pt 40

results for reinforced GCLs at high normal stress) and the other factors discussed above, the authors believe the assumption was prudent.

SHEAR STRENGTH OF GCL-GEOMEMBRANE INTERFACES

Direct Shear Testing Program

For a project located in the desert of southeastern California, the authors performed 14 interface direct shear tests on unhydrated GCL-textured HDPE geomembrane interfaces. The tests were performed in a 300 mm x 300 mm shear box following procedures in general accordance with ASTM D 5321. Three different GCLs were tested. The geomembrane used in the tests was from a single roll of material and samples were selected based on visual observation of a consistent degree of texturing. The tests were carried out in a manner that allowed shearing either at the GCL interface or internally within the GCL bentonite layer. Tests were carried out at normal stresses ranging between approximately 350 and 1,920 kPa. Sliding in the tests consistently occurred at the interface and not within the GCL. Thus, the test results correlate to interface failures and at the same time provide conservative lower bound unhydrated shear strengths for the tested GCLs under the project testing conditions.

Typical test results are presented in Figure 10 and summarized in Table 5. The tests correspond to two shearing rates, namely 0.016 mm/s and 0.0007 mm/s. Interface friction angles obtained from the tests at the slower shearing rate are 1° to 2° lower than interface friction angles obtained from tests at the higher shearing rate. The test results also reveal an interface shear strength stress-dependency with secant interface friction angles 5° to 10° lower at 1,920 kPa than at 350 kPa. The interfaces exhibited only minor amounts of shear softening (typically less than 1 to 2°) at test displacements of up to about 50 mm.

Comment on Results

The foregoing interface direct shear test results illustrate the ranges of shear strengths obtained and several of the factors that affect this strength including normal stress, displacement rate, and magnitude of displacement.

The authors note that they have observed relatively wide variances in the degree of texturing of geomembranes, even from a given manufacturer. The degree of texturing significantly influences the interface shear strength. Thus, the strength values reported above should not be considered appropriate for design. Interface shear strengths for design should be established on a project-specific basis and construction-phase quality control testing should be used to establish that materials delivered to the construction site can achieve the interface strengths established during design.

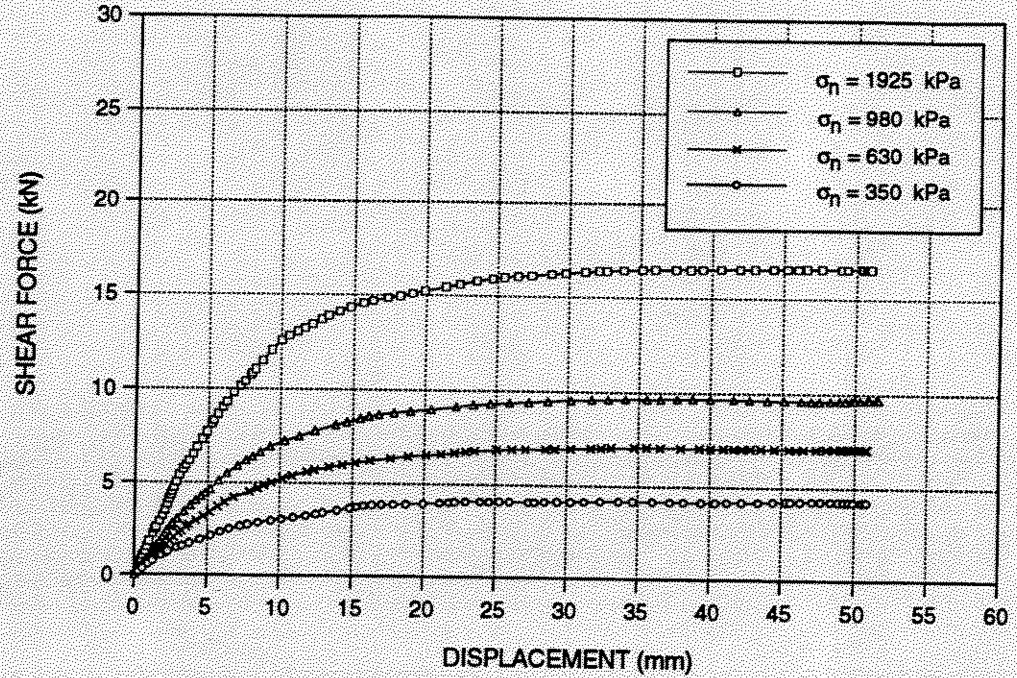

Figure 10. Results of direct shear tests on unhydrated Bentofix GCL-textured HDPE geomembrane interface.

HYDRATION OF GCLs ADJACENT TO SOIL LAYERS

Overview of Testing Program

The authors conducted an extensive laboratory testing program to evaluate the potential for hydration of GCLs placed against a compacted subgrade soil layer. Hydration tests were performed on three different GCL products to evaluate the effects of: (i) test duration (i.e., hydration time); (ii) soil initial water content; (iii) thickness of soil layer; and (iv) overburden pressure. Three commercially-available GCL products, namely, Claymax®, Bentomat®, and Bentofix® were used in the testing program. The soil used in the testing program was obtained from the USEPA GCL Field Test Site at the ELDA-RDF facility in Cincinnati, Ohio. This material is classified as low plasticity clay (CL) based on the Unified Soil Classification System (USCS). Tests were performed on two different soil samples and consistent results were obtained between samples. The results reported herein were obtained from tests on a sample with 99 percent of the soil passing the U.S. No. 200 standard sieve and 33 percent smaller than 2 μm (clay fraction). The liquid limit of the soil is 41 and the plasticity index is 19. The soil has an optimum moisture content (OMC) of 20 percent and a maximum dry unit weight of 16.7 kN/m^3 based on the standard Proctor compaction method (ASTM D 698).

Table 5. Direct shear test results of textured 80-mil HDPE geomembrane/unhydrated GCL interfaces[(1)].

Test Number	Type of GCL	Normal Stress (kPa)	Displacement Rate (mm/s)	Large Displacement Secant Friction Angle[(2)] (ϕ_{ld}°)
1	Bentomat GCL (nonwoven side)	350	0.016	24°
2	Bentomat GCL (nonwoven side)	620	0.016	24°
3	Bentomat GCL (nonwoven side)	960	0.016	23°
4	Bentomat GCL (nonwoven side)	960	0.0007	22°
5	Bentomat GCL (nonwoven side)	1,920	0.016	19°
6	Bentomat GCL (nonwoven side)	1,920	0.0007	17°
7	Bentofix GCL (nonwoven side)	350	0.016	28°
8	Bentofix GCL (nonwoven side)	620	0.016	26°
9	Bentofix GCL (nonwoven side)	960	0.016	23°
10	Bentofix GCL (nonwoven side)	1,920	0.016	21°
11	Gundseal GCL (bentonite granules side)	350	0.016	34°
12	Gundseal GCL (bentonite granules side)	620	0.016	29°
13	Gundseal GCL (bentonite granules side)	960	0.016	27°
14	Gundseal GCL (bentonite granules side)	1,920	0.016	24°

Notes:
(1) The tests were performed using unhydrated GCLs and in a manner that allowed shearing at the geomembrane/GCL interface, as well as within the GCL bentonite layer.
(2) Final displacements in the tests were in the range of 25 to 50 mm.

Testing Apparatus and Procedure

Figure 11 shows the apparatus specially designed to conduct the GCL hydration tests. The apparatus consists of a polypropylene mold 75 mm in diameter and 150 mm in height. A geomembrane/GCL/soil composite specimen is placed in the mold and covered with two layers of a thin vapor barrier. A loading platen is placed on the specimen for application of overburden pressure.

To process the soil, it was first passed through a U.S. No. 4 standard sieve. The soil was then moisture conditioned to achieve the desired moisture content. The moist soil was placed in the mold in a loose condition and statically compressed to 50-mm thick lifts. The soil was compacted to a dry unit weight equal to approximately 90 percent of the maximum dry unit weight based on the standard Proctor method (ASTM D 698). Two soil lifts were used giving a total thickness of 100 mm. The GCL and geomembrane specimens were carefully trimmed from the same sheets. The initial moisture content of the GCL was measured by taking a small sample from the same GCL sheet and measuring its weight before and after oven drying. The initial moisture content of the GCLs varied between 15 and 20 percent.

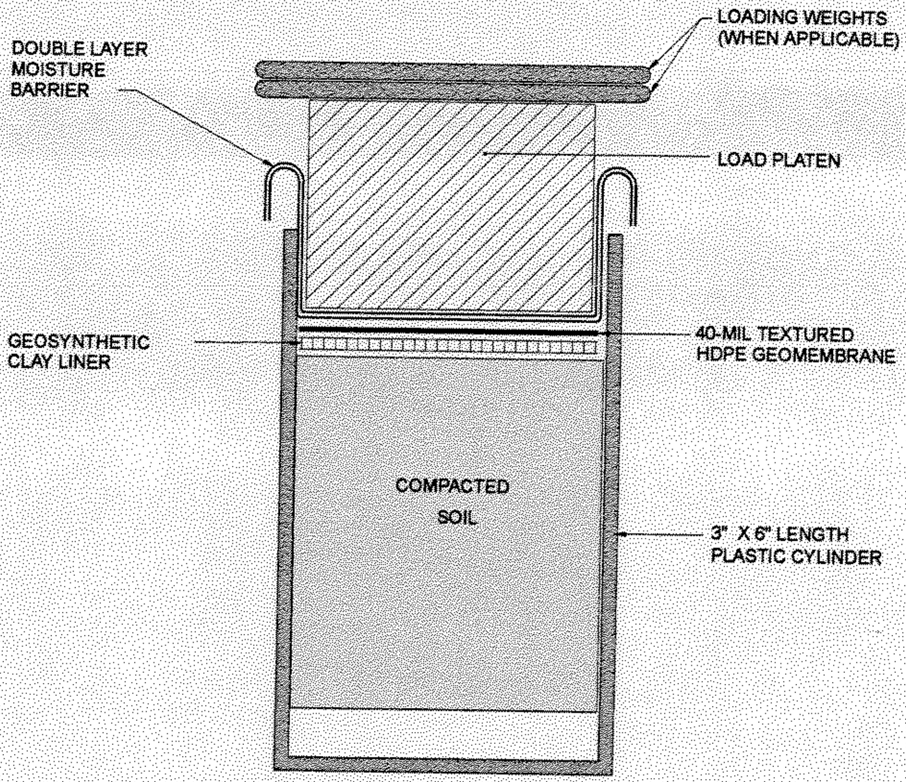

Figure 11. Simplified diagram of GCL hydration test set-up.

The GCL and geomembrane were placed on the soil and covered with the vapor barrier. The side of the GCL placed against the soil was woven in the case of Claymax® and nonwoven for Bentomat® and Bentofix®. Overburden pressure of 10 kPa was applied on the composite specimen utilizing standard weights which were placed on the loading platen. The entire apparatus was then placed in a temperature and humidity controlled room for the desired hydration time period. At the end of the hydration period, the test specimen was removed and the water content of the GCL and soil were measured. The final moisture content of the GCL was measured by weighing the entire GCL specimen before and after oven drying. The final moisture content of the soil was measured as the average water content of three samples obtained from the top, middle, and bottom of the soil specimen.

Testing Conditions and Results

As previously described, test conditions were varied to evaluate the effects of several factors on the hydration of GCLs. To evaluate the effect of test duration, tests were performed where the GCL was in contact with the soil for 5, 25, and 75 days. Soil specimens were compacted to initial moisture contents equal to OMC, 4 percentage points dry of OMC, and 4 percentage points wet of OMC to evaluate the effect of soil initial moisture content on GCL hydration.

