Candi Browne
Ex 6
[redacted]

Sent electronically March 4, 2012, 3:05 pm COPY
To: Doug Haywood, BLM Project Manager, dhaywood@blm.gov
Mr. Haywood then forwarded my comments on for inclusion in the **Scoping Process**

29 February 2012
These are some of my Concerns about the possible construction, operation & reclamation & time after the reclamation of the Copper Flat Mine, Sierra County, New Mexico. Please add them for evaluation in the BLM, Las Cruces District, Environmental Impact Statement. Thank you. Candi Browne

The following are extracted from my 2012 Scoping Process comments and are meant to show that these Concerns, etc were made in 2012, 4 years ago & are to be included in my 2016 Comments, Concerns, Omissions and Inadequacies of the NMCC DEIS Nov 2015 for the Copper Flat Mine:

10 TAILINGS IMPOUNDMENT – after monitoring stops

If the BLM approves this NMCC Plan of Operation for the *proposed* Copper Flat Mine Project, Sierra County, New Mexico, I am concerned about what will happen **after** the monitoring of the 547 acre Tailings Impoundment ends.

In the NMCC Mining Plan of Operation it is stated that monitoring will last only 12 years after the Project is deemed finished.

I am concerned that there is a significant potential for **Acid Mine Drainage Leakage** from the Tailings Impoundment and other toxic/polluting effects that will **continue into perpetuity**.

I am concerned because an accident of this type could occur **AFTER THE MINE RECLAMATION IS FINISHED AND NMCC IS NO LONGER INVOLVED OR LIABLE FOR ANY DAMAGE.**

I am concerned that with no regular monitoring following the reclamation phase of the Copper Flat mine, a leakage or a breach could get into the local ground water and contaminate it with toxins.

I am concerned that with no regular monitoring a **breach** of the Tailings Impoundment, which has a significant *hazard potential* classification, would not receive the necessary Rapid Response and could cause untold toxic damage to the environment wherever the contents of the Tailings Impoundment discharge to including the surrounding water, soils, air, wildlife, and endangering Highway 152 and any traffic.

- AMD is the mining industry's greatest **environmental problem** and its greatest liability Once it starts, AMD can effectively **sterilize an entire water system** for generations to come - turning it into a biological wasteland and a huge economic burden."
- 'the present state-of-the-art does not provide any universal solutions' for AMD."
- The sulphide sulphur in the ore continually reacts with air and water to form sulphuric acid, which leaches out the heavy metals, especially copper."

- The science of predicting AMD is still far from conclusive. The gap between the theoretical tests and the real world dynamics of AMD provides reason for caution when mines are assessed and permitted.

I suggest that the BLM & the other State or Federal agencies involved in this EIS process need to apply the principle of 'cumulative effects' (as it is specified in the NEPA handbook on the EIS process) to the Social and Economic hardship this might cause.

I suggest a detailed study of this and a detailed plan for eliminating this potential problem needs to be included in BLM & the other State or Federal agencies involved in this EIS process consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.
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11 LINER

If the BLM approves this NMCC Plan of Operation for the proposed Copper Flat Mine Project, Sierra County, New Mexico, I am concerned about the deterioration of the
HDPE geomembrane **<u>LINER</u>** by any **<u>chemicals</u>** in the fluids that come into contact with the LINER.

I am concerned about

- the <u>cumulative effect</u> of this toxic fluid,
- any increased deterioration due to the **<u>desert summer temperatures</u>**
- and the direct effect of the **<u>high altitude sun</u>** with high temperature on the LINER.

I am concerned because an accident of this type could occur **AFTER THE MINE RECLAMATION IS FINISHED AND NMCC IS NO LONGER INVOLVED OR LIABLE FOR ANY DAMAGE.**

I suggest a detailed study of this and a detailed plan for eliminating any potential problems stated or newly found needs to be included in the BLM & the other State or Federal agencies involved in this EIS process consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.
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11 A HDPE GEOMEMBRANE LINER – LONG TERM effect

If the BLM approves this NMCC Plan of Operation for the proposed Copper Flat Mine Project, Sierra County, New Mexico, I am concerned about the long term effects of the **<u>LINER.</u>**

I am concerned about how this 547 acres piece of HDPE geomembrane will **<u>affect the environment over it's life span of hundreds of years.</u>**
I am concerned about what may happen as it **deteriorates**, etc.
I am concerned that the material itself will pollute the soil or cause other harmful effects.

What is the life span of this particular liner – HDPE geomembrane that NMCC will be using?

I am concerned because an accident of this type could occur **AFTER THE MINE RECLAMATION IS FINISHED AND NMCC IS NO LONGER INVOLVED OR LIABLE FOR ANY DAMAGE.**

I suggest a detailed study of this and a detailed plan for eliminating this potential problem needs to be included in the BLM & the other State or Federal agencies involved in this EIS process consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.
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12 A LINER SEAMS

If the BLM approves this NMCC Plan of Operation for the proposed Copper Flat Mine Project, Sierra County, New Mexico, I am concerned that as the tailings impoundment HDPE geomembrane **liner** sections are joined together the **seams** will not **hold** and over time they may crack or buckle or slip or break and there may be leakage of acid mine tailings drainage that can harm our environment by polluting the surrounding ground, water, soil, vegetation, wildlife, etc.
I am concerned because an accident of this type could occur **AFTER THE MINE RECLAMATION IS FINISHED AND NMCC IS NO LONGER INVOLVED OR LIABLE FOR ANY DAMAGE.**

I suggest a detailed study of this possibility and a detailed plan for eliminating this potential problem needs to be included in BLM's consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.
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24 HDPE GEOMEMBRANE LINER

If the BLM approves this NMCC Plan of Operation for the proposed Copper Flat Mine Project, Sierra County, New Mexico, I am concerned about the adequacy of the HDPE geomembrane liner that they plan to use under the 547 acre tailings impoundment.

First there is no information given in their Mining Plan of Operation about the liner itself.

I am concerned because HDPE GEOMEMBRANE LINERS are known to frequently fail.

I am concerned because an accident of this type could occur **AFTER THE MINE RECLAMATION IS FINISHED AND NMCC IS NO LONGER INVOLVED OR LIABLE FOR ANY DAMAGE.**

I am concerned because it's such a new technology and many geotechnical and civil engineers, regulators, and general contractors may not be thoroughly familiar with the performance characteristics of viscoelastic engineering polymer products.

Ultimately my concern is toxic AMD (acid mine drainage) leaking from the liner &/or a break or failure that could contaminate and endanger areas of land, air, water, wildlife, humans, ranchers, agriculture, etc. as detailed in other of my concerns.

I suggest that the BLM & the other State or Federal agencies involved in this EIS process need to apply the principle of 'cumulative effects' (as it is specified in the NEPA handbook on the EIS process) to the Social and Economic hardship this might cause.

I suggest detailed information on the HDPE geomembrane that NMCC plans to use needs to be included in BLM's consideration of this Mining Plan of Operation.

I suggest the information on any HDPE GEOMEMBRANE LINER that NMCC plans to use needs to include detailed information on each of these aspects:

- highest quality design co-ordinated with the manufacturing & the installation, etc.
- highest quality specifications of the materials (resin) for this particular tailings impoundment use, climate, etc. A project specification document specific to the Copper Flat Project
- highest quality manufacture of the liner
- highest quality installation without damage
- highest quality effective seaming and trial seaming
  [about 19% of leaks occur at seams]
- highest quality filling or covering the liner for initial operation without damage
  [over 70% of leaks occur when the liner is covered by soil or stone, therefore covering is a critical stage for a geomembrane]
- highest quality proper preparation of the ground &/or surface upon which the liner will be placed.
- continual testing of the highest quality in each of these areas done by an independent contractor reporting to appropriate New Mexico State Agencies responsible for this area of the Copper Flat Project oversight.

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I suggest that a plan for a quality independent company, chosen by BLM, paid for by NMCC and reporting to the appropriate New Mexico State Agencies responsible for this area of the Copper Flat Project oversight be required with this independent company monitoring every aspect of the liner from it's manufacturing to each detail of it's installation, seaming, covering and ongoing integrity oversight.

I suggest a current, up-to-date, detailed study of this and a detailed plan for eliminating this potential problem needs to be included in the BLM & the other State or Federal agencies involved in this EIS process consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.
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12 B HDPE geomembrane LINER - Wells

If the BLM approves this NMCC Plan of Operation for the proposed Copper Flat Mine Project, Sierra County, New Mexico, I am concerned that as the Tailings Impoundment is enlarged in size and goes into areas where there are **existing wells drilled into the ground water;** that in the event of any **leakage of acid mine tailings** under the **liner** this **contaminated fluid** may migrate into these **well casings** and get into the ground water polluting it.

I am concerned because there is no plan included showing how this will be prevented and within the MPO the statement is made that the well casings will be removed "*if possible*", which indicates that it may NOT be possible..

I am concerned because an accident of this type could occur **AFTER THE MINE RECLAMATION IS FINISHED AND NMCC IS NO LONGER INVOLVED OR LIABLE FOR ANY DAMAGE.**

I suggest a detailed study of this and a detailed plan for eliminating this potential problem needs to be included in the BLM & the other State or Federal agencies involved in this EIS process consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.
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12 C TAILINGS LINER- BREACH /BREAK – Greyback Arroyo

If the BLM approves this NMCC Plan of Operation for the proposed Copper Flat Mine Project, Sierra County, New Mexico, I am concerned that there may be **a breach or break** in the **Tailings Impoundment dam or** HDPE geomembrane **liner** that would carry toxic contents (acid mine drainage) & the tailings into the **Greyback Wash/Arroyo**.

I am concerned about the damage this would do to the environment.

- AMD is the mining industry's greatest **environmental problem** and its greatest liability Once it starts, AMD can effectively **sterilize an entire water system** for generations to come - turning it into a biological wasteland and a huge economic burden."
- 'the present state-of-the-art does not provide any universal solutions' for AMD."
- The sulphide sulphur in the ore continually reacts with air and water to form sulphuric acid, which leaches out the heavy metals, especially copper."
- The science of predicting AMD is still far from conclusive. The gap between the theoretical tests and the real world dynamics of AMD provides reason for caution when mines are assessed and permitted.

I am concerned about the potential for toxic contents to spill onto **Highway 152** which the Greyback Arroyo crosses close to the mine site area.

I am concerned about all our national **BLM lands** that the Greyback Arroyo goes through and the environmental damage from toxic acid mine drainage that could occur on these lands if there is an impoundment dam or liner breach or break.

I am concerned about the **wildlife** that would be adversely impacted.

I am concerned about the **cattle** that graze on the BLM land under BLM Grazing Leases which include area of the Greyback Arroyo.

I suggest that the BLM & the other State or Federal agencies involved in this EIS process need to apply the principle of 'cumulative effects' (as it is specified in the NEPA handbook on the EIS process) to the Social and Economic hardship this might cause.

I am concerned because there is no detailed study of these possibilities.

I am concerned because there is no plan to minimize any breach of the tailings impoundment.

I am concerned because an accident of this type could occur **AFTER THE MINE RECLAMATION IS FINISHED AND NMCC IS NO LONGER INVOLVED OR LIABLE FOR ANY DAMAGE.**

I suggest a detailed study of this and a detailed plan for eliminating this potential problem needs to be included in the BLM & the other State or Federal agencies involved in this EIS process consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.
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12 D TAILINGS LINER- BREACH /BREAK – Greyback Arroyo

If the BLM approves this NMCC Plan of Operation for the proposed Copper Flat Mine Project, Sierra County, New Mexico, I am concerned that there may be **a breach or break** in the **Tailings Impoundment**
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dam or HDPE geomembrane **liner** that would carry toxic contents (acid mine drainage) into the **Greyback Wash/Arroyo**. I am concerned about the damage this could cause to the environment.

I am concerned about all our national **BLM lands** that the Greyback Arroyo goes through and environmental damage from toxic acid mine drainage.

I am concerned that **cattle** that graze on the BLM land under grazing leases included in the Greyback Arroyo. Cattle could be harmed. This would adversely affect the **Ranchers** and the BLM since Greyback Arroyo is a part of BLM Grazing Allotment land.

A spill into Greyback Arroyo could also make the land there toxic for any growth of edible plants. **Wildlife and cattle** could be adversely affected by eating this tainted vegetation.

Any **tailings** that might settle into depressions and remain in the Greyback Arroyo could become **areas/pools of polluted water** following any subsequent rainfalls.
This tainted/toxic water could be harmful to wildlife and cattle. The effect of this could go on for hundreds of years.

I am concerned because an accident of this type could occur **AFTER THE MINE RECLAMATION IS FINISHED AND NMCC IS NO LONGER INVOLVED OR LIABLE FOR ANY DAMAGE.**

I suggest that the BLM & the other State or Federal agencies involved in this EIS process need to apply the principle of 'cumulative effects' (as it is specified in the NEPA handbook on the EIS process) to the Social and Economic hardship this might cause.

I am concerned because there is no detailed study of these possibilities.

I suggest the BLM consider a plan to have **the complete area of the Greyback Arroyo fenced by NMCC to prevent grazing cattle from being injured** in the event of a tailings impoundment breach that could cause the contents of the impoundment to run down the Arroyo. This would be a fence that would remain after NMCC finishes its mining Project to protect cattle since the tailings impoundment will be a source of concern for eons.
I am concerned about wildlife, but am aware that fences seldom stop wildlife.

I suggest a detailed study of this and a detailed plan for eliminating this potential problem needs to be included in the BLM & the other State or Federal agencies involved in this EIS process consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.
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12 E TAILINGS LINER- BREACH /BREAK - Electricity

If the BLM approves this NMCC Plan of Operation for the proposed Copper Flat Mine Project, Sierra County, New Mexico, I am concerned that there may be **a breach or break** in the **Tailings Impoundment dam or liner** that would carry toxic contents (acid mine drainage) into the area outside of the confines of the tailings impoundment.

I am concerned about the damage this would to the environment, wildlife, plants &/or domestic cattle.

I am concerned because there is no Contingency Plan for the possible event of a long outage of **electricity.**
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In our locality electrical outages are likely to occur during seasonal summer lightening storms with or without accompanying heavy rainstorm.

The electrical lines that come up from the power plant booster station located close to I-25 are the tall objects along their 7-8 mile path and therefore are prime targets for lightening hits.

My concern is that the tailings impoundment is normally constantly being pumped out so that the impoundment liquid can be recycled and re-used in the milling operation and saturated tailings are constantly being added to the tailings pile adding more liquid.

If an electrical outage goes out for some extended period of time and a rainstorm drops large amounts of rain onto the 547 acre impoundment and the tailings are at the same time draining down, then all of this liquid will be going into the impoundment 'catchment pond' while no liquid will be removed because the pump will not be functional if it is powered by electricity.

If the catchment pond is overwhelmed this may cause it to overflow or cause a breach.

I suggest a detailed study of this and a detailed plan for eliminating this potential problem needs to be included in the BLM & the other State or Federal agencies involved in this EIS process consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.
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12 F Pit Wall or TAILINGS LINER- BREACH /BREAK Acid Rock Drainage

If the BLM approves this NMCC Plan of Operation for the Copper Flat Mine Project, Sierra County, New Mexico, I am concerned that there may be **a breach or break** in the **Tailings Impoundment dam or liner or pit walls** that would carry toxic contents (acid rock drainage) into the area outside of the confines of the tailings impoundment.

My concerns are:

- When sulfide ore, waste rock, pit walls or the tailings are exposed to air and moisture, a chemical reaction can create sulfuric acid. (Iron ores are in oxide, not sulfide, formations.)
- Precipitation water can cause sulfuric acid compounds to drain from the mine site -- called acid mine drainage (AMD, sometimes called acid rock drainage or ARD).
- AMD can enter nearby surface water and groundwater resources and thereby harm people, plants, animals, metal and concrete structures.
- There has never been a metallic sulfide mine that has not polluted water resources where water was present.
- AMD also dissolves toxic heavy metals (e.g. lead, zinc, copper, and mercury), allowing them to enter surface water and groundwater.
- AMD can form red, orange or yellow sediments in the bottom of streams, which can disrupt the growth and reproduction of animals on which they feed.
- AMD is very difficult to confine and treat (clean up) properly. It can be very expensive to clean up and has costly impacts on local communities.
- It may take several years before AMD reaches toxic levels, and water contamination can then last for centuries, or even millennia.

I am concerned because an accident of this type could occur **AFTER THE MINE RECLAMATION IS FINISHED AND NMCC IS NO LONGER INVOLVED OR LIABLE FOR ANY DAMAGE.**
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Historical mining disasters in New Mexico such at the tailings impoundment breach at Church Rock by the town of Grant, NM must be taken into consideration.

I suggest a detailed Up-to-date study of this and a detailed plan for eliminating this potential problem needs to be included in the BLM & the other State or Federal agencies involved in this EIS process consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.
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15 WASTE ROCK

If the BLM approves this NMCC Plan of Operation for the proposed Copper Flat Mine Project, Sierra County, New Mexico, I am concerned about any **toxic run-off** coming from the **waste rock disposal areas** containing partially oxidized and unoxidized material &/or **low-grade ore stockpiles**.

I am concerned about our local summer storm pattern of sudden intense rainfall including:

- how quickly ditches fill and overflow during these storms
- and how powerful the rushing raging water can be and how often this onslaught of water breaks through ditches that are man-made.

I am concerned because of how large these disposal areas and stockpile areas will be. In the MPO, Page 3-6, 3.2.2 Waste Rock Disposal Area and Low-Grade Stockpile, NMCC says "These disposal areas would be expanded under the current MPO to cover approximately **210 acres** (Appendix B).

After the close of the mine the MPO states that there would be approximately 37 million tons of waste rock and 19 tons of low-grade ore.

I am concerned about the quantity of rainwater during a major summer rainstorm landing on this large acreage could carry toxic fluid from the wasterock area and eventually seep into ground water.

I am concerned about the high winds that are more and more prevalent in our area and the **dust** that can contaminate our air from this ore wasterock sitting out in the open.

I am concerned because an accident of this type could occur **AFTER THE MINE RECLAMATION IS FINISHED AND NMCC IS NO LONGER INVOLVED OR LIABLE FOR ANY DAMAGE.**

I suggest a detailed study of this and a detailed plan for eliminating this potential problem needs to be included in the BLM & the other State or Federal agencies involved in this EIS process consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.

26 Data Missing from the NMCC Mining Plan of Operation

If the BLM approves this NMCC Plan of Operation for the *proposed* Copper Flat Mine Project, Sierra County, New Mexico, I am concerned about all the places in the Plan of Operation where data is missing.

I am concerned because there are places where instead of data it just says:

- "Pending"
- "will be determined….."
- "will be added as design studies go forward…."
- and other similar statements that are used in place of adequate data, studies, plans, reports, etc concerning the actual Plan of Operation
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I am concerned because there is no way to know if what may be added as data, studies, plans, reports, etc concerning the actual Plan of Operation might be a CONCERN and the public, who is supposed to have an opportunity to share concerns during the SCOPING PROCESS, has NO WAY to voice it's CONCERNS if it does not have a chance to see this information.

To permit an identified acid generating mine means that we are asking future generations to take on the responsibility for toxic waste sites that are going to have to be managed for possibly hundreds of years. Predictions about the success of managing this waste in the long term are, at best, speculative.

I suggest that any **new information added to the currently available** **NMCC Mining Plan of Operation** needs to be made available to the public with adequate time to study it and adequate time to share CONCERNS within the NEPA-BLM Draft EIS process so that any concerns can be included in the BLM & the other State or Federal agencies involved in this EIS process consideration of the possible approval or denial of this Mining Plan of Operation. Thank you.

Some of the Research documents used to support my CONCERNS

Comparison of Predicted and Actual Water Quality at Hardrock Mines, The reliability of predictions in Environmental Impact Statements by Ann S. Maest - Buka Environmental, Boulder, CO and James R. Kuipers, Kuipers & Associates, Butte, Montana, 2006, www.kuipersassoc.com or EARTHWORKS, www.mineralpolicy.org/earthworks_at_home.cfm

Predicting Water Quality Problems at Hardrock Mines, A Failure of Science, Oversight, and Good Practice by Alan Septoff, EARTHWORKS, 2006
"Summitville Mine". ***Region 8 - Superfund*****. U.S. Environmental Protection Agency**. Archived from the original on 2006-10-10.
http://web.archive.org/web/20061010032331/http://epa.gov/region8/sf/sites/co/sville.html
Retrieved 2007-01-04.

Effects of Surface Mining on Ground Water Quality, Nature of Ground-water pollution by surface mining by Henry Rauch

HARDROCK MINING IN NEW MEXICO, 2006
EARTHWORKS 2007, Cathy Carlson and Jonathan Schwartz
www.earthworksactio.org
Abandoned Mines: The counties with the most abandoned mines are Grant, McKinley and **Sierra**.
The state does not have dedicated funding for cleaning up pollution from abandoned mines. The New Mexico Abandoned Mine Land Bureau gets funding from the federal Surface Mining Control and Reclamation Act to mitigate only physical hazards at abandoned hardrock mines.

New Mexico Department of Health, January 2007, Sulfate In Drinking Water
Natural levels can be increased by contamination from **mines**, **mills**, landfills, sewage and other manmade sources.
What level of sulfate is recommended for drinking water?
New Mexico Environment Department (NMED) and the Environmental Protection Agency (EPA) recommend that public water systems not have sulfate above 250 milligrams per liter (mg/L).
The EPA has also established a drinking water health advisory of 500 mg/L to prevent loose stool and diarrhea in persons not used to high levels of sulfate.
What are the health effects of sulfate in drinking water?

Drinking water with sulfate at levels exceeding 500 mg/L can cause strong laxative effects, such as diarrhea.
Animals are also sensitive to high levels of sulfate.

National Sanitation Foundation
http://www.nsf.org/ or at toll-free at 1-877-8-NSF-HELP (1-877-867-3435).

What is Metallic Sulfide Mining?
http://waterlegacy.orgt/sulfide_mining
Metallic sulfide mining is a Midwest US term for hardrock mining for metals in sulfur-bearing rock, as differentiated from coal, iron ore, or gravel extraction.
Metallic sulfide mining is the practice of extracting metals from a sulfide ore body.
In Minnesota, these metals include copper and nickel with trace amounts of cobalt, platinum, palladium, and gold.
Toxic metals in acid mine drainage (AMD) have polluted waters everywhere.
The U.S. EPA (Environmental protection Agency) has extensive information about AMD

THEMAC Resources, New Mexico Copper Corporation, Copper Flat
Mine Plan of Operations Report
prepared for U.S. Department of the Interior Bureau of Land Management Lac Cruces District Office , December 2010, Revised June 2011.
NMCC_PoO_191000_03_20111120_FNL.doc.
electronic copy, 358 pages

Environmental Mining Council of British Columbia
www.miningwatch.org/emcbc/publications/amd_water.htm
ACID MINE DRAINAGE or AMD

- AMD is the mining industry's greatest **environmental problem** and its greatest liability Once it starts, AMD can effectively **sterilize an entire water system** for generations to come - turning it into a biological wasteland and a huge economic burden."
- 'the present state-of-the-art does not provide any universal solutions' for AMD."
- The sulphide sulphur in the ore continually reacts with air and water to form sulphuric acid, which leaches out the heavy metals, especially copper."
- When the mining industry argues that new mining development is "essential" to our way of life, it tends to understate the fact that we could and should achieve many of our metals needs through better re-use and recycling of existing metal products.
- The science of predicting AMD is still far from conclusive. The gap between the theoretical tests and the real world dynamics of AMD provides reason for caution when mines are assessed and permitted.
- To permit an identified acid generating mine means that we are asking future generations to take on the responsibility for toxic waste sites that are going to have to be managed for possibly hundreds of years. Predictions about the success of managing this waste in the long term are, at best, speculative.

Preventing & Mitigating Acid Mine Drainage

- Containing the waste material and runoff (with liners, impervious pads, diversion and collection ditches, etc.) *sometimes* keeps the pollutants from running off the mine site into surrounding groundwater or streams.
- most reliable strategy for preventing AMD is to *submerge the waste rock or tailings under* (behind an impoundment or in a natural water body) to prevent exposure to oxygen.
- mix it with *lime*, then cover it with one metre of till
- bring the leachate to a *treatment plant* using alkaline and sludge measures.

- *paste backfilling*
- *blended dumps.*

None of these solutions worked without other adverse consequences.

NEPA Handbook, H-1790.2k8.01.30[1]
BLM National Environmental Policy Act, January 2008
pdf, 184 pages

US DEPT OF THE INTERIOR, BLM, Instruction Memorandum No. CO-2004-014
Updated Environmental Assessment (EA), Categorical Exclusion (CE), and Documentation of Land Use Plan Conformance and National Environmental Policy Act (NEPA) Adequacy (DNA) Templates, Updated List of Critical Elements of the Human Environment in Bureau of Land Management (BLM) NEPA Handbook (H-1790-1) and EA-Level Guidance

1976 Federal Land Policy management Act, or FLPMA (Pub. L. 94-579)
FILED IN US Dept & LAWS
The Federal Land Policy and Management Act of 1976 As Amended Compiled by U.S. Department of the Interior Bureau of Land Management and Office of the Solicitor Washington, D.C, October 2001. pdf, 78 pages

ANDACOLLO COPPER CONCENTRATE MATERIAL SAFETY DATA SHEET
TECK METALS LTD, Suite 3300, 550 Burrard St, Vancouver, BC, V6C 0B3
30 January 2012
Copper Concentrate
Composition/ Information on Ingredients
Hazards Identification
First Aid Measures
Fire Fighting Measures
Accidental Release Measures
Handling and Storage
Exposure Controls / Personal Protection
Physical and Chemical Properties
Stability and Reactivity
Toxicological Information
Ecological Information
Transport Information
Regulatory Information
U.S.
Ingredients Listed on TSCA Inventory **Yes**
Hazardous Under Hazard Communication Standard **Yes**
CERCLA Section 103 Hazardous Substances **Yes**…….Copper ……RQ : 5,000 lbs. (2270 kg.)
[CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act - Superfund]
EPCRA Section 313 Toxic Release Inventory (Supplier Notification):…Copper….
CAS No. 7440-50-8. % by Weight – 24-28%

Other Information: References

Memorandum on HDPE Liners at Copper Flat Mine

To: The Bureau of Land Management
Department of the Interior

CC: Mining and Minerals Division
NM EMNR Department

Mining Environmental Compliance Section
Ground Water Quality Bureau
NM Environment Department

From: Max Yeh
Ex 6 [redacted]

Date: January 21, 2012

Re: Use of HDPE liners at Copper Flat Mine

We want to begin with a reference to J.P. Giroud's 2005 Vienna Terzaghi Lecture, "Geosynthetics Engineering: Successes, Failures, and Lessons Learned." Dr. Giroud is a major pioneer of geosynthetic use, who forty years ago invented the terms "geotextile" and "geomembrane." At the time of the lecture, he was synopsizing his life experiences in geosynthetics in a 1,000 page book entitled "Lessons Learned from Failures Associated with Geosynthetics." In the Terzaghi Lecture, he argues that decisions on geosynthetic uses must be based on analysis and engineering principles and not on what he calls "common sense" and "engineering judgment," that is, common-sensical, rule of thumb assumptions. We urge this philosophical principle in BLM's considerations of geomembrane liners.

For example, the fact that signficant failures occur only about 0.1% of the time does not imply geomembranes can be assumed safe. Since geomembranes are used in millions of situations, the number of failures amount to thousands, and these cases arise in stressed situations such as in mining uses. With HDPE, favored because of its low cost and not its

safety, both physical stresses (because it is relatively inelastic) and chemical stresses (because it is susceptible to oxidation) are major problems in mining uses. The use of HDPE liners at Copper Flat increases the stresses: the high elevation increases ultraviolet deterioration, the seismic activity of the area increases chances of subsidence and resulting stresses, flash floods can cause undercutting, the daily alternations in temperatures in the winter from freezing nights to warm days increase the possibility of ice forming under the liners and causing slippage, the summer heat deteriorates the physical qualities of the membrane, proximity to constant and repeated explosions increases radically the abrasion factor. The things that go wrong with HDPE liners are many, so that a whole industry has grown up to mitigate HDPE failures, and life expectancies of HDPE have been lowering.

Unfortunately, research is only now catching up with practice. Since HDPE liners were used extensively in landfills before their widespread use in mining, historical information on durations mostly deals with landfills; however, the chemical and physical situations are largely different in tailings ponds and landfills. We, therefore, expect analysis to be specific to mining applications rather than relying on landfill data.

Laboratory testing of HDPE have shown wide variations in the qualities of membranes. Not all HDPE are the same: "Specifying 'HDPE' for a critical geomembrane is akin to specifying 'Steel' for bridge construction without identifying types and grades" [Peggs, "Geomembrane Liner Durability: Contributing Factors and Status Quo," 2003]. Selecting HDPE for Copper Flat applications needs to depend, again, on comparative analysis rather than cost estimates or business networking.

The universally used Giroud equations for estimating migration of liquids through geomembranes assume that impermeability is a myth, so that in all cases one is dealing with risk management. These equations distinguish between different levels of installation quality,

so as to suggest that besides the theoretical risks of HDPE there is a very high degree of human failure in geomembrane use, accidents and poor design. In application, the difference between leakage through a well installed liner and a poorly installed one can result in a factor of 12 [see Beck, Smith, and Sample, "Design Considerations for the Use of Geomembranes for Phosphate Tailings Impoundments," 2009].

Another indication of permeability is the persistent problem of "whales," the bubbling up of membranes as a result of gas forming organic reactions in soils underneath liners [Peggs, "The Pond Edge: Geomembrane Liners in Wastewater Treatment Ponds: Whales, and Their Prevention," 2006, where there is a very impressive photograph of a giant whale in a tailings pond].

