Liner Systems in Waste Management Units:
Design, Installation and Verification Testing

Presented by

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TRI ENVIRONMENTAL

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Outline

- Opening Comments
- Design elements and basics
- Installation (lessons learned)
- Quality Control and Quality Assurance – each step of the way
- Good News!

Initial Comments

- Waste containment systems have never been better, and are continually improving
- Geosynthetics have made current level of containment possible – technically and economically
- No cookie-cutter solution; site-specific design calculations necessary for effective, economic design
- Good performance is function of design, material quality, and installation
- You get what you pay for
- Leak-free system can be achieved with planning and verification

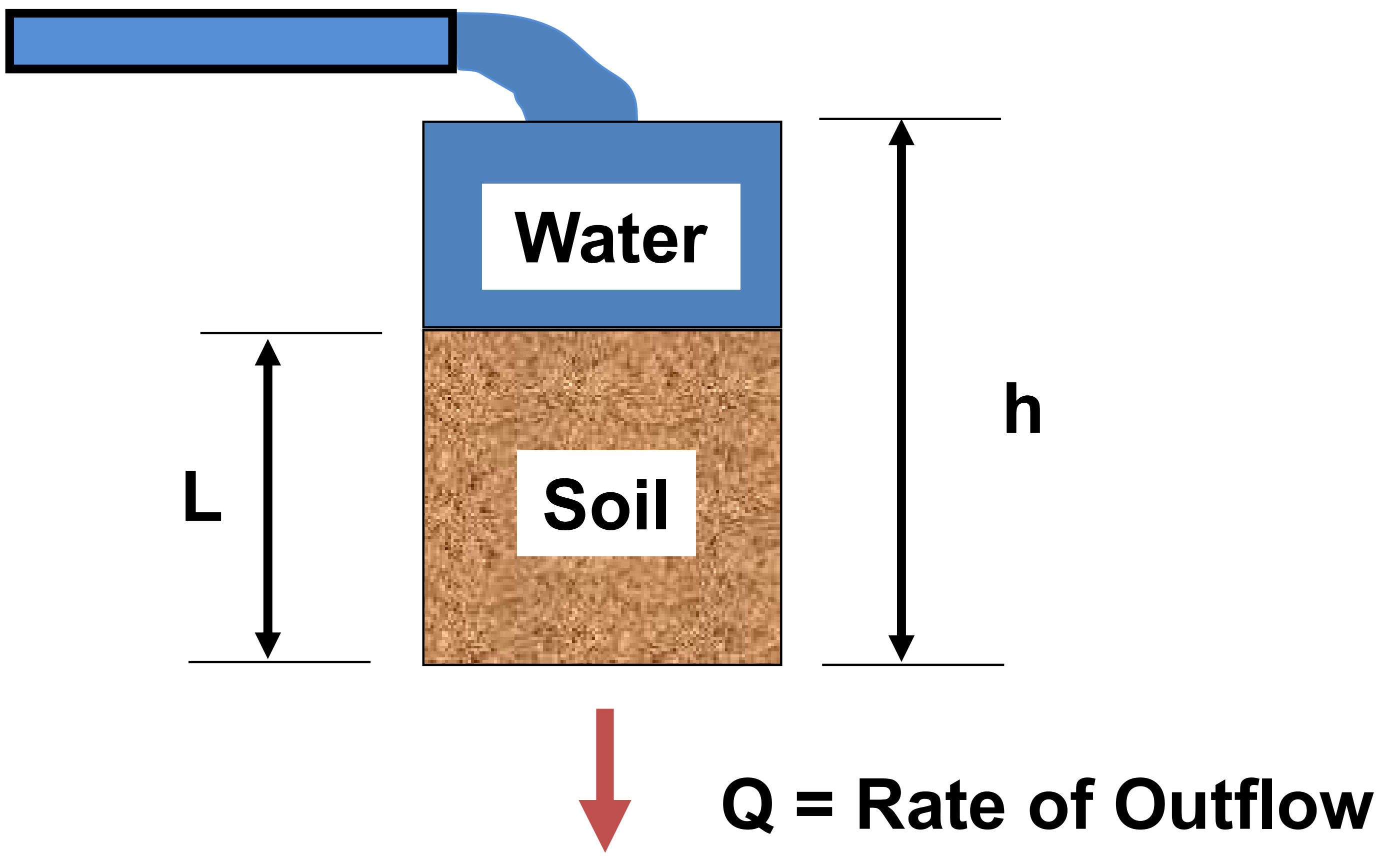
Motives for Environmental Containment

- Ground water protection
- Surface water protection
- Air protection
- Risk Management
- Safety (e.g. landfill gas)
- Reduce after-care maintenance
- Land reclamation of waste sites

Hydraulic Conductivity

	K (cm/s)
Gravel	1 to 100
Sand	10^{-3} to 1
Silt	10^{-6} to 10^{-3}
Clay	10^{-9} to 10^{-6}

It all started with .....



