Polyflex, Inc. is acknowledged for providing the linear low density polyethylene (LLDPE) liner for the surface cover system at a reduced price.

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, especially the design and operation team.

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

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I. INTRODUCTION AND BACKGROUND

LANDFILLS AND LANDFILL METHANE RECOVERY

Sanitary landfilling is the main method of waste disposal in the United States. The EPA estimates about 70% of U. S. municipal solid waste, amounting to about 150 million tons/year over the past decade, is landfilled (Kaldjian, 1990). With conventional landfilling, waste is placed in conformance to existing regulations. Waste deposited in landfills is compacted daily with a soil cover to reduce blowing litter, manage bird and rodent activity, and control odors. This process continues until a planned waste depth is reached. The waste is then covered with an impermeable cover layer, usually clay. In most cases, there is no attempt to manage or monitor conditions within the landfill for biological activity.

PROJECT DESCRIPTION

The objective of this project is the design and construction of two landfill demonstration cells to test the operation of a landfill as a biological treatment system. The landfill environment is manipulated to achieve rapid biological stabilization, accelerating the rate of generation of methane and maximizing gas capture. This will be accomplished through additions and recirculation of liquids (water and leachate) to improve biological reaction conditions in the landfill. Further investigations will include: the potential for landfill leachate treatment through leachate recycle; the extension of landfill life resulting from waste settlement during rapid biological conversion of solid waste to gas and liquid; the assessment of the environmental impacts of the approach in order to provide regulatory agencies with information that can be used to develop guidelines for its application. The monitoring program will provide the data necessary to achieve these objectives. The nature of the monitoring program will allow changes in technique as warranted by ongoing evaluations.

The overall project objectives are as follows:

- The principle project objective is to demonstrate substantially accelerated landfill gas generation and biological stabilization while maximizing landfill gas capture.
- To monitor the biological conditions within the landfill cells.
- To demonstrate that the recirculation of leachate is an effective leachate treatment strategy.
- To demonstrate the landfill life extension that can be realized through more rapid conversion of landfilled solids to gas.
- To provide regulatory agencies with information that can be used to develop guidelines for the application of this technology.

- To better understand the movement of moisture through landfills.

BACKGROUND

Bacterial generation of methane, carbon dioxide, and other trace gases, occurs in almost all landfills containing municipal wastes. Although methane production is significant enough that gas is often usable for energy generation (Augenstein and Pacey, 1992), recovery rates and yields are far under their maximum potential. Maximum methane yield, as demonstrated in laboratory tests, might provide combustible gas having 40 to 50% of the waste's energy content. However only a portion of the methane energy potential is normally realized. Waste decomposition to landfill gas proceeds only slowly, over many decades in conventional, dry landfills. This may be inferred from low gas recovery rates and from recovery of intact, legible reading material after many decades in the landfill (Rathje 1989).

Recovery of landfill gas has been driven by the 1991 Federal Clean Air Act, and by policies of state agencies such as the California Air Resources Board. Of primary interest has been the issue of energy recovery, however, conventional approaches utilizing clay caps and vertical wells are likely to collect between 70 to 90 percent of the gas generated, allowing the remainder to escape to the atmosphere. Reasons for this include:

- Cover porosity. Field experience shows in-place clay final cover to be significantly porous. Augenstein and Pacey (1991) estimate fugitive emissions during operation may be 10 to 60 percent of the gas generated, depending on the site. The California Air Resources Board estimates escape at 40 to 60% of the amount of gas collected (SCM, 1990), which implies fugitive emissions about 30-40% . Walsh estimates fugitive gas per VOC fractions at 25 to 75% (SCS Engineers, 1994).
- Low generation rates. Of methane generated, high fractions can be emitted to the atmosphere at both early and late stages in "conventional" filling. Gas generation may begin, shortly after waste is placed, and before welling can capture gas with high fractional efficiency. At long times after filling and closure, gas generation may continue. Its collection may be less efficient then because continuing collection of low-rate gas generation is less cost effective, and equipment may no longer operate (or may be less well maintained). The amount of gas thus escaping long-term may be considerable; EPA and other models suggest that 20 to 40 percent of total gas generation may occur after 30 year post-closure collection period mandated by the EPA. Thus high collection efficiency of 70 percent or more by a well operated system at peak gas generation rates is reduced by both early and long term fugitive emission when the entire landfill methane generation cycle is considered.

Efficient use of landfill-generated gas is hampered by equipment considerations. To use the gas efficiently, collection and conversion equipment must have capacities which are close to the actual volume of gas produced. Because volume projections may differ from actual results by as much as 50%, selection of appropriate equipment can be difficult.

In summary, methane recovery from landfilled waste is typically less than half of the maximum potential for reasons of inefficient recovery, inability to confidently size equipment to make best use of available gas, and slow and incomplete generation of gas. Conventional landfilling generally results in slow decomposition of wastes over time, and gaseous emissions that are difficult to manage. It also presents various long-term expenses involving gas system and containment maintenance, leachate management, and problems with continuing subsidence. The YCCL Demonstration Project is intended to address these problems.

PAST APPROACHES

Previous attempts to recover methane energy from municipal wastes have involved a variety of waste-to-methane approaches. Early successful solid waste fermentations were conducted in mixed-tank equipment similar to those used to digest sewage solids (Goluecke, 1969, Pfeffer, 1974). However, drawbacks included parasitic energy consumption and high capital equipment costs.

Disadvantages with mixed tank approaches have prompted other work exploring the potential of "static" or unmixed digestion in low-cost reactors which can include landfills (Augenstein et. al., 1976). Calculations of diffusional transport rates, and subsequent laboratory experience, show that waste can be digested without mixing, at high solids levels characteristic of a landfill. In-landfill methane generation has pronounced advantages, namely:

- The reactor is basically "free" in terms of incremental cost
- In-landfill fermentation can easily tolerate inerts (waste components like rocks)
- Laboratory work has shown methane yields comparable to or better than for stirred tank work, so that expensive pre-processing can be avoided.

For these reasons, in-landfill fermentation appears to be the most attractive means of generating methane from municipal wastes, and is currently receiving worldwide attention (Lawson et. al. 1991).

This report presents only a brief background on enhanced landfilling. Readers desiring more background on the subject may refer to the original Proposal to the California Energy Commission (Yolo County, 1991). The following report summarizes various issues involved, and discusses how containment and optimization of biological conditions may be combined to maximize methane recovery.

TRIALS ELSEWHERE

Field trials to accelerate landfill decomposition have already been attempted. It may be useful to briefly review efforts at landfill enhancement that have occurred elsewhere.

- The earliest trial involving detailed measurements of gas generation and other relevant parameters was the field demonstration in Mountain View, CA, in which six cells were operated with a variety of amendments (Pacey et. al., 1987). The test cells were unexpectedly warm (40 °C) at time of construction, possibly due to limited aerobic composting of waste prior to placement of cover soil. Cell temperature continued to rise as methane was generated until several reached temperatures of 50-60 °C, at which time gas generation rates dropped while temperatures remained constant. However, gas production ultimately resumed. Other Mountain View problems included gas leaks, leachate buildup in cells due to inadequate drainage, and various measurement difficulties. Despite problems, this test successfully demonstrated generation rates three to five times that of conventional landfills in the area.
- Tests were conducted at Brogborough, UK, in which 4 cells were used to test the effects of liquid recycle, waste amendments and other variables (Campbell, 1991). Results are difficult to evaluate as cell sizes and contents were approximately doubled two years into the program for reasons having to do with operation of the surrounding landfill. Also, the gas collection efficiency is not well known and may be very poor, as the conventional clay cover is cracked. Failure of temperature probes has also occurred.
- A program was conducted at Binghampton in the early 1980's through the New York State Energy Research and Development Administration (NYSERDA) to test leachate recycle.
- The Delaware Solid Waste Authority (DSWA) is conducting a program wherein two one-acre cells containing 11,000 tons of waste each are testing the effect of leachate recycling. This project has been successful at improving leachate quality and determining liquid retention time in the waste. Waste temperature monitoring has been lost as temperature probes, placed with the waste as it was filled, have failed.

The objectives of earlier trials included waste stabilization, volume reduction, energy recovery, and convenient leachate disposal. Emission abatement had low priority, in part because the environmental impacts of VOC's, particularly methane, had less recognition than currently. The trials have provided some interesting results, but all experienced problems and limitations. Experiences and limitations with these other tests have been considered in planning the YCCL Demonstration project.

Problems with liquid handling occurred at both Mountain View and Brogborough due to design problems and component failure. Difficulties also arose with gas collection, leaks, and measurement of gas flow at Brogborough, Binghampton and for a time, Mountain View.

LANDFILL CONTAINMENT AND MANAGEMENT ISSUES

One general consideration is that any process must be economically compatible with current landfill practice. It must also satisfy present and pending federal/state regulations regarding landfills. The strongest regulatory constraint is that leachate contamination of strata beneath the landfill, or threat of it, must be avoided by appropriate containment and prevention of hydrostatic head on the base liner. Additionally, to maximize gas capture, the landfill surface should be covered by an impermeable membrane.

SURFACE MEMBRANES. Gas recovery efficiency can be greatly improved by use of gas-impermeable membranes. These are coming into wide use (Booth, 1991; Rice, 1994) and may become a post-closure requirement for landfills in the future (Federal Register, June 26, 1992). Synthetic membranes, in contrast to conventional clay caps, have gas permeabilities that are, for practical purposes, negligible. Membranes over gas-conducting layers (such as shredded tires) can capture essentially 100% of gas per VOC's generated. However, such membranes, when used alone, have a serious disadvantage. Surface membranes will maintain waste at low initial moisture levels (20-25%) which simply extends the time for decomposition to as much as a century. Field results have confirmed the substantial slowing of decomposition beneath impermeable membranes (Kraemer, 1993; Leszkiewicz 1995). Such dry containment approaches have been termed "dry tomb" technology (Lee, 1990), and pose the following problems:

- Economics will be very poor for capture and utilization of gas generated at low rates for extremely long periods.
- Membrane and other waste containment integrity must be maintained over longer periods as "entombed" waste decomposes slowly. Leachate generated under such conditions carries a high pollutant load well into the future, incurring high maintenance costs, and liability for groundwater contamination.

Simply covering a landfill with an impermeable membrane will not greatly increase energy recovery, but may create difficulties. To avoid long-term problems associated with conventional landfilling it is also necessary to enhance waste decomposition to speed completion of methane generation. The Yolo County landfill project combines membrane capture with optimization of the methane generation process to complete production within much shorter intervals.

ACCELERATING WASTE DECOMPOSITION AND METHANE GENERATION

Waste decomposition with gas generation can be promoted by control of moisture, temperature, pH management, and nutrients. While other factors can be important, moisture is crucial for biological activities associated with methane generation. Moisture control is the primary method used to enhance generation in this demonstration project, and is the most easily applied enhancement amendment.

Leachate management can be an important major aspect of landfill moisture control. Collection and reinjection of this liquid to the waste mass (commonly referred to as "leachate recycle") is a advocated practice (Pohland, 1989), and could be effective as a means for enhancing methane generation and accelerating stabilization in conventional landfills. However, newer landfills are much deeper and have less permeable covers. Precipitation infiltration, and consequently leachate availability for recycle, is restricted (Leszkiewicz, 1995). Thus, liquid supplements from outside sources may be necessary to increase the moisture content of the waste sufficiently for effective enhancement.

Given measurement limitations in other demonstration projects, a major objective is to instrument and carry out measurements to "fill in the gaps" left by other projects. A key measurement will be that of liquid movement through the cell, providing important information on waste permeability and recoverability of generated gas. Additional measurements include temperature, gas pressure and composition, leachate quality, and containment integrity.

GENERAL APPROACH

The design guidelines adopted for the Yolo County Demonstration Project are as follows:

- To avoid the threat of leachate contamination of underlying strata, the landfill shall have a composite or double base lining, as mandated in all new landfills or landfill expansions.
- To have a highly permeable bottom drainage layer to preclude build up static head.
- Cells shall be filled with waste according to standard landfill practice, except that temporary cover shall consist of materials not restrictive to the flow of liquid. For demonstration purposes, moisture, temperature and pressure sensors shall be placed in the waste to monitor decomposition.
- Temperature, moisture and pressure sensors shall be placed in the waste as the cells are filled in order to monitor processes within the waste mass.
- Provisions for uniform surface liquid addition, such as infiltration trenches, shall be constructed on the surface of the filled waste.
- A porous surface layer, such as shredded tires, shall be placed to create a highly conductive gas collection space for the capture and conduction of gas to collection points.
- Filled cells shall be covered with an impermeable membrane.
- Liquids shall be added as needed to maximize biological activity and gas generation. Liquid addition shall be managed as needed to preclude the development of hydrostatic head on the base liner.

PROJECT PERFORMANCE OBJECTIVES

The project consists of two test cells, each with about 9,000 tons of waste (enhanced cell 8,568 tons and control cell 8,737 tons). These test cells are large enough to represent both the compaction and heat transfer of large-scale landfills at normal waste depth. Techniques to enhance methane production will be applied to one cell (the enhanced cell), with the other serving as the control. The enhanced cell has been provided with means for controlled liquid addition to increase moisture content for methane generation. The cells are instrumented to monitor moisture and temperature at multiple points within the waste. Volume reduction, leachate flow and quality, static head on the base liner, containment integrity and other parameters of interest are also to be monitored. Gas-tight waste containment will allow accurate measurement of methane generation using positive displacement meters.

Performance objectives include:

Estimated Methane Generation: Based on the assumptions stated under heading ENERGY POTENTIAL in Section V, the enhanced demonstration cell is expected to generate about 22.0 million cubic feet of methane, while the control cell is expected to produce only 7.9 million cubic feet. The difference between these values amounts to a net gain of 14.1 million cubic feet of methane, which is the equivalent of 2,430 barrels of oil. These methane volumes should be produced in the enhanced cell within 5 to 10 years of initial liquid addition, whereas, for an unenhanced cell, such gas volumes may take from 30 to 50 years or longer to produce. If decomposition can be brought to completion within 5 years, the average gas flow rate over this period would be about 8 cubic feet per minute, and if the process should reach completion within 1 year (very unlikely rapid decomposition rate), the flow rate would still average to about 42 cubic feet per minute. These flow rates are well within design parameters for pipe size and flow measurement devices.

Volume Reduction and Settlement: The volume reduction brought about by the conversion to methane of the organic fraction of the waste is estimated to account for about 20 to 30 percent of the as-placed volume. The estimated average settlement in the enhanced demonstration cell should be about nine feet, based on a volume reduction of 20 percent. Such settlement corresponds to a recovered landfill volume sufficient to place an additional 1,700 tons of waste.

Water Addition Requirements: The water content of as-placed waste is typically between 20 and 30 percent, and may need to approach 40 to 50 percent for optimal methane-generating conditions. Assuming the initial water content of as-placed waste to be 25 percent, 1 million gallons of water must be added to the enhanced cell to achieve field capacity. Allowing for a transmissivity of 10^{-4} cm per second, water added to the cell should require about 5 months to seep down through the (average) 40 foot depth of waste. The total addition of 1 million gallons of water over a 5 month period dictates a rate of addition of about 10 gallons per minute cumulative for all 14 injection points. The addition of this quantity of water should bring the waste to its field capacity for moisture.

Reduction in Leachate Strength: As water is added beyond field capacity leachate is produced which is collected at the bottom of the cell and recirculated through the waste. After one year of leachate recirculation the following is expected to occur:

- Reduction of Biochemical Oxygen Demand
- Virtually complete elimination of organic acids
- pH brought to near neutrality (6.5 to 8.0)

SUMMARY OF EXPECTED ENERGY BENEFITS

A number of energy, environmental, and landfill operations benefits are expected to result from enhanced landfilling and are summarized below.

- Higher methane yield, higher generation rates, significantly shorter decomposition time.
- Better economics of scale for energy use due to greater quantities of captured gas in significantly shorter time.
- Completion of waste decomposition over shorter terms, reducing long-term risks to the environment and reducing long-term gas collection and other management costs.
- Predictable completion of waste decomposition such that landfill-gas fueled energy equipment may be sized to make maximum use of the gas generated.
- Emission of methane gas into the atmosphere is expected to be virtually eliminated, along with its contribution to global climate change.

SUMMARY OF EXPECTED WASTE MANAGEMENT BENEFITS

- Potential for landfill life extension by volume reduction, and thus, reduced land use.
- Leachate quality improvements and correspondingly reduced threat to groundwater, as well as reduced costs for off-site disposal and treatment.
- Reduced emissions of Volatile Organic Compounds and other air pollutants.
- Reduced costs for post-closure landfill maintenance and gas system operations due to earlier completion of landfill gas generation and waste stabilization.

PROJECT STATUS WITH REGARD TO PERFORMANCE OBJECTIVES WITHIN CEC CONTRACT DOCUMENTS

To date, the Project Objectives, as described in the Project Activities section of the contract with the California Energy Commission, have been achieved. Briefly, these activities include:

Design and Construction of Base Liner: The primary base liner components were designed and constructed as planned. Some of the primary components of the designed system include the following:

- A double composite liner system for the enhanced cell and the single composite liner for the control cell. Current regulations prohibit the introduction of liquids as is

required for enhanced landfilling. However, an "engineering alternative" (double composite liner system) to the prescriptive regulations (single composite system) was obtained to demonstrate to the regulatory agencies that benefits can be realized without increasing environmental hazards.
- Leachate collection and removal systems for the cells.
- Perimeter levees for containment of refuse and anchoring the geosynthetic materials.
- Leachate management system.

Construction of the base liner was completed $14,000 below the budget allowance.

Design and Construction of Levees: Construction of the clay levee side walls was conducted while waste was being placed inside and outside of the cell in order to avoid unbalanced loading of the sidewalls. The five-foot lifts of sidewall material and waste were designed to minimize clay use and maximize waste volume. During the winter of 1994, due to reduction of daily waste tonnage and operational difficulties at the landfill, the filling of the demonstration cells was postponed from April of 1994 to April of 1995. A contractor was chosen on a time-and-materials basis which resulted in a substantial increase in the cost of construction. The original construction estimate of $40,000 was amended to $106,000, and an additional $14,000 was expended to construct the instrumentation and gas collection risers within the waste mass. The new contractor completed this $120,000 phase of the project. Part of the added cost was covered by a grant from the California Integrated Waste Management Board.

Design and Construction of The Waste Monitoring System: Thermistor type temperature sensors, custom-made PCV moisture sensors, and agricultural soil moisture sensors were selected and installed within both demonstration cells. The control cell contains 11 temperature and 19 moisture sensors, while the enhanced cell is equipped with 13 temperature sensors and 37 moisture sensors. Wire leads from the sensors were enclosed in a housing of nylon-reinforced flexible PVC tubing for protection against damage. Additional slack was provided for these leads to prevent breakage as settlement occurred. A Druck pressure transducer was placed within the leachate collection trench to measure hydrostatic head above the base liner. All wire leads were connected to a Micrologger and a remote transmitting unit. Construction of the waste monitoring system was completed within budget.

Design and Construction of Landfill Gas Collection and Removal System: Vertical and horizontal gas collection systems were designed and constructed. The vertical gas wells in each cell were constructed of perforated 4-inch diameter PVC pipes; one well in each cell surrounded by gravel and the other by shredded tires enclosed in wire mesh. The horizontal gas collection system was constructed from the surface of the waste upward, beginning with a perforated 4-inch diameter PVC pipe placed within a compressed layer of shredded tires at least one foot thick. A protective, 12 oz. per square foot geotextile layer was placed above the shredded tires followed by a compacted layer of clay 1.5 feet thick. All of this was finally covered with a 40 mil, linear low density polyethylene (LLDPE) impermeable membrane. Gas can be extracted either by the vertical or horizontal pipe system, or by a combination of both.

The gas removal system was designed and constructed to handle a volume flow rate much higher than that which is to be expected from these cells. The gas is conducted from the cells to the power plant via a 6-inch diameter PVC pipe. Landfill gas flowing from each cell is measured separately by a positive displacement rotary gas meter installed after the condensate knockout and trap system. Each meter is capable of measuring flows from 42 cubic feet per hour to 5,000 cubic feet per hour. The condensate that drains from the knockout and main 6-inch header is collected disposed of in the landfill leachate management system. The gas recovery system was constructed within budget.

Design and Construction of Leachate Recirculation and Pumping System: The leachate recirculation and pumping system was designed to collect and distribute liquid within the enhanced cell. The primary components include the following:

- A leachate pumping system capable of pumping a maximum of 12 gallons per minute.
- A leachate flow metering system for both cells.
- A pipe system to conduct leachate to the holding tank and back to the cells.
- A distribution system for the enhanced cell.

The distribution system in the enhanced cell consists of 14 injection points distributed over the waste, below the surface membrane, 20 feet apart on center. Liquid will be injected to each point at a rate of about 0.71 gallons per minute per injector for a total of 10 gallons per minute. Each injection point has a measuring instrument to determine the depth of liquid on the waste surface, which is recorded automatically. It was initially anticipated that if the average depth of half the injection points were greater than a preset depth, the pump would automatically shut off until the liquid level had declined to an acceptable level. However, this leachte inflow management plan was abondoned to preserve memory in the datalogger for other data measurements considered to be more important. The liquid depth sensors are still used to monitor liquid depths in the infiltration trenches but are not used to control the pumping of liquid to the enhanced cell. This system was constructed within budget.

Design and Construction of the Cover System: A composite liner system was designed and constructed for the final cover for both cells. The LLDPE liner system was not covered with soil as originally intended. This was intended for ease of inspection and any repairs that might be required. The liner was weighted down with sand bags. The pressure under the liner will be controlled so that no billowing of the liner will occur. As an extra precaution, rubber blow-out caps were installed to relieve pressure build up in case the automatic pressure adjustment system fails. A porous layer of shredded tires was used instead of drain rock for gas collection with a geotextile to protect the liner. In December of 1995, during the construction of the LLDPE liner, a windy storm occurred which damaged the liner resulting in $20,000 in repair costs. Yolo County's insurance company covered some of the cost incurred, though $5,000 had to be paid out of the contingency portion of the contract. Excepting this unavoidable cost, the cover system was completed within budget.

Although module construction, cell construction and all subsequent steps were delayed, all major project tasks have been accomplished. The original CEC funded portion of the project has brought the cells to the point of operation.

We have accomplished the steps necessary to arrive at the fundamental purpose of the project, namely, to apply enhanced landfill techniques to a waste management unit in order to accelerate the stabilization of the waste and monitor effects within the waste.

Liquid addition to the enhanced cell and the application of a vacuum to both the enhanced and control cells to collect lndfill gas occurred in October, 1996. Preliminary data is presented elsewhere in this report.

II. DESIGN AND CONSTRUCTION

ENGINEERING DRAWINGS
A large number of detailed engineering and construction drawings were prepared for this project. Many project details are best seen by reference to selected drawings. Drawings are contained in the Appendix 1.

GENERAL OVERVIEW OF DEMONSTRATION CELL CONSTRUCTION
The bases and drainage structures for the two 10,000 feet square test cells were constructed in 1993 in conjunction with a 22-acre landfill expansion (Module B) at the Yolo County Central Landfill (YCCL) outside Davis, California (see Photo 2, upper). The general location of the test cells within Module B and the larger landfill are shown in Drawing II-1 "SITE PLAN". Configuration of the base is shown in Drawing II-2, CEC CELLS-VIEWING NORTH-WEST (see Photo 2, lower). From April through October 1995 the test cells were filled with municipal solid waste to depths of approximately 50 feet. Waste was placed in each cell in 5 foot lifts, each lift was overlain by about 1 foot of chipped greenwaste to serve as daily cover and surrounded by compacted clay levee side walls. Moisture and temperature sensors were embedded in the waste at various levels during waste placement. The sensor wires run horizontally through the waste and then rise vertically to the surface in flexible vertical risers constructed by filling wire mesh cylinders with gravel, which also serve as gas collection wells. Following waste placement, the cells were covered with a layer of shredded scrap tires (to serve as a horizontal gas collection system), geotextile, cover soil, and then a geosynthetic cover. The sensor wires are connected to a central data logger which is programmed to take periodic readings of the sensors. The collected data is then transmitted off site via radio link. The major elements of the completed test cells are illustrated in Drawing II-3, entitled "METHANE ENHANCEMENT BY ACCELERATED ANAEROBIC COMPOSTING AT THE YOLO COUNTY CENTRAL LANDFILL".

DETAILS OF DEMONSTRATION CELL CONSTRUCTION
The methods of construction of the different system components are described below.

Base layers: Base lining layers for both cells consist of a soil and gravel operations layer over geotextile, drainage net, a 60 mil (0.060 inch thick) high density polyethylene (HDPE) geomembrane, and a 2 foot layer of compacted clay as illustrated in Drawing II-4 MODULE B AND CEC CONTROL CELL COMPOSITE LINER SYSTEM DETAIL (see Photo 3). For the enhanced cell, a secondary containment system was constructed on top of the base lining system as shown in Drawing II-5 CEC ENHANCED CELL COMPOSITE LINER SYSTEM DETAIL (see Photo 3). The double containment was required by the Regional Water Quality Control Board due to the liquid additions that will occur in the enhanced cell. In the enhanced cell, the soil operations layer was compacted, a one-foot thick layer of compacted clay liner was placed, and a 60-mil HDPE liner was installed (see Photo 4). The bottom of both cells slope at 2% in a southerly direction towards a gravel filled trench containing a perforated leachate collection and removal pipe as shown in Drawing II-6 CEC CONTROL AND ENHANCED CELL GRADING PLAN (see Photos 4 - 6).

Leachate Drainage to Manhole: The leachate that is collected in each cell flows through solid pipes in Module B which convey the leachate to separate manholes at the perimeter of Module B (a distance of approximately 650 feet) for measurement, and in the case of the enhanced cell, recirculation. This is illustrated in Drawing II-7 MODULE B PLATE LYSIMETER AND LEACHATE COLLECTION TRENCH CROSS SECTION and Drawing II-8 NORTH AND SOUTH MANHOLES LAYOUT. To prevent the loss of landfill gas through the leachate removal lines, U-traps with 24 inches of liquid head were constructed at the pipe outflows in the manholes (see Photo 7).

Enhanced Cell Secondary Liner: For the enhanced cell, one objective is to demonstrate integrity and leak-free performance of the primary liner system (a regulatory concern). The double containment system incorporated into the enhanced cell will allow for leak detection and leakage volume measurement. Any leakage through the enhanced cell's primary liner system will be captured by the cell's secondary liner system. The secondary liner system drains to its own leachate collection trench, and then through a solid pipe in Module B to a manhole at the edge of Module B. Outflow at this manhole would indicate leaks in the enhanced cell's primary liner system.

Manholes: Manholes (prefabricated HDPE, of conventional commercial construction) are used to collect and hold leachate draining from cells. The enhanced cell manhole also serves as a reservoir to which water can be initially added, and leachate subsequently recirculated to the enhanced cell as needed. The manholes are designed to allow drainage into the landfill leachate disposal system if required, but are valved so that volumetric measurements can be made prior to draining. The manhole for the enhanced cell is shown in Drawing II-9 MANHOLE 1 PLAN AND SECTION (see Photo 7).

Compacted clay sidewalls: The clay used to construct the cell sidewalls was taken from the on-site borrow source, and was of the same type used to construct the compacted clay liner system for the demonstration cells and module B. The clay was pre-moistened at the borrow site using a water truck and disc, and a minimum of 24 hours was allowed for the water to fully saturate and soften the clods. The moisture content of the soil was adjusted to a value between 0 and 3 percent above optimum.

Scrapers were used to transport the clay for the construction of the levees. The subgrade was scarified and moistened to a depth of 2 to 4 inches before the clay was spread to an even 8-inch loose thickness. Four to six passes of a Tenco 5X 5 sheepsfoot compactor pulled by a Caterpillar D8 were needed to achieve a final compacted lift thickness of 6 inches at 95% relative compaction (see Photo 11). The mating surface of each lift was left rough and kept moist to make sure that a potential flow path for gases or liquids was not created. Each subsequent lift was placed over the prior lift using the above procedure.

Following compaction of each lift, 6 inches of clay was cut away and the previous lift was tested for density according to ASTM D 2922 (nuclear gage) (see Photo 11) and moisture content according to ASTM D 1557 (oven drying). Areas which tested below 95% relative compaction were reworked and tested. If the moisture content of the clay was not acceptable, it was adjusted by wetting or aerating, as required, to within 0 to 3 percent above optimum moisture content.

Although permeability tests were not conducted during the construction of the clay levees, but since the above procedure were strictly followed, it has been shown in previous clay liner construction projects that with the on-site soil permeabilities of 10^{-7} cm/sec or lower can easily be achieved.

It was important to place waste on both sides of the sidewalls, as they were constructed, to shore and maintain their integrity. First, clay was placed in lifts until the sidewalls reached a height of 5 feet. A five foot lift of waste was then placed inside this perimeter, and then a waste lift was placed outside the clay sidewall perimeter. The addition of waste lifts and sidewall construction continued until the desired cell waste and sidewall depth was reached. Drawing II-10 FILL PLAN, Drawing II-11 CROSS SECTIONS LEVEE CONSTRUCTION 5 FOOT LIFTS, AND Drawing II-12 CROSS SECTIONS FILLING SEQUENCE 5 FOOT LIFTS.

Waste Selection for Cells: The waste placed in the cells was deposited by waste trucks (packer trucks) containing residential or commercial solid wastes. This waste is from typical packer truck collection routes serving households or commercial establishments such as small businesses, restaurants, markets, etc. Self-haul vehicles were diverted from the cells since they tend to have loads containing bulkier items than packer trucks. No waste entering the landfill on weekends was placed in the cells since the majority of weekend waste is from self haul vehicles. Other bulky loads or loads that consisted of nearly all of the same material were also diverted from the demonstration cells. All loads entering the landfill are weighed and a log of tonnages placed in the demonstration cells was maintained (see Photos 8 and 9).

Waste Placement: The bottom of the control cell lies about 2.5 feet lower than that of the enhanced cell due to the placement of the secondary liner in the enhanced cell. Therefore, the control cell contains slightly more waste than does the enhanced cell, as they were both filled to the same height. The control cell received 8,737 tons of waste and the enhanced cell received 8,568 tons. Placement of waste was in five-foot deep lifts. A total of nine lifts were required to fill cells to their final configuration. An alternative daily cover of chipped greenwaste about 1 foot thick was used to cover the waste. It is expected that chipped greenwaste as daily cover rather than soil will facilitate necessary liquid permeation. Normal waste compaction procedures were followed; this involved about 5 passes over each lift resulting in an average waste density of 1,027 pounds per cubic yard for the enhanced cell and 1,014 pounds per cubic yard for the control cell (see Photos 8, 9 and 16). These densities include all material placed in the cells; both the solid waste and alternative daily cover.

Placement of In-Waste Sensors: As waste was placed in cells, instrumentation was installed at design levels. Drawing II-17 show views of the layout of sensors for moisture and temperature monitoring at three levels within the control cell and four levels within the enhanced cell (see Photo 13). The positions of the instrumentation layers are shown in Drawing II-13 MONITORING SYSTEM FOR WASTE MASS-CROSS SECTION. A Druck PTX 164 pressure transducer was placed in the leachate collection pipe of the enhanced cell to measure the buildup of hydrostatic head in the leachate trench.

Moisture Sensors: In-waste moisture sensors are of two types; gypsum blocks manufactured by Electronics Unlimited, and perforated 1.5-inch diameter PVC pipes filled with pea-gravel with three electrodes spaced 8 inches apart. The gypsum blocks are of the type typically used for soil moisture determinations in agricultural applications. Initial tests prior to actual placement of the gypsum blocks in the cells showed that they deteriorated rapidly in leachate. To increase their life, each gypsum block was embedded in a quart-sized block of plaster of paris. The PVC moisture sensors will send a signal when the surrounding conditions are at or near saturation conditions. The purpose of the PVC moisture sensors is to provide some means of verification of the data provided by the gypsum blocks and for this reason they are placed very near one another. If a PVC moisture sensor is sending a signal the gypsum block would be expected to indicate very high moisture content. The control cell contains 15 gypsum blocks and 4 PVC moisture sensors. The enhanced contains 25 gypsum blocks and 12 PVC moisture sensors. This arrangement is shown in the detail "Gypsum Moisture/PVC Moisture Sensor" of Drawing II-14 MONITORING SYSTEM FOR WASTE MASS-DETAILS.

Temperature Sensors: Temperature sensors are 10 k ohm thermistors encased in 1/4" diameter by 4 inch long stainless steel cylinders manufactured by Thermometrics, Inc. They were also embedded in plaster of paris blocks along with the gypsum blocks. This arrangement allows correlations to be made between temperature and moisture conditions. This arrangement is shown in Drawing II-14 MONITORING SYSTEM FOR WASTE MASS-DETAILS. The control cell contains 11 temperature sensors and the enhanced cell contains 13.

Instrumentation Leads: Forces on wire leads buried within waste can easily break unprotected leads due to waste compaction and subsidence. This problem has been experienced repeatedly in other projects. Thus leads were enclosed in a housing consisting of nylon reinforced PVC flexible tubing. Substantial slack was also left in lead lines as a further measure to limit breakage (see Photos 14 and 15). Leads from sensors run through the waste to a gravel riser which is shown in detail "Settlement Provision Detail" in Drawing II-15 MONITORING SYSTEM FOR WASTE MASS-GRAVEL RISER DETAILS. Within this riser they lead to the surface, and connect to a Micrologger and a remote transmitting unit. This approach to instrumentation lead protection has proven quite successful as all emplaced sensors are providing data. A schematic illustration of the paths of instrumentation leads is shown in Drawing II-17.

Liquid Infiltration System: The basic enhancement strategy is to bring waste up to optimum moisture content for biological reactions by controlled additions of liquid (initially water and later leachate). To facilitate necessary liquid additions, the waste surface was constructed with 14 "trenches" filled with shredded tires as shown in Drawing II-18, CEC ENHANCED CELL LEACHATE INJECTION SYSTEM. The trenches are approximately 3 feet wide, 5 feet deep, and 10 feet long. A 3-inch perforated PVC pipe was placed vertically at the bottom of each trench for leachate injection, and backfilled with shredded tires. Liquid is distributed to each trench by a distribution manifold as shown in Drawing II-18 (see Photos 23 and 24). Liquid levels in these pits are sensed by probes which are constructed of 2-foot sections of 1.5-inch perforated PVC pipe filled with pea gravel, fitted with electrodes spaced 12-inches apart. These electrodes indicate when the depth of liquid in the pits has reached depths of approximately one and two feet. The data logger records the information from the probes and the inflow of liquid to the cell is shut off when the average depth in seven of the pits exceeds one or two feet, depending on the settings in the program. Liquid in the pits then drains into and permeates waste at rates controlled by the waste's permeability. When the average of the probe readings indicates that the average liquid depth is below the 2 feet level, pit filling is resumed. This procedure is repeated until indices, including moisture readings and/or leachate outflow, show that desired moisture levels have been reached.

Liquid pumping: Initially, water will be added to the enhanced cell from a groundwater extraction system at the YCCL. Later, leachate generated by the enhanced cell will be recirculated. A Grundfos 10E8 submersible pump capable of pumping 12 gallons per minute to the enhanced cell is permanently installed in the enhanced cell manhole. The pump was sized based on expected liquid needs and permeability of waste which was estimated to be about 10^{-4} cm/sec. Using this permeability rate, it is estimated that the enhanced cell will reach moisture capacity in approximately 5 months without interruptions on delays in pump run times. Groundwater flow into the enhanced cell manhole is monitored with a Signet 2535 low-flow flowmeter. Leachate flow out of the manhole is measured with a Sparling FM625 Tigermag flowmeter. A manually operated pump was installed in the control cell manhole to allow any leachate that accumulates to be pumped into the landfill leachate collection system. Leachate from the control cell manhole is monitored with a Signet 2535 low-flow flowmeter.

Vertical Gas Wells: Gas collection for each cell is by two vertical wells within the waste and through the surface permeable layer of shredded tires. The vertical gas wells in each cell are constructed of a perforated 4-inch diameter PVC pipe with one well surrounded by gravel and the other by shredded tires enclosed in wire mesh (see Photos 12, 13 and 14).[1] The vertical wells were not drilled after filling but were constructed as the waste

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[1] (One project purpose has been to demonstrate beneficial use of scrap tires in landfill construction and particularly in landfill gas extraction. Scrap tires pose a major disposal problem throughout the U. S.)

was placed, increasing the height of the wells as the waste was placed. Vertical gas well construction is shown in Drawing II-15 MONITORING SYSTEM FOR WASTE MASS-GRAVEL RISER DETAILS and Drawing II-16 MONITORING SYSTEM FOR WASTE MASS-TIRE RISER DETAILS. One key parameter of well performance and a measure of waste permeability is the change in the gas pressure in the waste surrounding the well, induced by extraction of gas at various rates from the well. To assess pressure/flow relations, monitoring lines have been installed for pressure measurements in the waste surrounding the wells (see Photo 24). These consist of 1/4 inch diameter HDPE tubes protected by PVC conduit extended out at various radii from the well. These detect the pressure at their endpoints, thus giving in-waste pressure data as withdrawal proceeds and as the rate of withdrawal is adjusted. The design of the pressure probes is shown in the "Gas Pressure Sensor" detail of Drawing II-14 MONITORING SYSTEM FOR WASTE MASS- DETAILS (see Photo 17). The gas pressure sensor layout is shown in Drawing II-19 CEC HORIZONTAL GAS COLLECTION AND PRESSURE MEASUREMENT LAYOUT and more details are provided in Drawing II-20 GAS SYSTEM DETAILS.