It should be recognized that the design of liners to fit specific situations presents problems that may not be soluble. For example, to minimize ultraviolet radiation carbon is added to the polymer, and that would be desirable at Copper Flat. However, black HDPE, as opposed to white HDPE, increases the material's caloric intake and so promotes heat deterioration. Tests and analyses should be required to determine an adequate compromise (in the quantity of added carbon?). Another example: seams can be inspected and pressure tested, but no test except a totally destructive test can detect an internal flaw. Furthermore, seams cause delamination (SIP) of the base material in 1% of cases, even when the seam itself is perfect [Smith, "SIP in Geomembrane Liners: An Acceptable Condition?" 2001], and seams recreate unusually angled tensions that can cause tears [Giroud, *op. cit.*]. The wide ambient temperature variation is another insoluble problem that must balance between lateral stress caused by temperature induced contraction and the use of extra material which is conducive to folds and creases. Therefore, requiring full Construction Quality Assurance and third party geoelectrical leak detection for installation may not be sufficient.

Oxidation is a primary concern, which distinguishes the requirements of a tailings pond liner from a landfill. Although HDPE manufacturers claim it is resistant to acids, the antioxidants added to the polymer can quickly lose their effectiveness. Studies of HDPE water pipes show serious degradation in 5 years or less from chlorinated water [Duvall and Edwards, "Oxidative Degradation of High Density Polyethylene Pipes from Exposure to Drinking Water Disinfectants," 2009]. At Copper Flat the flocking agents and flotation agents would need to be considered; for example, are isinglas or gelatin or gar gum possible alternatives?

Finally, we wish to ask for an analysis of risk reduction in the use of double liners. While it may seem common sense to think that two liners are better than one, that may not be the case. A multiple liner (and there are landfills with as many as 6 liners) is still, after all, a single containing liner with backups. If a very high percent of liner failures result from installation (seaming, accidental punctures, jointures between HDPE pipes and the membrane—which is what failed last year at BHP Billiton's Olympic Dam project.), doubling the liners doubles these possibilities, so that the risk is not lessened, though there might be other reasons why risk is lessened (for example, double liners allow installing a detection system). The question is whether the use of two HDPE liners is like trying to contain hydrochloric acid within two metal cans or whether it is like a double hulled ship. In the one case, there is only a matter of delay, and in the other there is a degree of protection. We feel it imperative that the issue be studied rather than be decided by "engineering judgment."

If multiplying liners does increase safety, we suggest consideration of more than two layers. If multiplying liners does not increase safety, we suggest a dry stack process for the tailings. In such an alternative, additional study would have to be done to consider the

increased instability of a single HDPE liner system which might necessitate a stronger retaining dam.

It is not out of place to conclude by reminding everyone that the Superfund site at the gold mine at Summitville, Colorado, just north of us near the headwaters of the Rio Grande, is the result of a torn HDPE liner.

APPENDIX N

GEOTECHNICAL CONSTRUCTION QUALITY ASSURANCE (CQA) PLAN FOR CONSTRUCTION OF THE LINER SYSTEM

GEOTECHNICAL CONSTRUCTION QUALITY ASSURANCE (CQA) PLAN FOR CONSTRUCTION OF THE COMPOSITE LINER SYSTEM AT GREGORY CANYON LANDFILL

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GEOTECHNICAL CONSTRUCTION QUALITY ASSURANCE (CQA) PLAN FOR CONSTRUCTION OF THE COMPOSITE LINER SYSTEM AT GREGORY CANYON LANDFILL

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1.0 INTRODUCTION

A Construction Quality Assurance (CQA) program consists of selected testing, inspection and documentation of a final construction product in order to provide the Owner/Agencies an evaluation of whether the end product is of the specified quality of materials and workmanship. Because of possible conflicts of interest, the Contractor should not undertake the CQA function directly. Rather, CQA inspection and testing should be left under the objective authority of a single team of inspection professionals.

A Construction Quality Control (CQC) program consists of selected tests and inspections performed by the Contractor during production which can assist the Contractor in producing the quality product required. While the CQC function is the sole responsibility of the Contractor, the Project Manager may, at his/her discretion, provide information regarding the ongoing CQA monitoring for the Contractor's use in implementing his/her CQC function. Release of the CQA data to the Contractor is for convenience only and, in no way, relieves the Contractor from their responsibility to fulfill the project requirements.

The composite liner system proposed for the GCLF consists of individual discrete layers of earth and synthetic materials which will function as a unit to form the containment system for the waste management area. A geocomposite drainage layer and additional layers of GCL and geomembrane will also be installed on benches and under the LCRS mainline as shown on the Project Drawings.

Each of these components functions as an integral part of the composite liner system and consequently must become a finished product during the course of construction. As a result, it is important that each layer or component of the composite liner be completed to the design specifications prior to construction of successive or overlying layers. For this reason, it is both inefficient and impractical to withhold CQA testing until completion of the liner and it is necessary to conduct an ongoing CQA program during construction.

This document presents the geotechnical Construction Quality Assurance (CQA) Plan for installation of the earthwork and geosynthetic components of the composite liner system for the Gregory Canyon Landfill (GCLF) in San Diego County, California. This CQA Plan is to be used in conjunction with the Preliminary Engineering Design and Phased Development Plans (September 2001) and Specifications prepared for the GCLF.

This plan includes:

- A Quality Assurance Program to be implemented during earthwork and geosynthetic material construction; including field observation, laboratory and field testing, and acceptance criteria for constructed work;

- Recording and documentation procedures to be employed for demonstrating that the constructed earthwork and geosynthetic liner components meet the requirements of the Project Plans and Specifications;

- Lines of communication, responsibilities and roles of the Construction Quality Assurance team and other related Project Personnel.

1.1 PROJECT REQUIREMENTS

In order to satisfy the requirements established by the governing regulatory agencies, the following composite liner system design has been proposed for the GCLF.

In floor areas (gradient less than 5:1 horizontal:vertical), the composite liner system designs will be composed of the following elements:

- Subgrade prepared to the requirements of the Project Documents;
- A one-foot thick subdrain gravel layer composed of select drainage gravel materials;
- A twelve (12)-ounce per square yard non-woven geotextile fabric;
- A minimum two (2) foot thick compacted soil liner yielding a permeability of less than 1.0×10^{-7} cm/sec;
- A 60-mil thick double-sided textured HDPE geomembrane;
- A sixteen (16) ounce per square yard non-woven geotextile fabric;
- A nine-inch minimum thickness gravel or equivalent drainage layer;
- A sixteen (16) ounce per square yard non-woven geotextile fabric;
- A 60-mil thick double-sided textured HDPE geomembrane;
- A geosynthetic clay liner (GCL);
- An 80-mil thick double-sided textured HDPE geomembrane;
- A sixteen (16) ounce per square yard non-woven geotextile fabric;
- A one (1) foot thick leachate collection layer composed of select drainage gravel materials;
- A twelve (12) ounce per square yard non-woven geotextile fabric;
- A two (2) foot thick protective cover soil layer (operations layer) composed of select on-site soil materials. Said materials shall be screened to exclude particles in excess of one-inch in maximum dimension.

In slope areas (gradient steeper than 5:1 horizontal:vertical) the liner system will be composed of the following elements:

- Subgrade prepared to the requirements of the Project Documents;
- A minimum two (2) foot thick compacted soil liner yielding a permeability of less than 1.0×10^{-7} cm/sec;
- A 60-mil thick double-sided textured HDPE geomembrane;
- A geosynthetic clay liner (GCL);
- An 80-mil thick single-sided textured HDPE geomembrane (textured side placed down);
- A sixteen (16) ounce per square yard non-woven geotextile placed immediately on top of the geomembrane;
- A minimum two (2) foot thick protective soil cover (operations layer) composed of select on-site soil materials. Said materials shall be screened to exclude particles in excess of one-inch in maximum dimension.

All materials used to construct the composite liner system must meet or exceed the criteria established in this CQA document and the Project Plans and Specifications. Any deviation from these criteria must be pre-approved by the Engineer and the Geotechnical CQA Consultant.

2.0 RESPONSIBLE PARTIES AND DEFINITIONS

2.1 RESPONSIBLE PARTIES

The responsible parties for all composite liner system construction activities at the GCLF, as set forth herein, are as follows:

Owner:

Gregory Canyon Ltd.
3 Embarcadero Center, Suite 2360
San Francisco, California 94111
Phone: (415) 391-2833
Contact: General Manager, Dr. Jerry Riessen

Landfill Operator:

Gregory Canyon Ltd.
3 Embarcadero Center, Suite 2360
San Francisco, California 94111
Phone: (415) 391-2833
Contact: General Manager, Dr. Jerry Riessen

Landfill Engineer:

Bryan A. Stirrat & Associates
1360 Valley Vista Drive
Diamond Bar, California 91765
Phone: (909) 860-7777
Contact: Mr. Mike Cullinane

Construction Manager:

To Be Determined

Geotechnical CQA Consultant:

To Be Determined

2.2 DEFINITIONS

"Construction Manager" - Person(s) or firm(s) authorized by the Owner to manage and oversee the administration of the Construction Contract. The Construction Manager shall be responsible for evaluating lines and grades (survey control) for the individual liner elements as well as verification of payment request, submittal acceptance, and change orders.

"Contractor" - The firm responsible for all elements of construction of the containment system. In this regard, the Contractor's responsibilities includes but are not limited to: preparation of subgrade and supporting surfaces (generally soil) for the geosynthetic installation; installation of the HDPE and geosynthetics; and placing earth and granular materials over the installed synthetic systems. The Contractor is further responsible for all activities of Subcontractors including but not limited to the geosynthetics Subcontractor.

"Geosynthetics" - A generic classification given to synthetic (man-made plastic and fabric) materials used in geotechnical and construction applications. Included are geomembrane or flexible membrane liners (i.e., HDPEs), geotextiles, geosynthetic clay liner (GCL), geonets, geogrids, geocomposites and geocells. At the GCLF, the term geosynthetics is used to refer to the HDPE, GCL, geocomposites and geotextiles.

"Geosynthetic Subcontractor" - The firm responsible for handling, storing, placing, seaming, and other aspects of the installation of the geosynthetics included in the composite liner system.

"Geotechnical CQA Officer" - The individual or firm serving under the direction of the Geotechnical Project Director and responsible for day to day geotechnical Construction Quality Assurance (CQA).

"Geotechnical CQA Monitors" - The individuals working under the direction of the Geotechnical CQA Officer who are routinely involved in the construction process. Such personnel include "Technicians", "Field Engineers" and "Field Geologists" representing the Geotechnical Consultant. CQA Monitors responsible for the geosynthetics and earthwork, shall be experienced in landfill construction monitoring, geosynthetic material installation, low-permeability soil construction and testing, and compaction testing during grading operations.

"Geotechnical Consultant" - Geotechnical firm responsible for the design and specifications for the earthwork and geosynthetic elements of the Project Plans and Specifications. The Geotechnical Consultant or his/her representative is also responsible for observing, testing, and documenting activities related to quality assurance for all geotechnical and geosynthetic aspects of construction except for engineering and survey control. All completed geotechnical work is subject to approval by the Geotechnical Consultant.

"Geotechnical Project Director" - Geological/geotechnical professional registered in the State of California who, under the employ of the Geotechnical Consultant is responsible for earthwork observation, monitoring and testing.

"Geotechnical Construction Quality Assurance for Earthwork" - The protocols to be followed in evaluating the adequacy of the Contractor's work with regard to all elements of earthworks construction with the exception of line and grade (survey) control. Said work shall include but need not be limited to all CQA activities delineated herein and in the Specifications. Geotechnical CQA is to be provided by a party independent of the Contractor.

"Geotextile" - A permeable synthetic fabric used with soil, rock, sand, gravel or any other similar materials as an integral part of the composite liner system. It can provide protection to other systems or serve to separate different materials.

"Independent Testing Laboratory" - The firm responsible for conducting selected tests of materials and/or products used for the project, such as conformance testing. The laboratory shall be independent of the Manufacturer, Contractor, Geosynthetics Subcontractor and any party involved with the manufacture and/or installation of any product to be tested.

"Landfill Engineer" - The firm responsible for the design and preparation of the Project Plans and Specifications including the containment system that fulfills the regulatory and operational requirements of the permitting agencies and Owner,

respectively. The Landfill Engineer, also known as the Engineer, is also responsible to modify or change the design if unexpected or unanticipated site conditions are encountered during construction.

"Project Documents" - Project Documents include all Construction Drawings, Record Drawings, Construction Specifications, CQA Plans, Health and Safety Plans and Project Schedules and Contractor Submittals.

"Project Manager" - The Owner's designated representative responsible for the Project.

"Project Drawings and Specifications" - All project related Drawings and Specifications including Design Modifications and Record Drawings.

"Quality Assurance" - Actions taken by the Owner or his representative necessary to evaluate whether the earthen and geosynthetic materials and workmanship meet the requirements of the Project Plans and Specifications.

"Quality Control" - Actions taken by the Contractor, Subcontractors and/or Liner Manufacturer(s) to ensure that the earthen and geosynthetic materials and workmanship meet the requirements of the Project Plans and Specifications.

"Work" - All tools, equipment, supervision, labor, and materials or supplies necessary to complete the project as specified herein and as shown on the Project Drawings.

3.0 GEOTECHNICAL CQA ORGANIZATION

The Geotechnical CQA Team for composite liner system construction will be composed of design and field personnel with specific experience in the inspection and Geotechnical CQA monitoring of earthwork, low-permeability liner soils and geosynthetic materials specifically related to landfill liner construction. The principal categories of personnel assigned to the Geotechnical CQA Team are presented below.

3.1 GEOTECHNICAL PROJECT DIRECTOR

The Geotechnical Project Director shall be a representative of the Geotechnical CQA Consultant and shall have overall responsibility for all geotechnical CQA activities and have specific experience in managing landfill liner construction projects.

The Geotechnical Project Director will be responsible for reviewing all earthwork or geosynthetic issues which may arise during construction. The Geotechnical Project Director's approval will be required for any earth or geosynthetic material modifications or for any design modifications which may impact the performance of the earth or geosynthetic materials.

3.2 GEOTECHNICAL CQA OFFICER

The Geotechnical CQA Officer will serve as the Geotechnical Project Director's on-site representative. All Geotechnical CQA functions will be his/her direct responsibility. All coordination, reporting and issues related to earthwork and/or geosynthetics non-compliance will be directed through the CQA Officer. In addition, he/she will participate with the Landfill Engineer and Geotechnical Project Director in all decisions related to design issues which arise during the course of construction.

The Geotechnical CQA Officer shall be responsible for overall review, observation, sampling, and testing of activities utilized for Construction Quality Assurance (CQA). The Geotechnical CQA Officer shall have prior experience serving as the CQA Officer on similar liner construction projects. Specific duties of the CQA Officer include:

- Review of all designs, Project Plans, and Specifications;
- Implementation of the Geotechnical CQA program including: assignment and management of all Geotechnical CQA personnel; review of all field reports; and review of all Geotechnical CQA related issues;
- Review of design changes and coordination of such changes with the Engineer;
- Serving as the on-site representative of the Geotechnical Project Director;
- Familiarization of all Geotechnical CQA Monitors with the site and the Geotechnical CQA requirements of the project;
- Attendance at Geotechnical CQA related meetings (i.e., preconstruction, progress, and special meetings as required);
- Review of all Liner Manufacturer and Liner Subcontractor certifications and documentation and development of appropriate recommendations;
- Designation of a senior Geotechnical CQA Monitor to act on his/her behalf at the site while he/she is absent and operations are ongoing;
- Notation of any on-site activities that could result in damage to the geosynthetics;

- Review of the Liner Subcontractor's personnel qualifications for conformance with project requirements;
- Selection of locations for destructive test sampling;
- Oversight of the ongoing preparation of "As-Built" Plan(s);
- Review of all Geotechnical CQA Monitors daily reports and logs;
- Reporting to the Construction Manager and logging in his/her daily report any relevant observations reported to him by the Geotechnical CQA Monitors;
- Oversight of the marking, packaging and shipping of all laboratory test samples;
- Review of the results of laboratory testing and presentation of appropriate recommendations;
- Preparation of a monthly summary of Geotechnical CQA activities;
- Reporting of any unresolved deviations from the Geotechnical CQA Plan to the Construction Manager;
- Preparation of the final "As-Built" report for all completed geosynthetic construction activities;

3.3 GEOTECHNICAL CQA MONITORS

3.3.1 FIELD ENGINEER/FIELD GEOLOGIST

The Field Engineer/Field Geologist will be a representative of the Geotechnical CQA Consultant and will be responsible for evaluating whether earth and/or synthetic materials conform to the requirements of the Project Drawings and Specifications. The Field Engineer/Field Geologist will have specific experience in landfill construction monitoring, compaction observation and testing during grading operations, and geosynthetic material observation, monitoring and documentation. Duties of the Field Engineer/Field Geologist will include the following:

- Subgrade inspection, review, testing and documentation.
- Review of the adequacy of all clearing, grubbing, stripping and preparation of areas to receive fill.
- Monitoring and evaluation of any soil blending, mixing and processing operations.

- Evaluation of the engineering characteristics of the processed and constructed earth materials.

- Observation and evaluation of all cuts which may be impacted by geologic conditions.

3.3.2 GEOTECHNICAL CQA TECHNICIANS

Geotechnical CQA Technicians will be representatives of the Geotechnical CQA Consultant and will continuously observe all grading and geosynthetic operations to provide a basis for concluding that construction is carried out in conformance with the Project Drawings and Specifications. The duties of the Geotechnical CQA Technicians include monitoring, observing and testing all earthwork as well as monitoring, logging and documenting all geosynthetic installation operations.

The operations to be monitored observed and/or tested for the earthwork include:

- Observation of subgrade surface preparation.

- Verification that liner soils are derived from appropriate sources.

- Visual evaluation of the soil physical properties for consistency with the Project Drawings and Specifications.

- Evaluation of all moisture conditioning and processing operations to evaluate uniformity of material and moisture content.

- Evaluation of the constructed low-permeability liner material for conformance with the Project Drawings and Specifications.

- Identification of deleterious materials or other deficiencies in soil characteristics to minimize the possibility that these materials are incorporated into the composite liner system.

- Monitoring of activities for the removal and/or disaggregation of oversize material.

- Observation of uniformity of coverage of compaction equipment, especially at fill edges, turnaround areas and on slope faces.

- Monitoring of lift thickness.

- Observation of the active fill pad at the beginning of each grading day and establishment of requirements for wetting/drying and/or processing of exposed surfaces prior to placement of additional fill.

- Undertaking field tests including but not limited to BAT permeability and field moisture/density testing at the minimum frequencies noted herein or at any time that a deficiency is suspected.

- Recovery of samples for laboratory testing.

- Completion, evaluation and/or documentation of laboratory testing of the permeability, grain size distribution, Atterberg Limits, in-place moisture content and density of the low-permeability layer materials in accordance with the requirements of the Specifications (including retests, if necessary).

- Confirmation that the test results are in accordance with the Project Specifications (including retests of any previously failed areas).

The operations to be observed and monitored for all geosynthetics include:

- Material delivery.
- Unloading and on-site transport and storage.
- Placement/deployment operations.
- Joining and/or seaming operations.
- Repair operations.

Specifically, the seaming operations to be monitored include:

- The condition of panels as placed.
- Trial seams.
- Seam preparation.
- Seaming.
- Nondestructive seam testing.
- Sampling for destructive seam testing.
- Laboratory test sample marking.
- Repair operations.
- Reviewing the final certification of seams.

All observations shall be reported in a timely manner to the CQA Officer and the Construction Manager.

3.4 INDEPENDENT TESTING LABORATORY

The Independent Testing Laboratory shall be certified by the Geosynthetic Accreditation Institute (GAI) in the specific tests to be performed and will perform all conformance testing of geosynthetics and all destructive laboratory testing of field seams.

4.0 MEETINGS

In order to facilitate construction of the composite liner system, close coordination between the Construction Manager, Engineer, Geotechnical CQA Consultant, Contractor, Liner Subcontractor and Geotechnical CQA personnel is essential. To this end the following meetings will be scheduled.

4.1 PRE-CONSTRUCTION MEETINGS

A Pre-construction Meeting will be held at the site. At a minimum, the meeting shall be attended by the Owner (or designated representative), the Construction Manager, the Landfill Engineer, the Geotechnical Consultant (or designated representative), the Contractor and appropriate Geotechnical CQA staff. Specific items to be considered at this meeting will include:

- Any appropriate modifications to the Geotechnical CQA requirements.
- Development of a format for site specific documentation.
- Review of the responsibilities of each party.
- Review of the lines of authority and communication.
- Review of work area security and safety protocol.
- Review of the procedures for project documentation and reporting, and distribution of documents and reports.
- Review of procedures for submittals, change orders and extra work efforts.
- Review of the Contractor's proposed methods of construction, (including equipment), with specific emphasis on methods of select grading, soil mixing, stockpiling, processing, moisture conditioning and compaction.
- Review of the procedures for field and laboratory CQA testing.
- Establishment of procedures for correcting and documenting construction deficiencies.
- Conducting an initial site inspection to discuss work areas, stockpile areas, mixing tables, laydown areas, access roads, haul roads, and related items.
- Review of the project schedule.

The meeting shall be documented by the Construction Manager and minutes shall be distributed to all parties.

4.2 WEEKLY PROGRESS MEETINGS

Progress Meetings shall be held weekly. At a minimum, these meetings shall be attended by the Owner (or designated representative), the Construction Manager, the Geotechnical CQA Officer and/or the Geotechnical CQA Monitors, and the Contractor. Weekly progress meetings shall be documented by the Construction Manager or his/her representative and minutes shall be distributed to all parties. The purpose of these meetings is to:

- Discuss any health and safety related issues.
- Review scheduled work activities.
- Discuss project related problems.
- Review laboratory and field test data.
- Discuss the Contractor's personnel and equipment assignments.
- Review the previous week's activities and accomplishments.

4.3 SPECIAL MEETINGS

Special meetings will be conducted as required to discuss any problems or deficiencies. At a minimum, these meetings will be attended by the Owner (or designated representative), Construction Manager, appropriate Geotechnical CQA staff and the Contractor. If correction of a problem requires a design modification, the Landfill Engineer and the Geotechnical Project Director will also be present. The purpose of these meetings is to:

- Define and discuss any problems or deficiencies in the Project.
- Review possible corrective actions or solutions.
- Implement an action plan to resolve the problems or deficiencies.

Special meetings shall be documented by the Construction Manager or his/her representative and minutes shall be distributed to all parties.

4.4 GEOSYNTHETIC MATERIAL PRE-INSTALLATION MEETING

A Geosynthetic Material Pre-installation Meeting shall be held at the site before installation of the geosynthetics. At a minimum, the meeting shall be attended by the Construction Manager, the Engineer, the Contractor, the Liner Subcontractor, and Geotechnical CQA staff. The Pre-Installation Meeting will not be conducted until all Manufacturer Certifications required by the Project Specifications and this document are received, reviewed and approved.

Specific items to be addressed at this meeting include:

- Submittal and review of relevant documents.
- Definition of appropriate modifications to the Geosynthetic Geotechnical CQA requirements.
- Development of a format for site specific documentation.
- Definition of the responsibilities of each party.
- Definition of lines of authority and communication.
- Review of work area security and safety protocol.
- Definition of methods for documenting and reporting, including distributions.
- Selection of welding equipment and procedures.
- A field welded seam(s) demonstration.
- Identification of testing equipment and procedures, including peel and shear tests, and procedures for communicating laboratory test results.
- Identification of procedures for correcting and documenting construction deficiencies.
- A site inspection to discuss storage areas, work areas, storage areas and protocols, laydown areas, access roads, haul roads, and related items.
- Review of the project schedule.

The meeting shall be documented by the Construction Manager and minutes shall be distributed to all parties.

4.5 DAILY PROGRESS MEETINGS (if necessary)

Daily Progress Meeting shall be held in the field before the start of work each day. At a minimum, this meeting shall be attended by the Geotechnical CQA Officer or his/her representative, Geotechnical CQA Monitors, the Contractor and the Liner Subcontractor. The purpose of this meeting is to:

- Review and coordinate scheduled work activities between the Geotechnical CQA monitors and the Liner Subcontractor's crew.
- Discuss any problems.
- Review test data.

- Discuss the Liner Subcontractor's personnel and equipment assignments for the day.

- Review the previous day's activities, accomplishments and/or deficiencies.

4.6 MANUFACTURING PLANT VISIT(S)

The Liner Subcontractor shall make arrangements with the Liner Manufacturer(s) to allow the Geotechnical CQA Officer or his/her designee to visit the geosynthetics manufacturing plant(s) during manufacture of the liner material for this project and to observe manufacturing methods and quality control of manufactured materials. If appropriate, the Geotechnical CQA Officer or his/her designee shall review the manufacturing process, quality control, laboratory facilities and testing procedures.

During the plant visit, those visiting shall:

- Observe that the geosynthetic properties presented in the Liner Manufacturer's certification documents meet the Project Specifications.

- Verify that the measurements of properties by the Liner Manufacturer are properly documented and test methods used are acceptable.

- Spot inspect some of the geomembrane rolls and verify that they are free of holes, blisters, or any sign of contamination by foreign matter.

- Review packaging and transportation procedures to verify that these procedures are not damaging the geosynthetics.

- Observe that roll packages have a label indicating the name of the Liner Manufacturer, type of geosynthetic, its roll/panel number and other required information.

- Verify that extrusion rods and/or beads are derived from the same base resin type as the geomembrane.

5.0 GEOTECHNICAL CQA MONITORING FOR EARTH MATERIALS

5.1 GENERAL

Construction of the earth materials portion of the composite liner system shall be performed in accordance with the Project Drawings and Specifications and shall be continuously observed, and routinely sampled and tested by the Geotechnical CQA Monitors for the physical parameters described in this section.

The testing frequency presented herein is a minimum. Additional tests will be conducted by the Geotechnical CQA Monitor for retests and at any time that in the opinion of the Geotechnical CQA Monitor, additional testing is required and/or a deficiency is suspected. Retests of previously failed areas will be performed at the discretion of the Geotechnical CQA Monitor when, in his/her opinion, sufficient reworking of the area has been performed to warrant a retest.

5.2 LOW-PERMEABILITY MATERIALS

The low-permeability layer of the composite liner system will be constructed with on-site or import soils derived from a source approved by the Geotechnical Consultant. Low-permeability liner materials will be evaluated by the Geotechnical Consultant according to the following minimum testing schedule in order to characterize material properties:

Low-Permeability Import Material Testing Type and Frequency

Test Description	Test Designation	Minimum Test Frequency
Particle Size Analysis	ASTM D422	One per 2000 yds^3 stockpiled or one per production day (minimum)
Atterberg Limits	ASTM D4318	One per 2000 yds^3 stockpiled or one per production day (minimum)
Classification of Soils for Engineering Purposes	ASTM D2487	One per 2000 yds^3 stockpiled or one per production day (minimum)
Processed Moisture Content (following moisture conditioning)	ASTM D4643 (microwave) or ASTM D2216 (oven)	Two per construction day
Laboratory Permeability	ASTM D5084/EPA 9100 or USBR Modified E-13	One per 10,000 c.y
Moisture/Density Relationship	ASTM D1557	One per 10,000 c.y.
Visual Inspection	ASTM D2488	Daily while stockpiling

No soils other than those obtained from the approved borrow source and/or approved by the Geotechnical Consultant are to be used in liner construction.

5.3 DEMONSTRATION FILL (TEST FILL PAD)

A Demonstration Fill (Test Fill Pad) will be constructed prior to actual liner construction to evaluate both the low-permeability soil proposed for liner construction and the Contractor's equipment and methods for constructing and maintaining the integrity of the low-permeability liner soils. The Demonstration Fill will be constructed by the Contractor selected to complete liner construction and as specified in the Project Specifications. Construction of the Demonstration Fill shall be completed a minimum of two weeks prior to the actual low-permeability liner construction. The Contractor shall construct the Demonstration Fill using the same earthwork equipment and Specifications to be used for liner construction to determine if the specified density/moisture content/hydraulic conductivity relationships determined in the laboratory can be achieved in the field with the compaction equipment to be used and at the specified lift thickness.

Soil sampling will be performed by the Geotechnical CQA Monitor(s) during and after construction of the Demonstration Fill to provide data regarding soil properties obtainable using the proposed design and construction methods. All criteria for Demonstration Fill construction, including low-permeability material processing, amount of compaction, moisture content, etc., will be the same as those required and anticipated for actual liner construction.

The purpose of the Demonstration Fill is to: 1) evaluate the performance of the construction equipment to be used for soil blending, processing, placement and maintaining the low-permeability soils under actual construction conditions; 2) evaluate the field performance of the low-permeability soil material through laboratory and field tests; 3) compare field (BAT) and laboratory permeability test results; and 4) develop a database of test results and performance standards prior to full-scale liner construction in order to substantiate the Construction Specifications. If necessary, the results from the Demonstration Fill construction and testing program will be used to modify the Project Specifications for low-permeability liner construction.

The Demonstration Fill will measure roughly 150 feet by 50 feet and will consist of an approximately 24-inch thick section of blended, processed, cured and compacted low-permeability soils, placed on slope and floor areas. The Demonstration Fill shall be constructed using the methods, materials and equipment to be employed during construction of the actual low-permeability layer. Processed low-permeability materials will be placed in six to eight inch lifts. Construction will be continuously observed and tested by the Geotechnical CQA Monitor and/or his/her representative.

The testing frequency used in construction and monitoring of the Demonstration Fill will be more stringent than that to be maintained during construction of the actual liner. Minimum testing requirements for Demonstration Fill construction will include:

1. Full-Time observation.
2. Density tests (ASTM D1556, D2937, or D2922) taken at a rate of at least one (1) test per 100 cubic yards of fill placed or one (1) per 6 inches of fill thickness. At a minimum, ten (10) in-place moisture/density tests will be completed.
3. At least two (2) maximum density tests (ASTM D1557) will be completed.
4. Five (5) in-situ BAT permeability tests will be conducted.
5. Five (5) laboratory permeability tests on relatively undisturbed samples (Modified USBR E-13 or ASTM D5084) will be conducted including at least one triaxial cell permeability test (ASTM D5084).
6. Five (5) Atterberg Limit tests (ASTM D4318) and five (5) grain size analyses (ASTM D422) will be completed.