Hydraulic Conductivity

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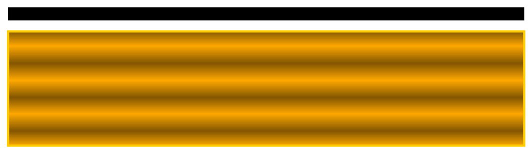
Clay	10^{-9} to 10^{-6}
Intact Geomembrane	10^{-12} to 10^{-11}

Hydraulic Conductivity

	K (cm/s)
Gravel	1 to 100
GN/GC →	
Sand	10^{-3} to 1
Silt	10^{-6} to 10^{-3}
Clay	10^{-9} to 10^{-6}
GCL →	
Intact Geomembrane	10^{-12} to 10^{-11}

Example Configurations

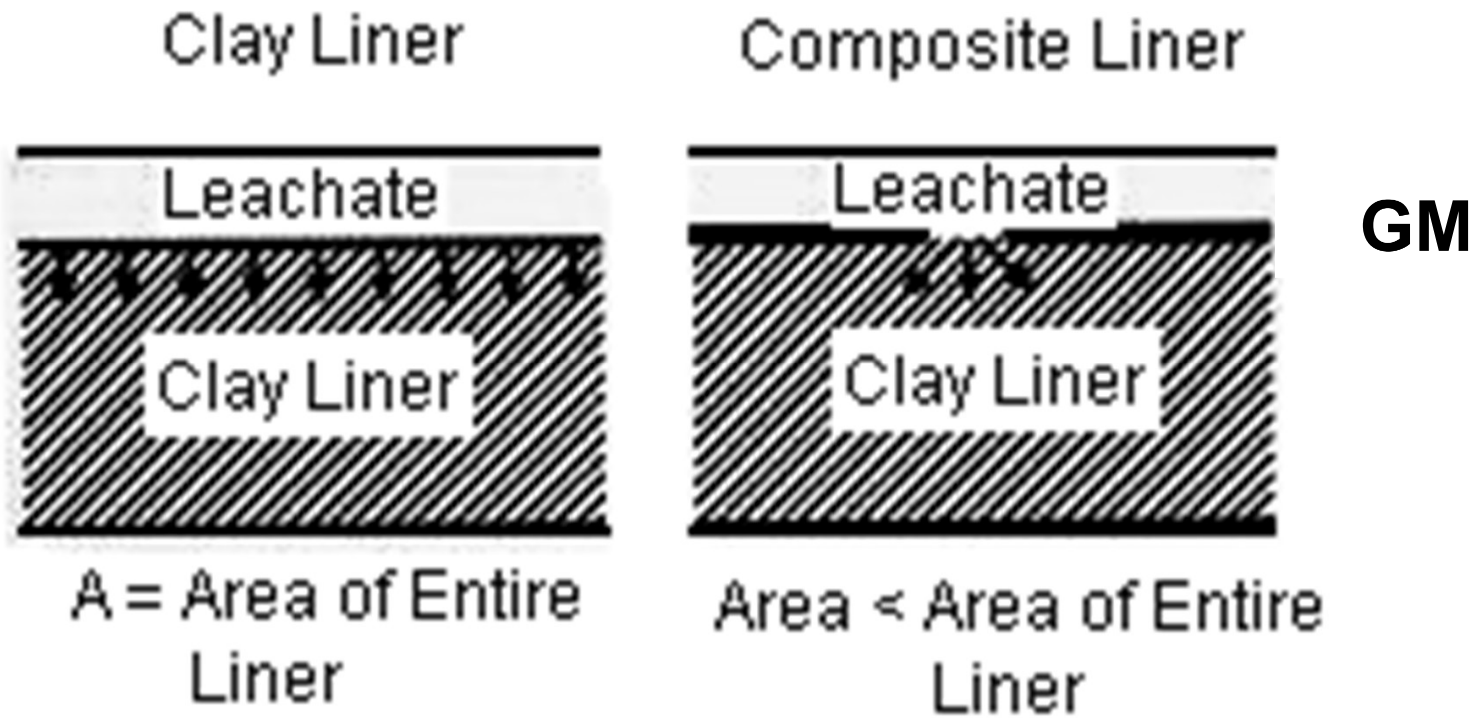
Composite Liner



Double Liner System

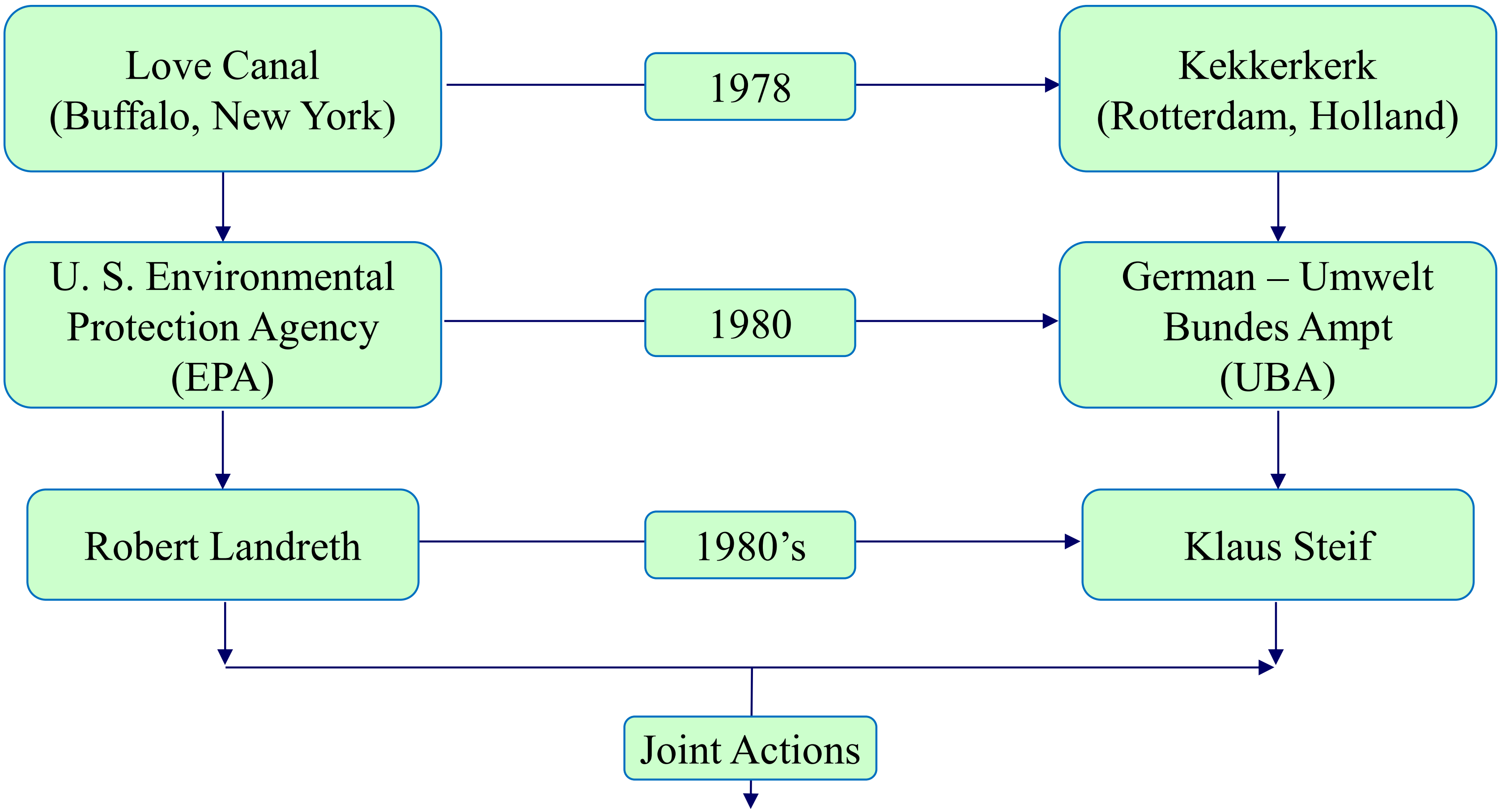
Clay Liner vs Composite Liner

Flow rate through Liner Systems



100,000 vs 10 lphd

Ground Contaminated by Chemical Wastes



1. kCCL ≤ 1 × 10-7 cm/sec
2. Composite GM/CCL liner concept
3. Intimate contact required
4. Leachate head ≤ 30 cm
5. Gravity flow drainage systems
6. Major R & D Funding