Figures 12, 13, and 14 present the results of the hydration tests for the GCL products Claymax®, Bentomat®, and Bentofix®, respectively. These figures show that the moisture content of all three GCLs increased significantly as a result of contact with compacted subgrade soil. The increase in GCL water content was significant after only five days of hydration. With increasing time, GCL water content continued to increase at a decreasing rate. For most tests, GCL water content reached a maximum value after about 25 days of soil contact and for some of the tests water content continued to increase even after 75 days of hydration. It is interesting to note that all three GCL products showed relatively similar behavior. Increases in water content were comparable for the three GCL products despite differences in GCL fabric (i.e., woven vs. nonwoven) and types of bentonite clay used to manufacture the GCLs.

Figures 12, 13, and 14 illustrate the influence of soil subgrade initial moisture content on the hydration of GCLs. From these figures, it is evident that the moisture content of the GCL for any particular hydration time increases as the initial moisture content of the soil increases. These figures also show that a small increase in soil initial moisture content can have a significant impact on GCL moisture content. For example, after 75 days of hydration, the moisture content of Claymax® was approximately 16 percent higher when the initial moisture content of the soil was equal to OMC than when it was 4 percentage points drier than OMC. This behavior is expected because more water is available in the soil for the GCL to hydrate.

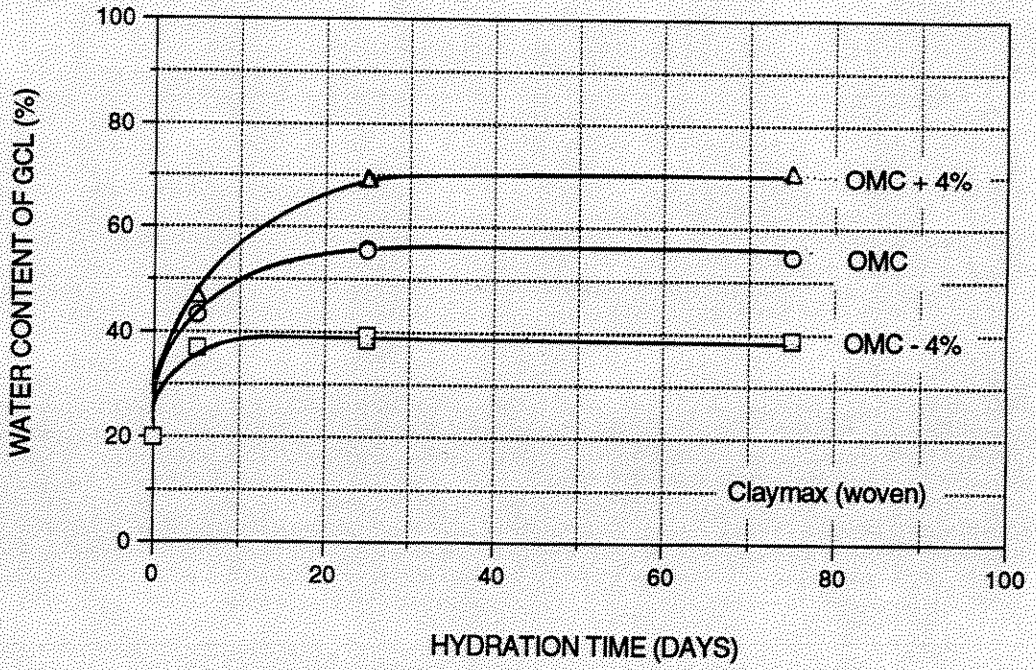

Figure 12. Increase in GCL moisture content due to contact with compacted subgrade soil: Claymax® with woven geotextile against soil.

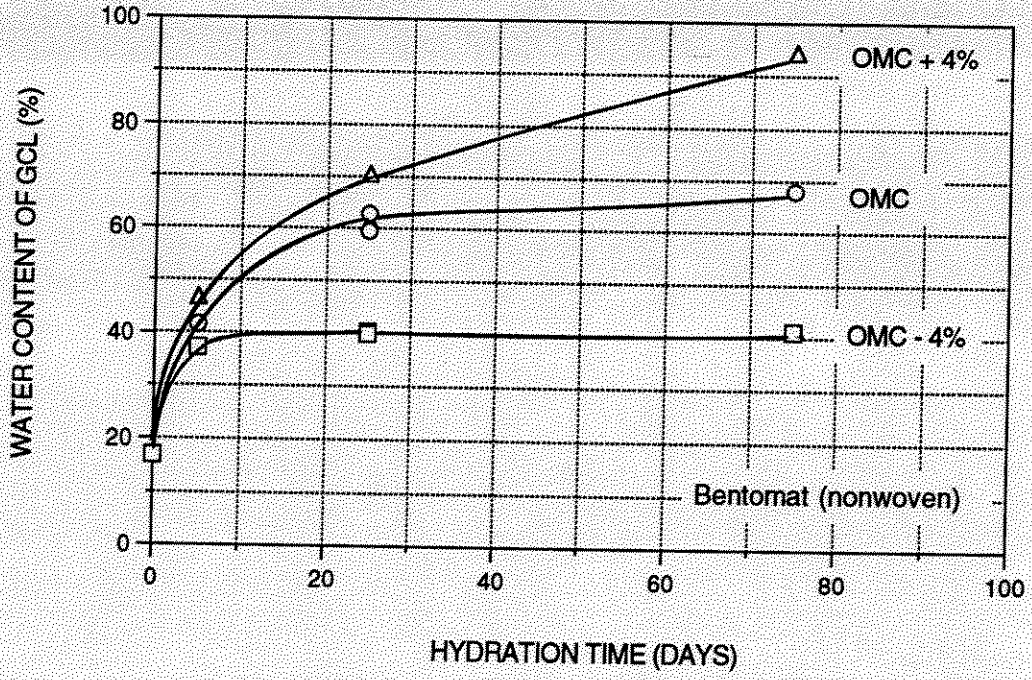

Figure 13. Increase in GCL moisture content due to contact with compacted subgrade soil: Bentomat® with nonwoven geotextile against soil.

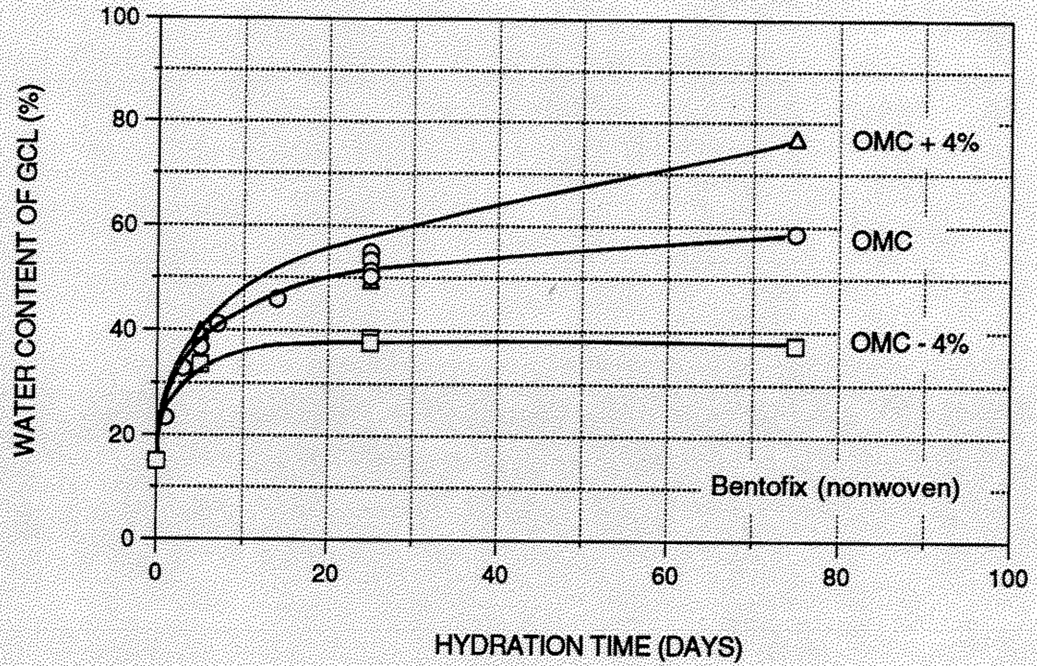

Figure 14. Increase in GCL moisture content due to contact with compacted subgrade soil: Bentofix® with nonwoven geotextile against soil.

The examination of the curves shown in Figures 12, 13, and 14 shows that the time required for the GCL to reach its final moisture content is less in the case of a dry soil than in the case of a wet soil. At the lowest soil initial moisture content tested, GCL moisture content ceased to increase after about 5 to 25 days. At the highest initial moisture content tested, the Bentomat® and Bentofix® GCLs continued to increase in moisture content after 75 days of hydration.

To evaluate the effect of soil layer thickness, specimens were prepared using 50, 100, 150, and 200 mm of soil thickness. Soil initial moisture content was 20 percent and dry unit weight was 14.9 kN/m^3 for all specimens. Figure 15 shows the results of hydration tests for the Bentofix® GCL after 25 days of hydration. The GCL moisture content increased with the increase of the soil layer thickness. However, it appears that only a small change in moisture content increase occurs for thicknesses greater than 100 mm.

The effect of overburden pressure on GCL hydration is illustrated in Figure 16 for the Bentofix® GCL. As shown in this figure, overburden pressure in the range of 5 to 390 kPa did not significantly affect the rate of GCL hydration during the 25-day test duration.

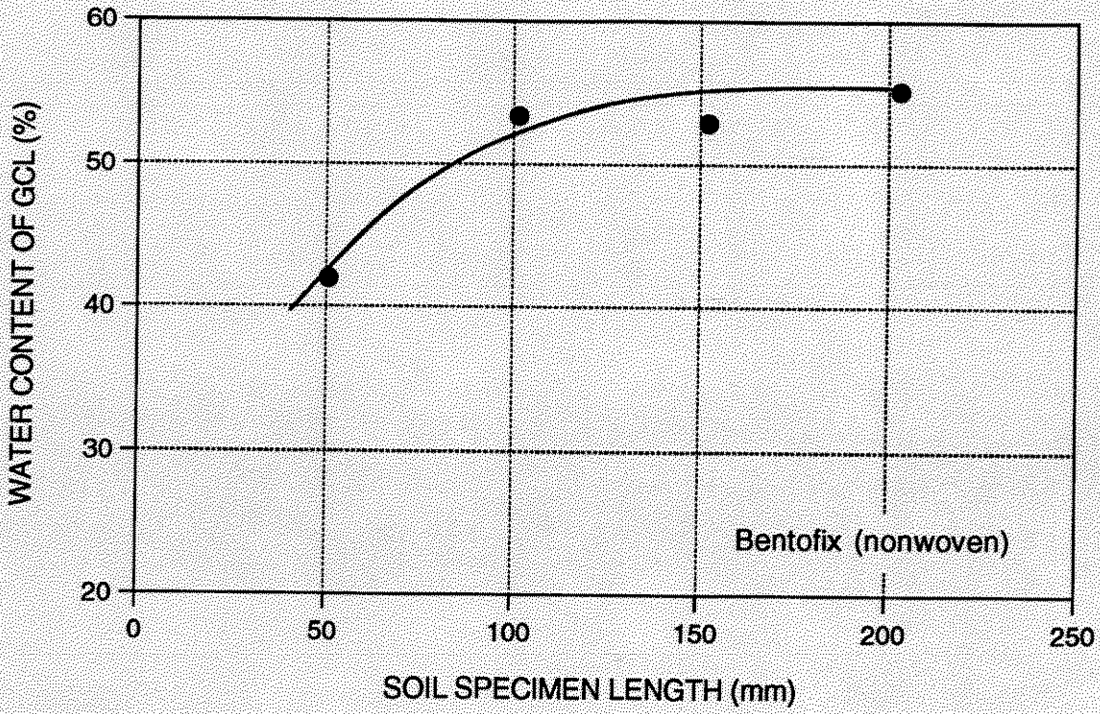

Figure 15. Influence of subgrade soil layer thickness on GCL moisture content.