Cell Surface Layers and Membrane Containment: The surface of the waste is completely overlain by a minimum 1-foot compressed layer of shredded tires which are highly permeable to gas flow (see Photo 20). This permeable layer serves to collect and conduct gas to a horizontal, perforated 4 inch diameter PVC pipe placed in the shredded tire layer (see Photo 17). The shredded tire layer is covered by a geotextile and over the geotextile is a layer of soil approximately one foot thick (see Photo 21). The soil layer is capped by a surface membrane for overall gas containment. The surface membrane is anchored and sealed at cell sidewalls as seen in Drawing II-21 COVER DESIGN and Drawing II-22 COVER SYSTEM DESIGN DETAILS. The membrane material is 40 mil linear low-density polyethylene (LLDPE) manufactured by Polyflex, Inc. which was chosen because of its ability to accommodate waste subsidence by stretching without breaking (see Photo 25).

Gas Extraction: Gas can be extracted by either the perforated vertical wells, or through the perforated horizontal pipe in the surface permeable layer of shredded tires, or by combinations of both. The gas flow from the surface permeable layer and vertical gas well extraction can be adjusted in any desired ratio by valve adjustments. This allows well performance tests at all possible flow rates up to the rate of gas generation. A plan view of the gas extraction system is shown in Drawing II-23 GAS EXTRACTION SYSTEM LAYOUT and details are shown in Drawing II-24 GAS SYSTEM DETAILS.

Gas Condensate Removal: As the warm, moisture-saturated gas exits the test cells and cools, liquid condensate forms. This condensate must be drained at low points in the gas system or it may pool and block lines. The landfill gas exits each demonstration cell in a 4 inch diameter pipe and is conveyed to an 8 inch diameter, 10 foot long PVC pipe located just upstream from the gas meters and shown in the detail, "Condensate Knockout and Gas Flowmeter Detail" of Drawing II-24. The purpose of the 8 inch diameter pipe is to provide a larger area for gas flow, thereby reducing the velocity of the flow and facilitating the removal of landfill gas condensate. Condensate that drains from the system is conveyed to a 2,000 gallon HDPE tank. The level of condensate in the tank is measured and the volume calculated prior to draining into the landfill leachate management system. The conveyance of the condensate is entirely by gravity flow. To prevent the entry of air into the system U-traps are installed where a condensate line is open to the atmosphere.

Gas Flow Measurement: Landfill gas flow from each cell is measured separately by corrosion resistant, positive displacement rotary gas meters manufactured by Dresser Industries, Inc. (Model 5M175). The meter is a special service meter, designed for sewage and production gas measurement. These are continuous duty meters which tolerate small quantities of entrained fluids and corrosive gases. Each meter is capable of measuring flows from 42 cubic feet per hour to 5,000 cubic feet per hour with a maximum pressure of 175 pounds per square inch. These meters are temperature compensated and have externally mounted pulsers that send volumetric data to the data logger. The meters are installed after the condensate trap of each cell as shown in "Condensate Knockout and Gas Flowmeter Detail" of Drawing II-24 GAS SYSTEM DETAILS.

Landfill Gas Warming: Most condensate in the gas flowing into the positive displacement meter would be removed by the trap discussed above. However gas exits the trap at 100% relative humidity and more condensation can occur as the gas moves to the meter. To further limit the possibility of any condensate entering the meter, the galvanized steel pipes just prior to the meter are heated by electric heat tapes. A temperature increase of 10 °F between the 8 inch PVC pipe and the meter was deemed sufficient to maintain the remaining moisture in the vapor phase while passing through the meter. The power required to accomplish this at the peak estimated gas flow rate is 500 watts for each cell. To satisfy this requirement each pipe was wrapped with a heat tape 8 feet long and capable of dissipating 72 watts per foot, for a total of 576 watts per pipe. This arrangement is shown in "Condensate Knockout and Gas Flowmeter Detail" of Drawing II-24 GAS SYSTEM DETAILS.

Gas Collection Pipes Connection to Main System: The landfill gas from the demonstration cells will be collected under a vacuum induced by a blower located at the landfill gas-to-electricity facility located at the Yolo County Central Landfill. The blower at this facility applies a vacuum to the gas collection system for the entire landfill, not just the demonstration cells. This includes 83 vertical wells distributed over about 110 acres; the two demonstration cells are tied into this system. The vacuum applied at the blower varies between -10 and -50 inches water depending on the time of year, whether or not electricity is being generated, etc. However, the average applied vacuum at the blower is about -25 inches water, which corresponds to a vacuum at the demonstration cells of about -15 inches water. After passing through the cell, condensate trap, and flowmeter measurement station, the gas enters a 6-inch diameter PVC pipe that conveys the gas to the main gas collection header pipe. This configuration is shown in Drawing II-25 GAS EXTRACTION SYSTEM LAYOUT.

Leak Detection: Leaks through the surface membranes or piping should be shown by the presence of oxygen or nitrogen in the recovered gas. Sources of leaks in pipes can be traced by upstream/downstream measurements in the gas collection pipes.

System Gas Pressure: Gas pressure or pump suction in the methane recovery network can be monitored on-site using a hand-held Pocket Digital Manometer, model PDM205, manufactured by Air-Neotronics Ltd., England.

Gas Quality Analysis: One means of monitoring the processes occurring in the demonstration cells is to analyze the gas they produce. This is accomplished by having a technician sample the gas at the collection wells, and run it through an MTI P200H gas chromatograph. Comparing the landfill gas to a laboratory-prepared reference gas, the chromatograph can provide information about the relative concentrations of carbon dioxide, methane and nitrogen.

Weather Conditions: Wind speed and direction, rainfall, temperature and barometric pressure are monitored by a Davis Instruments Weather Monitor II weather station. Data is transmitted to the Davis office of the DIWM via modem, and logged to pre-configured IBM clone.

Demonstration Cell Data Acquisition: The enhanced and control cells are monitored for moisture, temperature, and pressure by 112 sensors (see plans, Section II) which are wired to three AM416 Multiplexers connected to a 21X "Micrologger" (Campbell Scientific, Inc) (see Photo 24). The Micrologger polls the sensors for information at preset intervals, and stores the values until they are downloaded. Data is downloaded to the office of the Division of Integrated Waste Management in Davis, CA, at programmable intervals via a dedicated radio link to the Micrologger. A computer at the Davis office runs a program which initiates contact with the Micrologger, downloads the information and stores it in a file. The file may then be processed using a proprietary application called Split, which sorts and prepares the raw data. Once the data has been processed it can be imported to a database or spreadsheet program for graphing or trend analysis.

Data Analysis: Data received from the landfill is analyzed by selective sorting and plotting using the spreadsheet program Excel. Staff at the Davis office of the DIWM are currently exploring the option of writing a specialized application for the database program Access, which will take raw data as transmitted from the landfill, format it and apply analysis profiles automatically.

PLANNED MONITORING PROGRAM

Much of the data acquired from the test cells will be collected and transmitted by the Micrologger using the following regimen: Data will be collected from the sensors at 15 minute intervals, and averaged hourly (four readings). The hourly averages will be stored for later transmission, generally at 2-hour intervals. The following parameters shall be monitored:

1. Temperature. Thermistors in the waste mass will yield temperature data which will be stored in a Micrologger until downloaded to a computer at the office of the Division of Integrated Waste Management. Sampling frequency as stated above.
2. Moisture content. Moisture data will be collected using agricultural moisture sensors. The data will be stored and transmitted to the office computer as with the temperature data. Sampling frequency as stated above.
3. Leachate depth on the base liner. Leachate depth on the base liner of the enhanced cell will be monitored with a pressure transducer that has been placed in the leachate collection trench of the enhanced cell. The purpose of the transducer is to demonstrate that liquid additions can be controlled to prevent the buildup of excessive hydrostatic head on the liner. Sampling frequency as stated above.
4. Liquid volumes. All liquid additions will be metered and recorded. Liquid will be added to the cell continuously at a very slow rate to bring the waste to field capacity. This rate should be approximately 12 gpm for all 14 injection wells. All liquid leaving the cells through the leachate collection and removal system flows to one of two manholes, one for each cell. The volume of liquid in these manholes will be measured prior to recirculation or removal, as needed. The secondary containment liner of the enhanced cell drains to a third manhole to monitor leakage through the primary liner, should any occur. Sampling frequency as stated above.
5. Landfill gas volumes. Landfill gas volumes will be metered and reported automatically to the Micrologger by an appropriate in-line device. Sampling frequency as stated above, except that the data collected at 15 minute intervals will represent integrated volume flow rates during the interval.
6. Landfill gas composition. Gas composition is determined using an MTI gas chromatograph model P200H. Gases of interest are methane, carbon dioxide, and nitrogen. Measurements are planned once weekly for the first 8 months and monthly thereafter. Measured directly by DIWM personnel.
7. Landfill settlement. Surveys will be performed every six months to track the change in elevation of surface monuments placed on the demonstration cells. Measured directly by DIWM personnel.
8. Leachate composition. Leachate characteristics will be analyzed, providing information concerning bacterial activity and strength of leachate. Leachate from the enhanced cell is expected to have a reduced pollution strength with respect to the control cell. Measured directly by DIWM personnel (see Table 1., below).

Table 1
Planned Leachate Testing Program.

PARAMETER	FREQUENCY
Field Testing: pH, Alkalinity, Acidity.	Average of thirteen times per month.
Chemical oxygen demand, ammonia, nitrate, total Kjeldahl nitrogen, total phosphorous, total dissolved solids, sulfide, sulfate, total organic carbon.	- First two months: Each cell once per week - Remainder of first year: Each cell once every two weeks - After first year: Quarterly
Volatile organic compounds	Quarterly
Metals	Quarterly

III. PROJECTED ECONOMICS

CAPITAL AND OPERATIONS AND MAINTENANCE COSTS FOR THE PROJECT ONLY

Thus far, operations and maintenance costs have not been incurred by the project. All costs incurred so far have been due to design, construction and startup of the system. The cost of the project to date has been approximately $563,000, as shown in Table 2.

Table 2.
Costs of the Enhanced Landfill Demonstration Project

COST AREA	CAPITAL COST
Project Capital Costs	
Construction of Base Liner	$114,000
Construction of Clay Levees	$120,000
Construction of Waste Monitoring System	$40,000
Construction of Landfill Gas Collection and Removal System	$34,500
Construction of Leachate Recirculation/Pumping System	$47,500
Construction of Cover System	$52,000
Initial Cell Operation and Testing	$7,000
SUBTOTAL OF CAPITAL COSTS	**$415,000**
Project Associated Costs	
Design of all Systems	$73,000
Project Final Report and Quarterly Reporting	$25,000
Project Contingencies	$50,000
SUBTOTAL OF ASSOCIATED COSTS	**$148,000**
TOTAL PROJECT COST	**$563,000**

Note: See project budget to get the $ amounts.

Estimated operations and maintenance costs over the first two years of the project monitoring phase are shown in Table 3.

Table 3.
Projected Operations, Monitoring, and Maintenance Costs, First Two Years.

CATEGORY	COST
Laboratory	$15,000
Personnel	$158,000
Surveying	$2,000
General Contingency	$10,000
Outside Consultant	$10,000
General Maintenance	$25,000
Total Over Two Years	$220,000

Note: Costs will drop off with time as frequency of measurements decrease.

<u>COSTS FOR A COMMERCIAL SYSTEM</u>

Construction costs at the Yolo County Central Landfill can be used to estimate construction costs for a commercial scale system. Waste Management Units are constructed and filled at the landfill about every three years. These units cover 22 acres with a maximum depth of solid waste of about 58 feet. Solid waste inflow averages between 450 and 500 tons per day.

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
- Waste coverage with a low permeability liner is required in any event.
- The installation of a landfill gas recovery system is required if certain emissions criteria are to be met. These criteria are set forth in the Federal Clean Air Act and by local air pollution control districts.

- All normal operation and maintenance work will be incurred in any case.

BASE LINER COST

Current state regulations in California prohibit the introduction of liquids, including leachate for recirculation, into a Class III Waste Management Unit. A goal of the project is to demonstrate that liquid addition and leachate recirculation can be practiced without causing a buildup of hydrostatic head on the landfill liner. It is hoped that the data gathered through this project will show that a single-lined landfill provides adequate environmental protection, however, the State Water Quality Control Board may continue to require double-lined systems. To account for such uncertainties, three cases are submitted and examined from a cost perspective.

Option 1 Single-lined landfill cell (Drawing III-1).

Option 2 Double-lined cell with a cross section identical to that used in the enhanced cell for the project (Drawing III-2).

Option3 Double-lined cell using a cross section similar to that used in a liquid waste surface impoundment existing at the Yolo County Central Landfill (Drawing III-3).

Costs for landfill construction for each option on a per acre basis are provided in Tables 4, 5, and 6. Option 1 describes the cost of base liner construction if leachate recirculation is not practiced or double containment is not required. The difference between Options 2 and 1 or between Options 3 and 1 is the incremental increase in costs that can be assigned to enhanced landfilling.

Table 4
Component Costs of an Enhanced Landfill, Option 1
(Single composite liner system)

Base layers: (Listed from the bottom up)	Costs per Acre
Purchase and Transportation of Soil ($2.50/yd^3)	$19,000
Compacted clay liner (2 feet clay)	$12,000
60 mil HDPE base membrane	$15,000
HDPE geonet (drainage layer)	$8,000
Geotextile	$8,000
Operations layer	$6,000
HDPE pipes, 4" diam.	$4,000
(Leachate collection and removal system, LCRS)	
Subtotal base layers for Option 1:	$72,000
Other associated costs:	
Engineering and Design (8%)	$5,800
Quality assurance/quality control for construction	$12,000
Contingencies at 10 %	$7,200
Total other costs:	$25,000
TOTAL OPTION 1 COSTS	$97,000

Table 5
Component Costs of an Enhanced Landfill, Option 2
(Double lined using enhanced cell design)

Base layers (listed from the bottom up):	Cost Per Acre
Purchase and Transportation of Soil ($2.50/yd^3)	$45,000
Compacted clay secondary liner (2 feet clay)	$12,000
60 mil HDPE secondary liner	$15,000
HDPE geonet (secondary drainage layer)	$8,000
Geotextile (secondary liner)	$8,000
HDPE pipe, 2-inch diameter (secondary LCRS)	$2,500
Operations layer (secondary liner protection, 1.5 feet)	$9,000
Compacted clay primary liner (1 foot clay)	$6,000
60 mil HDPE primary liner	$15,000
HDPE geonet (primary drainage layer)	$8,000
Geotextile (primary liner)	$8,000
HDPE pipes, 4" diam. (Primary LCRS)	$4,000
Operations layer (secondary liner protection, 1 foot)	$6,000
Subtotal base layers for Option 2:	$146,500
Other associated costs:	
Engineering and Design (8%)	$11,800
Quality assurance/quality control for construction	$15,000
Contingencies at 10 %	$14,700
Total other costs:	$41,500
TOTAL OPTION 2 COSTS	$214,500

Table 6.
Component Costs of an Enhanced Landfill, Option 3
(Double lined using YCCL liquid waste surface impoundment design)

Base layers (listed from the bottom up):	Costs per Acre
Purchase and Transportation of Soil ($2.50/yd^3)	$19,000
Compacted clay liner (2 feet clay)	$12,000
60 mil HDPE, secondary liner	$15,000
HDPE geonet (secondary drainage layer)	$8,000
HDPE pipe, 2" diameter (secondary LCRS)	$2,500
60 mil HDPE, secondary liner	$15,000
HDPE geonet (primary drainage layer)	$8,000
Geotextile	$8,000
Operations layer	$6,000
HDPE pipes, 4" diam. (primary LCRS)	$4,000
Subtotal base layers for Option 3:	$97,500
Other associated costs:	
Engineering and Design (8%)	$7,800
Quality assurance/quality control for construction	$17,500
Contingencies at 10 %	$9,800
Total other costs:	$35,100
TOTAL OPTION 3 COSTS	$132,600

SURFACE LINER COST

Regulations governing landfills require that all landfills be covered with a low permeability liner after filling; this process is referred to as "landfill closure". Clay has been the most often used liner material but synthetic membrane liners are becoming increasingly popular due to the high cost of importing clay to landfills without on-site sources of clay. Coverage with a synthetic membrane makes possible the recovery of nearly all of the gas produced. Because landfill closure is a requirement of normal landfill operations it is not considered an added cost of enhanced landfilling. However, because it is necessary to maximize landfill gas capture, estimated per-acre costs for a surface liner system incorporating a geosynthetic membrane are shown in Table 7. Costs are estimated using construction costs at the Yolo County Central Landfill.

Table 7.
Component Costs of a Landfill Surface Liner System

Surface layers (listed from the bottom up):	Costs per Acre
Purchase and Transportation of Soil ($2.50/yd^3)	$16,000
Foundation layer (2 feet)	$16,000
Geotextile	$8,000
Geonet	$8,000
Geotextile	$8,000
40 mil LLDPE (linear low density polyethylene)	$15,000
Vegetative layer (1 foot)	$5,000
Hydroseeding	$1,500
Subtotal base layers for Option 3:	$77,500
Other associated costs:	
Engineering and Design (8%)	$6,200
Quality assurance/quality control for construction of base and	$12,000
Contingencies at 10 %	$7,800
Total other costs:	$26,000
TOTAL COST PER ACRE	$103,500

LIQUID HANDLING EQUIPMENT COST

Liquid addition and leachate recirculation can occur in a number of ways. Liquid can be applied to the waste as it is being placed or liquid can be added to a separate leachate collection and removal system upon final waste placement. Liquid can be added using the surface of the landfill as a leach field, through injection wells, or a combination of both. The quantity and timing of liquid additions would depend on the objective, such as methane gas enhancement, leachate management, rapid landfill stabilization, etc. A cost analysis for a commercial scale leachate recirculation system was not within the scope of this report. Rather, the Delaware Solid Waste Authority (DSWA) was contacted, as they have constructed large scale leachate recirculation facilities within the past several years. The DSWA system utilizes both leach fields and interconnected injection wells. The cost estimate of $10,000 per acre is approximate as it is difficult to separate the recirculation system costs from the overall landfill construction costs, but seems reasonable based on construction costs at Yolo County Central Landfill.

LANDFILL GAS RECOVERY AND UTILIZATION COST

The conventional manner of collecting landfill gas is to drill vertical wells after waste placement and connect them to horizontal headers. In some landfills, particularly large, deep landfills, horizontal collection pipes are placed to begin gas collection before the landfill is full. Another possibility, is to place a porous layer within the final cover that will transmit the landfill gas to horizontal collection pipes. This porous layer could consist of chipped tires or gravel. The Yolo County project uses a combination of vertical wells and a porous, horizontal collection layer.

Typically, the installation of a gas collection system would be required to control emissions and would not be installed solely to recover methane for utilization. The generation of energy with the collected landfill gas is an alternative to flaring of the gas which should have been collected anyway. Therefore, the cost of installing a landfill gas collection system would not be considered an incremental increase in operating costs resulting from landfill enhancement.

As enhanced landfilling has not been widely practiced on a commercial scale, the economics of landfill gas-to-energy projects are evaluated assuming conventional landfill practices. For this reason, it is difficult to consider the costs of energy generation as an increase in expenses that result from enhanced landfilling. However, if an investment were made in landfill gas to energy equipment with the intention of practicing enhanced landfilling, additional power generating capacity would be required to take advantage of the increased methane generation rate. In this case, the additional capacity could be compared to the incremental increase in revenue resulting from increased methane generation. Estimated costs for a hypothetical 1,000 kW plant are shown in Table 8.

INCREASED OPERATIONAL COSTS RESULTING FROM ENHANCED LANDFILLING

Again, much of the operational expense of collecting and utilizing landfill gas would be incurred regardless of whether or not enhanced landfilling were practiced. Estimated operational costs are shown in Table 9. Only the maintenance of the liquid handling equipment and the increased monitoring costs are considered to accrue from the practice of enhanced landfilling. The other two costs, maintenance of the landfill gas collection system and the energy generating facility are assumed to be costs that would have accrued regardless of the application of enhanced landfilling. It should be noted that the greater volumes of gas generated by enhanced landfilling may actually enable significant economics of scale for energy equipment and operations cost.

Table 8.
Capital Cost Estimate for a Hypothetical 1,000 kW Plant

COMPONENT	COST	PERCENTAGE
Collection System	$200,000	13.3
Fees - Planning/Environmental	$15,000	1.0
Legal Fees	$15,000	1.0
Interconnect Cost	$75,000	5.0
Generating Equipment	$970,000	64.7
Contingency	$225,000	15.0
TOTAL	$1,500,000	100.0

Source: Laidlaw Gas Recovery Systems, Jansen, G.R., (1992).

Table 9.
Estimated Operational Expenses for Enhanced Landfilling with a Landfill Gas-to-Energy Facility

COMPONENT	ANNUAL COST	SOURCE
Maintenance and Monitoring of Gas Field (40 acres) [2]	$10,000[1]	Yolo County estimate
Maintenance and Monitoring of Electrical Generating Facility (1,000 kW)	$150,000[1]	Laidlaw Gas Recovery Systems Jansen, G.R. (1992)
Increased Monitoring Costs	$5,000	Yolo County estimate
Maintenance and Management of Liquid Handling Equipment	$25,000	Yolo County estimate
TOTAL	$205,000	

1. These costs are assumed to be incurred whether or not enhancement is practiced as discussed in the text. Includes operation and maintenance of the landfill gas collection system.
2. Landfill gas from 40 acres of enhanced landfill is consistent with one MW of power generation.

POTENTIAL INCREASE IN REVENUE FROM GAS-TO-ENERGY CONVERSION

Methane recovery with enhanced landfilling may be conservatively assumed at 1.7 ft^3 per pound of dry waste (Augenstein, et. al. 1976a, 1976b, Barlaz, 1990). This is about threefold the "normally" observed recovery of around 0.6 ft^3 per dry pound because of higher generation rates and increased recovery efficiency. The surface membrane containment technology proposed for capture of essentially all generated gas is commercially available and effective (Booth, 1991, Rice, 1994.) For a landfill receiving 500 tons per day, the methane recovery at ultimate steady state is thus 1.5 million ft^3 per day, enough to produce about 2 megawatts.

As previously discussed, gas generation from conventional landfilling is usually slow, sporadic and incomplete due to efforts to maintain the landfilled waste in as dry a state as possible. Also, well maintained clay surface liners can significantly reduce landfill gas production by effectively excluding moisture from the landfill while still allowing gas emissions to the atmosphere. Economic prospects for recovery of landfill gas and subsequent energy generation under these conditions are very poor. Landfills wishing to use landfill gas as an energy source can accrue substantial benefits from practicing enhanced landfilling, where the moisture regime in the landfill is controlled to accelerate decomposition, and the gas produced is effectively contained and collected.

ECONOMIC ANALYSIS OF ENHANCED LANDFILLING WITH ENERGY GENERATION

An economic analysis of enhanced landfilling at the Yolo County Central Landfill (YCCL) is presented in this section. A description of the analysis is provided below with assumptions and references for costs and benefit estimations.

The accounting stance taken in this economic analysis is that of an owner/operator of both the landfill and the power generation from landfill gas facility. At the Yolo County Central Landfill this is not the existing situation. Yolo County contracts with a private enterprise in the energy industry to operate the electricity generation facility. A result of this accounting stance is that royalties paid by the producer of electrical power (the private enterprise) to the owner of the landfill (Yolo County) are not considered.

It is assumed that in the year 1997 a module at the YCCL is constructed and begins accepting waste. It is further assumed that waste placed in this module and subsequently modules will experience liquid additions similar to those in the enhanced cell of the demonstration project. The tonnages of waste placed in the landfill each year in this analysis are based on waste disposal projections for the YCCL. These are shown in Table 1 in Appendix 3. The waste disposal projections determine the landfill module construction schedule and the amount of landfill gas generation that can be estimated each year. Based on these projections and currently estimated landfill capacity, the landfill capacity is calculated to be exhausted in the year 2020. Leachate recirculation is assumed to continue for an additional ten years when landfill gas generation is assumed to cease. This is discussed further in the following section.

The average depth of waste at the Yolo County Central Landfill is 40 feet. The economics of enhanced landfilling will be different for landfills with waste depths different than at Yolo County.

The inflation adjusted discount rate used in this analysis is 3% (Anex, 1996).

A spreadsheet is used for all calculations associated with this analysis. The spreadsheets generated in conducting this analysis are shown in Appendix 3.

Landfill Methane Generation

The amount of landfill methane generation is estimated at 1.8 ft^3 per dry pound of municipal solid waste (Augenstein etal., 1976a, 1976b, Barlaz, 1990). The moisture content of as-placed municipal solid waste is estimated at 25% on a weight basis. Therefore, the equation used to estimate methane potential for a given tonnage of waste is as follows.

Methane potential = (Tons landfilled)*(2000 lbs./ton)*(75 lbs. dry waste/100 lbs. as-placed waste)*(1.8 ft^3 CH_4/dry lb. waste)

It is assumed that with enhanced landfilling, the rate of generation of landfill gas will be accelerated such that landfill gas generation would cease after 10 years. Therefore, the ultimate methane yield would be realized in 10 years and the landfilled waste would possess no potential for further methane generation. For simplification, the yearly methane generation is assumed to be steady state and equal to the methane potential of the waste divided by 10 years.

It is assumed that waste placed in Year(i) would not begin generating methane until Year (i +1). Furthermore, it is assumed that during the first year of landfill gas generation there is no landfill gas recovery. This is because it takes time to construct the landfill gas recovery system and landfill gas recovery would not occur during this time. Therefore, 10% of the total methane potential of the waste is assumed to be lost due to the fact that the collection system is not yet in place. Therefore, in this analysis, methane recovery from waste placed in Year(i) would not occur until Year(i + 2). Of course, landfill gas will begin to be generated soon after waste placement, however, not at the accelerated rate that will occur with enhanced landfilling. Since liquid addition is not expected to begin until after the landfill gas recovery system is in place, the estimate of 10% of landfill gas being lost is a conservative estimate that does not serve to improve the economics of enhanced landfilling.

It is also assumed that a permeable layer is placed over the waste, such as a shredded tire layer, and that a synthetic liner is placed over the permeable layer, enabling a high recovery efficiency of 95% of methane gas generated. Methane flowrates from the Yolo County Central Landfill (YCCL), assuming that enhancement is applied, are shown in Table 1 in Appendix 3.

The method of using a spreadsheet to add the individual contributions from the tonnage of waste landfilled in each year is shown in Table 2. Each year's tonnage is assumed to generate an equal amount of landfill gas over ten years, although only 9 years worth of this gas is assumed to be recovered.

Energy Content of Landfill Methane

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, one million cubic feet of landfill methane has a BTU content of (900 BTU/ft^3 CH_4)(1,000,000 ft^3 CH_4) = 900,000,000 BTU. The electrical energy potential for one million cubic feet of landfill methane is estimated as (900,000,000 BTU/12,500 BTU per kWh) = 72,000 kWh. Energy potential of landfill methane generated at the YCCL is shown in Table 3 in Appendix 3.

Incremental Increase in Cost of Enhanced Landfilling above Conventional Landfilling

This analysis considers costs that would be incurred in the practice of enhanced landfilling that would not be incurred if conventional landfilling is practiced. Some cost components are considered mandatory for conventional landfill operations and, therefore, are not considered as costs accruing to enhanced landfilling. For example, the cost of the surface liner system that is placed at landfill closure is considered to be a cost for both conventional and enhanced landfills and is therefore not considered to be a cost accruing to enhanced landfilling. The same is true for the construction, operation, and maintenance of the landfill gas recovery system. Any landfill large enough that energy generation would be considered would be required to install a gas recovery system simply to comply with the US Clean Air Act.

Costs Associated with Enhanced Landfilling

In this analysis, all of the costs associated with energy generation are considered as accruing to enhanced landfilling even though energy generation could also be practiced with conventional landfilling. In the case of energy recovery with conventional landfilling, equipment costs will be spread out over more years because the methane gas is generated slower than with enhanced landfilling. Also, with conventional landfilling, the amount of energy generating equipment required to maximize energy generation from landfill methane is less than with enhanced landfilling. This is because the energy generation rate and methane yield is less with conventional landfilling; with enhanced landfilling more energy generating equipment is required over a shorter period of time to take advantage of the increased methane available. Therefore, with regards to the cost of acquiring energy generation equipment, this analysis is conservative with respect to enhanced landfilling. Rather than considering the incremental increase in cost to acquire the additional energy generating equipment to burn the incremental increase in methane available from enhancement, all of the energy generating equipment is accrued to enhanced landfilling.

Energy Generating Equipment

The cost to acquire energy generating equipment is $970,000 (1992 dollars) per megawatt (MW) of power generation capacity. The cost of operations and maintenance is estimated at $100,000 (1992 dollars) per MW of power generated. The source of this information is Laidlaw Gas Recovery Systems (Augenstein and Pacey, 1992). The permitting fees, legal fees, interconnect costs, and contingency total $300,000 in year 1992 dollars.

Decommissioning of the energy generating facility is estimated at $250,000 in the year 2030.

Additional Liner Costs
Additional waste management units are constructed at the Yolo County Central Landfill about every two years. The projected surface area of a module is about 22 acres. Depending on the regulatory perspective in a given area and specific site conditions, a conventional composite landfill liner system (single synthetic liner) may be allowed when enhanced landfilling is practiced. However, a double liner system may be required by regulators if liquid is to be added to the landfill. The additional cost to construct a secondary liner system is estimated at $50,000 per acre (Yolo County cost estimate, 1997 dollars).

Liquid System Management System Construction and O&M Costs
The system required to add liquid or recycle leachate into the landfill is considered a cost accruing to enhanced landfilling. However, some of the equipment that would be used to manage leachate for enhanced landfilling would also be required if conventional landfilling were practiced. The estimated cost to construct a landfill liquid addition/leachate recirculation system is $200,000 in 1997 dollars for a landfill module with a base surface area of 22 acres. This includes pumps, pipelines, and infiltration systems. Operations and maintenance of the liquid management system is estimated at $25,000, beginning in the year 2000. This includes monitoring the system, maintaining the infrastructure, and additional electricity costs above those accrued from conventional landfilling.

<u>Benefits of Enhanced Landfilling</u>
The most obvious benefit of enhanced landfilling is energy generation from landfill methane. Other benefits are derived from leachate management and early stabilization of the landfilled waste. These benefits are discussed below.

Landfill Methane to Energy Revenue
This analysis assumes that landfill methane is converted to electrical energy. The selling price per kWh is varied; a sensitivity analysis is conducted to determine the selling price per kWh required to achieve a benefit to cost ratio of one for four scenarios. These scenarios are described later in this report. The benefit to cost ratio is defined as the present value of benefits divided by the present value of costs. In the computation of energy revenue from landfill gas a down-time for energy generating equipment of 20% is assumed.

Tax Credits
Tax credits are available to producers of energy from landfill gas until the 2007. The tax credit available in 1997 is $1.00 per BTU of landfill methane generated. Following the year 1997, the tax credit is increased in each subsequent until the year 2007 (NEO Corporation). Of course, a public agency that does not pay taxes will not benefit from tax credits. However, a partnership with a private enterprise can be formed that would allow

at least some portion of the tax credit benefit to be realized. The tax credits are shown in the benefit spreadsheets in Appendix 3.

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 flowrate. This can reduce treatment costs and reduce the need to construct leachate storage facilities. The estimated benefit is $25,000 in 1999, the first year that a leachate treatment benefit is expected to accrue. The $25,000 leachate treatment cost is assumed to increase to $250,000 in 2029. The projected cost of leachate treatment is uncertain and is based on the avoided cost of leachate pre-treatment prior to discharge, and the avoided cost of additional leachate surface impoundments.

Landfill Life Extension Benefits

The accelerated stabilization of the landfill will result in accelerated settlement of the landfill and, possibly, landfill life extension. Typically, in conventional landfills, this settlement occurs over a period of time too long to take advantage of the increased landfill airspace. To achieve this benefit it would be necessary to return to already stabilized landfill modules and add additional waste to increase the landfill height to its pre-settlement elevation. This approach might not be cost effective if a final cover system had already been placed on the landfill module. However, if this accelerated settlement were reliable, it might be possible to gain regulatory approval to landfill waste to an elevation higher than the ultimate regulated elevation knowing that with enhanced landfilling the final elevation would be within the maximum allowed height. For example, if the maximum regulated height were 80 feet, it might be possible to landfill to an elevation of 84 feet knowing that within 10 years the final elevation would settle to 80 feet or less.

This analysis assumes a landfill life extension of 5 years due to accelerated settlement for a landfill life of 23 years. The value placed on this airspace gained is the calculated as follows. The cost to permit and construct another landfill is estimated at between 11 and 12 million dollars in 1997 dollars. Using a discount rate of 3%, and a cost to open a new landfill in 1997 of $11,590,000, the discounted cost in the year 2020 is $22,873,867. However, it is assumed that enhanced landfilling has resulted in an extension of landfill life for an additional five years. Therefore, the expense of opening a new landfill can be postponed for five years. The increase in value of the $22,873,867 over that five year period, still using a 3% discount rate, is 3.64 million dollars. This benefit is assigned in the year 2025.

Post-Closure Monitoring and Maintenance Savings

If the landfill is stabilized in ten years following closure, the monitoring and maintenance of the gas recovery system can be discontinued. The cost to perform these tasks have been estimated at $20,000 per year in 1997 dollars.

Salvage Value of Electrical Power Generating Equipment
The salvage value of the electrical power generating equipment is assumed to be $60,000 per MW. This cost was not discounted. The salvage value is assumed to be the same at all points in time.

RESULTS
A sensitivity analysis was done to assess how uncertainty in certain assumptions would affect the results of the analysis. The analysis is performed with and without the cost of a double composite liner, and with and without the benefit of landfill life extension. This results in four scenarios being analyzed. The approach of the sensitivity analysis is to adjust the selling price of energy, the amount paid per kilowatt-hour, until the benefit to cost ratio is equal to one. Four cases were analyzed and are described below.

CASE 1: Case 1 assumes that liquid addition and leachate recirculation will be allowed without a double liner. Additionally, Case 1 assumes that the five year landfill life extension would be realized. For Case 1 only, the discount rate is also varied from 2 to 4% to evaluate the change in electricity selling price if the benefit to cost ratio is held equal to one.

CASE 2: Case 2 also assumes that the construction of a double liner will not be necessary. However, Case 2 differs from Case 1 in that no landfill life extension is realized. The benefit from the five year landfill life extension is eliminated.

CASE 3: Case 3 assumes that a double liner will be necessary at a cost of $50,000 per acre for additional construction costs. Case 3 also assumes that there will be a five year landfill life extension.

CASE 4: Case 4 assumes that a double liner at $50,000 per acre will be required and that there will not be any landfill life extension.

Table 10
Enhanced Landfilling Economic Sensitivity Analysis

SCENARIO	DESCRIPTION	cents/kWh for B/C = 1
Case 1	Single composite liner with landfill life extension of five years.	3.49
Case 2	Single composite liner with no landfill life extension.	3.93
Case 3	Double liner system with a five year landfill life extension.	7.77
Case 4	Double liner system without any landfill life extension.	8.22

B/C = benefit to cost ratio

TABLE 11
EFFECT OF ELIMINATING TAX CREDITS
B/C HELD CONSTANT AT 1

SCENARIO	ENERGY SELLING PRICE WITHOUT TAX CREDITS (cents per kWh)	INCREASE IN ENERGY SELLING PRICE FROM SCENARIOS WITH TAX CREDITS (cents per kWh)
Case 1	4.05	0.56
Case 2	4.45	0.52
Case 3	8.30	0.53
Case 4	8.75	0.53

Results of the sensitivity analysis are presented in Table 10 of this section. The effect of eliminating tax credits as a benefit are shown in Tale 11 of this section. Spreadsheets showing the costs and benefits throughout landfill life are shown in Tables 4 - 11 of Appendix 3. The present values of costs and benefits over the analysis period (1997 - 2050) are shown for all cases in Figures 1 - 4 of Appendix 3. It can be seen in Figures 1 - 4 that even though the benefit to cost ratio may be equal to one, there remain a number of years when cash flows are negative. This is due to the fact that energy generation equipment is expensive and these purchases occur relatively early in the project compared to some of the benefits. The information presented in Table 10 is also presented graphically in Figures 5 - 8 (Appendix 3), which show the change in benefit to cost ratios for a range of energy selling prices. The changes in energy selling price ($ per kWh) for a range of discount rates are shown graphically in Figure 9 of Appendix 3.

CONCLUSION

There is considerable uncertainty involved in this analysis. Economic projections 30-50 years into the future can only be considered to be very approximate. Regulatory requirements are difficult to predict, the energy industry is undergoing restructuring, the discount rate of 3% could change in the future. The analysis used Yolo County Central Landfill as a model; other sites could have conditions that are completely different than Yolo County and render the application of these results difficult. However, given the assumptions used in this analysis, enhanced landfilling can be accomplished with a benefit to cost ratio equal to one at a selling price for electricity of 3.5 - 4 cents per kWh for Cases 1 & 2 when a double composite liner system is not required. Requiring the use of a double liner system would render enhanced landfilling uneconomical. Electrical generation equipment is expensive to purchase and operate and increases in costs of this component would adversely affect the economics of enhanced landfilling. Also, because cash flows are often negative in spite of the benefit to cost ratios being equal to one, cash flow difficulties can be a problem during the period of landfill gas generation and energy recovery.

IV. REPAYMENT

REGULATORY IMPACT ON THE COMMERCIALIZATION OF ENHANCED LANDFILL TECHNOLOGY

The California Regional Water Quality Control Board-Central Valley Region (RWQCB-CVR), one of the agencies that regulates the Yolo County Central Landfill, will not allow liquid to be added to a conventional Class III landfill cell. The reason for this is the concern that the addition of liquid would result in increased hydrostatic head on the landfill base liner resulting in increased risk of groundwater contamination. The enhanced cell for this project was required to be constructed with a double liner system, as normally required for liquid waste surface impoundments. The requirement of a double liner increased the cost of the enhanced cell considerably. It is estimated that a double liner system for a full-scale landfill would increase the cost of landfill construction by at least $50,000 per acre (see Projected Economics Section). This requirement could render the application of this technology economically prohibitive.

