County of Yolo

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January 20, 2000

Mr. Gary M. Carlton
Executive Officer
California Regional Water Quality Control Board
Central Valley Region
3443 Routier Road, Suite A
Sacramento, California 95827-3003

Re: PROPOSED LANDFILL BIOREACTOR PROJECT, YOLO COUNTY CENTRAL LANDFILL, YOLO COUNTY

Dear Mr. Carlton,

PURPOSE OF LETTER

The County is requesting to operate the Module D WMU as a bioreactor. Based on the information provided within this letter, it is the County's opinion that all of the RWQCB's concerns have been addressed. The County will be submitting the proposed revisions to its operating permit in the form of a JTD on February 1, 2000. We hope that this letter addresses the concerns that the RWQCB have regarding the operation of the Module D WMU as a bioreactor.

BACKGROUND

As you are aware, the County of Yolo Department of Planning and Public Works (County) is proposing to operate its Waste Management Unit 6, Module D as a landfill bioreactor. The design report and CQA Plan for Module D was approved for use as a Class III Landfill by the Regional Water Quality Control Board, Central Valley Region (RWQCB) on July 8, 1999. On August 18, 1999, an additional letter was sent from the RWQCB discussing an August 10, 1999 meeting between the RWQCB, County, and US EPA concerning the proposed bioreactor. That letter expressed reservations by the RWQCB over operation of the Module D unit as a bioreactor. The reservations listed in the August 18, 1999 letter included State regulatory, design, and operational issues regarding the proposed landfill bioreactor.

The Yolo County Central Landfill bioreactor project is being proposed as a partnership with regulatory agencies and other entities pursuant to the US EPA XL Program. The purpose of this US EPA Program is to increase regulatory flexibility for technologies that can attain environmental benefits and/or cost-effectiveness superior to "conventional" practice. Under the XL Program, the County is currently preparing a draft Final Project Agreement (FPA) for review by project partners in mid January. Following review and comments, the final FPA will be completed by February 14, 2000.

On December 15, 1999, a meeting was held with RWCQB staff, the County, and the engineering consultants involved with the construction and design of the new leachate surface impoundment (WMU H) and Module D (Vector Engineering, Inc. and Golder Associates). At this meeting, the final construction quality assurance certification reports for WMU H and Module D were presented for approval. In addition, a presentation on the Project XL Bioreactor Landfill Proposal was presented followed by a discussion as to the suitability of Module D for use as a bioreactor. Based on the discussion, the following letter has been prepared to address the RWQCB's concerns.

This letter has been organized to provide the history of previous bioreactor experience at the Yolo County Central Landfill, a general description and current operation of bioreactors, present the State regulatory authority to operate Module D as a bioreactor, address the design elements of the Module D construction that make it suitable for use as a bioreactor, discuss the operational procedures that will be employed, and lastly present the conclusion. The County will be applying for a revision to its current landfill permit in the form of a Joint Technical Document to be submitted February 1, 2000.

YOLO COUNTY BIOREACTOR EXPERIENCE

During the construction of the Module B WMU in 1993, the County included the design and installation of two 10,000 square foot test cells. One cell (Control Cell) simulated normal landfill operations and waste containment. The second cell (Enhanced Cell) was operated as a landfill bioreactor with liquid recirculation. The test cells were filled with municipal solid waste to depths of approximately 45 feet and surrounded by compacted clay levee sidewalls. Following waste placement, a layer of shredded tires was placed over the top of the refuse as a horizontal gas collection layer and then a geosynthetic cap was installed. A paper by Augenstein[1] discusses the demonstration project.

Moisture and temperature sensors were embedded in the waste at various levels during refuse placement. A liquid pressure transducer was placed in the leachate collection pipe on the base of the cells to monitor the build-up of hydrostatic head. In order to distribute liquid throughout the enhanced test cell, a liquid infiltration system using

[1] Augenstein, Don et al, "Yolo County Controlled Landfill Demonstration Project", SWANA Landfill Gas Symposium, Monterey, California, March 1997

horizontal trenches with a distribution manifold was installed. Landfill gas was extracted with vertical wells in conjunction with the shredded tire layer below the cap. The landfill gas collected from the test cells was connected to the main collection system and flow was measured separately by corrosion resistant positive displacement rotary gas meters.

Because of the low moisture in "typical" municipal refuse, leachate generation is limited and is generally not sufficient as the sole means of liquid enhancement. For a bioreactor, the moisture content of the refuse is brought up to its field capacity. For the enhanced cell, a combination of leachate and groundwater was used as the source of liquid. The amount of liquid was carefully controlled using the pipe manifold and monitoring the moisture sensors in the refuse. The volume of groundwater/leachate added and the amount of leachate generated during the enhancement was monitored to estimate the moisture necessary to obtain field capacity as well as evaluate liquid channeling through the waste.

Waste field capacity is the maximum moisture content that a solid waste sample can hold without draining, disregarding the effects of channeling. The total amount of supplemental liquid added to the enhanced cell was 377,690 gallons. After stopping the addition of supplemental liquid, the leachate generated was recirculated and continued to be absorbed by the waste. Using the initial waste mass and a 20% as-placed moisture content, the moisture content of the waste after absorption of the supplemental liquid was 48% on a dry weight basis. Because virtually all of the supplemental liquid added has been absorbed, it is surmised that the moisture content has not yet exceeded field capacity. Additional findings from the demonstration project were discussed in a paper by Moore, Dahl, and Yazdani[2]. This was verified by drilling into the waste and obtaining samples at various depths last fall, October 1999. In no samples was free liquid present in the waste.

