EBA ENGINEERING
CIVIL & ENVIRONMENTAL ENGINEERS

March 11, 2003

Ms. Terri Kinney
California Regional Water Quality Control Board
North Coast Region (RWQCB)
5550 Skylane Blvd., Ste. A
Santa Rosa, CA 95403

RE: ENGINEERED ALTERNATIVE ANALYSIS
CITY OF UKIAH LANDFILL, MENDOCINO COUNTY, CALIFORNIA
EBA Project No. 02-907 (Task 5)

Dear Ms. Kinney:

This letter is being submitted by EBA Engineering (EBA) on behalf of the City of Ukiah, Department of Public Works (City) for purposes of presenting an engineered alternative cover for final closure of the City of Ukiah Landfill (Landfill). The proposed engineered alternative presented herein substitutes a geosynthetic clay liner (GCL) in lieu of the prescriptive standard (i.e., compacted clay liner [CCL]) required under Title 27 of the California Code of Regulations (27 CCR). Regulatory consideration of an engineered alternative is allowed under 27 CCR, §20080(b), which stipulates that that an engineered alternative may be considered if construction of the prescriptive standard is unreasonably and unnecessarily burdensome and will cost substantially more than the proposed alternative. Furthermore, the engineered alternative must be consistent with the performance goal addressed by the prescriptive standard and afford equivalent protection against water quality impairment. The following information has been compiled to demonstrate compliance with these criteria and includes data regarding the properties of GCLs, as well as comparisons of performance and site-specific construction costs of the proposed GCL engineered alternative to that of the prescriptive standard.

DESCRIPTION OF PROPOSED ENGINEERED ALTERNATIVE

As outlined above, the engineered alternative cover proposed for the Landfill incorporates a GCL in lieu of the CCL prescriptive standard. The design characteristics of the proposed alternative cover includes the following final cover system components (in ascending order):

- A 24-inch-thick vegetative layer, track-walked to achieve a firm consistency;

825 Sonoma Avenue, Suite C Santa Rosa, California 95404 (707) 544-0784 FAX (707) 544-0866
Also in Southern California

- A geonet composite drainage layer consisting of a high-density polyethylene (HDPE), high capacity drainage net (geonet) heat bonded with a non-woven, needle-punched polyester geotextile filter fabric;

- A reinforced, double non-woven, needle-punched GCL; and

- A 12-inch-thick (minimum) foundation layer moisture conditioned and compacted to 90 percent relative compaction.

The GCL represents the primary component of the alternative cover design that will dictate compliance equivalency with respect to the prescriptive standard. A detailed discussion of the GCL performance characteristics as compared to the CCL prescriptive standard is presented in the following subsection. However, it should be noted that the alternative cover design also incorporates several other characteristics that deviate from the prescriptive standard. These design components and the corresponding rationales are as follows:

- The proposed foundation layer thickness of 12 inches is half of the prescriptive standard thickness of 24 inches. The primary purpose of the foundation layer for the prescriptive standard scenario is to provide a firm surface for compaction of a CCL. However, based on the physical characteristics and installation procedures associated with a GCL, the construction of a 24-inch-thick foundation layer is not necessary or critical in the overall performance of the GCL. Thus, a minimum12-inch-thick foundation layer is considered sufficient to provide protection from differential settlement, given the proposed postclosure land use, and to provide a firm and smooth surface upon which to place the GCL.

- The geonet composite drainage layer is proposed as a mitigation measure against the potential development of excessive pore pressures in the overlying vegetative layer material. This design feature is considered critical due to the steep nature of the final cover slopes (2 horizontal to 1 vertical [2H:1V]). Since the potential development of excessive pore pressures would also apply to a prescriptive standard final cover system, a geonet composite drainage layer would also be required under the CCL scenario. In addition, the presence a geonet composite provides additional protection to the GCL from potential rodent damage and, combined with the selection of shallow rooted plant species for reseeding, protects against tap root damage from deeper rooted plants.

- The proposed vegetative cover thickness of 24 inches is double the prescriptive standard thickness of 12 inches. The bottom 12 inches will serve to provide confining overburden pressure for the GCL material, whereas the upper 12 inches will serve to harbor vegetative growth. In addition, the increase in vegetative cover thickness is intended to further reduce the potential for damage to the GCL by rodents and/or deeper rooted plants. Furthermore, the overburden pressure induced by the 24 inches of vegetative cover material will serve to counteract any landfill gas (LFG) pressures that may develop below the GCL and aid in maintaining the integrity of GCL seam areas.

It should be noted that in the Fall of 2001, Rau and Associates, Inc. (RAI) of Ukiah, California conducted a comprehensive survey of the landfill surface to evaluate the thickness of existing interim soil cover (RAI, 2001). The survey consisted of a series of shallow borings drilled at a spacing of approximately 50 feet apart on the roads and benches and approximately 100-foot spacing on the slopes. A total of 433 borings were drilled using a hydraulic drill motor (mounted on a backhoe boom) equipped with 4-inch diameter solid-stem augers. A hand-operated post-hole digger was used in areas not accessible by the backhoe-mounted drill. Findings from the survey revealed that the existing interim soil cover thickness is equal to or greater than 12 inches for over 90 percent of the landfill surface. Based on these conditions, the existing interim soil cover will be scarified, moisture conditioned within 3 percent of optimum moisture content and recompacted to 90 percent relative compaction to meet the minimum 12-inch-thick foundation layer requirement. Those areas determined by RAI's survey to have an existing interim cover thickness of less than 12 inches, additional foundation layer material will be placed and subsequently prepared and compacted according to the same specifications described above.

REGULATORY HISTORY

Since 1995, more than 31 GCL landfill final cover closures have been approved by various RWQCBs and constructed in California. Additional GCL caps have been approved by the Department of Toxic Substances Control (DTSC), and the U.S. Environmental Protection Agency (USEPA) for landfills, hazardous waste sites, and remediation sites in California. Overall, GCLs have been used in landfill applications since 1986 (Koerner, 1996).

COMPARISON OF GCL AND CCL PROPERTIES

The following subsections provide a comparison of pertinent properties of the GCL and CCL prescriptive standard as a mechanism to demonstrate equivalency. The various properties compared include physical and mechanical, hydraulic, stability, installation and repair. Also addressed are some miscellaneous issues that have been raised by the RWQCB during previous correspondence regarding the potential application of GCL at the site.

Physical and Mechanical Properties

- GCLs are generally considered superior to CCLs in terms of their ability to resist damage from differential settlement. Laboratory testing of GCLs has demonstrated its ability to withstand relatively high levels of tensile strain (at least 5 percent) without undergoing significant increases in permeability (Koerner and Daniel, 1993). Standard CCLs, in turn, generally cannot tolerate strains approaching 1 percent without cracking (LaGatta et al., 1997).

- GCLs outperform CCLs with respect to desiccation caused by repeated wetting and drying cycles. CCLs are subject to desiccation from above and/or below and crack unless adequately protected from changes in moisture content following construction or as caused by climate changes (Koerner and Daniel, 1992). The GCL's ability to expand upon hydration and "self-heal" reduces detrimental effects to the GCL that may occur during and after installation.