The view of the Yolo County Division of Integrated Waste Management is that the addition of liquid to the landfilled waste is possible without causing excessive hydrostatic head on the base liner. The goal is not to saturate the waste, but rather, to add liquid in a managed way, until the waste reaches its field capacity (the point at which liquid begins to drain). Managed liquid additions, when used with an efficient leachate removal system, should preclude the buildup of hydrostatic head. A pressure transducer was placed at the lowest point in the leachate collection trench in order to monitor this assumption. Information from this transducer will be used to guide the liquid management program for the project. Data collected in this way will be provided to the RWQCB-CVR for evaluation and recommendations. If the collected data supports the notion that hydrostatic head can be avoided, the RWQCB-CVR would be asked to allow the managed addition of liquid to the landfilled waste placed in conventional waste management units with composite liners.

The acceptance or rejection of a single liner model by the RWQCB could very well determine the future of the enhanced landfill project at YCCL. A double liner requirement would severely impact the economic feasibility of large scale applications, thus, a decision must be made with regard to the increased costs of a double liner system. In any case, if the RWQCB continues to require a double liner system where liquid additions are used, it does not mean the technology could not be applied elsewhere with only a single liner. Site specific conditions at other locations might permit local regulators to allow such an implementation.

It is expected that at least two years of operations and monitoring of the enhanced cell will be required before enough data can be accumulated to develop a presentation to the RWQCB. At that time, if the data warranted it, a revision to our Waste Discharge

Requirements would be requested which would allow liquid addition to the waste in Module C, to be constructed during the summer of 1996. It is assumed that gas generation well beyond that expected from conventional landfilling would be seen within one to two years, with a corresponding increase in revenue to Yolo County. Based on this scenario, repayment could begin within five years, allowing two years to gather data, a year for Waste Discharge Requirement revisions, and another two years for increased revenue from gas production to be realized.

METHANE POWER GENERATION AND THE CALIFORNIA PUC

The cost of full-scale application must be justified by prospective incremental energy revenue to Yolo County. With utility deregulation and other factors, the possible incremental energy revenue is much less certain. The contract existing prior to March 1995 between the Pacific Gas and Electric Company (PG&E) and Yolo Energy Partners, whereby PG&E had agreed to purchase electricity at favorable rates until 1998 (Standard Offer 4) was bought out by PG&E. Termination of the contract occurred without either knowledge or participation of the two other stockholders, EMCON and Yolo County. Yolo County is hopeful that the restructuring of the energy market currently underway by the California Public Utilities Commission will result in favorable prospects for landfill gas utilization.

CURRENT STATUS OF THE YCCL METHANE POWER FACILITY

The generating facility has now been idle for about a year, however, the facility was recently purchased by the Northern State Power company, a subsidiary of Minnesota Power and Light. The plan calls for the Minnesota Methane company to produce and sell power to Southern California Edison using PG&E's transmission lines. A final agreement as to how all this will work is not finalized, however, and it seems likely that the sale of electricity under a new contract will be at a lower rate. Should electricity sales be possible at a sufficiently attractive rate, enhanced landfilling will be implemented in new modules at Yolo County as originally planned.

V. EXPECTED BENEFITS, CONCLUSIONS AND RECOMMENDATIONS

CRITERIA FOR EVALUATING BENEFITS

A variety of criteria may be used in evaluating benefits based on the assumption that enhanced landfilling will be applied to a major fraction of the wastes (50 to 75% depending on example) landfilled in California. Projections are also made for the United States as a whole.

ENERGY POTENTIAL

The CEC's and Yolo County's principal interest in enhanced landfilling is the recovered energy and resulting revenue derived from applying the process to municipal wastes in California. Derivation of the incremental energy potential is detailed below, with assumptions stated:

1. Municipal landfill waste generation in California will be at the national average rate of 3.5 pounds (2.63 pounds dry) per person per day, based on EPA statistics (Kaldjian, 1990) This waste amounts to 17×10^6 tons as-placed or 12.75×10^6 dry tons per year.
2. Methane generation from one dry pound of waste in a dry unenhanced landfill is about 1.0 ft^3 (Augenstein and Pacey, 1990)
3. Recovery efficiency of methane with conventional well systems is about 60 percent so that about 0.6 ft^3/ lb (dry waste) of methane is recovered.
4. Methane generation from one dry pound of waste in an enhanced landfill is about 1.8 ft^3.
5. Recovery efficiency of methane from an enhanced landfill using a surface membrane is about 95 percent so that about 1.71 ft^3/lb (dry waste) of methane is recovered.
6. For simplification, transients are ignored, and operation is assumed to be at steady state.
7. Methane recovery estimates for conventional landfills assume that 50% of California waste would enter landfills with gas systems where the recovery rate is 0.6 ft^3/lb, for a recovery of 7.65×10^9 ft^3/year.
8. The minimum landfill size where enhancement is economical is assumed to be that supporting 1 megawatt of electric power production, at a conversion rate of 0.09 kWh/ft^3. At per capita waste generation of 2.63 dry pounds per day this requires the landfill serve about 60,000 people.
9. 75% of California's landfilled waste will enter landfills of a size such that enhancement is economical.

Using assumptions 1-9 above, the recovery of methane without enhancement would be 7.6×10^9 ft^3, as follows:

17×10^6 tons/year × 2000 pounds/ton × 0.75 (dry/wet weight) × 0.6 ft^3 of methane recovered × 0.5 (fraction of landfilled waste subject to recovery) = 7.6×10^9 ft^3

With enhancement, methane gas recovery would be 32.7×10^9 ft^3.

17×10^6 tons/year × 2000 pounds/ton × 0.75 (dry/wet weight) × 1.71 ft^3/lb of methane recovered × 0.75 (fraction of landfilled waste subject to recovery) = 32.7×10^9 ft^3.

This is equivalent to a net gain of 25.7×10^9 ft^3 of natural gas, which is equivalent to more than 4 million barrels of oil a year. A rough projection for the increase in the domestic energy supply for the U. S. as a whole suggests a figure of at least 100,000 barrels of oil per day. These are preliminary estimates and final numbers will not be known, assuming the approach is successful, for several years. However, they are based on reasonable assumptions and field and laboratory experience.

VALUATION OF ENERGY

Several valuations are possible for the energy that might result from accelerated anaerobic composting of municipal wastes in California. The increased gas volume recovered may be roughly estimated at 25×10^9 ft^3 per year. If valued for energy at a cited wellhead price of $2.00 per million Btu, the value would be $75 million. Converted to electricity at a rate of 0.09 kWh/ft^3 and sold (or wheeled) to a combination of grid and retail users at an average of $0.04/kWh, the valuation of electric power would be closer to 100 million dollars per year. Similar calculations suggest energy values could be several hundred million dollars a year for the US as a whole.

The above defines, grossly, energy produced whose value might lie between $50 and 100 million for California. The economic activity promoted by the energy value, alone, should be of at least similar magnitude. For the specific case where extra gas offsets fuel use and thus reduces expenditures for fuel which would otherwise be purchased outside the state, the state's economy is favorably affected. This is economically equivalent to spending the $50 million or so within the state.

ABATEMENT OF GREENHOUSE GAS EMISSIONS

Currently, uncontrolled emissions of United States landfill methane into the atmosphere contribute to atmospheric methane buildup. Evaluation of the impact of landfill methane on this atmospheric buildup, and its adverse climate change consequences, has been conducted by one of the project participants (Augenstein, D., 1992, and Blake, D., 1994). In summary, U. S. landfill methane emissions are of high significance in contribution to climate change, and in fact may constitute about 1-2% of the totality of the climate change problem.

The assumptions used above for energy calculations for California can also be applied in estimating methane emission abatement. Calculations suggest that applying enhancement to the degree assumed, with the same assumed capture efficiencies, would result in a yearly reduction of methane emissions of about 20×10^9 ft^3 for California (about 40 to 50 percent). Initial studies suggest that enhanced landfilling could also cut total emissions by half, nationwide. This would result in a reduction of about 1% in the annual global warming potential due to buildup of greenhouse gases in the earth's atmosphere. Such a degree of abatement is regarded by those in the atmospheric sciences as a major benefit (Cicerone, R., personal comm., Blake and Augenstein, 1994.)

"Climate change equivalence" of methane to carbon dioxide on a molecular basis can vary, depending on timespan, nature of emission over time, and other factors. One widely applied equivalence ratio of methane to carbon dioxide is that adopted by the Intergovernmental Panel on Climate Change (IPCC). The IPCC assumes equal quantities of methane and carbon dioxide are generated, then integrates the greenhouse effects of both over a 100 year period. Using this approach, the IPCC evaluates methane climate change potency as eight-fold that of carbon dioxide on a per-molecule basis. The abatement of 20×10^9 ft^3 of emitted methane per year in California would equate, by the IPCC standard, to mitigation of about 2.5 million tons of carbon emission (as CO_2). In greenhouse terms, this would equate to a reduction in consumption of 18 million barrels of oil annually for California and about 150 million barrels a year for the U. S. as a whole.

One economic criterion for evaluating greenhouse gas abatement is the expense to mitigate emission of one ton of carbon as CO_2, or the "greenhouse equivalent" of another gas. Costs for CO_2 carbon mitigation range from zero (for some economically self-supporting steps such as conservation) to well over 100 dollars per ton, with higher costs being more typical. US electric utilities participating in the EPA Climate Challenge Program are typically considering steps that cost $10-20 per ton of carbon abated.

It must be pointed out that cost of methane mitigation by enhanced landfilling might vary depending on a number of factors, however, a range of $0.50 to $2.00 per million Btu's to mitigate landfill methane emission seems to be a reasonable assumption. This is equivalent to an abatement cost of approximately $3.00 - $15.00 per ton of CO_2 carbon, which is rather low. Thus, enhanced landfilling appears to be an attractive route to mitigation of emissions of greenhouse gases. Alternatively, the mitigation of 20 billion cubic feet/year of methane emissions to the atmosphere is equivalent by the accepted IPCC standards to the mitigation of 2.5 million tons of CO_2 carbon/year. At $15/ton mitigated, this would have a value of $37.5 million annually.

WASTE VOLUME REDUCTION AND LANDFILL LIFE EXTENSION

Enhanced and conventional landfills experience volume reduction, a key factor in extending the useful life of the facility. Over time, the waste is slowly converted to gas and leachate, with a resulting decrease in volume. In the case of conventional landfills, this volume reduction occurs slowly over time and is of limited value to the landfill operator. In addition, as the waste slowly subsides, the convex cover layer sags, sometimes forming collection ponds for rainwater, and a potential threat to groundwater due to the accumulation of high-strength leachate within the fill. To cope with this, the operator must periodically move additional cover material over the fill, to maintain convexity in order to shed rainwater. In the case of enhanced landfills, volume reduction can be accelerated to the point that stabilization may occur within a decade of placement. The ability to recover this volume for further filling is certainly beneficial, especially if it can be accomplished within a short, predictable time period. On the other hand, if a landfill operator has gone to the expense of installing an impermeable final cover system, it may be impractical to remove that cover at a later date in order to add more waste. If, however, this objective were planned for early, it might be possible to use a "temporary" final cover during the time of landfill decomposition so that it would not be economically prohibitive to place more waste at a later date.

For the unenhanced case, generation of 2 ft^3 of landfill gas (1 ft^3 of methane with 1 ft^3 of associated CO_2) from one dry pound of waste represents the conversion of 15.8% of the waste dry weight to gas. The enhanced generation of 3.6 ft^3 of landfill gas per dry pound (1.8 ft^3 of methane) would represent conversion of 28.5 % of the waste to gas. Volume reduction proportional to the loss of dry waste seems a realistic assumption. Assuming that such waste volume losses will occur, waste ultimately reposing in the landfill will be changed from 84.2% of the incoming waste, without enhancement, to 71.5%, with enhancement.

This estimated volume reduction is significant because it suggests landfill life can be extended by 10 to 15%, assuming a cost-effective means can be found to add waste after closure. As with energy, several methods could be used to valuate landfill life extension. One way in which savings might occur is that five landfills might suffice for a given inflow of waste if enhanced landfilling were applied, whereas six might be needed otherwise. The savings would include the costs of siting, permitting, land, lining, filling operations and maintenance. One prediction is that by the year 2000 half of the collected gate fees will be used to maintain the waste ultimately remaining in the landfill. This volume reduction is assumed to apply to 75% of the waste produced in California, for an additional waste capacity of 12.75 million tons per year. This leads to an estimated savings of about $30 million annually.

REDUCTIONS OF OTHER POLLUTANT EMISSIONS

Landfill gas contains significant quantities of air pollutants such as volatile organic compounds (VOC's) or non-methane organic compounds (NMOC's). The California Air Resources Board, US EPA and others variously estimate their emissions to be somewhere between 0.1 and 1.0 pounds per cubic foot of methane generated. Assuming that this ratio of NMOC's to total methane is unaffected by enhancement, the abatement of NMOC emissions to the atmosphere associated with a reduction of 20 billion cubic feet of methane emissions per year would be between 2000 and 20,000 tons/year. A nominal value for cost of abatement of emissions from other sources is about $2.50/lb. This would place a value for this degree of NMOC abatement at somewhere between $5-50 million per year for California alone.

REDUCED POST-CLOSURE LANDFILL MAINTENANCE

The effort now required for post-closure landfill maintenance under Title 14 of the CCR, is considerable. This effort is necessary to maintain containment and particularly gas systems. Typical vertical well gas systems require continuing well-by-well adjustments of gas extraction so that gas is captured with reasonable efficiency while air entrainment is avoided.

Flow maintenance of current, well-based extraction systems is labor-intensive, and may periodically involve drilling new wells, maintaining pipes and blowers, and so on. The result is that gas system costs alone can be estimated at between $0.01 and 0.10 per ton of in-place waste, while gas recovery continues. All of the costs associated with the gas system monitoring and maintenance would be expected to cease if gas production were to end (i.e., reach 95+ % completion) earlier than the mandated 30 years. By reducing the maintenance period of a gas recovery system from 30 years to 10, assuming this reduction applied to the amount of California waste which is landfilled, a savings of $0.04 per ton per year, or $10 million dollars annually, should be realized.

EMPLOYMENT IN CALIFORNIA

Above estimates suggest benefits on the order of several hundred million dollars per year if enhanced landfilling is applied to half of California's solid waste. Employment effects are difficult to predict at this stage.

STEPS NEEDED TO MOVE ENHANCED LANDFILL TECHNOLOGY INTO THE MARKETPLACE

This enhanced landfill demonstration project is being conducted with the intention of eventual full-scale application, as described in the original project proposal to the California Energy Commission.

Application at a full-scale landfill is the logical next step toward bringing the technology to commercial feasibility. However, within California, two factors now impede progress in that direction:

- Deregulation of the electric utility industry has reduced prospective sales revenue from electricity.
- The California regulatory approval process to allow enhanced landfilling appears to require considerable effort, possibly due to the newness of the approach. Regulatory issues at the federal level appear to be resolved at this time.[2]

[2] Personal communications: Andrew Teplitzsky, Chief, Residuals Management (i.e. landfilling), U. S. EPA and Simon Friedrich, Head, Municipal Solid Waste Energy Research and Development, U. S. Department of Energy. Communications with Don Augenstein in 1993, 1994 and 1995.

For these reasons, larger scale applications may need to be considered in other states or countries where circumstances are more favorable. Desirable characteristics of a location for full-scale application include:

- The selling price of electricity should be as favorable as possible (preferably $0.05 per kWh or more within the United States), either due to prevailing rates (avoided costs under PURPA) or because of a given electric utility's commitment to renewable power, as in states such as Minnesota and Wisconsin and in the service territories of New England Power.
- Local regulatory authorities should be willing to permit enhanced landfilling without imposing unduly stringent and time-consuming demands. This should be the case where regulatory authorities are familiar with the technology, its environmental benefits and potential. States that are likely to be receptive are Florida and Delaware, because of landfill test work that has been undertaken in those locations, and North Carolina and Ohio, because of EPA offices in those states which endorse and support bioreactor landfill work.
- There should be willingness of state agencies to provide at least some degree of supplemental funding for the first full-scale application.

Enhanced landfill technology can also be moved forward by organizations which are involved in its implementation. The Institute for Environmental Management (IEM), a consultant to Yolo County on this project, wishes to help other parties undertake enhanced landfilling. IEM has conducted discussions with major landfill engineering firms so that enhanced landfilling services could be provided by IEM and the partner firm. As the technology is successfully demonstrated at one or more landfills, a marketing effort could promote the technology's implementation at other landfills that are likely candidates for successful application.

The time necessary to lay the groundwork for a full-scale project can be roughly estimated at 1-2 years (permitting accounting for a large portion) once the decision is made to initiate a full-scale project. Startup would require another year or more, with perhaps five years needed to determine complete performance characteristics at full scale. Yolo County expects to implement this technology in future landfill modules if the test cells are successful operationally and economically. Other steps that will be taken by the county toward moving this technology to market shall include the following:

- Preliminary data will be distributed in reports and published in technical journals.
- Reports will be provided to other public agencies in areas where this technology could be implemented, such as Sacramento County, Solano County, and Sonoma counties.
- Data and reports will be made available to interested parties such as: universities (UC Davis, University of Central Florida, etc.); local and state agencies (California Integrated Waste Management Board, California Regional Water Quality Control Board, and California State Water Resource Control Board); federal agencies (EPA's Risk Reduction and Engineering Laboratory); for further dissemination.

- Based on recent proposed contract with Western Regional Biomass Energy Program and Urban Consortium Energy Task Force the monitoring data will be made available for further dissemination to the public sector.

<u>OVERALL CONCLUSIONS</u>

This report has described the planning, engineering, construction and startup of two test cells at the Yolo County Central Landfill. The purpose of this project is to demonstrate "enhanced landfilling". Major benefits of this technique are expected to include maximum methane yield, higher generation rate, signifcantly shorter decomposition.

Construction of the test cells has been successfully completed as noted above, and initial data is being collected. A comprehensive measurement program shall run over the next several years, until the methane generation and waste stabilization are near complete. Other benefits might include landfill life extension (or reduced use), reduction of costs for landfill management, and mitigation of environmental impacts from leachate.

It is hoped that successful execution of this demonstration project will lead to much wider application of the technology at sites in the US and worldwide. It is strongly recommended that further development and application of enhanced landfilling be pursued.

VI. REFERENCES AND BIBLIOGRAPHY

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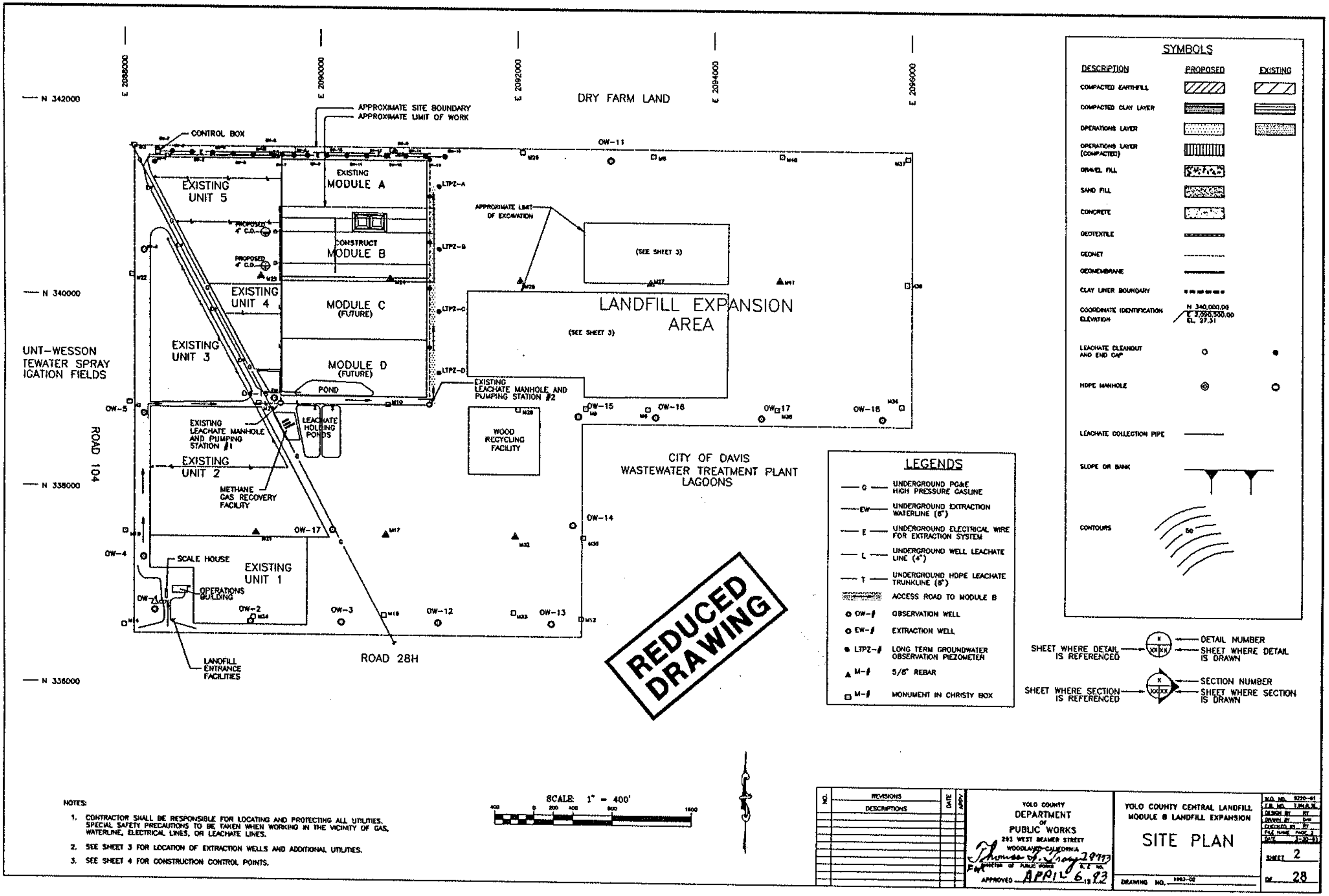
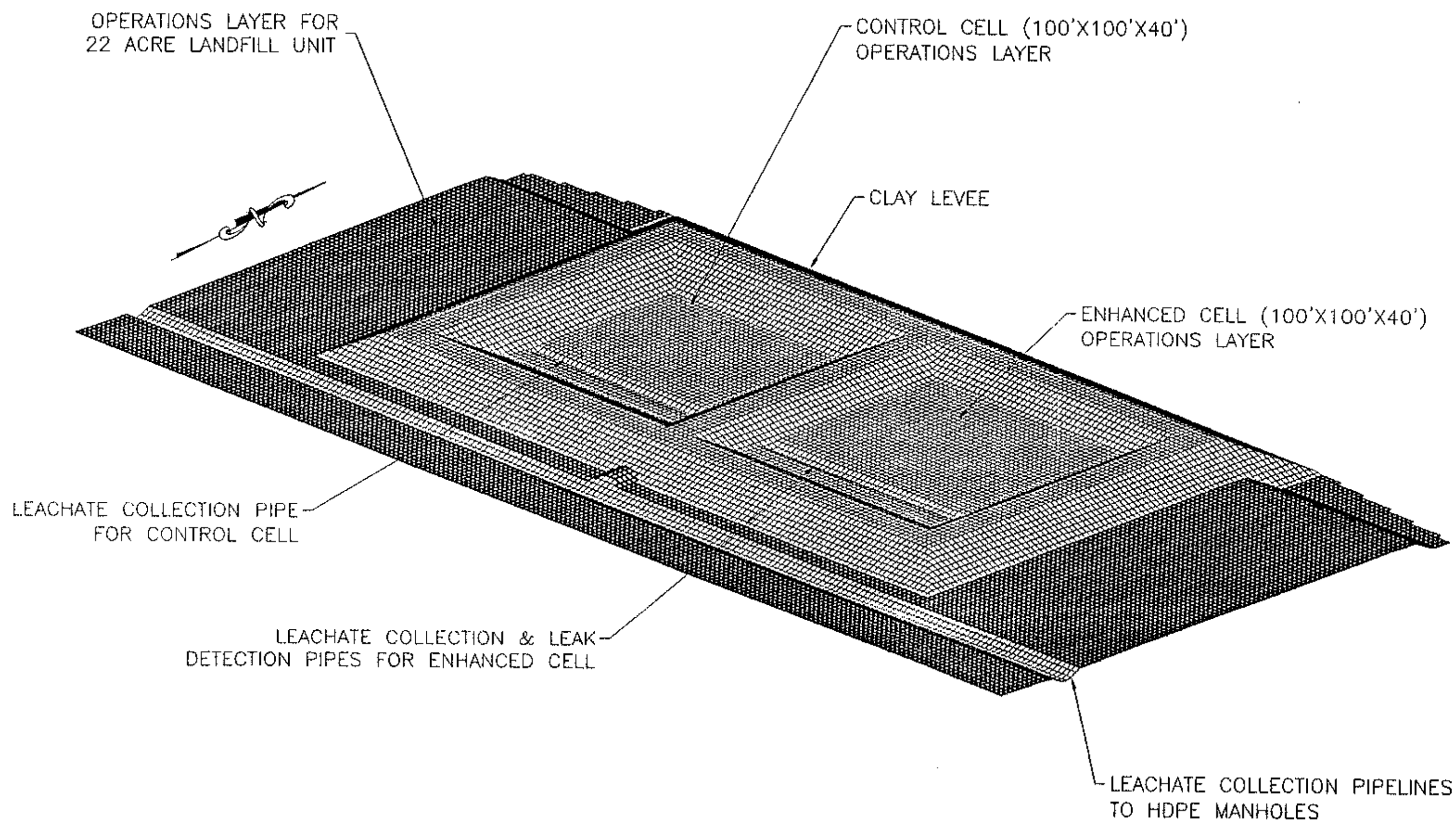
APPENDIX - 1

DRAWINGS


DRY FARM LAND
APPROXIMATE SITE BOUNDARY
APPROXIMATE LIMIT OF WORK
CONTROL BOX
EXISTING UNIT 5
EXISTING MODULE A
CONSTRUCT MODULE B
MODULE C (FUTURE)
MODULE D (FUTURE)
EXISTING UNIT 4
EXISTING UNIT 3
EXISTING UNIT 2
EXISTING UNIT 1
POND
LEACHATE HOLDING PONDS
EXISTING LEACHATE MANHOLE AND PUMPING STATION #1
EXISTING LEACHATE MANHOLE AND PUMPING STATION #2
METHANE GAS RECOVERY FACILITY
SCALE HOUSE
OPERATIONS BUILDING
LANDFILL ENTRANCE FACILITIES
WOOD RECYCLING FACILITY
APPROXIMATE LIMIT OF EXCAVATION
LANDFILL EXPANSION AREA
(SEE SHEET 3)
CITY OF DAVIS WASTEWATER TREATMENT PLANT LAGOONS
UNT-WESSON TEWATER SPRAY IGATION FIELDS
ROAD 104
ROAD 28H
N 342000
N 340000
N 338000
N 336000
E 2088000
E 2090000
E 2092000
E 2094000
E 2096000
OW-11
OW-15
OW-16
OW-17
OW-18
OW-14
OW-13
OW-12
OW-3
OW-2
OW-4
OW-5
LTPZ-A
LTPZ-B
LTPZ-C
LTPZ-D
REDUCED DRAWING
SYMBOLS
DESCRIPTION
PROPOSED
EXISTING
COMPACTED EARTHFILL
COMPACTED CLAY LAYER
OPERATIONS LAYER
OPERATIONS LAYER (COMPACTED)
GRAVEL FILL
SAND FILL
CONCRETE
GEOTEXTILE
GEONET
GEOMEMBRANE
CLAY LINER BOUNDARY
COORDINATE IDENTIFICATION ELEVATION
N 340,000.00
E 2,090,500.00
EL. 27.31
LEACHATE CLEANOUT AND END CAP
HDPE MANHOLE
LEACHATE COLLECTION PIPE
SLOPE OR BANK
CONTOURS
LEGENDS
UNDERGROUND PG&E HIGH PRESSURE GASLINE
UNDERGROUND EXTRACTION WATERLINE (6")
UNDERGROUND ELECTRICAL WIRE FOR EXTRACTION SYSTEM
UNDERGROUND WELL LEACHATE LINE (4")
UNDERGROUND HDPE LEACHATE TRUNKLINE (6")
ACCESS ROAD TO MODULE B
OW-# OBSERVATION WELL
EW-# EXTRACTION WELL
LTPZ-# LONG TERM GROUNDWATER OBSERVATION PIEZOMETER
M-# 5/8" REBAR
M-# MONUMENT IN CHRISTY BOX
DETAIL NUMBER
SHEET WHERE DETAIL IS REFERENCED
SHEET WHERE DETAIL IS DRAWN
SECTION NUMBER
SHEET WHERE SECTION IS REFERENCED
SHEET WHERE SECTION IS DRAWN
NOTES:
1. CONTRACTOR SHALL BE RESPONSIBLE FOR LOCATING AND PROTECTING ALL UTILITIES. SPECIAL SAFETY PRECAUTIONS TO BE TAKEN WHEN WORKING IN THE VICINITY OF GAS, WATERLINE, ELECTRICAL LINES, OR LEACHATE LINES.
2. SEE SHEET 3 FOR LOCATION OF EXTRACTION WELLS AND ADDITIONAL UTILITIES.
3. SEE SHEET 4 FOR CONSTRUCTION CONTROL POINTS.
SCALE: 1" = 400'
REVISIONS
NO.
DESCRIPTIONS
DATE
APP'V
YOLO COUNTY
DEPARTMENT OF PUBLIC WORKS
292 WEST BEAMER STREET
WOODLAND, CALIFORNIA
DIRECTOR OF PUBLIC WORKS
APPROVED APRIL 6, 1993
YOLO COUNTY CENTRAL LANDFILL
MODULE B LANDFILL EXPANSION
SITE PLAN
DRAWING NO. 1993-02
SHEET 2
OF 28

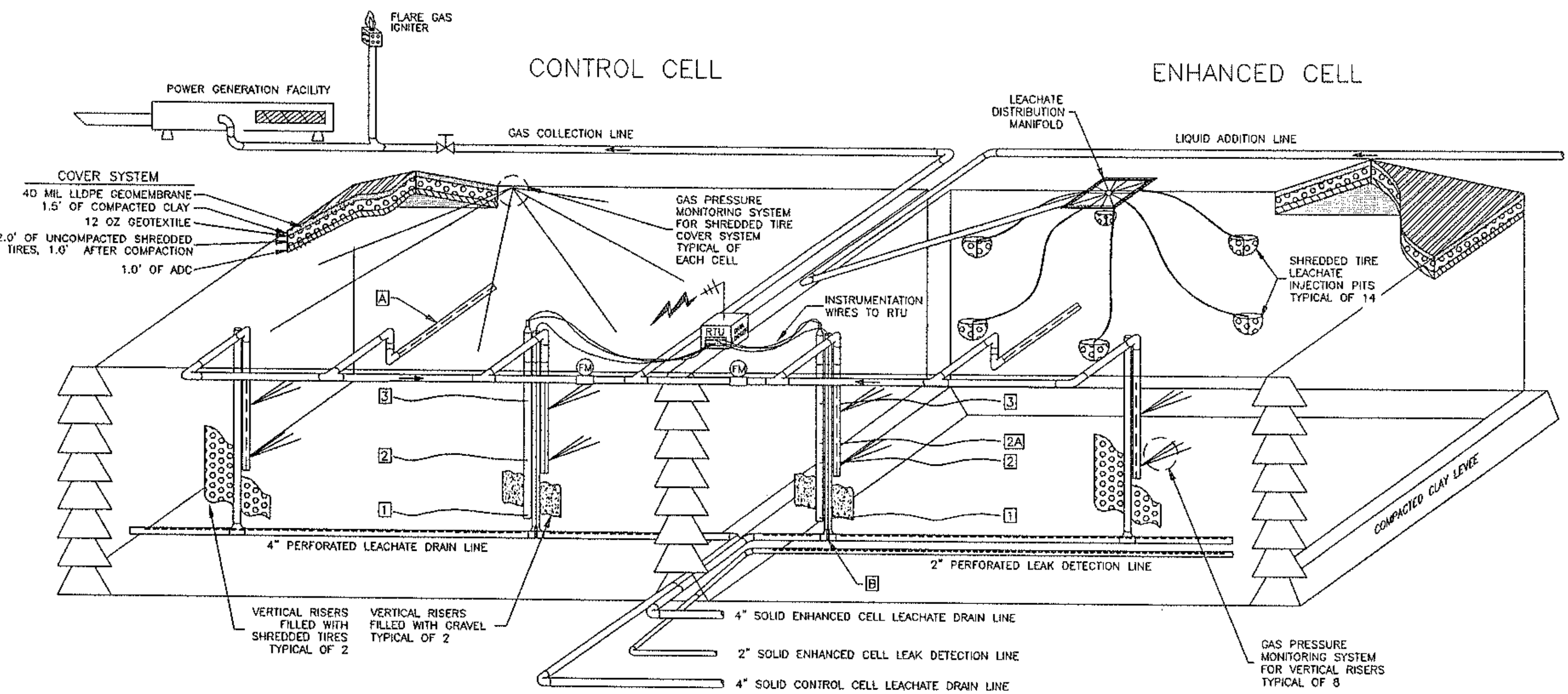
DRAWING II-1



PROJECT CELLS - BASE PRIOR TO WASTE PLACEMENT

DRAWING II-2

METHANE ENHANCEMENT BY ACCELERATED ANAEROBIC COMPOSTING DEMONSTRATION PROJECT AT THE YOLO COUNTY CENTRAL LANDFILL



FEATURE KEY

- [1] LEVEL 1 INSTRUMENTATION (MOISTURE AND TEMPERATURE)
- [2] LEVEL 2 INSTRUMENTATION (MOISTURE AND TEMPERATURE)
- [2A] LEVEL 2A INSTRUMENTATION (MOISTURE ONLY)
- [3] LEVEL 3 INSTRUMENTATION (MOISTURE AND TEMPERATURE)
- [A] PERFORATED 4" PVC HORIZONTAL GAS EXTRACTION LINE TYPICAL OF 2
- [B] PRESSURE TRANSDUCER FOR LIQUID LEVEL MEASUREMENT, TYPICAL OF 2