5.4 LOW-PERMEABILITY FILL PLACEMENT

Select low-permeability liner soils shall be screened (if necessary), dried, and/or moisture conditioned until uniformly blended material characteristics and moisture condition are attained. Moisture conditioning, if required will allow for a minimum 48-hour curing period. Field and laboratory testing for moisture content, in-place dry density, and other engineering properties including saturated hydraulic conductivity during construction of the low-permeability layer of the liner system will be completed according to the following minimum schedule:

Low-Permeability Fill Testing Type and Frequency

Test Description	Test Designation	Minimum Test Frequency
Processed Moisture Content (following moisture conditioning)	ASTM D4643 (microwave) or ASTM D2216 (oven)	Two per construction day
Moisture-Density Relationship	ASTM D1557	One per 5,000 cubic yards or per change in material type
In-Place Moisture-Density (Nuclear and/or Drive Ring)	ASTM D2922 ASTM D3017 ASTM D2937	One per 250 cubic yards placed
In-Place Density and Moisture Content (Sand-Cone)	ASTM D1556	One per 1,000 cubic yards placed or 20 percent of total In-Place tests (whichever is greater)
Particle Size Analysis	ASTM D422	One per 5,000 yd^3 (conducted on samples retrieved for laboratory permeability testing)
Atterberg Limits	ASTM D4318	One per 5,000 yd^3 (conducted on samples retrieved for laboratory permeability testing)
Laboratory Permeability	ASTM D5084/EPA 9100 or USBR Modified E-13	One per 5,000 cubic yards placed
BAT Permeability		One per 2,500 cubic yards placed
Visual Inspection	ASTM D2488	Daily

5.5 ACCEPTANCE CRITERIA

5.5.1 GENERAL

Where test results indicate that the lift thickness, maximum particle size, homogeneity of material, cure time, moisture content, density, or permeability of any portion of the work is below the project requirements, that particular portion shall be retested and/or reworked or replaced until the required condition has been attained and the resulting product meets or exceeds the requirements of the Project Specifications. No additional fill shall be placed over an area until the existing fill has been tested horizontally and vertically and determined by the Geotechnical CQA Monitor to meet the Project Earthwork Specifications. The area to be reworked will be verified by survey if in the opinion of the Geotechnical CQA Monitor conditions warrant.

5.5.2 MOISTURE CONTENT AND DENSITY

If in the opinion of the Geotechnical CQA Officer or the Senior Geotechnical CQA Technician, low-permeability materials which have been placed and/or are

ready to be placed, do not visually have a uniform and homogeneous moisture content throughout the material in question, these materials will be removed, without testing, and will be reprocessed and/or reworked until, in the opinion of the Geotechnical CQA Officer or his/her designated representative, they are uniform in appearance.

For all fill materials placed, if test results indicate a relative dry density of less than that required or a moisture content outside the limits specified, then the area will be considered inadequate and will be reworked. Any reworked areas will be retested by the Geotechnical CQA Monitor to verify the reworked area meets the density and moisture content requirements.

The following table lists the minimum moisture/density requirements for fill materials placed. The in-place moisture content and dry density requirements are relative to the maximum dry density and optimum moisture content as determined by ASTM D1557.

Fill Type	Minimum Density (percent)	Moisture Content
Low-Permeability Layer Material	90	2 – 4% above optimum
Unclassified Fill	90	Optimum to 2% above
Protective Cover Soil	85	Optimum ± 2%

5.5.3 PERMEABILITY

If a BAT or laboratory permeability test results in a value exceeding the defined maximum of 1.0 E-07 cm/sec, two (2) additional tests of the same type will be taken in the immediate vicinity. [At the discretion of the Geotechnical CQA Consultant, BAT permeability tests may be taken in lieu of failed laboratory tests to expedite the CQA testing procedure.] If either of the additional tests fails to meet the minimum requirements, the area represented by the test will be considered inadequate and will be removed or reprocessed and recompacted.

5.5.4 LIFT THICKNESS AND PROCESSING

If at any time the CQA Monitor observes an uncompacted lift thickness in excess of eight inches or observes material being placed without meeting the requirements for processing, stockpiling and curing, the Contractor shall immediately discontinue placing additional fills in that area. For an over thick lift, the Contractor shall immediately blade the surface to reduce the lift thickness to the Project Specifications prior to compaction. If inadequately mixed materials are placed, the Contractor shall immediately remove these materials and return them to the stockpile/processing area where they will be reprocessed.

5.5.5 GEOMEMBRANE SUBGRADE

The CQA Monitor and the geomembrane installation Contractor will observe and approve the geomembrane subgrade prior to geosynthetic material deployment. The finish surface shall be free of abrupt breaks, sharp objects, or other foreign material which may damage the overlying geomembrane. The subgrade shall be unyielding, smooth and uniform and the surface shall not be pebbly or tracked and rutted by equipment.
Immediately prior to geomembrane deployment, all subgrade surfaces (i.e., floor and slopes), will be proof-rolled with a steel drum roller weighting not less than 200 pounds per lineal inch of drum width.

Geomembrane deployment shall not proceed until the surface has been approved by the CQA Monitor and accepted by the geomembrane installation Contractor.

6.0 GEOTECHNICAL CQA MONITORING FOR GEOSYNTHETICS

6.1 GEOMEMBRANE (HDPE)

Delivery of geomembrane to the site will not be allowed until all required documentation and/or certifications are approved by the CM/Geotechnical CQA Team. It is the responsibility of the Contractor/Subcontractor to ensure that all required documentation and/or certifications are approved prior to shipment.

6.1.1 HDPE MANUFACTURING

Prior to the delivery of any geosynthetic material, the Liner Manufacturer shall provide the Construction Manager with the following:

- A properties sheet for the rolls to be delivered including all specified properties measured using test methods indicated in the specifications.
- The sampling procedure and results of testing.
- A certification for each roll stating that property values given in the properties sheet are guaranteed by the Liner Manufacturer.

The Geotechnical CQA Officer shall verify that:

- The property values certified by the Liner Manufacturer meet the project specifications.
- The measurements of properties by the Liner Manufacturer are properly documented and that the test methods used are acceptable.

Prior to shipment, the Liner Manufacturer shall provide the Construction Manager with a quality control certificate for each roll of geomembrane. The quality control certificate(s) shall be signed by a responsible person employed by the Liner Manufacturer and shall include:

- Lot and roll numbers and identification.
- Sampling procedures and results of quality control tests. At a minimum, results shall be given for those properties identified in the Project Specifications.

The Geotechnical CQA Officer shall:

- Verify that the quality control certificates have been provided at the specified frequency for all rolls, and that each certificate identifies the rolls related to it.
- Review the quality control certificates and verify that the certified roll properties meet the specifications.

6.1.2 GEOMEMBRANE DELIVERY

Prior to delivery, all individual roll manufacturer certifications required by this document and/or the Project Specifications must be received and approved by the Construction Manager. Delivery of any unapproved roll will not be allowed and unapproved rolls will be transported off-site at the Contractors expense.

6.1.2.1 Transportation and Handling

All transportation and on-site handling of the geomembrane is the responsibility of the Contractor and Liner Subcontractor.

The Geotechnical CQA Officer shall observe the handling equipment used on the site and provide comment on whether it might pose a risk of damage to the geomembrane. The Geotechnical CQA Officer will also observe the Contractor and Liner Subcontractor personnel's handling of the geomembrane and provide comment on whether appropriate care is being taken. Finally, the Geotechnical CQA monitor shall verify that all documentation required upon delivery has been received.

Upon delivery at the site, the Contractor, Liner Subcontractor and the Geotechnical CQA Monitor shall complete a surface observation of all rolls for defects and damage. This inspection shall be conducted without unrolling rolls unless defects or damage are found or suspected. The Geotechnical CQA Officer shall report the following to the Construction Manager:

- Rolls, or portions thereof, which should be rejected and removed from the site because they have severe flaws.

- Rolls which visually include minor repairable flaws.

Any damaged rolls shall be rejected and removed from the site or be stored at a location separate from accepted rolls as designated by the Construction Manager. All rolls which do not have proper Liner Manufacturer's documentation shall be removed from the site at the Contractors expense until all required documentation has been received and approved.

A log of all HDPE received shall be maintained by the Geotechnical CQA Monitors and recorded on an appropriate form (Form B-1 attached).

6.1.2.2 Geomembrane Storage

The Contractor and Liner Subcontractor shall be responsible for storage of the HDPE on-site and shall ensure the storage is consistent with the Manufacturer's recommendations. The Contractor shall coordinate with the Construction Manager to ensure that storage space is provided in a location (or several locations) such that on-site transportation and handling are minimized. Storage space shall be protected by the Contractor and Liner Subcontractor from theft, vandalism, and damage from actions of man, weather, animals and other sources. The Geotechnical CQA Monitors shall observe that the materials are not stored directly on the ground and storage of the HDPE is completed in a fashion that protects against damage.

6.1.3 HDPE CONFORMANCE TESTING

6.1.3.1 Tests

Upon delivery of the HDPE, the Contractor or Liner Subcontractor shall ensure that conformance samples are obtained and forwarded to the Independent Testing Laboratory at the frequency required for testing to ensure conformance with the Project Specifications. All conformance samples will be obtained in the presence of the Geotechnical CQA Monitor or his/her designated representative.

At a minimum, conformance tests will include determination of the following characteristics for the HDPE:

- Density (ASTM D1505A).

- Environmental Stress Crack (ASTM D5397).

- Tear Resistance (ASTM D1004 Die C).

- Carbon black content (ASTM D1603).
- Thickness (ASTM D5199).
- Tensile characteristics (yield strength, elongation at yield, break strength, elongation at break) (ASTM D638).
- Interface shear strength testing as described in the Project Specifications. Direct shear testing for interface strength shall be carried out in accordance with ASTM D-5321 "Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method." Issues and procedures related to soil preparation shall be governed by ASTM D3080.
- Puncture resistance (ASTM D4833).

Where optional procedures are noted in the test method, the requirements of the Project Specifications shall prevail.

6.1.3.2 Sampling and Testing Frequency

Unless otherwise specified, conformance samples shall be taken and tested at a rate of one per lot or one per 100,000 square feet, whichever results in the greater number of tests. Testing for interface shear will be conducted at a rate of one per 200,000 square feet.

6.1.3.3 Sampling Procedures

Samples shall be taken across the entire width of the roll and shall not include the first three feet. Unless otherwise specified, samples shall be 3 ft. long by the roll width. The Geotechnical CQA Monitors shall mark the machine direction on the samples with an arrow, and the Liner Manufacturer's roll identification number.

6.1.3.4 Test Results

The results of Conformance Testing will be documented on the appropriate forms and the Geotechnical CQA Officer shall examine all conformance testing results and report any non-conformance to the Construction Manager, the Contractor and the Lining Subcontractor.

All specimens tested shall pass. If any specimen fails, the entire sample shall be considered as a failure and rejected. In this event, the material represented by the sample shall be considered nonconformant with the Specifications, and corrective measures shall be implemented. Corrective measures shall include a rerun of the conformance testing using a portion of the same sample. If the second test passes, the Geotechnical CQA Officer may assume an error was made in the first test and

the HDPE material can be accepted. If the second test fails, the Liner Subcontractor shall remove all material represented by the sample from the work area.

All conformance test results must be approved by the Construction Manager prior to the HDPE represented by the test being approved for deployment/installation. The decision of the Construction Manager shall be final.

6.1.4 HDPE INSTALLATION

6.1.4.1 Earthwork

Surface Preparation

The Contractor shall be responsible for preparing the supporting soil according to the Project Specifications.

Prior to liner installation, the Contractor and Liner Subcontractor shall verify and the Construction Manager and Geotechnical CQA Monitor shall observe that:

- All lines and grades have been checked by survey and approved by the Construction Manager.
- The subgrade has been prepared in accordance with the Project Specifications.
- The surface has been rolled and compacted to be free of surface irregularities, loose soil, and protrusions.
- The supporting soil surfaces do not contain stones or other sharp protrusions which could damage the HDPE.
- There are no excessively soft areas which could result in HDPE damage.
- All construction stakes, hubs or other items used for grade control and/or verification have been removed.
- The Liner Subcontractor has certified in writing that the surface on which the HDPE will be installed is acceptable using an appropriate form (Form B-3 attached).

The certificate of acceptance shall be given by the Liner Subcontractor to the Contractor and the Construction Manager prior to commencement of HDPE installation in the area under consideration. The Geotechnical CQA Monitors shall have a copy of this certificate before installation of HDPE commences in any given area.

After the supporting surface has been accepted by the Contractor and Liner Subcontractor, it shall be the Contractor and Liner Subcontractor's responsibility to indicate to the Construction Manager any change in the supporting soil condition that may require repair work. If the Construction Manager concurs with the Contractor and Liner Subcontractor, then the Construction Manager shall coordinate the repair of the supporting surface. The subject area will also be observed by the Geotechnical CQA Monitors who shall have the authority to reject an area even after it has been accepted by the Contractor and Liner Subcontractor.

Anchor Trench

Anchor trenches shall be excavated to the lines and widths shown on the Project Drawings, prior to HDPE placement. The Geotechnical CQA Monitors shall observe that the anchor trenches have been constructed according to the project documents.

Slightly rounded corners shall be provided where the HDPE adjoins the trench so as to avoid sharp bends in the HDPE. No loose soil shall be allowed to underlie the HDPE in the anchor trench.

Anchor trench backfill shall be compacted to at least 90 percent relative compaction (ASTM D1557) as outlined in the Specifications.

Care shall be taken when backfilling the trenches to prevent any damage to the geosynthetics. The Geotechnical CQA Monitors shall observe the backfilling operation and advise the Construction Manager of any problems.

6.1.4.2 HDPE Placement

Field Panel Identification

A field panel (sheet) is a discrete and integral area of HDPE which is to be seamed in the field along the edges to other field panels (i.e., a field panel is a roll or a single portion of a single roll). The Contractor or Liner Subcontractor shall assign each panel over 25 sq. feet an identification code which shall be agreed to and used by the Geotechnical CQA Monitors, Construction Manager, Contractor and the Liner Subcontractor. The Contractor or Liner Subcontractor shall locate the code with identifying roll number near the middle of panels less than 50 feet in length and at both ends of any panel over 50 feet in length. The Geotechnical CQA Monitors shall establish a chart showing correspondence between roll numbers, certification reports, and the panel identification code. The field panel identification code shall be used for all Geotechnical CQA records. An HDPE panel placement log will be maintained by the Geotechnical CQA Monitors on appropriate forms (Forms B-4 and B-5 attached).

Field Panel Placement

The Geotechnical CQA Monitors shall record the identification code, location and date of installation of each field panel.

During panel placement, the Geotechnical CQA Monitors shall:

- Verify that field panels are installed in general accordance with the panel layout plan, as approved or modified by the Construction Manager/Engineer.
- Observe the panel surface as it is deployed and record all panel defects and disposition of the defects. All repairs are to be made in accordance with the Specifications.
- Observe that the equipment used does not damage the HDPE by handling, trafficking, leakage of hydrocarbons, or by other means.
- Observe that the surface beneath the HDPE has not deteriorated since previous acceptance.
- Observe that there are no stones, construction debris, or other items beneath the HDPE which could cause damage.
- Observe that the HDPE is not dragged across an unprepared surface. If the HDPE is dragged across an unprepared surface, it shall be inspected for scratches and repaired or rejected, if necessary.
- Observe that the method used to unroll the panels does not cause scratches or crimps in the HDPE and does not damage the supporting soil surface.
- Record weather conditions including temperature, wind, and humidity. The HDPE shall not be deployed in the presence of excess moisture (fog, dew, mist, etc.), high winds and extreme temperatures as determined by the Geotechnical CQA Officer.
- Observe that people working during the installation of HDPE do not smoke, wear shoes which could damage the HDPE, or engage in activities which could damage the HDPE.
- Observe that the method used to deploy the HDPE panels minimizes wrinkles and that the panels are anchored to prevent movement by the wind.
- Observe that direct contact with the HDPE is minimized; (i.e., the HDPE is protected by geotextiles, extra HDPE, or other suitable materials, in areas where excessive traffic may be expected).

The Geotechnical CQA Monitors shall inform the Contractor, the Liner Subcontractor and the Construction Manager if the above conditions are not met.

After placement and prior to seaming, the Geotechnical CQA Monitors shall inspect each panel for damage. The Geotechnical CQA Monitors shall advise the Construction Manager which panels, or portions of panels, should be rejected, repaired, or accepted. Damaged panels or portions of damaged panels which have been rejected shall be marked and their removal from the work area recorded by the Geotechnical CQA Monitors.

6.1.4.3 Field Seaming

The Contractor shall provide the Construction Manager and Geotechnical CQA Officer with a seam and panel layout plan and shall update this plan daily as the job proceeds. No panels shall be seamed until the panel layout plan has been approved by the Construction Manager. A seam numbering system shall be agreed to by the Geotechnical CQA Monitors, Construction Manager, Contractor and Liner Subcontractor prior to the start of seaming operations.

Prior to seaming, each seaming apparatus (welder) shall be tested in accordance with the Specifications to determine if the equipment is functioning properly. The Geotechnical CQA Monitors shall observe all trial weld operations and record the results. It is important that the trial welds be completed under conditions similar to those under which the panels will be seamed. If at any time the Geotechnical CQA Monitor believes that an operator or seaming apparatus is not functioning properly, a test shall be performed on a trial weld. If there are large changes in temperature, humidity, or wind speed, the trial weld test shall be repeated. Laboratory tests may be carried out at the discretion of the Geotechnical CQA Monitors to verify field test results.

During seaming operations the Geotechnical CQA Monitors shall observe that:

- The Liner Subcontractor has the number of welders and spare parts agreed to in the pre-construction meeting.
- Equipment used for seaming will not damage the HDPE.
- The extruder is purged prior to beginning a seam until all the heat-degraded extrudate is removed (extrusion welding only).
- Seam grinding has been completed less than 1 hour before seam welding (extrusion welding only).
- The ambient temperature measured 6 inches above the HDPE surface is between 40 and 105 degrees Fahrenheit and relative humidity is less than 80 percent.

- The end of welds more than 5 minutes old, are ground to expose new material before restarting a weld (extrusion welding only).
- The weld is free of dust and other debris.
- For cross seams, the seam is ground to a smooth incline prior to welding.
- The seams are overlapped in a downgradient direction with a minimum overlap of 4 inches.
- No solvents or adhesives are present in the seam area.
- The procedure used to temporarily hold the panels together does not damage the panels and does not preclude Geotechnical CQA testing.
- The panels are being seamed in accordance with the Project Plans and Specifications using approved equipment with gauges giving applicable temperatures.
- There is no free moisture in the weld area.
- The electric generator is placed on a smooth base such that no damage occurs to the HDPE.
- A smooth insulating plate or fabric is placed beneath the hot welding apparatus after use.
- The geomembrane is protected from damage in heavily trafficked areas.

The Geotechnical CQA Monitors shall log all appropriate temperatures and conditions, and shall log and report to the Geotechnical CQA Officer any non-compliance.

Trial Seams

Trial seam samples are not removed from installed seams, but are made along side the seaming work area by the Liner Subcontractor using a fragment of the same HDPE sheet and the same installation procedures as for the HDPE installation itself. As such, they are considered nondestructive samples. Such trial seams shall be made at the beginning of each seaming period (start of day, mid-day, and anytime the equipment is shut down or the seaming operation is suspended for more than 1/2 hour) for each piece of seaming equipment used that day. In addition, each welder shall make at least one trial seam each day. Trial seams shall be made under the same conditions as those anticipated for actual seams.

The trial seam sample shall be at least 3 ft. long by 1 ft. plus the seam width wide (after seaming) with the seam centered lengthwise. Seam overlap shall be as per the Specifications.

Two opposite specimens, each 1 inch wide, shall be cut from the trial seam sample by the Contractor and/or Liner Subcontractor. Under the observation of a Geotechnical CQA Monitor, the specimens shall be tested by the Liner Subcontractor in shear and peel using a field tensiometer to verify that seams satisfy peel and tensile strength requirements. If a specimen fails, the seaming equipment and seamer shall not be accepted and shall not be used for seaming until the deficiencies are corrected and two consecutive successful full trial welds are achieved. After completing a successful trial/nondestructive sample, the Contractor and/or Liner Subcontractor shall cut a 2' x 2' remnant from the sample and mark the welder number, date, time, ambient temperature, welder temperature, and speed and submit it to the Geotechnical CQA Monitor who will assign an identification number and enter the information on the non-destructive sample form.

The results of field tests carried out on trial seams shall be documented by the Geotechnical CQA Monitors on appropriate form (Form B-6 attached).

General Seaming Procedure

Unless otherwise specified, the general seaming procedure to be used by the Contractor and/or Liner Subcontractor shall be as follows:

- All HDPE seams shall be overlapped a minimum of four (4) inches.
- "Fishmouths" or wrinkles at the seam overlaps shall be cut along the ridge of the wrinkle in order to achieve a flat overlap. The cut "fishmouths" or wrinkles shall be seamed and any portion where the overlap is inadequate shall then be patched with an oval or round patch of the same HDPE extending a minimum of 6 inches beyond the cut in all directions. All corners of the patch shall be rounded with a 1-inch minimum radius.
- Adjacent to anchor trenches, seaming shall extend up the panels a minimum of 12 inches past the crest of the anchor trench.
- All cross seams shall be offset at least two feet from the cross seam of the adjacent panel and be extrusion or wedge welded where they intersect.

The Geotechnical CQA Monitors shall observe that the above seaming procedures are followed, and shall inform the Construction Manager if they are not.

6.1.5 CONSTRUCTION TESTING

6.1.5.1 Nondestructive Seam Testing

The Contractor and/or Liner Subcontractor shall non-destructively test all field seams over their full length using a vacuum test unit, spark detector, or an air pressure test (for double wedge fusion seams only), as described below. The purpose of nondestructive tests is to check the continuity of seams. It does not provide any information on seam strength. Continuity testing shall be carried out as the seaming work progresses, not at the completion of field seaming.

Visual Inspection

All seams shall be visually evaluated by the Contractor and/or Liner Subcontractor as the installation progresses and again at completion of the installation. Defective and questionable sections shall be clearly marked and repaired as necessary.

Vacuum Box Testing

If the fillet weld, extrusion lap weld or single hot-wedge fusion lap weld technique is used to weld seams, the Contractor and/or Liner Subcontractor shall further test all seams and repairs in the HDPE by vacuum box. The vacuum box shall be an American Vacuum Seam Tester, Series A100 as manufactured by American Parts and Service Company, Alhambra, California, or an approved equal. All vacuum box testing shall be done in the presence of the Geotechnical CQA Monitor. The area to be tested shall be cleaned of all dust, debris, dirt and other foreign matter. A soap solution shall be applied to the test area with a brush, paint roller or spray bottle and a minimum vacuum of 10 inches of mercury (Hg) (5 psi) shall be induced and held as long as necessary to visually inspect and mark for repair any suspicious areas as evidenced by bubbles in the soap solution.

Spark Testing

If the fillet weld is used to weld seams, the Contractor and/or Liner Subcontractor may, in lieu of vacuum box testing, test all seams and repairs in the HDPE liner by using a high voltage spark detector, similar to Tinker and Rasor Holiday Detector (Model AP-W). The setting of the detector shall be 20,000 volts. In order to conduct this test, all seams to be tested shall be provided with 24-30 gauge copper wires properly embedded in the seams and grounded. All spark testing shall be done in the presence of the Geotechnical CQA Monitor. All defective areas shall be marked for repair.

Air Pressure Test

If the double hot-wedge welding technique is used, the Contractor and/or Liner Subcontractor shall further test all seams in the HDPE lining by using the air pressure test which consists of inserting a needle with gauge in the air space between welds. Air shall be pumped to 40 psi within the weld void and held for at least 5 minutes. If the pressure loss exceeds 2 psi within the weld void during air pressure testing, the outside weld edge (not free edge) shall be sprayed with a soap solution and visually examined for bubbles. If no bubbles appear, the problem is with the inside weld and the seam is acceptable. If any bubbles appear, the defect shall be repaired by extrusion welding and tested by vacuum box and spark detector.

If pressure loss is not more than 2 psi, the opposite end of the seam will be punctured to release the air. If a blockage is present, it will be located and tests on both sides of the blockage will be completed. All penetration holes created during testing shall be sealed by patching and extrusion welding.

Electrical Leak Location Survey

To aid in CQA monitoring of the geomembrane construction, an independent contractor will conduct an electrical leak location survey as part of the final quality control for the geomembrane installation. The method is designed to identify holes in the geomembrane liner after the LCRS gravel, or LCRS gravel and operations layer soil, has been placed. The leak location survey contractor will make point-by-point electrical measurements on the soil above and below the liner. By this process, because the geomembrane liner is an electrical insulator, current will flow only through leaks in the liner, producing localized anomalous areas of high current density near the leaks. Any identified electrical anomaly will be investigated and the liner repaired as described in Section 6.1.6, as necessary.

Responsibilities of the Geotechnical CQA Monitors

The Geotechnical CQA Monitor/Officer shall:

- Observe and record the continuity of all testing.
- Record the location seam/panel number, date, time, equipment number, Geotechnical CQA Monitor name , test number, welding technician's name, weld, sheet and ambient temperatures and results of all testing on appropriate forms (Form B-7 attached).
- Mark the failed areas with a waterproof marker compatible with the lining material and inform the Contractor and/or Liner Subcontractor and the Construction Manager of any required repairs.

- Observe that all testing is completed in accordance with the Project Specifications.

- Observe that all repairs are completed and tested in accordance with the Project Specifications.

6.1.5.2 Destructive Seam Testing

Destructive seam tests shall be performed at selected locations. The purpose of these tests is to evaluate seam strength. Seam strength testing shall be done as the seaming work progresses, not at the completion of all field seaming.

Destructive sampling involves samples which have been removed from the installed field seams by the Contractor/Liner Subcontractor. Test locations shall be determined at the discretion of the Geotechnical CQA Monitors and the Contractor/Liner Subcontractor shall not be informed in advance of the locations where the seam samples will be made or will be removed.

Destructive samples shall be delivered to the Geotechnical CQA Officer by the Contractor/Liner Subcontractor and shipped to the Independent Testing Laboratory. All costs associated with the collection, repair, shipping and testing of destructive samples will be borne by the Contractor/Liner Subcontractor.

A minimum of one destructive sample per 500 feet of field seam shall be obtained. This average frequency will be used for the entire installation with the actual frequency of samples based on performance as determined by the Geotechnical CQA Officer.

Additional samples may be removed if the Geotechnical CQA Monitor observes a suspect seam.

6.1.5.3 Sampling Procedures

Samples shall be made or removed by the Contractor/Liner Subcontractor at locations selected by the Geotechnical CQA Monitors as the seaming operation progresses. The Geotechnical CQA Monitor shall:

- Observe making and/or removal of samples.

- Mark each sample with an identifying number which contains the seam number. (For nondestructive samples the seam number welded just prior to making a sample will be marked on the sample).

- Record sample locations on the panel layout drawing and enter the information on a Destructive Sample Log Form.

- Record the sample location, date and time taken, weather conditions, and reason the sample was made and/or taken (e.g., random sample, visual appearance, result of a previous failure, etc.).

- Mark sample identifying number on HDPE adjacent to the location where the sample was taken.

All holes in the HDPE resulting from destructive seam sampling shall be immediately repaired in accordance with repair procedures described herein. The continuity of the new seams in the repaired area shall be tested according to procedures described herein.

6.1.5.4 Size of Samples

Two types of samples shall be made or removed at each location. First, two samples shall be removed for field testing. Each of these samples shall be 1 inch wide with a length of 12 inches plus the seam width. For destructive sampling, the sample shall be taken perpendicular to the seam and the distance between these two samples shall be 38 inches. Samples designated for laboratory testing shall be that portion of seam located between the two samples taken for field testing. The samples for laboratory testing shall be 36 inches long with a width of 12 inches plus the seam width. The seam shall be centered lengthwise. The samples for laboratory testing shall be cut into three equal parts and distributed as follows:

- One part for the Independent Testing Laboratory for testing.
- One part to the Contractor/Liner Subcontractor.
- One part to the Construction Manager for archive storage.

6.1.5.5 Field Testing

The two 1 inch wide samples shall be tested in the field for peel adhesion and bonded seam strength (shear) by the Contractor/Liner Subcontractor, and shall not fail in the seam, but shall have a film tearing bond (FTB). If one or both of the samples fails in either peel or shear, the Contractor/Liner Subcontractor can, at his/her discretion, (1) reconstruct or cap strip the seam between passed test locations, or (2) take two additional test samples 10 feet on either side of the point of the failed test and repeat this procedure. If the second test passes, the Contractor/Liner Subcontractor shall reconstruct or cap strip the same between the two passed test locations. If subsequent tests fail, the procedure is repeated until the length of the poor quality seam is established. Repeated failures indicate that either the seaming equipment and/or operator is not performing properly, and appropriate action shall be taken.

6.1.5.6 Laboratory Testing

Once the field tests have passed, a sample shall be recovered from between passing field sample locations for testing by the Independent Testing Laboratory. Destructive test samples shall be packaged and shipped to the laboratory by the Geotechnical CQA Monitors and will be handled in a manner which will not damage the test sample. The Construction Manager will be responsible for storing the archive samples.

All specimens of a field weld sample tested by the Independent Testing Laboratory shall pass. If any specimen fails, the entire sample shall be considered as a failure, and the field weld shall be rejected. In this event, the field seam(s) shall be rejected as being nonconformant with the Specifications, and corrective measures shall be implemented.