- As a result of the "self-healing" characteristics described above upon rewetting, GCLs also outperform CCLs with respect to freeze-thaw conditions (Koerner and Daniel, 1993; and Daniel, 1996).

- The bearing capacity of GCLs under hydrated conditions is less than that of CCLs, thereby making the GCL more susceptible to physical damage due to heavy loads. However, laboratory testing (Narejo et al., 1996) and field observations (Brown et al., 2001) has demonstrated that such concerns are negated provided that the cover soil thickness is greater than the footprint of any concentrated bearing load on the GCL (i.e., vehicle tires). The 24-inch-thick vegetative layer proposed as part of the final cover design satisfies the concentrated bearing load criteria stated above and should be more than sufficient to provide adequate protection.

  Please note that the construction specifications for the GCL will include protocols designed to protect the GCL from excessive load damage during installation. These protocols will include: 1) deployment of the GCL under unhydrated conditions; 2) placement of vegetative layer material onto the GCL by spreading each full lift thickness in advance of a low ground pressure, wide-tracked bulldozer (Maximum Size: Caterpillar D6 or equivalent); 3) covering of all GCL installed during any given working day with vegetative layer material to protect against overnight hydration due to precipitation, condensation, or other causes; and 4) prohibiting vehicle access onto the GCL until the placement of vegetative layer material is complete. Furthermore, upon completion of the final cover system installation, future vehicle access within the limits of the GCL footprint will be limited to designated access roadways constructed as part of the final closure activities.

- GCLs are more vulnerable to puncturing than CCLs. The primary potential sources of puncturing include manufacturing defects, subgrade protrusions, and penetration by sharp objects through the foundation and/or vegetative layers. However, protection against these sources can be provided through the employment of quality assurance procedures and design controls. As a mechanism to protect against manufacturing defects, a comprehensive manufacturer's quality control (MQC) program will be implemented to monitor the quality and integrity of the GCL material delivered to the site. Prior to installation, the completed foundation layer surface (i.e., GCL subgrade) will be inspected for the identification and subsequent removal of any sharp objects that could puncture the GCL. Finally, in regards to penetration of sharp objects through the foundation and/or vegetative layers, such an incident is considered unlikely following installation based on the thickness of the respective layers.

Hydraulic Properties

- For equivalence to a 12-inch CCL with a hydraulic conductivity of 1×10^{-6} centimeters per second (cm/sec), the required hydraulic conductivity of a GCL is 3.9×10^{-8} cm/sec. Typical hydraulic conductivities for CGLs range from 1 to 5×10^{-9} cm/sec under low compressive stresses with a conservatively high 12-inch hydraulic head of water (Koerner and Daniel, 1993). More recent testing of various GCLs found that hydraulic conductivities range from 2×10^{-10} to 1×10^{-9} cm/sec under a compressive stress of 150 pounds per square foot (psf)

(Daniel, 1996), conservatively less than the anticipated normal load for the proposed engineered alternative for the Ukiah landfill.

- It has been documented that certain chemical interactions between the GCL and the permeating liquid can adversely affect the hydraulic conductivity performance of the GCL (GSE Lining Technology, 2001). Parameters of concern with respect to the permeating liquid include its dielectric constant, salt concentration, pH, and cation exchange capacity. However, these chemical interactions only come into play with highly concentrated liquids such as leachates or brines. Since the permeating liquid for the final cover system corresponds to percolating rainwater, the potential for adverse chemical interactions with the final cover system's GCL component is negligible.

Stability Properties

Interface direct shear tests were conducted to evaluate the interface shear strength between the GCL and underlying site soil subgrade. Sample preparation and testing conditions were selected to simulate field conditions. Interface direct shear tests (ASTM D5321) were conducted at normal compressive stresses of 100 psf, 400 psf, and 800 psf. The GCL samples were tested under conservatively hydrated conditions by allowing the GCL sample to hydrate for 24 hours under no confining load prior to shear testing. A bulk sample of representative site subgrade soil was remolded to 90 percent R.C. at just below optimum moisture content to simulate in-place prepared subgrade. Results of the interface shear testing indicate a peak friction angle of 30.3° and a residual friction angle of 28.8°. Peak and post-peak adhesion was measured at 114.1 psf and 107.5 psf, respectively. A summary of laboratory test results is presented in Appendix A. The following values were used in performing the stability analyses, as described below:

Unit Weight of Soil	110.0 pcf
Cohesion	107 psf
Friction Angle	28.0 degrees

Final cover requirements stipulated in 27 CCR, §21090(a) require that a slope stability analysis be performed for final cover systems equipped with a geosynthetic component. Based on this requirement, the stability of the proposed GCL final cover system was evaluated using an infinite slope stability analysis. This method assumes failure of an infinitely long block and neglects resisting forces at the toe and along the sides of the failure. Hence, this analysis provides a conservative stability evaluation for shallow failures of constant thickness and slope. Analyses were performed for the proposed GCL final cover system using a soil thickness of 2 feet and a maximum slope 26.5 degrees (2H:1V). Findings from the analysis revealed that the lowest factor of safety during trial runs occurred for failures passing through the soil/GCL interface. The corresponding minimum factor of safety for this scenario is 2.28 under unsaturated conditions.

Determination of the yield acceleration for the GCL final cover system was accomplished through performance of a psuedo-static, infinite slope stability analysis. The yield acceleration was determined by iteratively choosing a horizontal acceleration that reduced the factor of safety to unity. The resulting yield acceleration for the proposed GCL final cover system for unsaturated conditions was 0.51 g. Using this value and time histories of horizontal acceleration at the top of the refuse mass as determined from previous seismic analyses (EBA, 2000b), a deformation analysis was performed to evaluate permanent seismic displacements at the soil/GCL interface during dynamic loading. The analysis was performed using the computer model YSLIP_PM (Matasovic, 1997). Findings from this analysis indicate that permanent seismic displacements at the soil/GCL interface for the proposed GCL final cover system will be less than 2 inches.

In summary, findings from the stability analyses reveal that the proposed GCL final cover system is statically stable and will yield less than 2 inches of permanent displacement under seismic loading conditions. Based on these characteristics, the proposed GCL final cover system is considered feasible from a technical standpoint. Please refer to Appendix A of this report for supporting documentation and data used in the respective analyses.

Installation/Repair Properties

- The installation of a GCL is significantly easier than a CCL. Particularly on steeper slopes such as those at the Ukiah landfill. In general, GCL deployment is very straightforward, both from a placement and seaming standpoint. Furthermore, heavy equipment requirements for GCL deployment are limited primarily to a rubber-tire forklift or equivalent. Conversely, CCL construction is very labor intensive with substantial reliance on heavy equipment (i.e., scrapers, dozers, compactors, etc.).

- Less construction quality assurance (CQA) is required for GCLs due to the consistency of the materials and manufacturing process. CQA testing for a CCL, in turn, is more extensive and occurs at a higher frequency to verify the consistency of borrow source materials and the contractor's ability to achieve moisture content, compaction, and hydraulic conductivity during construction.