To determine the effectiveness of operating a landfill as a bioreactor, settlement, gas generation, and leachate quality were analyzed for both the enhanced and control cells. As of May 1999, settlement in the enhanced cell was over six times that of the control cell. Leachate quality in the enhanced cell showed significant improvement over a four-year monitoring period. The enhanced cell generated significantly more landfill gas with a higher methane content than the control cell. In all respects, the small-scale demonstration project showed significant benefits of operating a landfill as a bioreactor.

LANDFILL BIOREACTORS

In order to give the RWQCB a broad overview of landfill bioreactor technology and usage, this section of the letter is intended to describe bioreactors in general, discuss

[2] Moore, Dahl, and Yazdani, "Hydraulic Characteristics of Municipal Solid Waste: Findings of the Yolo County Bioreactor Landfill Project", Thirteenth International Conference on Solid Waste Technology and Management, Philadelphia, PA, November 1997.

their benefits, provide a few examples regarding operating bioreactors, and present the proposed bioreactor for Module D. More detailed information regarding bioreactor landfills can be found in a paper by Pacey[3].

A bioreactor landfill is a sanitary landfill that uses enhanced microbiological processes to transform and stabilize the readily and moderately decomposable organic waste constituents within 5 to 10 years of bioreactor process implementation. The bioreactor landfill significantly increases the extent of organic waste decomposition, conversion rates, and process effectiveness over what would otherwise occur within the landfill. Stabilization means that the environmental performance measurement parameters (landfill gas composition and generation rate and leachate constituent concentrations) remain at steady levels, and should not increase in the event of any partial containment system failures beyond 5 to 10 years of bioreactor process implementation.

The bioreactor landfill requires certain specific management activities and operational modifications to enhance microbial decomposition processes. The single most important and cost-effective method is liquid addition and management. Other strategies, including waste shredding, pH adjustment, nutrient addition, waste pre-disposal and post-disposal conditioning, and temperature management, may also serve to optimize the bioreactor process. Successful implementation also requires the development and implementation of focused operational and development plans.

In effect, the bioreactor landfill is merely an extension of the accepted Subtitle D leachate recirculation landfill option. However, the bioreactor process requires significant liquid addition to reach and maintain optimal conditions. Leachate alone is usually not available in sufficient quantity to sustain the bioreactor process. Water or other non-toxic or non-hazardous liquids and semi-liquids are suitable amendments to supplement leachate (depending on climatic conditions and regulatory approval). Other process amendment strategies may also be included, subject to regulatory approval.

Shortly following closure of a bioreactor landfill, the landfill gas generation rate will usually be at its highest. It will then quickly decline over the next 5 to 10 years to a stable and relatively low and declining rate. Similarly, shortly after landfill closure, many leachate contaminant concentrations will change from levels regarded as highly polluted to much lower levels normally characteristic of extended stabilization. The leachate quantity at closure will be a finite amount, amenable to on-site treatment with limited need for off-site transfer, treatment, and disposal. In the event of post-closure partial containment system failure, the quality of the leachate generated from infiltration into a bioreactor landfill will be much better than other drier Subtitle D landfills.

Evidence suggests that bioreactor landfills can meet Subtitle D requirements. A 1997 SWANA survey of 130 US bioreactor landfills indicates that most environmental and

[3] Pacey et al. "The Bioreactor Landfill- An Innovation In Solid Waste Management", 3rd Annual SWANA Landfill Symposium, Palm Beach Gardens, Florida, June 1998.

other relevant concerns have been resolved; information on leachate recirculating landfills in existence worldwide is similarly positive.

Numerous benefits can be derived from the bioreactor landfill. These are situation-dependent and can affect different parties or stakeholders in different ways. They can accrue in the form of environmental, regulatory, monetary and social benefits. Some of the key benefits include:

Rapid organic waste conversion/ stabilization

- Rapid settlement - volume reduced and stabilization within 5 to 10 years of bioreactor process implementation.
- Increased gas unit yield, total yield and flow rate – almost all of the rapid and moderately decomposable organic constituents will be degraded within 5 to 10 years of closure.
- Improved leachate quality - stabilizes within 3 to 10 years after closure.
- Early land use possible following closure.

Maximizing of landfill gas capture for energy recovery projects

- Significant increase in total gas available for energy use, which provides entrepreneurial opportunities.
- Potential increase in total landfill gas extraction efficiency (enabled over a shorter generation period).
- Increased greenhouse gas reduction from lessened emissions.
- Increase in fossil fuel offsets due to increased gas energy sales.
- Assistance in defraying landfill gas non-funded environmental costs.
- Significant economy of scale advantage due to high generation rate over relatively short time.

Increased landfill space capacity reuse due to rapid settlement during operational time period

- Increase in the amount of waste that can be placed into the permitted landfill airspace (effective density increase).
- Extension of landfill life through additional waste placement.
- Deferred capital and financing costs needed to locate, permit, and construct replacement landfill results in capital and interest savings.
- Significant increase in realized waste disposal revenues.