For destructive samples which have failed, corrective measures shall include a rerun of the weld test using the same sample. If the second test passes, the Geotechnical CQA Monitor may assume an error was made in the first test and the field seam may be accepted. If the second test fails, the Contractor/Liner Subcontractor shall reconstruct or cap strip the field seam between any two previous passed seam locations which include the failed seam or shall go on both sides of the failed seam location (10-feet minimum), take another sample each side and test both in the independent laboratory.

If both samples pass, the Contractor/Liner Subcontractor shall reconstruct or cap strip the field seam between the two passing locations. If either fails, the Contractor/Liner Subcontractor shall repeat the process of taking samples for testing by the Independent Testing Laboratory. In all cases, acceptable field seams must be bounded by two passed test locations. In cases involving more than 50 feet of reconstructed or cap stripped seam, the reconstructed or cap stripped seam shall also be tested. The results of the Independent Testing Laboratory govern seam acceptance. In no case shall field testing of installed seams be used for final acceptance.

Testing shall include peel adhesion and bonded seam strength (shear; ASTM D6392). At least five specimens each shall be tested for peel and sheer. Minimum test values are presented in the Specifications. The Independent Testing Laboratory shall provide test results within 24 hours after receipt of samples for testing. Certified test results shall be provided within 5 days. The Geotechnical CQA Monitor shall document all test results on an appropriate form (Form B-8 attached) and shall immediately notify the Geotechnical CQA Officer, Construction Manager and/or Contractor/Liner Subcontractor in the event of a failed test.

The Contractor/Liner Subcontractor's laboratory test results shall be presented to the Geotechnical CQA Officer for comments.

6.1.6 DEFECTS AND REPAIRS

6.1.6.1 Identification

All seams and non-seam areas of the HDPE shall be examined by the Geotechnical CQA Monitors for identification of defects, holes, blisters, undispersed raw materials and any sign of contamination by foreign matter. Because light reflected by the HDPE helps to detect defects, the surface of the HDPE shall be clean at the time of examination. The HDPE surface shall be cleaned by the Contractor/Liner Subcontractor if the amount of dust or mud inhibits examination.

Each suspect location as identified by the Geotechnical CQA Monitors, both in seam and non-seam areas, shall be non-destructively tested using the methods described herein, as appropriate. Each location which fails the nondestructive testing shall be marked by the Geotechnical CQA Monitor and then repaired and re-tested by the Contractor/Liner Subcontractor. Work shall not proceed with any materials which will cover locations which have been repaired until laboratory test results with passing values have been obtained.

6.1.6.2 Repair Procedures

Any portion of the HDPE with a flaw or which fails a nondestructive or destructive test shall be repaired in accordance with the Specifications. The Geotechnical CQA Monitor shall locate and describe all repairs on the appropriate forms. Repair procedures include:

- Patching - used to repair large holes, tears, large panel defects, and destructive sample locations which are less than 25 sq. feet in total area.
- Extrusion - used to repair relatively small defects in panels and seams.
- Capping - used to repair failed welds or liner seams where welds cannot be non-destructively tested.
- Removal - used to replace areas with large defects where the preceding methods are not appropriate. Also used to remove excess material (wrinkles) from the installed HDPE.

6.1.6.3 Seam Test Summary

Documentation of all nondestructive and destructive seam testing results, including repairs, shall be summarized by the Geotechnical CQA Officer on Form B-9 attached.

6.1.7 WRINKLES

When placing soil or drain materials over the HDPE, temperature changes or creep may cause wrinkles to develop in the HDPE. Any wrinkles which can fold over shall be repaired either by cutting out excess material or, if possible, allowing the HDPE to contract due to temperature reduction. In no case shall material be placed over the HDPE which could result in the HDPE folding. All folded HDPE shall be removed. No material shall be placed in areas where liner is not in contact with the supporting subgrade.

6.1.8 ANCHOR TRENCH

The anchor trench shall be adequately drained to prevent ponding or softening of the adjacent soils while the trench is open. The anchor trench shall be backfilled and compacted as outlined in the Specifications. Fill soils shall consist of on-site granular soil essentially free of organic and deleterious material and approved by the Geotechnical CQA Monitor and Construction Manager. The material shall have a maximum particle size of 1 inch.

Care shall be taken when backfilling the trenches to prevent any damage to the geosynthetics. The Geotechnical CQA Monitor shall observe the bottom of the trenches prior to fill placement to ensure they are free of loose and disturbed materials. The Geotechnical CQA Monitor shall also observe the backfilling and compaction operation, and shall notify the Geotechnical CQA Officer and the Construction Manager of work performed not in accordance with the Project Specifications.

6.1.9 HDPE ACCEPTANCE

The Contractor/Liner Subcontractor shall retain all ownership and responsibility for the HDPE until acceptance by the Owner. The HDPE shall be accepted by Owner when:

- The installation is finished and approved.
- All seams have been inspected and approved.
- All required laboratory tests have been completed and approved.

- All required Contractor/Liner Subcontractor supplied documentation has been received and approved.

- All record drawings have been completed and approved.

6.1.10 LINER MATERIALS

The Geotechnical CQA procedures indicated in this section are intended to allow the installation of materials in contact with the HDPE without causing damage to it.

Important points for Quality Assurance of materials in contact with HDPE include:

- A geotextile or drainage medium approved by the Construction Manager shall be installed above the HDPE.

- Equipment used for placing soil shall not be driven directly on the HDPE/geotextile.

- In heavily trafficked areas, such as access ramps, soil thickness should be at least three (3) feet over the geosynthetics.

- Placement of soils, gravels, sand or other types of earth materials on top of the HDPE/geotextile shall not be performed until all destructive and nondestructive testing has been performed and accepted.

- Placement of overlying earth materials shall be performed in a manner to minimize wrinkles. Equipment operators shall be briefed on methods of placement relative to thermal expansion and contraction of the HDPE.

- Soil material(s) placed on top of the HDPE/geotextile shall be stockpiled and displaced off the stockpile to create a cascading effect of the material on top of the HDPE/geotextile.

The Geotechnical CQA Monitors shall inform the Geotechnical CQA Officer if the above conditions are not fulfilled.

6.2 GEOSYNTHETIC CLAY LINER (GCL)

The Contractor/GCL Manufacturer shall provide the Construction Manager with the following documentation:

- A properties sheet for geotextile and bentonite materials which includes all specified properties measured using test methods indicated in the Project Specifications.

- Certificates for raw bentonite and geotextile materials which indicate that materials provided meet or exceed all applicable specification requirements.

- Manufacturer's Quality Control Certificates.

- Internal shear strength certificate in accordance with specification requirements.

- A panel placement plan.

The Geotechnical CQA Officer shall verify that:

- The property values certified by the GCL Manufacturer meet or exceed the Project Specifications.

- The measurement of properties by the GCL Manufacturer are properly documented and the test methods used are acceptable.

Prior to shipment, the Contractor/GCL Manufacturer shall provide the Construction Manager with a quality control certificate for each GCL roll which is intended for use on the project. The quality control certificate(s) shall be signed by a responsible person employed by the Manufacturer, and shall include roll numbers and identification.

The Geotechnical CQA Officer shall:

- Verify that the quality control certificates have been provided at the specified frequency for all rolls, and that each certificate identifies the rolls to be delivered.

- Review the quality control certificates and verify that the certified roll properties meet the Project Specifications.

6.2.1 GCL DELIVERY

The Contractor/GCL Subcontractor shall submit for approval by the Construction Manager, method(s) for handling and storage of GCL material(s) prior to installation. The Geotechnical CQA Monitor shall observe that:

- Equipment used to unload the rolls will not damage the material.
- Care is used to unload the rolls.
- All documentation required by the specifications has been received.

Upon delivery at the site, the Geotechnical CQA Monitor(s) shall conduct a surface inspection of all rolls for defects and damage. This inspection shall be conducted without unrolling rolls unless defects or damage are found or suspected. The Geotechnical CQA Monitor(s) shall report to the Construction

Any damaged rolls shall be rejected and removed from the site or stored at a location, designated by the Construction Manager separate from accepted rolls. All rolls which do not have proper documentation from the Manufacturer shall also be stored at a separate location until all documentation has been received and approved. A log of the GCL material(s) received shall be maintained by the Geotechnical CQA Monitor(s).

The Construction Manager shall designate storage space in a location (or several locations) on-site. Storage space shall be protected by the Contractor from theft, vandalism, damage from the actions of Manufacturer, weather, animals and other sources. The Geotechnical CQA Monitor(s) shall observe that the materials are stored in accordance with Manufacturers recommendations and are protected against damage pursuant to ASTM D4873.

6.2.2 GCL CONFORMANCE TESTING

6.2.2.1 Tests

Upon delivery of the GCL material(s), the Geotechnical CQA Monitor shall ensure that the Contractor obtains and forwards samples to the approved Independent Testing Laboratory for testing of conformance with the design specifications. Conformance tests, including interface direct shear, will be performed as detailed in the Project Specifications.

Where optional procedures are noted in the test method, the requirements of the specifications shall prevail. Updated or alternative test methods may be used to determine the physical properties of the GCL materials at the discretion of the Construction Manager.

The results of Conformance Testing will be documented by the Geotechnical CQA Officer.

6.2.2.2 Sampling Procedures

Samples shall be taken across the entire width of the roll(s) and shall not include the first three feet. Unless otherwise specified, samples shall be three (3) feet long by the roll width. The Geotechnical CQA Monitor shall mark the machine direction on the samples with an arrow, and the Manufacturers roll identification number.

6.2.2.3 Test Results

The Geotechnical CQA Officer shall examine all results from the laboratory conformance testing. All specimens tested shall pass. If any specimen fails, the entire sample shall be considered as a failure and rejected. In this event, the GCL

material represented by the sample shall be considered non-conformant with the specifications, and corrective measures shall be implemented. Corrective measures shall include a rerun of the conformance testing using a portion of the same sample. If the second test passes, the Geotechnical CQA Officer may assume an error was made in the first test and the GCL material can be accepted. If the second test fails, the Contractor/GCL Subcontractor shall remove all material represented by the sample from the work area. The decision of the Construction Manager shall be final.

6.2.3 GCL INSTALLATION

6.2.3.1 Surface Preparation

Prior to installation, the Construction Manager and Geotechnical CQA Monitor(s) shall observe that:

- All lines and grades have been verified by the project surveyor.
- The supporting surface does not contain rocks or irregular surfaces which could damage the GCL.
- There are no excessive soft spots or ponded water which could result in damage to the GCL.
- The Contractor/GCL Subcontractor has certified in writing that the surface on which the GCL will be installed is acceptable.
- The Contractor/GCL Subcontractor shall give each GCL panel an identification number which shall be agreed to and used by the Geotechnical CQA Monitor(s) and the Contractor/GCL Subcontractor. The Geotechnical CQA Monitor shall establish a chart showing correspondence between roll numbers, certification reports and panel numbers.

During placement, the Geotechnical CQA Monitor(s) shall:

- Observe the GCL as it is placed and record all defects and disposition of the defects (panel rejects, patch installed, etc.). All repairs are to be made in accordance with the Project Specifications.
- Observe that Manufacturer's defects do not exceed that allowed by the Project Specifications.
- Observe that equipment used does not damage the GCL by handling, traffic, leakage of hydrocarbons, or other means.

- Observe that people working during installation of the GCL do not smoke, wear shoes that could damage the GCL, or engage in other activities that could damage the GCL.

- Observe that the GCL is anchored to prevent movement by the wind.

- Observe that adjacent panels of GCL are properly overlapped and the proper amount and type of bentonite is installed along the full length of all seams.

- Observe that the number of panels deployed are covered and protected from moisture at the end of the work day.

The Geotechnical CQA Monitor(s) shall inform both the Contractor/GCL Subcontractor and the Construction Manager if the above minimum conditions are not met.

The Contractor/GCL Subcontractor shall provide the Construction Manager with a panel layout plan, and shall update this plan daily as the job proceeds. No GCL shall be placed until the panel layout plan has been approved by the Construction Manager. During panel placement, the Geotechnical CQA Monitor(s) shall also observe the following:

- That GCL material is cut with an approved GCL cutter, and is not torn or ripped.

- The bentonite to be used on all seams meets the requirements of the Project Specifications.

- That the panels are overlapped and sealed in accordance with the Project Plans and Specifications.

6.2.4 REPAIRS

Any necessary repairs to the GCL shall be made with approved GCL material, using approved overlaps, materials, equipment and techniques. The patch size shall be 12 inches or larger in all directions than the area to be patched.

6.3 GEOTEXTILES

The Contractor/Liner Manufacturer shall provide the Construction Manager with the following documentation:

- A properties sheet which includes all specified properties measured using test methods indicated in the specifications.

- A description of the sampling procedure and appropriate test results.

- A certification that values given in the properties sheet are guaranteed by the Liner Manufacturer.

The Geotechnical CQA Officer shall verify that:

- The property values certified by the Liner Manufacturer meet or exceed the project specifications.

- The measurement of properties by the Liner Manufacturer are properly documented and the test methods used are acceptable.

Prior to shipment, the Contractor/Liner Manufacturer shall provide the Construction Manager with a quality control certificate for each roll of geotextile. The quality control certificate shall be signed by a responsible person employed by the Liner Manufacturer, and shall include roll number and identification.

The Geotechnical CQA Officer shall:

- Verify that the quality control certificates have been provided at the specified frequency for all rolls, and that each certificate identifies the rolls to be delivered.

- Review the quality control certificates and verify that the certified roll properties meet the project specifications.

6.3.1 GEOTEXTILE DELIVERY

The Contractor/Liner Subcontractor shall submit for approval by the Construction Manager, method(s) for handling and storage of geotextile material(s) prior to installation. The Geotechnical CQA Monitor shall observe that:

- Equipment used to unload the rolls will not damage the geotextile.
- Care is used to unload the rolls.
- All documentation required by the Specifications has been received.

Upon delivery at the site, the Geotechnical CQA Monitors shall conduct a surface inspection of all rolls for defects and damage. This inspection shall be conducted without unrolling rolls unless defects or damage are found or suspected. The Geotechnical CQA Monitors shall indicate to the Geotechnical CQA Officer any rolls, or portions thereof, which should be rejected and removed from the site because they have severe flaws. These rolls shall be clearly marked as rejected.

Any damaged rolls shall be rejected and removed from the site or stored at a location, designated by the Construction Manager separate from accepted rolls. All rolls which do not have proper documentation from the manufacturer shall also be stored at a separate location until all documentation has been received and

approved. A log of the geotextile material(s) received shall be maintained by the Geotechnical CQA Monitors on an appropriate form (Form B-10 attached).

The Construction Manager shall designate storage space in a location (or several locations) on-site. Storage space shall be protected by the Contractor from theft, vandalism, damage from the actions of man, weather, animals and other sources. The Geotechnical CQA Monitors shall observe that the material is not stored directly on the ground and that storage of the geotextile provides protection against damage pursuant to ASTM D4873.

6.3.2 GEOTEXTILE CONFORMANCE TESTING

6.3.2.1 Tests

Upon delivery of the geotextile, the Geotechnical CQA Monitor shall ensure that samples are obtained and forwarded to an Independent Laboratory for testing of conformance with the design specifications. As a minimum, the following tests will be performed to ensure that geotextile materials are in conformance with the design specifications.

- Thickness (ASTM D1777)
- Mass per unit Area (ASTM D3776)
- Burst Strength (ASTM D3786)
- Puncture Strength (ASTM D4833)
- Permittivity (ASTM D4491)
- Grab Tensile Tests (ASTM D4632)
- Apparent Opening Size (ASTM D4751)
- Appropriate interface shear testing as noted of the Specifications

Where optional procedures are noted in the test method, the requirements of the Specifications shall prevail. Updated or alternative ASTM Test Methods may be used to determine the physical properties of the geotextile materials at the discretion of the Construction Manager.

The results of Conformance Testing will be documented by the Geotechnical CQA Officer on an appropriate form (Form B-11 attached).

6.3.2.2 Sampling Procedures

Samples shall be taken across the entire width of the roll and shall not include the first three feet. Unless otherwise specified, samples shall be three feet long by the roll width. The Geotechnical CQA Monitor shall mark the machine direction on the samples with an arrow, and the Manufacturer's roll identification number.

Unless otherwise specified, samples shall be taken at a rate of one per lot or one per 100,000 square feet, whichever results in the greater number of samples.

6.3.2.3 Test Results

The Geotechnical CQA Officer shall examine all results from the laboratory conformance testing. All specimens tested shall pass. If any specimen fails, the entire sample shall be considered as a failure and rejected. In this event, the geotextile material represented by the sample shall be considered nonconformant with the Specifications, and corrective measures shall be implemented. Corrective measures shall include a rerun of the conformance testing using a portion of the same sample. If the second test passes, the Geotechnical CQA Officer may assume an error was made in the first test and the geotextile material can be accepted. If the second test fails, the Contractor/Liner Subcontractor shall remove all material represented by the sample from the work area. The decision of the Construction Manager shall be final.

6.3.3 GEOTEXTILE INSTALLATION

6.3.3.1 Surface Preparation

Prior to installation, the Construction Manager and Geotechnical CQA Monitors shall observe that:

- All lines and grades have been verified.
- The subgrade has been prepared in accordance with the Project Specifications and the supporting surface does not contain rocks or irregular surfaces which could damage the geotextile.
- There are no excessively soft areas which could result in damage to the geotextile.
- The Contractor/Liner Subcontractor has certified in writing that the surface on which the geotextile will be installed is acceptable.

6.3.3.2 Placement

The Contractor/Subcontractor shall give each geotextile panel an identification number which shall be agreed to and used by the Geotechnical CQA Monitors and the Contractor/Liner Subcontractor. The Geotechnical CQA Monitor shall establish a chart showing correspondence between roll numbers, certification reports, and panel numbers on an appropriate form (Form B-12 attached).

During panel placement, the Geotechnical CQA Monitor shall:

- Observe the geotextile as it is placed and record all defects and disposition of the defects (panel rejected, patch installed, etc.). All repairs are to be made in accordance with the Specifications.

- Observe that equipment used does not damage the geotextile by handling, traffic, leakage of hydrocarbons, or other means;

- Observe that people working during installation of geotextile do not smoke, wear shoes that could damage the geotextile, or engage in other activities that could damage the geotextile

- Observe that the geotextile is anchored to prevent movement by the wind.

- Observe that adjacent panels of geotextile are overlapped a minimum of 18 inches where the fabric is not seamed (welded or sewn). When seamed, a three inch minimum overlap will be required.

The Geotechnical CQA Monitors shall inform both the Contractor/Liner Subcontractor and the Geotechnical CQA Officer if the above minimum conditions are not met.

The Contractor/Liner Subcontractor shall provide the Construction Manager with a panel layout plan, and shall update this plan daily as the job proceeds. No geotextile shall be placed until the panel layout plan has been approved by the Construction Manager. During geotextile placement, the Geotechnical CQA Monitors shall observe that:

- The geotextile is cut only with an approved geotextile cutter, and is not torn or ripped.

- The thread and sewing machinery meet the Project requirements (if sewing is the elected method of joining panels).

- The panels are being overlapped or joined in accordance with the Project Plans and Specifications.

- Any roll of geotextile with a tear exceeding 10 percent of roll width is removed and replaced.

6.3.4 REPAIRS

Any necessary repairs to the geotextile shall be made with the geotextile material itself, using approved overlaps or sewing systems, equipment and techniques. The patch size shall be 18 inches or larger in all directions than the area to be patched and all corners shall be rounded.

6.4 GEOCOMPOSITE

The Contractor/Liner Manufacturer shall provide the Construction Manager with the following documentation:

- A properties sheet which includes all specified properties measured using test methods indicated in the specifications.
- A description of the sampling procedure and appropriate test results.
- A certification that values given in the properties sheet are guaranteed by the Liner Manufacturer.

The Geotechnical CQA Officer shall verify that:

- The property values certified by the Liner Manufacturer meet or exceed the project specifications.
- The measurement of properties by the Liner Manufacturer are properly documented and the test methods used are acceptable.

Prior to shipment, the Contractor/Liner Manufacturer shall provide the Construction Manager with a quality control certificate for each roll of geocomposite. The quality control certificate shall be signed by a responsible person employed by the Liner Manufacturer, and shall include roll number and identification.

The Geotechnical CQA Officer shall:

- Verify that the quality control certificates have been provided at the specified frequency for all rolls, and that each certificate identifies the rolls to be delivered.
- Review the quality control certificates and verify that the certified roll properties meet the project specifications.

6.4.1 GEOCOMPOSITE DELIVERY

The Contractor/Liner Subcontractor shall submit for approval by the Construction Manager, method(s) for handling and storage of geocomposite material(s) prior to installation. The Geotechnical CQA Monitor shall observe that:

- Equipment used to unload the rolls will not damage the geocomposite.
- Care is used to unload the rolls.
- All documentation required by the Specifications has been received.

Upon delivery at the site, the Geotechnical CQA Monitors shall conduct a surface inspection of all rolls for defects and damage. This inspection shall be conducted without unrolling rolls unless defects or damage are found or suspected. The Geotechnical CQA Monitors shall indicate to the Geotechnical CQA Officer any

rolls, or portions thereof, which should be rejected and removed from the site because they have severe flaws.

Any damaged rolls shall be marked as rejected and removed from the site or stored at a location, designated by the Construction Manager separate from accepted rolls. All rolls which do not have proper documentation from the manufacturer shall also be stored at a separate location until all documentation has been received and approved. A log of the geocomposite material(s) received shall be maintained by the Geotechnical CQA Monitors.

The Construction Manager shall designate storage space in a location (or several locations) on-site. Storage space shall be protected by the Contractor from theft, vandalism, damage from the actions of man, weather, animals and other sources. The Geotechnical CQA Monitors shall observe that the material is not stored directly on the ground and that storage of the geocomposite provides protection against damage pursuant to ASTM D4873.

6.4.2 GEOCOMPOSITE CONFORMANCE TESTING

6.4.2.1 Tests

Upon delivery of the geocomposite, the Geotechnical CQA Monitor shall ensure that samples are obtained and forwarded to a GAI certified Independent Laboratory for testing of conformance with the design specifications. Conformance sampling and testing will be conducted in accordance with Section D of the Project Specifications.

- Thickness (ASTM D1777)
- Mass per unit area (ASTM D3776)
- Hydraulic Transmissivity (ASTM D4716
- Carbon Black Content (ASTM D1603)
- Tensile Strength (machine direction; ASTM D1682)

Where optional procedures are noted in the test method, the requirements of the Specifications shall prevail. Updated or alternative ASTM Test Methods may be used to determine the physical properties of the geocomposite materials at the discretion of the Construction Manager.

The results of Conformance Testing will be documented by the Geotechnical CQA Officer.

6.4.2.2 Sampling Procedures

Samples shall be taken across the entire width of the roll and shall not include the first three feet. Unless otherwise specified, samples shall be three feet long by the

roll width. The Geotechnical CQA Monitor shall mark the machine direction on the samples with an arrow, and the Manufacturer's roll identification number.

Unless otherwise specified, samples shall be taken at a rate of one per lot or one per 100,000 square feet, whichever results in the greater number of samples.

6.4.2.3 Test Results

The Geotechnical CQA Officer shall examine all results from the laboratory conformance testing. All specimens tested shall pass. If any specimen fails, the entire sample shall be considered as a failure and rejected. In this event, the geocomposite material represented by the sample shall be considered nonconformant with the Specifications, and corrective measures shall be implemented. Corrective measures shall include a rerun of the conformance testing using a portion of the same sample. If the second test passes, the Geotechnical CQA Officer may assume an error was made in the first test and the geotextile material can be accepted. If the second test fails, the Contractor/Liner Subcontractor shall remove all material represented by the sample from the work area. The decision of the Construction Manager shall be final.

6.4.3 GEOCOMPOSITE INSTALLATION

6.4.3.1 Surface Preparation

Prior to installation, the Construction Manager and Geotechnical CQA Monitors shall observe that:

- All lines and grades have been verified.
- The subgrade has been prepared in accordance with the Project Specifications and the supporting surface does not contain rocks or irregular surfaces which could damage the geocomposite.
- There are no excessively soft areas which could result in damage to the geocomposite.
- All construction stakes and hubs have been removed.
- The Contractor/Liner Subcontractor has certified in writing that the surface on which the geocomposite will be installed is acceptable.

6.4.3.2 Placement

The Contractor/Subcontractor shall give each geocomposite panel an identification number which shall be agreed to and used by the Geotechnical CQA Monitors and the Contractor/Liner Subcontractor. The Geotechnical CQA Monitor shall establish a chart showing correspondence between roll numbers, certification reports, and panel numbers.

During panel placement, the Geotechnical CQA Monitor shall:

- Observe the geocomposite as it is placed and record all defects and disposition of the defects (panel rejected, patch installed, etc.). All repairs are to be made in accordance with the Specifications.
- Observe that equipment used does not damage the geocomposite by handling, traffic, leakage of hydrocarbons, or other means.
- Observe that people working during installation of geocomposite do not smoke, wear shoes that could damage the geocomposite, or engage in other activities that could damage the geocomposite.
- Observe that the geocomposite is anchored to prevent movement by the wind.
- Observe that adjacent panels of geocomposite are overlapped a minimum of 18 inches where the fabric is not seamed (welded or sewn). When seamed, a three inch minimum overlap will be required.

The Geotechnical CQA Monitors shall inform both the Contractor/Liner Subcontractor and the Geotechnical CQA Officer if the above minimum conditions are not met.

The Contractor/Liner Subcontractor shall provide the Construction Manager with a panel layout plan, and shall update this plan daily as the job proceeds. No geocomposite shall be placed until the panel layout plan has been approved by the Construction Manager. During geocomposite placement, the Geotechnical CQA Monitors shall observe that:

- The geocomposite is cut only with an approved cutter, and is not torn or ripped.
- Geocomposite seaming equipment meet the Project requirements.
- The panels are being overlapped or joined in accordance with the Project Plans and Specifications.
- Any damaged roll of geocomposite is removed and replaced.

6.4.4 REPAIRS

Any necessary repairs to the geocomposite shall be made with the geocomposite material itself, using approved overlaps or seaming systems, equipment, and techniques. The patch size shall be 18 inches or larger in all directions than the area to be patched and all corners shall be rounded.

7.0 DOCUMENTATION

The Geotechnical CQA Plan depends on thorough monitoring and documentation of all construction activities. Therefore, the Geotechnical CQA Officer shall document that all Geotechnical CQA requirements have been addressed and satisfied. Documentation shall consist of daily reports, construction problem reports, photographs, design and specification revisions, and a certification report.

7.1 DAILY SUMMARY REPORTS

Daily summary reports provide a chronological framework for identifying and recording all other reports and shall consist of field notes, summary of the daily meeting with the Contractor/Liner Subcontractor, observation and data sheets (including a record of field and/or laboratory tests) and construction corrective measures reports. This information shall be submitted daily to the Geotechnical CQA Officer for review and approval. The summary of the daily meeting with the Contractor/Liner Subcontractor shall include:

- Date, project name, and location.
- Names of parties attending.
- Scheduled activities.
- Items discussed.
- Signature of Geotechnical CQA Monitor.

The corrective measures report will include detailed descriptions of materials and/or workmanship that do not meet a specified design and will be cross referenced to the specific inspection data sheets where the problem was identified and corrected.

7.2 OBSERVATION AND TEST DATA REPORTS

Observation and test data reports shall include:

- Date, project name, and location.
- Weather data.
- A reduced scale site plan showing work areas, including sample and test locations.
- A description of ongoing construction.

- A summary of test results identified as passing, failing, or, in the event of a failed test, retest.
- Test equipment calibrations, if applicable.
- A summary of decisions regarding acceptance of the work and/or corrective actions taken.
- The signature of the Geotechnical CQA Monitor.

A summary of observation and test data reports shall be submitted on a schedule mutually agreeable to the Construction Manager and Geotechnical CQA Officer.

7.3 CONSTRUCTION CORRECTIVE MEASURES REPORTS

These reports identify and document construction problems and solutions. They are intended to document problems involving significant rework, and are not intended to document problems which are easily corrected unless the problems are recurring. Each report shall include:

- A detailed description of the problem.
- The location and cause of the problem
- The solution to the problem.
- The personnel involved.
- Signatures of the Geotechnical CQA Officer and Construction Manager.

7.4 DESIGN AND SPECIFICATION REVISIONS

Design and specification revisions may be required during construction. In such cases, the Geotechnical CQA Officer shall notify the Construction Manager. Design and specification revisions shall become official only after written approval of the Construction Manager.

7.5 PHOTOGRAPHS

Construction activities will be photographed, including significant problems and remedial actions. The photographs will be identified by location, time, date, and photographer.

7.6 AS-BUILT PLANS

As-built plans shall be prepared by the Contractor/Subcontractor from surveying and base maps prepared by a Registered Land Surveyor. The Geotechnical CQA Monitors shall observe that the "As-Built" plans include:

- Dimensions of all field panels;
- Location of each panel relative to the surveyor's plan;
- Identification of all panels and seams (including manufacturer's roll identification numbers);
- Location of all patches and repairs;
- Location of all nondestructive and destructive test sampling;
- Identification of problems or unusual conditions.

7.7 FINAL CERTIFICATION REPORT

At completion of the work, the Geotechnical CQA Officer shall prepare and submit a final certification report. This report shall render an opinion as to whether the work was performed in compliance with the project plans and specifications.

As a minimum, the final certification report shall include:

- A summary of all construction activities;
- Laboratory and field test results;
- Observation and test data sheets;
- Sampling and testing location plans;
- A description of significant construction problems and the solutions of these problems;
- A list of revisions from the construction plans and specifications, and the justification for these revisions;
- A certification statement signed and sealed by a Civil Engineer or Certified Engineering Geologist registered in the State of California.

Upon completion of construction, the facility will store all original documents so that they are protected from damage throughout the post-closure maintenance period, yet can be readily accessed.