Courtesy of
Bob Koerner

USA (RCRA
Subtitle C for haz; Subtitle D for MSW)

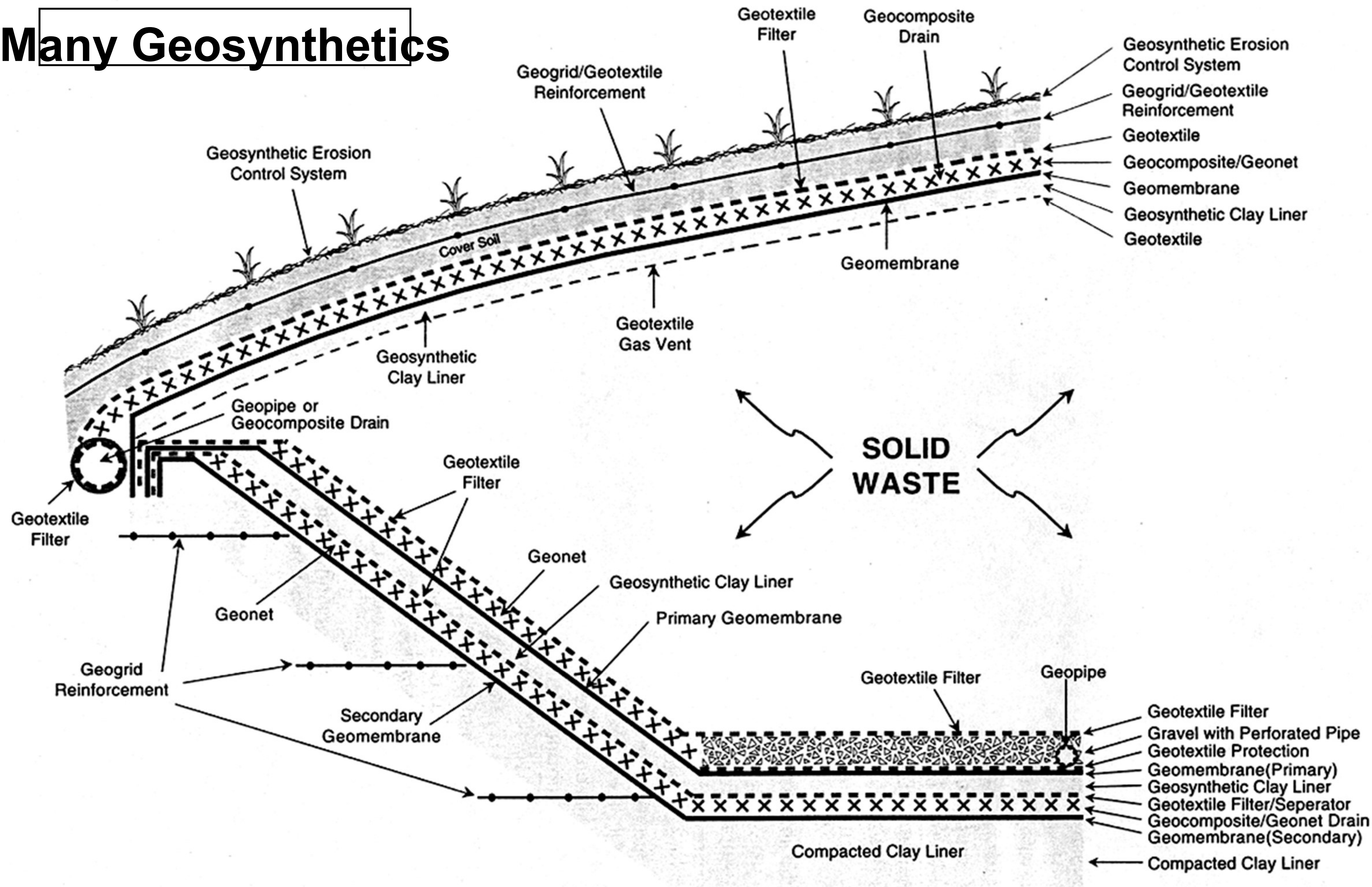
- 900 mm (3 ft) CCL (HAZ) or 600 mm (2 ft)(MSW)
- 0.75 or 1.5 mm (40-60 mil) GM
- site-specific GM type
- performance drainage
- double liners/leak detection for haz