Improved leachate treatment and storage

- Low cost partial or complete treatment; significant biological and chemical transformation of both organic and inorganic constituents, although mostly relevant to the organic constituents.
- Reintroduction of all leachate over most of the operational and post-closure care period significantly reduces leachate disposal costs.

- Absorption of leachate within landfill available up to field capacity.

Reduction in post-closure care, maintenance and risk

- Rapid waste stabilization (within 5 to 10 years) minimizes environmental risk and liability due to settlement, leachate, and gas.
- Landfill operation and maintenance activities are considerably reduced.
- Landfill monitoring activities can be reduced.
- Reduction of financial package requirement.
- In the event of partial liner failure, there should be no risk of increased gas generation, worsening leachate quality, increased settlement rate or magnitude.

Another major benefit of bioreactors may come from greenhouse gas abatement. Bioreactors can generally rapidly complete methane generation while attaining maximum yield. This can be combined with nearly complete capture of generated gas using the bioreactor landfill in combination with a landfill gas to energy project. With this approach, the high generation level and gas capture efficiency maximizes landfill greenhouse gas offset potential.

Example Bioreactor Landfill Activities

Several demonstration and full-scale bioreactor projects are on going throughout the United States. A brief listing of a few of these projects in several states is presented below.

- **California:** Since 1993, Yolo County began operating a bioreactor demonstration cell that contains 9,000 tons of refuse.
- **Delaware:** The Delaware Solid Waste Authority has operated the Major Landfill (largest in the state) at Sandtown as a bioreactor for more than 10 years.
- **Florida:** The state recently allocated more than 3.2 million dollars to establish a demonstration bioreactor landfill.
- **Georgia:** Two aerobic bioreactor landfill projects are operational; one at the Live Oak Landfill in Atlanta, the other at the Baker Road Landfill in Columbia County
- **Iowa:** The Bluestem Solid Waste Authority has received a $500,000 state grant for its bioreactor project at the Bluestem #2 Landfill near Marion. Waste placement commenced in December 1998 and the demonstration project should receive final cover in June 1999.
- **New York State:** An anaerobic bioreactor operation is being carried out at the Mill Seat Landfill; a pretreatment aerobic bioreactor activity is operational at Elmira.
- **South Carolina:** The State Research and, Development and Demonstration Program is sponsoring an aerobic activity at the Aiken County Landfill.
- **Washington State:** Washington Administrative Code 173-351-200(9) specifically permits bioreactor landfills. The pertinent section on operating criteria on liquid restrictions states, "Bulk or non-containerized liquid waste may

not be placed in MSWLF units unless: (ii) the waste is leachate or gas condensate derived from the MSWLF unit, or water added in a controlled fashion and necessary for enhancing decomposition of solid waste, as approved during the permitting process of WAC 173-351-700, whether it is a new or existing MSLF or lateral expansion."

Yolo County is proposing to implement Module D with both anaerobic and aerobic bioreactor sections. A major part of the landfill module will be operated in an anaerobic manner. The anaerobic process performance has already been well documented with encouraging findings demonstrated for over three years of operation at the 9,000-ton scale. An aerobic sector will also be constructed, of a size large enough (roughly six acres) to determine performance parameters at depths and compactions typical of expected full-scale operation. The anaerobic and aerobic operations can be summarized very briefly.

The full-scale Yolo County anaerobic bioreactor "controlled" landfill will combine two key elements:

a) Acceleration of waste decomposition and leachate treatment, via liquid amendments and recirculation through a piping network. This is to accomplish rapid completion of waste stabilization and generation of methane to the maximum practical yield.

b) Highly efficient capture of nearly all generated methane, via a freely gas-permeable shredded tire collection layer beneath a very low-permeability cap. The shredded tire collection layer has a gas permeability from 3 to 5 orders of magnitude higher than the overlying soil. Near-complete extraction with this system has already been demonstrated in the 9,000-ton test cell.

Compared to the anaerobic bioreactor, the aerobic bioreactor decomposes the organic fraction of the refuse by circulating air as well as moisture through the waste. This aeration is considered to result in rapid oxidation of the degradable waste components, (although rate measurements have been limited). The aerobic process also, through heating and oxygen inhibition effects, reduces methane generation per unit waste destroyed. The aerobic landfill bioreactor thus accomplishes waste destruction in a manner closely analogous to waste composting in windrows, the major difference being that waste organic composting occurs within the landfill itself.

REGULATIONS REGARDING RECIRCULATION OF LIQUIDS

Several sections of the California Code of Regulations (CCR), Title 27, Environmental Protection, address the recirculation of liquids in lined municipal waste landfills. While the regulations do not specifically endorse bioreactors like the regulations in the State of

Washington, regulatory flexibility is provided. This portion of the letter will describe specific regulations in Title 27 regarding recirculation. Later sections of this letter will provide design and operational procedures that will be implemented within Module D to allow the RWQCB to grant the exception allowed by the regulations.

Title 27, Chapter 3, Subchapter 2, Article 2, Section 20200, Part (d)(3), *Management of liquids at Landfills and Waste Piles* states the following:

"Liquid or semi-solid waste (i. e. waste containing less than 50% solids, by weight), other than dewatered sewage or water treatment sludge as described in § 20220 (c), shall not be discharged to Class III landfills. Exceptions may be granted by the RWQCB if the discharger can demonstrate that such discharge will not exceed the moisture holding capacity of the waste either initially, or as the result of waste management operations, compaction, or settlement, so long as such discharge is not otherwise prohibited by applicable state or federal requirements".