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B-1
FML RECEIVED

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Date Received	QA Monitor	Roll Number	Lot Number (Railcar)	AREA					CQC Doc. Received	CQA Sample Sent to Lab	CQA Test Received	CQA Test Result	Status I/P/F
				Length feet	Width feet	Area sq. ft.	Cumm. Sq. Ft. Rcvd. By Lot	Cumm. Sq. Ft. Rcvd. Total					

Manufacturer:

Type:

CQC – Construction Quality Control
CQA – Construction Quality Assurance

Status:

I – In progress
P – Pass
F – Fail

Notes:

Checked By:

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B-1A
GCL RECEIVED

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Date Received	QA Monitor	Roll Number	Lot Number (Railcar)	AREA					CQC Doc. Received	CQA Sample Sent to Lab	CQA Test Received	CQA Test Result	Status I/P/F
				Length feet	Width feet	Area sq. ft.	Cumm. Sq. Ft. Rcvd. By Lot	Cumm. Sq. Ft. Rcvd. Total					

Manufacturer:

Type:

CQC – Construction Quality Control
CQA – Construction Quality Assurance

Status:

I – In progress
P – Pass
F – Fail

Notes:

Checked By:

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B-1B
GEOCOMPOSITE RECEIVED

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Date Received	QA Monitor	Roll Number	Lot Number (Railcar)	AREA					CQC Doc. Received	CQA Sample Sent to Lab	CQA Test Received	CQA Test Result	Status I/P/F
				Length feet	Width feet	Area sq. ft.	Cumm. Sq. Ft. Rcvd. By Lot	Cumm. Sq. Ft. Rcvd. Total					

Manufacturer:

Type:

CQC – Construction Quality Control
CQA – Construction Quality Assurance

Status:

I – In progress
P – Pass
F – Fail

Notes:

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B-2
FML CONFORMANCE TEST

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Test Number	Date	Roll Number	Lot Number (Railcar)	Type								Roll Length feet	Roll Width feet	Material Represented Sq.Ft.	Status I/P/F	Remarks
FML Specification																
Acceptable Limits																

Manufacturer:

Status:

I – In progress
P – Pass
F – Fail

Notes:

Checked By:

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B-2A
GCL CONFORMANCE TEST

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Test Number	Date	Roll Number	Lot Number (Railcar)	Type								Roll Length feet	Roll Width feet	Material Represented Sq.Ft.	Status I/P/F	Remarks
Acceptable Limits																

Manufacturer:

Status:

I – In progress
P – Pass
F – Fail

Notes:

Checked By:

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B-2B
GEOCOMPOSITE CONFORMANCE TEST

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Test Number	Date	Roll Number	Lot Number (Railcar)	Type								Roll Length feet	Roll Width feet	Material Represented Sq.Ft.	Status I/P/F	Remarks
Acceptable Limits																

Manufacturer:

Status:

I – In progress
P – Pass
F – Fail

Notes:

Checked By:

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B-4
FML PANEL PLACEMENT LOG SUMMARY

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Date	QA Monitor	Panel Number	Location (Work Area)	Roll Number	Lot/ Batch Number	AREA					REPAIRS				Date Covered	Remarks
						Length 1	Length 2	Width	Sq. Ft.	Cumm. Feet	Y/N	Date Repaired	Date Tested	P/F		

Manufacturer:

Type:

Notes:

Checked By:

ACCEPTANCE OF SOIL SUBGRADE FOR THE SUPPORT OF GEOSYNTHETIC LINER (FML)

PROJECT NAME: GREGORY CANYON LANDFILL
COMPOSITE LINER SYSTEM CONSTRUCTION

LINER CONTRACTOR:
AREA APPROVED: _____

_____

_____

I, the undersigned, duly authorized representative of the LINER CONTRACTOR, accept the soil subgrade for the support of the geosynthetic liner in the aforementioned area. I shall be responsible for maintaining its integrity and suitability, in accordance with the project specifications from this date to completion of the installation in this area. I do not accept any responsibility for the conditions or character of the subsurface soil.

NAME (PRINT)	SIGNATURE	TITLE	DATE

ACKNOWLEDGED BY QA MONITOR

NAME (PRINT)	SIGNATURE	COMPANY/TITLE	DATE

B-4A

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GCL PANEL PLACEMENT LOG SUMMARY

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Date	QA Monitor	Panel Number	Location (Work Area)	Roll Number	Lot/ Batch Number	AREA					REPAIRS				Date Covered	Remarks
						Length 1	Length 2	Width	Sq. Ft.	Cumm. Feet	Y/N	Date Repaired	Date Tested	P/F		

Manufacturer:

Type:

Notes:

Checked By:

B-4B

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GEOCOMPOSITE PANEL PLACEMENT LOG SUMMARY

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Date	QA Monitor	Panel Number	Location (Work Area)	Roll Number	Lot/ Batch Number	AREA					REPAIRS				Date Covered	Remarks
						Length 1	Length 2	Width	Sq. Ft.	Cumm. Feet	Y/N	Date Repaired	Date Tested	P/F		

Manufacturer:

Type:

Notes:

Checked By:

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B-5
FML PANEL PLACEMENT LOG

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

CAP REPAIRED TESTED CHK'D BY: _____

PATCH REPAIRED TESTED EXTRUDATE REPAIRED TESTED

DATE:	TIME:	REMARKS
QA MONITOR:	AMB:	
PANEL #	ROLL #	

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B-6
FML SEAM TRIAL WELDS

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Sample Number (Daily)	Date Completed	Welder Number	Technician	Time (AM/PM)	Temperature				Test Results						Remarks
					Ambient	Wedge	Extrudate	Preheat	Peel FTB	Strength (lbs/in)	Shear FTB	Strength (lbs/in)	Mills	QA Monitor	

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B-7
FML SEAMING LOG SUMMARY

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Seam Number	Date Seamed	Seam Length feet	Equipment Number	Tech	Time Seamed	Wind Speed m.p.h.	Temperature		Non-Destructive Tests				Repairs			Destructive Sample				Status I/P/F/A
							Sheet Deg. F	Amb Deg. F	Probe/ V1	VT.	ST.	AP.	Yes/No	Date Repaired	Date Tested	Sample Number	P/F	Date Repaired	Date Tested	

NOTES:

VT –Vaccum Test
ST –Spark Test
AP –Air Pressure Test
VI –Visual Inspection

STATUS:

I –In Progress
P –Pass
F –Fail
A –As built In

Checked By:_____

Seam Length:

This page_____

Total previous page(s)_____

Grand Total:_____

B-8

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FML DESTRUCTIVE TEST SUMMARY

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Sample Number	Seam Type (wedge/ extrusion)	Date Seamed	Equipment Number	Tech	Seam Number	Ambient Temperature (Deg. F) at time seamed	Bonded Seam Strength		P/F	Seam Peel Adhesion		P/F	Remarks
							FTB	Strength (lbs./inch)		FTB/ (FTB+Peel)	Adhesion (lbs./inch)		

Type:

FTB – Film Tear Bond

Notes:

Checked By:

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B-9
FML SEAMING LOG SUMMARY

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Seam Number	Seam Type	Date Seamed	Seam Length feet		Equipment		Tech	Time Seamed	Wind Speed	Temperature		Non-Destructive Tests			Repairs				Destructive Sample				Status I/P/F/A	QA Monitor
			Init.	As blt.	Number	Temp.		am/pm	m.p.h.	Sheet Deg. F	Amb Deg. F	Type*	Date	P/F	Y/N	Date Repaired	Date Tested	P/F	Sample Number	P/F	Date Repaired	Date Tested		

Seam Number	Seam Type	Date Seamed	Seam Length feet		Equipment		Tech	Time Seamed	Wind Speed	Temperature		Non-Destructive Tests			Repairs				Destructive Sample				Status I/P/F/A	QA Monitor
			Init.	As blt.	Number	Temp.		am/pm	m.p.h.	Sheet Deg. F	Amb Deg. F	Type*	Date	P/F	Y/N	Date Repaired	Date Tested	P/F	Sample Number	P/F	Date Repaired	Date Tested		

Seam Number	Seam Type	Date Seamed	Seam Length feet		Equipment		Tech	Time Seamed	Wind Speed	Temperature		Non-Destructive Tests			Repairs				Destructive Sample				Status I/P/F/A	QA Monitor
			Init.	As blt.	Number	Temp.		am/pm	m.p.h.	Sheet Deg. F	Amb Deg. F	Type*	Date	P/F	Y/N	Date Repaired	Date Tested	P/F	Sample Number	P/F	Date Repaired	Date Tested		

* – Note what type of test was used:

VT – Vaccum Test
ST – Spark Test
AP – Air Pressure Test

STATUS:

I – In Progress
P – Pass
F – Fail
A – As built In

SEAM TYPE:

EW – Extrusion Weld Seam
WW – Wedge Weld Seam

Checked By: _____

Seam Length (this page): _____

Total (previous pages): _____

Grand Total: _____

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B-10
GEOTEXTILE RECEIVED

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Date Received	QA Monitor	Roll Number	Lot/Batch Number	AREA				CQC Doc. Received	CQA Sample Sent to Lab	CQA Test Received	CQA Test Result	Status I/P/F
				Length feet	Width feet	Area sq. ft.	Cumulative Sq. Ft. Rcvd.					

Manufacturer:

Type:

CQC – Construction Quality Control
CQA – Construction Quality Assurance

Status:

I – In progress
P – Pass
F – Fail

Notes:

Checked By:

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B-11
GEOTEXTILE CONFORMANCE TEST

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Test Number	Date	Roll Number	Lot Number (Railcar)	Type								Roll Length feet	Roll Width feet	Material Represented Sq. ft.	Status I/P/F	Remarks
Specification																
Acceptable Limits																

Manufacturer:

Status:

I – In progress
P – Pass
F – Fail

Notes:

Checked By:

GeoLogic Associates
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B-12
GEOTEXTILE PLACEMENT LOG

PROJECT NO.: 9539 PROJECT: GREGORY CANYON LANDFILL, COMPOSITE LINER SYSTEM CONSTRUCTION LOCATION: SAN DIEGO COUNTY, CA

Date	QA Monitor	Panel Number	Location (Work Area)	Roll Number	Lot/ Batch Number	AREA					REPAIRS			Date Covered	Remarks
						Length 1	Length 2	Width	Sq. Ft.	Cumm. Ft.	Yes/No	Date Repaired	Date Tested		

Manufacturer:

Type:

Notes:

Checked By:

Part IV
Protecting Ground Water

Chapter 7: Section B
Designing and Installing Liners

Technical Considerations for New Surface Impoundments, Landfills, and Waste Piles

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Designing and Installing Liners—Technical Considerations for New Surface Impoundments, Landfills, and Waste Piles

This chapter will help you:

- *Employ liner systems where needed to protect ground water from contamination.*
- *Select from clay liners, synthetic liners, composite liners, leachate collection systems, and leak detection systems as appropriate.*
- *Consider technical issues carefully to ensure that the liner system will function as designed.*

Once risk has been characterized and the most appropriate design system is chosen, the next step is unit design. The Industrial Waste Management Evaluation Model (IWEM), discussed in Chapter 7, Section A—Assessing Risk can be used to determine appropriate design system recommendations. A critical part of this design for new landfills, waste piles, and surface impoundments is the liner system. The liner system recommendations in the Guide do not apply to land application units, since such operations generally do not include a liner system as part of their design. (For design of land application units, refer to Chapter 7, Section C—Designing a Land Application Program.) You should work with your state agency to ensure consideration of any applicable design system requirements, recommendations, or standard practices the state might have. In this chapter, sections I though IV discuss four design options—no liner/in-situ soils, single liner, composite liner, and double liner. Section V covers leachate collection and leak detection systems, and section VI discusses construction quality assurance and quality control.

I. In-Situ Soil Liners

For the purpose of the Guide, in-situ soil refers to simple, excavated areas or impoundments, without any additional engineering controls. The ability of natural soils to hinder transport and reduce the concentration of constituent levels through dilution and attenuation can provide sufficient protection when the initial constituent levels in the waste stream are very low, when the wastes are inert, or when the hydrogeologic setting affords sufficient protection.

What are the recommendations for in-situ soils?

The soil below and adjacent to a waste management unit should be suitable for construction. It should provide a firm foundation for the waste. Due to the low risk associated with wastes being managed in these units, a liner might not be necessary; however, it is still helpful to review the recommended location considerations and operating practices for the unit.

What technical issues should be considered with the use of in-situ soils?

In units using in-situ natural soils, construction and design of an engineered liner will not be necessary; however, there are still technical concerns to consider. These include the following:

- The stability of foundation soils.
- The compatibility of the waste with native soils.
- The location where the unit will be sited.
- The potential to recompact existing soils.

Potential instability can occur in the foundation soil, if its load-bearing capacity and resistance to movement or consolidation are insufficient to support the waste. The groundwater table or a weak soil layer also can influence the stability of the unit. You should take measures, such as designing maximum slopes, to avoid slope failure during construction and operation of the waste management unit. Most soil slopes are stable at a 3:1 horizontal to vertical inclination. There are common sense operating practices to ensure that any wastes to be managed on in-situ soils will not inappropriately interact with the soils. When using in-situ soils, refer to Chapter 4—Considering the Site. Selecting an appropriate location will be of increased importance, since the added barrier of an engineered liner will not be present. Because in-situ soil can have non-homogeneous material, root holes, and cracks, its performance can be improved by scarifying and compacting the top portion of the in-situ natural soils.

II. Single Liners

If the risk evaluation recommended the use of a single liner, the next step is to determine the type of single liner system most appropriate for the site. The discussion below addresses three types of single liner systems: compacted clay liners, geomembrane liners, and geosynthetic clay liners. Determining which material, or combination of materials, is important for protecting human health and the environment.[1]

A. Compacted Clay Liners

A compacted clay liner can serve as a single liner or as part of a composite or double liner system. Compacted clay liners are composed of natural mineral materials (natural soils), bentonite-soil blends, and other materials placed and compacted in layers called lifts. If natural soils at the site contain a significant quantity of clay, then liner materials can be excavated from onsite locations known as borrow pits. Alternatively, if onsite soils do not contain sufficient clay, clay materials can be hauled from offsite sources, often referred to as commercial pits.

Compacted clay liners can be designed to work effectively as hydraulic barriers. To ensure that compacted clay liners are well constructed and perform as they are designed, it is important to implement effective quality control methods emphasizing soil investigations and construction practices. Three objectives of quality assurance and quality control for compacted soil liners are to ensure that 1) selected liner materials are suitable, 2) liner materials are properly placed and compacted, and 3) the completed liner is properly protected before, during, and after construction. Quality assurance and quality control are discussed in greater detail in section VI.

[1] Many industry and trade periodicals, such as Waste Age, MSW Management, Solid Waste Technologies, and World Wastes, have articles on liner types and their corresponding costs, as well as advertisements and lists of vendors.

What are the thickness and hydraulic conductivity recommendations for compacted clay liners?

Compacted clay liners should be at least 2 feet thick and have a maximum hydraulic conductivity of 1 x 10^{-7} cm/sec (4 x 10^{-8} in/sec). Hydraulic conductivity refers to the degree of ease with which a fluid can flow through a material. A low hydraulic conductivity will help minimize leachate migration out of a unit. Designing a compacted clay liner with a thickness ranging from 2 to 5 feet will help ensure that the liner meets desired hydraulic conductivity standards and will also minimize leachate migration as a result of any cracks or imperfections present in the liner. Thicker compacted clay liners provide additional time to minimize leachate migration prior to the clay becoming saturated.

What issues should be considered in the design of a compacted clay liner?

The first step in designing a compacted clay liner is selecting the clay material. The quality and properties of the material will influence the performance of the liner. The most common type of compacted soil is one that is constructed from naturally occurring soils that contain a significant quantity of clay. Such soils are usually classified as CL, CH, or SC in the Unified Soil Classification System (USCS). Some of the factors to consider in choosing a soil include soil properties, interaction with wastes, and test results for potentially available materials.

Soil Properties

Minimizing hydraulic conductivity is the primary goal in constructing a soil liner. Factors to consider are water content, plasticity characteristics, percent fines, and percent gravel, as these properties affect the soil's ability to achieve a specified hydraulic conductivity.

Hydraulic conductivity. It is important to select compacted clay liner materials so that remolding and compacting of the materials will produce a low hydraulic conductivity. Factors influencing the hydraulic conductivity at a particular site include: the degree of compaction, compaction method, type of clay material used, soil moisture content, and density of the soil during liner construction. The hydraulic conductivity of a soil also depends on the viscosity and density of the fluid flowing through it. Consider measuring hydraulic conductivity using methods such as American Society of Testing and Materials (ASTM) D-5084.[2]

Water content. Water content refers to the amount of liquid, or free water, contained in a given amount of material. Measuring water content can help determine whether a clay material needs preprocessing, such as moisture adjustment or soil amendments, to yield a specified density or hydraulic conductivity. Compaction curves can be used to depict moisture and density relationships, using either ASTM D-698 or ASTM D-1557, the standard or modified Proctor test methods, depending on the compaction equipment used and the degree of firmness in the foundation materials.[3] The critical relationship between clay soil moisture content and density is explained thoroughly in Chapter 2 of EPA's 1993 technical guidance document *Quality*

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[2] ASTM D-5084, Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.

[3] ASTM D-698, Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3)).
ASTM D-1557, Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3)).

Assurance and Quality Control for Waste Containment Facilities (U.S. EPA, 1993c).

Plasticity characteristics. Plasticity characteristics describe a material's ability to behave as a plastic or moldable material. Soils containing clay are generally categorized as plastic. Soils that do not contain clay are non-plastic and typically considered unsuitable materials for compacted clay liners, unless soil amendments such as bentonite clay are introduced.

Plasticity characteristics are quantified by three parameters: liquid limit, plastic limit, and plasticity index. The liquid limit is defined as the minimum moisture content (in percent of oven-dried weight) at which a soil-water mixture can flow. The plastic limit is the minimum moisture content at which a soil can be molded. The plasticity index is defined as the liquid limit minus the plastic limit and defines the range of moisture content over which a soil exhibits plastic behavior. When soils with high plastic limits are too dry during placement, they tend to form clods, or hardened clumps, that are difficult to break down during compaction. As a result, preferential pathways can form around these clumps allowing leachate to flow through the material at a higher rate. Soil plasticity indices typically range from 10 percent to 30 percent. Soils with a plasticity index greater than 30 percent are cohesive, sticky, and difficult to work with in the field. Common testing methods for plasticity characteristics include the methods specified in ASTM D-4318, also known as Atterberg limits tests.[4]

Percent fines and percent gravel. Typical soil liner materials contain at least 30 percent fines and can contain up to 50 percent gravel, by weight. Common testing methods for percent fines and percent gravel are specified in ASTM D-422, also referred to as grain size distribution tests.[5] Fines refer to silt and clay-sized particles. Soils with less than 30 percent fines can be worked to obtain hydraulic conductivities below 1×10^{-7} cm/sec (4×10^{-8} in./sec), but use of these soils requires more careful construction practices.

Gravel is defined as particles unable to pass through the openings of a Number 4 sieve, which has an opening size equal to 4.76 mm (0.2 in.). Although gravel itself has a high hydraulic conductivity, relatively large amounts of gravel, up to 50 percent by weight, can be uniformly mixed with clay materials without significantly increasing the hydraulic conductivity of the material. Clay materials fill voids created between gravel particles, thereby creating a gravel-clay mixture with a low hydraulic conductivity. As long as the percent gravel in a compacted clay mixture remains below 50 percent, creating a uniform mixture of clay and gravel, where clay can fill in gaps, is more critical than the actual gravel content of the mixture.

You should pay close attention to the percent gravel in cases where a compacted clay liner functions as a bottom layer to a geosynthetic, as gravel can cause puncturing in geosynthetic materials. Controlling the maximum particle size and angularity of the gravel should help prevent puncturing, as well as prevent gravel from creating preferential flow paths. Similar to gravel, soil particles or rock fragments also can create preferential flow paths. To help prevent the development of preferential pathways and an increased hydraulic conductivity, it is best to use soil liner materials where the soil particles and rock fragments are typically small (e.g., 3/4 inch in diameter).

Interactions With Waste

Waste placed in a unit can interact with compacted clay liner materials, thereby influencing soil properties such as hydraulic con-

[4] ASTM D-4318, Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

[5] ASTM D-422, Standard Test Method for Particle-Size Analysis of Soils.

ductivity and permeability. Two ways that waste materials can influence the hydraulic conductivity of the liner materials are through dissolution of soil minerals and changes in clay structure. Soil minerals can be dissolved, or reduced to liquid form, as a result of interaction with acids and bases. For example, aluminum and iron in the soil can be dissolved by acids, and silica can be dissolved by bases. While some plugging of soil pores by dissolved minerals can lower hydraulic conductivity in the short term, the creation of piping and channels over time can lead to an increased hydraulic conductivity in the long term. The interaction of waste and clay materials can also cause the creation of positive ions, or cations. The presence of cations such as sodium, potassium, calcium, and magnesium can change the clay structure, thereby influencing the hydraulic conductivity of the liner. Depending on the cation type and the clay mineral, an increased presence of such cations can cause the clay minerals to form clusters and increase the permeability of the clay. Therefore, before selecting a compacted clay liner material, it is important to develop a good understanding of the composition of the waste that will be placed in the waste management unit. EPA's Method 9100, in publication SW-846, measures the hydraulic conductivity of soil samples before and after exposure to permeants.[6]

Locating and Testing Material

Although the selection process for compacted clay liner construction materials can vary from project to project, some common material selection steps include locating and testing materials at a potential borrow or commercial pit before construction, and observing and testing material performance throughout construction. First, investigate a potential borrow or commercial pit to determine the volume of materials available. The next step is to test a representative sample of soil to determine material properties such as plasticity characteristics, percent gravel, and percent fines. To confirm the suitability of the materials once construction begins, you should consider requesting that representative samples from the materials in the borrow or commercial pit be tested periodically after work has started.

Material selection steps will vary, depending on the origin of the materials for the project. For example, if a commercial pit provides the materials, locating an appropriate onsite borrow pit is not necessary. In addition to the tests performed on the material, it is recommended that a qualified inspector make visual observations throughout the construction process to ensure that harmful materials, such as stones or other large matter, are not present in the liner material.

What issues should be considered in the construction of a liner and the operation of a unit?

You should develop test pads to demonstrate construction techniques and material performance on a small scale. During unit construction and operation, some additional factors influencing the performance of the liner include: preprocessing, subgrade preparation, method of compaction, and protection against desiccation and cracking. Each of these steps, from preprocessing through protection against desiccation and cracking, should be repeated for each lift or layer of soil.

Test Pads

Preparing a test pad for the compacted clay liner helps verify that the materials and methods proposed will yield a liner that meets the desired hydraulic conductivity. A test pad also provides an opportunity to

[6] SW-846, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods.*

demonstrate the performance of alternative materials or methods of construction. A test pad should be constructed with the soil liner materials proposed for a particular project, using the same preprocessing procedures, compaction equipment, and construction practices proposed for the actual liner. A complete discussion of test pads (covering dimensions, materials, and construction) can be found in Chapter 2 of EPA's 1993 technical guidance document *Quality Assurance and Quality Control for Waste Containment Facilities* (U.S. EPA, 1993c). A discussion of commonly used methods to measure in-situ hydraulic conductivity is also contained in that chapter.

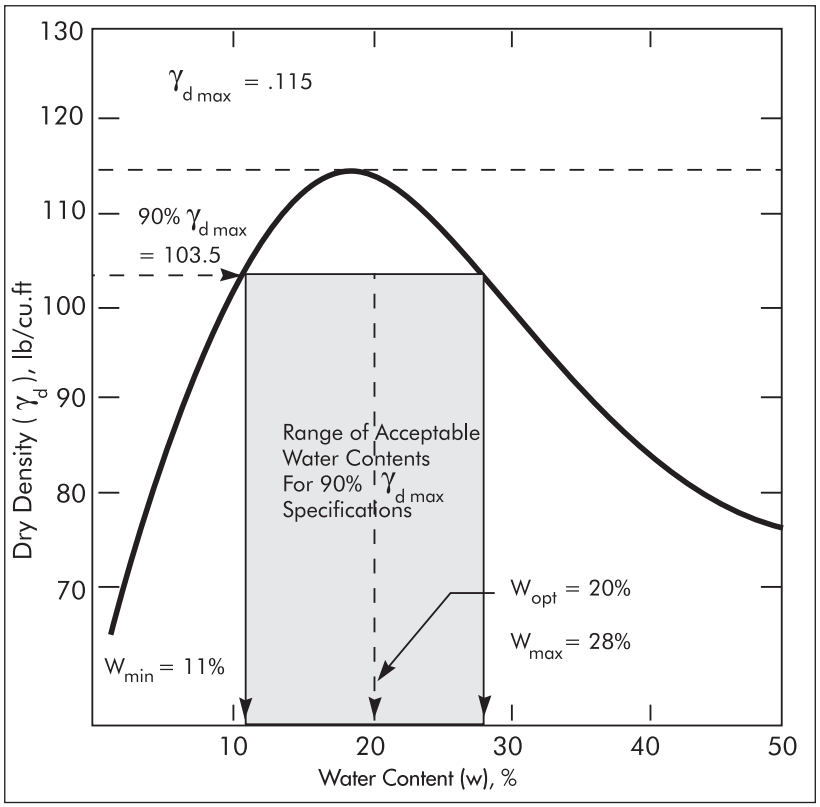
Preprocessing

Although some liner materials can be ready for use in construction immediately after they are excavated, many materials will require some degree of preprocessing. Preprocessing methods include: water content adjustment, removal of oversized particles, pulverization of any clumps, homogenization of the soils, and introduction of additives, such as bentonite.

Water content adjustment. For natural soils, the degree of saturation of the soil liner at the time of compaction, known as molding water content, influences the engineering properties of the compacted material. Soils compacted at water contents less than optimum tend to have a relatively high hydraulic conductivity. Soils compacted at water contents greater than optimum tend to have low hydraulic conductivity and low strength.

Proper soil water content revolves around achieving a minimum dry density, which is expressed as a percentage of the soil's maximum dry density. The minimum dry density typically falls in the range of 90 to 95 percent of the soil's maximum dry density value. From the minimum dry density range, the required water content range can be calculated, as shown in Figure 1. In this example the soil has a maximum dry density of 115 lb/cu ft. Based upon a required minimum dry density value of 90 percent of maximum dry density,

Figure 1.
Water Content for Achieving a Specific Density



Source: U.S. EPA, 1988.

which is equal to 103.5 lb/cu ft, the required water content ranges from 10 to 28 percent.

It is less problematic to compact clay soil at the lower end of the required water content range because it is easier to add water to the clay soil than to remove it. Thus, if precipitation occurs during construction of a site which is being placed at the lower end of the required water content range, the additional water might not result in a soil water content greater than the required range. Conversely, if the site is being placed at the upper end of the range, for example at 25 percent, any additional moisture will be excessive, resulting in water content over 28 percent and making the 90 percent maximum dry density unattainable. Under such conditions construction should halt while the soil is aerated and excess moisture is allowed to evaporate.

Removal of oversized particles. Preprocessing clay materials, to remove cobbles or large stones that exceed the maximum allowable particle size, can improve the soil's compactibility and protect any adjacent geomembrane from puncture. Particle size should be small (e.g., 3/4 inch in diameter) for compaction purposes. If a geomembrane will be placed over the compacted clay, only the upper lift of clay needs to address concerns regarding puncture resistance. Observation by quality assurance and quality control personnel is the most effective method to identify areas where oversized particles need to be removed. Cobbles and stones are not the only materials that can interfere with compactive efforts. Chunks of dry, hard clay, also known as clods, often need to be broken into smaller pieces to be properly hydrated, remolded, and compacted. In wet clay, clods are less of a concern since wet clods can often be remolded with a reasonable compactive effort.

Soil amendments. If the soils at a unit do not have a sufficient percentage of clay, a common practice is to blend bentonite with them to reduce the hydraulic conductivity. Bentonite is a clay mineral that expands when it comes into contact with water. Relatively small amounts of bentonite, on the order of 5 to 10 percent, can be added to sand or other noncohesive soils to increase the cohesion of the material and reduce hydraulic conductivity.

Sodium bentonite is a common additive used to amend soils. However, this additive is vulnerable to degradation as a result of contact with certain chemicals and waste leachates. Calcium bentonite, a more permeable material than sodium bentonite, is another common additive used to amend soils. Approximately twice as much calcium bentonite is needed to achieve a hydraulic conductivity comparable to that of sodium bentonite. Amended soil mixtures generally require mixing in a pug mill, cement mixer, or other mixing equipment that allows water to be added during the mixing process. Throughout the mixing and placement processes, water content, bentonite content, and particle distribution should be controlled. Other materials that can be used as soil additives include lime cement and other clay minerals, such as atapulgite. It can be difficult to mix additives thoroughly with cohesive soils, or clays; the resultant mixture might not achieve the desired level of hydraulic conductivity throughout the entire liner.