YOLO COUNTY CENTRAL LANDFILL
CEC PROJECT

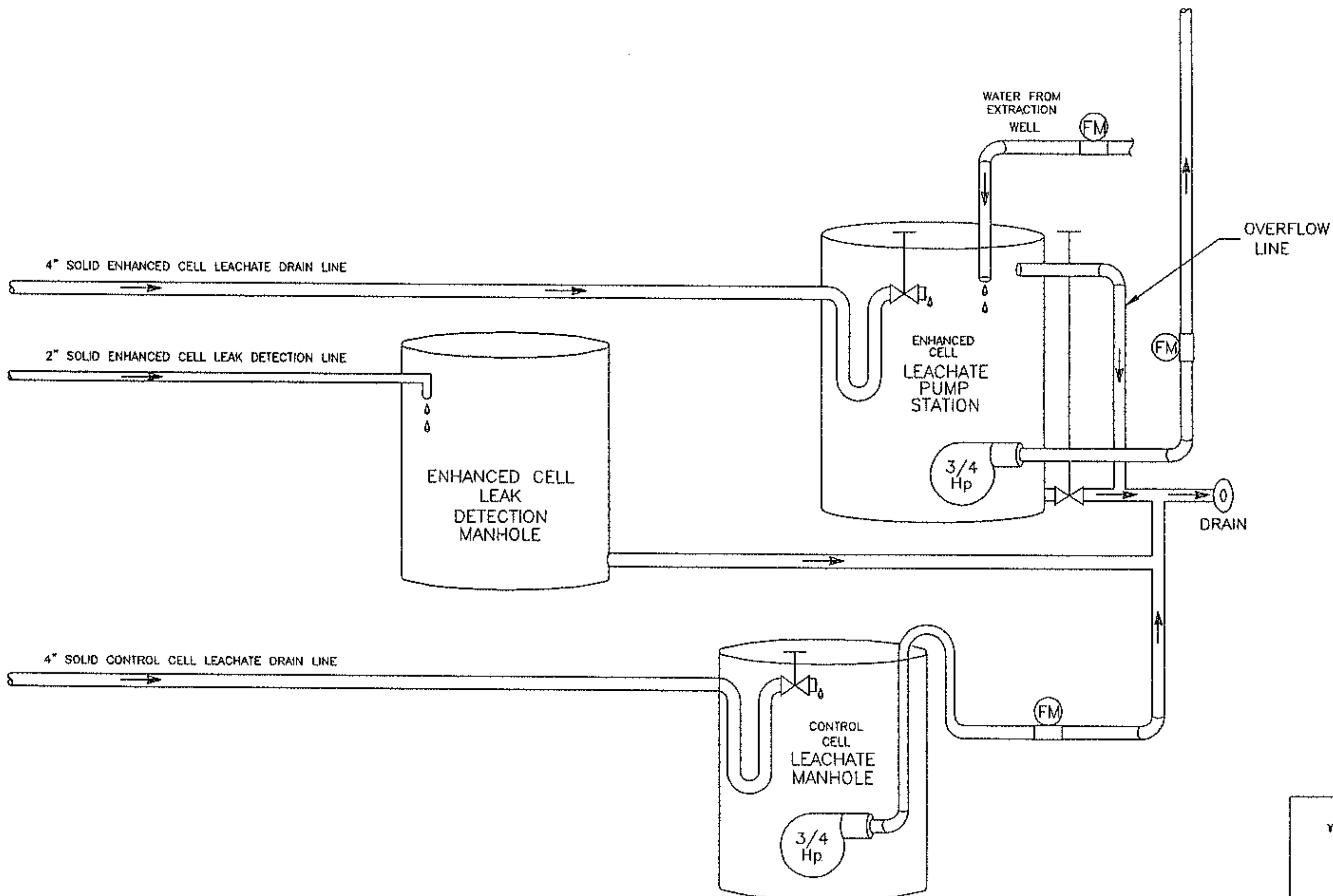
PRINCIPAL SYSTEM COMPONENTS

CUTAWAY VIEW LOOKING NORTH

FILE NAME: ORTHO_2A
DATE: 2/13/97

DRAWING II-3A

CEC METHANE ENHANCEMENT PROJECT
LIQUID RETENTION AND LEAK DETECTION MANHOLES



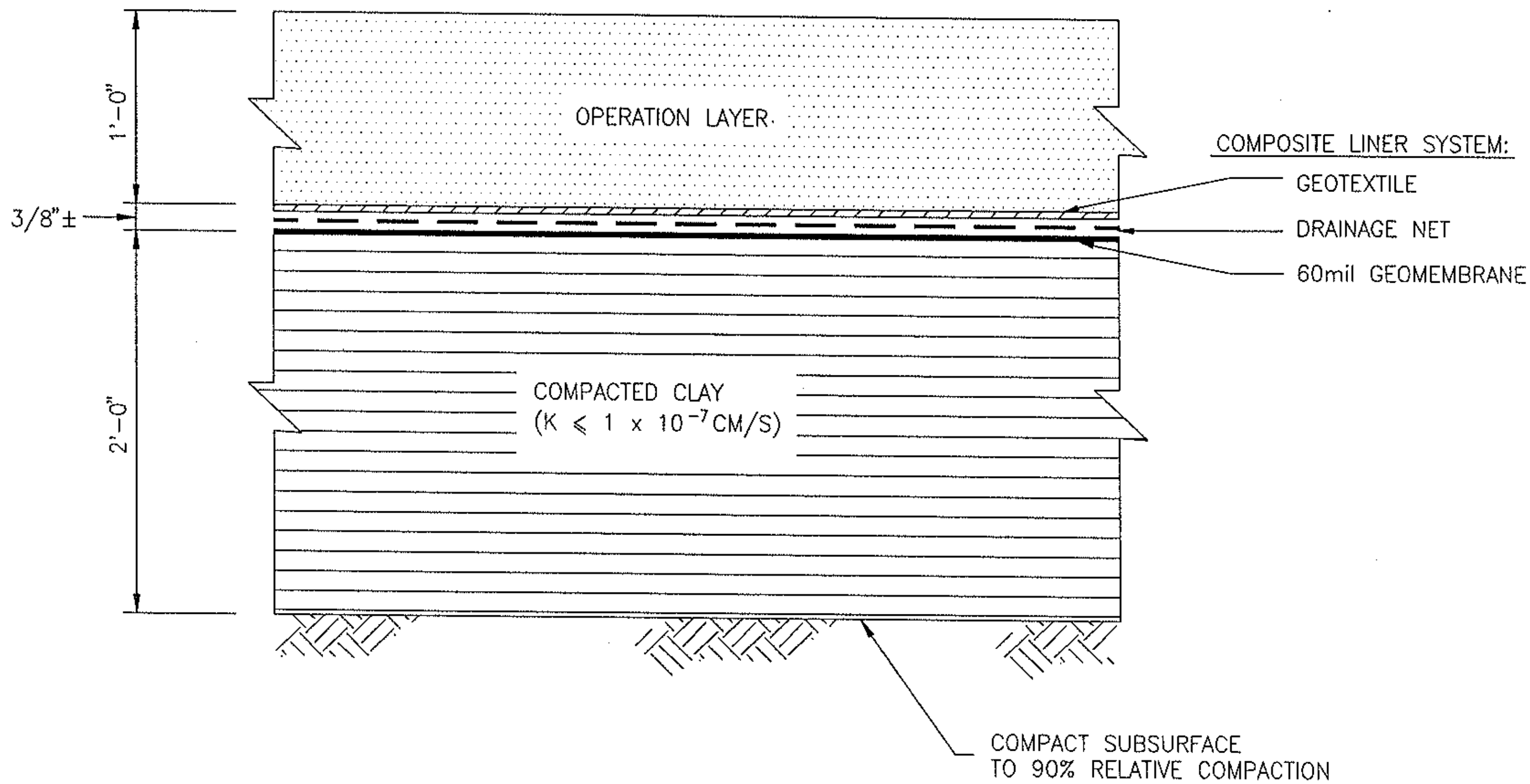
YOLO COUNTY CENTRAL LANDFILL
CEC PROJECT

PRINCIPAL SYSTEM COMPONENTS

CUTAWAY VIEW LOOKING NORTH

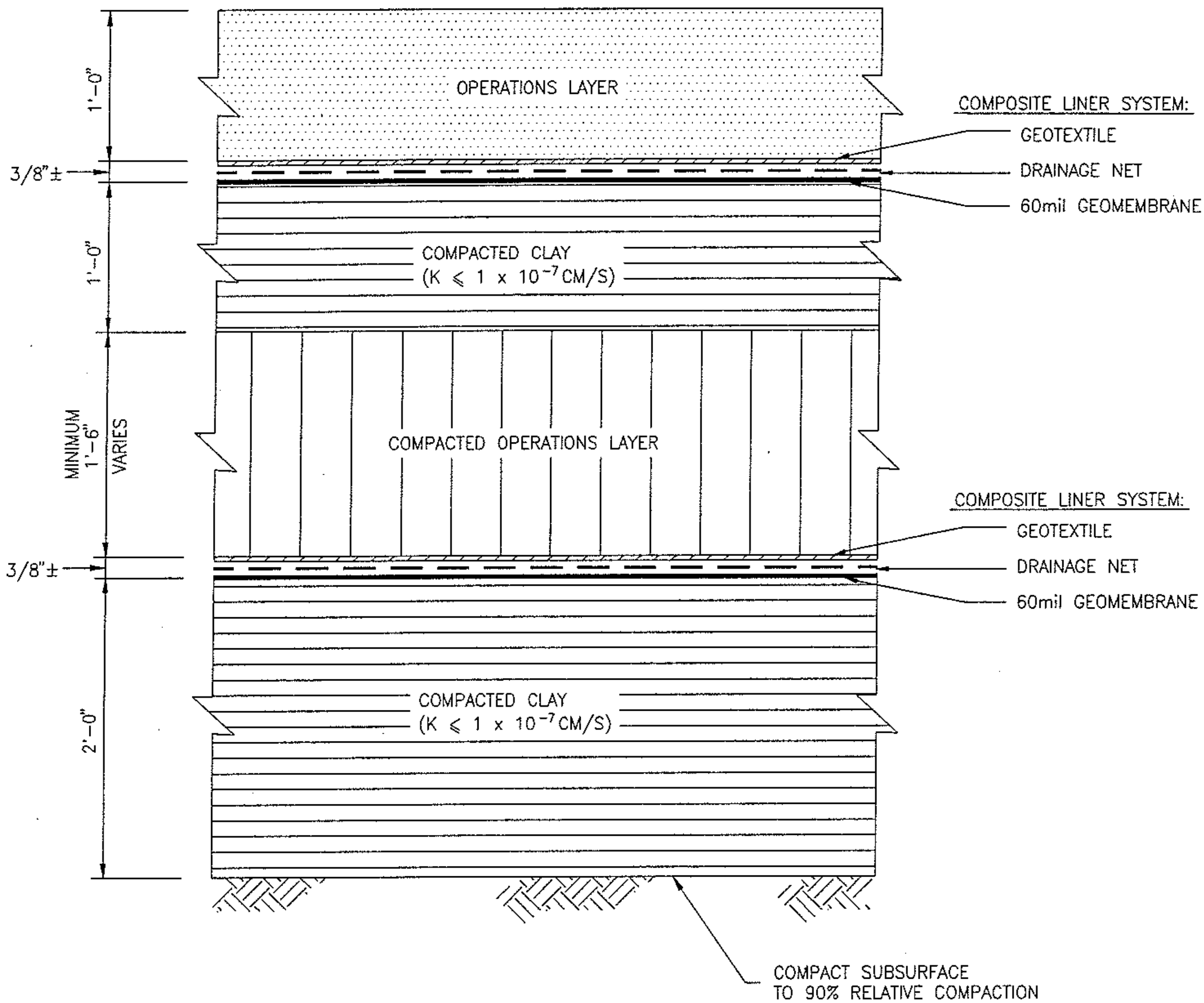
FILE NAME: ORTHO_2B
DATE: 2/13/97

DRAWING II-3B



MODULE B AND CEC CONTROL CELL
COMPOSITE LINER SYSTEM DETAIL

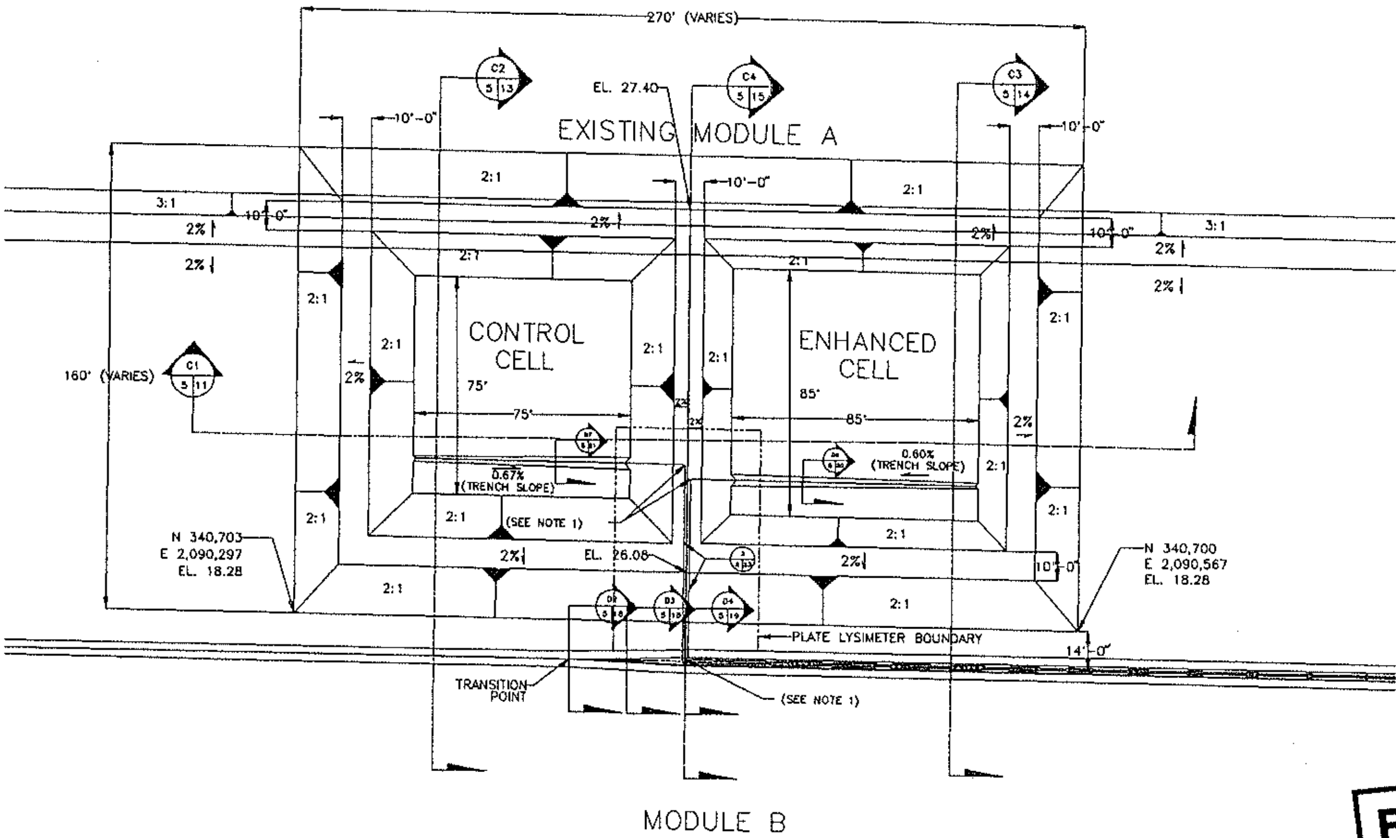
DRAWING II-4



CEC ENHANCED CELL
COMPOSITE LINER SYSTEM DETAIL

SCALE: 1" = 1'-0"

DRAWING II-5



CEC CONTROL AND ENHANCED CELL GRADING PLAN

SCALE: 1" = 20'-0"

NOTES:

1. ALL PIPE BENDS OUTSIDE MANHOLES SHALL BE "LONG SWEEP" BENDS.
2. GRADES SHOWN ARE FINAL GRADES ON TOP OF OPERATIONS LAYER AND COMPACTED FILL. (SEE SHEETS 9 THRU 12 FOR SECTIONS)

YOLO COUNTY DEPARTMENT OF PUBLIC WORKS
292 WEST BEAMER STREET
WOODLAND, CALIFORNIA

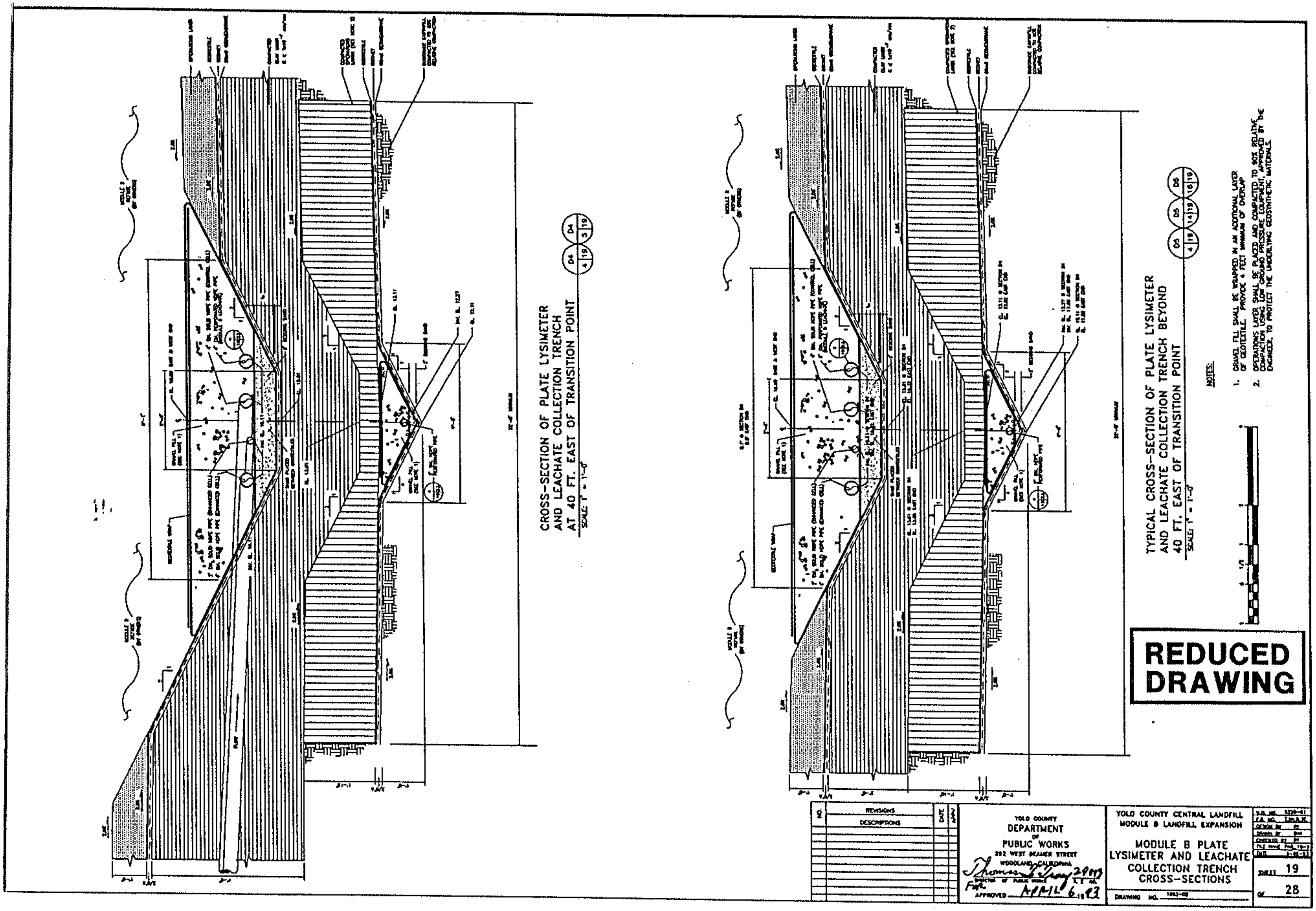
APPROVED APRIL 6, 1993

YOLO COUNTY CENTRAL LANDFILL MODULE B LANDFILL EXPANSION

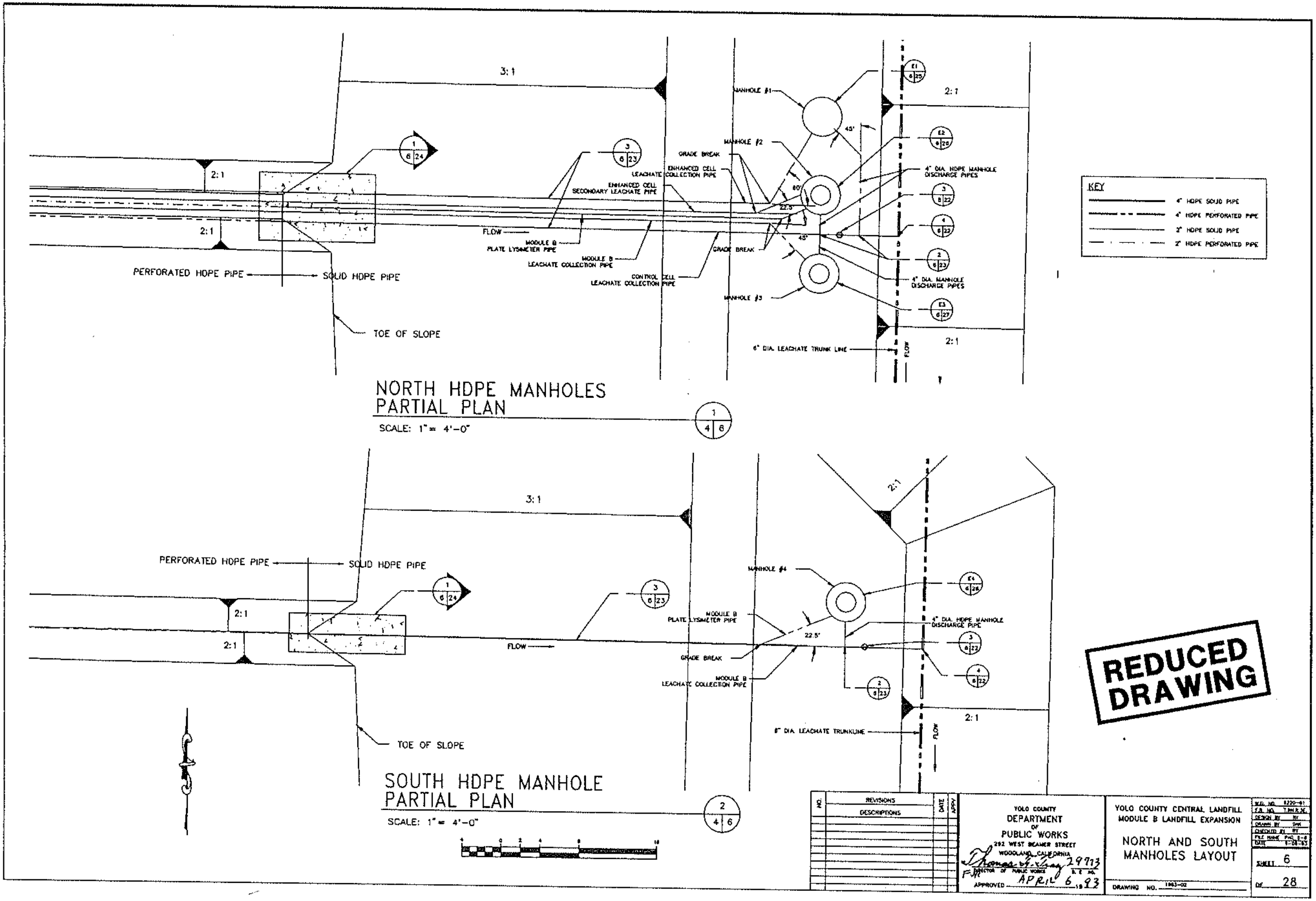
CEC CONTROL AND ENHANCED CELL GRADING PLAN

SHEET 5 OF 28

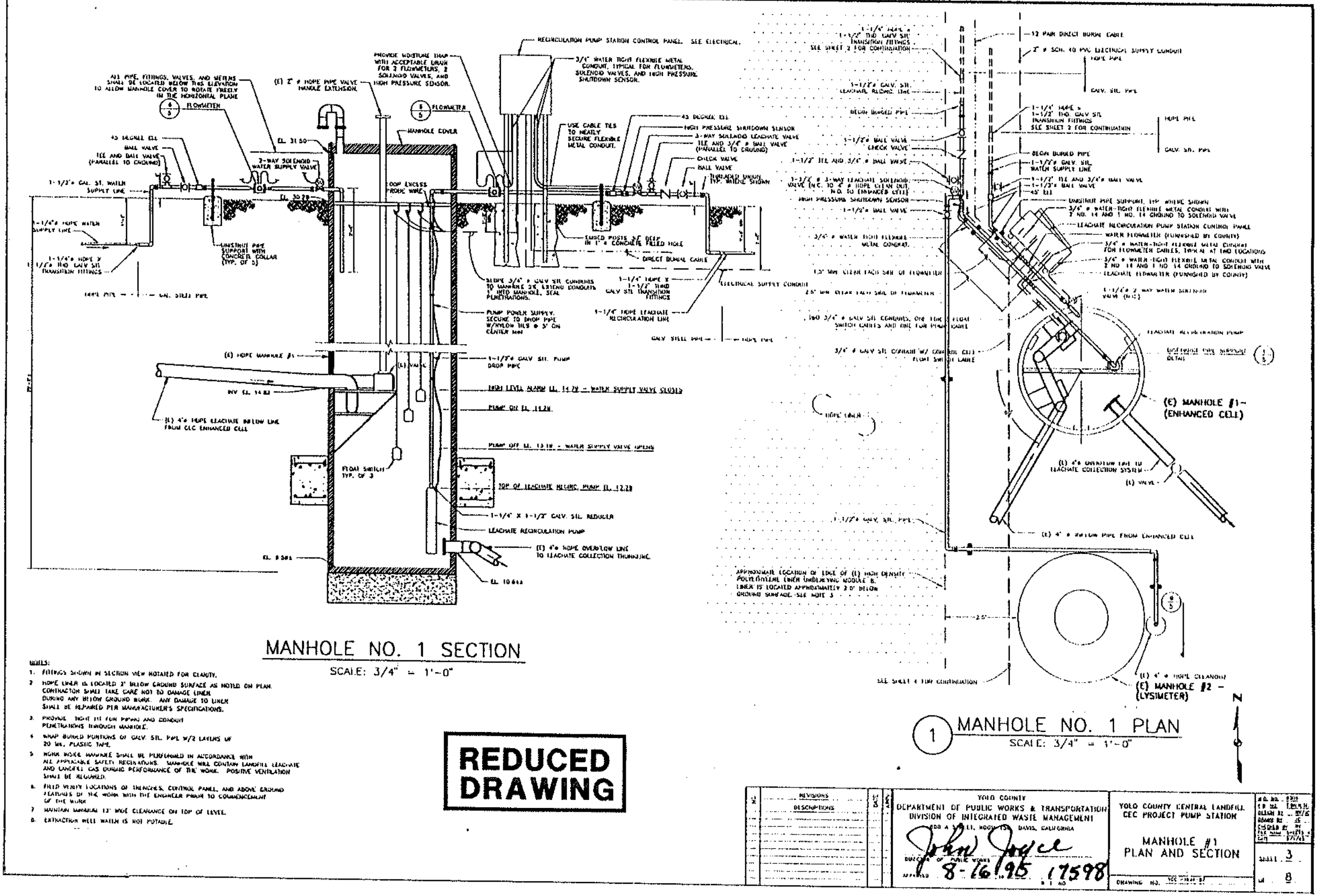
DRAWING II-6


CROSS-SECTION OF PLATE LYSIMETER
AND LEACHATE COLLECTION TRENCH
AT 40 FT. EAST OF TRANSITION POINT
SCALE: 1" = 1'-0"
TYPICAL CROSS-SECTION OF PLATE LYSIMETER
AND LEACHATE COLLECTION TRENCH BEYOND
40 FT. EAST OF TRANSITION POINT
SCALE: 1" = 1'-0"
NOTES:
1. GRAVEL FILL SHALL BE WRAPPED IN AN ADDITIONAL LAYER OF GEOTEXTILE. PROVIDE 4 FEET MINIMUM OF OVERLAP
2. OPERATIONS LAYER SHALL BE PLACED AND COMPACTED TO 90% RELATIVE COMPACTION USING LOW GROUND PRESSURE EQUIPMENT, APPROVED BY THE ENGINEER, TO PROTECT THE UNDERLYING GEOSYNTHETIC MATERIALS.
REDUCED DRAWING
REVISIONS
DESCRIPTIONS
NO.
DATE
APPV
YOLO COUNTY
DEPARTMENT OF PUBLIC WORKS
292 WEST BEAMER STREET
WOODLAND, CALIFORNIA
APPROVED APRIL 6, 1993
YOLO COUNTY CENTRAL LANDFILL
MODULE B LANDFILL EXPANSION
MODULE B PLATE
LYSIMETER AND LEACHATE
COLLECTION TRENCH
CROSS-SECTIONS
DRAWING NO.
SHEET 19
OF 28

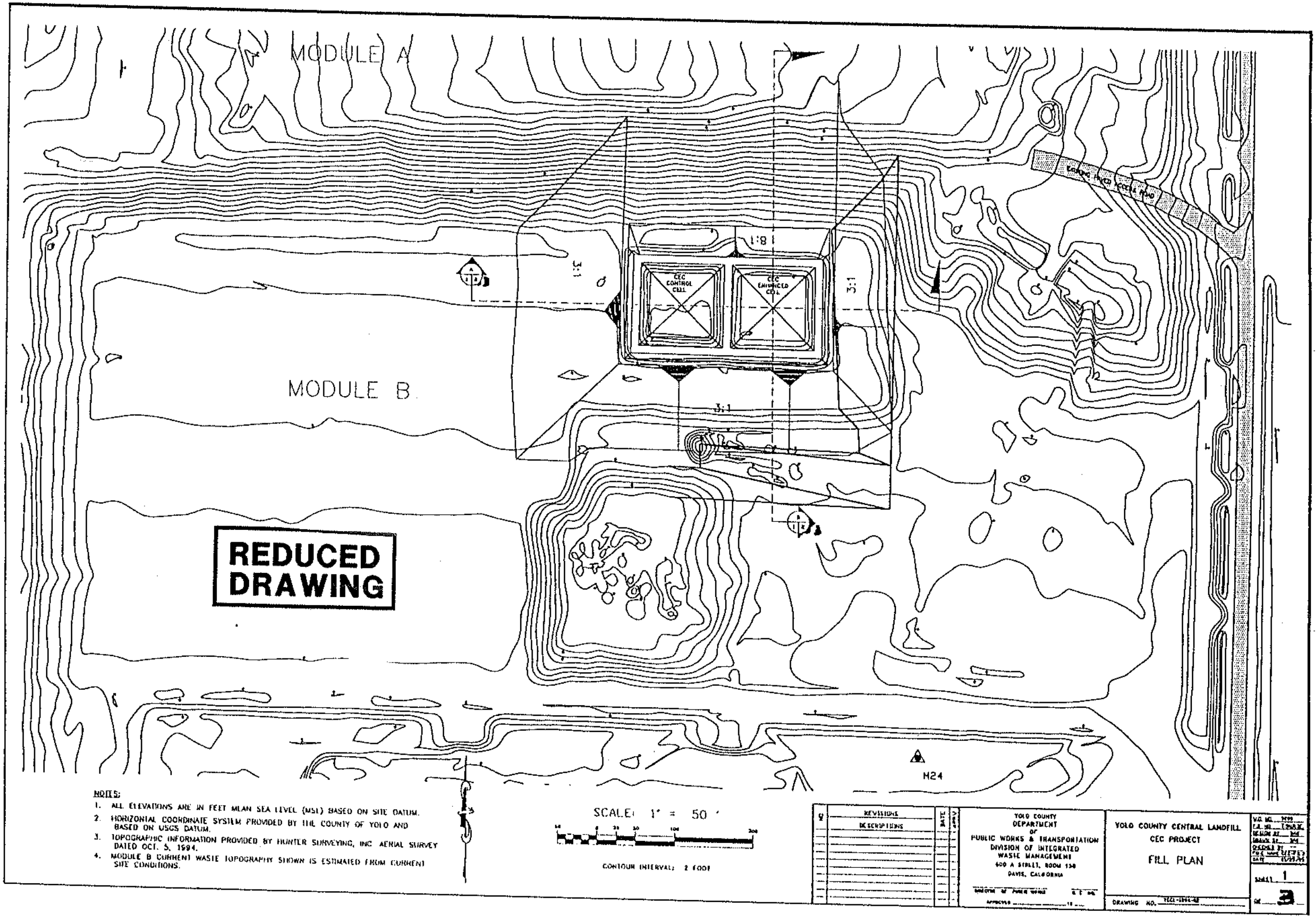
DRAWING II-7


NORTH HDPE MANHOLES PARTIAL PLAN
SCALE: 1" = 4'-0"
SOUTH HDPE MANHOLE PARTIAL PLAN
SCALE: 1" = 4'-0"
KEY
4" HDPE SOLID PIPE
4" HDPE PERFORATED PIPE
2" HDPE SOLID PIPE
2" HDPE PERFORATED PIPE
MANHOLE #1
MANHOLE #2
MANHOLE #3
MANHOLE #4
GRADE BREAK
ENHANCED CELL LEACHATE COLLECTION PIPE
ENHANCED CELL SECONDARY LEACHATE PIPE
MODULE B PLATE LYSIMETER PIPE
MODULE B LEACHATE COLLECTION PIPE
CONTROL CELL LEACHATE COLLECTION PIPE
4" DIA. HDPE MANHOLE DISCHARGE PIPES
4" DIA. MANHOLE DISCHARGE PIPES
4" DIA. HDPE MANHOLE DISCHARGE PIPE
6" DIA. LEACHATE TRUNK LINE
8" DIA. LEACHATE TRUNKLINE
PERFORATED HDPE PIPE
SOLID HDPE PIPE
TOE OF SLOPE
FLOW
3:1
2:1
REDUCED DRAWING
REVISIONS
NO.
DESCRIPTIONS
DATE
APPV
YOLO COUNTY DEPARTMENT OF PUBLIC WORKS
292 WEST BEAMER STREET
WOODLAND, CALIFORNIA
DIRECTOR OF PUBLIC WORKS
APPROVED APRIL 6, 1993
YOLO COUNTY CENTRAL LANDFILL
MODULE B LANDFILL EXPANSION
NORTH AND SOUTH MANHOLES LAYOUT
SHEET 6
OF 28

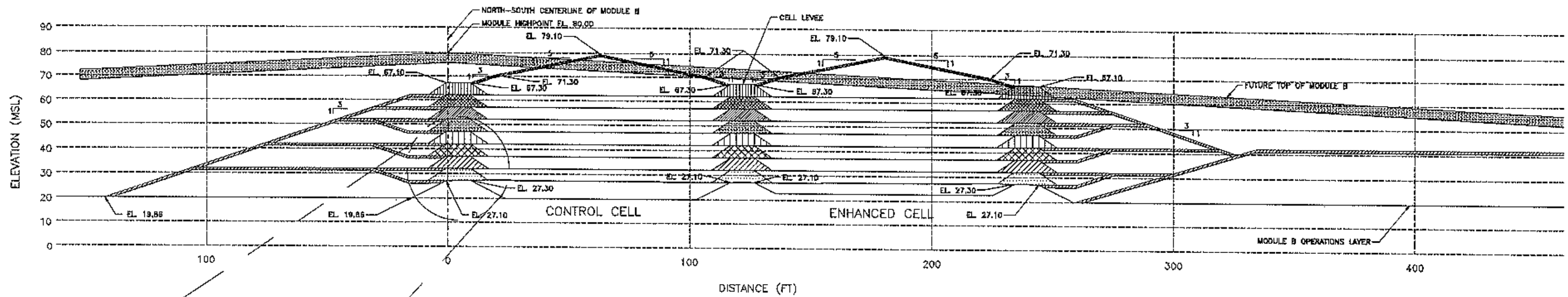
DRAWING II-8

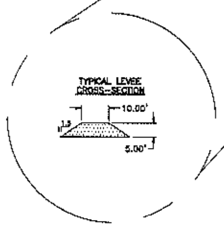

MANHOLE NO. 1 SECTION
SCALE: 3/4" = 1'-0"
MANHOLE NO. 1 PLAN
SCALE: 3/4" = 1'-0"
(E) MANHOLE #1-
(ENHANCED CELL)
(E) MANHOLE #2 -
(LYSIMETER)
N
REDUCED
DRAWING
NOTES:
1. FITTINGS SHOWN IN SECTION VIEW ROTATED FOR CLARITY.
7. MAINTAIN MINIMUM 12" WIDE CLEARANCE ON TOP OF LEVEL.
8. EXTRACTION WELL WATER IS NOT POTABLE.
YOLO COUNTY
DEPARTMENT OF PUBLIC WORKS & TRANSPORTATION
DIVISION OF INTEGRATED WASTE MANAGEMENT
DAVIS, CALIFORNIA
8-16-95
17598
YOLO COUNTY CENTRAL LANDFILL
CEC PROJECT PUMP STATION
MANHOLE #1
PLAN AND SECTION
SHEET 3
OF 8

DRAWING II-9



DRAWING II-10

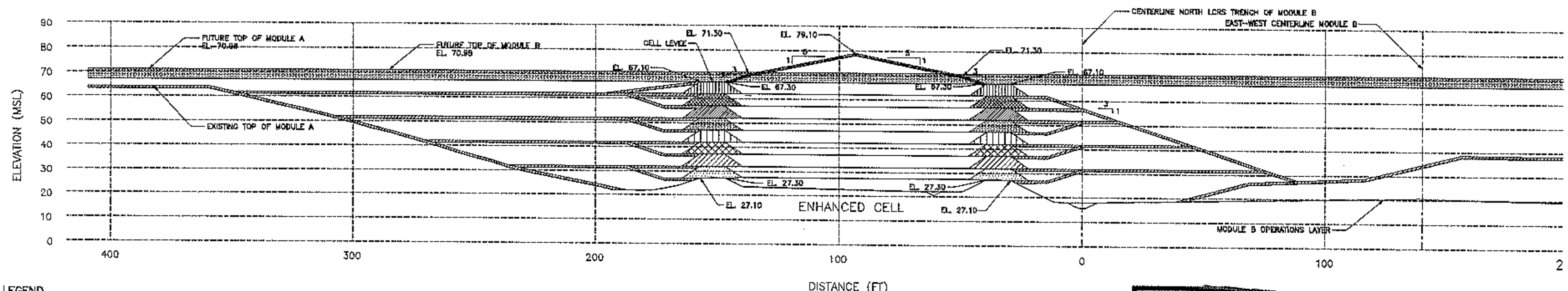




TYPICAL CROSS-SECTION
THROUGH CEC CELLS

SCALE: 1" = 20'

A 1|2



TYPICAL CROSS-SECTION
THROUGH ENHANCED CELL

SCALE: 1" = 20'

B 1|2

LEGEND

PHASE	SYMBOL	START DATE	COMPLETION DATE
PHASE 1		MARCH 20, 1995	MARCH 26, 1995
PHASE 2		MAY 16, 1995	MAY 20, 1995
PHASE 3		JUNE 2, 1995	JUNE 7, 1995
PHASE 4		JUNE 28, 1995	JUNE 30, 1995
PHASE 5		JULY 13, 1995	JULY 18, 1995
PHASE 6		AUGUST 1, 1995	AUGUST 5, 1995
PHASE 7		AUGUST 17, 1995	AUGUST 22, 1995
PHASE 8		AUGUST 31, 1995	SEPTEMBER 5, 1995

COVER SOIL (BY OTHERS)

NOTES

1. THE TOP OF MODULE B IS SHOWN WITH 4 FT. OF FINAL COVER.
2. THE TOP OF MODULE B IS ASSUMED TO NOT EXCEED 80 FT MSL.
3. PHASES OF LEVEE CONSTRUCTION ARE TO TAKE PLACE DURING BREAKS IN WASTE LIFT FILLING.
4. NO SOIL COVER WILL BE PLACED OVER WASTE LIFTS WITHIN THE CEC CELLS.