The above regulation specifically allows the RWQCB the ability to grant an exception regarding the discharge of liquids into a Class III landfill providing the moisture holding capacity is not exceeded. The previous demonstration project at the Yolo County Central Landfill provided a working demonstration as to the feasibility of the proposed bioreactor project. Through monitoring, instrumentation, and testing, it was demonstrated that liquid could be added in such a way that the holding capacity of the refuse is not exceeded. The same equipment and procedures will be utilized for the Module D bioreactor. Specific sections of this letter provide details regarding the method of liquid recirculation as well as design improvements for Module D that will ensure groundwater protection.

It should be noted that the preceding Part in the regulations (Section 20200, Part (d)(2) addresses the discharge of waste containing free liquids and does not apply to this application. The County is not proposing to discharge wastes containing free liquids, but is instead proposing to add liquids or semi-solid waste to the refuse already in-place. While the regulations state that wastes containing free liquids must be discharged to a Class II waste pile, the addition of liquids to existing waste in a Class III landfill is allowed by the regulations if an exception is granted by the RWQCB.

Title 27, Chapter 3, Subchapter 2, Article 4, Section 20340, Part (g)(1,2,3), *Leachate Collection and Removal Systems* states the following:

"Leachate Handling – Except as otherwise provided under SWRCB Resolution No. 93-62 (for MSW landfills subject to 40CFR258.28), collected leachate shall be returned to the Unit(s) from which it came or discharged in another manner approved by the RWQCB. Collected leachate can be discharged to a different Unit only if:

(1) the receiving Unit has an LCRS, contains wastes which are similar in classification and characteristics to those in the Unit(s) from which leachate

was extracted, and has at least the same classification (under Article 3 of this subchapter) as the Unit(s) from which leachate was extracted;

(2) the discharge to a different Unit is approved by the RWQCB;

(3) the discharge of leachate to a different Unit shall not exceed the moisture-holding capacity of the receiving unit, and shall comply with § 20200 (d)."

The above section of Title 27 specifically allows the RWQCB to approve the discharge of leachate from other Units within a landfill to a receiving Unit as long as the wastes have similar classification and characteristics, the receiving Unit has an LCRS, and the moisture-holding capacity of the refuse is not exceeded. As demonstrated in the sections of this letter regarding design and operation of the bioreactor, the moisture holding capacity of the waste will not be exceeded. The other criteria for discharge are also satisfied in that the wastes are similar throughout the landfill and Module D has a LCRS. Based on satisfying all of the conditions listed in the above regulatory requirement, the County is seeking approval from the RWQCB to discharge leachate generated from other Units within the Yolo County Central Landfill into Module D.

Title 27, Chapter 3, Subchapter 2, Article 5, Section 20937, Part (b)(4), *CIWMB – Control* states the following:

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

As demonstrated in the sections of this letter regarding the design and operation of the Module D bioreactor, the LCRS and liner system are in place to allow for the recirculation of gas condensate. The County has submitted the analysis of constituents within the gas condensate in the site monitoring reports. Based on these factors, the County is seeking approval from the RWQCB to recirculate the condensate.

In reviewing the regulations regarding the recirculation of leachate and gas condensate, it appears that the County has satisfied all criteria enabling the RWQCB to grant approval for leachate/condensate recirculation in Module D. However, as previously discussed, the refuse deposited at the Yolo County Central Landfill is relatively dry. In order to have proper operation of a landfill bioreactor, the waste must attain its moisture holding capacity. This moisture level can not be reached with the addition of leachate and condensate alone. The County is proposing to supplement the liquid addition with ground water, but would like to obtain the flexibility to utilize other liquids such as septic waste, food-processing wastes from the Hunt-Wesson tomato plant that is currently land applied.

As discussed within this section of the letter, the regulations allow for the addition of "liquids or semi-solid waste" to a Class III landfill if the moisture holding capacity is not exceeded and the RWQCB grants an exception. By slowly adding liquid through the distribution system, regulating the moisture content of the refuse with moisture sensors and the piping manifold, monitoring the head build-up over the base liner, and improving the LCRS and liner systems, the County believes that the design, monitoring, and operational safeguards are in-place to allow the RWQCB to grant an exception for liquid addition. Further details on the design and operations are presented in the following sections of this letter.

DESIGN AND OPERATIONS OF PROPOSED MODULE D BIOREACTOR

As described above, Module D was approved and constructed as a Class III disposal cell in the fall of 1999. The liner system was designed to exceed the requirements of Title 27 of CCR and Subtitle D of the Federal guidelines and was upgraded from other liner systems used previously at the site. The County believes that given the constructed configuration discussed herein and the stringent monitoring and operational requirements proposed for Module D, the proposed liner system will be suitable for use in the bioreactor operations.

Under current plans, the first phase of Module D will be further subdivided into two independent bioreactor systems the aerobic system and the anaerobic system. Module D was designed and constructed in a ridge and swale configuration to optimize landfill space and to maintain good drainage for the collection system. The blanket drainage layer slopes at 2% inward to two central collection v-notch trenches. Each of the trenches drain at 1% to their prospective leachate collection sumps located at the south side of the module. This grading configuration is an upgrade from previous designs at the site because it is steeper, thus, maintaining better drainage throughout its design life. Phase 2 of Module D will also be constructed in a similar manner with two additional collection trenches and sumps.