Subgrade Preparation

It is important to ensure that the subgrade on which a compacted clay liner will be constructed is properly prepared. When a compacted clay liner is the lowest component of a liner system, the subgrade consists of native soil or rock. Subgrade preparation for these systems involves compacting the native soil to remove any soft spots and adding water to or removing water from the native soil to obtain a specified firmness. Alternatively, in

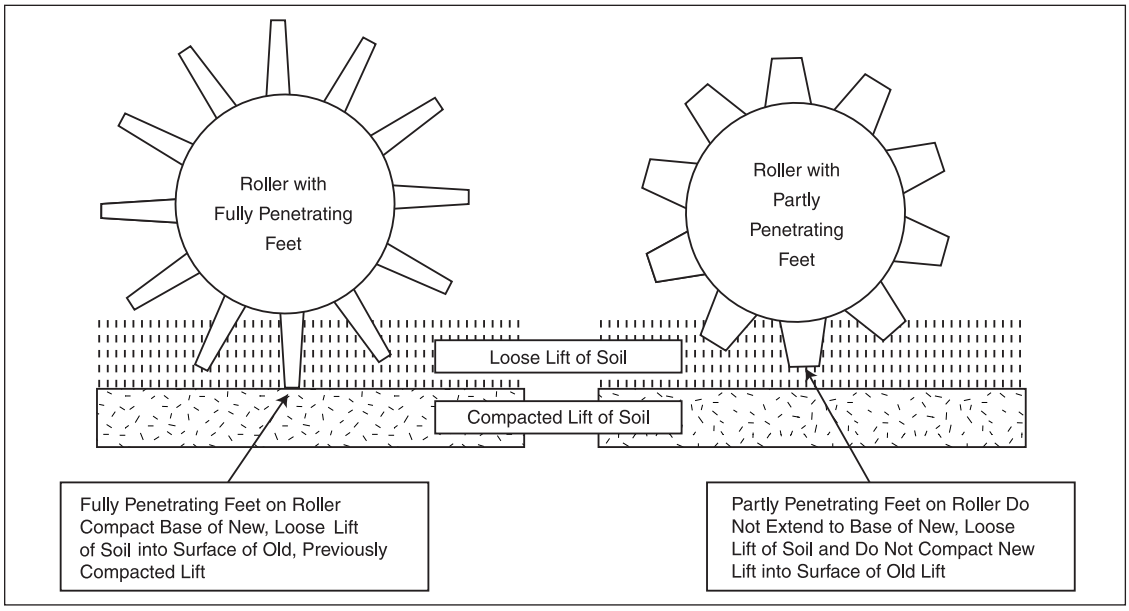
some cases, the compacted clay liner can be placed on top of a geosynthetic material, such as a geotextile. In such cases, subgrade preparation involves ensuring the smoothness of the geosynthetic on which the clay liner will be placed and the conformity of the geosynthetic material to the underlying material.

Compaction

The main purpose of compaction is to densify the clay materials by breaking and remolding clods of material into a uniform mass. Since amended soils usually do not develop clumps, the primary objective of compaction for such materials is to increase the material's density. Proper compaction of liner materials is essential to ensure that a compacted clay liner meets specified hydraulic conductivity standards. Factors influencing the effectiveness of compaction efforts include: the type of equipment selected, the number of passes made over the materials by such equipment, the lift thickness, and the bonding between the lifts. Molding water content, described earlier under preprocessing, is another factor influencing the effectiveness of compaction.

Type of equipment. Factors to consider when selecting compaction equipment include: the type and weight of the compactor, the characteristics of any feet on the drum, and the weight of the roller per unit length of drummed surface. Heavy compactors, weighing more than 50,000 pounds, with feet long enough to penetrate a loose lift of soil, are often the best types of compactor for clay liners. For bentonite-soil mixtures, a footed roller might not be appropriate. For these mixtures, where densification of the material is more important than kneading or remolding it to meet low hydraulic conductivity specifications, a smooth-drum roller or a rubber- tired roller might produce better results. Figure 2 depicts two types of footed rollers, a fully penetrating footed roller and a partially-penetrating footed roller.

Figure 2 Two Types of Footed Rollers



Source: U.S. EPA, 1993c.

For placement of liners on side slopes, consider the angle and length of the slope. Placing continuous lifts on a gradually inclined slope will provide better continuity between the bottom and sidewalls of the liner. Since continuous lifts might be impossible to construct on steeper slopes due to the difficulties of operating heavy compaction equipment on these slopes, materials might need to be placed and compacted in horizontal lifts. When sidewalls are compacted horizontally, it is important to avoid creating seepage planes, by securely connecting the edges of the horizontal lift with the bottom of the liner. Because the lift needs to be wide enough to accommodate compaction equipment, the thickness of the horizontal lift is often greater than the thickness specified in the design. In such cases, you should consider trimming soil material from the constructed side slopes and sealing the trimmed surface using a sealed drum roller.

It is common for contractors to use several different types of compaction equipment during liner construction. Initial lifts might need the use of a footed roller to fully penetrate a loose lift. Final lifts also might need the use of a footed roller for compaction, however, they might be formed better by using a smooth roller after the lift has been compacted to smooth the surface of the lift in preparation for placement of an overlying geomembrane.

Number of passes. The number of passes made by a compactor over clay materials can influence the overall hydraulic conductivity of the liner. The minimum number of passes that is reasonable depends on a variety of site-specific factors and cannot be generalized. In some cases, where a minimum coverage is specified, it might be possible to calculate the minimum number of passes to meet such a specification. At least 5 to 15 passes with a compactor over a given point are usually necessary to remold and compact clay liner materials thoroughly.

An equipment pass can be defined as one pass of the compaction equipment or as one pass of a drum over a given area of soil. It is important to clearly define what is meant by a pass in any quality assurance or quality control plans. It does not matter which definition is agreed upon, as long as the definition is used consistently throughout the project.

Lift thickness. You should determine the appropriate thickness (as measured before compaction) of each of the several lifts that will make up the clay liner. The initial thickness of a loose lift will affect the compactive effort needed to reach the lower portions of the lift. Thinner lifts allow compactive efforts to reach the bottom of a lift and provide greater assurance that compaction will be sufficient to allow homogenous bonding between subsequent lifts. Loose lift thicknesses typically range between 13 and 25 cm (5 and 10 in.). Factors influencing lift thickness are: soil characteristics, compaction equipment, firmness of the foundation materials, and the anticipated compaction necessary to meet hydraulic conductivity requirements.

Bonding between lifts. Since it is inevitable that some zones of higher and lower hydraulic conductivity, also known as preferential pathways, will be present within each lift, lifts should be joined or bonded in a way that minimizes extending these zones or pathways between lifts. If good bonding is achieved, the preferential pathways will be truncated by the bonded zone between the lifts. At least two recommended methods exist for preparing proper bonds. The first method involves kneading, or blending the new lift with the previously compacted lift using a footed roller. Using a roller with feet long enough to fully penetrate through the top lift and knead the previous lift improves the quality of the bond. A second method

involves using a disc harrow or similar equipment to scarify, or roughen, and wet the top inch of the recently placed lift, prior to placing the next lift.

Protection Against Desiccation and Cracking

You should consider how to protect compacted clay liners against desiccation and freezing during and after construction. Protection against desiccation is important, because clay soil shrinks as it dries. Depending on the extent of shrinkage, it can crack. Deep cracks, extending through more than one lift, can cause problems. You should measure water content to determine whether desiccation is occurring.

There are several ways to protect compacted clay liners from desiccation. One preventive measure is to smooth roll the surface with a steel drummed roller to produce a thin, dense skin of soil; this layer can help minimize the movement of water into or out of the compacted material. Another option is to wet the clay periodically in a uniform manner; however, it is important to make sure to avoid creating areas of excessive wetness. A third measure involves covering compacted clay liner materials with a sheet of white or clear plastic or tarp to help prevent against desiccation and cracking. The cover should be weighted down with sandbags or other material to minimize exposure of the underlying materials to air. Using a light-colored plastic will help prevent overheating, which can dry out the clay materials. If the clay liner is not being covered with a geosynthetic, another method to prevent desiccation involves covering the clay with a layer of protective cover soil or intentionally overbuilding the clay liner and shaving it down to liner grade.

Protection against freezing is another important consideration, because freezing can increase the hydraulic conductivity of a liner. It is important to avoid construction during freezing weather. If freezing does occur and the damage affects only a shallow depth, the liner can be repaired by rerolling the surface. If deeper freezing occurs, the repairs might be more complicated. For a general guide to frost depths, see Figure 1 of Chapter 11—Performing Closure and Post-Closure Care.

B. Geomembranes or Flexible Membrane Liners

Geomembranes or flexible membrane liners are used to contain or prevent waste constituents and leachate from escaping a waste management unit. Geomembranes are made by combining one or more plastic polymers with ingredients such as carbon black, pigments, fillers, plasticizers, processing aids, crosslinking chemicals, anti-degradants, and biocides. A wide range of plastic resins are used for geomembranes, including high density polyethylene (HDPE), linear low density polyethylene (LLDPE), low density linear polyethlene (LDLPE), very low density polyethlene (VLDPE), polyvinyl chloride (PVC), flexible polypropylene (fPP), chlorosulfonated polyethylene (CSPE or Hypalon), and ethylene propylene diene termonomer (EPDM). Most manufacturers produce geomembranes through extrusion or calendering. In the extrusion process, a molten polymer is stretched into a nonreinforced sheet; extruded geomembranes are usually made of HDPE and LLDPE. During the calendering process, a heated polymeric compound is passed through a series of rollers. In this process, a geomembrane can be reinforced with a woven fabric or fibers. Calendered geomembranes are usually made of PVC and CSPE.

What are the thickness recommendations for geomembrane liners?

Geomembranes range in thicknesses from 20 to 120 mil (1 mil = 0.001 in.). A good design should include a minimum thickness of 30 mil, except for HDPE liners, which should have a minimum thickness of 60 mil. These recommended minimum thicknesses ensure that the liner material will withstand the stress of construction and the weight load of the waste, and allow adequate seaming to bind separate geomembrane panels. Reducing the potential for tearing or puncture, through proper construction and quality control, is essential for a geomembrane to perform effectively.

What issues should be considered in the design of a geomembrane liner?

Several factors to address in the design include: determining appropriate material properties and testing to ensure these properties are met, understanding how the liner will interact with the intended waste stream, accounting for all stresses imposed by the design, and ensuring adequate friction.

Material Properties and Selection

When designing a geomembrane liner, you should examine several properties of the geomembrane material in addition to thickness, including: tensile behavior, tear resistance, puncture resistance, susceptibility to environmental stress cracks, ultraviolet resistance, and carbon black content.

Tensile behavior. Tensile behavior refers to the tensile strength of a material and its ability to elongate under strain. Tensile strength is the ability of a material to resist pulling stresses without tearing. The tensile properties of a geomembrane must be sufficient to satisfy the stresses anticipated during its service life. These stresses include the self-weight of the geomembrane and any down drag caused by waste settlement on side slope liners.

Puncture and tear resistance. Geomembrane liners can be subject to tearing during installation due to high winds or handling. Puncture resistance is also important to consider since geomembranes are often placed above or below materials that might have jagged or angular edges. For example, geomembranes might be installed above a granular drainage system that includes gravel.

Susceptibility to environmental stress cracks. Environmental factors can cause cracks or failures before a liner is stressed to its manufactured strength. These imperfections, referred to as environmental stress cracks, often occur in areas where a liner has been scratched or stressed by fatigue. These cracks can also result in areas where excess surface wetting agents have been applied. In surface impoundments, where the geomembrane liner has greater exposure to the atmosphere and temperature changes, such exposure can increase the potential for environmental stress cracking.

Ultraviolet resistance. Ultraviolet resistance is another factor to consider in the design of geomembrane liners, especially in cases where the liner might be exposed to ultraviolet radiation for prolonged periods of time. In such cases, which often occur in surface impoundments, ultraviolet radiation can cause degradation and cracking in the geomembrane. Adding carbon black or other additives during the manufacturing process can increase a geomembrane's ultraviolet resistance. Backfilling over the exposed geomembrane also works to prevent degradation due to ultraviolet radiation.

Interactions With Waste

Since the main purpose of a geomembrane is to provide a barrier and prevent contami-

nants from penetrating through the geomembrane, chemical resistance is a critical consideration. Testing for chemical resistance might be warranted depending on the type, volumes, and characteristics of waste managed at a particular unit and the type of geomembrane to be used. An established method for testing the chemical resistance of geomembranes, EPA Method 9090, can be found in SW-846. ASTM has also adopted standards for testing the chemical compatibility of various geosynthetics, including geomembranes, with leachates from waste management units. ASTM D-5747 provides a standard for testing the chemical compatibility of geomembranes.[7]

Stresses Imposed by Liner Design

A liner design should take into account the stresses imposed on the liner by the design configuration. These stresses include: the differential settlement in foundation soil, strain requirements at the anchor trench, strain requirements over long, steep side slopes, stresses resulting from compaction, and seismic stresses. Often an anchor trench designed to secure the geomembrane during construction is prepared along the perimeter of a unit cell. This action can help prevent the geomembrane from slipping down the interior side slopes. Trench designs should include a depth of burial sufficient to hold the specified length of liner. If forces larger than the tensile strength of the liner are inadvertently developed, then the liner could tear. For this reason, the geomembrane liner should be allowed to slip or give in the trench after construction to prevent such tearing. To help reduce unnecessary stresses in the liner design, it is advisable to avoid using horizontal seams. For more information on design stresses, consult *Geosynthetic Guidance for Hazardous Waste Landfill Cells and Surface Impoundments* (U.S. EPA, 1987).

Designing for Adequate Friction

Adequate friction between the geomembrane liner and the soil subgrade, as well as between any geosynthetic components, is necessary to prevent extensive slippage or sloughing on the slopes of a unit. Design equations for such components should evaluate: 1) the ability of a liner to support its own weight on side slopes, 2) the ability of a liner to withstand down-dragging during and after waste placement, 3) the best anchorage configuration for the liner, 4) the stability of soil cover on top of a liner, and 5) the stability of other geosynthetic components, such as geotextiles or geonets, on top of a liner. An evaluation of these issues can affect the choice of geomembrane material, polymer type, fabric reinforcement, thickness, and texture necessary to achieve the design requirements. Interface strengths can be significantly improved by using textured geomembranes.

What issues should be considered in the construction of a geomembrane liner?

When preparing to construct a geomembrane liner, you should plan appropriate shipment and handling procedures, perform testing prior to construction, prepare the subgrade, consider temperature effects, and account for wind effects. In addition, you should select a seaming process, determine a material for and method of backfilling, and plan for testing during construction.

Shipment, Handling, and Site Storage

You should follow quality assurance and quality control procedures to ensure proper handling of geomembranes. Different types of geomembrane liners require different types of packaging for shipment and storage. Typically a geomembrane manufacturer will provide specific instructions outlining the

[7] ASTM D-5747, Practice for Tests to Evaluate the Chemical Resistance of Geomembranes to Liquids.

handling, storage, and construction specifications for a product. In general, HDPE and LLDPE geomembrane liners are packaged in a roll form, while PVC and CSPE-R liners (CSPE-R refers to a CSPE geomembrane liner reinforced with a fabric layer) are packaged in panels, accordion-folded in two directions, and placed onto pallets. Whether the liner is shipped in rolls or panels, you should provide for proper storage. The rolls and panels should be packaged so that fork lifts or other equipment can safely transport them. For rolls, this involves preparing the roll to have a sufficient inside diameter so that a fork lift with a long rod, known as a stinger, can be used for lifting and moving. For accordion panels, proper packaging involves using a structurally-sound pallet, wrapping panels in treated cardboard or plastic wrapping to protect against ultraviolet exposure, and using banding straps with appropriate cushioning. Once the liners have been transported to the site, the rolls or panels can be stored until the subgrade or subbase (either natural soils or another geosynthetic) is prepared.

Subgrade Preparation

Before a geomembrane liner is installed, you should prepare the subgrade or subbase. The subgrade material should meet specified grading, moisture content, and density requirements. In the case of a soil subgrade, it is important to prevent construction equipment used to place the liner from deforming the underlying materials. If the underlying materials are geosynthetics, such as geonets or geotextiles, you should remove all folds and wrinkles before the liner is placed. For further information on geomembrane placement, see Chapter 3 of EPA's *Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities* (U.S. EPA, 1993c).

Testing Prior to Construction

Before any construction begins, is it recommended that you test both the geomembrane materials from the manufacturer and the installation procedures. Acceptance and conformance testing is used to evaluate the performance of the manufactured geomembranes. Constructing test strips can help evaluate how well the intended construction process and quality control procedures will work.

Acceptance and conformance testing. You should perform acceptance and conformance testing on the geomembrane liner received from the manufacturer to determine whether the materials meet the specifications requested. While the specific ASTM test methods vary depending on geomembrane type, recommended acceptance and conformance testing for geomembranes includes evaluations of thickness, tensile strength and elongation, and puncture and tear resistance testing, as appropriate. For most geomembrane liner types, the recommended ASTM method for testing thickness is ASTM D-5199.[8] For measuring the thickness of textured geomembranes, you should use ASTM D-5994.[9] For tensile strength and elongation, ASTM D-638 is recommended for the HDPE and LLDPE sheets, while ASTM D-882 and ASTM D-751 are recommended for PVC and CSPE geomembranes, respectively.[10] Puncture resistance testing is typically recommended for HDPE and LLDPE geomembranes using ASTM D-4833.[11] To evaluate tear resistance for HDPE, LLDPE, and PVC geomembrane

[8] ASTM D-5199, Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.

[9] ASTM D-5994, Measuring Core Thickness of Textured Geomembranes.

[10] ASTM D-638, Standard Test Method for Tensile Properties of Plastics.
ASTM D-882, Standard Test Methods for Tensile Properties of Thin Plastic Sheeting.
ASTM D-751, Standard Test Methods for Coated Fabrics.

[11] ASTM D-4833, Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.

liners, the recommended testing method is ASTM D-1004, Die C.[12] For CSPE-R geomembranes, ply adhesion is more of a concern than tear or puncture resistance and can be evaluated using ASTM D-413, Machine Method, Type A.[13]

Test strips. In preparation for liner placement and field seaming, you should develop test strips and trial seams as part of the construction process. Construction of such samples should be performed in a manner that reproduces all aspects of field production. Providing an opportunity to test seaming methods and workmanship helps ensure that the quality of the seams remains constant and meets specifications throughout the entire seaming process.

Temperature Effects

Liner material properties can be altered by extreme temperatures. High temperatures can cause geomembrane liner surfaces to stick together, a process commonly referred to as blocking. On the other hand, low temperature can cause the liner to crack when unrolled or unfolded. Recommended maximum and minimum allowable sheet temperatures for unrolling or unfolding geomembrane liners are 50°C (122°F) and 0°C (32°F), respectively. In addition to sticking and cracking, extreme temperatures can cause geomembranes to contract or expand. Polyethylene geomembranes expand when heated and contract when cooled. Other geomembranes can contract slightly when heated. Those responsible for placing the liner should take temperature effects into account as they place, seam, and backfill in the field.

Wind Effects

It is recommended that you take measures to protect geomembrane liners from wind damage. Windy conditions can increase the potential for tearing as a result of uplift. If wind uplift is a potential problem, panels can be weighted down with sand bags.

Seaming Processes

Once panels or rolls have been placed, another critical step involves field-seaming the separate panels or rolls together. The selected seaming process, such as thermal or chemical seaming, will depend on the chemical composition of the liner. To ensure the integrity of the seam, you should use the seaming method recommended by the manufacturer. Thermal seaming uses heat to bond together the geomembrane panels. Examples of thermal seaming processes include extrusion welding and thermal fusion (or melt bonding). Chemical seaming involves the use of solvents, cement, or an adhesive. Chemical seaming processes include chemical fusion and adhesive seaming. For more information on seaming methods, *Technical Guidance Document: Inspection Techniques for the Fabrication of Geomembrane Field Seams* (U.S. EPA, 1991c), contains a full chapter on each of the traditional seaming methods and additional discussion of emerging techniques, such as ultrasonic, electrical conduction, and magnetic energy source methods.

Consistent quality in fabricating field seams is paramount to liner performance. Conditions that could affect seaming should be monitored and controlled during installation. Factors influencing seam construction and performance include: ambient temperature, relative humidity, wind uplift, changes in geomembrane temperature, subsurface water content, type of supporting surface used, skill of the seaming crew, quality and consistency of chemical or welding materials, preparation of liner surfaces to be joined, moisture at the seam interface, and cleanliness of the seam interface.

[12] ASTM D-1004, Standard Test Method for Initial Tear Resistance of Plastic Film and Sheeting.

[13] ASTM D-413, Standard Test Methods for Rubber Property-Adhesion to Flexible Substrate.

To help control some of these factors, no more than the amount of sheeting that can be used during a shift or a work day should be deployed at one time. To prevent erosion of the underlying soil surface or washout of the geomembrane, proper storm water control measures should be employed. Ambient temperature can become a concern, if the geomembrane liner has a high percentage of carbon black. Although the carbon black will help to prevent damage resulting from ultraviolet radiation, because its dark color absorbs heat, it can increase the ambient temperature of the geomembrane, making installation more complicated. To avoid surface moisture or high subsurface water content, geomembranes should not be deployed when the subgrade is wet.

Regardless of how well a geomembrane liner is designed, its ability to meet performance standards depends on proper quality assurance and quality control during installation. Geomembrane sheets and seams are subject to tearing and puncture during installation; punctures or tears can result from contact with jagged edges or underlying materials or by applying stresses greater than the geomembrane sheet can handle. Proper quality assurance and quality control can help minimize the occurrence of pinhole or seam leaks. For example, properly preparing the underlying layer and ensuring that the gravel is of an acceptable size reduces the potential for punctures.

Protection and Backfilling

Geomembrane liners that can be damaged by exposure to weather or work activities should be covered with a layer of soil or a geosynthetic as soon as possible after quality assurance activities associated with geomembrane testing are completed. If the backfill layer is a soil material, it will typically be a drainage material like sand or gravel. If the cover layer is a geosynthetic, it will typically be a geonet or geocomposite drain placed directly over the geomembrane. Careful placement of backfill materials is critical to avoid puncturing or tearing the geomembrane material.

For soil covers, three considerations determine the amount of slack to be placed in the underlying geomembrane. These considerations include selecting the appropriate type of soil, using the proper type of equipment, and establishing a placement procedure for the soil. When selecting a soil for backfilling, characteristics to consider include particle size, hardness, and angularity, as each of these can affect the potential for tearing or puncturing the liner. To prevent wrinkling, soil covers should be placed over the geomembrane in such a way that construction vehicles do not drive directly on the liner. Care should be taken not to push heavy loads of soil over the geomembrane in a continuous manner. Forward pushing can cause localized wrinkles to develop and overturn in the direction of movement. Overturned wrinkles create sharp creases and localized stress in the liner and can lead to premature failure. A recommended method for placing soil involves continually placing small amounts of soil or drainage material and working outward over the toe of the previously placed material.

Another recommended method involves placing soil over the liner with a large backhoe and spreading it with a bulldozer or similar equipment. If a predetermined amount of slack is to be placed in the geomembrane, the temperature of the liner becomes an important factor, as it will effect the ability of the liner to contract and expand. Although the recommended methods for covering geomembrane liners with soil can take more time than backfilling with larger amounts of soil, these methods are designed to prevent damage caused by covering the liner with too

much soil too quickly. In the long run, preventing premature liner failure can be faster and more cost-effective than having to repair a damaged liner.

The types of geosynthetics that are often used as protective covering include geotextiles and geonets. Geogrids and drainage geocomposites can be used for cover soil reinforcement on slopes. The appendix at the end of this chapter provides additional information on geosynthetic materials. For geosynthetic protective covers, as with soil backfilling, to prevent tearing or puncturing, most construction vehicles should not be permitted to move directly on the geomembrane. Some possible exceptions include small, 4-wheel, all terrain vehicles or other types of low ground pressure equipment. Even with these types of vehicles, drivers should take extreme care to avoid movements, such as sudden starts, stops, and turns, which can damage the geomembrane. Seaming-related equipment should be allowed on the geomembrane liner, as long as it does not damage the liner. Geosynthetic materials are placed directly on the liner and are not bonded to it.

Testing During Construction

Testing during construction enables assessment of the integrity of the seams connecting the geomembrane panels. Tests performed on the geomembrane seams are categorized as either destructive or nondestructive.

Destructive testing. Destructive testing refers to removing a sample from the liner seam or sheet and performing tests on the sample. For liner seams, destructive testing includes shear testing and peel testing; for liner sheets, it involves tensile testing. While quality control procedures often require destructive testing prior to construction, in order to ensure that the installed seams and sheets meet performance standards, destructive testing should be performed during construction also. For increased quality assurance, it is recommended that peel and shear tests on samples from the installed geomembrane be performed by an independent laboratory. Testing methods for shear testing, peel testing, and tensile testing vary for different geomembrane liner types.

Determining the number of samples to take is a difficult step. Taking too few samples results in a poor statistical representation of the geomembrane quality. On the other hand, taking too many samples requires additional costs and increases the potential for defects. Defects can result from the repair patches used to cover the areas from which samples were taken.

A common sampling strategy is “fixed increment sampling” where samples are taken at a fixed increment along the length of the geomembrane. Increments range from 80 to 300 m (250 to 1,000 ft). The type of welding, such as extrusion or fusion welding, used to connect the seams and the type of geomembrane liner can also help determine the appropriate sampling interval. For example, extrusion seams on HDPE require grinding prior to welding and if extensive grinding occurs, the strength of the HDPE might decrease. In such cases, sampling at closer intervals, such as 90 to 120 m (300 to 400 ft), might provide a more accurate description of material properties. If the seam is a dual hot edge seam, both the inner and outer seams might need to be sampled and tested.

If test results for the seam or sheet samples do not meet the acceptance criteria for the destructive tests, you should continue testing the area surrounding the rejected sample to determine the limits of the low quality seam. Once the area of low quality has been identified, then corrective measures, such as seaming a cap over the length of the seam or reseaming the affected area, might be necessary.

Nondestructive testing. Unlike destructive tests, which examine samples taken from the geomembrane liner in the containment area, nondestructive tests are designed to evaluate the integrity of larger portions of geomembrane seams without removing pieces of the geomembrane for testing. Common nondestructive testing methods include: the probe test, air lance, vacuum box, ultrasonic methods (pulse echo, shadow, and impedance planes), electrical spark test, pressurized dual seam, and electrical resistivity. You should select the test method most appropriate for the material and seaming method. If sections of a seam fail to meet the acceptable criteria of the appropriate nondestructive test, then those sections need to be delineated and patched, reseamed, or retested. If repairing such sections results in large patches or areas of reseaming, then destructive test methods are recommended to verify the integrity of such pieces.

C. Geosynthetic Clay Liners

If a risk evaluation recommended the use of a single liner, another option to consider is a geosynthetic clay liner (GCL). GCLs are factory-manufactured, hydraulic barriers typically consisting of bentonite clay (or other very low permeability materials), supported by geotextiles or geomembranes held together by needling, stitching, or chemical adhesives. GCLs can be used to augment or replace compacted clay liners or geomembranes, or they can be used in a composite manner to augment the more traditional compacted clay or geomembrane materials. GCLs are typically used in areas where clay is not readily available or where conserving air space is an important factor. As GCLs do not have the level of long-term field performance data that geomembranes or compacted clay liners do, states might request a demonstration that performance of the GCL design will be comparable to that of compacted clay or geomembrane liners.

What are the mass per unit area and hydraulic conductivity recommendations for geosynthetic clay liners?

Geosynthetic clay liners are often designed to perform the same function as compacted clay and geomembrane liner components. For geosynthetic clay liners, you should design for a minimum of 3.7 kg/m^2 (0.75 lb/ft^2) dry weight (oven dried at 105°C) of bentonite clay with a hydrated hydraulic conductivity of no more than 5 x 10^{-9} cm/sec (2 x 10^{-9} in/sec). It is important to follow manufacturer specifications for proper GCL installation.

What issues should be considered in the design of a geosynthetic clay liner?

Factors to consider in GCL design are the specific material properties needed for the liner and the chemical interaction or compatibility of the waste with the GCL. When considering material properties, it is important to keep in mind that bentonite has a low shear strength when it is hydrated. Manufacturers have developed products designed to increase shear strength.

Materials Selection and Properties

For an effective GCL design, material properties should be clearly defined in the specifications used during both manufacture and construction. The properties that should be specified include: type of bonds, thickness, moisture content, mass per unit area, shear strength, and tensile strength. Each of these properties is described below.

Type of bonds. Geosynthetic clay liners are available with a variety of bonding designs, which include a combination of clay, adhesives, and geomembranes or geotextiles. The type of adhesives, geotextiles, and geomembranes used as components of GCLs varies widely. One type of available GCL design uses a bentonite clay mixed with an adhesive bound on each side by geotextiles. A variation on this design involves stitching the upper and lower geotextiles together through the clay layer. Alternatively, another option is to use a GCL where geotextiles on each side of adhesive or nonadhesive bentonite clay are connected by needle punching. A fourth variation uses a clay mixed with an adhesive bound to a geomembrane on one side; the geomembrane can be either the lower or the upper surface. Figure 3 displays cross section sketches of the four variations of GCL bonds. While these options describe GCLs available at the time of this Guide, emerging technologies in GCL designs should also be reviewed and considered.

Thickness. The thickness of the various available GCL products ranges from 4 to 6 mm (160 to 320 mil). Thickness measurements are product dependent. Some GCLs can be quality controlled for thickness while others cannot.

Moisture content. GCLs are delivered to the job site at moisture contents ranging from 5 to 23 percent, referred to as the "dry" state. GCLs are delivered dry to prevent premature hydration, which can cause unwanted variations in the thickness of the clay component as a result of uneven swelling.

Stability and shear strength. GCLs should be manufactured and selected to meet the shear strength requirements specified in design plans. In this context, shear strength is the ability of two layers to resist forces moving them in opposite directions. Since hydrated bentonite clay has low shear strength, bentonite clay can be placed between geotextiles and stitch bonded or needle- punched to provide additional stability. For example, a GCL with geotextiles supported by stitch bonding has greater internal resistance to shear in the clay layer than a GCL without any stitching. Needle-punched GCLs tend to provide greater resistance than stitch-bonded GCLs and can also provide increased friction resistance against an adjoining layer, because they require the use of nonwoven geotextiles. Increased friction is an important consideration on side slopes.

Mass per unit area. Mass per unit area refers to the bentonite content of a GCL. It is important to distribute bentonite evenly throughout the GCL in order to meet desired hydraulic conductivity specifications. All GCL products available in North America use a sodium bentonite clay with a mass per unit area ranging from 3.2 to 6.0 kg/m^2 (0.66 to 1.2 lb/ft^2), as manufactured.