- Installation of a sealed, double-ring infiltrometer (SDRI) is required to test the field permeability of CCLs, which is costly and time consuming. Such a provision is not required for a GCL.

- Postclosure repair of a GCL final cover is less involved than the repair of a CCL final cover system. Repair of a GCL is performed by exposing the damaged liner, rolling out new GCL material, and covering the damaged portion of the liner with a GCL patch. Repair of a CCL, in turn, requires the procurement of low-hydraulic conductivity material, mobilization of heavy equipment, moisture conditioning, compaction, and CQA testing to verify placement in accordance with the original specifications.

Miscellaneous Issues

A number of site-specific issues with regards to the potential application of GCL at the site have been previously raised by the RWQCB. These issues include the potential for damage to the GCL by rodent activity and deep penetrating roots, as well as the ability to retrofit the landfill in the future with a LFG collection system if deemed necessary. Evaluations regarding each of these issues are provided below.

- *Rodent Damage:* Based on the thickness of the vegetative cover (24 inches) for the proposed GCL final cover system, the GCL is no more susceptible to burrowing rodent damage than the CCL prescriptive standard. In fact, the GCL final cover system is probably less susceptible since rodents would have to penetrate a full 24 inches of vegetative cover material and the geonet composite drainage layer before reaching the GCL. In the case of the CCL prescriptive standard, a similar burrowing depth would result in complete penetration of the CCL.
  One other aspect that should be noted is that the GCL does not contain any plasticizers. The breakdown of plasticizer products has been documented to serve as a potential food source to rodents in some cases. As a result of its absence in the GCL materials, there is no physical aspect of the GCL component that would attract or promote rodent activity.

- *Root Damage:* The GCL's potential vulnerability to root damage should be effectively negated by the final cover revegetation provisions. As outlined in the Final Closure and Postclosure Maintenance Plan (FCPMP) (EBA, 1999), the vegetative layer will be reseeded with plant species having shallow root systems. Furthermore, the geonet composite drainage layer will also inhibit penetration of the GCL by root systems. Whereas the potential exists for the introduction of different plant species with deeper root systems via wind-blown seed deposition, such conditions have not been observed to date in the soil borrow areas that have undergone comparable reseeding processes. Thus, there is no current evidence to suggest that the site will be susceptible to this concern.

- *Retrofitting of LFG Collection System:* As discussed in the previous subsection, repairs to the GCL final cover system are relatively simple to implement based on the nature of the installation process. As a result, the same conditions apply to penetrating and resealing the GCL for the purpose of installing LFG extraction wells if such provisions are necessary in the future. Installation of an extraction well would require exposing a small portion of the GCL and cutting a hole slightly larger than the diameter of the drill auger or bucket. Following drilling and installation, a polyvinyl chloride (PVC) well bore seal would be placed around the casing and secured, followed by placement of a GCL patch over the PVC well bore seal. Finally, the seams along the edges of the GCL patch would be augmented with powdered bentonite and the area backfilled with vegetative layer material. Appropriate precautions would be implemented to ensure that mobilization of the drill rig to the respective drill sites does not damage the underlying GCL.

ECONOMIC ANALYSIS

As noted at the outset of this report, one of the criteria for an engineered alternative approval corresponds to cost and demonstration that the proposed alternative offers a significant cost savings as compared to the prescriptive standard. Based on this criterion, an economic analysis was performed to compare overall closure costs for the CCL prescriptive standard and the proposed GCL final cover system alternative. The results of the economic analysis are presented below in Table 1. Please refer to Appendix B for a more detailed breakdown and supporting data for the costs presented in Table 1.

TABLE 1 ECONOMIC ANALYSIS OF FINAL CLOSURE COSTS PRESCRIPTIVE STANDARD vs. ENGINEERED ALTERNATIVE		
Item	**Prescriptive Standard[1]**	**Engineered Alternative[2]**
Construction Facilities and Controls	$ 45,000	$ 45,000
General Earthwork and Test Pad[3]	$ 60,300	$ 45,300
Foundation Layer	$ 764,731	$ 192,971
Low Hydraulic Conductivity Layer	$ 2,036,904	$ 1,917,623
Vegetative Layer	$ 428,820	$ 857,640
Drainage System	$ 336,070	$ 336,070
Site Security	$ 2,000	$ 2,000
Revegetation	$ 428,020	$ 428,020
Access Roads	$ 16,500	$ 16,500
Sedimentation Basins	$ 36,500	$ 36,500
Borrow Area Reclamation	$ 229,700	$ 205,700
Final Design and Construction Quality Assurance	$ 316,321	$ 233,007
Subtotal	$ 4,700,866	$ 4,316,331
20 Percent Contingency	$ 940,173	$ 863,266
TOTAL	**$ 5,641,039**	**$ 5,179,597**

[1]Design includes the following construction (in ascending order): 24" foundation layer; 12" compacted clay liner; geonet composite drainage layer; and 12" vegetative layer.

[2]Design includes the following construction (in ascending order): 12" foundation layer; geosynthetic clay liner; geonet composite drainage layer; and 24" vegetative layer.

[3]Test pad only pertains to the prescriptive standard scenario.

As presented in Table 1, the proposed engineered alternative offers a significant cost savings as compared to the prescriptive standard. The cost differential between the two final cover systems is approximately $461,000. The items primarily responsible for the difference in cost include: reduction in foundation layer thickness for the GCL scenario ($571,800 cost savings); lower installation costs for the low hydraulic conductivity layer component ($119,300 cost savings); and lower design/CQA costs ($83,300 cost savings). The one cost item for the engineered alternative that exceeds the prescriptive standard by approximately $428,800 is the vegetative layer component due to the need for 24 inches of vegetative layer material as opposed to 12 inches for the prescriptive standard. However, based on the overall reduction in cost of almost 10 percent, the proposed engineered alternative meets the cost savings criteria specified in 27 CCR, §20080(b).

It should be noted that the cost differential calculated in the economic analysis is considered to represent a conservatively low difference because the bid cost of installing a CCL can vary widely. Estimates of the cost to excavate and place a 12-inch thick CCL at the Ukiah landfill were provided by five different earthwork contractors surveyed for this project. Cost estimates ranged from $6 per cubic yard (cy) to $25/cy. The variation in costs illustrates the uncertainty inherent in estimating earthwork on steep slopes. For this analysis, EBA used an median cost of $15/cy. It is probable that the cost for placement of CCL will be significantly higher at the time of construction bidding. In contrast, the variance in cost of GCL procurement and placement has historically been relatively low and stable.

In addition, the potential exists for higher CCL costs due to variability of the clay borrow source. As referenced in the borrow source investigation conducted by EBA in 1999 (EBA, 1999 and EBA, 2000a), the excavation of low hydraulic conductivity materials may be hindered by conglomerate beds occurring at various depths in the borrow source area. Such conditions, if encountered, would result in higher material handling costs, as well as higher CQA inspection and testing costs. Since GCL is a manufactured product, such concerns are not an issue. As a result, actual GCL costs are more predictable and not subject to significant change due to conditions encountered in the field.