Liner and LCRS System Components

The prescriptive liner for Class III landfills consists, from top to bottom, of an operations/drainage layer capable of maintaining less than one foot of head over the liner, a 60-mil high density polyethylene (HDPE) liner, and 2 feet of compacted clay ($k< 1 \times 10^{-7}$ cm/sec).

The Module D liner and leachate collection system consists, from top to bottom, of a 2 foot thick chipped tire operations/drainage layer ($k> 1$ cm/sec), a blanket geocomposite drainage layer, a 60-mil HDPE liner, 2 feet of compacted clay ($k<6 \times 10^{-9}$ cm/sec), 3 feet of compacted earth fill ($k< 1 \times 10^{-6}$ cm/sec), and a 40 mil HDPE vapor barrier layer[4] (see

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

Figure 1). The chipped tire operations layer was not placed during construction but will be placed immediately before waste placement, which is scheduled for spring of the year 2000.

As shown, the permeability of the clay liner, as constructed, was on the average about 6 x 10^{-9} cm/sec and the earth fill averaged about 1 x 10^{-8} cm/s. These two layers in effect provide a 5 foot thick composite liner. This fact, coupled with the lower permeability, will result in a significantly more effective barrier to leachate migration than the prescriptive liner system.

The liner system within the collection trenches and sump areas was upgraded further to a double composite liner to account for infringement on the 5 foot groundwater offset and to minimize potential leakage in these critical collection areas where head on the primary liner will be at its greatest. The liner and leachate collection system in the collection trenches and sumps consists from top to bottom of a minimum of 2 feet of gravel drainage material, a protective geotextile, a blanket geocomposite drainage layer, a primary 60-mil HDPE liner, a geosynthetic clay liner (GCL) ($k < 5 \times 10^{-9}$ cm/sec), a secondary 60-mil HDPE liner, 2 feet of compacted clay ($k < 6 \times 10^{-9}$ cm/sec), a minimum of 0.5 feet of compacted earth fill ($k < 1 \times 10^{-8}$ cm/sec), and a 40-mil HDPE vapor barrier layer (see Figure 2). The thickness of the compacted earth fill actually varies from a minimum at the south end of the trench of 0.5 feet to a maximum of about 2.5 feet at the upper, north end of the leachate collection trench. Leachate collection pipes were also placed in the collection trench and at other locations on top of the primary liner to transport leachate immediately to the sumps for recovery, removal, and recirculation, as needed.

LCRS and Liner Performance

As described above, the more rigorous Module D LCRS and liner system will outperform the Title 27 and Subtitle D prescriptive liner. The leachate collection and recovery system (LCRS) has been designed and constructed to be free-draining throughout the life of the module and will maintain less head over the primary liner system than prescribed by Title 27 and Subtitle D.

The LCRS system has been constructed with a geocomposite layer, which has over 10 times the required capacity and will maintain the head over the liner system to less than 0.3 inches during liquid application periods. In addition, the chipped tire layer will provide a level of redundancy in the event that the geocomposite becomes clogged or otherwise nonfunctional. The tire chips alone will maintain less than 4 inches of head over the primary liner. These issues are discussed in more detail in the following paragraphs.

It is estimated that up to 10 gpm of liquid per 10,000 square feet (44 gpm per acre) of disposal area will be typically delivered to the waste once the module has reached its design height. According to results of the bioreactor demonstration project by Moore et al[5], the average leachate generated during liquid introduction peaked at about 47% of the liquid delivery rate, which would equate to approximately 20 gpm per acre for the proposed program. Given a 6-acre drainage area, the total anticipated flow into any given sump would be approximately 120 gpm (173,000 gallons per day).

Based on the estimated leachate production, drainage into the leachate collection layer will be about 4.6 x 10^{-4} gpm per square foot of disposal area. It is approximately 200 feet between the ridge and collection trench. Using these values, the peak flow through the geocomposite will be about 0.09 gpm per linear foot of trench. The geocomposite for Module D has a measured capacity of 1.0 gpm per foot[6]. Therefore, the geocomposite has over 10 times capacity required under peak conditions.

The flow rate provided assumes that depth of the water over the liner does not exceed the compressed thickness of the geocomposite. The geocomposite has an uncompressed thickness of approximately 0.3 inches. When compressed, the geocomposite will be somewhat less than this value; therefore, the water level or head over the main portion of the liner will be less than this value.

Although clogging of the geocomposite layer is not anticipated, the LCRS has been designed under the conservative assumption that clogging may occur. In the event that the geocomposite were to become clogged or otherwise nonfunctional, the proposed chipped tire operations layer will also provide adequate drainage. Due to the large particle size of the chipped tires (>6 inches), the permeability of the tire layer is estimated to be greater than 1.0 cm/sec. Given this value, it has a flow rate capacity on the order of 0.025 gpm per inch of thickness per one foot width. Therefore, at the calculated maximum inflow rate of 0.09 gpm per foot width, the head over the liner would not exceed 4 inches. Typically, collection systems are designed to maintain less than one foot of head over the liner. Therefore, this system has over three times the required flow capacity at the allowable prescriptive level of one foot.