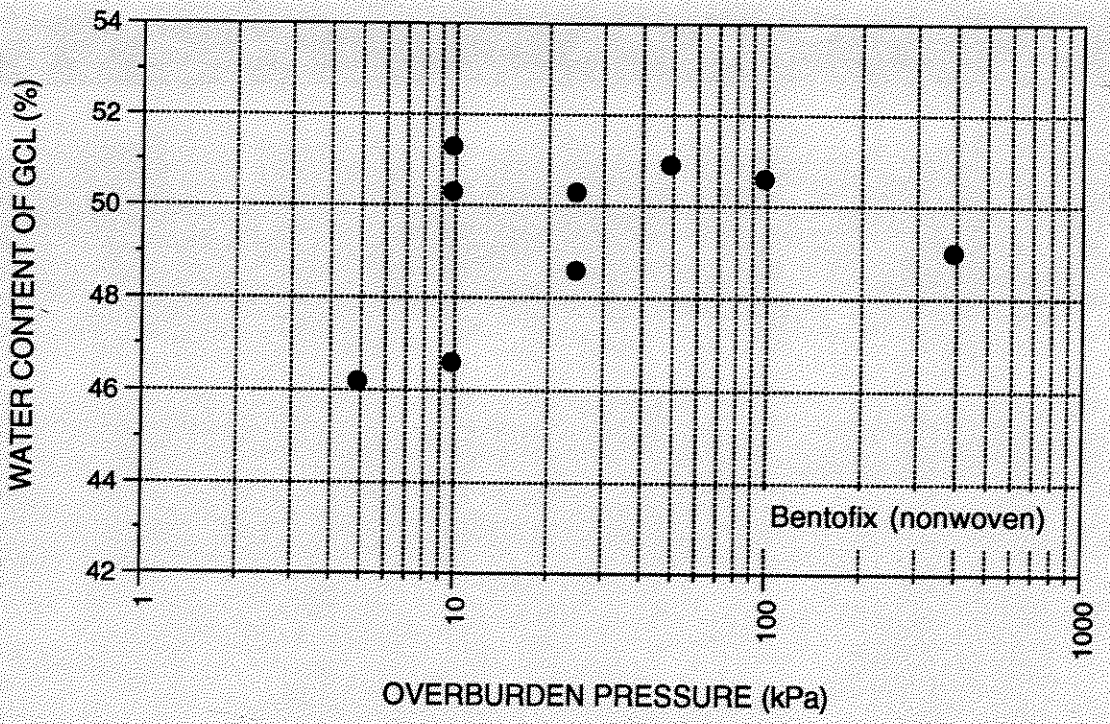

Figure 16. Influence of overburden pressure on the increase in GCL moisture content.

Summary

From the testing program results described above, the following can be concluded:

- GCLs will hydrate when placed in contact with subgrade soils compacted within the range of moisture contents typically found in earthwork construction specifications; this conclusion is consistent with data provided by Daniel et al. [1993]; even for the driest soil (compacted 4 percentage points dry of OMC), GCL moisture contents consistently increased from an initial value in the range of 15 to 20 percent up to about 40 percent within a 100-day period; it should thus be anticipated that GCLs placed even against relatively dry compacted subgrades will undergo substantial hydration;

- given that Daniel et al. [1993] have shown that long-term GCL shear strengths are insensitive to water content for water contents above about 50 percent, stability analyses involving GCLs placed in contact with compacted subgrade soils should be based on hydrated GCL shear strengths;

- significant increases in GCL moisture contents may occur within a few days of GCL contact with a moist soil; the rate of GCL hydration is initially highest and then decreases with increasing time;

- within the range of conditions tested a higher soil moisture content results in a higher GCL moisture content;

- larger soil layer thickness results in a larger increase in GCL moisture content, however, for soil layer thicknesses greater than 100 mm only insignificant increases were observed with increasing soil layer thickness;

- overburden pressure within the range tested (i.e., 5 to 390 kPa) did not influence the hydration process; and

- differences between GCL products tested (i.e., type of bentonite clay and fabric) did not seem to significantly affect the test results.

FAILURE OF LANDFILL COVER SYSTEM CONTAINING A GCL

Description of Cover System

The authors recently investigated the failure of a cover system for a municipal solid waste landfill near Atlanta, Georgia. The failure is described in more detail by Vander Linde et al. [1995]. The cover system was constructed in the fall of 1994 on 3H:1V (horizontal:vertical) side slopes to a maximum height above surrounding ground of approximately 18 m. The cover system consisted of, from top to bottom:

- 300-mm thick layer of final cover soil which is classified as silty sand containing approximately 40 percent fines based on ASTM D 2487, and which has a hydraulic conductivity in the range of 10^{-4} to 10^{-3} cm/s;

- stitch-bonded reinforced GCL; and

- 150- to 300-mm thick layer of intermediate cover soil which served as a foundation for the overlying final cover components.

Failure of System

During the winter of 1995, the cover system experienced several episodes of downslope movement. The first major episode occurred approximately one month after the completion of construction; the movement occurred after a three-day period in which 58 mm of rain fell at the site. The next major episode occurred six weeks later, after two days of inclement weather generated about 41 mm of rainfall at the site. Total downslope movements exceeded 1 m at some locations. The observed failure mechanism was sliding of the final cover soil on top of the GCL.

Analysis of Failure

The episodes of downslope movement both followed periods of extended rainfall at the site. A slope stability back-analysis of the cover system was performed which accounted for the influence of rainfall-induced seepage forces on cover system factor of safety against downslope sliding. The back-analysis involved two steps:

- estimating seepage forces within the cover soil using several different calculation methods and parameter values; and

- calculating the resulting slope stability factors of safety for the range of estimated seepage forces.

The evaluation of seepage forces involved calculating the water build-up (i.e., hydraulic head) within the final cover soil on top of the GCL. Head was calculated using a methodology developed by Giroud and Houlihan [1995] and checked using the United States Environmental Protection Agency (USEPA) Hydrologic Evaluation of Landfill Performance (HELP) computer program Version 3.03 [USEPA, 1994a, 1994b]. The values of head calculated using these approaches ranged from 150 mm to the full thickness of the cover soil layer, 300 mm.

Calculations to obtain slope stability factors of safety were performed using the equations presented by Giroud et al. [1995a, 1995b]. An important input to the equations is the shear strength of the interface between the cover soil and GCL. Tests to evaluate the shear strength of this interface had not been carried out as part of the original design. For the back-analysis of the failure, a range of friction angles (20° to 26°) was considered for the cover soil-GCL interface; this range likely brackets the actual interface strength and includes the value of 24° originally assumed by the design engineer. Calculations were performed and the following results were obtained:

Interface Friction Angle (degrees)	Factor of Safety (FS) vs. Hydraulic Head		
	0 mm	100 mm	200 mm
20°	1.09	0.84	0.60
24°	1.35	1.04	0.73
26°	1.47	1.13	0.80

These calculation results demonstrate the significant impact of seepage forces on the stability of the final cover soil. Even with the largest assumed interface strength, only 140 mm of head buildup is required to decrease the slope stability factor of safety to less than 1.0. Interface shear strength tests performed after the completion of the back analyses resulted in peak and large-displacement secant friction angles for the GCL-cover soil interface, at the applicable normal stress, of 23° and 21°, respectively.

Summary

The primary factor contributing to the observed final cover soil movements was the build-up of seepage forces in the final cover soil during periods of heavy rain. Seepage forces were not accounted for in the design. If seepage forces had been accounted for, the potential for instability likely would have been identified during preparation of the design. The development of seepage forces in cover soils is typically minimized by the inclusion of a drainage layer above the low-permeability barrier component of the cover (in this case, the GCL). A secondary factor contributing to the movements was a final cover soil-GCL interface shear strength lower than assumed in the design. An interface friction angle of 24° was assumed by the design engineer, based on information provided by the GCL manufacturer. The actual project-specific interface shear strength was closer to 21°. This result highlights the fact that actual interface strengths can only be assessed by project-specific testing; such testing was not performed for the project.

ACKNOWLEDGEMENTS

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Waste Containment Systems

Life time Assessment
Geomembranes
Geosynthetic Rese. Inst.
Bob Koerner - (sending abstract)
215-895-2343

Performance of Engineered Containment
GeoSyntec Consultants
Rudy Bonaparte!
404-705-9500
Majdi Othman

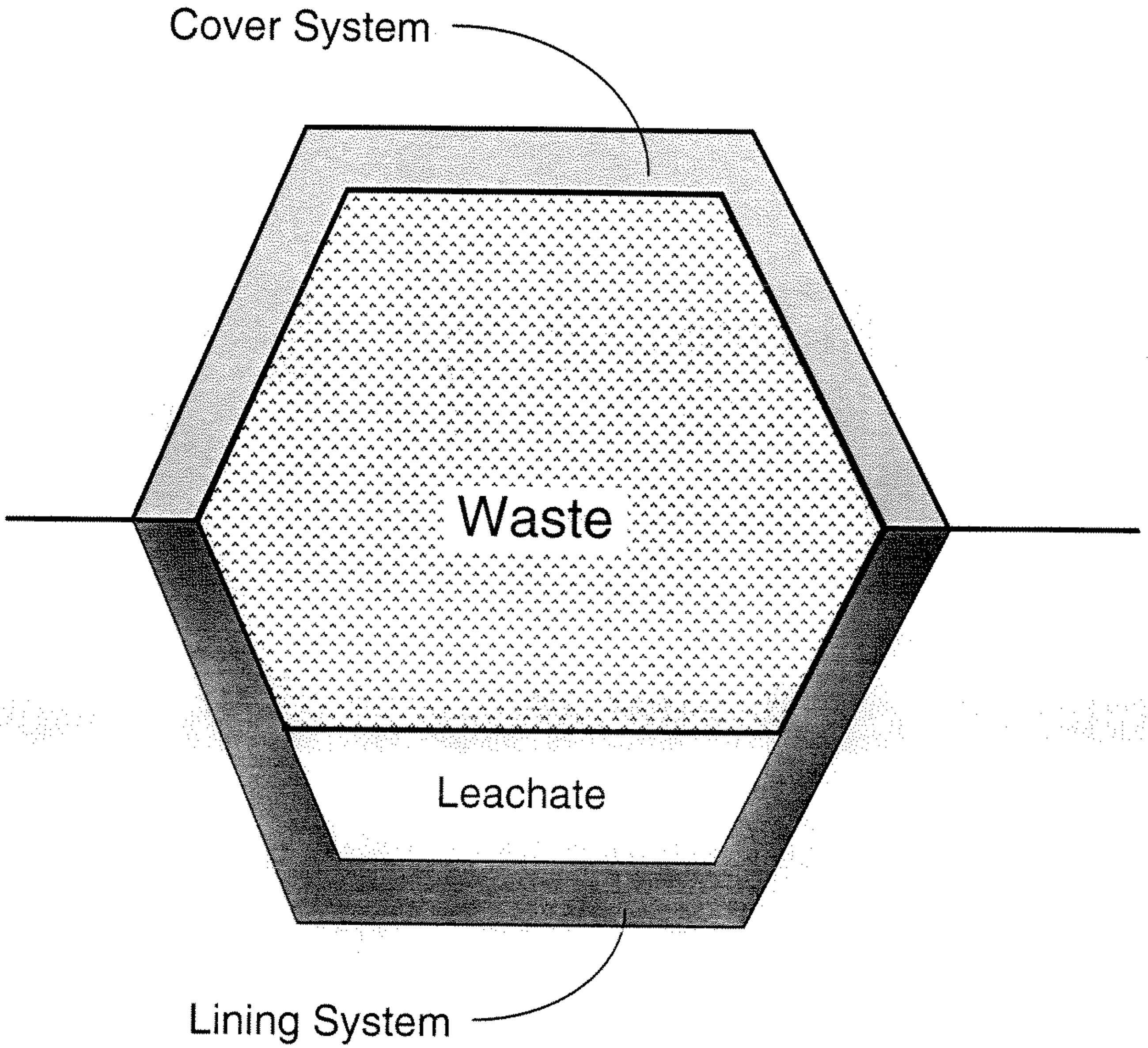
Dr. Craig H. Benson

Prof. of Civil and Environmental Engineering
University of Wisconsin-Madison

April 15, 1997

4 yrs. of study for EPA
draft reports - internal
Some published papers -
on Performance
of Engin. Containment.
Will send 10-28-99