Germany

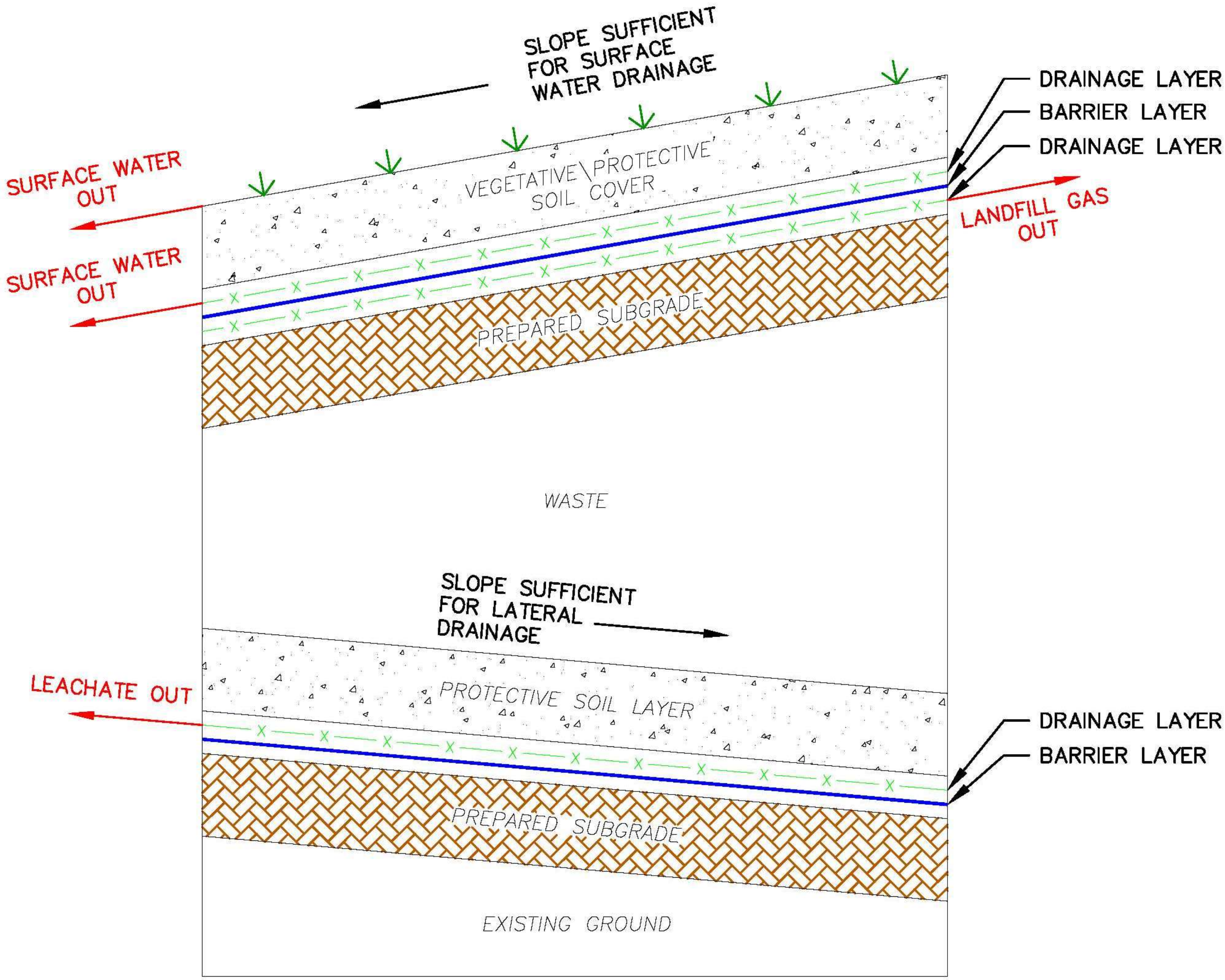
- 1000 mm CCL
- 2.0 or 2.5 mm GM
- requires HDPE
- prescriptive drainage
- single composite liner