In addition to the upgraded LCRS, the primary composite liner is better than the Title 27 prescriptive system. This is based on the reduced permeability (k) of the clay soil used during construction of the module. The permeability of the clay soil used in construction of the Module D liner is significantly lower than the prescriptive 1 x 10^{-7} cm/sec. Based on the results of the laboratory testing performed during construction of Module D, the clay liner has an average permeability on the order of 6 x 10^{-9} cm/sec. Using standard leakage rate analyses by Giroud and Bonaparte[7], the leakage from the Title 27 system (with one foot of head over a HDPE geomembrane and 1 x 10^{-7} cm/sec clay liner) would

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[5] Moore et al. "Hydraulic Characteristics of Municipal Solid Waste Findings of the Yolo County Bioreactor Landfill Project.", Thirteenth International Conference on Solid Waste Technology and Management, Philadelphia, PA, November 1997.
[6] Golder Associates, "Final Report, Construction Quality Assurance, Yolo County Central Landfill, WMU 6, Module D, Phase 1 Expansion", December 1999.
[7] Giroud, J.P. and Bonaparte, R., "Leakage Through Liners Constructed With Geomembranes – Part I. Geomembrane Liners." Geotextile and Geomembranes, Eslvier Science Publishers Ltd., England, 1989.

be 1×10^{-4} gpm from a standard 1 cm^2 hole in the liner. With the Module D liner (4 inches of head over a HDPE geomembrane and 6×10^{-9} cm/sec clay liner), the leakage would be 5×10^{-6} gpm; less than 1/20 of the flow.

In the event that leakage were to occur through the 5-foot thick primary composite liner, the vapor barrier would provide secondary containment. Secondary containment is not required by Title 27 or Subtitle D. As constructed, the vapor barrier will minimize further downward migration and aid in detection of migrating leachate. The 40-mil HDPE vapor barrier was sloped to mirror the primary liner. Geocomposite strip drains were also installed diagonally across the top of the vapor barrier to act as drainage pathways to the pan lysimeter located immediately beneath each of the leachate collection sumps. The strip drains and lysimeter will act as a vadose zone monitoring system for early detection of leakage across the entire Module D disposal area. This added feature provides another level of protection to the groundwater that standard Title 27 systems do not have.

Specialized Design Considerations During Operation

Liquid will be applied during strategic periods to temporarily raise the moisture content of the waste to provide optimum conditions for rapid degradation and improved gas production. This liquid will initially consist of a mixture of leachate from other WMUs and ground water delivered through a series of pipes and drip irrigation or other application system after the landfill reaches its design height. The water will continually be introduced (as needed) to raise the moisture content within the waste to near its field capacity (estimated to be about 50% by dry weight). The liquid application system will be constructed such that solution can be applied or discontinued at designated locations to raise and lower the moisture within the waste.

Moisture content will be monitored throughout the life of the module through the use of a network of moisture sensors to be installed during waste placement. The moisture sensor system used during the bioreactor demonstration project in Module B proved to be very effective and will be the basis for the layout in Module D. At this time, the moisture sensors are planned to be installed at 20-foot increments of depth at a spacing of about 200 feet on center. Using these sensors, the County can determine where liquid application can be increased or decreased to optimize the effectiveness of the system and to prevent build-up of head over the liner.

The quantity of leachate and applied liquid will be measured throughout the life of the module. Once leachate is produced, it will supplement the system and be re-circulated; thereby, reducing the amount of clean water used. Liquid will be quantified using flow sensors installed on the leachate discharge line, re-circulation line, and liquid application line. These sensors will provide direct flow readout for determining flow rates in the pipelines and flow totalizing to quantify all of the liquid used and leachate produced.

Due to the critical nature of this project, the head over the liner will also be monitored after waste placement using a network of pressure transducers. These devices will installed on the primary liner, immediately before waste placement, to provide measurements of the leachate depth. Several of these transducers were installed in the LCRS during the Module D construction.

In the event that the transducers indicate that the head is going to exceed the allowable value, the system will automatically start pumps to reduce the liquid level and shot-off valves to reduce the liquid application rate. These measures would include but not be limited to reducing the liquid application rate across the entire module or specifically, in the area of head build-up. Generally, application of the liquid will only be continued until the gas generation phase of the unit is complete at which time leachate production is anticipated to continually decrease until conclusion of the post-closure period. The quality of the leachate will also be closely monitored to evaluate the system, determine the methods for future leachate treatment, and provide a basis for future use of similar bioreactors at the site or elsewhere.

In addition to liquid delivery to the waste, air will be delivered to the aerobic half of the bioreactor disposal area. This will "in effect" dry out the waste mass. Since the decomposition of the waste and gas generation is also dependent on keeping it moist, the liquid addition will be increased to accommodate any drying effects. However, the leachate generated within the aerobic bioreactor LCRS is not anticipated to increase significantly compared to the anaerobic area.

The degradation and gas production of the waste is also related to the temperature within the decomposing waste. The effectiveness of both aerobic and anaerobic bioreactors is dependent on keeping within optimum temperatures; therefore, temperature gauges will also be installed to aid in operation of the system. As with the moisture sensors, temperature gauges were also placed in the waste of the demonstration bioreactor and proved to be very effective. The temperature gauge network will be placed in a similar pattern to the moisture sensors at designated intervals throughout the waste mass.