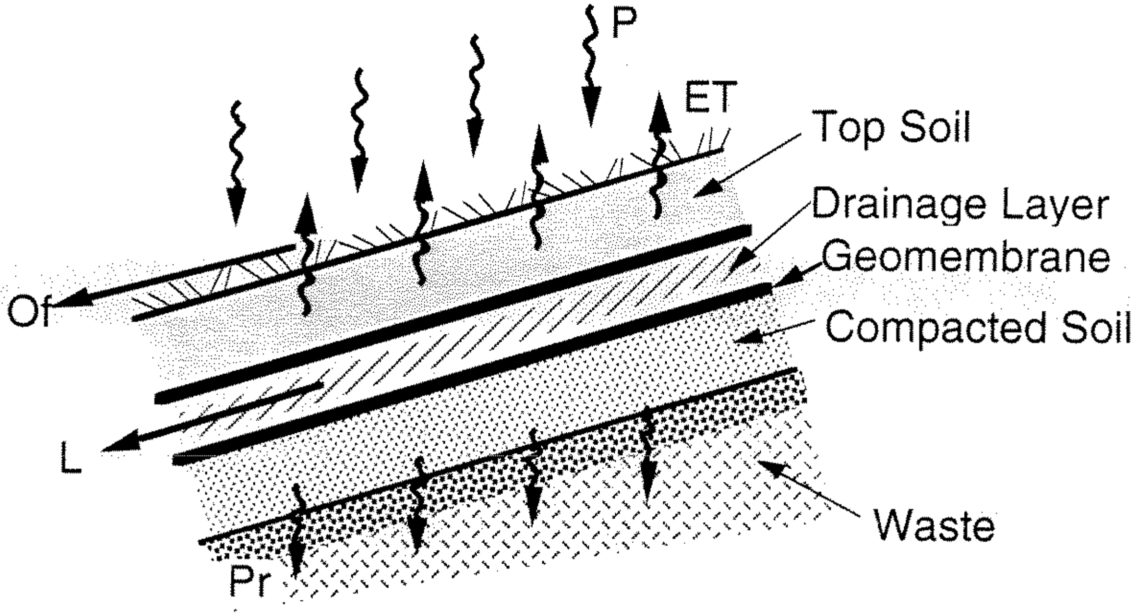
phone
262-7242
UW Madison


Cover System
Waste
Leachate
Lining System

Covers and Caps

Objective: Limit entry of water and oxygen

Layers: Vegetative Layer, Rooting/Protective Layer,
Drainage Layer, Barrier Layer



Importance of Cover/Cap

- Long-term barrier to infiltration

- Long-term barrier to oxygen diffusion

- Repairable without extensive cost

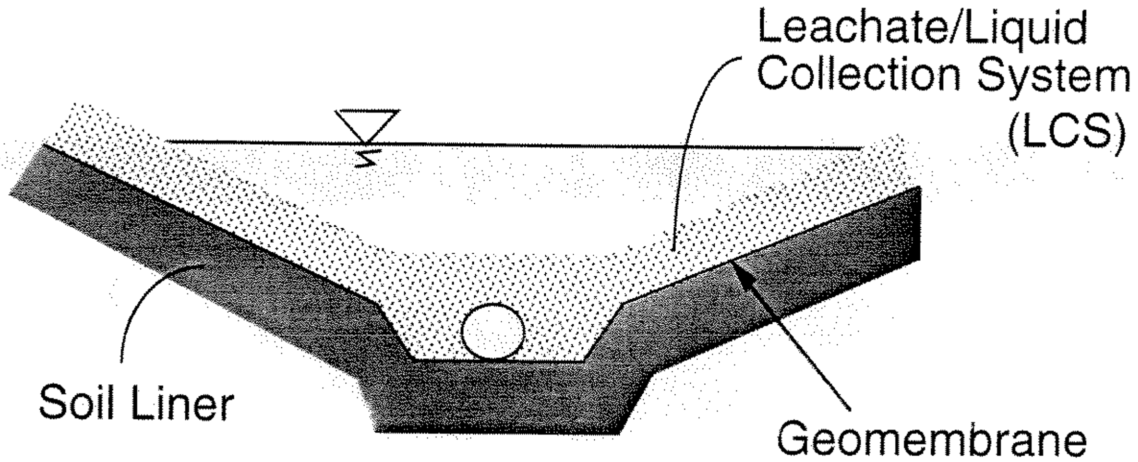
- Long-term exfiltration from waste limited to percolation through cap

- Percolation through composite cap is approximately 0.5 mm/yr with little maintenance

Liners

Objective: Facilitate leachate collection, limit contaminant migration

Layers: Drainage Layer, Barrier Layer



Materials of Construction

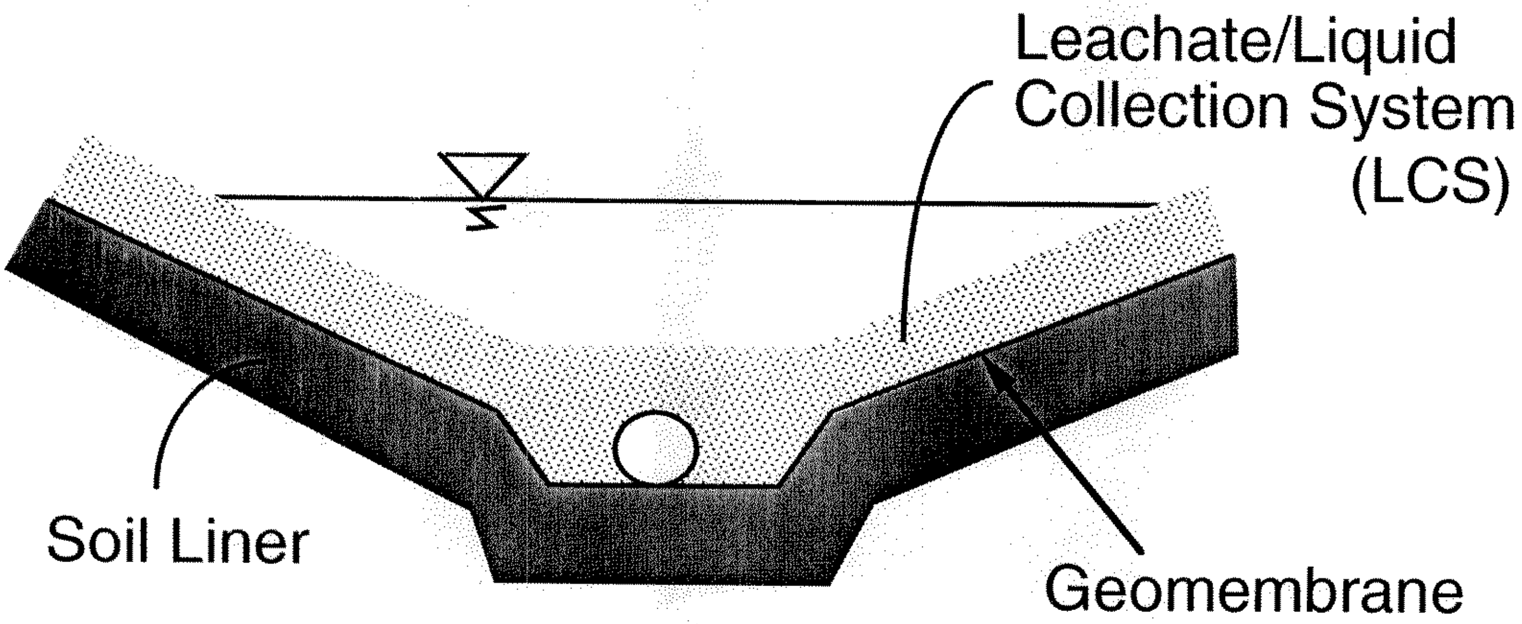
Drainage Layers:

- Sands, Gravels, Geonets
- Examples

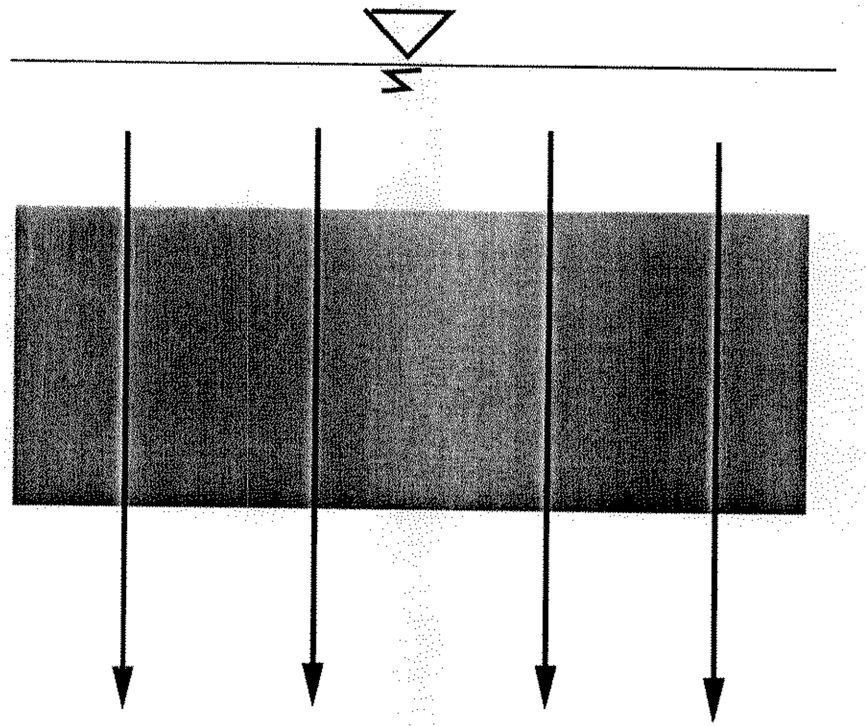
Barrier Layers:

- Clays, Geomembranes, GCLs
- Examples

Composite Liners

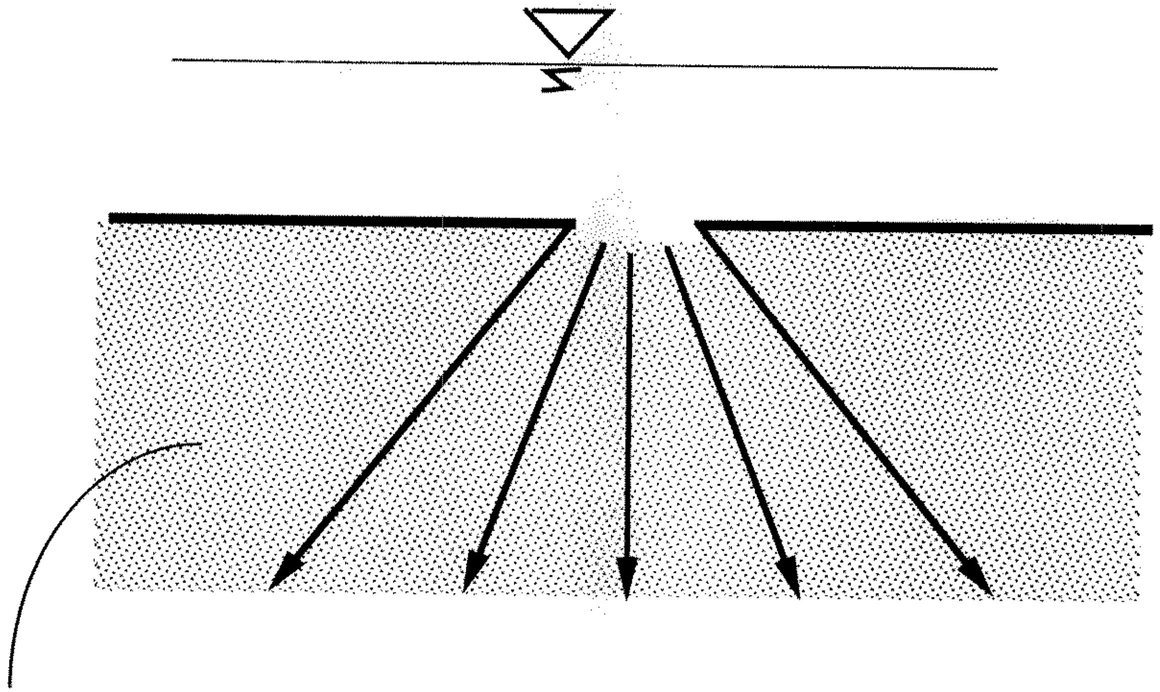


Soil Liner Alone



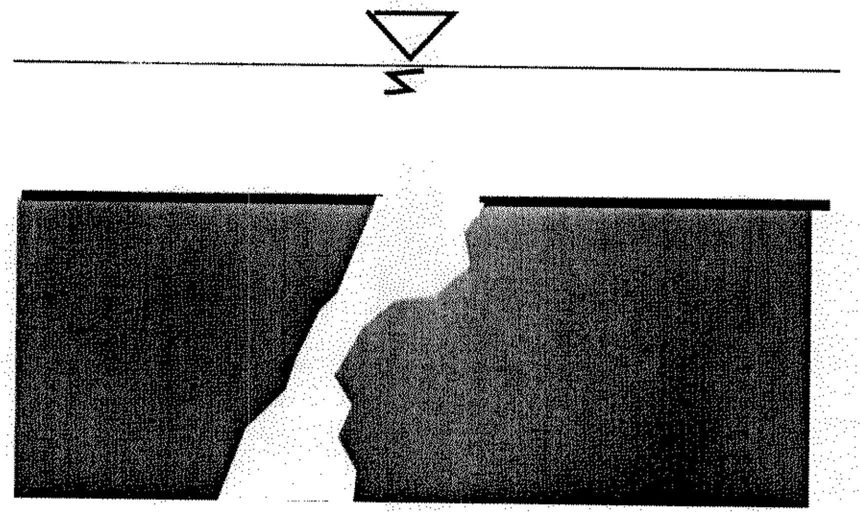
Large Cross-Sectional Area for Restricted Flow

Geomembrane Alone

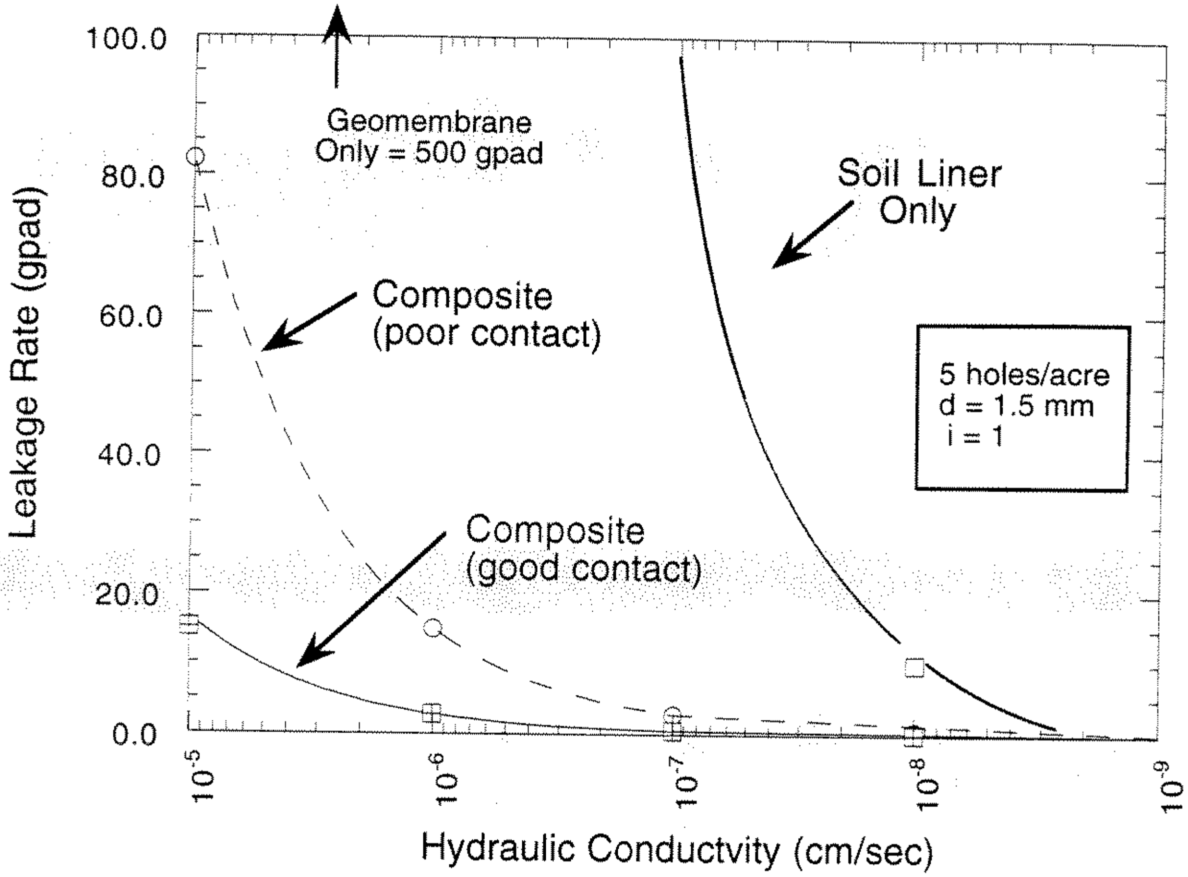


Restricted Cross-Section but no Resistance to Flow

Composite Liner



Reduced Cross-Section and Restricted Flow


100.0
80.0
60.0
40.0
20.0
0.0
Leakage Rate (gpad)
Geomembrane Only = 500 gpad
Soil Liner Only
Composite (poor contact)
Composite (good contact)
5 holes/acre
d = 1.5 mm
i = 1
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
Hydraulic Conductvity (cm/sec)

Geomembranes

- Polymer: High Density Polyethylene

- Why: Durable, Chemically Resistant, Easily Installed, Readily Welded

- Examples of Use:
  - Children's Toys (Little Tykes)
  - Gasoline Tanks in Cars
  - Chemical Storage Tanks
  - Liquid and Gas Pipelines
  - Pesticide Tanks

Applications require rigorous, flexible material that is extremely chemically resistant

Construction of Geomembrane Liners

- Deployed in rolls

- Welded with precision welders designed for lining systems

- Double-track weld used for continuous testing of seams

- Each seam completely leak tested by pressure or vacuum

- Each seam mechanically tested to ensure weld is as strong as parent material

- Entire liner can be tested using spark testing or electrical leak location survey

Lifetime of Geomembrane Liners

- Oxidation is primary factor degrading polymer structure

- Geomembrane lifetime consists of three stages
  - antioxidant depletion
  - induction time
  - degradation

- Research funded by USEPA and National Science Foundation shows that
  - anti-oxidant depletion time typically > 200 yr.
  - induction time (oxygen diffuses into geomembrane) ~ 200 yr.
  - degradation to 50% change in properties (e.g., leakage rate) ~ 100 years

Estimated Time for Significant Deterioration ~ 800 to 1000 yr.

Lifetime of Clay Liners or GCLs

GCLs:

- Bentonite age is measured in geologic terms
- Properties have unchanged for 10,000 years

Clay Liners:

- Mineralogical composition unchanged for 10,000 years
- Extremely low leakage rates if properly placed
- Maintain integrity if properly protected from drying, frost, and biota (rooting/protective layer)
- Natural clay barriers exist for thousands of years as hydrogeological units: aquitards

Long-Term Performance

Applicable Technology ~ 15 yr. old.

- municipal solid waste
- hazardous waste

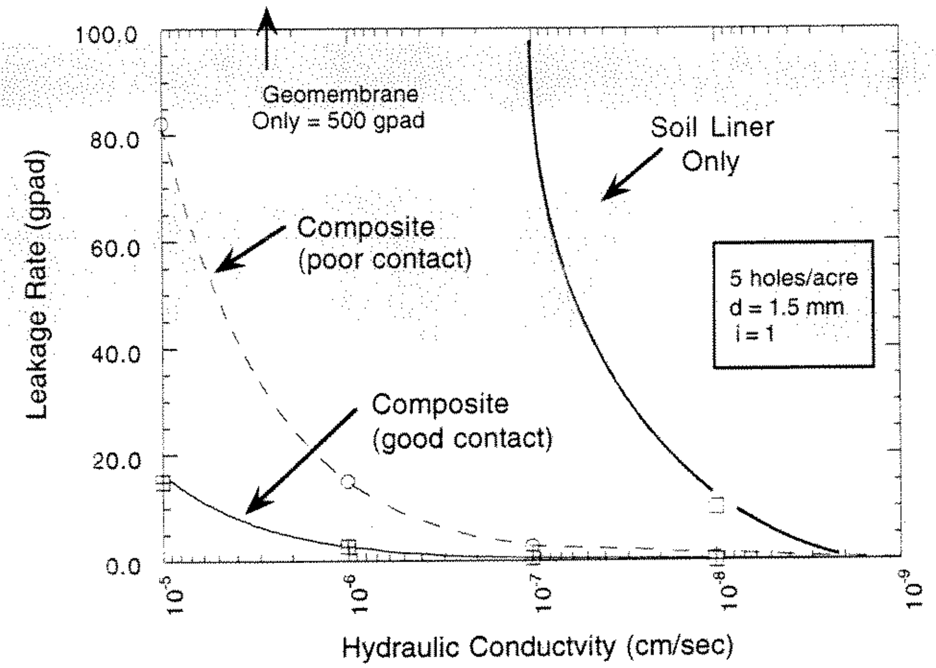
Long-Term Performance Studies:

- USEPA studies on existing liners and covers
- German study
- Wisconsin experience

USEPA Study on Performance of Liners:

- Composite liner leakage rates from 194 cells
- Clay composite-lined cells typically less than 2 l/ha-d (~ 1 quart per acre per day)
- GCL composite-lined cells ~ 0

~ 0.01% of natural recharge



USEPA Study on Performance of Covers:

- Caps on 194 cells
- Percolation range 0.002 to 1 mm/yr

German Study at Hamburg Landfill

- constructed five different types of covers
- instrumented each cover to follow water movement
- composite cap leakage < 0.5 mm/yr

Wisconsin Experience:

- no groundwater contamination problems from engineered facilities

Construction Quality:

The Key to Successful Waste Containment

- Careful attention to construction details and specifications
- Intensive testing and evaluation
- Detailed construction documentation
- Continual peer and regulatory review
- Importance illustrated by EPA Guidance Document
- WDNR example was model for national practice

Mining Applications:

- heap leach pads (very strenuous application)
- caps over tailings piles, sulphidic rock
- S. Dakota, Arizona

Hazardous Waste Applications:

- standard technology for modern hazardous waste landfill design
- design for remedial action units, e.g. RMA, with 1000 year design life

MINING COMPANY FINANCIAL GUARANTEES AND PAYMENTS

Under Wisconsin law, mining companies already are subject to a variety of special insurance, bonding, and financial guarantee requirements. A list of these current requirements is attached to this memo.