Courtesy of Bob Koerner

Many Geosynthetics



Waste Containment (Top to Bottom)




GS Liner Systems; fast, successful

Containment System Principals

- Waste Containment (Top to Bottom)Minimize liquid entering waste mass to avoid generation of leachate
- Minimize leachate head over bottom barrier system (lateral drainage system design)
- Minimize breaches in bottom barrier system
- Design for longevity of components
- Make sure system is stable for all stages of site life

Slope Stability

- Slope Stability is probably the single most immediate and largest liability facing all stakeholders
- Liner systems are a set-up for instability. This goes for both bottom liners and cover systems.

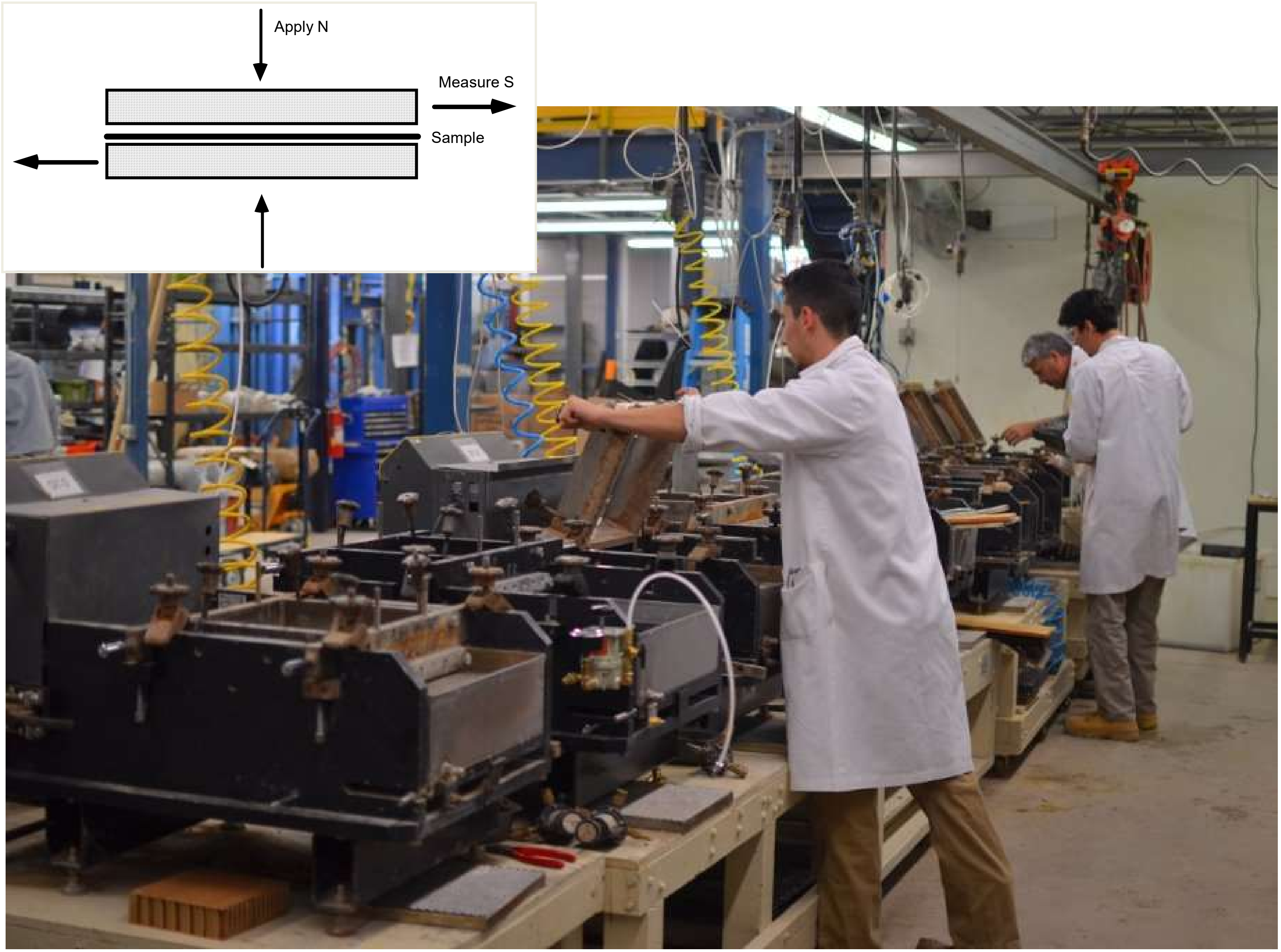
Failure of cover system during construction

Bottom Liner failure just before failure…

Just after failure.