REVISIONS TO FINAL CLOSURE AND POSTCLOSURE MAINTENANCE PLAN

Since the proposed engineered alternative represents a significant design change to the current final cover system design presented in the FCPMP, a Revised FCPMP would have to be prepared and submitted for regulatory approval to meet the requirements set forth in 27 CCR, §21890. Preparation of such a document would be contingent upon approval of the engineered alternative by the RWQCB. Specific sections and appendices of the FCPMP requiring revisions would include the following:

- Proposed Final Cover Design and Construction *(Section 2.9.2)*
- Proposed Final Cover Material Specifications *(Section 2.9.3)*
- Slope Stability *(Section 2.10.4 and Appendix C)*
- Construction Quality Assurance (CQA) Plan *(Section 2.16.1 and Appendix F)*
- Closure Construction Schedule *(Section 2.17)*
- Final Cover Inspection and Maintenance Program *(Section 3.9)*
- Closure and Postclosure Maintenance Cost Estimates *(Section 4 and Appendix G)*
- Fund Disbursement Schedule for Closure *(Section 5)*
- Final Closure Plan Drawings *(Section 8 and Sheets 1 through 5)*

As stipulated in 27 CCR, §21890(a), the Revised FCPMP would be submitted to the RWQCB, California Integrated Waste Management Board, and the Mendocino County Environmental Health Department (i.e., Local Enforcement Agency [LEA]) for final approval.

CONCLUSIONS

As demonstrated by the comparative information presented herein, the proposed GCL engineered alternative meets or exceeds the performance criteria addressed by the prescriptive standard. Furthermore, the economic analysis comparing construction costs for the two scenarios clearly shows that the CCL prescriptive standard is unreasonably and unnecessarily burdensome and will exceed the GCL engineered alternative construction cost by a conservative estimate of approximately $461,000. Based on these circumstances, it is EBA's conclusion that the GCL engineered alternative meets the qualifying criteria specified in 27 CCR, §20080(b).

CLOSING

We trust that this submittal includes all the necessary information and data needed for the RWQCB to approve the engineered alternative proposal. If you should have any questions regarding the information contained herein or need additional information, please do not hesitate to contact us.

Sincerely,
EBA ENGINEERING

Mike Delmanowski, C.E.G., C.Hg.
Senior Hydrogeologist

Damon Brown, C.E.G., C.Hg.
President

MD/DB/mc

cc: Ms. Diana Steele, City of Ukiah, Department of Public Works
Mr. Scott Humpert, California Integrated Waste Management Board
Mr. John Morley, Mendocino County Environmental Health Department

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APPENDIX A

STABILITY ANALYSIS

Consulting Engineers

Determining the Interface Friction of Geosynthetics
By the Direct Shear Method
ASTM D 5321

Laboratory Services Group 750 Corporate Woods Pkwy Vernon Hills, Illinois 60061 Phone: (847) 279-2500 Fax: (847) 279-2510

Determining the Coefficient of Friction of Geosynthetics
By the Direct Shear Method
ASTM D 5321

Project Name: CETCO, City of Ukiah Landfill STS Project # 29139-B
Date Tested: 10/25/2001

Test Parameters

Interface Tested: Top Layer: Silty Clay, little sand, gravel -- brown (CL)
Remolded to 109.8 pcf @11.0 %
Bot. Layer: GCL - Bentomat DN, Hydrated for 24 hours under no confining load

Shear Rate: 0.04 in/min

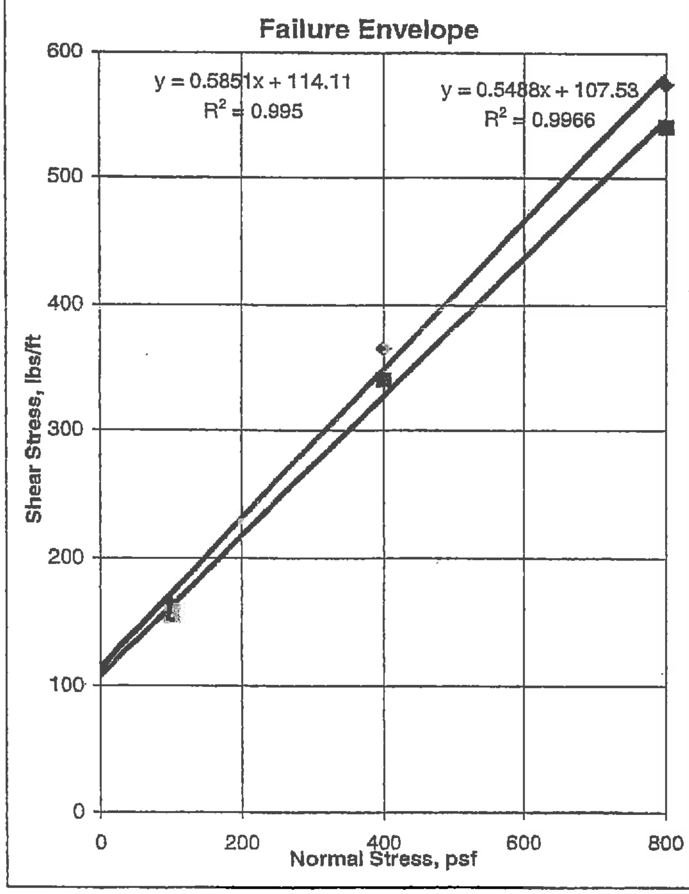
Test Results

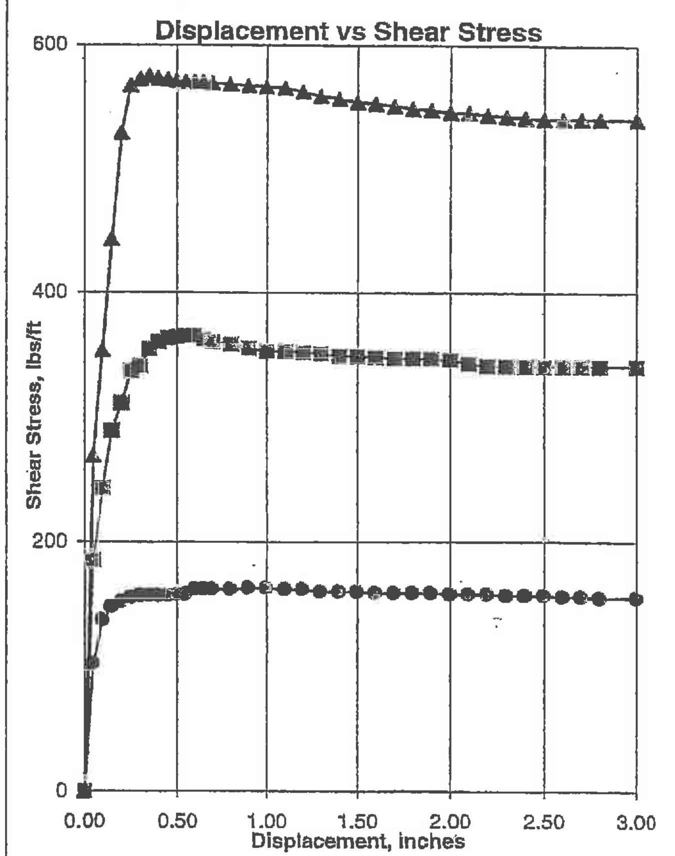
Normal Stress psf	Shear Stress psf	Residual Stress psf
100	163	155
400	365	340
800	575	541