In addition to these existing safeguards, the State is in the process of enacting a new rule that would impose an unprecedented "irrevocable trust fund" requirement on mining companies. This rulemaking was initiated by the DNR in July 1996 in response to a petition from a group of state legislators. The Natural Resources Board has adopted this new rule pursuant to Order SW-21-97(A), and the rule is currently undergoing legislative review. The new rule, to be codified as NR § 132.085, Wis. Admin. Code, can be summarized as follows:

- A mining company will now be required to create an "irrevocable trust fund" prior to the start of any mining activities. The DNR will be the sole beneficiary of the fund, and the trustee must either be an authorized "public entity" or a private bank or other financial institution. The mining company will have no control over the trust fund.

- "The trust fund shall be created and maintained in perpetuity with funds adequate for the following activities":

  -- "Remedial action required as the result of spills of hazardous substances"

  -- "Remedial action to mitigate any hazardous substances that escape from the mine workings into the surrounding environment after the mining operation has ceased"

  -- "Remedial action required as the result of failure of a mining waste facility to contain the waste"

  -- "Provision of a replacement water supply"

  -- "Preventive measures taken to avoid adverse environmental consequences, including measures such as replacement of components of waste disposal facilities"

- The amount of the fund will be determined through the Master Hearing process, which will allow all interested parties to comment on the level of appropriate funding. The DNR must follow "reasonable and conservative risk considerations."

- The irrevocable trust fund <u>will</u> <u>not</u> <u>replace</u> a mining company's liability under other provisions of law. Instead, it is designed to serve as a "backup source" of funding in order to provide added levels of protection.

MINING COMPANY FINANCIAL GUARANTEES AND PAYMENTS

EIS and Permit Costs - Mining companies must reimburse the DNR for the state's costs for reviewing permit applications and preparing Environmental Impact Statements. CMC has accrued $1.5M to date.

Liability for Damages During Operation - Mining Companies are responsible for the remediation of any and all environmental incidents occurring during construction and operation of the mine. Cost of these activities would be covered from normal operating funds.

Certification of Insurance - Mining Companies must submit a certificate of insurance certifying that the applicant has in force a liability insurance policy issued by an insurer authorized to do business in this state, or in lieu of a certificate of insurance evidence that the applicant has satisfied state or federal self-insurance requirements, covering all mining operations of the applicant in this state and affording personal injury and property damage protection in a total amount deemed adequate by the department but not less than $50,000.

Reclamation Bond - Mining Companies must provide bond or other financial assurance to cover the cost of reclaiming the site. The bond amount would vary year-to-year based upon what it would cost to reclaim the site at any point in the life of the project. The maximum bond amount is expected to occur just prior to reclamation. After reclamation is complete, the DNR must require a mining company to maintain a bond equal to "at least" 10% of the total reclamation cost, and this bond must be maintained for "20 years after issuance of the latest certificate or certificates of completion for the mining site." NR 132.13, Wis. Admin. Code.

Environmental Repair Fund - For use by the state in the investigation and remediation due to environmental contamination. A fee of one cent per ton of waste is assessed. Estimated CMC payments are $220K (in 1997$).

Groundwater Fee - Another one cent per ton fee for every ton of mine water must be paid into the groundwater fund. These funds are used for groundwater management activities by the DNR. Estimated CMC payments are $220K (in 1997$).

Long-Term Care - Operators of metallic mining operations are required to show financial capability for long-term care of mining waste facilities. Proof of financial responsibility for at least 40 years after the closure of the site must be shown. Proof may take the form of a performance or forfeiture bond; deposits of cash, certificates of deposit, or U.S. government securities; an escrow account; an irrevocable trust; a letter of credit; an insurance policy; satisfaction of a net worth test; or "other financial commitments" satisfactory to the DNR. The statutes and regulations specify various requirements for each form of proof. See § 144.443, Wis. Stats.; NR 182.17, Wis. Admin. Code.

Perpetual Financial Responsibility - Mine owners are perpetually liable for the environmental integrity of the site. The means for demonstrating financial responsibility are not specified.

Net Proceeds Tax - Special tax levied on mining to offset impacts of operation. Estimated CMC payments are $119M (in 1997$).

Analysis of the "Partial Closure" Amendment

SB 3 requires proof of other "mining operations" that have operated and been reclaimed without pollution. "Mining operation" is already a defined term of art in Wisconsin's mining law, and means "all or part of the process involved in the mining of metallic minerals ...." *See* Wis. Stats. § 293.01(9) (emphasis added). Given the underscored language, discrete mine waste facilities and mine workings may be used to satisfy the requirements of SB 3 even though they are "part of" a broader mining project.

This proposed amendment would provide that such discrete mine waste facilities and mine workings may be considered for purposes of SB 3 -- consistent with the definition of "mining operation" -- but only "to the extent the department determines that such facilities and workings can properly be evaluated under this section apart from the associated operation." Thus, this amendment would tighten the requirements of SB 3 by preventing reliance upon mine waste facilities and mine workings in cases where the DNR determines that ongoing related operations interfere with an accurate evaluation of the performance of the facilities and workings in question. The current version of SB 3 contains no such limitation.

As thus narrowed, this definition of "mining operation" is a fair, sensible approach to judging the environmental integrity of sulfide mining. Mining is often undertaken and completed in stages or phases. Such staged development can be found at many historic mines, and is now the norm in modern "reclaim-as-you-mine" operations. As a consequence, discrete waste disposal facilities and mine workings are often closed at various times during the life of a mining project.

As explained by its sponsors, the underlying purpose of SB 3's 10-year closure criterion is to seek proof that the mining of metallic sulfides can be undertaken without long-term pollution of groundwater and surface water. Information important to that determination may be found in elements of a project that have been closed for ten or more years, despite ongoing related mining activities. Thus, to ensure accuracy and fairness, the DNR should not be artificially prohibited from considering such information merely because other associated operations continue or do not yet meet the bill's proposed standards -- provided that the closed components may accurately be evaluated apart from the related operations.

In fact, these types of facilities will frequently be more likely to yield high-quality data about the performance of sulfide mining operations. Where associated mining activities are ongoing, there is a much greater likelihood that the closed facilities and workings will be subject to more rigorous and wide-ranging monitoring requirements than would otherwise be the case, which will result in a greater amount of information about their long-term performance.

Analysis of the "Due Process" Amendment

SB 3 requires proof of other sulfide mines that have operated and been closed without "pollution," defined as "degradation that results in any violation of any environmental law." The bill does not address how the existence of a "violation" is to be determined. This amendment clarifies that any such "violation" must have been "determined by an administrative proceeding, civil action, criminal action or other legal proceeding, if the proceeding affords to the alleged violator due process rights of notice and an opportunity for a contested hearing." This is an appropriate standard for several reasons:

- As the Wisconsin DNR has explained, "precedent, fairness and reason" require that a "violation" have actually been found either through a court adjudication or through a formal determination "by the agency that has jurisdiction over the environmental laws to which the [comparison] mine is subject." See May 12, 1997 testimony of Howard S. Druckenmiller. Any other approach would be unworkable and violate the most basic principles of due process of law. Are otherwise-exemplary mines to be rejected based simply on rumors, innuendo, and unsubstantiated claims that have never been verified by the proper authorities? Is the DNR Master Hearing to be turned into a never-ending inquisition of other mines in other parts of the country, with hired "experts" seeking to testify that, even though other mines have exemplary records, the regulators who oversee those operations do not know what they are doing? While the DNR has indicated that it will construe the existing language of SB 3 so as to require a "formal determination" of any alleged "violation," it is important to codify this interpretation in order to eliminate uncertainties and avoid future changes in the application of this ambiguous language.

- This approach is consistent with the so-called "bad actor" provisions of Wisconsin's mining laws, which require the DNR to deny a permit if the applicant has engaged in certain misconduct elsewhere. The DNR does not attempt to determine such issues from scratch itself, but rather is directed to verify whether there have been any convictions, forfeitures, permit revocations, or other such formal actions by the relevant authorities with jurisdiction over the activities in question. See Wis. Stats. §§ 293.37(2)(e), 293.49(2)(c)-(f). That is exactly the course the Legislature should follow here -- it should direct the DNR to verify whether there have been any violations as determined by the proper authorities through formal procedures that comport with due process guarantees.

- Regulators and operators sometimes reach negotiated settlements that avoid express findings of a "violation." Thus, this amendment also provides that "a stipulated fine, forfeiture or other penalty is considered a determination of a violation, regardless of whether there is a finding or admission of liability." This will enable the consideration of any incident that has actually been determined by the proper authorities to be a violation, while at the same time ensuring fair and orderly procedures.

PARENT LIABILITY UNDER WISCONSIN'S MINING LAWS

A mining company's "parents" are held perpetually liable for any pollution caused by mining operations -- even if the pollution does not occur until years after mining has ended, even if the land has been sold to someone else in the meantime, and even if the mining company has been dissolved or reorganized. This perpetual liability is imposed as the result of Wis. Stats. §§ 107.30, 107.32, and 893.925. These provisions, which were enacted as part of 1979 Senate Bill 570, accomplish essentially three objectives:

First, the Legislature wanted to cure "[t]he inability to hold a parent corporation liable if the injury was caused by a subsidiary." See Wisconsin Legislative Council Report No. 33 to the 1979 Legislature, p. 5 [hereinafter "Report"]. Thus, a "mining company" subject to the special liability rules is defined as "any person who, either directly or through subsidiaries, affiliates, contractors or other business arrangements, engages in prospecting, mining, refining or smelting." Wis. Stats. § 107.30(9) (emphasis added). The result of this definition, in the words of the Legislative Council's Chief Staff Attorney, is that:

> "parent and subsidiary corporations [are] considered as one. In other words, although a subsidiary may have been created to carry out the mining activity, and was later dissolved, liability of the parent would co-exist during the time of dual existence and would continue to exist after dissolution, merger or other disappearance of the subsidiary."

See Sept. 14, 1979 memo from David J. Stute to Legislative Council Committee on Mining, p. 4.