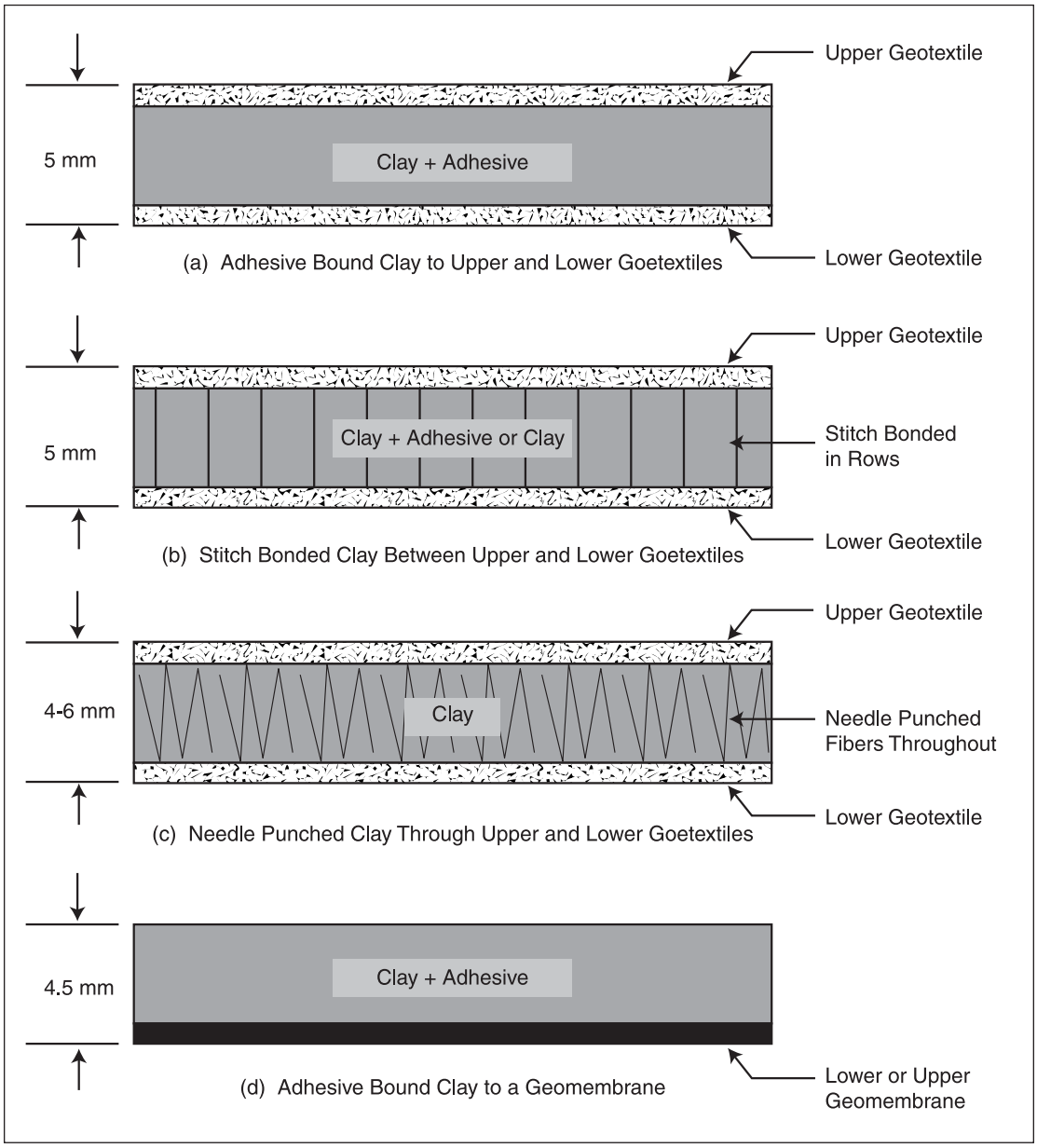
Interaction With Waste

During the selection process for a GCL liner, you should evaluate the chemical compatibility of the liner materials with the types of waste that are expected to be placed in the unit. Certain chemicals, such as calcium, can have an adverse effect on GCLs, resulting in a loss of liner integrity. Specific information on GCL compatibilities should be available from the manufacturer.

What issues should be considered in the construction of a geosynthetic clay liner?

Prior to and during construction, it is recommended that a qualified professional should prepare construction specifications for the GCL. In these specifications, procedures for shipping and storing materials, as well as performing acceptance testing on delivered

Figure 3
Four Variations of GCL Bonding Methods



Source: U.S. EPA, 1993c.

materials, should be identified. The specifications should also address methods for subgrade preparation, joining panels, repairing sections, and protective backfilling.

Shipment, Handling, and Site Storage

GCLs are manufactured in widths of approximately 2 to 5 m (7 to 17 ft) and lengths of 30 to 60 m (100 to 200 ft). Directly after manufacturing, GCLs are rolled around a core and covered with a thin plastic protective covering. This waterproof covering serves to protect the material from premature hydration. GCLs should be stored at the factory with these protective coverings. Typical storage lengths range from a few days to 6 months. To ensure protection of the plastic covering and the rolls themselves during loading and unloading, it is recommended that qualified professionals specify the equipment needed at the site to lift and deploy the rolls properly.

To reduce the potential for accidental damage or for GCLs to absorb moisture at the site, you should try to arrange for "just-in-time-delivery" for GCLs transported from the factory to the field. Even with "just-in-time-delivery," it might be necessary to store GCLs for short periods of time at the site. Often the rolls can be delivered in trailers, which can then serve as temporary storage. To help protect the GCLs prior to deployment, you should use wooden pallets to keep the rolls off the ground, placing heavy, waterproof tarps over the GCL rolls to protect them from precipitation, and using sandbags to help keep the tarps in place.

Manufacturer specifications should also indicate how high rolls of GCLs can be stacked horizontally during storage. Overstacking can cause compression of the core around which the GCL is wrapped. A damaged core makes deployment more difficult and can lead to other problems. For example, rolls are sometimes handled by a fork lift with a stinger attached. The stinger is a long tapered rod that fits inside the core. If the core is crushed, the stinger can damage the liner during deployment.

Acceptance and Conformance Testing

Acceptance and conformance testing is recommended either upon delivery of the GCL rolls or at the manufacturer's facility prior to delivery. Conformance test samples are used to ensure that the GCL meets the project plans and specifications. GCLs should be rewrapped and replaced in dry storage areas immediately after test samples are removed. Liner specifications should prescribe sampling frequencies based on either total area or on number of rolls. Since variability in GCLs can exist between individual rolls, it is important for acceptance and conformance testing to account for this. Conformance testing can include the following.

Mass per unit area test. The purpose of evaluating mass per unit area is to ensure an even distribution of bentonite throughout the GCL panel. Although mass per unit area varies from manufacturer to manufacturer, a typical minimum value for oven dry weight is 3.7 kg/m^2 (0.75 lb/ft^2). Mass per unit area should be tested using ASTM D-5993.[14] This test measures the mass of bentonite per unit area of GCL. Sampling frequencies should be determined using ASTM D- 4354.[15]

Free swell test. Free swell refers to the ability of the clay to absorb liquid. Either ASTM D-5890 or GRI-GCL1, a test method developed by the Geosynthetic Research Institute, can be used to evaluate the free swell of the material.[16]

[14] ASTM D-5993, Standard Test Method for Measuring Mass per Unit Area of Geosynthetic Clay Liners.

[15] ASTM D-4354, Standard Practice for Sampling of Geosynthetics for Testing.

[16] ASTM D-5890, Test Method for Swell Index of Clay Mineral Components of Geosynthetic Clay Liners. GRI-GCL1, Swell Measurement of the Clay Component of Geosynthetic Clay Liners.

Direct shear test. Shear strength of the GCLs can be evaluated using ASTM D-5321.[17] The sampling frequency for this performance-oriented test is often based on area, such as one test per 10,000 m^2 (100,000 ft^2).

Hydraulic conductivity test. Either ASTM D-5084 (modified) or GRI-GCL2 will measure the ease with which liquids can move through the GCL.[18]

Other tests. Testing of any geotextiles or geomembranes should be made on the original rolls of the geotextiles or geomembranes and before they are fabricated into the GCL product. Once these materials have been made part of the GCL product, their properties can change as a result of any needling, stitching, or gluing. Additionally, any peel tests performed on needle punched or stitch bonded GCLs should use the modified ASTM D-413 with a recommended sampling frequency of one test per 2,000 m^2 (20,000 ft^2).[19]

Subgrade Preparation

Because the GCL layer is relatively thin, the first foot of soil underlying the GCL should have a hydraulic conductivity of 1×10^{-5} cm/sec or less. Proper subgrade preparation is essential to prevent damage to the GCL layer as it is installed. This includes clearing away any roots or large particles that could potentially puncture the GCL and its geotextile or geomembrane components. The soil subgrade should be of the specified grading, moisture content, and density required by the installer and approved by a construction quality assurance engineer for placement of the GCL. Construction equipment deploying the rolls should not deform or rut the soil subgrade excessively. To help ensure this, the soil subgrade should be smooth rolled with a smooth-wheel roller and maintained in a smooth condition prior to deployment.

Joining Panels

GCLs are typically joined by overlapping panels, without sewing or mechanically connecting pieces together. To ensure proper joints, you should specify minimum and maximum overlap distances. Typical overlap distances range from 150 to 300 mm (6 to 12 in.). For some GCLs, such as needle punched GCLs with nonwoven geotextiles, it might be necessary to place bentonite on the area of overlap. If this is necessary, you should take steps to prevent fugitive bentonite particles from coming into contact with the leachate collection system, as they can cause physical clogging.

Repair of Sections Damaged During Liner Placement

During installation, GCLs might incur some damage to either the clay component or to any geotextiles or geomembranes. For damage to geotextile or geomembrane components, repairs include patching using geotextile or geomembrane materials. If the clay component is disturbed, a patch made from the same GCL product should be used to perform any repairs.

Protective Backfilling

As soon as possible after completion of quality assurance and quality control activities, you should cover GCLs with either a soil layer or a geosynthetic layer to prevent hydration. The soil layer can be a compacted clay liner or a layer of coarse drainage material. The geosynthetic layer is typically a

[17] ASTM D-5321, Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.

[18] ASTM D-5084, Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.
GRI-GCL2, Permeability of Geosynthetic Clay Liners (GCLs).

[19] ASTM D-413, Standard Test Methods for Rubber Property-Adhesion to Flexible Substrate.

geomembrane; however, depending on site-specific designs, it can be a geotextile. As noted earlier, premature hydration before covering can lead to uneven swelling, resulting in a GCL with varied thickness. Therefore, a GCL should be covered with its subsequent soil or geosynthetic layer before a rainfall or snowfall occurs. Premature hydration is less of a concern for GCLs, where the geosynthetic components are needle punched or stitch bonded, because these types of connections can better limit clay expansion.

III. Composite Liners

A composite liner consists of both a geomembrane liner and natural soil. The geomembrane forms the upper component with the natural soil being the lower component. The ususal variations are:

- Geomembrane over compacted clay liner (GM/CCL).
- Geomembrane over geosynthetic clay liner (GM/GCL).
- Geomembrane over geosynthetic clay liner over compacted clay liner (GM/GCL/CCL).

A composite liner provides an effective hydraulic barrier by combining the complementary properties of the two different liners into one system. The geomembrane provides a highly impermeable layer to maximize leachate collection and removal. The natural soil liner serves as a backup in the event of any leakage from the geomembrane. With a composite liner design, you should construct a leachate collection and removal system above the geomembrane. Information on design and construction of leachate collection and removal systems is provided in Section V below.

What are the thickness and hydraulic conductivity recommendations for composite liners?

Each component of the composite liner should follow the recommendations for geomembranes, geosynthetic clay liners, and compacted clay liners described earlier. Geomembrane liners should have a minimum thickness of 30 mil, except for HDPE liners, which should have a minimum thickness of 60 mil. Similarly, compacted clay liners should be at least 2 feet thick and are typically 2 to 5 feet thick. For compacted clay liners and geosynthetic clay liners, you should use materials with maximum hydraulic conductivities of 1×10^{-7} cm/sec (4×10^{-8} in/sec) and 5×10^{-9} cm/sec (2×10^{-9} in/sec), respectively.

What issues should be considered in the design of a composite liner?

As a starting point, you should follow the design considerations discussed previously for single liners. In addition, to achieve the benefits of a combined liner system, you should install the geomembrane to ensure good contact with the compacted clay layer. The uniformity of contact between the geomembrane and the compacted clay layer helps control the flow of leachate. Porous material, such as drainage sand or a geonet, should not be placed between the geomembrane and the clay layer. Porous materials will create a layer of higher hydraulic conductivity, which will increase the amount of leakage below any geomembrane imperfection.

You should consider the friction or shear strength between a compacted clay layer and a geomembrane. The friction or shear stress at this surface is often low and can form a weak plane on which sliding can occur.

ASTM D-5321 provides a test method for determining the friction coefficient of soil and geomembranes.[20] When using bentonite-amended soils, it is important to account for how the percentage of bentonite added and the degree of saturation affect interface friction. To provide for stable slopes, it is important to control both the bentonite and moisture contents. A textured geomembrane can increase the friction with the clay layer and improve stability.

What issues should be considered in the construction of a composite liner?

To achieve good composite bonding, the geomembrane and the compacted clay layer should have good hydraulic contact. To improve good contact, you should smooth-roll the surface of the compacted clay layer using a smooth, steel-drummed roller and remove any stones. In addition, you should place and backfill the geomembrane so as to minimize wrinkles.

The placement of geomembranes onto a compacted clay layer poses a challenge, because workers cannot drive heavy machines over the clay surface without potentially damaging the compacted clay component. Even inappropriate footwear can leave imprints in the clay layer. It might be possible to drive some types of low ground pressure equipment or small, 4-wheel, all terrain vehicles over the clay surface, but drivers should take extreme care to avoid movements, such as sudden starts, stops, and turns, that could damage the surface. To avoid damaging the clay layer, it is recommended that you unroll geomembranes by lifting the rolls onto jacks at a cell side and pulling down on the geomembrane manually. Also, the entire roll with its core can be unrolled onto the cell (with auxiliary support using ropes on embankments).

To minimize desiccation of the compacted clay layer, you should place the geomembrane over the clay layer as soon as possible. Additional cover materials should also be placed over the geomembrane. Exposed geomembranes absorb heat, and high temperatures can dry out and crack an underlying compacted clay layer. Daily cyclic changes in temperature can draw water from the clay layer and cause this water to condense on the underside of the geomembrane. This withdrawal of water can lead to desiccation cracking and potential interface stability concerns.

IV. Double Liners (Primary and Secondary Lined Systems)

In a double-lined waste management unit, there are two distinct liners—one primary (top) liner and one secondary (bottom) liner. Each liner might consist of compacted clay, a geomembrane, or a composite (consisting of a geomembrane and a compacted clay layer or GCL). Above the primary liner, it is recommended that you construct a leachate collection and removal system to collect and convey liquids out of the waste management unit and to control the depth of liquids above the primary liner. In addition, you should place a leak detection, collection, and removal system between the primary and secondary liner. This leak detection system will provide leak warning, as well as collect and remove any liquid or leachate that has escaped the primary liner. See section V below for information on the design of leachate collection and removal systems and leak detection, collection, and removal systems.

[20] ASTM D-5321, Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.

What are the thickness and hydraulic conductivity recommendations for double liners?

Each component of the double liner should follow the recommendations for geomembranes, compacted clay liners, or composite liners described earlier. Geomembrane liners should have a minimum thickness of 30 mil, except for HDPE liners, which should have a minimum thickness of 60 mil. Similarly, compacted clay liners should be at least 2 feet thick and are typically 2 to 5 feet thick. For compacted clay liners and geosynthetic clay liners, use materials with maximum hydraulic conductivities of 1 x 10^{-7} cm/sec (4 x 10^{-8} in/sec) and 5 x 10^{-9} cm/sec (2 x 10^{-9} in/sec), respectively.

What issues should be considered in the design and construction of a double liner?

Like composite liners, double liners are composed of a combination of single liners. When planning to design and construct a double liner, you should consult the sections on composite and single liners first. In addition, you should consult the sections on leachate collection and removal systems and leak detection systems.

V. Leachate Collection and Leak Detection Systems

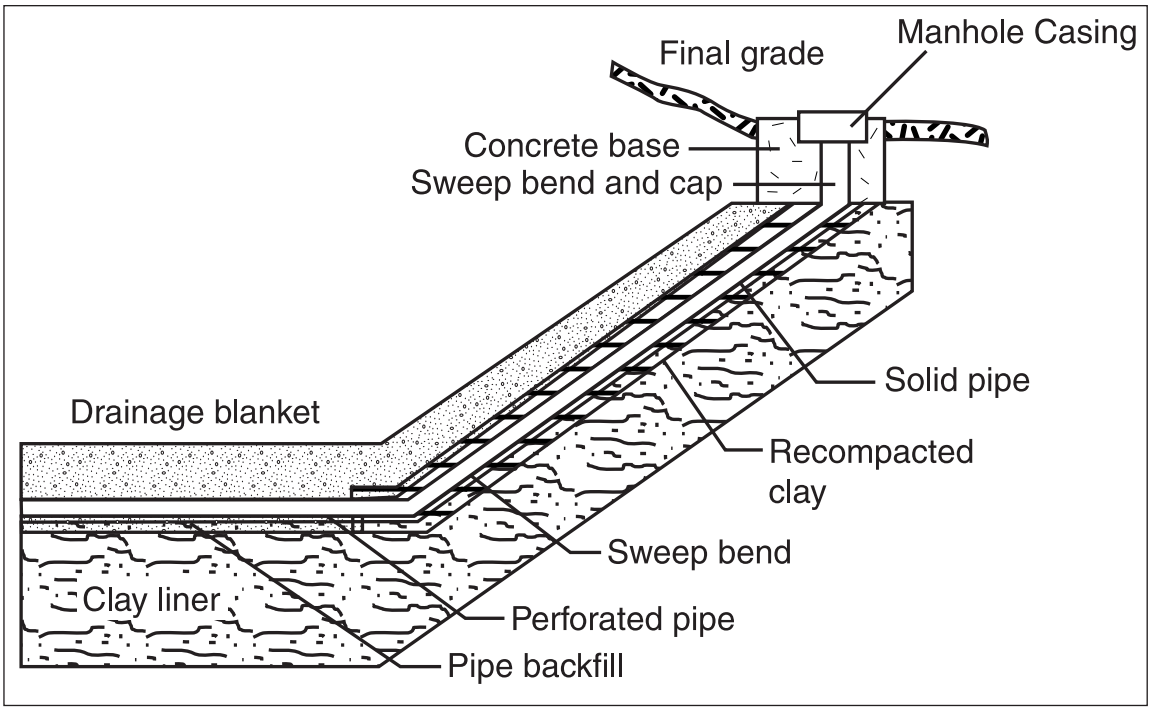
One of the most important functions of a waste management unit is controlling leachate and preventing contamination of the underlying ground water. Both leachate collection and removal systems and leak detection systems serve this purpose. You should consult with the state agency too determine if such systems are required. The primary function of a leachate collection and removal system is to collect and convey leachate out of a unit and to control the depth of leachate above a liner. The primary function of a leak detection system is to detect leachate that has escaped the primary liner. A leak detection system refers to drainage material located below the primary liner and above a secondary liner (if there is one); it acts as a secondary leachate collection and removal system. After the leachate has been removed and collected, a leachate treatment system might be incorporated to process the leachate and remove harmful constituents.

The information in this section on leachate collection and leak detection systems is applicable if the unit is a landfill or a waste pile. Surface impoundments, which manage liquid wastes, usually will not have leachate collection and removal systems unless they will be closed in-place as landfills; they might have leak detection systems to detect liquid wastes that have escaped the primary liner. Leachate collection or leak detection systems generally are not used with land application.

A. Leachate Collection System

A typical leachate collection system includes a drainage layer, collection pipes, a removal system, and a protective filter layer. Leachate collection systems are designed to collect leachate for treatment or alternate disposal and to reduce the buildup of leachate above the liner system. Figure 4 shows a cross section of a typical leachate collection system showing access to pipes for cleaning.

Figure 4
Typical Leachate Collection System



Source: U.S. EPA, 1995b

What are the recommendations for leachate collection and removal systems?

You should design a leachate collection and removal system to maintain less than 30 cm (12 in.) depth of leachate, or "head," above the liner if granular soil or a geosynthetic material is used. The reason for maintaining this level is to prevent excessive leachate from building up above the liner, which could jeopardize the liner's performance. This should be the underlying factor guiding the design, construction, and operation of the leachate collection and removal system.

You should design a leachate collection and removal system capable of controlling the estimated volume of leachate. To determine potential leachate generation, you should use water balance equations or models. The most commonly used method to estimate leachate generation is EPA's Hydrogeologic Evaluation of Landfill Performance (HELP) model.[21] This model uses weather, soil, and waste management unit design data to determine leachate generation rates.

What issues should be considered in the design of a leachate collection and removal system?

You should design a leachate collection and removal system to include the following elements: a low-permeability base, a high-permeability drainage layer, perforated leachate collection pipes, a protective filter layer, and a leachate removal system. During

[21] Available on the CD-ROM version of the Guide, as well as from the U.S. Army Corps of Engineers Web site **<www.wes.army.mil/el/elmodels/index.html#landfill>**

design, you should consider the stability of the base, the transmissivity of the drainage layers, and the strength of the collection pipes. It is also prudent to consider methods to minimize physical, biological, and chemical clogging within the system.

Low-Permeability Base

A leachate collection system is placed over the unit's liner system. The bottom liner should have a minimum slope of 2 percent to allow the leachate collection system to gravity flow to a collection sump. This grade is necessary to provide proper leachate drainage throughout the operation, closure, and post-closure of the unit. Estimates of foundation soil settlement should include this 2 percent grade as a post-settlement design.

High-Permeability Drainage Layer

A high-permeability drainage layer consists of drainage materials placed directly over the low-permeability base, at the same minimum 2 percent grade. The drainage materials can be either granular soil or geosynthetic materials. For soil drainage materials, a maximum of 12 inches of materials with a hydraulic conductivity of at least 1×10^{-2} cm/sec (4×10^{-3} in/sec) is recommended. For this reason, sand and gravel are the most common soil materials used. If the drainage layer is going to incorporate sand or gravel, it should be demonstrated that the layer will have sufficient bearing capacity to withstand the waste load of the full unit. Additionally, if the waste management unit is designed on grades of 15 percent or higher, it should be demonstrated that the soil drainage materials will be stable on the steepest slope in the design.

Geosynthetic drainage materials such as geonets can be used in addition to, or in place of, soil materials. Geonets promote rapid transmission of liquids and are most effective when used in conjunction with a filter layer or geotextile to prevent clogging. Geonets consist of integrally connected parallel sets of plastic ribs overlying similar sets at various angles. Geonets are often used on the side walls of waste management units because of their ease of installation. Figure 5 depicts a typical geonet material configuration.

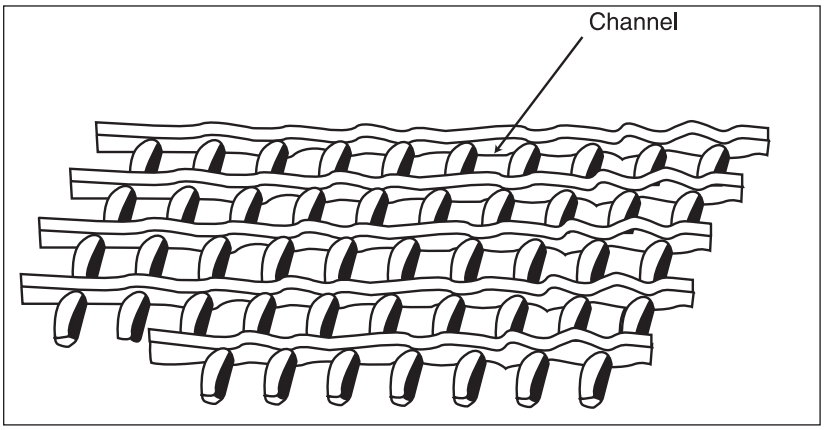
The most critical factor involved with using geonets in a high-permeability drainage layer is the material's ability to transmit fluids under load. The flow rate of a geonet can be evaluated by ASTM D-4716.[22] Several additional measures for determining the transmissivity of geonets are discussed in the *Solid Waste Disposal Facility Criteria: Technical Manual* (U.S. EPA, 1993b).

Perforated Leachate Collection Pipes

Whenever the leachate collection system is a natural soil, a perforated piping system should be located within it to rapidly transmit the leachate to a sump and removal system. Through the piping system, leachate flows gravitationally to a low point where the sump and removal system is located. The design of perforated leachate collection pipes, therefore, should consider necessary flow rates, pipe sizing, and pipe structural strength. After estimating the amount of leachate using the HELP model or a similar water balance model, it is possible to calculate the appropriate pipe diameter and spacing. For the leachate collection system design, you should select piping material that can withstand the anticipated weight of the waste, construction and operating equipment stresses, and foundation settling. Most leachate collection pipes used in modern waste management units are constructed of HDPE. HDPE pipes provide great structural strength, while allowing significant chemical resistance to the many constituents found in leachate. PVC pipes are also used in waste

[22] ASTM D-4716, Standard Test Method for Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products.

Figure 5
Typical Geonet Configuration



management units, but they are not as chemically resistant as HDPE pipes.

Protective Filter Layer

To protect the drainage layer and perforated leachate collection piping from clogging, you should place a filter layer over the high-permeability drainage layer. To prevent waste material from moving into the drainage layer, the filter layer should consist of a material with smaller pore space than the drainage layer materials or the perforation openings in the collection pipes. Sand and geotextiles are the two most common materials used for filtration. You should select sand that allows adequate flow of liquids, prevents migration of overlying solids or soils into the drainage layer, and minimizes clogging during the service life. In designing the sand filter, you should consider particle size and hydraulic conductivity. The advantages of using sand materials include common usage, traditional design, and durability.

Any evaluation of geotextile materials should address the same concerns but with a few differences. To begin with, the average pore size of the geotextile should be large enough to allow the finer soil particles to pass but small enough to retain larger soil particles. The number of openings in the geotextile should be large enough that, even if some of the openings clog, the remaining openings will be sufficient to pass the design flow rate. In addition to pore size, geotextile filter specifications should include durability requirements. The advantages of geotextile materials include vertical space savings and easy placement. Chapter 5 of *Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities* (U.S. EPA, 1993c) offers guidance on protection of drainage layers.

Leachate Removal System

Leachate removal often involves housing a sump within the leachate collection drainage layer. A sump is a low point in the liner constructed to collect leachate. Modern waste management unit sumps often consist of prefabricated polyethylene structures supported on a steel plate above the liner. Especially with geomembrane liners, the steel plate serves to support the weight of the sump and protect the liner from puncture. Gravel filled earthen depressions can serve as the sump. Reinforced concrete pipe and concrete flooring also can be used in place of the polyethylene structure but are considerably heavier.

To remove leachate that has collected in the sump, you should use a submersible pump. Ideally, the sump should be placed at a depth of 1 to 1.5 m (3 to 5 ft) to allow enough leachate collection to prevent the pump from running dry. You should consider

installing a level control, backup pump, and warning system to ensure proper sump operation. Also consider using a backup pump as an alternate to the primary pump and to assist it during high flow periods. A warning system should be used to indicate pump malfunction.

Standpipes, vertical pipes extending through the waste and cover system, offer one method of removing leachate from a sump without puncturing the liner. Alternatively, you can remove leachate from a sump using pipes that are designed to penetrate the liner. When installing pipe penetrations through the liner, you should proceed with extreme caution to prevent any liner damage that could result in uncontained leachate. Both of these options rely on gravity to direct leachate to a leachate collection pond or to an external pumping station.

Minimizing Clogging

Leachate collection and removal systems are susceptible to physical, biological, and chemical clogging. Physical clogging can occur through the migration of finer-grained materials into coarser-grained materials, thus reducing the hydraulic conductivity of the coarser-grained material. Biological clogging can occur through bacterial growth in the system due to the organic and nutrient materials in leachate. Chemical clogging can be caused by chemical precipitates, such as calcium carbonates, causing blockage or cementation of granular drainage material.

Proper selection of drainage and filter materials is essential to minimize clogging in the high-permeability drainage layer. Soil and geotextile filters can be used to minimize physical clogging of both granular drainage material and leachate collection pipes. When placed above granular drainage material, these filters can also double as an operations layer to prevent sharp waste from damaging the liner or leachate collection and removal systems. To minimize chemical and biological clogging for granular drainage material, the best procedure is to keep the interstices of the granular drainage material as open as possible.

The leachate collection pipes are also susceptible to similar clogging. To prevent this, you should incorporate measures into the design to allow for routine pipe cleaning, using either mechanical or hydraulic methods. The cleaning components can include pipes with a 15 cm (6 in) minimum diameter to facilitate cleaning; access located at major pipe intersections or bends to allow for inspections and cleaning; and valves, ports, or other appurtenances to introduce biocides and cleaning solutions. Also, you should check that the design does not include wrapping perforated leachate collection pipes directly with geotextile filters. If the geotextile becomes clogged, it can block flow into the pipe.

B. Leak Detection System

The leak detection system (LDS) is also known as the secondary leachate collection and removal system. It uses the same drainage and collection components as the primary leachate collection and removal system and identifies, collects, and removes any leakage from the primary system. The LDS should be located directly below the primary liner and above the secondary liner.

What are the recommendations for leak detection systems?

The LDS should be designed to assess the adequacy of the primary liner against leachate leakage; it should cover both the bottom and side walls of a waste management unit. The LDS should be designed to collect leakage through the primary layer and transport it to a sump within 24 hours.