Summary of Results

Peak Friction Angle = 30.3 Degrees
Adhesion = 114.1 lb/sq ft

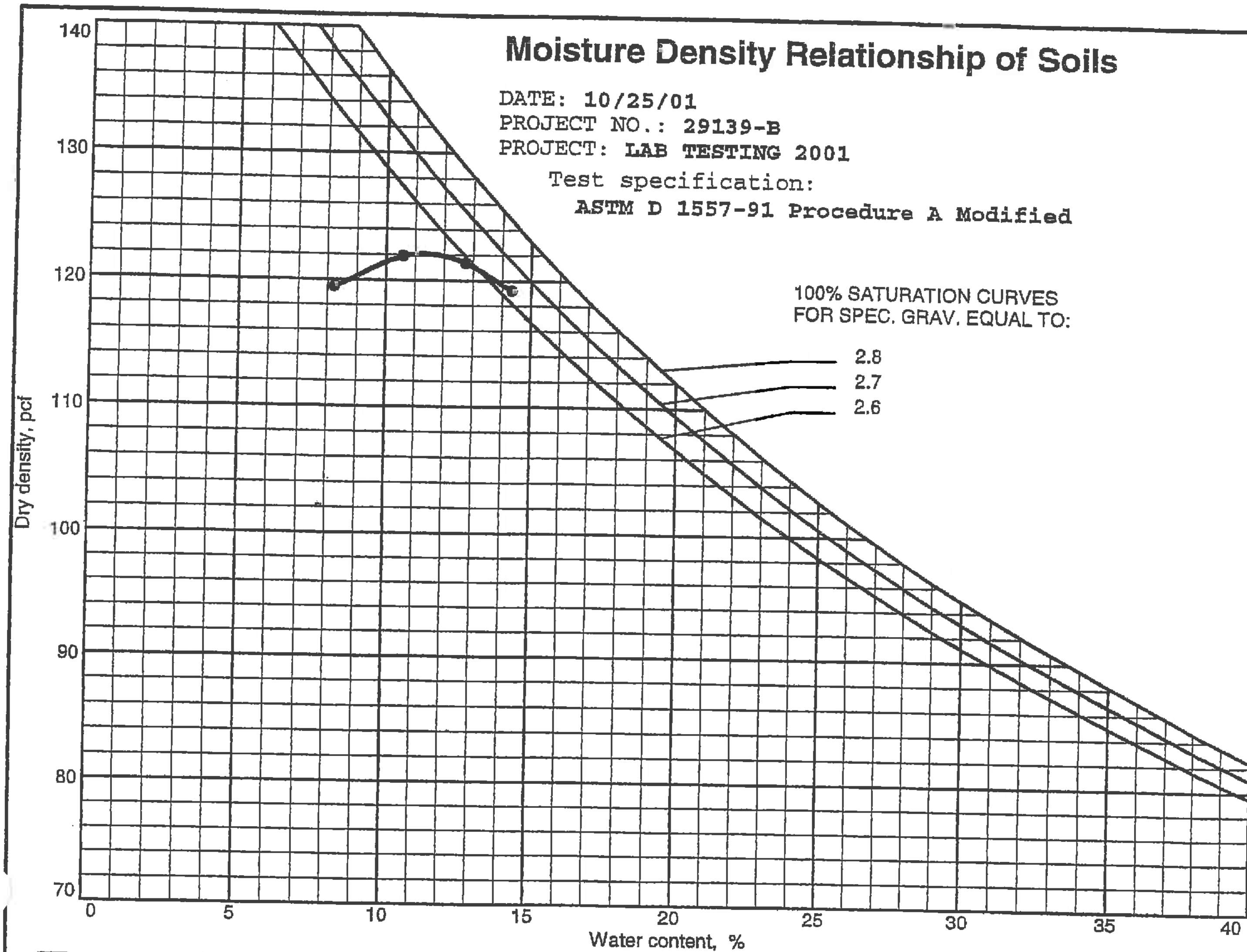
Residual Friction Angle = 28.8 Degrees
Adhesion = 107.5 lb/sq ft.





Moisture Density Relationship of Soils

DATE: 10/25/01
PROJECT NO.: 29139-B
PROJECT: LAB TESTING 2001
Test specification:
ASTM D 1557-91 Procedure A Modified



	Sample No.	Elev. or Depth	Material Description	SPECIFIC GRAVITY	LL	PL	% > No.4	% < #200
●	S-3		SILTY CLAY LITTLE F-C SAND LITTLE F GRAVEL - BROWN					

Sample No.	S-3			
Natural water content, percent	3.0			
Optimum water content, percent	11.5			
Max dry density, pcf	122			

Remarks

Project LAB TESTING 2001 | Project No. 29139-B

Location

Source

Plate

STS Consultants Ltd.
750 Corporate Woods Parkway
Vernon Hills, IL 60061

Infinite-Slope Stability Analysis with Parallel Seepage

Ukiah Municipal Solid Waste Disposal Site
GCL cap (revised 2002)

soil depth	z =	2.0	ft		
fraction sat.	m =	0.00		cos ß =	**0.8949**
slope angle	ß =	26.5	°	sin ß =	**0.4462**
				tan ß =	**0.4986**
soil unit. wt.	γ =	110.0	PCF		
cohesion	c' =	107	PSF		
friction angle	ø' =	28.0	°	tan ø =	**0.5317**
seismic coeff.	K_h =				
driving stress	τ =	**87.8**	PSF		
normal stress	σ =	**176.2**	PSF		
pore pressure	u =	**0.0**	PSF		
resisting stress	S =	**200.7**	PSF		

Factor of Safety **FS =** 2.28

Infinite-Slope Stability Analysis with Parallel Seepage

Ukiah Municipal Solid Waste Disposal Site
GCL cap (revised 2002)

soil depth	z =	2.0	ft		
fraction sat.	m =	0.00		cos ß =	**0.8949**
slope angle	ß =	26.5	°	sin ß =	**0.4462**
				tan ß =	**0.4986**
soil unit. wt.	γ =	110.0	PCF		
cohesion	c' =	107	PSF		
friction angle	ø' =	28.0	°	tan ø =	**0.5317**
seismic coeff.	K_h =	0.51			
driving stress	τ =	**177.7**	PSF		
normal stress	σ =	**131.4**	PSF		
pore pressure	u =	**0.0**	PSF		
resisting stress	S =	**176.9**	PSF		