20 0 10 20 40 80

REDUCED DRAWING

NO.	REVISIONS DESCRIPTIONS	DATE	APPV

YOLO COUNTY
DEPARTMENT OF PUBLIC WORKS
292 WEST BEAMER STREET
WOODLAND, CALIFORNIA

DIRECTOR OF PUBLIC WORKS R.E. NO.
APPROVED ______ 19__

YOLO COUNTY CENTRAL LANDFILL
CEC PROJECT

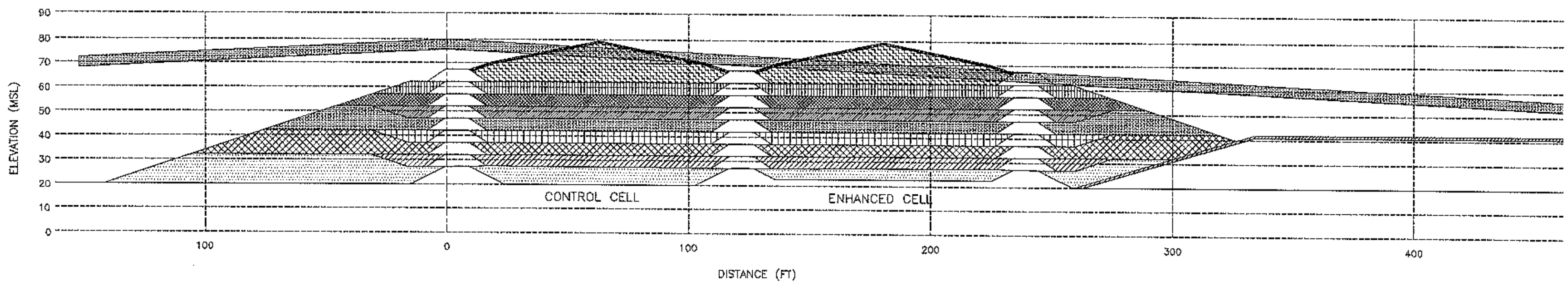
CROSS SECTIONS
LEVEE CONSTRUCTION
5 FOOT LIFTS

DRAWING NO. YCCL-1994-02

W.O. NO. 9659
F.B. NO. T.94R3C
DESIGN BY DAK
DRAWN BY DAK
CHECKED BY --
FILE NAME CEC-FLX3
DATE 01/09/95

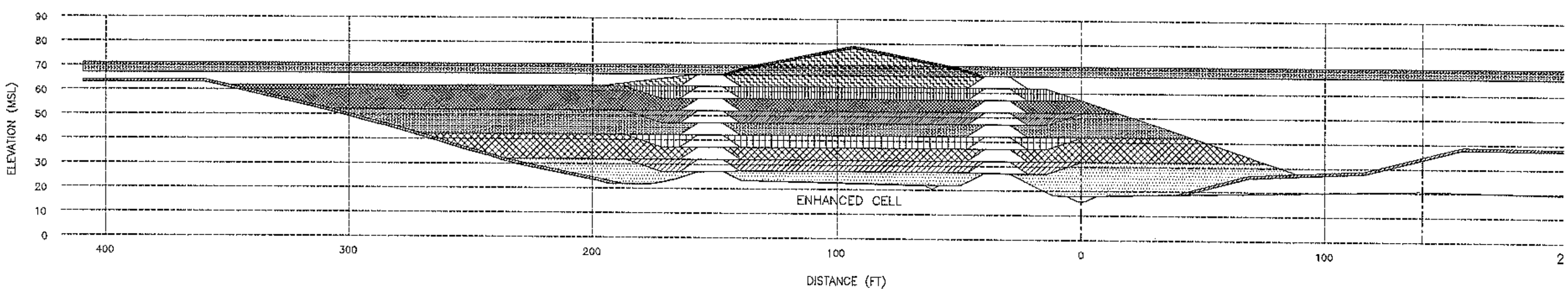
SHEET 2 OF 3

DRAWING II-11



TYPICAL CROSS-SECTION
THROUGH CEC CELLS
SCALE: 1" = 20'

A 1 2



TYPICAL CROSS-SECTION
THROUGH ENHANCED CELL
SCALE: 1" = 20'

B 1 2

LEGEND

PHASE	SYMBOL	START DATE	COMPLETION DATE	ESTIMATED DAYS TO FILL
PHASE 1		FEBRUARY 24, 1995	APRIL 14, 1995	32
PHASE 2		APRIL 26, 1995	MAY 3, 1995	7
PHASE 3		MAY 4, 1995	JUNE 1, 1995	25
PHASE 4		JUNE 8, 1995	JUNE 15, 1995	7
PHASE 5		JUNE 2, 1995	JULY 12, 1995	27
PHASE 6		JULY 19, 1995	JULY 26, 1995	7
PHASE 7		JULY 13, 1995	AUGUST 16, 1995	25
PHASE 8		AUGUST 23, 1995	AUGUST 30, 1995	7
PHASE 9		SEPTEMBER 5, 1995	SEPTEMBER 15, 1995	9

NOTES

1. THE TOP OF MODULE B IS SHOWN WITH 4 FT. OF FINAL COVER.
2. THE TOP OF MODULE B IS ASSUMED TO NOT EXCEED 80 FT MSL.
3. PHASES OF LEVEE CONSTRUCTION ARE TO TAKE PLACE DURING BREAKS IN WASTE LIFT FILLING.
4. NO SOIL COVER WILL BE PLACED OVER WASTE LIFTS WITHIN THE CEC CELLS.

REDUCED DRAWING

NO.	REVISIONS DESCRIPTIONS	DATE	APPV

YOLO COUNTY
DEPARTMENT
OF
PUBLIC WORKS
292 WEST BEAMER STREET
WOODLAND, CALIFORNIA

DIRECTOR OF PUBLIC WORKS R. E. NO.

APPROVED ______ 19 ____

YOLO COUNTY CENTRAL LANDFILL
CEC PROJECT

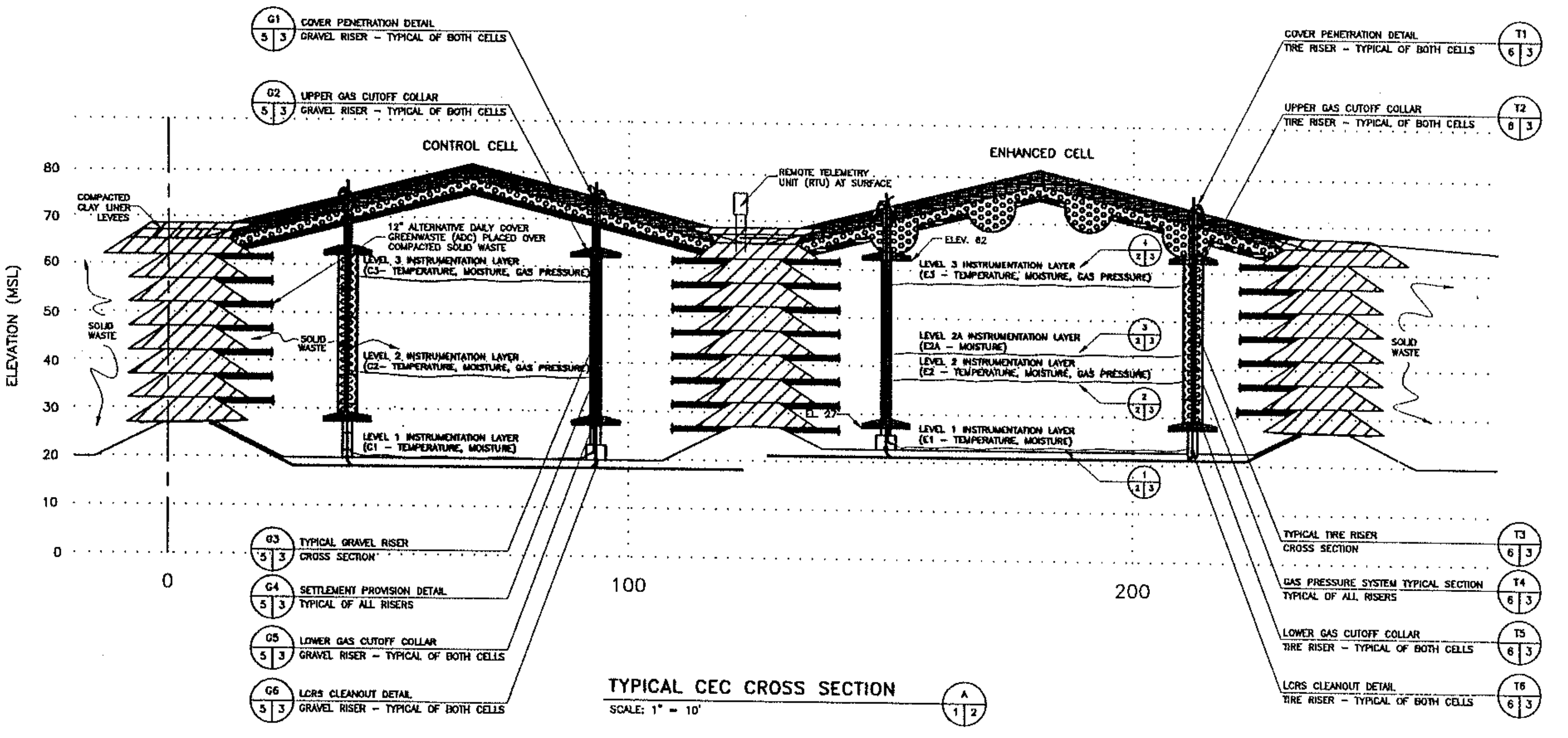
CROSS SECTIONS
FILLING SEQUENCE
5 FOOT LIFTS

DRAWING NO. YCCL-1994-02

W.O. NO. 9809
F.B. NO. T.9N.R.3E.
DESIGN BY DAK
DRAWN BY DAK
CHECKED BY —
FILE NAME CEC_FLIO
DATE 01/12/95

SHEET 3
OF 3

DRAWING II-12



TYPICAL CEC CROSS SECTION

SCALE: 1" = 10'

A 1 2

REDUCED DRAWING

SCALE: 1" = 10'

NO.	REVISIONS DESCRIPTIONS	DATE	APP'V

YOLO COUNTY
DEPARTMENT OF PUBLIC WORKS & TRANSPORTATION
DIVISION OF INTEGRATED WASTE MANAGEMENT
500 A STREET, ROOM 158 DAVIS, CALIFORNIA

DIRECTOR OF PUBLIC WORKS

APPROVED ____ 19 ____ R. E. NO.

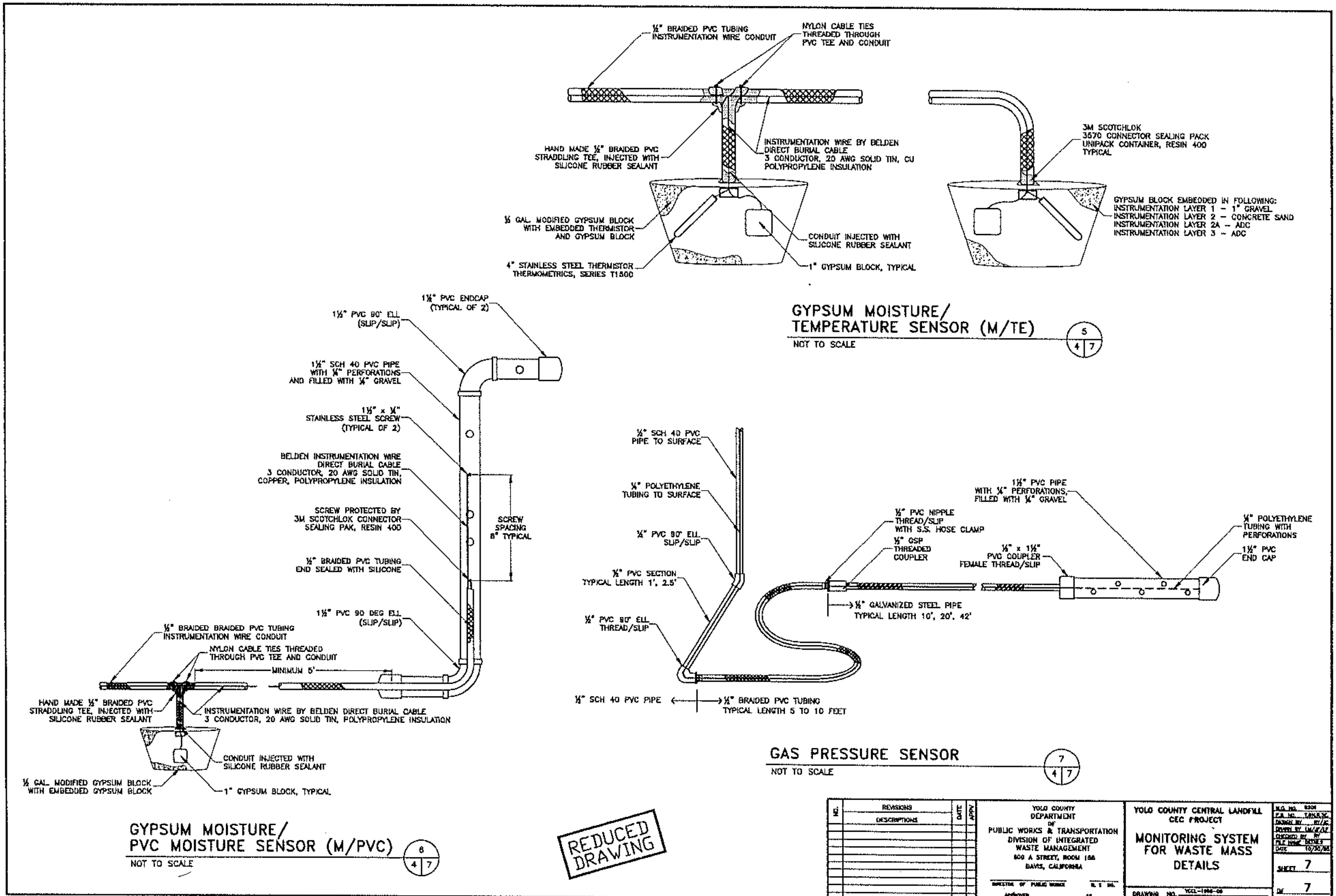
YOLO COUNTY CENTRAL LANDFILL
CEC CELLS

MONITORING SYSTEM FOR WASTE MASS

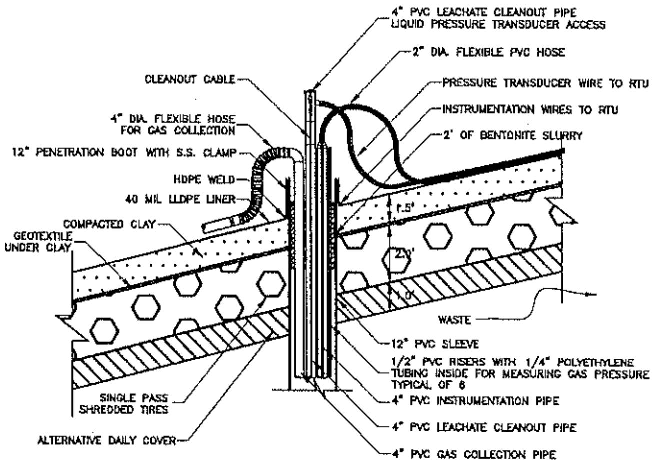
CROSS SECTION

SHEET 3 OF 7

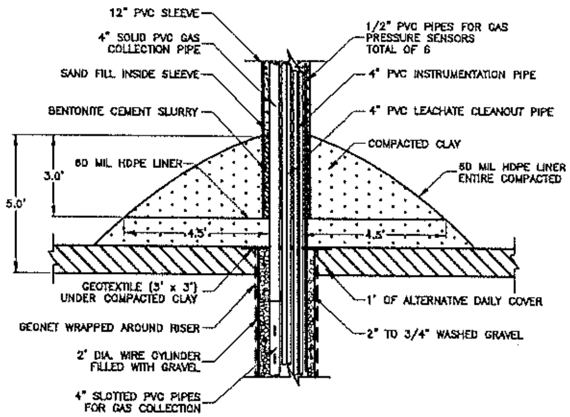
DRAWING II-13



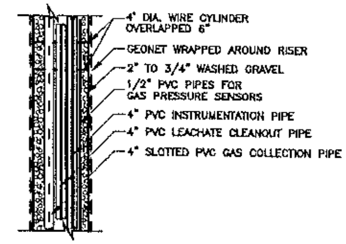
DRAWING II-14



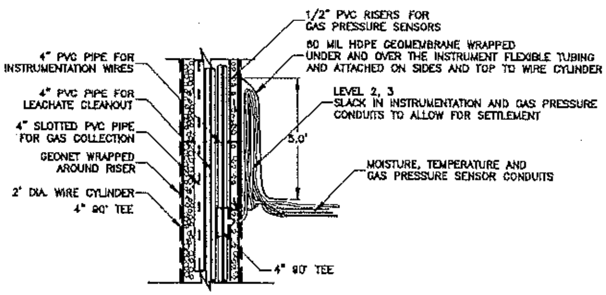
COVER PENETRATION DETAIL
NOT TO SCALE
G1 3|5



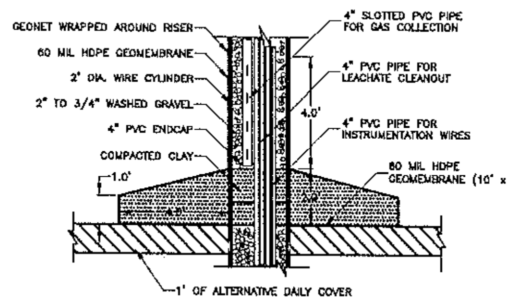
UPPER GAS CUTOFF COLLAR
NOT TO SCALE
G2 3|5



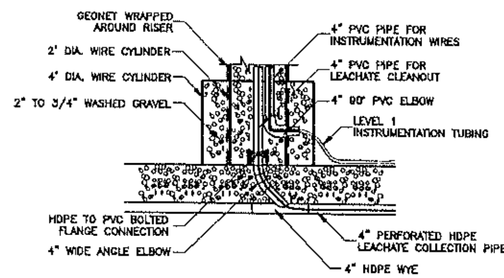
TYPICAL GRAVEL RISER CROSS SECTION
NOT TO SCALE
G3 3|5



SETTLEMENT PROVISION DETAIL
NOT TO SCALE
G4 3|5



LOWER GAS CUTOFF COLLAR
NOT TO SCALE
G5 3|5



LCRS CLEANOUT DETAIL
NOT TO SCALE
G6 3|5

REDUCED DRAWING

NO.	REVISIONS DESCRIPTIONS	DATE	APPV

YOLO COUNTY
DEPARTMENT OF PUBLIC WORKS & TRANSPORTATION
DIVISION OF INTEGRATED WASTE MANAGEMENT
300 A STREET, ROOM 188 DAVIS, CALIFORNIA

DIRECTOR OF PUBLIC WORKS

APPROVED ____ 19 ____ R. E. NO.

YOLO COUNTY CENTRAL LANDFILL
CEC CELLS

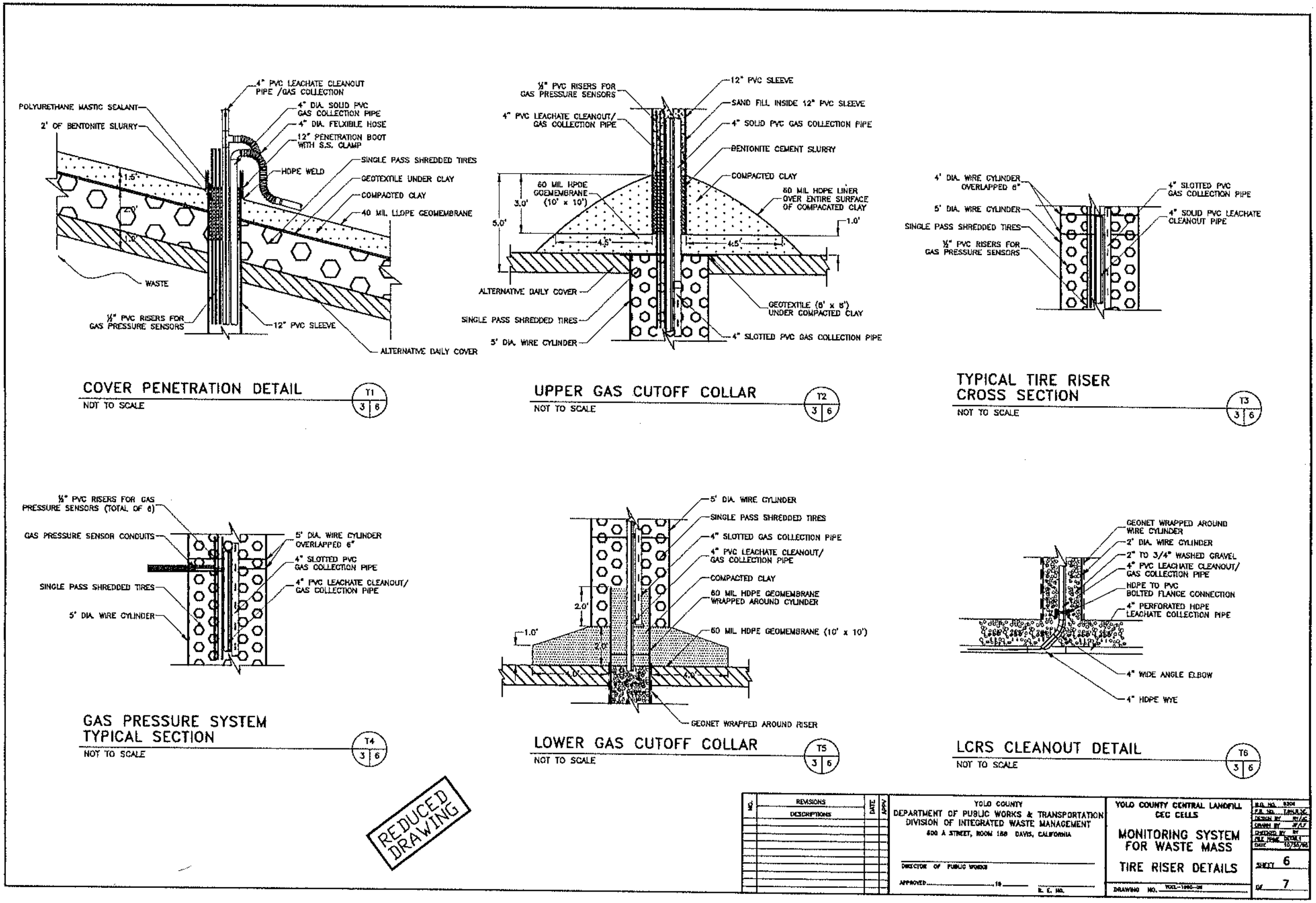
MONITORING SYSTEM FOR WASTE MASS

GRAVEL RISER DETAILS

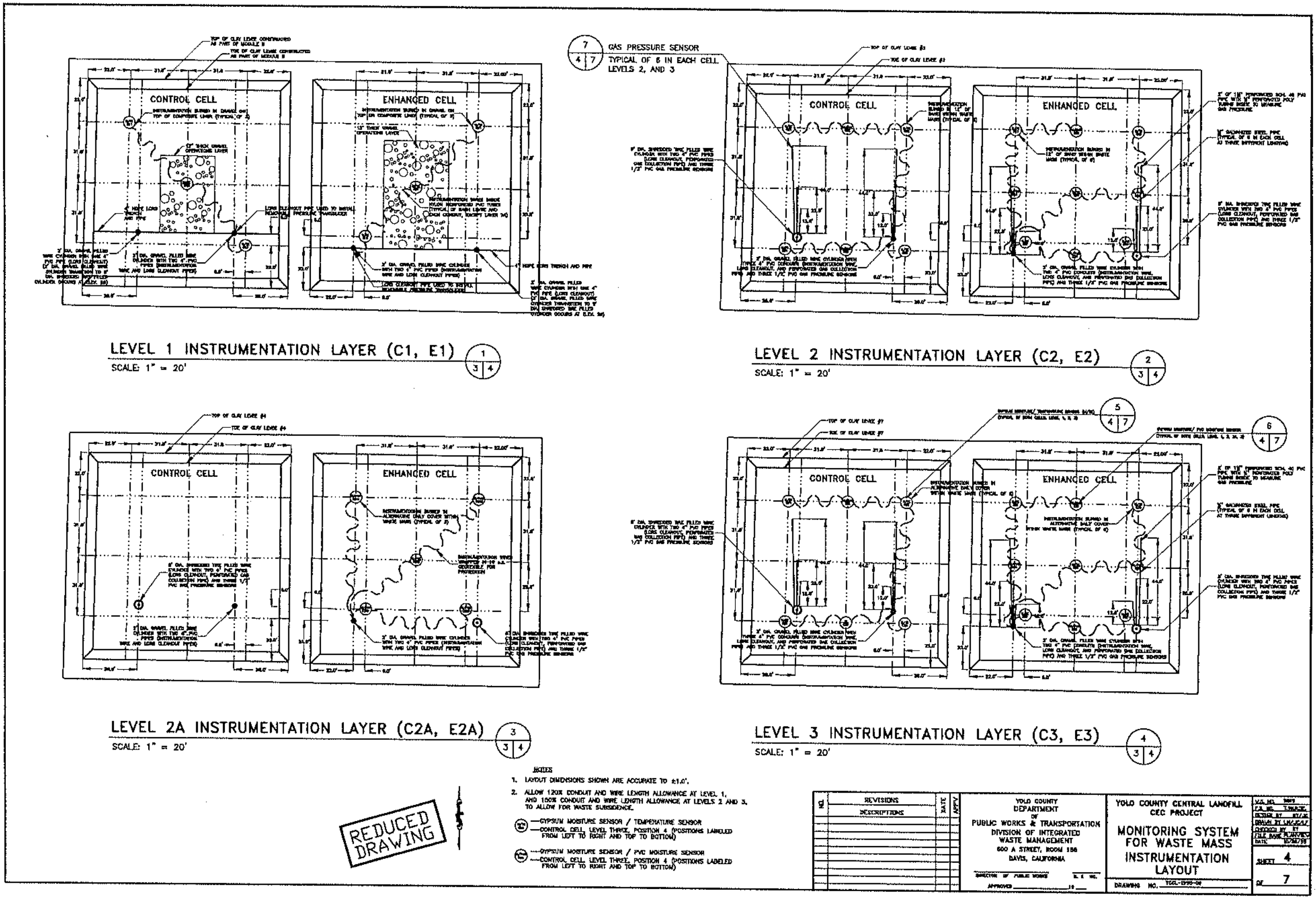
DRAWING NO. YOCL-1996-06

SHEET 5 OF 7

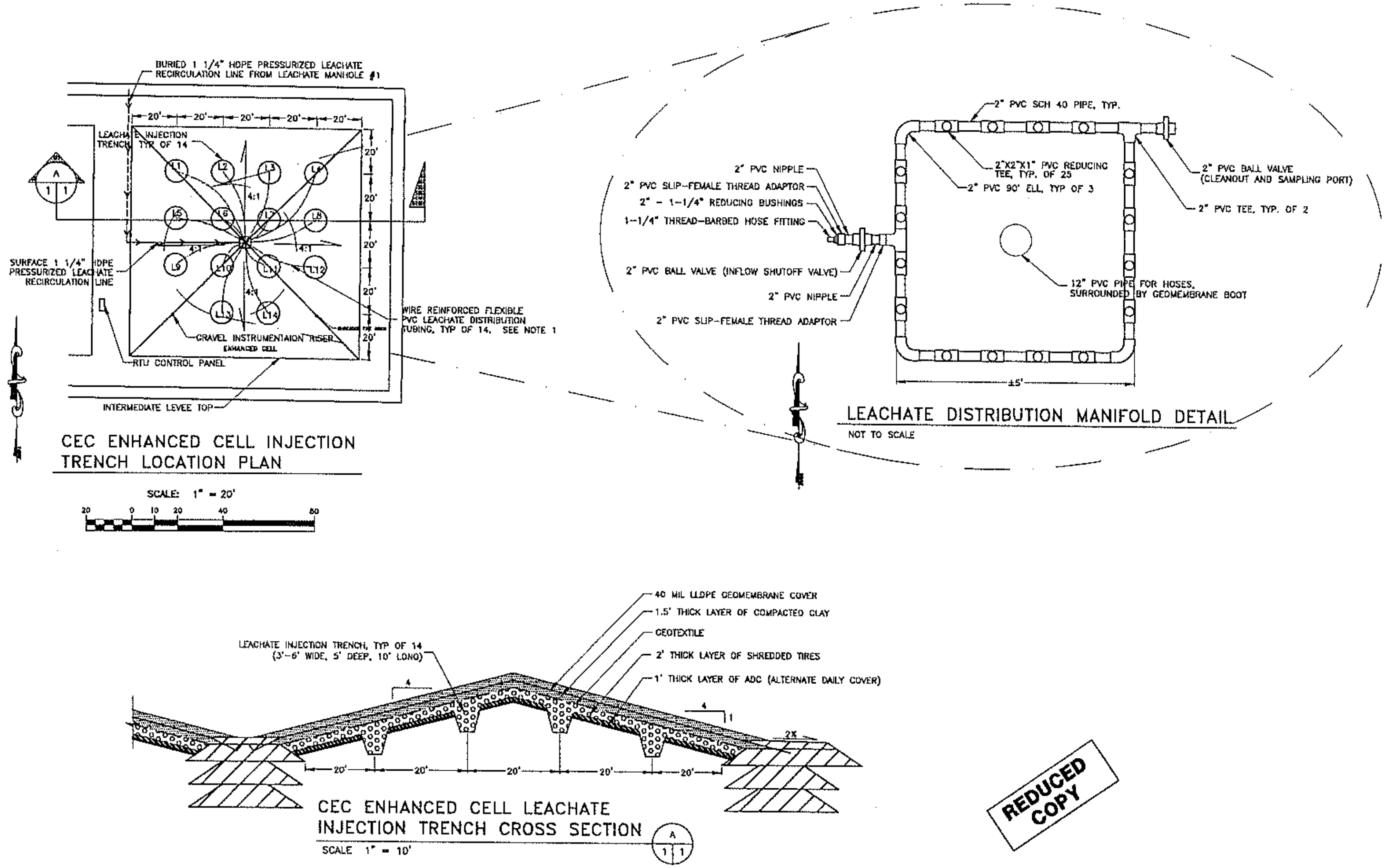
DRAWING II-15



DRAWING II-16



DRAWING II-17



NOTES:

1. LEACHATE DISTRIBUTION TUBING SHALL BE PLACED IN A "SNAKE LIKE" MANNER SUCH THAT THERE IS 13' OF TUBING FOR EVERY 10' OF DISTANCE.

NO.	REVISIONS DESCRIPTIONS	DATE	APPV

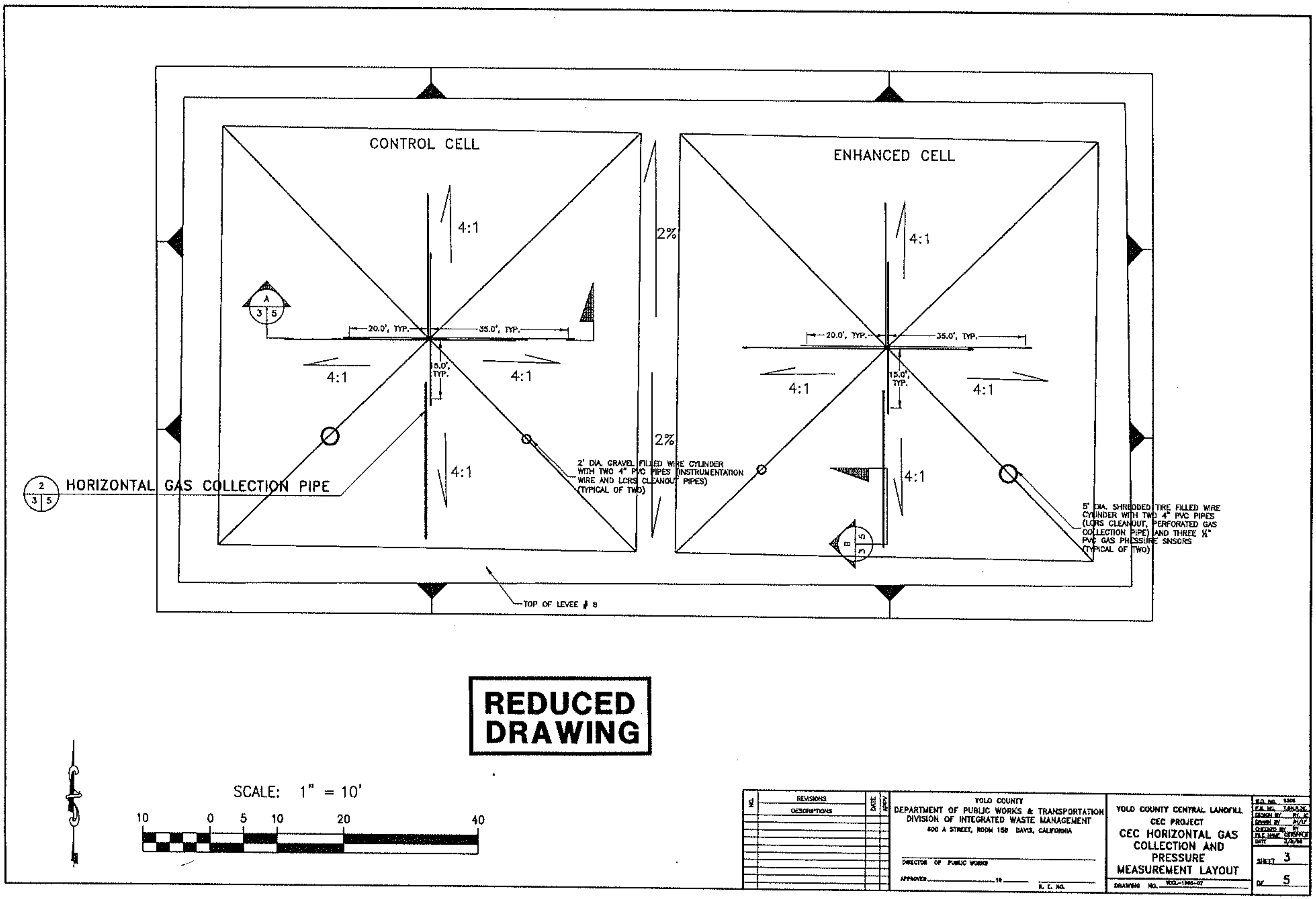
YOLO COUNTY DEPARTMENT OF PUBLIC WORKS & TRANSPORTATION DIVISION OF INTEGRATED WASTE MANAGEMENT 600 A STREET, ROOM 150 DAVIS, CALIFORNIA