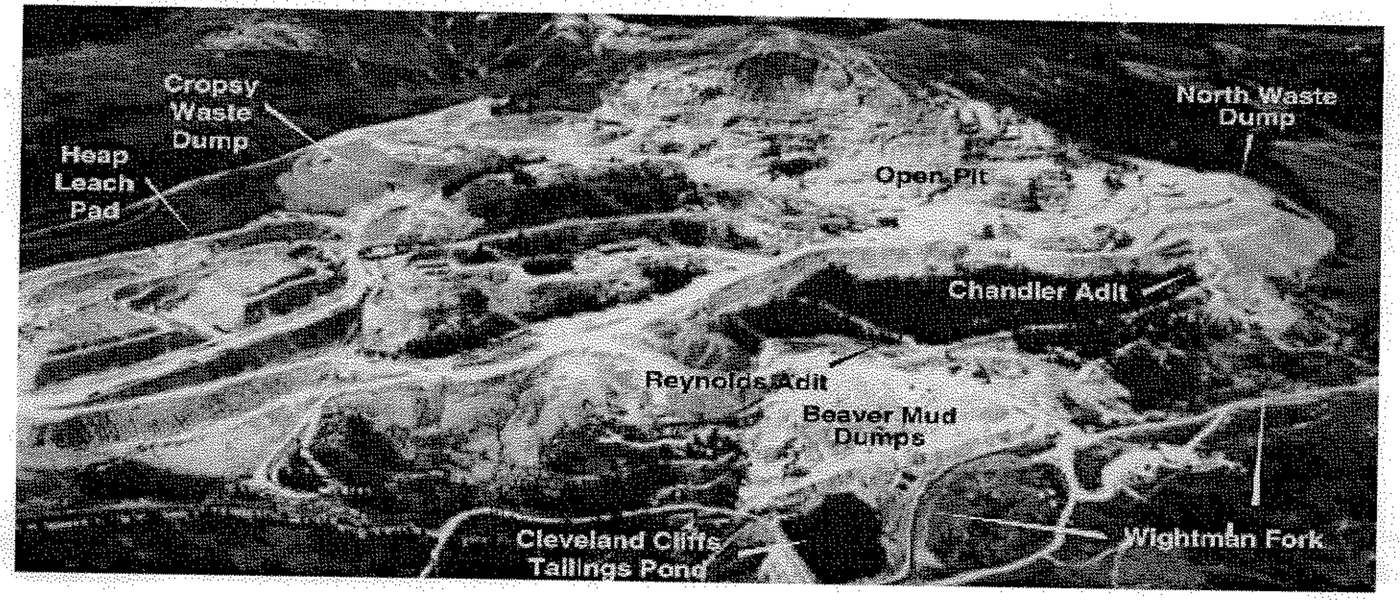
Second, and closely related to the first objective, the Legislature wanted to ensure that liability would continue notwithstanding any corporate reorganizations or sales of the mining lands. See Report, p. 5. Thus, liability is imposed on the "mining company" [defined to include its parents] "regardless of any change in the nature of the ownership of the interests in the prospecting or mining site, refinery or smelter held by the mining company and regardless of any reorganization, merger, consolidation or liquidation affecting the mining company." Wis. Stats. § 107.32 (emphasis added).

Third, the Legislature wanted to ensure that the statute of limitations would not begin to run until environmental pollution actually occurred and was discovered. See Report, p. 5. This is accomplished by Wis. Stats. § 893.925(2)(b), which provides that the statute does not begin to run until "the evidence of injury ... is sufficient to alert the injured party to the possibility of the injury." Thus, if a tailings facility were to begin leaking 100 years from now, the statute of limitations would not begin to run until evidence of any damage caused by that leaking could reasonably be discovered.

U.S.Geological Survey

THE SUMMITVILLE MINE AND ITS DOWNSTREAM EFFECTS

An ON-LINE UPDATE of Open File Report 95-23



Summitville CO, Oct. 1993, from aerial photo by IntraSearch Inc.

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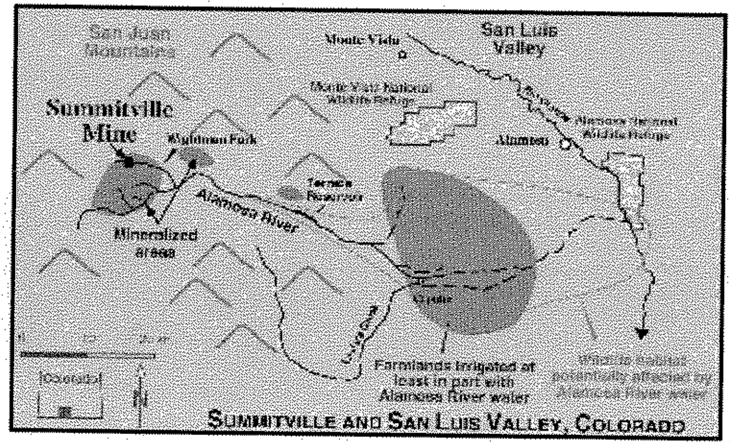
Work in Progress.: Last Updated: 11 July 1995

Introduction

The Summitville gold mine, located at ~3800 meters (11,500 ft) elevation in the San Juan Mountains of southwestern Colorado, was the focus of extensive public attention in 1992 and 1993 for environmental problems stemming from recent open-pit mining activities. Summitville catalyzed national debates about the environmental effects of modern mining activities, and became the focus of arguments for proposed revisions to the 1872 Mining Law governing mining activities on public lands. In early 1993, the State of Colorado, U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS), Colorado State University, San Luis Valley agencies, downstream water users, private companies, and individuals began a multi-disciplinary research program to provide needed scientific information on Summitville's environmental problems and downstream environmental effects. Detailed results of this multi-agency effort were presented, along with legal and policy issues, at the Summitville Forum in January, 1995, at Colorado State University, Fort Collins, Colorado.



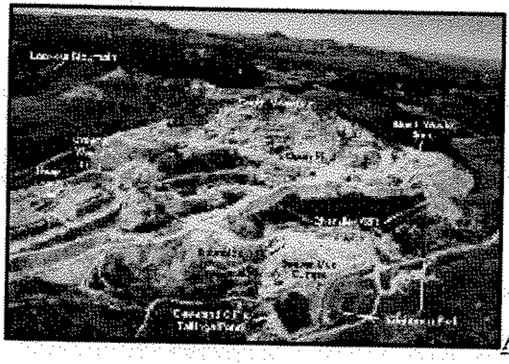
Area Map (750x495) 57Kb

This paper provides a scientific perspective on Summitville based on USGS study results as of early 1995. Further information on USGS studies are available in a separate general interest publication (King, 1995a) . The results demonstrate that earth science information is needed to develop more effective techniques for the prediction, assessment, mitigation, and remediation of the environmental effects of mining.

Background

Gold was first discovered at Summitville in 1870. Significant gold production from underground workings occurred prior to 1900. In 1903, the Reynolds aditwas driven to drain the underground workings and serve as an ore haulage tunnel. Production occurred sporadically through the 1950's. The district received some exploration attention in the 1970's as a copper prospect, but no mining for copper was pursued.

Similar to many historic gold mining districts in the western United States, Summitville received renewed interest in the early 1980's due to technological advances that allow extraction of low-grade ores with cyanide heap leach techniques. In 1984, Summitville Consolidated Mining Company, Inc. (SCMCI), initiated open pit mining of gold ore from rocks surrounding the historic underground workings, where gold concentrations had been too low to be economic for the underground mining operations. Ore from the pit was crushed and placed on a heap leach pad overlying a protective liner. Cyanide solutions were sprinkled onto the heap and trickled down through the crushed ore, dissolving the gold. The processing solutions were then collected from the base of the heap leach pile, and the gold was chemically extracted from the solutions.



Aerial Photo (933x706) 151Kb

Summitville CO, Oct. 1993, Aerial photo by IntraSearch Inc.

Environmental problems developed soon after the initiation of open-pit mining. Acidic, metal rich drainage into the Wightman Fork of the Alamosa River increased significantly from numerous sources on site, including the Reynolds adit and the Cropsy waste dump (Pendleton and others, 1995) . Cyanide-bearing processing solutions began leaking into an underdrain system beneath the heap leach pad, where they then mixed with acid ground waters from the Cropsy waste dump. Cyanide solutions also leaked from transfer pipes directly into the Wightman Fork several times over the course of mining.

SCMCI had ceased active mining and had begun environmental remediation when it declared bankruptcy in December 1992 and abandoned the mine site. The bankruptcy created several immediate concerns. Earlier in 1992, the company had brought a water treatment plant on line to begin treating the estimated 150 to 200 million gallons of spent cyanide processing solutions remaining in the heap; however, treatment was proceeding so slowly relative to influx of snowmelt waters that the waters were in danger of overtopping a containment dike and flowing directly into the Wightman Fork. In addition, piping carrying the processing solutions to the treatment plant would have frozen within several hours, releasing cyanide solutions and stopping water treatment.

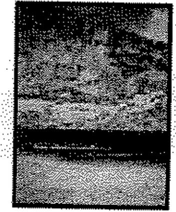
At the request of the State of Colorado, the U.S. Environmental Protection Agency (EPA) immediately took over the site under EPA Superfund Emergency Response authority and increased treatment of the heap leach solutions, thereby averting a catastrophic release of cyanide solutions from the heap. Summitville was added to the EPA National Priorities List in late May, 1994. Ongoing remediation efforts include decommissioning of the heap leach pad, plugging of the Reynolds and Chandler adits,backfilling of the open pit with acid-generating mine waste material, and capping of the backfilled pit to prevent water inflow. The total cost of the cleanup has been estimated to be from US $100 million to $120 million.

The environmental problems at Summitville have been of particular concern due to the extensive downstream use of Alamosa River water for livestock, agricultural irrigation, and wildlife habitat. Increased acid and metal loadings from Summitville are suspected to have caused the 1990 disappearance of stocked fish from Terrace Reservoir and farm holding ponds along the Alamosa River (Colo. Div. of Wildlife, oral comm., 1993). The Alamosa River is used extensively to irrigate crops in the southwestern San Luis Valley. Important crops include alfalfa (used for livestock feed), barley (used in beer production), wheat, and potatoes; there has been concern about potential adverse effects of the increased acid and metal loadings from Summitville on the metal content and viability of these crops. The Alamosa River also feeds wetlands that are habitat for aquatic life and migratory water fowl such as ducks and the endangered whooping crane; there are concerns about Summitville's effects on these wetlands and their associated wildlife.

Summitville Mine Site

USGS efforts at the Summitville site since open pit mining began include detailed geologic mapping in the open pit (Gray and Coolbaugh, 1994a), characterization of the site's environmental geology and geochemistry (Plumlee and others, 1995 a and b), studies of cyanide degradation (Plumlee and others, 1995b), and geophysical resistivity surveys (Bisdorf, 1995).

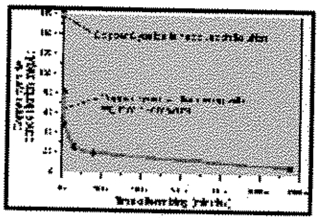
The Summitville mine drainage waters are among the most acidic and metal-rich in Colorado (Plumlee and others, 1995b), with pH generally below 3 and high to extreme concentrations of iron, aluminum, copper, zinc, arsenic, and other metals. The acidic, metal-rich nature of the waters is a predictable consequence of the deposit's geologic and geochemical characteristics(Plumlee and others, 1995 a; Gray and others, 1994b). Prior to mineralization, the volcanic dome rocks that host the deposit were intensely altered by highly acidic volcanic gas condensates. Sulfide-rich mineral assemblages containing pyrite, enargite, chalcopyrite, and other minerals were subsequently deposited in the altered host rocks by hydrothermal fluids. Open-pit mining exposed large volumes of previously unoxidized sulfides to weathering. Acid-mine drainage with high concentrations of metals forms by the reactions of these previously unoxidized sulfides with oxygenated groundwaters. Further, the highly altered host rocks have very little capacity to react with and consume the acid generated by sulfide oxidation, thereby providing little or no mitigation of the acid drainage. Evaporation further increases the concentrations of acid and metals in waters draining mine dumps and open-pit waters. Soluble salts such as chalcanthite (a copper sulfate), jarosite (a potassium-iron sulfate), and halotrichite (an iron-aluminum sulfate) form by the extreme evaporation of acid waters during dry periods; dissolution of these salts during snowmelt or summer storm events leads to the transient release of even more acidic and metal-rich water pulses from the site (Plumlee and others, 1995 a and b).