Factor of Safety **FS =** 1.00

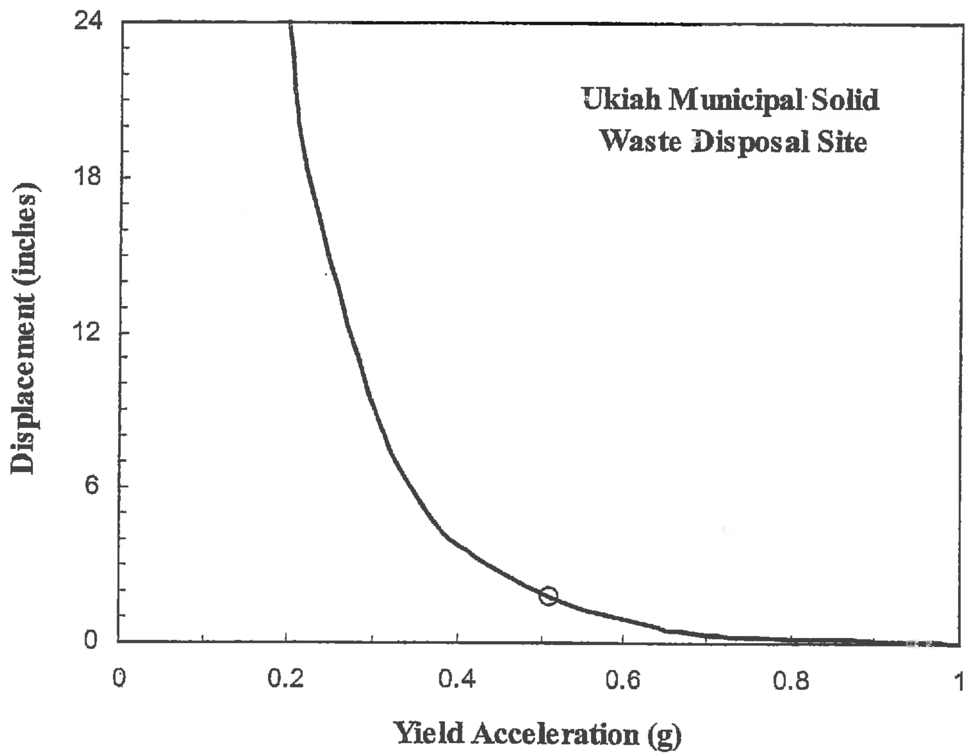


Figure 1. Plot of yield acceleration versus permanent seismic displacement for cover failure (filename COR50C62) and 50-foot waste profile. Open circle represents the yield acceleration calculated from the infinite slope stability analysis and the maximum displacement predicted by YSLIP_PM.

```
     ***********************************************
     **                                           **
     **                YSLIP_PM                   **
     **        (VERSION 2.2, JANUARY 1996)        **
     **                                           **
     **   A COMPUTER PROGRAM FOR SIMULATION OF    **
     **   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON    **
     **   AN INCLINED PLANE AND CALCULATION OF    **
     **   PERMANENT DISPLACEMENTS OF THE BLOCK    **
     **                                           **
     **                   BY                      **
     **                                           **
     **              Liping Yan                   **
     **            Neven Matasovic                **
     **        Edward Kavazanjian, Jr.            **
     **                                           **
     ***********************************************

     ***************REPRINT INPUT DATA**************

CARD  1: FILE CORGCL62.YSL
         UKIAH MUNICIPAL SOLID WASTE DISPOSAL SITE, REVISED 2002
CARD  2: SUBTITLE
         MCE CORRALITOS-LOMA PRIETA Kh=0.62g
CARD  3: KPAR  N     KACC  KCOM   g(ft/s/s)  KOUT   KSLIP  KDIR
         0     1     1     1      32.2       0      0      0
CARD  4: Ky(1), ..., Ky(N)
         0.51
CARD  5: YIELD ACCELERATION DEGRADATION DATA
         Ky is constant.
CARD  6: FILE NAME FOR HORIZONTAL ACC.
         cor50c62.hea
CARD  7: NIDH  KREAD     NP        NLINE     DT       APH
         4     1         1500      1500      0.02     0.0
CARD  8: FILE NAME FOR VERTICAL ACC.
         NO Av
CARD  9: NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
         NO INPUT
CARD 10: FILE NAME FOR OUTPUT OF SLIDING MOTION
         NO FILE
CARD 11: FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
         NO FILE

MAX. VALUE OF INPUT HORI. ACC. = 1.207951
INPUT HORI. ACC. TIMES A FACTOR = 1.000000 TO GET APH = 1.207951


     *****************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .510000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =    .8677 ft/sec
        PERMANENT SLIDING DISPLACEMENT =    .1505 ft

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =    .2870 ft/sec
        PERMANENT SLIDING DISPLACEMENT =    .0305 ft
```

```
**********************************************
**                                          **
**                YSLIP_PM                  **
**       (VERSION 2.2, JANUARY 1996)        **
**                                          **
**   A COMPUTER PROGRAM FOR SIMULATION OF   **
**   DYNAMIC BEHAVIOR OF A RIGID BLOCK ON   **
**   AN INCLINED PLANE AND CALCULATION OF   **
**   PERMANENT DISPLACEMENTS OF THE BLOCK   **
**                                          **
**                   BY                     **
**                                          **
**               Liping Yan                 **
**            Neven Matasovic               **
**         Edward Kavazanjian, Jr.          **
**                                          **
**********************************************

***************REPRINT INPUT DATA**************

CARD  1: FILE PACGCL68.YSL
         UKIAH MUNICIPAL SOLID WASTE DISPOSAL SITE, REVISED 2002
CARD  2: SUBTITLE
         MCE PACOIMA-NORTHRIDGE Kh=0.68g
CARD  3: KPAR  N     KACC  KCOM   g(ft/s/s)  KOUT   KSLIP  KDIR
         0     1     1     1      32.2       0      0      0
CARD  4: Ky(1), ..., Ky(N)
         0.51
CARD  5: YIELD ACCELERATION DEGRADATION DATA
         Ky is constant.
CARD  6: FILE NAME FOR HORIZONTAL ACC.
         pac50c68.hea
CARD  7: NIDH  KREAD     NP        NLINE      DT       APH
         4     1         1500      1500       0.02     0.0
CARD  8: FILE NAME FOR VERTICAL ACC.
         NO Av
CARD  9: NIDV  KREAD     NP        NLINE      DT       APV       TSHIFT
         NO INPUT
CARD 10: FILE NAME FOR OUTPUT OF SLIDING MOTION
         NO FILE
CARD 11: FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
         NO FILE

MAX. VALUE OF INPUT HORI. ACC. = 1.051902
INPUT HORI. ACC. TIMES A FACTOR = 1.000000 TO GET APH = 1.051902


          *****************RESULTS****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .510000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
                 MAX. SLIDING VELOCITY =    .7239 ft/sec
        PERMANENT SLIDING DISPLACEMENT =    .1095 ft

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
                 MAX. SLIDING VELOCITY =    .4770 ft/sec
        PERMANENT SLIDING DISPLACEMENT =    .0688 ft
```

```
*********************************************
**                                         **
**                YSLIP_PM                 **
**      (VERSION 2.2, JANUARY 1996)        **
**                                         **
**  A COMPUTER PROGRAM FOR SIMULATION OF   **
**  DYNAMIC BEHAVIOR OF A RIGID BLOCK ON   **
**  AN INCLINED PLANE AND CALCULATION OF   **
**  PERMANENT DISPLACEMENTS OF THE BLOCK   **
**                                         **
**                   BY                    **
**                                         **
**               Liping Yan                **
**            Neven Matasovic              **
**        Edward Kavazanjian, Jr.          **
**                                         **
*********************************************

***************REPRINT INPUT DATA**************

CARD  1: FILE SCZGCL66.YSL
         UKIAH MUNICIPAL SOLID WASTE DISPOSAL SITE, REVISED 2002
CARD  2: SUBTITLE
         MCE SANTA CRUZ-LOMA PRIETA Kh=0.66g
CARD  3: KPAR  N     KACC  KCOM   g(ft/s/s)  KOUT   KSLIP  KDIR
         0     1     1     1      32.2       0      0      0
CARD  4: Ky(1), ..., Ky(N)
         0.51
CARD  5: YIELD ACCELERATION DEGRADATION DATA
         Ky is constant.
CARD  6: FILE NAME FOR HORIZONTAL ACC.
         scz50c66.hea
CARD  7: NIDH  KREAD     NP        NLINE     DT       APH
         4     1         1500      1500      0.02     0.0
CARD  8: FILE NAME FOR VERTICAL ACC.
         NO Av
CARD  9: NIDV  KREAD     NP        NLINE     DT       APV       TSHIFT
         NO INPUT
CARD 10: FILE NAME FOR OUTPUT OF SLIDING MOTION
         NO FILE
CARD 11: FILE NAME FOR OUTPUT OF ABSOLUTE MOTION
         NO FILE

MAX. VALUE OF INPUT HORI. ACC. =  .660000
INPUT HORI. ACC. TIMES A FACTOR = 1.000000 TO GET APH =  .660000


         *****************RESULTS*****************

  RESULTS FOR DOWNSLOPE YIELD ACCELERATION (g) =   .510000

*** RUN 1: THE DIRECTION OF Ah IS AS INPUT ***
              MAX. SLIDING VELOCITY =   .1341 ft/sec
     PERMANENT SLIDING DISPLACEMENT =   .0048 ft

*** RUN 2: THE DIRECTION OF Ah IS REVERSED ***
              MAX. SLIDING VELOCITY =   .0576 ft/sec
     PERMANENT SLIDING DISPLACEMENT =   .0019 ft
```