YOLO COUNTY CENTRAL LANDFILL
CEC PROJECT

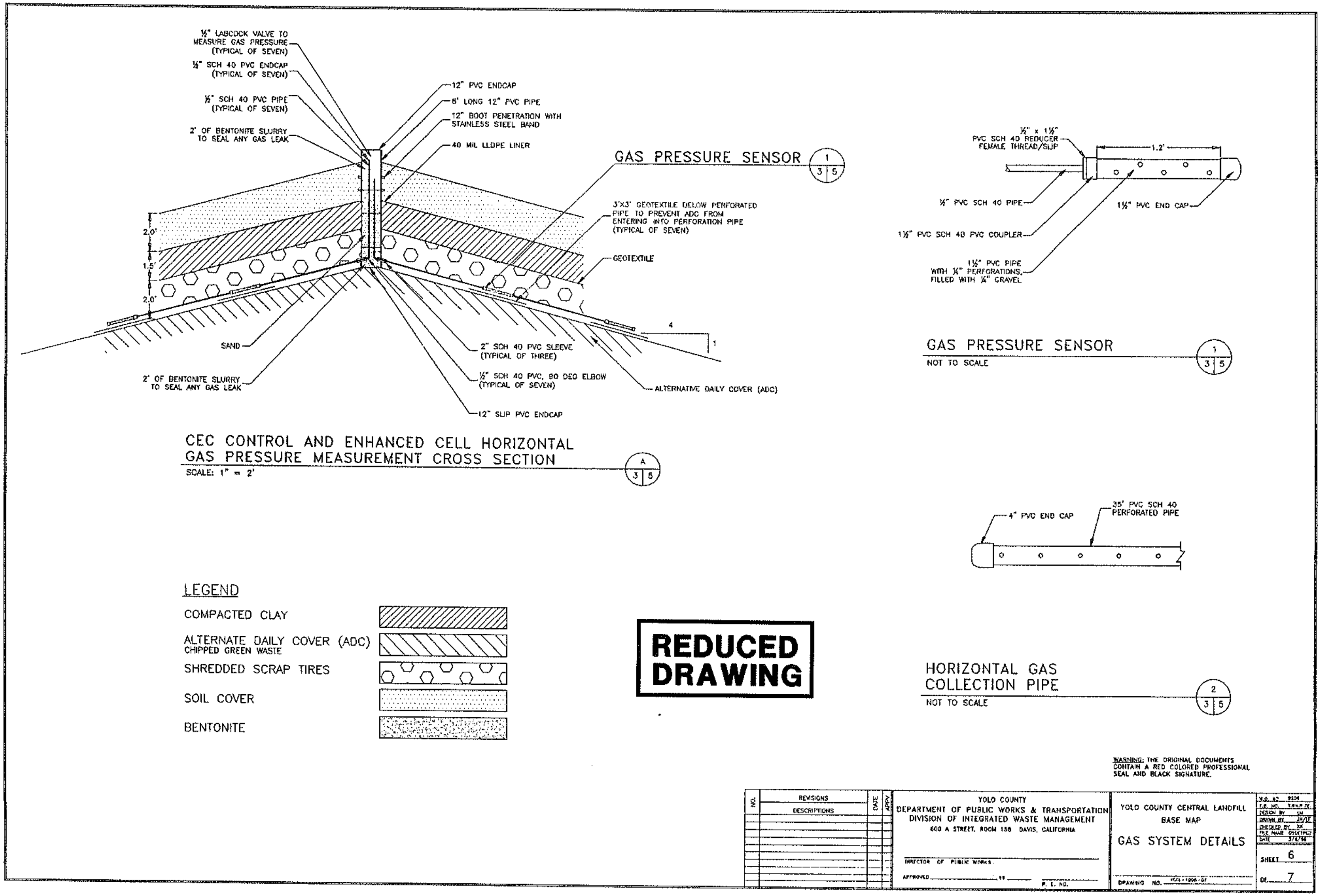
CEC ENHANCED CELL LEACHATE INJECTION SYSTEM

SHEET 1 OF 1

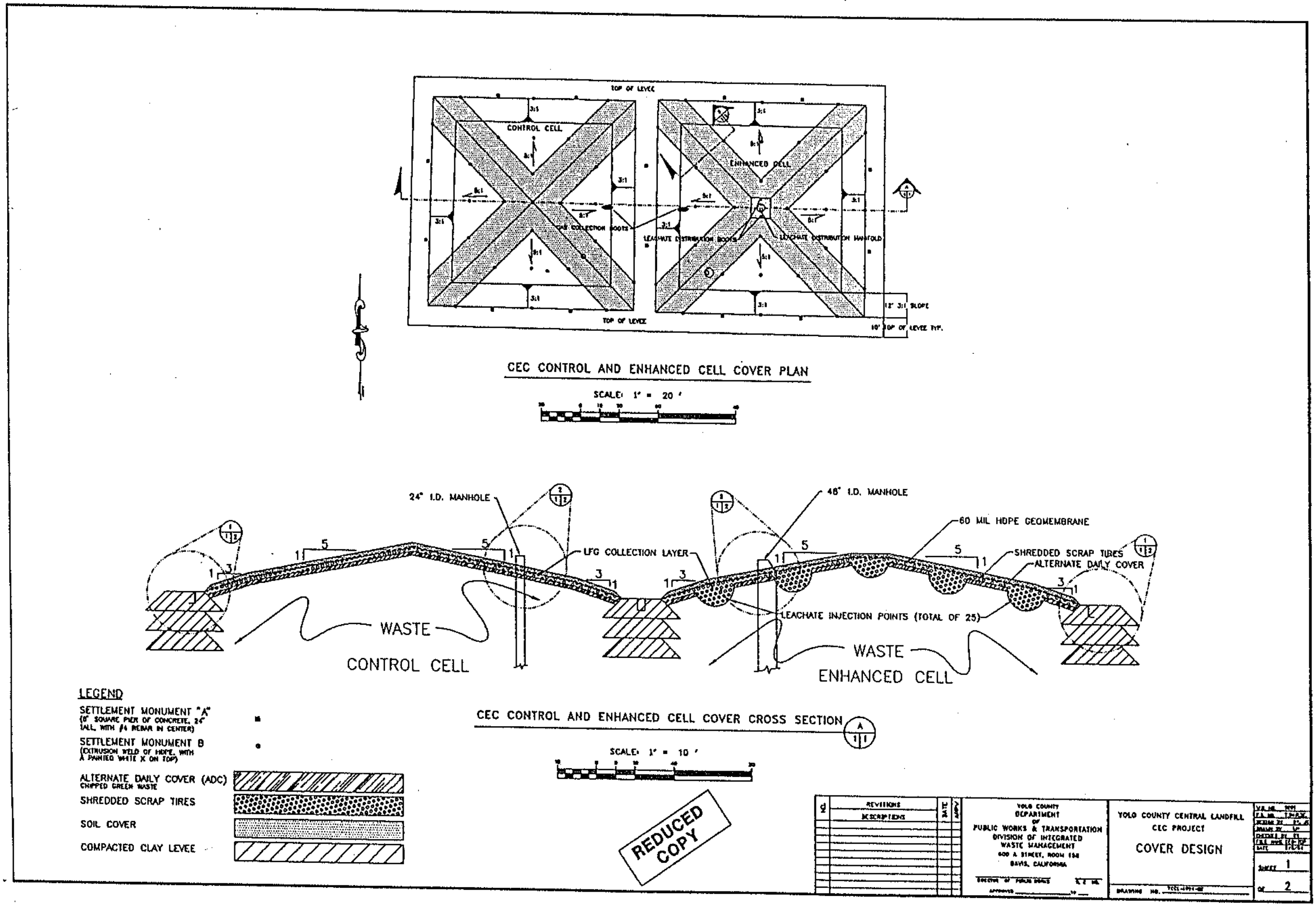
DRAWING II-18



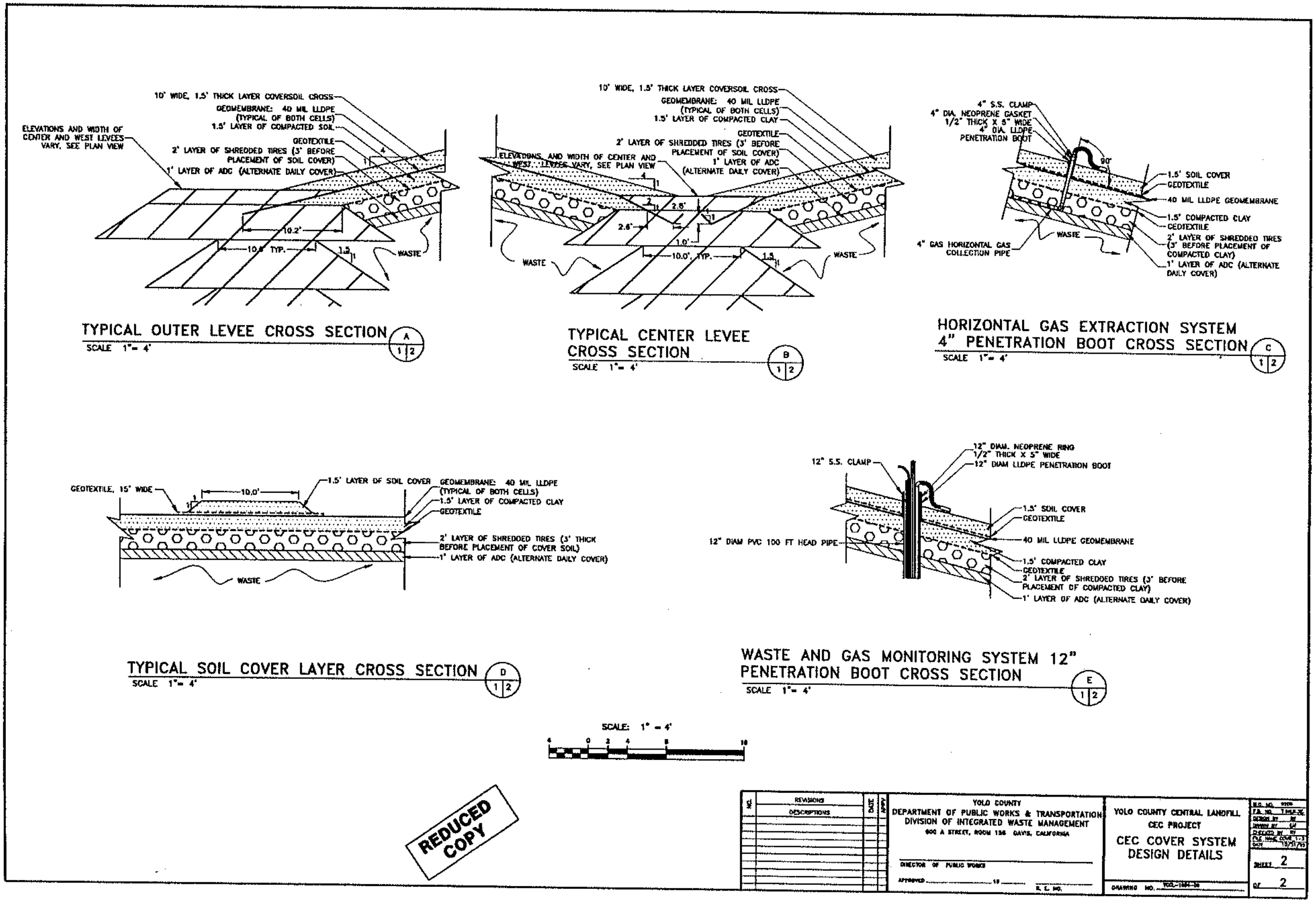
DRAWING II-19



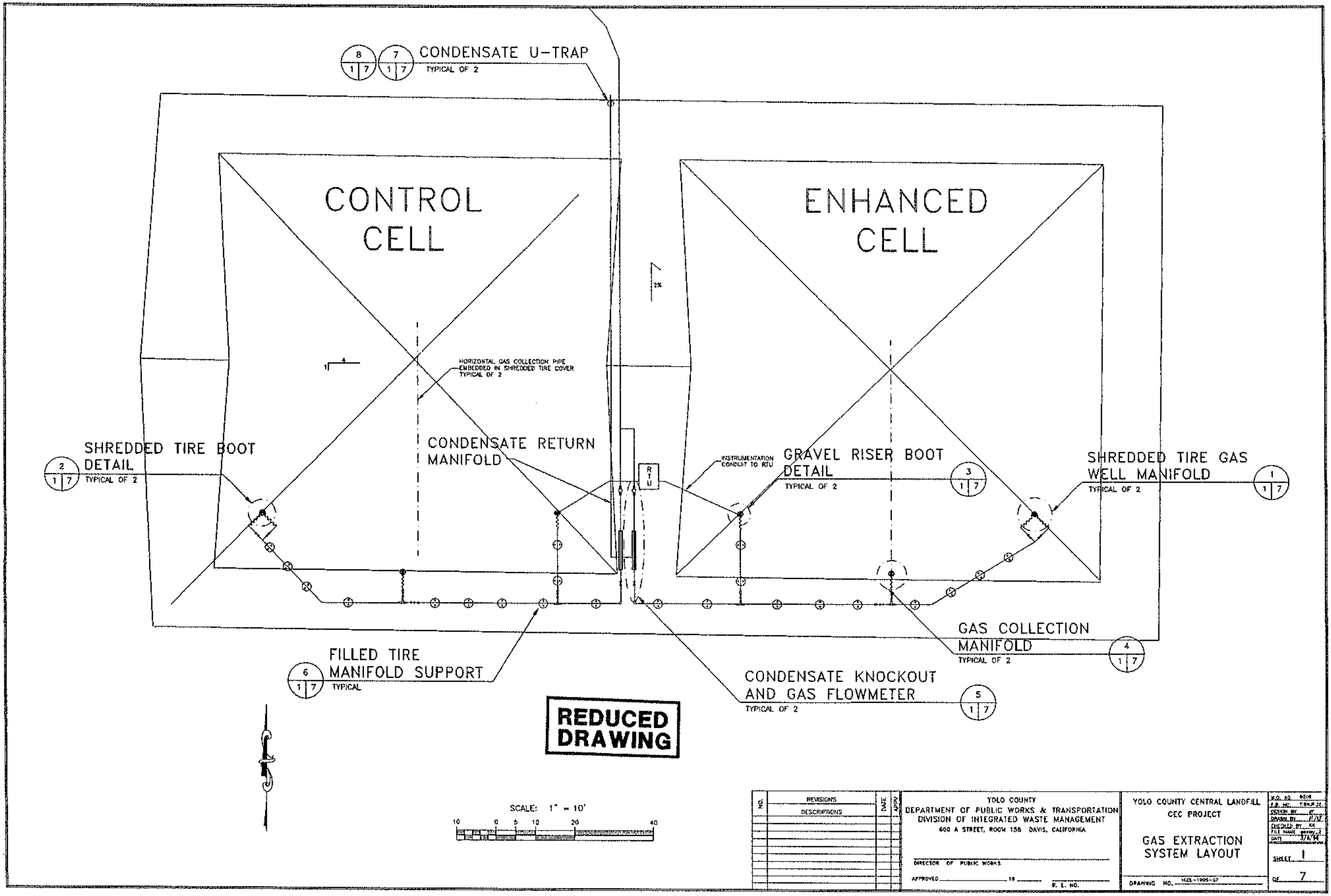
DRAWING II-20



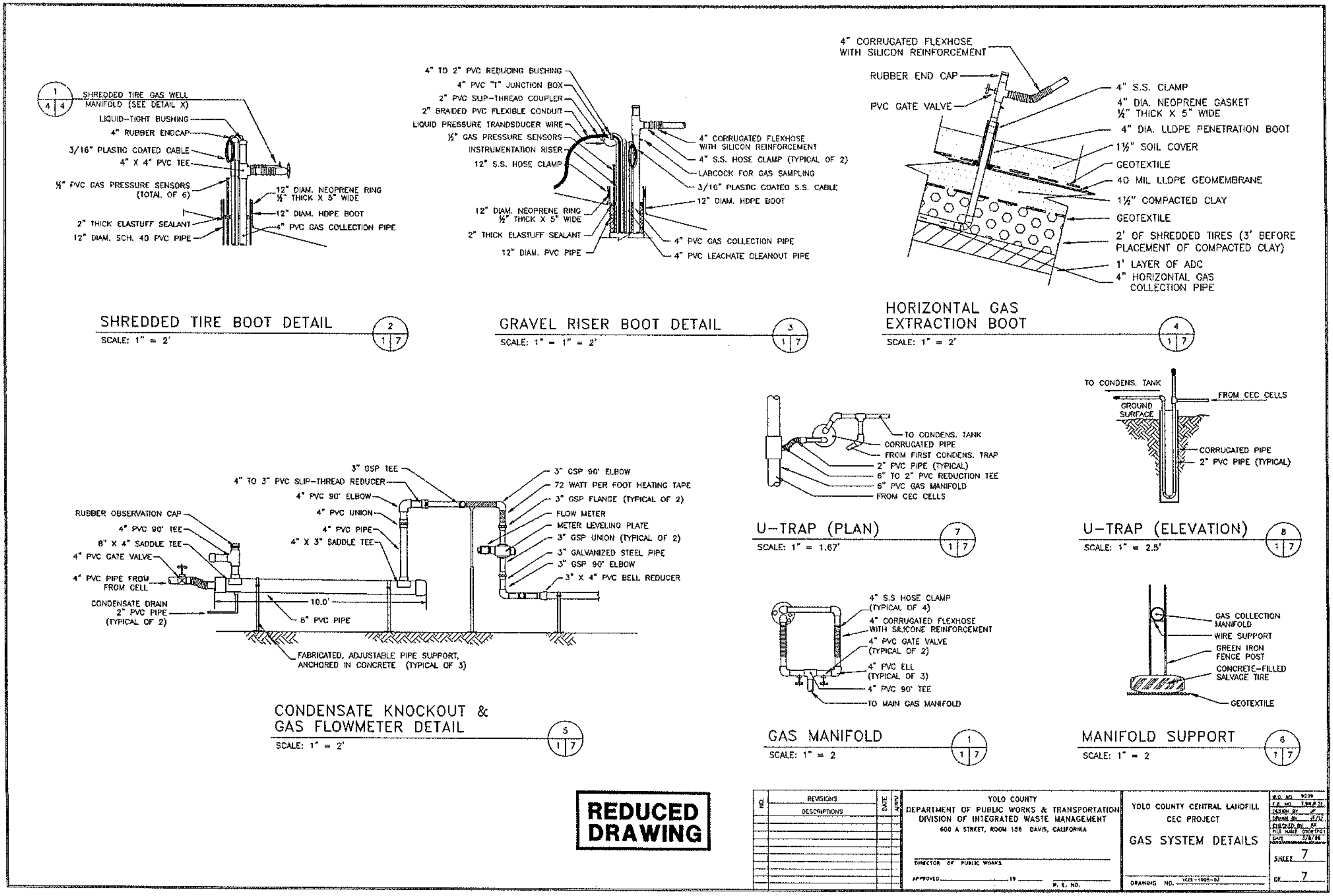
DRAWING II-21



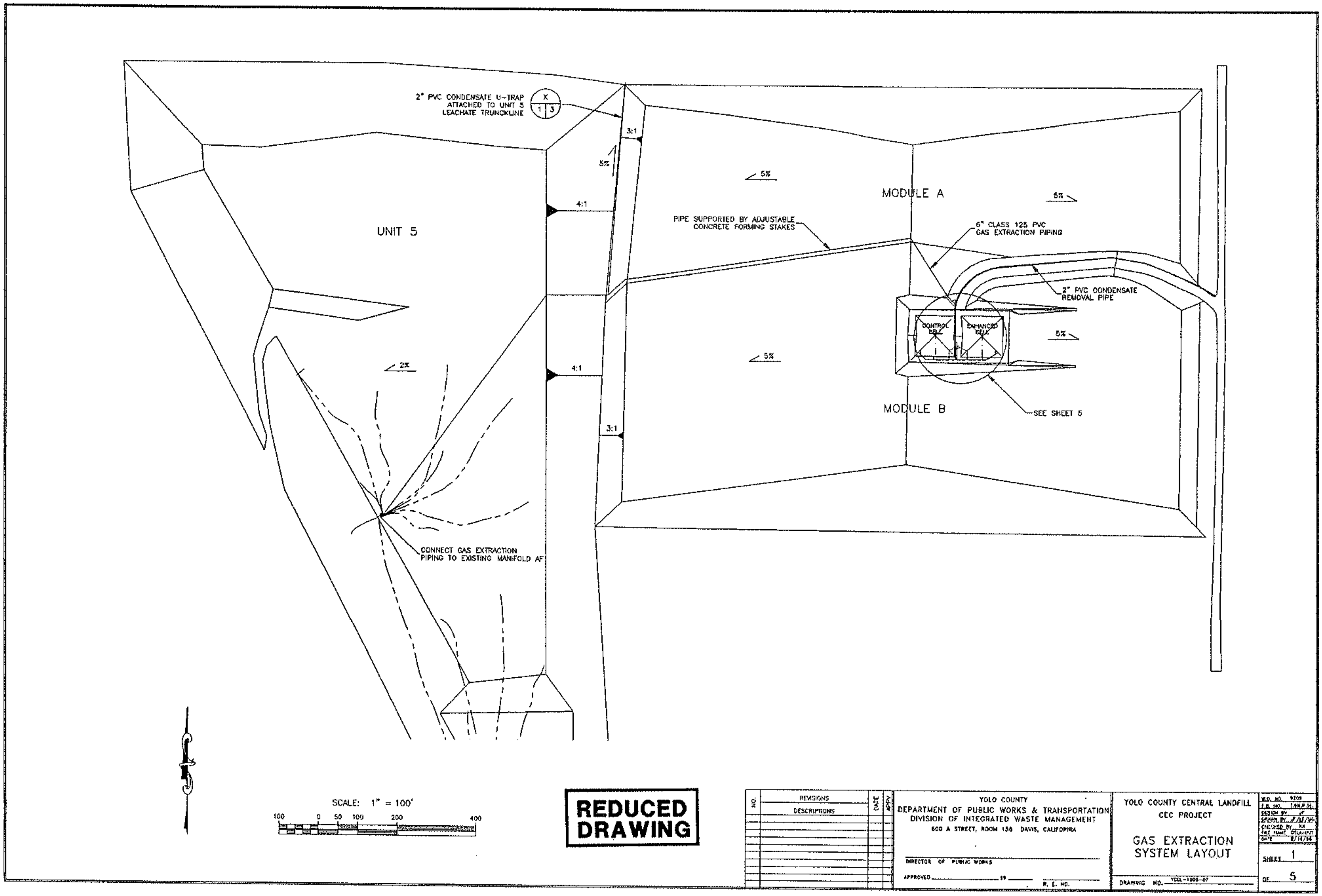
DRAWING II-22



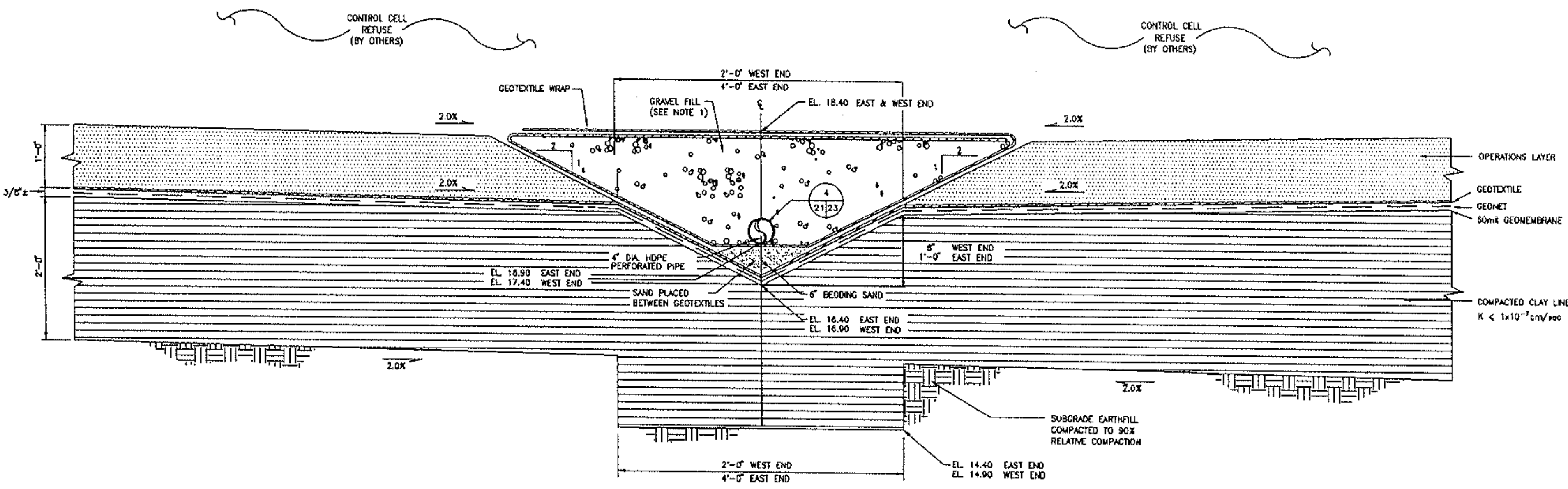
DRAWING II-23



DRAWING II-24



DRAWING II-25



REDUCED DRAWING

TYPICAL CEC CONTROL CELL LEACHATE COLLECTION TRENCH CROSS-SECTION

SCALE: 1 1/2" = 1'-0"

D7 5/21 D7 13/21

NOTES:

1. GRAVEL FILL SHALL BE WRAPPED IN AN ADDITIONAL LAYER OF GEOTEXTILE. PROVIDE 4 FEET MINIMUM OF OVERLAP.

NO.	REVISIONS DESCRIPTIONS	DATE	APPV

YOLO COUNTY
DEPARTMENT of PUBLIC WORKS
292 WEST BEAMER STREET
WOODLAND, CALIFORNIA

Director of Public Works, R.E. No. 29113
APPROVED APRIL 6, 1993

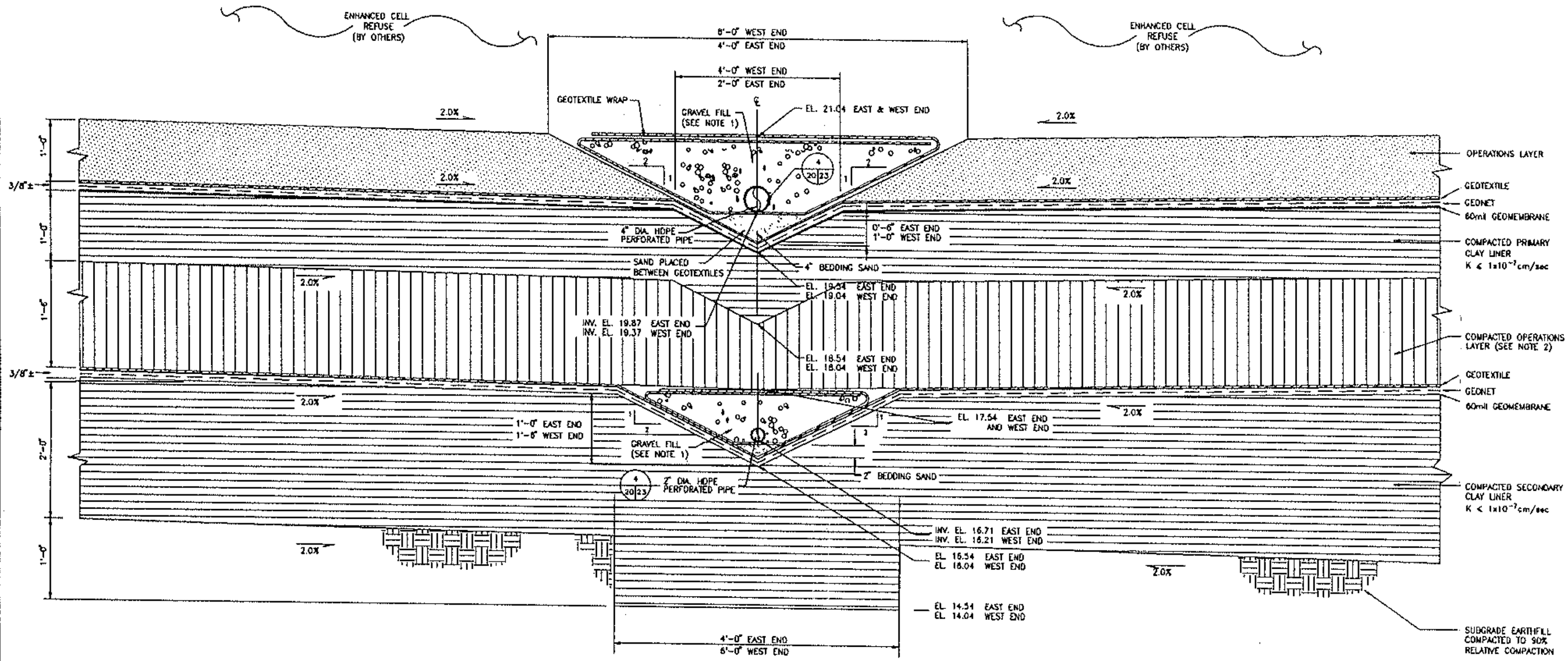
YOLO COUNTY CENTRAL LANDFILL
MODULE B LANDFILL EXPANSION

TYPICAL CEC CONTROL CELL LEACHATE COLLECTION TRENCH CROSS-SECTION

DRAWING NO. 1493-02

SHEET 21 OF 28

DRAWING III-1



TYPICAL CEC ENHANCED CELL PRIMARY AND SECONDARY LEACHATE COLLECTION TRENCH CROSS-SECTION

SCALE: 1 1/2" = 1'-0"

REDUCED DRAWING

NOTES:

1. GRAVEL FILL SHALL BE WRAPPED IN AN ADDITIONAL LAYER OF GEOTEXTILE. PROVIDE 4 FEET MINIMUM OF OVERLAP
2. OPERATIONS LAYER SHALL BE PLACED AND COMPACTED TO 90% RELATIVE COMPACTION USING LOW GROUND PRESSURE EQUIPMENT, APPROVED BY THE ENGINEER, TO PROTECT THE UNDERLYING GEOSYNTHETIC MATERIALS.

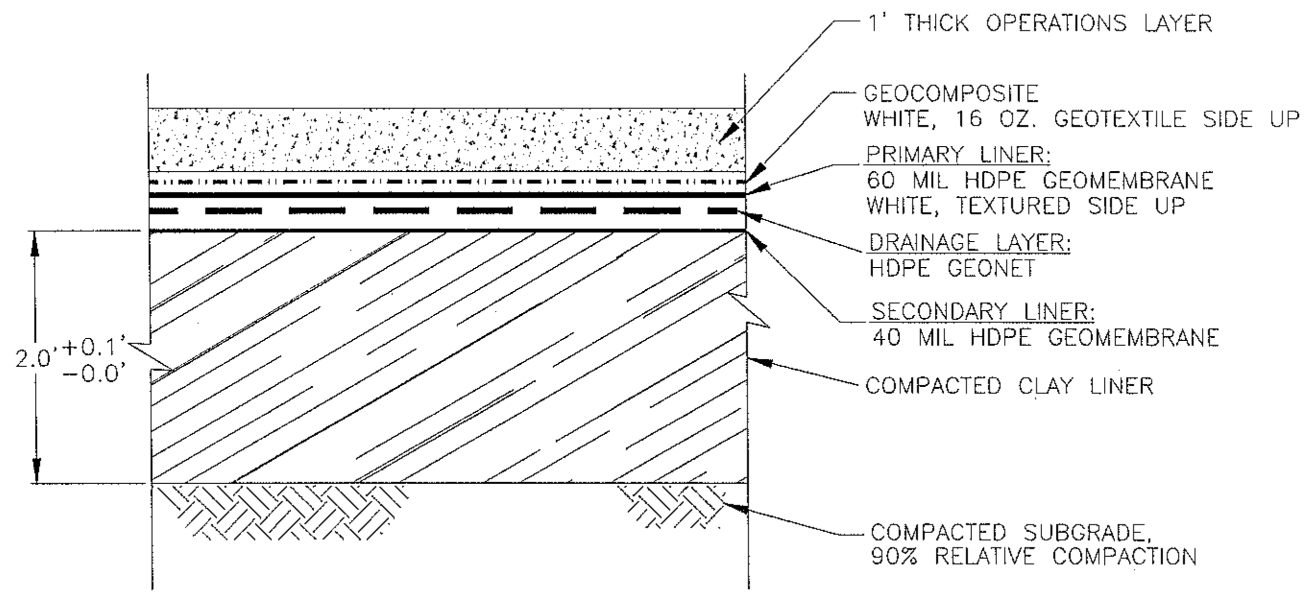
YOLO COUNTY DEPARTMENT of PUBLIC WORKS
292 WEST BEAMER STREET
WOODLAND, CALIFORNIA
DIRECTOR OF PUBLIC WORKS
APPROVED APRIL 6, 1993

YOLO COUNTY CENTRAL LANDFILL
MODULE B LANDFILL EXPANSION

TYPICAL CEC ENHANCED CELL PRIMARY AND SECONDARY LEACHATE COLLECTION TRENCH CROSS-SECTION

SHEET 20 OF 28

DRAWING III-2



NO.	REVISIONS DESCRIPTIONS	DATE	APPV

YOLO COUNTY
DEPARTMENT OF PUBLIC WORKS & TRANSPORTATION
DIVISION OF INTEGRATED WASTE MANAGEMENT
600 A STREET, ROOM 158 DAVIS, CALIFORNIA

DIRECTOR OF PUBLIC WORKS

APPROVED ______ 19 ______ R. E. NO.

YOLO COUNTY CENTRAL LANDFILL
LIQUID WASTE
SURFACE IMPOUNDMENT

DOUBLE LINER SECTION

DRAWING NO. YOOL-1998-01

SHEET 1 OF 1

DRAWING III-3

APPENDIX - 2

PHOTOS

APPENDIX - 3

ECONOMIC ANALYSIS TABLES AND FIGURES

TABLE 1. CALCULATION OF METHANE FLOWRATE

Year	tons per year brought to landfill	tons per day brought to landfill	tons per year landfilled (no soil or inerts included)	tons landfilled per day	total cubic feet of CH4 in waste landfilled in year(i)	yearly CH4 generation (10 years) from year(i) waste only	Total yearly CH4 generation from all waste (95% recovery)	CH4 Flow Rate for 95% (cfd)	Total yearly CH4 generation from all waste (75% recovery)	CH4 Flow Rate for 75% (cfd)
1997	241000	660	168,700	462	455490000	45549000				
1998	248200	680	173,740	476	469098000	46909800	0	0	0	0
1999	255400	700	178,780	490	482706000	48270600	43271550	118,552	34,161,750	93,594
2000	262600	719	183,820	504	496314000	49631400	87835860	240,646	69,344,100	189,984
2001	269800	739	188,860	517	509922000	50992200	133692930	366,282	105,547,050	289,170
2002	277000	759	193,900	531	523530000	52353000	180842760	495,460	142,770,600	391,152
2003	284200	779	198,940	545	537138000	53713800	229285350	628,179	181,014,750	495,931
2004	291400	798	203,980	559	550746000	55074600	279020700	764,440	220,279,500	603,505
2005	298600	818	209,020	573	564354000	56435400	330048810	904,243	260,564,850	713,876
2006	305800	838	214,060	586	577962000	57796200	382369680	1,047,588	301,870,800	827,043
2007	313000	858	219,100	600	591570000	59157000	435983310	1,194,475	344,197,350	943,006
2008	320200	877	224,140	614	605178000	60517800	447618150	1,226,351	353,382,750	968,172
2009	327400	897	229,180	628	618786000	61878600	459252990	1,258,227	362,568,150	993,337
2010	334600	917	234,220	642	632394000	63239400	470887830	1,290,104	371,753,550	1,018,503
2011	341800	936	239,260	656	646002000	64600200	482522670	1,321,980	380,938,950	1,043,668
2012	349000	956	244,300	669	659610000	65961000	494157510	1,353,856	390,124,350	1,068,834
2013	356200	976	249,340	683	673218000	67321800	505792350	1,385,732	399,309,750	1,093,999
2014	363400	996	254,380	697	686826000	68682600	517427190	1,417,609	408,495,150	1,119,165
2015	370600	1015	259,420	711	700434000	70043400	529062030	1,449,485	417,680,550	1,144,330
2016	377800	1035	264,460	725	714042000	71404200	540696870	1,481,361	426,865,950	1,169,496
2017	385000	1055	269,500	738	727650000	72765000	552331710	1,513,238	436,051,350	1,194,661
2018	392200	1075	274,540	752	741258000	74125800	563966550	1,545,114	445,236,750	1,219,827
2019	399400	1094	279,580	766	754866000	75486600	575601390	1,576,990	454,422,150	1,244,992
2020	406600	1114	284,620	780	768474000	76847400	587236230	1,608,866	463,607,550	1,270,158
2021		0	0	0	0	0	598871070	1,640,743	472,792,950	1,295,323
2022		0	0	0	0	0	610505910	1,672,619	481,978,350	1,320,489
2023		0	0	0	0	0	547842960	1,500,940	432,507,600	1,184,952
2024		0	0	0	0	0	483887250	1,325,718	382,016,250	1,046,620
2025		0	0	0	0	0	418638780	1,146,956	330,504,300	905,491
2026							352097550	964,651	277,971,750	761,566
2027							284263560	778,804	224,418,600	614,845
2028							215136810	589,416	169,844,850	465,328
2029							144717300	396,486	114,250,500	313,015
2030							73005030	200,014	57,635,550	157,906

TABLE 2. YEARLY CONTRIBUTION TO METHANE FLOWRATE

YEAR	ASSUMES THAT DURING THE FIRST YEAR, ALL GAS GENERATED IS LOST BECAUSE RECOVERY SYSTEM IS NOT YET ON-LINE																											
1997																												
1998																												
1999	4.6E+07																											
2000	4.6E+07	4.7E+07																										
2001	4.6E+07	4.7E+07	4.8E+07																									
2002	4.6E+07	4.7E+07	4.8E+07	5E+07																								
2003	4.6E+07	4.7E+07	4.8E+07	5E+07	5.1E+07																							
2004	4.6E+07	4.7E+07	4.8E+07	5E+07	5.1E+07	5.2E+07																						
2005	4.6E+07	4.7E+07	4.8E+07	5E+07	5.1E+07	5.2E+07	5.4E+07																					
2006	4.6E+07	4.7E+07	4.8E+07	5E+07	5.1E+07	5.2E+07	5.4E+07	5.5E+07																				
2007	4.6E+07	4.7E+07	4.8E+07	5E+07	5.1E+07	5.2E+07	5.4E+07	5.5E+07	5.6E+07																			
2008		4.7E+07	4.8E+07	5E+07	5.1E+07	5.2E+07	5.4E+07	5.5E+07	5.6E+07	5.8E+07																		
2009			4.8E+07	5E+07	5.1E+07	5.2E+07	5.4E+07	5.5E+07	5.6E+07	5.8E+07	5.9E+07																	
2010				5E+07	5.1E+07	5.2E+07	5.4E+07	5.5E+07	5.6E+07	5.8E+07	5.9E+07	6.1E+07																
2011					5.1E+07	5.2E+07	5.4E+07	5.5E+07	5.6E+07	5.8E+07	5.9E+07	6.1E+07	6.2E+07															
2012						5.2E+07	5.4E+07	5.5E+07	5.6E+07	5.8E+07	5.9E+07	6.1E+07	6.2E+07	6.3E+07														
2013							5.4E+07	5.5E+07	5.6E+07	5.8E+07	5.9E+07	6.1E+07	6.2E+07	6.3E+07	6.5E+07													
2014								5.5E+07	5.6E+07	5.8E+07	5.9E+07	6.1E+07	6.2E+07	6.3E+07	6.5E+07	6.6E+07												
2015									5.6E+07	5.8E+07	5.9E+07	6.1E+07	6.2E+07	6.3E+07	6.5E+07	6.6E+07	6.7E+07											
2016										5.8E+07	5.9E+07	6.1E+07	6.2E+07	6.3E+07	6.5E+07	6.6E+07	6.7E+07	6.9E+07										
2017											5.9E+07	6.1E+07	6.2E+07	6.3E+07	6.5E+07	6.6E+07	6.7E+07	6.9E+07	7E+07									
2018												6.1E+07	6.2E+07	6.3E+07	6.5E+07	6.6E+07	6.7E+07	6.9E+07	7E+07	7.1E+07								
2019													6.2E+07	6.3E+07	6.5E+07	6.6E+07	6.7E+07	6.9E+07	7E+07	7.1E+07	7.3E+07							
2020														6.3E+07	6.5E+07	6.6E+07	6.7E+07	6.9E+07	7E+07	7.1E+07	7.3E+07	7.4E+07						
2021															6.5E+07	6.6E+07	6.7E+07	6.9E+07	7E+07	7.1E+07	7.3E+07	7.4E+07	7.5E+07					
2022																6.6E+07	6.7E+07	6.9E+07	7E+07	7.1E+07	7.3E+07	7.4E+07	7.5E+07	7.7E+07				
2023																	6.7E+07	6.9E+07	7E+07	7.1E+07	7.3E+07	7.4E+07	7.5E+07	7.7E+07	0			
2024																		6.9E+07	7E+07	7.1E+07	7.3E+07	7.4E+07	7.5E+07	7.7E+07	0	0		
2025																			7E+07	7.1E+07	7.3E+07	7.4E+07	7.5E+07	7.7E+07	0	0	0	
2026																				7.1E+07	7.3E+07	7.4E+07	7.5E+07	7.7E+07	0	0	0	0
2027																					7.3E+07	7.4E+07	7.5E+07	7.7E+07	0	0	0	0
2028																						7.4E+07	7.5E+07	7.7E+07	0	0	0	0
2029																							7.5E+07	7.7E+07	0	0	0	0
2030																								7.7E+07	0	0	0	0