The LDS should allow for monitoring and collection of leachate escaping the primary liner system. You should monitor the LDS on a regular basis. If the volume of leachate detected by the LDS appears to be increasing or is significant, you should consider a closer examination to determine possible remediation measures. A good rule of thumb is that if the LDS indicates a seepage level greater than 20 gallons per acre per day, the system might need closer monitoring or remediation.

C. Leachate Treatment System

Once the leachate has been removed from the unit and collected, you should consider taking measures to characterize the leachate in order to ensure proper management. There are several methods of disposal for leachate, and the treatment strategy will vary according to the disposal method chosen. Leachate disposal options include discharging to or pumping and hauling to a publicly owned treatment works or to an onsite treatment system; treating and discharging to the environment; land application; and natural or mechanical evaporation.

When discharging to or pumping and hauling leachate to a publicly owned treatment works, a typical treatment strategy includes pretreatment. Pretreatment could involve equalization, aeration, sedimentation, pH adjustment, or metals removal.[23] If the plan for leachate disposal does not involve a remote treatment facility, pretreatment alone usually is not sufficient.

There are two categories of leachate treatment, biological and physical/chemical. The most common method of biological treatment is activated sludge. Activated sludge is a "suspended-growth process that uses aerobic microorganisms to biodegrade organic contaminants in leachate."[24] Among physical/chemical treatment techniques, the carbon absorption process and reverse osmosis are the two most common methods. Carbon absorption uses carbon to remove dissolved organics from leachate and is very expensive. Reverse osmosis involves feeding leachate into a tubular chamber whose wall acts as a synthetic membrane, allowing water molecules to pass through but not pollutant molecules, thereby separating clean water from waste constituents.

What are the recommendations for leachate treatment systems?

You should review all applicable federal and state regulations and discharge standards to determine which treatment system will ensure long-term compliance and flexibility for the unit. Site-specific factors will also play a fundamental role in determining the proper leachate treatment system. For some facilities, onsite storage and treatment might not be an option due to space constraints. For other facilities, having a nearby, publicly owned treatment works might make pretreatment and discharge to the treatment works an attractive alternative.

VI. Construction Quality Assurance and Quality Control

Even the best unit design will not translate into a structure that is protective of human health and the environment, if the unit is not properly constructed. Manufacturing quality assurance and manufacturing quality control (MQA and MQC) are also important issues for the overall project; however, they are discussed only briefly here since they are primarily the responsibility of a manufacturer. Nonetheless, it is best to select a manufactur-

[23] Arts, Tom. "Alternative Approaches For Leachate Treatment." *World Wastes*.

[24] Ibid.

er who incorporates appropriate quality assurance and quality control (QA and QC) mechanisms as part of the manufacturing process. The remainder of this section provides a general description of the components of a construction quality assurance and construction quality control (CQA and CQC) program for a project. CQA and CQC are critical factors for waste management units. They are not interchangeable, and the distinction between them should be kept in mind when preparing plans. CQA is third party verification of quality, while CQC consists of in-process measures taken by the contractor or installer to maintain quality. You should establish clear protocols for identifying and addressing issues of concern throughout every stage of construction.

What is manufacturing quality assurance?

The desired characteristics of liner materials should be specified in the unit's contract with the manufacturer. The manufacturer should be responsible for certifying that materials delivered conform to those specifications. MQC implemented to ensure such conformance might take the form of process quality control or computer-aided quality control. If requested, the manufacturer should provide information on the MQC measures used, allow unit personnel or engineers to visit the manufacturing facility, and provide liner samples for testing. It is good practice for the manufacturer to have a dedicated individual in charge of MQC who would work with unit personnel in these areas.

What is construction quality assurance?

CQA is a verification tool employed by the facility manager or regulatory agency, consisting of a planned series of observations and tests designed to ensure that the final product meets project specifications. CQA testing, often referred to as acceptance inspection, provides a measure of the final product quality and its conformance with project plans and specifications. Performing acceptance inspections routinely, as portions of the project become complete, allows early detection and correction of deficiencies, before they become large and costly.

On routine construction projects, CQA is normally the concern of the facility manager and is usually performed by an independent, third-party testing firm. The independence of the testing firm is important, particularly when a facility manager has the capacity to perform the CQA activities. Although the

MQC, MQA, CQC, and CQA

Manufacturing quality control (MQC) is measures taken by the manufacturer to ensure compliance with the material and workmanship specifications of the facility manager.

Manufacturer quality assurance (MQA) is measures taken by facility personnel, or by an impartial party brought in expressly for the purpose, to determine if the manufacturer is in compliance with the specifications of the facility manager.

Construction quality control (CQC) is measures taken by the installer or contractor to ensure compliance with the installation specifications of the facility manager.

Construction quality assurance (CQA) is measures taken by facility personnel, or by an impartial party brought in expressly for the purpose, to determine if the installer or contractor is in compliance with the installation specifications of the facility manager.

facility's in-house CQA personnel might be registered professional engineers, a perception of misrepresentation might arise if CQA is not performed by an independent third party.

The independent party should designate a CQA officer and fully disclose any activities or relationships that the officer has with the facility manager that might impact his or her impartiality or objectivity. If such activities or relationships exist, the CQA officer should describe actions that have been or can be taken to avoid, mitigate, or neutralize the possibility they might affect the CQA officer's objectivity. State regulatory representatives can help evaluate whether these mechanisms are sufficient to ensure acceptable CQA.

What is construction quality control?

CQC is an ongoing process of measuring and controlling the characteristics of the product in order to meet manufacturer's or project specifications. CQC inspections are typically performed by the contractor to provide an in-process measure of construction quality and conformance with the project plans and specifications, thereby allowing the contractor to correct the construction process if the quality of the product is not meeting the specifications and plans. Since CQC is a production tool employed by the manufacturer of materials and by the contractor installing the materials at the site, the Guide does not cover CQC in detail. CQC is performed independently of CQA. For example, while a geomembrane liner installer will perform CQC testing of field seams, the CQA program should require independent testing of those same seams by a third-party inspector.

How can implementation of CQA and CQC plans be ensured?

When preparing to design and construct a waste management unit, regardless of design, you should develop CQA and CQC plans customized to the project. To help the project run smoothly, the CQA plan should be easy to follow. You should organize the CQA plan to reflect the sequence of construction and write it in language that will be familiar to an average field technician. For a more detailed discussion of specific CQA and CQC activities recommended for each type of waste management unit, you should consult *Technical Guidance Document: Quality Assurance and Quality Control for Waste Management Containment Facilities* (U.S. EPA, 1993c). This document provides information to develop comprehensive QA plans and to carry out QC procedures at waste management units.

CQA and CQC plans can be implemented through a series of meetings and inspections, which should be documented thoroughly. Communication among all parties involved in design and construction of a waste management unit is essential to ensuring a quality product. You should define responsibility and authority in written QA and QC plans and ensure that each party involved understands its role. Pre-construction meetings are one way to help clarify roles and responsibilities. During construction, meetings can continue to be useful to help resolve misunderstandings and to identify solutions to unanticipated problems that might develop. Some examples of typical meetings during the course of any construction project include pre-bid meetings, resolution meetings, pre-construction meetings, and progress meetings.

A. Compacted Clay Liner Quality Assurance and Quality Control

Although manufacturing quality control and quality assurance are often the responsibility of the materials manufacturer, in the case of soil components, manufacturing and construction quality control testing can be the responsibility of the facility manager. The CQA and CQC plans should specify procedures for quality assurance and quality control during construction of the compacted clay liners.

How can implementation of QA and QC be ensured for a compacted clay liner?

QC testing is typically performed by the contractor on materials used in construction of the liner. This testing examines material properties such as moisture content, soil density, Atterberg limits, grain size, and laboratory hydraulic conductivity. Additional testing of soil moisture content, density, lift thickness, and hydraulic conductivity helps ensure that the waste management unit has been constructed in accordance with the plans and technical specifications.

CQA testing for soil liners includes the same tests described for QC testing in the paragraph above. Generally, the tests are performed less frequently. CQA testing is performed by an individual or an entity independent of the contractor. Activities of the CQA officer are essential to document quality of construction. The responsibilities of the CQA officer and his or her staff might include communicating with the contractor; interpreting and clarifying project drawings and specifications with the designer, facility manager, and contractor; recommending acceptance or rejection by the facility manager of work completed by the construction contractor; and submitting blind samples, such as duplicates and blanks, for analysis by the contractor's testing staff or independent laboratories.

You should also consider constructing a test pad prior to full-scale construction as a CQA tool. As described earlier in the section on compacted clay liners, pilot construction or test fill of a small-scale test pad can be used to verify that the soil, equipment, and construction procedures can produce a liner that performs according to the construction drawings and specifications.

Specific factors to examine or test during construction of a test fill include: preparation and compaction of foundation material to the required bearing strength; methods of controlling uniformity of the soil material; compactive effort, such as type of equipment and number of passes needed to achieve required soil density and hydraulic conductivity; and lift thickness and placement procedures needed to achieve uniformity of density throughout a lift and prevent boundary effects between lifts or between placements in the same lift. Test pads can also provide a means to evaluate the ability of different types of soil to meet hydraulic conductivity requirements in the field. In addition to allowing an opportunity to evaluate material performance, test pads also allow evaluation of the skill and competence of the construction team, including equipment operators and QC specialists.

B. Geomembrane Liner Quality Assurance and Quality Control

As with the construction of soil liners, installation of geomembrane liners should be in conformance with a CQA and CQC plan. The responsibilities of the CQA personnel for the installation of the geomembrane are gen-

erally the same as the responsibilities for the construction of a compacted clay liner, with the addition of certain activities including observations of the liner storage area and liners in storage, and handling of the liner as the panels are positioned in the cell. Geomembrane CQA staff should also observe seam preparation, seam overlap, and materials underlying the liner.

How can implementation of QA and QC be ensured for a geomembrane liner?

Prior to installation, you should work with the geomembrane manufacturer to ensure the labeling system for the geomembrane rolls is clear and logical, allowing easy tracking of the placement of the rolls within the unit. It is important to examine the subgrade surface with both the subgrade contractor and the liner installer to ensure it conforms to specifications.

Once liner installation is underway, CQA staff might be responsible for observations of destructive testing conducted on scrap test welds prior to seaming. Geomembrane CQA staff might also be responsible for sending destructive seam sampling to an independent testing laboratory and reviewing the results for conformance to specifications. Other observations for which the CQA staff are typically responsible include observations of all seams and panels for defects due to manufacturing and handling, and placement and observations of all pipe penetrations through a liner.

Test methods, test parameters, and testing frequencies should be specified in the CQA plan to provide context for any data collected. It is prudent to allow for testing frequency to change, based on the performance of the geomembrane installer. If test results indicate poor workmanship, you should increase testing. If test results indicate high quality installation work, you can consider reducing testing frequencies. When varying testing frequency, you should establish well-defined procedures for modifying testing frequency. It is also important to evaluate testing methods, understand the differences among testing methods, and request those methods appropriate for the material and seaming method be used. Nondestructive testing methods are preferrable when possible to help reduce the number of holes cut into the geomembrane.

Geomembrane CQA staff also should document the results of their observations and prepare reports indicating the types of sampling conducted and sampling results, locations of destructive samples, locations of patches, locations of seams constructed, and any problems encountered. In some cases, they might need to prepare drawings of the liner installation. Record drawing preparation is frequently assigned to the contractor, to a representative of the facility manager, or to the engineer. You should request complete reports from any CQA staff and the installers. To ensure complete CQA documentation, it is important to maintain daily CQA reports and prepare weekly summaries.

C. Geosynthetic Clay Liner Quality Assurance and Quality Control

Construction quality assurance for geosynthetic clay liners is still a developing area; the GCL industry is continuing to establish standardized quality assurance and quality control procedures. The CQA recommendation for GCLs can serve as a starting point. You should check with the GCL manufacturer and installer for more specific information.

How can implementation of QA and QC be ensured for a geosynthetic clay liner?

It is recommended that you develop a detailed CQA plan, including product specifications; shipping, handling, and storage procedures; seaming methods; and placement of overlying material. It is important to work with the manufacturer to verify that the product meets specifications. Upon receipt of the GCL product, you should also verify that it has arrived in good condition.

During construction, CQA staff should ensure that seams are overlapped properly and conform to specifications. CQA staff should also check that panels, not deployed within a short period of time, are stored properly. In addition, as overlying material is placed on the GCL, it is important to restrict vehicle traffic directly on the GCL. You should prohibit direct vehicle traffic, with the exception of small, 4-wheel, all terrain vehicles. Even with the small all-terrain vehicles, drivers should take extreme care to avoid movements, such as sudden starts, stops, and turns, which can damage the GCL.

As part of the CQA documentation, it is important to maintain records of weather conditions, subgrade conditions, and GCL panel locations. Also, you should document any repairs that were necessary or other problems identified and addressed.

D. Leachate Collection System Quality Assurance and Quality Control

Leachate collection system CQC should be performed by the contractor. Similar activities should be performed for CQA by an independent party acting on behalf of the facility manager. The purpose of leachate collection system CQA is to document that the system is constructed in accordance with design specifications.

How can implementation of QA and QC be ensured for a leachate collection system?

Prior to construction, CQA staff should inspect all materials to confirm that they meet the construction plans and specifications. These materials include: geonets; geotextiles; pipes; granular material; mechanical, electrical, and monitoring equipment; concrete forms and reinforcements; and prefabricated structures such as sumps and manholes. The leachate collection system foundation, either a geomembrane or compacted clay liner, should also be inspected, upon its completion, to ensure that it has proper grading and is free of debris and liquids.

During construction, CQA staff should observe and document, as appropriate, the placement and installation of pipes, filter layers, drainage layers, geonets and geotextiles, sumps, and mechanical and electrical equipment. For pipes, observations might include descriptions of pipe bedding material, quality and thickness, as well as the total area covered by the bedding material. Observations of pipe installations should focus on the location, configuration, and grading of the pipes, as well as the quality of connections at joints.

For granular filter layers, CQA activities might include observing and documenting material thickness and quality during placement. For granular drainage layers, CQA might focus on the protection of underlying liners, material thickness, proper overlap with filter fabrics and geonets (if applicable), and documentation of any weather conditions that might affect the overall performance of the drainage layer. For geonets and

other geosynthetics, CQA observations should focus on the area of coverage and layout pattern, as well as the overlap between panels. For geonets, CQA staff might want to make sure that the materials do not become clogged by granular material that can be carried over, as a result of either wind or runoff during construction.

Upon completion of construction, each component should be inspected to identify any damage that might have occurred during its installation or during construction of another component. For example, a leachate collection pipe can be crushed during placement of a granular drainage layer. Any damage that does occur should be repaired, and the repairs should be documented in the CQA records.

Designing and Installing Liners Activity List

- ❑ Review the recommended location considerations and operating practices for the unit.
- ❑ Select appropriate liner type—single, composite, or double liner—or in-situ soils, based on risk characterization.
- ❑ Evaluate liner material properties and select appropriate clay, geosynthetic, or combination of materials; consider interactions of liner and soil material with waste.
- ❑ Develop a construction quality assurance (CQA) plan defining staff roles and responsibilities and specifying test methods, storage procedures, and construction protocols.
- ❑ Ensure a stable in-situ soil foundation, for nonengineered liners.
- ❑ Prepare and inspect subgrade for engineered liners.
- ❑ Work with manufacturer to ensure protective shipping, handling, and storage of all materials.
- ❑ Construct a test pad for compacted clay liners.
- ❑ Test compacted clay liner material before and during construction.
- ❑ Preprocess clay material to ensure proper water content, remove oversized particles, and add soil amendments, as applicable.
- ❑ Use proper lift thickness and number of equipment passes to achieve adequate compaction.
- ❑ Protect clay material from drying and cracking.
- ❑ Develop test strips and trial seams to evaluate geomembrane seaming method.
- ❑ Verify integrity of factory and field seams for geomembrane materials before and during construction.
- ❑ Backfill with soil or geosynthetics to protect geomembranes and geosynthetic clay liners during construction.
- ❑ Place backfill materials carefully to avoid damaging the underlying materials.
- ❑ Install geosynthetic clay liner with proper overlap.
- ❑ Patch any damage that occurs during geomembrane or geosynthetic clay liner installation.
- ❑ Design leachate collection and removal system to allow adequate flow and to minimize clogging; include leachate treatment and leak detection systems, as appropriate.
- ❑ Document all CQA activities, including meetings, inspections, and repairs.

Resources

ASTM D-413. 1993. Standard Test Methods for Rubber Property-Adhesion to Flexible Substrate.

ASTM D-422. 1990. Standard Test Method for Particle-Size Analysis of Soils.

ASTM D-638. 1991. Standard Test Method for Tensile Properties of Plastics.

ASTM D-698. 1991. Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3)).

ASTM D-751. 1989. Standard Test Methods for Coated Fabrics.

ASTM D-882. 1991. Standard Test Methods for Tensile Properties of Thin Plastic Sheeting.

ASTM D-1004. 1990. Standard Test Method for Initial Tear Resistance of Plastic Film and Sheeting.

ASTM D-1557. 1991. Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3)).

ASTM D-4318. 1993. Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

ASTM D-4354. 1989. Standard Practice for Sampling of Geosynthetics for Testing.

ASTM D-4716. 1987. Standard Test Method for Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products.

ASTM D-5084. 1990. Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.

ASTM D-5199. 1991. Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.

ASTM D-5261. 1992. Standard Test Method for Measuring Mass per Unit Area of Geotextiles.

ASTM D-5321. 1992. Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.

Resources (cont.)

Bagchi, A. 1994. Design, Construction, and Monitoring of Landfills.

Berg, R., and L. Well. 1996. A Position Paper on: The Use of Geosynthetic Barriers in Nonhazardous Industrial Waste Containment.

Berger, E. K. and R. Berger. 1997. The Global Water Cycle.

Borrelli, J. and D. Brosz. 1986. Effects of Soil Salinity on Crop Yields. **<hermes.ecn.purdue.edu/cgi/convwqtest?/b-803.wy.ascii>**

Boulding, J.R. 1995. Practical Handbook of Soil, Vadose Zone, and Ground Water Contamination: Assessment, Prevention and Remediation. Lewis Publishers.

Brandt, R.C. and K.S. Martin. 1996. The Food Processing Residual Management Manual. September.

Daniel, D.E., and R.M. Koerner. 1991. Landfill Liners from Top to Bottom. Civil Engineering. December.

Daniel, D.E., and R.M. Koerner. 1993. Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities. Prepared for U.S. EPA. EPA600-R-93-182.

Daniel, D.E., and R.M. Koerner. 1995. Waste Containment Facilities: Guidance for Construction, Quality Assurance and Quality Control of Liner and Cover Systems.

Evanylo, G.K. and W. L. Daniels. 1996. The Value and Suitability of Papermill Sludge and Sludge Compost as a Soil Amendment and Soilless Media Substitute. Final Report. The Virginia Department of Agriculture and Consumer Services, P.O. Box 1163, Room 402, Richmond, VA. April.

Federal Test Method Standard 101C. 1980. Puncture Resistance and Elongation Test (1/8 Inch Radius Probe Method).

Fipps, G. 1995. Managing Irrigation Water Salinity in the Lower Rio Grande Valley. **<hermes.ecn.purdue.edu/sgml/water_quality/texas/b1667.ascii>**

Geosynthetic Research Institute. 1993. GRI-GCL1, Swell Measurement of the Clay Component of GCLs.

Geosynthetic Research Institute. 1993. GRI-GCL2, Permeability of Geosynthetic Clay Liners (GCLs).

Resources (cont.)

Idaho Department of Health and Welfare. 1988. Guidelines for Land Application of Municipal and Industrial Wastewater. March.

Koerner, R.M. 1994. Designing with Geosynthetics, Third Edition.

McGrath, L., and P. Creamer. 1995. Geosynthetic Clay Liner Applications in Waste Disposal Facilities.

McGrath, L., and P. Creamer. 1995. Geosynthetic Clay Liner Applications. Waste Age. May.

Michigan Department of Natural Resources, Waste Characterization Unit. 1991. Guidance for Land Application of Wastewater Sludge in Michigan. March.

Michigan Department of Natural Resources, Waste Characterization Unit. 1991. Guide to Preparing a Residuals Management Plan. March.

Minnesota Pollution Control Agency. 1993. Land Treatment of Landfill Leachate. February.

Northeast Regional Agricultural Engineering Cooperative Extension. 1996. Nutrient Management Software: Proceedings from the Nutrient Management Software Workshop. NRAES-100. December.

Northeast Regional Agricultural Engineering Cooperative Extension. 1996. Animal Agriculture and the Environment: Nutrients, Pathogens, and Community Relations. NRAES-96. December.

Northeast Regional Agricultural Engineering Cooperative Extension. 1993. Utilization of Food Processing Residuals. Selected Papers Representing University, Industry, and Regulatory Applications. NRAES-69. March.

North Carolina Cooperative Extension Service. 1994. Soil facts: Careful Soil Sampling - The Key to Reliable Soil Test Information. AG-439-30.

Oklahoma Department of Environmental Quality. Title 252. Oklahoma Administrative Code, Chapter 647. Sludge and Land Application of Wastewater.

Sharma, H., and S. Lewis. 1994. Waste Containment Systems, Waste Stabilization, and Landfills: Design and Evaluation.

Smith, M.E., S. Purdy, and M. Hlinko. 1996. Some Do's and Don'ts of Construction Quality Assurance. Geotechnical Fabrics Report. January/February.

Resources (cont.)

Spellman, F. R. 1997. Wastewater Biosolids to Compost.

Texas Water Commission. 1983. Industrial Solid Waste Management Technical Guideline No. 5: Land Application. December.

Tsinger, L. 1996. Chemical Compatibility Testing: The State of Practice. Geotechnical Fabrics Report. October/November.

University of Nebraska Cooperative Extension Institute of Agriculture and Natural Resources. 1991. Guidelines for Soil Sampling. G91-1000-A. February.

U.S. EPA. 2001. Technical Resource Document: Assessment and recommendations for Improving the Performance of Waste Containment Systems. Draft.

U.S. EPA. 1996a. Issue Paper on Geosynthetic Clay Liners (GCLs).

U.S. EPA. 1996b. Report of 1995 Workshop on Geosynthetic Clay Liners. EPA600-R-96-149. June.

U.S. EPA. 1995a. A Guide to the Biosolids Risk Assessments for the EPA Part 503 Rule. EPA832-B-93-005. September.

U.S. EPA. 1995b. Decision Maker's Guide to Solid Waste Management. Volume II. EPA530-R-95-023.

U.S. EPA. 1995c. Laboratory Methods for Soil and Foliar Analysis in Long-Term Environmental Monitoring Programs. EPA600-R-95-077.

U.S. EPA. 1995d. Process Design Manual: Land Application of Sewage Sludge and Domestic Septage. EPA625-R-95-001. September.

U.S. EPA. 1995e. Process Design Manual: Surface Disposal of Sewage Sludge and Domestic Septage. EPA625-R-95-002. September.

U.S. EPA. 1994a. A Plain English Guide to the EPA Part 503 Biosolids Rule. EPA832-R-93-003. September.

U.S. EPA. 1994b. Biosolids Recycling: Beneficial Technology for a Better Environment. EPA832-R-94-009. June.

U.S. EPA. 1994c. Guide to Septage Treatment and Disposal. EPA625-R-94-002. September.

Resources (cont.)

U.S. EPA. 1994d. Land Application of Sewage Sludge: A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503. EPA831-B-93-002b. December.

U.S. EPA. 1994e. Seminar Publication: Design, Operation, and Closure of Municipal Solid Waste Landfills. EPA625-R-94-008.

U.S. EPA. 1993a. Domestic Septage Regulatory Guidance: A Guide to the EPA 503 Rule. EPA832-B-92-005. September.

U.S. EPA. 1993b. Solid Waste Disposal Facility Criteria: Technical Manual. EPA530-R-93-017.

U.S. EPA. 1993c. Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities. EPA600-R-93-182.

U.S. EPA. 1992. Control of Pathogens and Vector Attraction in Sewage Sludge. EPA625-R-92-013. December.

U.S. EPA. 1991a. Seminar Publication: Design and Construction of RCRA/CERCLA Final Covers. EPA625-4-91-025.

U.S. EPA. 1991b. Seminar Publication: Site Characterization for Subsurface Remediation. EPA625-4-91-026.

U.S. EPA. 1991c. Technical Guidance Document: Inspection Techniques for the Fabrication of Geomembrane Field Seams. EPA530-SW-91-051.

U.S. EPA. 1990. State Sludge Management Program Guidance Manual. October.

U.S. EPA. 1989a. Seminar Publication: Requirements for Hazardous Waste Landfill Design, Construction, and Closure. EPA625-4-89-022.

U.S. EPA. 1989b. Seminar Publication: Corrective Action: Technologies and Applications. EPA625-4-89-020.

U.S. EPA. 1988. Lining of Waste Containment and Other Impoundment Facilities. EPA600-2-88-052.

U.S. EPA. 1987. Geosynthetic Guidance for Hazardous Waste Landfill Cells and Surface Impoundments. EPA600-2-87-097.

Resources (cont.)

U.S. EPA. 1986a. Project Summary: Avoiding Failure of Leachate Collection and Cap Drainage Systems. EPA600-S2-86-058.

U.S. EPA. 1986b. Test Methods for Evaluating Solid Waste: Physical/Chemical Methods. EPASW-846.

U.S. EPA. 1983. Process Design Manual for Land Application of Municipal Sludge. EPA625-1-83-016. October.

U.S. EPA, U.S. Army Corps of Engineers, U.S. Department of Interior, and U.S. Department of Agriculture. 1981. Process Design Manual for Land Treatment of Municipal Wastewater. EPA625-1-81-013. October.

U.S. EPA. 1979. Methods for Chemical Analysis of Water and Wastes. EPA600-4-79-020.

Viessman Jr., W. and M.J. Hammer. 1985. Water Supply and Pollution Control. 4th ed.

Washington State Department of Ecology. 1993. Guidelines for Preparation of Engineering Reports for Industrial Wastewater Land Application Systems. Publication #93-36. May.

Webber, M.D. and S.S. Sing. 1995. Contamination of Agricultural Soils. In Action, D.F. and L.J. Gregorich, eds. The Health of Our Soils.

Wisconsin Department of Natural Resources. 1996. Chapter NR 518: Landspreading of Solid Waste. April.

Appendix

Geosynthetic Materials[25]

Geotextiles

Geotextiles form one of the two largest group of geosynthetics. Their rise in growth during the past fifteen years has been nothing short of awesome. They are indeed textiles in the traditional sense, but consist of synthetic fibers rather than natural ones such as cotton, wool, or silk. Thus biodegradation is not a problem. These synthetic fibers are made into a flexible, porous fabric by standard weaving machinery or are matted together in a random, or nonwoven, manner. Some are also knit. The major point is that they are porous to water flow across their manufactured plane and also within their plane, but to a widely varying degree. There are at least 80 specific application areas for geotextiles that have been developed; however, the fabric always performs at least one of five discrete functions:

1. Separation
2. Reinforcement
3. Filtration
4. Drainage
5. Moisture barrier (when impregnated)

Geogrids

Geogrids represent a rapidly growing segment within the geosynthetics area. Rather than being a woven, nonwoven or knit textile (or even a textile-like) fabric, geogrids are plastics formed into a very open, gridlike configuration (i.e., they have large apertures). Geogrids are either stretched in one or two directions for improved physical properties or made on weaving machinery by unique methods. By themselves, there are at least 25 application areas, however, they function almost exclusively as reinforcement materials.

Geonets

Geonets, called geospacers by some, constitute another specialized segment within the geosynthetic area. They are usually formed by a continuous extrusion of parallel sets of polymeric ribs at acute angles to one another. When the ribs are opened, relatively large apertures are formed into a netlike configuration. Their design function is completely within the drainage area where they have been used to convey fluids of all types.

Geomembranes

Geomembranes represent the other largest group of geosynthetics and in dollar volume their sales are probably larger than that of geotextiles. Their growth has been stimulated by governmental regulations originally enacted in 1982. The materials themselves are "impervious" thin sheets of rubber or plastic material used primarily for linings and covers of liquid- or solid-storage facilities. Thus the primary function is always as a liquid or vapor barrier. The range of applications, however, is very great, and at least 30 individual applications in civil engineering have been developed.

Geosynthetic Clay Liners

Geosynthetic clay liners (or GCLs) are the newest subset within geosynthetic materials. They are rolls of factory fabricated thin layers of bentonite clay sandwiched between two geotextiles or bonded to a geomembrane. Structural integrity is maintained by needle punching, stitching or physical bonding. They are seeing use as a composite compo-

[25] Created by Geosynthetic Research Institute. Accessed from the Internet on October 16, 2001 at **<www.drexel.edu/gri/gmat.html>**.

nent beneath a geomembrane or by themselves as primary or secondary liners.

Geopipe (aka Buried Plastic Pipe)

Perhaps the original geosynthetic material still available today is buried plastic pipe. This "orphan" of the Civil Engineering curriculum was included due to an awareness that plastic pipe is being used in all aspects of geotechnical, transportation, and environmental engineering with little design and testing awareness. This is felt to be due to a general lack of formalized training. The critical nature of leachate collection pipes coupled with high compressive loads makes geopipe a bona-fide member of the geosynthetics family. The function is clearly drainage.

Geocomposites

A geocomposite consists of a combination of geotextile and geogrid; or geogrid and geomembrane; or geotextile, geogrid, and geomembrane; or any one of these three materials with another material (e.g., deformed plastic sheets, steel cables, or steel anchors). This exciting area brings out the best creative efforts of the engineer, manufacturer, and contractor. The application areas are numerous and growing steadily. The major functions encompass the entire range of functions listed for geosynthetics discussed previously: separation, reinforcement, filtration, drainage, and liquid barrier.

"Geo-Others"

The general area of geosynthetics has exhibited such innovation that many systems defy categorization. For want of a better phrase, geo-others, describes items such as threaded soil masses, polymeric anchors, and encapsulated soil cells. As with geocomposites their primary function is product-dependent and can be any of the five major functions of geosynthetics.