APPENDIX B

ECONOMIC ANALYSIS

TABLE B-1
ECONOMIC ANALYSIS OF FINAL CLOSURE COSTS
PRESCRIPTIVE STANDARD vs. ENGINEERED ALTERNATIVE
CITY OF UKIAH LANDFILL

ITEM No.	ITEM	UNIT	UNIT PRICE	PRESCRIPTIVE STANDARD		ENGINEERED ALTERNATIVE	
				QTY	TOTAL PRICE	QTY	TOTAL PRICE
1.0	**CONSTRUCTION FACILITIES AND CONTROLS**						
1.1	Mobilization	LS	$ 20,000.00	1	$ 20,000	1	$ 20,000
1.2	Demobilization	LS	$ 10,000.00	1	$ 10,000	1	$ 10,000
1.3	Construction Facilities	LS	$ 5,000.00	1	$ 5,000	1	$ 5,000
1.4	Temporary Controls	LS	$ 10,000.00	1	$ 10,000	1	$ 10,000
	SUBTOTAL:				**$45,000**		**$45,000**
2.0	**GENERAL EARTHWORK & TEST PAD**						
2.1	Minor Excavation	CY	$ 2.00	500	$ 1,000	500	$ 1,000
2.2	Clear and Grub	AC	$ 1,000.00	44.3	$ 44,300	44.3	$ 44,300
2.3	Test Pad	LS	$ 15,000.00	1.0	$ 15,000	-	$ -
	SUBTOTAL:				**$60,300**		**$45,300**
2a	**FOUNDATION LAYER**						
2a.1	Foundation Layer (Existing 12")	AC	$ 4,356.00	44.3	$ 192,971	44.3	$ 192,971
2a.2	Foundation Layer (Additional 12")	CY	$ 8.00	71,470	$ 571,760	-	$ -
	SUBTOTAL:				**$764,731**		**$192,971**
3.0	**LOW HYDRAULIC CONDUCTIVITY LAYER**						
3.1	Compacted Clay Liner (CCL)	CY	$ 15.00	71,470	$ 1,072,050	-	$ -
3.2	GCL Subgrade Preparation (Top Deck)	AC	$ 800.00	-	$ -	3.5	$ 2,800
3.3	GCL Subgrade Preparation (Side Slopes)	AC	$ 2,000.00	-	$ -	40.8	$ 81,600
3.5	GCL - Supply and Install	SF	$ 0.45	-	$ -	1,929,708	$ 868,369
3.6	Drainage Layer Geonet Composite - Supply and Install	SF	$ 0.50	1,929,708	$ 964,854	1,929,708	$ 964,854
	SUBTOTAL:				**$2,036,904**		**$1,917,623**
4.0	**VEGETATIVE LAYER**						
4.1	Vegetative Layer (Bottom 12")	CY	$ 6.00	71,470	$ 428,820	71,470	$ 428,820
4.2	Vegetative Layer (Upper 12")	CY	$ 6.00	-	$ -	71,470	$ 428,820
	SUBTOTAL:				**$428,820**		**$857,640**
5.0	**DRAINAGE SYSTEM**						
5.1	Earthen Ditches	LF	$ 5.00	2,000	$ 10,000	2,000	$ 10,000
5.2	Riprap Ditches	LF	$ 20.00	1,800	$ 36,000	1,800	$ 36,000
5.3	24" HDPE Pipe	LF	$ 35.00	1,825	$ 63,875	1,825	$ 63,875
5.4	18" HDPE Pipe	LF	$ 25.00	2,575	$ 64,375	2,575	$ 64,375
5.5	15" HDPE Pipe	LF	$ 23.00	2,040	$ 46,920	2,040	$ 46,920
5.6	12" HDPE Pipe	LF	$ 20.00	3,020	$ 60,400	3,020	$ 60,400
5.7	Drainage Inlets	EA	$ 500.00	97	$ 48,500	97	$ 48,500
5.8	Concreted Rock Outlet	SF	$ 12.00	500	$ 6,000	500	$ 6,000
	SUBTOTAL:				**$336,070**		**$336,070**
6.0	**SITE SECURITY**						
8.1	Signs	LS	$ 2,000.00	1	$ 2,000	1	$ 2,000
	SUBTOTAL:				**$2,000**		**$2,000**
7.0	**REVEGETATION**						
7.1	Hydroseeding	AC	$ 1,400.00	44.3	$ 62,020	44.3	$ 62,020
7.2	Slope Protection	SF	$ 0.20	1,830,000	$ 366,000	1,830,000	$ 366,000
	SUBTOTAL:				**$428,020**		**$428,020**
8.0	**ACCESS ROADS**						
8.1	Aggregate Base Rock	SF	$ 1.10	15,000	$ 16,500	15,000	$ 16,500
	SUBTOTAL:				**$16,500**		**$16,500**
9.0	**SEDIMENTATION BASINS**						
9.1	Regrading	AC	$ 5,000.00	3	$ 12,500	3	$ 12,500
9.2	Outlet Structures	EA	$ 8,000.00	3	$ 24,000	3	$ 24,000
	SUBTOTAL:				**$36,500**		**$36,500**
10.0	**BORROW AREA RECLAMATION**						
10.1	Regrading	AC	$ 5,000.00	20	$ 100,000	17	$ 85,000
10.2	Soil Amendments and Revegetation	AC	$ 3,000.00	20	$ 60,000	17	$ 51,000
10.3	Slope Protection	SF	$ 0.20	348,500	$ 69,700	348,500	$ 69,700
	SUBTOTAL:				**$229,700**		**$205,700**
11.0	**FINAL DESIGN & CQA**						
11.1a	Construction Plans, Specifications & Bid Documents (CCL)	EA	$ 40,000.00	1	$ 40,000	-	$ -
11.1b	Construction Plans, Specifications & Bid Documents (GCL)	EA	$ 55,000.00	-	$ -	1	$ 55,000
11.1c	Redesign for CCL due to Change in Grades	EA	$ 10,000.00	1	$ 10,000	-	$ -
11.1d	Redesign for GCL	EA	$ 5,000.00	-	$ -	1	$ 5,000
11.2	Construction Administration & Supervision	EA	$ 25,000.00	1	$ 25,000	1	$ 25,000
11.3a	Daily Inspections, Recordkeeping & Reporting (CCL) (See Table B-1a)	EA	$ 155,009.67	1	$ 155,010	-	$ -
11.3b	Daily Inspections, Recordkeeping & Reporting (GCL) (See Table B-1a)	EA	$ 137,247.30	-	$ -	1	$ 137,247
11.4a	Sampling & Testing Program (CCL) (See Table B-1a)	EA	$ 86,311.40	1	$ 86,311	-	$ -
11.4b	Sampling & Testing Program (GCL) (See Table B-1a)	EA	$ 10,760.00	-	$ -	1	$ 10,760
	SUBTOTAL:				**$316,321**		**$233,007**
	TOTAL				**$4,700,866**		**$4,316,331**