TABLE 3. CALCULATION OF METHANE ENERGY POTENTIAL

ASSUMES 95% RECOVERY EFFICIENCY

YEAR	Total yearly CH4 generation from all waste (95% recovery) (cubic feet)	BTU Content (900 BTU per 1 ft3 of CH$)	kWh (12,500 BTU is 1 kWh)	kW of power (kWh / 8760 hr/yr)
1997	0	0	0	0
1998	43271550	38944395000	3,115,552	365
1999	87835860	79052274000	6,324,182	740
2000	133692930	1.20324E+11	9,625,891	1,127
2001	180842760	1.62758E+11	13,020,679	1,524
2002	229285350	2.06357E+11	16,508,545	1,932
2003	279020700	2.51119E+11	20,089,490	2,351
2004	330048810	2.97044E+11	23,763,514	2,781
2005	382369680	3.44133E+11	27,530,617	3,222
2006	435983310	3.92385E+11	31,390,798	3,674
2007	447618150	4.02856E+11	32,228,507	3,772
2008	459252990	4.13328E+11	33,066,215	3,870
2009	470887830	4.23799E+11	33,903,924	3,968
2010	482522670	4.3427E+11	34,741,632	4,066
2011	494157510	4.44742E+11	35,579,341	4,164
2012	505792350	4.55213E+11	36,417,049	4,262
2013	517427190	4.65684E+11	37,254,758	4,360
2014	529062030	4.76156E+11	38,092,466	4,458
2015	540696870	4.86627E+11	38,930,175	4,556
2016	552331710	4.97099E+11	39,767,883	4,654
2017	563966550	5.0757E+11	40,605,592	4,753
2018	575601390	5.18041E+11	41,443,300	4,851
2019	587236230	5.28513E+11	42,281,009	4,949
2020	598871070	5.38984E+11	43,118,717	5,047
2021	610505910	5.49455E+11	43,956,426	5,145
2022	547842960	4.93059E+11	39,444,693	4,617
2023	483887250	4.35499E+11	34,839,882	4,078
2024	418638780	3.76775E+11	30,141,992	3,528
2025	352097550	3.16888E+11	25,351,024	2,967
2026	284263560	2.55837E+11	20,466,976	2,395
2027	215136810	1.93623E+11	15,489,850	1,813
2028	144717300	1.30246E+11	10,419,646	1,220
2029	73005030	65704527000	5,256,362	615
2030	0	0	0	0

ASSUMES 75% RECOVERY EFFICIENCY

YEAR	Total yearly CH4 generation from all waste (75% recovery)	BTU Content (900 BTU in 1 ft3 of CH$)	kWh (12,500 BTU is 1 kWh)	kW of power (kWh/8760 hr)
1997	0	0	0	0
1998	34161750	30745575000	2,459,646	288
1999	69344100	62409690000	4,992,775	584
2000	105547050	94992345000	7,599,388	889
2001	142770600	1.28494E+11	10,279,483	1,203
2002	181014750	1.62913E+11	13,033,062	1,525
2003	220279500	1.98252E+11	15,860,124	1,856
2004	260564850	2.34508E+11	18,760,669	2,196
2005	301870800	2.71684E+11	21,734,698	2,544
2006	344197350	3.09778E+11	24,782,209	2,901
2007	353382750	3.18044E+11	25,443,558	2,978
2008	362568150	3.26311E+11	26,104,907	3,055
2009	371753550	3.34578E+11	26,766,256	3,133
2010	380938950	3.42845E+11	27,427,604	3,210
2011	390124350	3.51112E+11	28,088,953	3,288
2012	399309750	3.59379E+11	28,750,302	3,365
2013	408495150	3.67646E+11	29,411,651	3,442
2014	417680550	3.75912E+11	30,073,000	3,520
2015	426865950	3.84179E+11	30,734,348	3,597
2016	436051350	3.92446E+11	31,395,697	3,675
2017	445236750	4.00713E+11	32,057,046	3,752
2018	454422150	4.0898E+11	32,718,395	3,829
2019	463607550	4.17247E+11	33,379,744	3,907
2020	472792950	4.25514E+11	34,041,092	3,984
2021	481978350	4.33781E+11	34,702,441	4,062
2022	432507600	3.89257E+11	31,140,547	3,645
2023	382016250	3.43815E+11	27,505,170	3,219
2024	330504300	2.97454E+11	23,796,310	2,785
2025	277971750	2.50175E+11	20,013,966	2,342
2026	224418600	2.01977E+11	16,158,139	1,891
2027	169844850	1.5286E+11	12,228,829	1,431
2028	114250500	1.02825E+11	8,226,036	963
2029	57635550	51871995000	4,149,760	486
2030	0	0	0	0

TABLE 4. COST TO GENERATE ELECTRICITY FROM ENHANCED LANDFILLING FOR CASE 1

Benefit to Cost Ratio =1; Energy Sale Price = 3.49 cents per kWh; Discount Rate = 3%

Year	Additional Liner Const. Costs	Module under const.	Liquid Management System Const. Costs	Surface Liner Const. Costs	Gas Recovery System Costs	Electric Generation Equipment (principal)	Electric Generation Equipment (interest)	Equip Capacity (MgW)	Interconnect, other fees and contingency	$100,000/MW per MW Energy equip O & M	Equipment Decom-missioning cost	Increased Gas and Leachate Monitoring Costs	Liquid System Maint.	Collection System O&M	Royalty	TOTAL COSTS
1997	$ -	C	$ 200,000													$ 200,000
1998												$ 5,000				$ 5,000
1999	$ -	D	$ 212,180									$ 5,150				$ 217,330
2000						$ 1,228,767		1.0	$ 380,000	$ 126,677		$ 5,305	$ 25,000			$1,765,748
2001	$ -	E	$ 225,102					1.0		$ 130,477		$ 5,464	$ 25,250			$ 386,293
2002						$ 651,799		1.5		$ 201,587		$ 5,628	$ 25,503			$ 884,517
2003	$ -	F	$ 238,810			$ 671,353		2.0		$ 276,847		$ 5,796	$ 25,758			$1,218,565
2004								2.0		$ 285,152		$ 5,970	$ 26,015			$ 317,138
2005	$ -	G	$ 253,354			$ 712,239		2.5		$ 367,133		$ 6,149	$ 26,275			$1,365,151
2006								2.5		$ 378,147		$ 6,334	$ 26,538			$ 411,019
2007	$ -	H	$ 268,783			$ 755,614		3.0		$ 467,390		$ 6,524	$ 26,803			$1,525,115
2008								3.0		$ 481,412		$ 6,720	$ 27,071			$ 515,203
2009	$ -	I	$ 285,152					3.0		$ 495,854		$ 6,921	$ 27,342			$ 815,270
2010						$ 825,680		3.5		$ 595,852		$ 7,129	$ 27,616			$1,456,276
2011	$ -	J	$ 302,518					3.5		$ 613,727		$ 7,343	$ 27,892			$ 951,479
2012								3.5		$ 632,139		$ 7,563	$ 28,171			$ 667,873
2013	$ -	K	$ 320,941					3.5		$ 651,103		$ 7,790	$ 28,452			$1,008,287
2014								3.5		$ 670,636		$ 8,024	$ 28,737			$ 707,397
2015	$ -	L	$ 340,487			$ 957,189		4.0		$ 789,435		$ 8,264	$ 29,024			$2,124,399
2016								4.0		$ 813,118		$ 8,512	$ 29,314			$ 850,944
2017	$ -	M	$ 361,222					4.0		$ 837,511		$ 8,768	$ 29,608			$1,237,109
2018	$ -	N	$ 372,059					4.0		$ 862,637		$ 9,031	$ 29,904			$1,273,630
2019	$ -	O	$ 383,221					4.0		$ 888,516		$ 9,301	$ 30,203			$1,311,240
2020	$ -	P	$ 394,717			$ 1,109,645		4.5		$ 1,029,567		$ 9,581	$ 30,505			$2,574,015
2021								4.5		$ 1,060,454		$ 9,868	$ 30,810			$1,101,132
2022								4.0		$ 970,905		$ 10,164	$ 31,118			$1,012,187
2023								4.0		$ 1,000,032		$ 10,469	$ 31,429			$1,041,930
2024								3.0		$ 772,525		$ 10,783	$ 31,743			$ 815,051
2025								2.0		$ 530,467		$ 11,106	$ 32,061			$ 573,634
2026								2.0		$ 546,381		$ 11,440	$ 32,381			$ 590,202
2027								1.5		$ 422,079		$ 11,783	$ 32,705			$ 466,567
2028								0.5		$ 144,914		$ 12,136	$ 33,032			$ 190,083
2029								-		$ -		$ 12,500	$ 33,363			$ 45,863
2030								-		$ -	$ 250,000	$ 12,875	$ 33,696			$ 296,572

TABLE 5. BENEFIT TO GENERATE ELECTRICITY FROM ENHANCED LANDFILLING FOR CASE 1

Benefit to Cost Ratio =1; Energy Sale Price = 3.93 cents per kWh; Discount Rate = 3%

Year	BTU Content (900 BTU per 1 ft3 of CH$)	kWh (12,500 BTU is 1 kWh)	kW of power (kWh/ 8760 hr/yr)	Equip Capacity MW	Tax Credit multiplier	Energy Sales (20% down-time)	Tax Credit Revenue	Leachate Treatment Savings	Landfill Life Extension	Closure Cost Savings	Royalty	Elec Equipment Salvage	TOTAL BENEFITS
1997	-	-	-		1.00	$ -	$ -						$ -
1998	38,944,395,000	3,115,552	365		1.03	$ -	$ 40,113						$ 40,113
1999	79,052,274,000	6,324,182	740		1.06	$ -	$ 83,795	$ 25,000					$ 108,795
2000	120,323,637,000	9,625,891	1,127	1.0	1.09	$ 244,579	$ 131,153	$ 32,500					$ 408,232
2001	162,758,484,000	13,020,679	1,524	1.0	1.13	$ 244,579	$ 183,917	$ 40,000					$ 468,496
2002	206,356,815,000	16,508,545	1,932	1.5	1.16	$ 366,869	$ 239,374	$ 47,500					$ 653,743
2003	251,118,630,000	20,089,490	2,351	2.0	1.19	$ 489,158	$ 298,831	$ 55,000					$ 842,990
2004	297,043,929,000	23,763,514	2,781	2.0	1.23	$ 489,158	$ 365,364	$ 62,500					$ 917,022
2005	344,132,712,000	27,530,617	3,222	2.5	1.27	$ 611,448	$ 437,049	$ 70,000					$ 1,118,497
2006	392,384,979,000	31,390,798	3,674	2.5	1.30	$ 611,448	$ 510,100	$ 77,500					$ 1,199,048
2007	402,856,335,000	32,228,507	3,772	3.0		$ 733,738	$ -	$ 85,000					$ 818,738
2008	413,327,691,000	33,066,215	3,870	3.0		$ 733,738	$ -	$ 92,500					$ 826,238
2009	423,799,047,000	33,903,924	3,968	3.0		$ 733,738	$ -	$100,000					$ 833,738
2010	434,270,403,000	34,741,632	4,066	3.5		$ 856,027	$ -	$107,500					$ 963,527
2011	444,741,759,000	35,579,341	4,164	3.5		$ 856,027	$ -	$115,000					$ 971,027
2012	455,213,115,000	36,417,049	4,262	3.5		$ 856,027	$ -	$122,500					$ 978,527
2013	465,684,471,000	37,254,758	4,360	3.5		$ 856,027	$ -	$130,000					$ 986,027
2014	476,155,827,000	38,092,466	4,458	3.5		$ 856,027	$ -	$137,500					$ 993,527
2015	486,627,183,000	38,930,175	4,556	4.0		$ 978,317	$ -	$145,000					$ 1,123,317
2016	497,098,539,000	39,767,883	4,654	4.0		$ 978,317	$ -	$152,500					$ 1,130,817
2017	507,569,895,000	40,605,592	4,753	4.0		$ 978,317	$ -	$160,000					$ 1,138,317
2018	518,041,251,000	41,443,300	4,851	4.0		$ 978,317	$ -	$167,500					$ 1,145,817
2019	528,512,607,000	42,281,009	4,949	4.0		$ 978,317	$ -	$175,000					$ 1,153,317
2020	538,983,963,000	43,118,717	5,047	4.5		$ 1,100,606	$ -	$182,500					$ 1,283,106
2021	549,455,319,000	43,956,426	5,145	4.5		$ 1,100,606	$ -	$190,000					$ 1,290,606
2022	493,058,664,000	39,444,693	4,617	4.0		$ 978,317	$ -	$197,500				$ 30,000	$ 1,205,817
2023	435,498,525,000	34,839,882	4,078	4.0		$ 978,317	$ -	$205,000				$ 60,000	$ 1,243,317
2024	376,774,902,000	30,141,992	3,528	3.0		$ 733,738	$ -	$212,500					$ 946,238
2025	316,887,795,000	25,351,024	2,967	2.0		$ 489,158	$ -	$220,000	$ 3,644,076			$ 60,000	$ 4,413,234
2026	255,837,204,000	20,466,976	2,395	2.0		$ 489,158	$ -	$227,500					$ 716,658
2027	193,623,129,000	15,489,850	1,813	1.5		$ 366,869	$ -	$235,000				$ 30,000	$ 631,869
2028	130,245,570,000	10,419,646	1,220	0.5		$ 122,290	$ -	$242,500				$ 60,000	$ 424,790
2029	65,704,527,000	5,256,362	615	-		$ -	$ -	$250,000				$ 30,000	$ 280,000
2030	-	-	-	-		$ -	$ -						$ -
2031										$ 54,638			$ 54,638
2032										$ 56,277			$ 56,277
2033										$ 57,966			$ 57,966
2034										$ 59,705			$ 59,705
2035										$ 61,496			$ 61,496
2036										$ 63,341			$ 63,341
2037										$ 65,241			$ 65,241
2038										$ 67,198			$ 67,198
2039										$ 69,214			$ 69,214
2040										$ 71,290			$ 71,290
2041										$ 73,429			$ 73,429
2042										$ 75,632			$ 75,632
2043										$ 77,901			$ 77,901
2044										$ 80,238			$ 80,238
2045										$ 82,645			$ 82,645
2046										$ 85,124			$ 85,124
2047										$ 87,678			$ 87,678
2048										$ 90,308			$ 90,308
2049										$ 93,018			$ 93,018
2050										$ 95,808			$ 95,808

TABLE 6. COST TO GENERATE ELECTRICITY FROM ENHANCED LANDFILLING FOR CASE 2

Benefit to Cost Ratio =1; Energy Sale Price = 3.93 cents per kWh; Discount Rate = 3%

Year	Additional Liner Const. Costs	Module under const.	Liquid Management System Const. Costs	Surface Liner Const. Costs	Gas Recovery System Costs	Electric Generation Equipment (principal)	Electric Generation Equipment (interest)	Equip Capacity (MgW)	Interconnect, other fees and contingency	$100,000/MW per MW Energy equip O & M	Equipment Decom-missioning cost	Increased Gas and Leachate Monitoring Costs	Liquid System Maint.	Collection System O&M	Royalty	TOTAL COSTS
1997	$ -	C	$ 200,000													$ 200,000
1998												$ 5,000				$ 5,000
1999	$ -	D	$ 212,180									$ 5,150				$ 217,330
2000						$ 1,228,767		1.0	$ 380,000	$ 126,677		$ 5,305	$ 25,000			$1,765,748
2001	$ -	E	$ 225,102					1.0		$ 130,477		$ 5,464	$ 25,250			$ 386,293
2002						$ 651,799		1.5		$ 201,587		$ 5,628	$ 25,503			$ 884,517
2003	$ -	F	$ 238,810			$ 671,353		2.0		$ 276,847		$ 5,796	$ 25,758			$1,218,565
2004								2.0		$ 285,152		$ 5,970	$ 26,015			$ 317,138
2005	$ -	G	$ 253,354			$ 712,239		2.5		$ 367,133		$ 6,149	$ 26,275			$1,365,151
2006								2.5		$ 378,147		$ 6,334	$ 26,538			$ 411,019
2007	$ -	H	$ 268,783			$ 755,614		3.0		$ 467,390		$ 6,524	$ 26,803			$1,525,115
2008								3.0		$ 481,412		$ 6,720	$ 27,071			$ 515,203
2009	$ -	I	$ 285,152					3.0		$ 495,854		$ 6,921	$ 27,342			$ 815,270
2010						$ 825,680		3.5		$ 595,852		$ 7,129	$ 27,616			$1,456,276
2011	$ -	J	$ 302,518					3.5		$ 613,727		$ 7,343	$ 27,892			$ 951,479
2012								3.5		$ 632,139		$ 7,563	$ 28,171			$ 667,873
2013	$ -	K	$ 320,941					3.5		$ 651,103		$ 7,790	$ 28,452			$1,008,287
2014								3.5		$ 670,636		$ 8,024	$ 28,737			$ 707,397
2015	$ -	L	$ 340,487			$ 957,189		4.0		$ 789,435		$ 8,264	$ 29,024			$2,124,399
2016								4.0		$ 813,118		$ 8,512	$ 29,314			$ 850,944
2017	$ -	M	$ 361,222					4.0		$ 837,511		$ 8,768	$ 29,608			$1,237,109
2018	$ -	N	$ 372,059					4.0		$ 862,637		$ 9,031	$ 29,904			$1,273,630
2019	$ -	O	$ 383,221					4.0		$ 888,516		$ 9,301	$ 30,203			$1,311,240
2020	$ -	P	$ 394,717			$ 1,109,645		4.5		$ 1,029,567		$ 9,581	$ 30,505			$2,574,015
2021								4.5		$ 1,060,454		$ 9,868	$ 30,810			$1,101,132
2022								4.0		$ 970,905		$ 10,164	$ 31,118			$1,012,187
2023								4.0		$ 1,000,032		$ 10,469	$ 31,429			$1,041,930
2024								3.0		$ 772,525		$ 10,783	$ 31,743			$ 815,051
2025								2.0		$ 530,467		$ 11,106	$ 32,061			$ 573,634
2026								2.0		$ 546,381		$ 11,440	$ 32,381			$ 590,202
2027								1.5		$ 422,079		$ 11,783	$ 32,705			$ 466,567
2028								0.5		$ 144,914		$ 12,136	$ 33,032			$ 190,083
2029								-		$ -		$ 12,500	$ 33,363			$ 45,863
2030								-		$ -	$ 250,000	$ 12,875	$ 33,696			$ 296,572

TABLE 7. BENEFIT TO GENERATE ELECTRICITY FROM ENHANCED LANDFILLING FOR CASE 2

Benefit to Cost Ratio =1; Energy Sale Price = 3.93 cents per kWh; Discount Rate = 3%

Year	BTU Content (900 BTU per 1 ft3 of CH$)	kWh (12,500 BTU is 1 kWh)	kW of power (kWh/ 8760 hr/yr)	Equip Capacity MW	Tax Credit multiplier	Energy Sales (20% down-time)	Tax Credit Revenue	Leachate Treatment Savings	Landfill Life Extension	Closure Cost Savings	Royalty	Elec Equipment Salvage	TOTAL BENEFITS
1997	-	-	-		1.00	$ -	$ -						$ -
1998	38,944,395,000	3,115,552	365		1.03	$ -	$ 40,113						$ 40,113
1999	79,052,274,000	6,324,182	740		1.06	$ -	$ 83,795	$ 25,000					$ 108,795
2000	120,323,637,000	9,625,891	1,127	1.0	1.09	$ 275,414	$ 131,153	$ 32,500					$ 439,067
2001	162,758,484,000	13,020,679	1,524	1.0	1.13	$ 275,414	$ 183,917	$ 40,000					$ 499,331
2002	206,356,815,000	16,508,545	1,932	1.5	1.16	$ 413,122	$ 239,374	$ 47,500					$ 699,996
2003	251,118,630,000	20,089,490	2,351	2.0	1.19	$ 550,829	$ 298,831	$ 55,000					$ 904,660
2004	297,043,929,000	23,763,514	2,781	2.0	1.23	$ 550,829	$ 365,364	$ 62,500					$ 978,693
2005	344,132,712,000	27,530,617	3,222	2.5	1.27	$ 688,536	$ 437,049	$ 70,000					$ 1,195,585
2006	392,384,979,000	31,390,798	3,674	2.5	1.30	$ 688,536	$ 510,100	$ 77,500					$ 1,276,136
2007	402,856,335,000	32,228,507	3,772	3.0		$ 826,243	$ -	$ 85,000					$ 911,243
2008	413,327,691,000	33,066,215	3,870	3.0		$ 826,243	$ -	$ 92,500					$ 918,743
2009	423,799,047,000	33,903,924	3,968	3.0		$ 826,243	$ -	$100,000					$ 926,243
2010	434,270,403,000	34,741,632	4,066	3.5		$ 963,950	$ -	$107,500					$ 1,071,450
2011	444,741,759,000	35,579,341	4,164	3.5		$ 963,950	$ -	$115,000					$ 1,078,950
2012	455,213,115,000	36,417,049	4,262	3.5		$ 963,950	$ -	$122,500					$ 1,086,450
2013	465,684,471,000	37,254,758	4,360	3.5		$ 963,950	$ -	$130,000					$ 1,093,950
2014	476,155,827,000	38,092,466	4,458	3.5		$ 963,950	$ -	$137,500					$ 1,101,450
2015	486,627,183,000	38,930,175	4,556	4.0		$ 1,101,658	$ -	$145,000					$ 1,246,658
2016	497,098,539,000	39,767,883	4,654	4.0		$ 1,101,658	$ -	$152,500					$ 1,254,158
2017	507,569,895,000	40,605,592	4,753	4.0		$ 1,101,658	$ -	$160,000					$ 1,261,658
2018	518,041,251,000	41,443,300	4,851	4.0		$ 1,101,658	$ -	$167,500					$ 1,269,158
2019	528,512,607,000	42,281,009	4,949	4.0		$ 1,101,658	$ -	$175,000					$ 1,276,658
2020	538,983,963,000	43,118,717	5,047	4.5		$ 1,239,365	$ -	$182,500					$ 1,421,865
2021	549,455,319,000	43,956,426	5,145	4.5		$ 1,239,365	$ -	$190,000					$ 1,429,365
2022	493,058,664,000	39,444,693	4,617	4.0		$ 1,101,658	$ -	$197,500				$ 30,000	$ 1,329,158
2023	435,498,525,000	34,839,882	4,078	4.0		$ 1,101,658	$ -	$205,000				$ 60,000	$ 1,366,658
2024	376,774,902,000	30,141,992	3,528	3.0		$ 826,243	$ -	$212,500					$ 1,038,743
2025	316,887,795,000	25,351,024	2,967	2.0		$ 550,829	$ -	$220,000	$ -			$ 60,000	$ 830,829
2026	255,837,204,000	20,466,976	2,395	2.0		$ 550,829	$ -	$227,500					$ 778,329
2027	193,623,129,000	15,489,850	1,813	1.5		$ 413,122	$ -	$235,000				$ 30,000	$ 678,122
2028	130,245,570,000	10,419,646	1,220	0.5		$ 137,707	$ -	$242,500				$ 60,000	$ 440,207
2029	65,704,527,000	5,256,362	615	-		$ -	$ -	$250,000				$ 30,000	$ 280,000
2030	-	-	-	-		$ -	$ -						$ -
2031										$ 54,638			$ 54,638
2032										$ 56,277			$ 56,277
2033										$ 57,966			$ 57,966
2034										$ 59,705			$ 59,705
2035										$ 61,496			$ 61,496
2036										$ 63,341			$ 63,341
2037										$ 65,241			$ 65,241
2038										$ 67,198			$ 67,198
2039										$ 69,214			$ 69,214
2040										$ 71,290			$ 71,290
2041										$ 73,429			$ 73,429
2042										$ 75,632			$ 75,632
2043										$ 77,901			$ 77,901
2044										$ 80,238			$ 80,238
2045										$ 82,645			$ 82,645
2046										$ 85,124			$ 85,124
2047										$ 87,678			$ 87,678
2048										$ 90,308			$ 90,308
2049										$ 93,018			$ 93,018
2050										$ 95,808			$ 95,808

TABLE 8. COST TO GENERATE ELECTRICITY FROM ENHANCED LANDFILLING FOR CASE 3

Benefit to Cost Ratio =1; Energy Sale Price = 7.77 cents per kWh; Discount Rate = 3%

Year	Additional Liner Const. Costs	Module under const.	Liquid Management System Const. Costs	Surface Liner Const. Costs	Gas Recovery System Costs	Electric Generation Equipment (principal)	Electric Generation Equipment (interest)	Equip Capacity (MgW)	Interconnect, other fees and contingency	$100,000/MW per MW Energy equip O & M	Equipment Decom-missioning cost	Increased Gas and Leachate Monitoring Costs	Liquid System Maint.	Collection System O&M	Royalty	TOTAL COSTS
1997	$ 1,100,000	C	$ 200,000													$1,300,000
1998												$ 5,000				$ 5,000
1999	$ 1,166,990	D	$ 212,180									$ 5,150				$1,384,320
2000						$ 1,228,767		1.0	$ 380,000	$ 126,677		$ 5,305	$ 25,000			$1,765,748
2001	$ 1,238,060	E	$ 225,102					1.0		$ 130,477		$ 5,464	$ 25,250			$1,624,352
2002						$ 651,799		1.5		$ 201,587		$ 5,628	$ 25,503			$ 884,517
2003	$ 1,313,458	F	$ 238,810			$ 671,353		2.0		$ 276,847		$ 5,796	$ 25,758			$2,532,022
2004								2.0		$ 285,152		$ 5,970	$ 26,015			$ 317,138
2005	$ 1,393,447	G	$ 253,354			$ 712,239		2.5		$ 367,133		$ 6,149	$ 26,275			$2,758,598
2006								2.5		$ 378,147		$ 6,334	$ 26,538			$ 411,019
2007	$ 1,478,308	H	$ 268,783			$ 755,614		3.0		$ 467,390		$ 6,524	$ 26,803			$3,003,423
2008								3.0		$ 481,412		$ 6,720	$ 27,071			$ 515,203
2009	$ 1,568,337	I	$ 285,152					3.0		$ 495,854		$ 6,921	$ 27,342			$2,383,607
2010						$ 825,680		3.5		$ 595,852		$ 7,129	$ 27,616			$1,456,276
2011	$ 1,663,849	J	$ 302,518					3.5		$ 613,727		$ 7,343	$ 27,892			$2,615,328
2012								3.5		$ 632,139		$ 7,563	$ 28,171			$ 667,873
2013	$ 1,765,177	K	$ 320,941					3.5		$ 651,103		$ 7,790	$ 28,452			$2,773,464
2014								3.5		$ 670,636		$ 8,024	$ 28,737			$ 707,397
2015	$ 1,872,676	L	$ 340,487			$ 957,189		4.0		$ 789,435		$ 8,264	$ 29,024			$3,997,076
2016								4.0		$ 813,118		$ 8,512	$ 29,314			$ 850,944
2017	$ 1,986,722	M	$ 361,222					4.0		$ 837,511		$ 8,768	$ 29,608			$3,223,831
2018	$ 2,046,324	N	$ 372,059					4.0		$ 862,637		$ 9,031	$ 29,904			$3,319,954
2019	$ 2,107,714	O	$ 383,221					4.0		$ 888,516		$ 9,301	$ 30,203			$3,418,954
2020	$ 2,170,945	P	$ 394,717			$ 1,109,645		4.5		$ 1,029,567		$ 9,581	$ 30,505			$4,744,960
2021								4.5		$ 1,060,454		$ 9,868	$ 30,810			$1,101,132
2022								4.0		$ 970,905		$ 10,164	$ 31,118			$1,012,187
2023								4.0		$ 1,000,032		$ 10,469	$ 31,429			$1,041,930
2024								3.0		$ 772,525		$ 10,783	$ 31,743			$ 815,051
2025								2.0		$ 530,467		$ 11,106	$ 32,061			$ 573,634
2026								2.0		$ 546,381		$ 11,440	$ 32,381			$ 590,202
2027								1.5		$ 422,079		$ 11,783	$ 32,705			$ 466,567
2028								0.5		$ 144,914		$ 12,136	$ 33,032			$ 190,083
2029								-		$ -		$ 12,500	$ 33,363			$ 45,863
2030								-		$ -	$ 250,000	$ 12,875	$ 33,696			$ 296,572

TABLE 9. BENEFIT TO GENERATE ELECTRICITY FROM ENHANCED LANDFILLING FOR CASE 3

Benefit to Cost Ratio =1; Energy Sale Price = 7.77 cents per kWh; Discount Rate = 3%

Year	BTU Content (900 BTU per 1 ft3 of CH$)	kWh (12,500 BTU is 1 KWh)	kW of power (kWh/ 8760 hr/yr)	Equip Capacity MW	Tax Credit multiplier	Energy Sales (20% down-time)	Tax Credit Revenue	Leachate Treatment Savings	Landfill Life Extension	Closure Cost Savings	Royalty	Elec Equipment Salvage	TOTAL BENEFITS
1997	-	-	-		1.00	$ -	$ -						$ -
1998	38,944,395,000	3,115,552	365		1.03	$ -	$ 40,113						$ 40,113
1999	79,052,274,000	6,324,182	740		1.06	$ -	$ 83,795	$ 25,000					$ 108,795
2000	120,323,637,000	9,625,891	1,127	1.0	1.09	$ 544,522	$ 131,153	$ 32,500					$ 708,174
2001	162,758,484,000	13,020,679	1,524	1.0	1.13	$ 544,522	$ 183,917	$ 40,000					$ 768,439
2002	206,356,815,000	16,508,545	1,932	1.5	1.16	$ 816,782	$ 239,374	$ 47,500					$ 1,103,656
2003	251,118,630,000	20,089,490	2,351	2.0	1.19	$ 1,089,043	$ 298,831	$ 55,000					$ 1,442,874
2004	297,043,929,000	23,763,514	2,781	2.0	1.23	$ 1,089,043	$ 365,364	$ 62,500					$ 1,516,907
2005	344,132,712,000	27,530,617	3,222	2.5	1.27	$ 1,361,304	$ 437,049	$ 70,000					$ 1,868,353
2006	392,384,979,000	31,390,798	3,674	2.5	1.30	$ 1,361,304	$ 510,100	$ 77,500					$ 1,948,904
2007	402,856,335,000	32,228,507	3,772	3.0		$ 1,633,565	$ -	$ 85,000					$ 1,718,565
2008	413,327,691,000	33,066,215	3,870	3.0		$ 1,633,565	$ -	$ 92,500					$ 1,726,065
2009	423,799,047,000	33,903,924	3,968	3.0		$ 1,633,565	$ -	$100,000					$ 1,733,565
2010	434,270,403,000	34,741,632	4,066	3.5		$ 1,905,826	$ -	$107,500					$ 2,013,326
2011	444,741,759,000	35,579,341	4,164	3.5		$ 1,905,826	$ -	$115,000					$ 2,020,826
2012	455,213,115,000	36,417,049	4,262	3.5		$ 1,905,826	$ -	$122,500					$ 2,028,326
2013	465,684,471,000	37,254,758	4,360	3.5		$ 1,905,826	$ -	$130,000					$ 2,035,826
2014	476,155,827,000	38,092,466	4,458	3.5		$ 1,905,826	$ -	$137,500					$ 2,043,326
2015	486,627,183,000	38,930,175	4,556	4.0		$ 2,178,086	$ -	$145,000					$ 2,323,086
2016	497,098,539,000	39,767,883	4,654	4.0		$ 2,178,086	$ -	$152,500					$ 2,330,586
2017	507,569,895,000	40,605,592	4,753	4.0		$ 2,178,086	$ -	$160,000					$ 2,338,086
2018	518,041,251,000	41,443,300	4,851	4.0		$ 2,178,086	$ -	$167,500					$ 2,345,586
2019	528,512,607,000	42,281,009	4,949	4.0		$ 2,178,086	$ -	$175,000					$ 2,353,086
2020	538,983,963,000	43,118,717	5,047	4.5		$ 2,450,347	$ -	$182,500					$ 2,632,847
2021	549,455,319,000	43,956,426	5,145	4.5		$ 2,450,347	$ -	$190,000					$ 2,640,347
2022	493,058,664,000	39,444,693	4,617	4.0		$ 2,178,086	$ -	$197,500				$ 30,000	$ 2,405,586
2023	435,498,525,000	34,839,882	4,078	4.0		$ 2,178,086	$ -	$205,000				$ 60,000	$ 2,443,086
2024	376,774,902,000	30,141,992	3,528	3.0		$ 1,633,565	$ -	$212,500					$ 1,846,065
2025	316,887,795,000	25,351,024	2,967	2.0		$ 1,089,043	$ -	$220,000	$ 3,644,076			$ 60,000	$ 5,013,119
2026	255,837,204,000	20,466,976	2,395	2.0		$ 1,089,043	$ -	$227,500					$ 1,316,543
2027	193,623,129,000	15,489,850	1,813	1.5		$ 816,782	$ -	$235,000				$ 30,000	$ 1,081,782
2028	130,245,570,000	10,419,646	1,220	0.5		$ 272,261	$ -	$242,500				$ 60,000	$ 574,761
2029	65,704,527,000	5,256,362	615	-		$ -	$ -	$250,000				$ 30,000	$ 280,000
2030	-	-	-	-		$ -	$ -						$ -
2031										$ 54,638			$ 54,638
2032										$ 56,277			$ 56,277
2033										$ 57,966			$ 57,966
2034										$ 59,705			$ 59,705
2035										$ 61,496			$ 61,496
2036										$ 63,341			$ 63,341
2037										$ 65,241			$ 65,241
2038										$ 67,198			$ 67,198
2039										$ 69,214			$ 69,214
2040										$ 71,290			$ 71,290
2041										$ 73,429			$ 73,429
2042										$ 75,632			$ 75,632
2043										$ 77,901			$ 77,901
2044										$ 80,238			$ 80,238
2045										$ 82,645			$ 82,645
2046										$ 85,124			$ 85,124
2047										$ 87,678			$ 87,678
2048										$ 90,308			$ 90,308
2049										$ 93,018			$ 93,018
2050										$ 95,808			$ 95,808

TABLE 10. COST TO GENERATE ELECTRICITY FROM ENHANCED LANDFILLING FOR CASE 4

Benefit to Cost Ratio =1; Energy Sale Price = 8.22 cents per kWh; Discount Rate = 3%

Year	Additional Liner Const. Costs	Module under const.	Liquid Management System Const. Costs	Surface Liner Const. Costs	Gas Recovery System Costs	Electric Generation Equipment (principal)	Electric Generation Equipment (interest)	Equip Capacity (MgW)	Interconnect, other fees and contingency	$100,000/MW per MW Energy equip O & M	Equipment Decom-missioning cost	Increased Gas and Leachate Monitoring Costs	Liquid System Maint.	Collection System O&M	Royalty	TOTAL COSTS
1997	$ 1,100,000	C	$ 200,000													$1,300,000
1998												$ 5,000				$ 5,000
1999	$ 1,166,990	D	$ 212,180									$ 5,150				$1,384,320
2000						$ 1,228,767		1.0	$ 380,000	$ 126,677		$ 5,305	$ 25,000			$1,765,748
2001	$ 1,238,060	E	$ 225,102					1.0		$ 130,477		$ 5,464	$ 25,250			$1,624,352
2002						$ 651,799		1.5		$ 201,587		$ 5,628	$ 25,503			$ 884,517
2003	$ 1,313,458	F	$ 238,810			$ 671,353		2.0		$ 276,847		$ 5,796	$ 25,758			$2,532,022
2004								2.0		$ 285,152		$ 5,970	$ 26,015			$ 317,138
2005	$ 1,393,447	G	$ 253,354			$ 712,239		2.5		$ 367,133		$ 6,149	$ 26,275			$2,758,598
2006								2.5		$ 378,147		$ 6,334	$ 26,538			$ 411,019
2007	$ 1,478,308	H	$ 268,783			$ 755,614		3.0		$ 467,390		$ 6,524	$ 26,803			$3,003,423
2008								3.0		$ 481,412		$ 6,720	$ 27,071			$ 515,203
2009	$ 1,568,337	I	$ 285,152					3.0		$ 495,854		$ 6,921	$ 27,342			$2,383,607
2010						$ 825,680		3.5		$ 595,852		$ 7,129	$ 27,616			$1,456,276
2011	$ 1,663,849	J	$ 302,518					3.5		$ 613,727		$ 7,343	$ 27,892			$2,615,328
2012								3.5		$ 632,139		$ 7,563	$ 28,171			$ 667,873
2013	$ 1,765,177	K	$ 320,941					3.5		$ 651,103		$ 7,790	$ 28,452			$2,773,464
2014								3.5		$ 670,636		$ 8,024	$ 28,737			$ 707,397
2015	$ 1,872,676	L	$ 340,487			$ 957,189		4.0		$ 789,435		$ 8,264	$ 29,024			$3,997,076
2016								4.0		$ 813,118		$ 8,512	$ 29,314			$ 850,944
2017	$ 1,986,722	M	$ 361,222					4.0		$ 837,511		$ 8,768	$ 29,608			$3,223,831
2018	$ 2,046,324	N	$ 372,059					4.0		$ 862,637		$ 9,031	$ 29,904			$3,319,954
2019	$ 2,107,714	O	$ 383,221					4.0		$ 888,516		$ 9,301	$ 30,203			$3,418,954
2020	$ 2,170,945	P	$ 394,717			$ 1,109,645		4.5		$ 1,029,567		$ 9,581	$ 30,505			$4,744,960
2021								4.5		$ 1,060,454		$ 9,868	$ 30,810			$1,101,132
2022								4.0		$ 970,905		$ 10,164	$ 31,118			$1,012,187
2023								4.0		$ 1,000,032		$ 10,469	$ 31,429			$1,041,930
2024								3.0		$ 772,525		$ 10,783	$ 31,743			$ 815,051
2025								2.0		$ 530,467		$ 11,106	$ 32,061			$ 573,634
2026								2.0		$ 546,381		$ 11,440	$ 32,381			$ 590,202
2027								1.5		$ 422,079		$ 11,783	$ 32,705			$ 466,567
2028								0.5		$ 144,914		$ 12,136	$ 33,032			$ 190,083
2029								-		$ -		$ 12,500	$ 33,363			$ 45,863
2030								-		$ -	$ 250,000	$ 12,875	$ 33,696			$ 296,572