In the aerobic half, during filling, horizontal gas conduits will be installed in similar manner to those of the anaerobic bioreactor. However conduit spacing may be closer. After filling, conduits will be used to pull atmospheric air through the waste. It is expected that this will increase the rate of degradation but inhibit methane formation.

As with the aerobic half, horizontal gas wells will also be incorporated in the waste as filling proceeds In the anaerobic area. Waste will be placed at 10 feet high lifts. The gas well spacing will be 50 feet on center. Gas will also be extracted from the base LCRS layer via the conduit collection pipe as filling proceeds. The purpose of this extraction is to lower methane emissions that would normally occur to the atmosphere during filling.

Separation of the two bioreactor systems will be performed using a low permeability isolation layer that is advanced as waste is placed. This layer may include but would not be limited to a compacted clay berm, a clay filled trench, or geomembrane. Final selection will be based on its ability to appropriately isolate each area, ability to accommodate settlement, ease of installation, and cost.

Daily cover operations will be performed in a similar fashion to the methods currently employed at the landfill. This includes the use of alternative daily covers such as greenwaste and tarps. Final cover will consist of a gas collection layer of constructed using chipped tires and piping. The liquid injection system will also be placed on this layer to allow continued delivery of liquid to the waste. This layer will be overlain with a flexible geomembrane cover to control moisture conditions, control gas emissions, and satisfy regulatory requirements to control vectors, fires, odors, blowing litter, and scavenging.

As areas of the module reach their design grade, monuments will be installed to monitor settlement caused by degradation of the waste. These monuments will be checked at a higher (quarterly) at first and less often (biannually) as the rate of settlement begins to slow. Annual aerial topographic surveys will also be performed to aid in the evaluation of settlement and the effectiveness of the bioreactor system.

With all of these operational systems in place, the performance of the bioreactor and effectiveness of the LCRS and gas collection system can be thoroughly monitored. These operational systems far exceed the requirements of Title 27 and Subtitle D; thus, providing another basis for allowance of the Module D bioreactor project.

CONCLUSION

The County is requesting to operate the Module D WMU as a bioreactor. In the August 18, 1999 letter from the RWQCB, several concerns were expressed regarding regulatory flexibility, groundwater degradation, leachate collection and removal, and the lack of performance data on bioreactors. Based on the information provided within this letter, it is the County's opinion that all of the RWQCB's concerns have been addressed.

Title 27 of the California Code of Regulations allows for leachate and condensate to be recirculated into the Unit. The regulations also allow for liquids and semi-solid waste to be discharged to a Class III landfill if the moisture-holding capacity of the waste is not exceeded and an exception is granted by the RWQCB. Since waste containing free liquids is not be disposed of within Module D, the regulations requiring the installation of a Class II impoundment liner system do not apply to the proposed bioreactor. Therefore, flexibility in the regulations is available to allow the modification of the Waste Discharge Requirements for operation of Module as a bioreactor. A JTD will be submitted on February 1, 2000 seeking a revision to the operating permit.

The design of the Module D liner system has been upgraded significantly over the standard Class III design of the Title 27. This upgrade will ensure that potential degradation of the groundwater does not occur from the unit. As discussed previously, the in-place composite liner system has a leakage rate over 20 times lower than a standard liner. The geocomposite leachate collection system has been upgraded and is capable of collecting all of the additional liquid recirculated within the Unit with no additional build-up of head on the liner. It should be noted that an operational layer composed of shredded tires will be placed over the geocomposite LCRS and is capable of handling all of the leachate flow should the geocomposite fail. In essence, a redundant system is in place, each component independently capable of collecting all of the recirculated liquid while maintaining a low head build-up over the liner (head will be monitored with pressure transducers). This redundant system is capable of handling all exiting and recirculating leachate. Test cell operation substantiates that added liquid can be carefully controlled to just meet moisture holding capacity of waste with less than 1% of the added liquid to be stored in an external reservoir, located outside of the waste cell footprint.

The critical factor in obtaining regulatory approval is ensuring that the refuse does not exceed its moisture holding capacity. This is achieved by discharging the liquid slowly over the entire top deck utilizing a shredded tire layer and piping manifold system. The moisture content of the waste will be continuously monitored with moisture sensors and adjustments to the liquid distribution made as necessary. The feasibility of operating the bioreactor without exceeding the moisture holding capacity of the refuse was shown by the demonstration project conducted at the site. Further evidence was obtained by drilling and sampling the waste within the test cells, verifying that the refuse was not over its moisture holding capacity.

Some of the benefits of operating landfills as bioreactors have been presented within this letter. The more significant benefits include expedited methane generation and recovery, extension of landfill life due to enhanced settlement, and improved leachate quality. The rapid degradation of the refuse within a bioreactor will be beneficial for long term health and safety and environmental protection over the post-closure period of the landfill. The expedited methane generation will also provide the potential for additional beneficial uses of landfill gas.

Finally, by approving the operation of the Module D WMU as a bioreactor, the RWQCB will facilitate the opportunity to greatly expand the current knowledge and understanding of bioreactors. In a recent article in *MSW Management*[8], John Skinner, the executive director and CEO of the Solid Waste Association of North America, said the following: "A new, unconventional landfill management strategy is being tested in several innovative demonstration projects. It involves designing and operating a landfill as a bioreactor to achieve a more rapid degradation of wastes. This could result in a number of very significant environmental and economic benefits for landfilling, including

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[8] Skinner, John, "Muses for the Millennium", *MSW Management*, December 1999.

increasing landfill life and reducing the period and costs of postclosure care. Bioreactor landfills might be the next great advancement in landfilling technology. The results of this research could permanently change the way landfills are designed and operated."