Acidic metal-rich puddles in the Summitville open pit formed by dissolved secondary salts in rainwater.

The backfilling and capping of the open pit will help reduce acid drainage from Summitville by reducing water- and snow-catchment and by decreasing the amounts of exposed sulfides and soluble salts. However, some level of acid discharge will likely continue from the site. Significant volumes of unweathered sulfides and soluble salts are dispersed throughout the site on roadways, in soils, and in other surficial materials. These solids are a long-term source of metals and acid that will be difficult to remediate. In May, 1994, four months after the Reynolds adit was plugged, a plug on the Chandler adit (located 150 feet above and 2400 feet north of the Reynolds adit) failed and began leaking acidic, metal-rich waters into the Wightman Fork. Although the Chandler is currently being re-plugged, the leak underscores the fact that it is difficult to prevent leakage of groundwaters from a highly fractured and mined mountain. The plugging of the Reynolds adit also resulted in the predictable reactivation of acid seeps and springs that had drained the site prior to underground mining; these natural seeps had left behind extensive, mappable deposits of brown iron hydroxide minerals(Plumlee and others, 1995b). Long-term leakage of acid groundwaters from these natural discharge points is unavoidable.

USGS studies show that the severe acid drainage problems at Summitville may have actually helped mitigate the effects of accidental cyanide releases. Experiments in which Summitville heap leach solutions were mixed with acid-drainage waters from the site indicate that metal-cyanide complexes in the heap leach solutions react readily with acid in the drainage waters to form hydrogen cyanide, which then volatilizes into the atmosphere (Plumlee and others, 1995b).

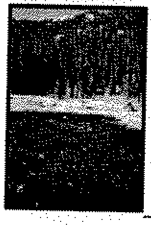

Plot of cyanide concentration vs. time in heap leach effluents reacting with acid mine drainage.

In addition, copper cyanide in the heap leach solutions reacts with iron from the drainage waters to form solid copper-iron cyanide compounds, which are then degraded through reactions catalyzed by sunlight. Thus, most cyanide species that were accidentally leaked into the Wightman Fork (Fig. 2) probably degraded rather rapidly due to mixing with the site's acid drainage, especially if the leaks occurred on sunny summer days optimal for maximum cyanide volatilization and photolytic degradation. However, if leaks occurred in the winter, cyanide may have persisted considerably farther downstream due to reduced rates of volatilization. Relatively high concentrations of thiocyanate may have persisted downstream due to its stability in acidic solutions.

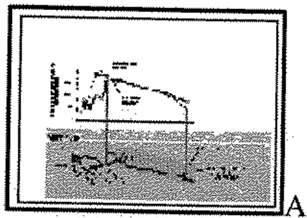
Effects on the Alamosa River

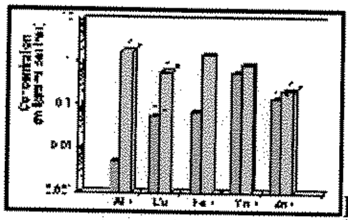
Increased acid and metal loadings from Summitville are suspected to have caused the 1990 disappearance of stocked fish from Terrace Reservoir and farm holding ponds downstream on the Alamosa River (Colo. Div. of Wildlife, oral comm., 1993). However, significant natural contamination also enters the Alamosa from unmined or minimally mined mineralized areas (Walton-Day and others, 1995; Miller and others, 1995a, 1995b; Miller and McHugh, 1994). Creek names such as Iron, Alum, and Bitter attest to the degraded quality of waters emanating from these areas.


Mineralized areas in and near the Alamosa River basin


Natural acidic iron spring, Alamosa River headwaters

Geologic studies (Bove and others, 1995) of the mineralized areas south of Summitville have shown that hydrothermally-altered and sulfide-mineralized rocks are the source for numerous acid springs and seeps. In addition, physical erosion rates greatly exceed chemical weathering rates in the most highly altered areas. In these areas, unoxidized sulfides are exposed at the ground surface and are transported as sediments into the Alamosa River, where they serve as further sources for acid and metals.


Aluminum concentrations along the Alamosa River, April and June 1993; Walton-Day and others, 1995


Effects of a thunderstorm on Alamosa River metal concentrations; Ortiz and others, 1995b

Synoptic water sampling studies show that concentrations of aluminum, iron, and acid derived from mineralized areas other than Summitville can exceed aquatic life standards in Alamosa River waters during some times of the year, such as during early spring snowmelt and summer thunderstorms. (Walton-Day and others, 1995; Ortiz and others, 1995b; Ward and Walton-Day, 1995; von Guerard and Ortiz, 1995) However, during much of the year, Summitville is the dominant source of iron, aluminum, copper, manganese, zinc, and acidity in the Alamosa River. Remote imaging spectroscopy studies (King and others, 1995b) also document the contributions of metal-bearing sediments in the Alamosa River from both Summitville and the unmined mineralized areas.

USGS studies are currently underway to estimate baseline metal and pH conditions that may have existed in the Alamosa River basin prior to mining (Miller and others, 1995a, 1995b); results of these studies should be used to determine how much remediation at Summitville is necessary and realistic in a basin-wide context.

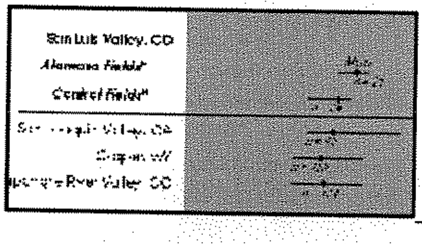

Terrace Reservoir may serve as a sink and/or source for metals in the Alamosa River. For example the reservoir serves as a sink for metals sorbed onto particulates that settle to form bottom sediments. USGS studies are currently underway to evaluate whether metals can be liberated from the sediments under favorable geochemical conditions (Edelmann and others, 1995; Ortiz and others, 1995a; Horowitz and Elrick, 1995).

Effects on soils, agriculture, and wetlands in the San Luis Valley

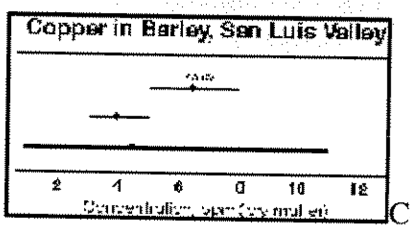
A regional geochemical survey of the San Luis Valley shows that soils on the Alamosa River alluvial fan in the southwestern San Luis valley contain anomalous concentrations of copper and other metals (Tidball and others, 1995 in press). These metal anomalies largely reflect the pre-mining erosion of mineralized areas in the Alamosa River basin. Effects of irrigation with Alamosa River water on soil metal levels may be generally secondary compared to the effects of the mineralized source material for the soils (Erdman and Smith, 1993).

Studies of San Luis valley irrigation waters taken from the Alamosa River show that degraded water quality can persist more than 60 km downstream from Summitville (Smith and others, 1995). This results from (1) natural acid and metal contamination from other mineralized areas; (2) the lack of large diluting tributaries to the Alamosa River, and; (3) the lack of acid-buffering capacity of the volcanic rocks through which the Alamosa River and tributaries flow (Plumlee and others, 1995a in press).

There has been considerable concern about crops irrigated with Alamosa River water. Dominant crops include barley (used in the beer brewing industry) and alfalfa (used as livestock feed). Results of 1993 USGS studies show that irrigation with Alamosa River waters led to slightly increased concentrations of copper and other metals in the alfalfa and barley relative to levels of these metals in alfalfa and barley irrigated with water from other sources Erdman and Smith, 1993



Copper concentrations in alfalfa ; Erdman and others, 1995b



Copper concentrations in barley ; Stout and Emerick, 1995

However, these 1993 metal concentrations were well within the concentration ranges of copper measured in alfalfa and barley grown elsewhere in the United States. The copper concentrations in alfalfa were also well below the maximum levels tolerable in cattle (Erdman and Smith, 1993; Erdman and others, 1995b). Some local farmers feel that, because copper is an essential nutrient for livestock and is generally low to deficient in feed grown in the San Luis valley (Brown, 1995), the nutritional quality of the alfalfa is enhanced, not diminished, by irrigation with Alamosa River waters. However, the metal content and acidity of Alamosa River irrigation waters increased substantially in July and August of 1994 (Smith and others, 1995). Data from alfalfa sampled in 1994 indicate that the increased levels of metals and acid in the waters resulted in further increases in copper content of the alfalfa that, while optimal for dairy cattle, may be approaching the maximum levels tolerable for sheep in some samples (Erdman and Smith, 1995a in press).

Studies are currently underway to assess the use of multi-spectral remote sensing data to map soil mineralogy and vegetation characteristics in the San Luis Valley (Clark and others, 1995). Mapping of crop type and stress levels has been successful using this technique. Ongoing studies are investigating whether mapped crop stress levels can be correlated with source of irrigation water.

Studies of wetlands in the San Luis Valley show that concentrations of copper and zinc in sediments and plants are greater in wetlands receiving Alamosa River water than in a wetland fed by water from other sources; this indicates that some copper from Summitville and zinc from Summitville and other sources are reaching the wetlands (Balistrieri and others, 1995 in press). However, the Alamosa River-fed wetland waters have basic pH values and very low metal concentrations. Impacts on aquatic life and waterfowl are currently under evaluation.

Tree-ring chemistry was also evaluated to help assess impacts of Summitville on plant ecosystems (Gough and others, 1995 in press): the metal content of sequential tree rings, spanning 30 years of growth, was measured in cottonwoods and aspens along the Alamosa River from the Wightman Fork downstream into the San Luis Valley. Results for Cu and Zn show no clear effects from Summitville, and the limited number of analyses completed to date preclude a detailed interpretation of the results (Gough and others, 1995 in press).

Summary

Although final scientific judgments about Summitville and its environmental effects await the outcome of ongoing research, some preliminary conclusions can be drawn: (1) Extreme acid rock drainage, rather than cyanide releases, is the dominant long-term environmental concern at Summitville. Extensive remedial efforts will be required to minimize weathering and dissolution of unweathered sulfides and soluble metal salts. Some level of long-term acid- and metal-release into the Wightman Fork will likely occur in spite of the remedial efforts, however, due to leakage from natural discharge points and the wide distribution of acid-generating material throughout the site. (2) It is likely that natural contamination adversely affected water quality and fish habitat in the Alamosa River prior to mining, and will continue to have adverse effects even when acid drainage from Summitville is remediated. Thus, realistic geochemical baselines for the Alamosa River basin must be defined in order to set realistic remediation standards for the Summitville site. (3) As of late 1993, Summitville apparently had no discernible short-term adverse effects on the barley or alfalfa crops irrigated with Alamosa River water. However, increases in metal content of irrigation waters and alfalfa measured in the summer of 1994 underscore the need for prompt and effective remediation at the site to ensure that no adverse effects develop over the longer term.

Results of Summitville research to date underscore the crucial need for geoscientific information in predicting, assessing, and remediating the environmental effects of mining. For example, Summitville shows how geologic and geochemical information should be used in the future to more effectively anticipate and mitigate potential environmental effects of metal mining. Similarly, a careful consideration of Summitville's geologic and geochemical characteristics (and their controls on hydrology and acid-drainage formation) is needed to help refine and anticipate the effectiveness of remedial measures at the site. In the assessment of Summitville's downstream environmental effects, geoscience studies contribute much by: (1) providing a scientific evaluation of the actual, rather than perceived, environmental problems and their effects; (2) showing that natural environmental effects of other mineralized areas must also be considered, and; (3) showing that Summitville's effects on aquatic life, agriculture, and wetlands ecosystems can best be understood only when examined in an integrated geologic, geochemical, and biological context.

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conservancy districts, and water users.

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