TABLE 11. BENEFIT TO GENERATE ELECTRICITY FROM ENHANCED LANDFILLING FOR CASE 4

Benefit to Cost Ratio =1; Energy Sale Price = 8.22 cents per kWh; Discount Rate = 3%

Year	BTU Content (900 BTU per 1 ft3 of CH$)	kWh (12,500 BTU is 1 kWh)	kW of power (kWh/ 8760 hr/yr)	Equip Capacity MW	Tax Credit multiplier	Energy Sales (20% down-time)	Tax Credit Revenue	Leachate Treatment Savings	Landfill Life Extension	Closure Cost Savings	Royalty	Elec Equipment Salvage	TOTAL BENEFITS
1997	-	-	-		1.00	$ -	$ -						$ -
1998	38,944,395,000	3,115,552	365		1.03	$ -	$ 40,113						$ 40,113
1999	79,052,274,000	6,324,182	740		1.06	$ -	$ 83,795	$ 25,000					$ 108,795
2000	120,323,637,000	9,625,891	1,127	1.0	1.09	$ 576,058	$ 131,153	$ 32,500					$ 739,710
2001	162,758,484,000	13,020,679	1,524	1.0	1.13	$ 576,058	$ 183,917	$ 40,000					$ 799,975
2002	206,356,815,000	16,508,545	1,932	1.5	1.16	$ 864,086	$ 239,374	$ 47,500					$ 1,150,960
2003	251,118,630,000	20,089,490	2,351	2.0	1.19	$ 1,152,115	$ 298,831	$ 55,000					$ 1,505,946
2004	297,043,929,000	23,763,514	2,781	2.0	1.23	$ 1,152,115	$ 365,364	$ 62,500					$ 1,579,979
2005	344,132,712,000	27,530,617	3,222	2.5	1.27	$ 1,440,144	$ 437,049	$ 70,000					$ 1,947,193
2006	392,384,979,000	31,390,798	3,674	2.5	1.30	$ 1,440,144	$ 510,100	$ 77,500					$ 2,027,744
2007	402,856,335,000	32,228,507	3,772	3.0		$ 1,728,173	$ -	$ 85,000					$ 1,813,173
2008	413,327,691,000	33,066,215	3,870	3.0		$ 1,728,173	$ -	$ 92,500					$ 1,820,673
2009	423,799,047,000	33,903,924	3,968	3.0		$ 1,728,173	$ -	$100,000					$ 1,828,173
2010	434,270,403,000	34,741,632	4,066	3.5		$ 2,016,202	$ -	$107,500					$ 2,123,702
2011	444,741,759,000	35,579,341	4,164	3.5		$ 2,016,202	$ -	$115,000					$ 2,131,202
2012	455,213,115,000	36,417,049	4,262	3.5		$ 2,016,202	$ -	$122,500					$ 2,138,702
2013	465,684,471,000	37,254,758	4,360	3.5		$ 2,016,202	$ -	$130,000					$ 2,146,202
2014	476,155,827,000	38,092,466	4,458	3.5		$ 2,016,202	$ -	$137,500					$ 2,153,702
2015	486,627,183,000	38,930,175	4,556	4.0		$ 2,304,230	$ -	$145,000					$ 2,449,230
2016	497,098,539,000	39,767,883	4,654	4.0		$ 2,304,230	$ -	$152,500					$ 2,456,730
2017	507,569,895,000	40,605,592	4,753	4.0		$ 2,304,230	$ -	$160,000					$ 2,464,230
2018	518,041,251,000	41,443,300	4,851	4.0		$ 2,304,230	$ -	$167,500					$ 2,471,730
2019	528,512,607,000	42,281,009	4,949	4.0		$ 2,304,230	$ -	$175,000					$ 2,479,230
2020	538,983,963,000	43,118,717	5,047	4.5		$ 2,592,259	$ -	$182,500					$ 2,774,759
2021	549,455,319,000	43,956,426	5,145	4.5		$ 2,592,259	$ -	$190,000					$ 2,782,259
2022	493,058,664,000	39,444,693	4,617	4.0		$ 2,304,230	$ -	$197,500				$ 30,000	$ 2,531,730
2023	435,498,525,000	34,839,882	4,078	4.0		$ 2,304,230	$ -	$205,000				$ 60,000	$ 2,569,230
2024	376,774,902,000	30,141,992	3,528	3.0		$ 1,728,173	$ -	$212,500					$ 1,940,673
2025	316,887,795,000	25,351,024	2,967	2.0		$ 1,152,115	$ -	$220,000	$ -			$ 60,000	$ 1,432,115
2026	255,837,204,000	20,466,976	2,395	2.0		$ 1,152,115	$ -	$227,500					$ 1,379,615
2027	193,623,129,000	15,489,850	1,813	1.5		$ 864,086	$ -	$235,000				$ 30,000	$ 1,129,086
2028	130,245,570,000	10,419,646	1,220	0.5		$ 288,029	$ -	$242,500				$ 60,000	$ 590,529
2029	65,704,527,000	5,256,362	615	-		$ -	$ -	$250,000				$ 30,000	$ 280,000
2030	-	-	-	-		$ -	$ -						$ -
2031										$ 54,638			$ 54,638
2032										$ 56,277			$ 56,277
2033										$ 57,966			$ 57,966
2034										$ 59,705			$ 59,705
2035										$ 61,496			$ 61,496
2036										$ 63,341			$ 63,341
2037										$ 65,241			$ 65,241
2038										$ 67,198			$ 67,198
2039										$ 69,214			$ 69,214
2040										$ 71,290			$ 71,290
2041										$ 73,429			$ 73,429
2042										$ 75,632			$ 75,632
2043										$ 77,901			$ 77,901
2044										$ 80,238			$ 80,238
2045										$ 82,645			$ 82,645
2046										$ 85,124			$ 85,124
2047										$ 87,678			$ 87,678
2048										$ 90,308			$ 90,308
2049										$ 93,018			$ 93,018
2050										$ 95,808			$ 95,808

Figure 1. CASE 1, PRESENT VALUE OF COSTS AND BENEFITS
Shown in 1997 Dollars
Benefit to Cost Ratio = 1.0 Energy Sale Price = 3.49 cents/kWh Discount Rate = 3%

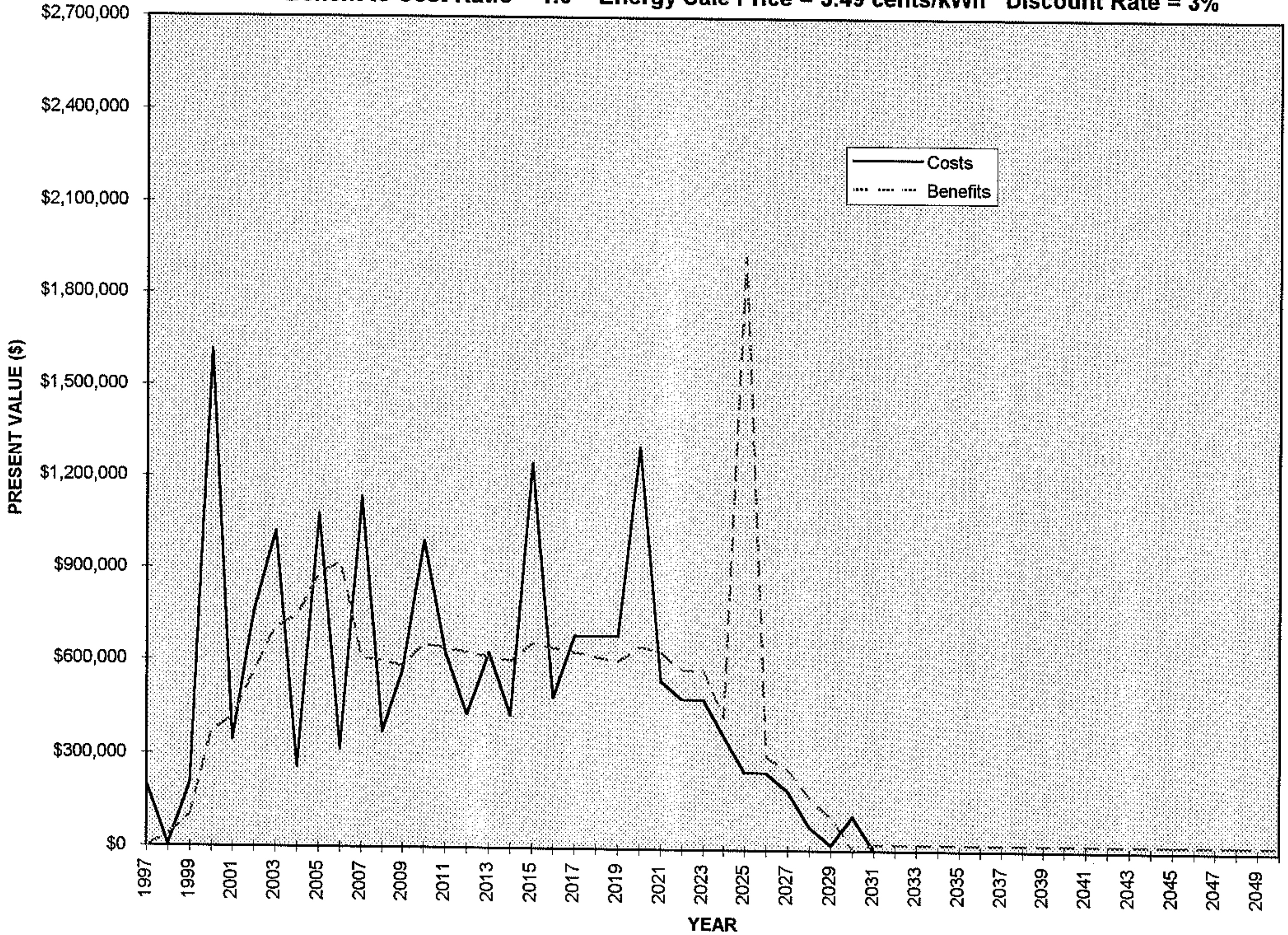


Figure 2. CASE 2, PRESENT VALUE OF COSTS AND BENEFITS
Shown in 1997 Dollars
Benefit to Cost Ratio = 1.0 Energy Sale Price = 3.93 cents/kWh Discount Rate = 3%

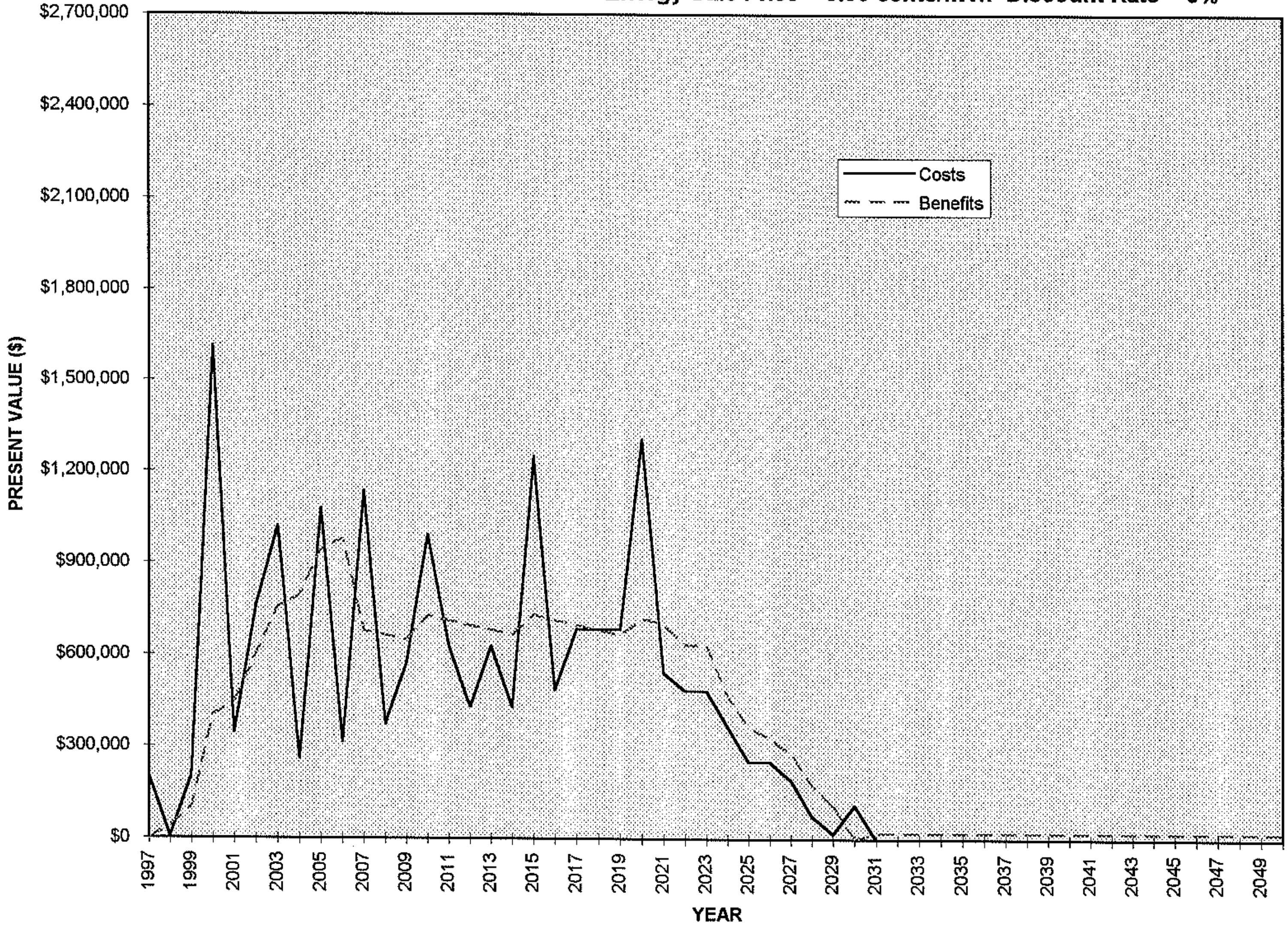


Figure 3. CASE 3, PRESENT VALUE OF COSTS AND BENEFITS
Shown in 1997 Dollars
Benefit to Cost Ratio = 1.0 Energy Sale Price = 7.77 cents/kWh Discount Rate = 3%

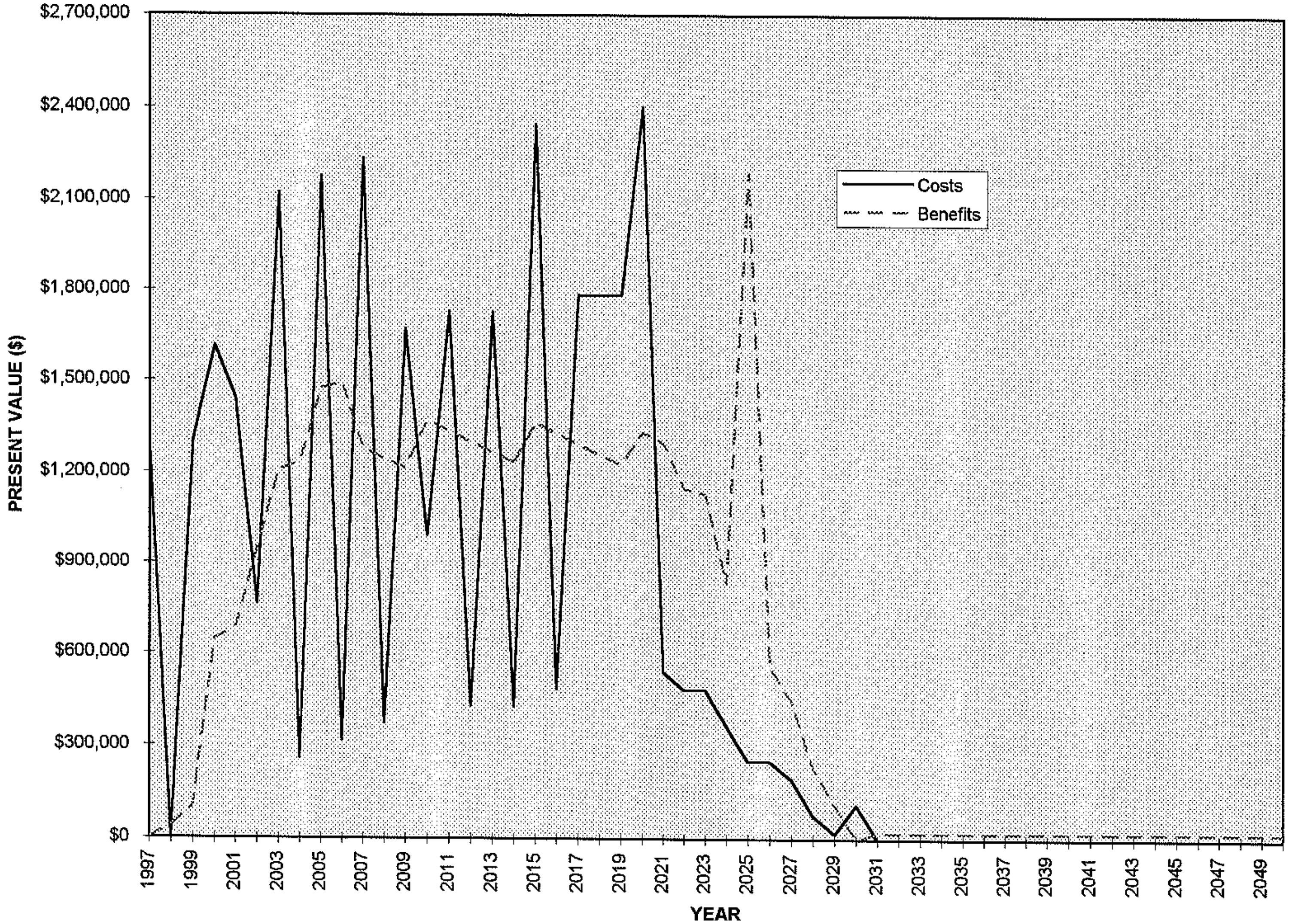


Figure 4. CASE 4, PRESENT VALUE OF COSTS AND BENEFITS
Shown in 1997 Dollars
Benefit to Cost Ratio = 1.0 Energy Sale Price = 8.22 cents/kWh Discount Rate = 3%

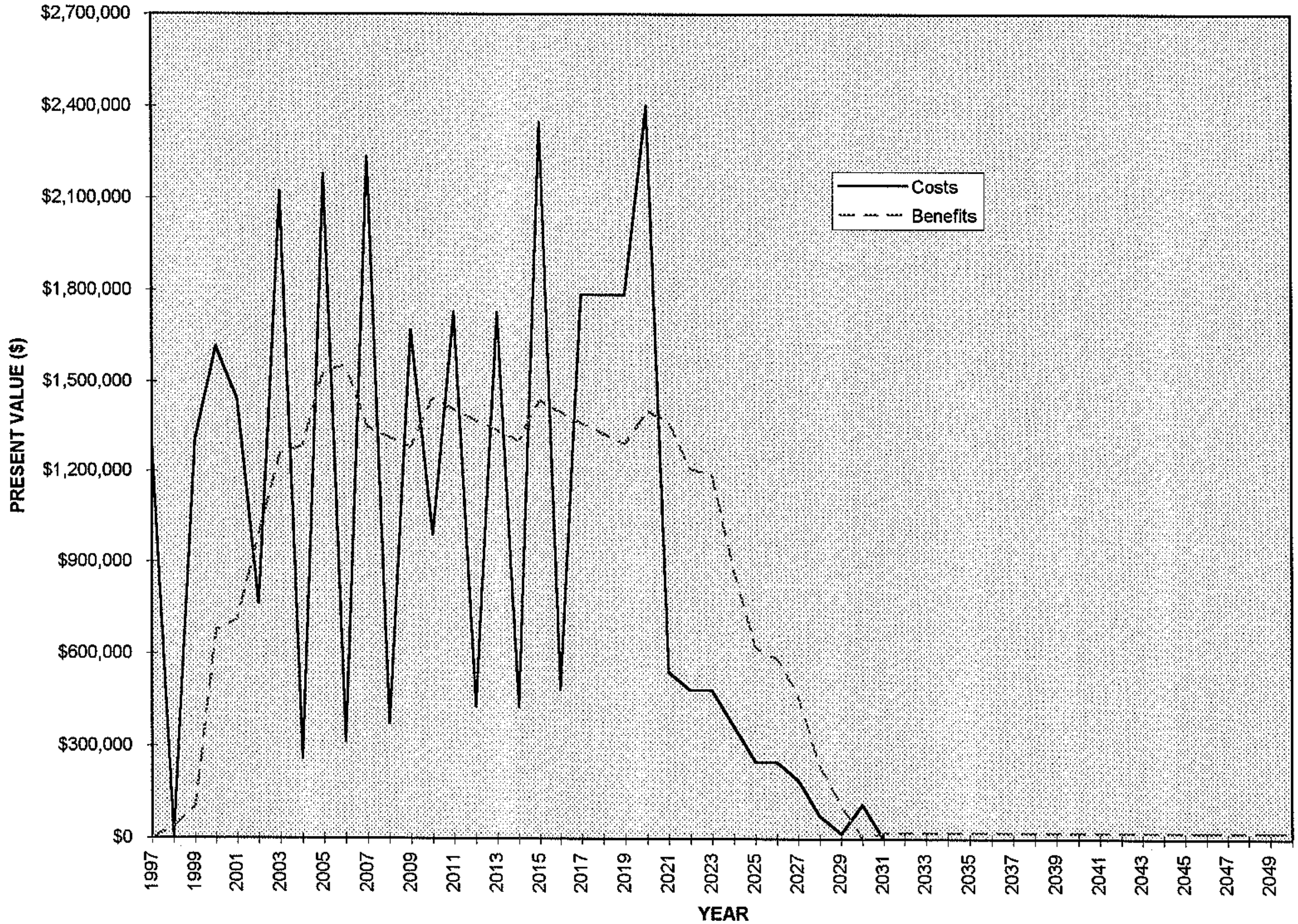


Figure 5. Benefit to Cost Ratio Versus Energy Sale Price for Case 1

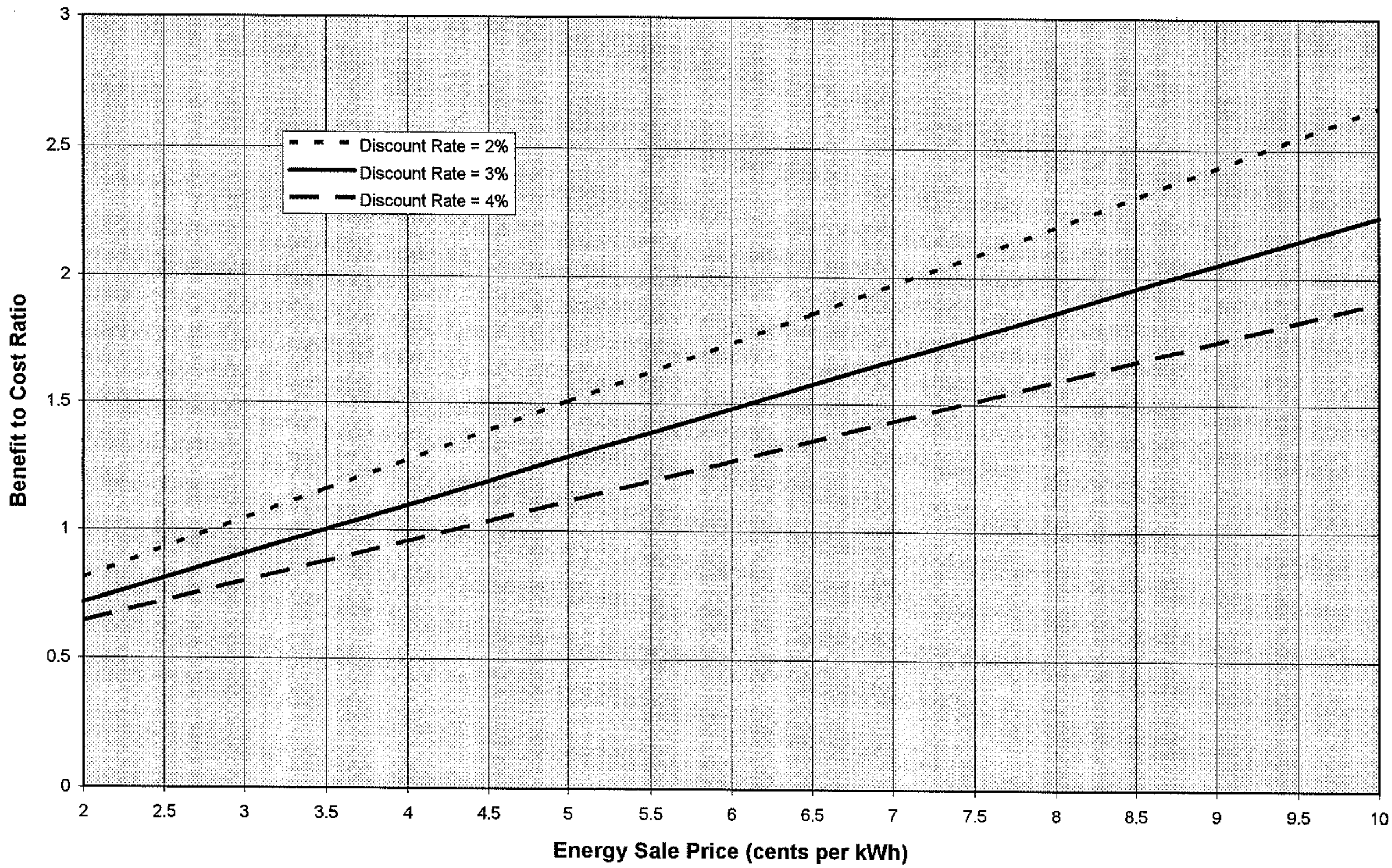


Figure 6. Benefit to Cost Ratio Versus Energy Sale Price for Case 2

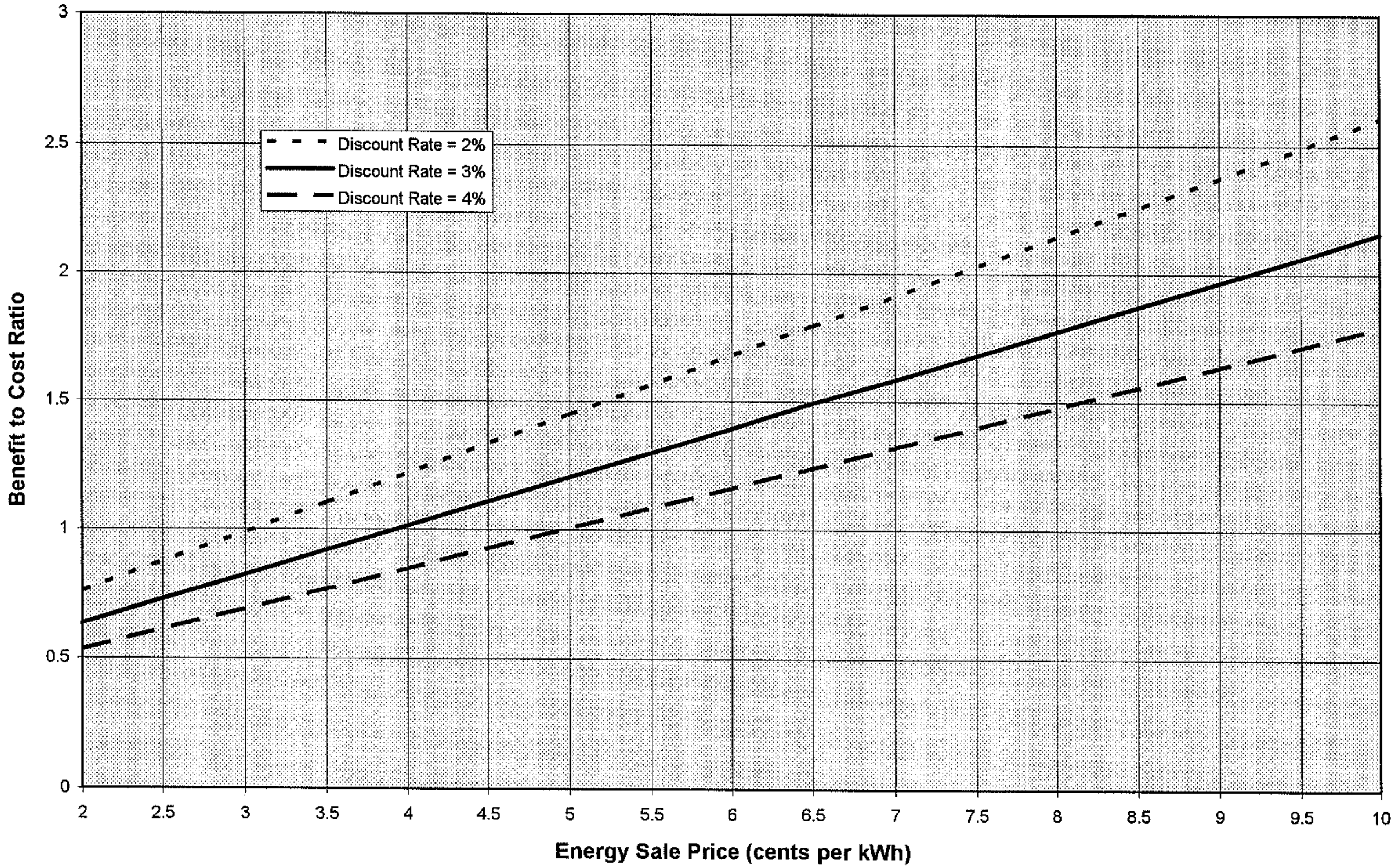


Figure 7. Benefit to Cost Ratio Versus Energy Sale Price for Case 3

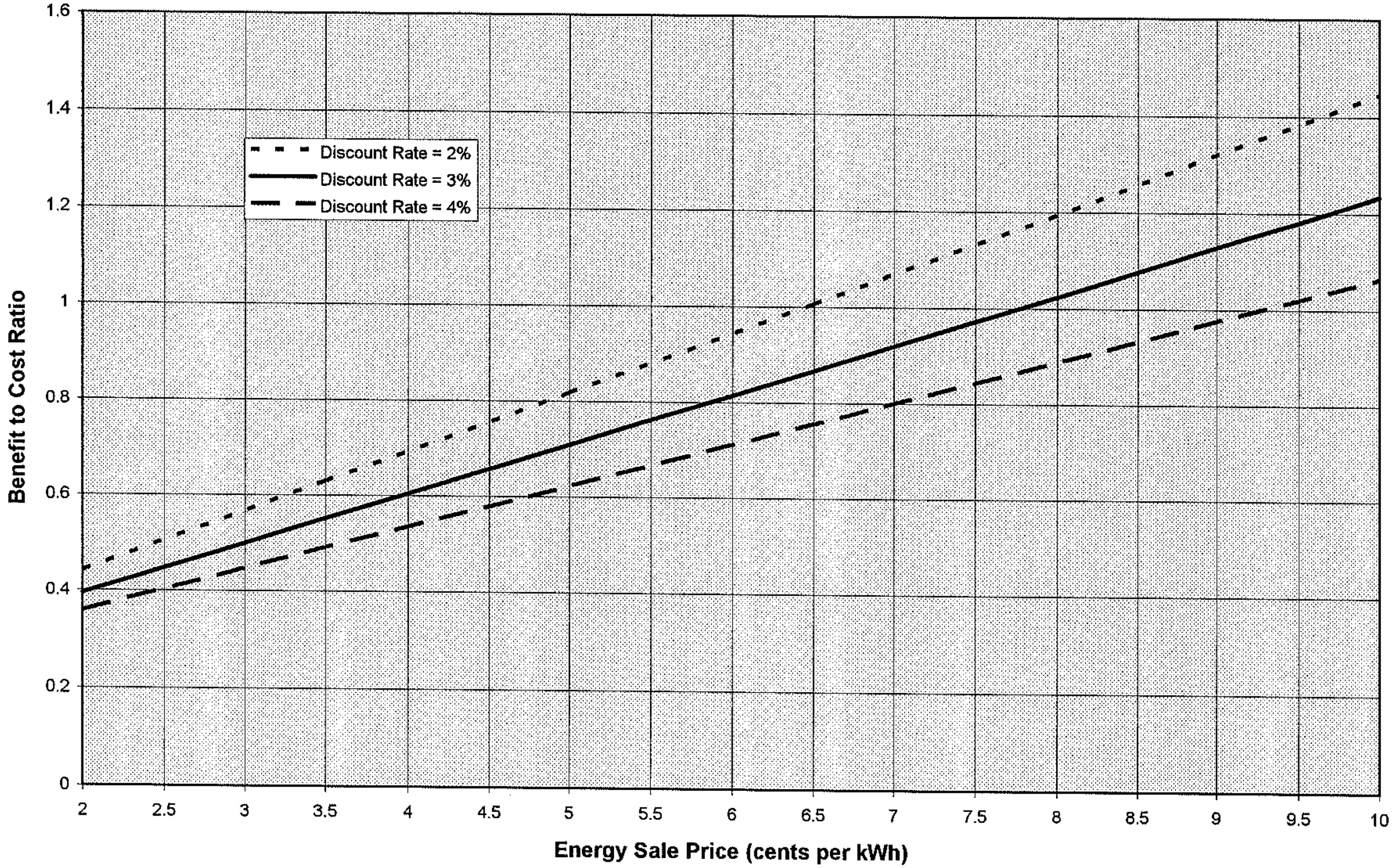


Figure 8. Benefit to Cost Ratio Versus Energy Sale Price for Case 4

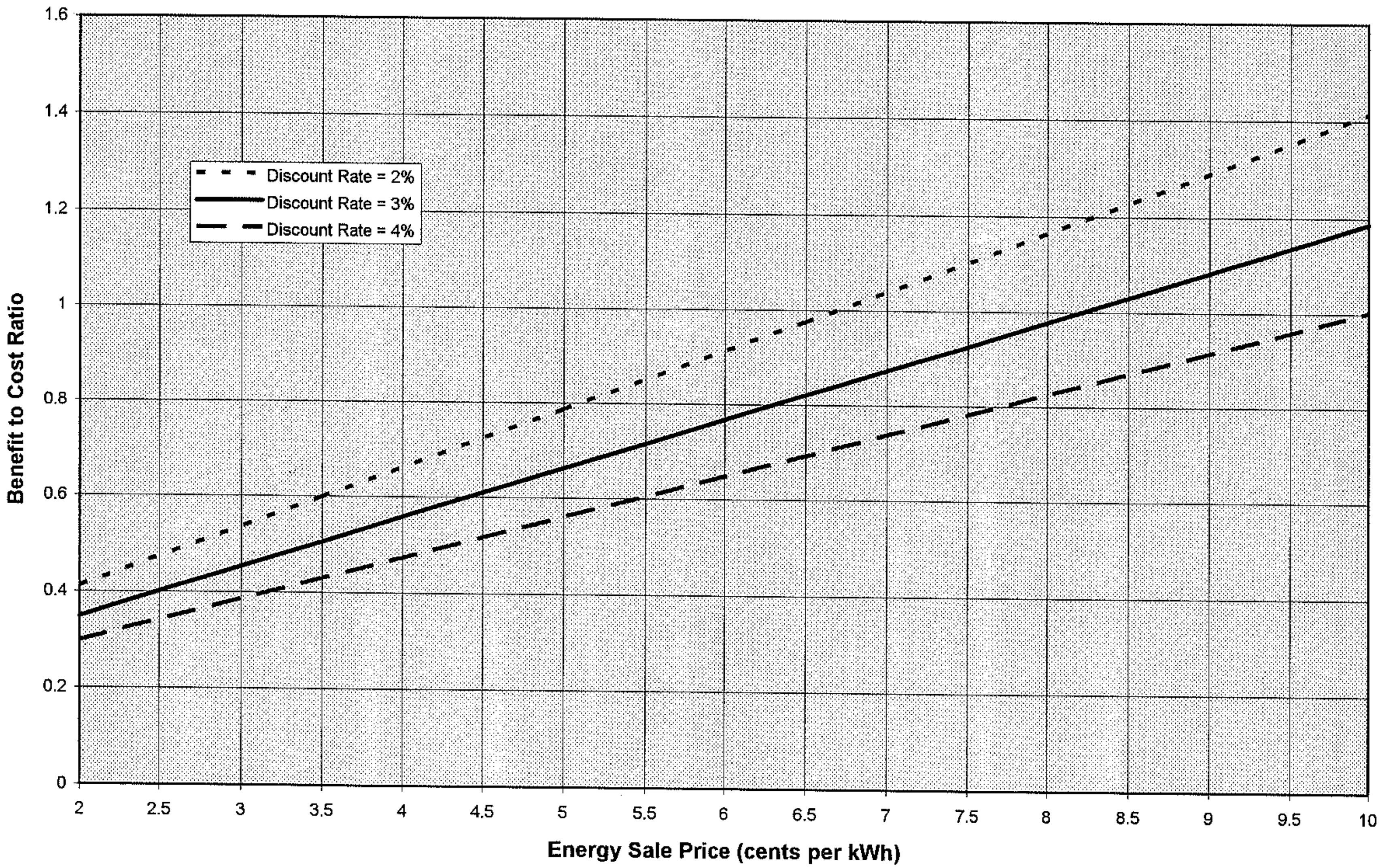


Figure 9. **Energy Sale Price Versus Discount Rate for Benefit to Cost Ratio = 1**