The County will be submitting the proposed revisions to its operating permit in the form of a JTD on February 1, 2000. We hope that this letter addresses the concerns that the RWQCB have regarding the operation of the Module D WMU as a bioreactor. If you require any additional information, please do not hesitate to call the undersigned at (530) 666-8848.

Sincerely,
Yolo County Department of Planning and Public Works

Ramin Yazdani

Ramin Yazdani, P.E.
Chief County Engineer

cc: Mr. Mark Samolis, Solid Waste Section, US EPA, San Francisco
Mr. Steve Wall, Solid Waste Section, US EPA, San Francisco
Ms. Frances McChesney, Office of Chief Counsel, State Water Resources Control Board, Sacramento
Ms. Liz Haven, Division of Clean Water Programs, State Water Resources Control Board, Sacramento
Mr. Scott Walker, California Integrated Waste Management Board, Sacramento
Mr. Jeff Pinnow, Yolo County Division of Environmental Health Services, Woodland
Mr. Don Augenstein, IEM, Palo Alto
Mr. John Pacey, EMCON/IT Corporation, San Mateo

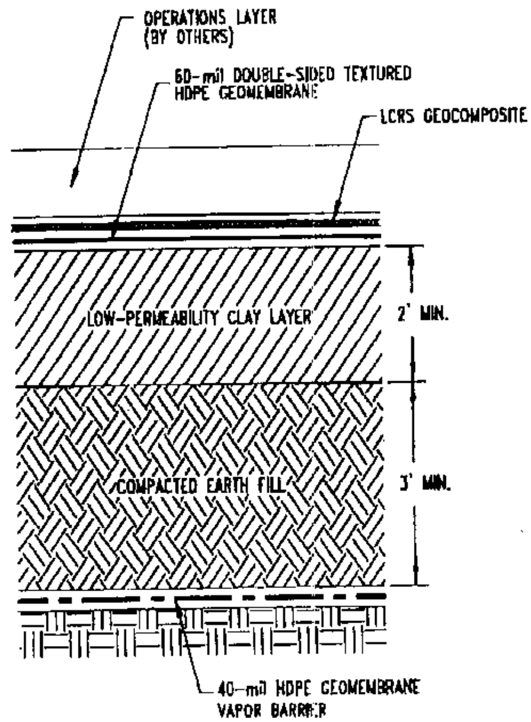

Figure 1- Typical Module D Liner Cross-section

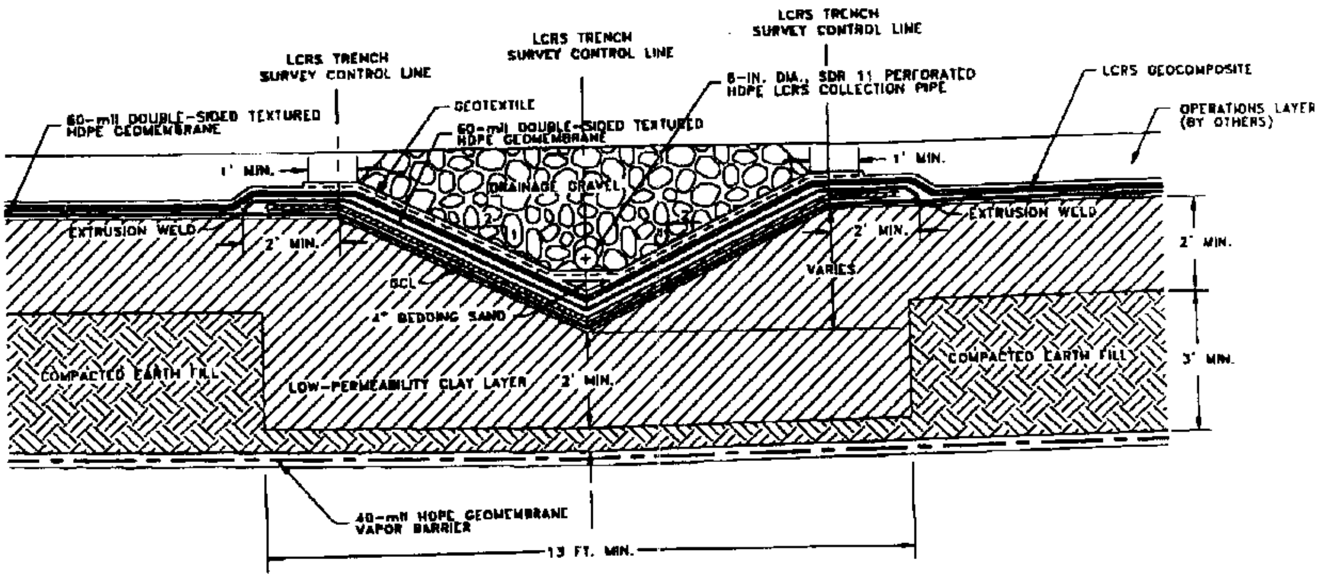

Figure 2 – Typical Module D LCRS Cross-section