LS: Lump Sum
CY: Cubic Yard
AC: Acre
SF: Square Feet
LF: Linear Feet

EA: Each
CCL: Compacted Clay Liner
GC L: Geosynthetic Clay Liner
HPDE: High-Density Polyethylene

TABLE B-1a
INSPECTION, TESTING AND REPORTING COSTS
CITY OF UKIAH LANDFILL

ITEM No.	*ITEM*	*UNIT*	*UNIT PRICE*	*PRESCRIPTIVE STANDARD*		*ENGINEERED ALTERNATIVE*	
				QTY	*TOTAL PRICE*	*QTY*	*TOTAL PRICE*
11.3	**DAILY INSPECTION, RECORDKEEPING & REPORTING**						
11.3-1	EBA - Daily Inspections	Day	$ 720.00	65	$ 46,800	21	$ 15,120
11.3-2	EBA - SDRI Installation	Day	$ 720.00	2	$ 1,440	-	$ -
11.3-3	EBA - Travel and Per Diem	Trip	$ 225.00	15	$ 3,375	13	$ 2,925
11.3-4	Contractor - Daily Geotechnical Inspections (FL/CCL)	Day	$ 805.00	80	$ 64,400	48	$ 38,640
11.3-5	Contractor - Daily Geotechnical Inspections (VL)	Day	$ 805.00	17	$ 13,685	34	$ 27,370
11.3-6	Contractor - Daily GCL Inspections	Day	$ 747.50	-	$ -	45	$ 33,638
11.3-7	Contractor - Travel	Trip	$ 15.53	214	$ 3,323	160	$ 2,485
11.3-8	Contractor - Project Management	Hr	$ 86.25	81	$ 6,986	24	$ 2,070
11.3-9	Final Construction Report	EA	$ 15,000.00	1	$ 15,000	1	$ 15,000
	SUBTOTAL:				**$ 155,010**		**$ 137,247**
11.4	**SAMPLING & TESTING PROGRAM**						
11.4-1	ASTM D 5093 (SDRI Installation)	EA	$ 7,600.00	1	$ 7,600	-	$ -
11.4-2	ASTM D 5093 (SDRI Monitoring)	EA	$ 4,894.40	1	$ 4,894	-	$ -
11.4-3	ASTM D 2487	EA	$ 51.75	115	$ 5,951	-	$ -
11.4-4	ASTM D 422	EA	$ 34.50	115	$ 3,968	-	$ -
11.4-5	ASTM D 4318	EA	$ 92.00	114	$ 10,488	-	$ -
11.4-6	ASTM D 1557	EA	$ 126.50	56	$ 7,084	-	$ -
11.4-7	ASTM D 5084	EA	$ 408.25	105	$ 42,866	-	$ -
11.4-8	ASTM D 2488	EA	$ -	-	$ -	-	$ -
11.4-9	ASTM D 1556	EA	$ -	-	$ -	-	$ -
11.4-10	ASTM D 2922	EA	$ -	-	$ -	-	$ -
11.4-11	ASTM D 2216	EA	$ -	-	$ -	-	$ -
11.4-12	ASTM D 5035 (GCDL)	EA	$ 55.00	20	$ 1,100	20	$ 1,100
11.4-13	ASTM D 5199 (GCDL)	EA	$ 18.00	20	$ 360	20	$ 360
11.4-14	ASTM D 1505 (GCDL)	EA	$ 30.00	20	$ 600	20	$ 600
11.4-15	ASTM D 3776 (GCDL)	EA	$ 18.00	20	$ 360	20	$ 360
11.4-16	ASTM D 4632 (GCDL)	EA	$ 52.00	20	$ 1,040	20	$ 1,040
11.4-17	ASTM D 5993 (GCL)	EA	$ 25.00	-	$ -	20	$ 500
11.4-18	ASTM D 5890 (GCL)	EA	$ 90.00	-	$ -	20	$ 1,800
11.4-19	ASTM D 5887 (GCL)	EA	$ 250.00	-	$ -	20	$ 5,000
	SUBTOTAL (Subcontractors):				**$ 86,311**		**$ 10,760**
	TOTAL				**$ 241,321**		**$ 148,007**

Hr: Hour
EA: Each
FL: Foundation Layer
VL: Vegetative Layer

CCL: Complacted Clay Liner
GCL: Geosynthetic Clay Liner
GCDL: Geonet Composite Drainage Layer
SDRI: Sealed Double-Ring Infiltrometer

Note: Items 11.4-8 through 11.4-11 included in cost for daily inspections (Item 11.3-4).