Swartklip Dam Failure – Feb. 2025

Large Scale Interface Friction / Direct Shear Testing



ASTM D5321 and D6243 – verifying slope stability

Geosynthetic Durability

- Chemical compatibility (reactions)
- Chemical equilibrium and stability (aging)
- Exposure to sun, wind, temperature, elements
- Stability under stresses and strains
- Dimensional stability
- Construction survivability (often the most significant factor)
- Operational durability

Approximate Geomembrane Formulations

Type	Resin	Plasticizer	Fillers	C.B.	Additives
HDPE	95-98	0	0	2-3	0.5-1*
LLDPE	94-96	0	0	2-3	1-4*
fPP	95-98	0	0	2-3	1-2*
PVC	50-70	25-35	0-10	2-5	2-5
PET	95-98	0	0	1	1
CSPE	40-60	0	40-50	5-40	5-15
EPDM	25-30	0	20-40	20-40	1-5

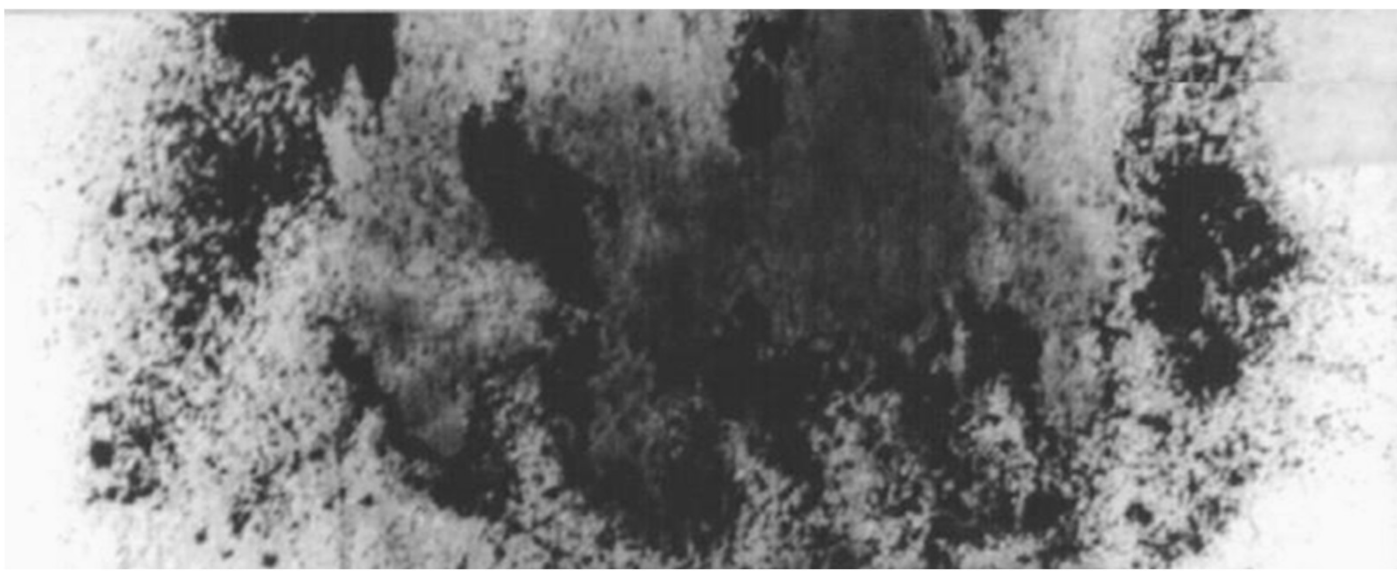
***additives are various antioxidants and process stabilizers**

What happens when you have insufficient durability?

- Shriveling, cracking, loss of ductility
- Holes, rips, tears, punctures
- Shrinkage and separation
- Change in permeability

polyethylene pellets

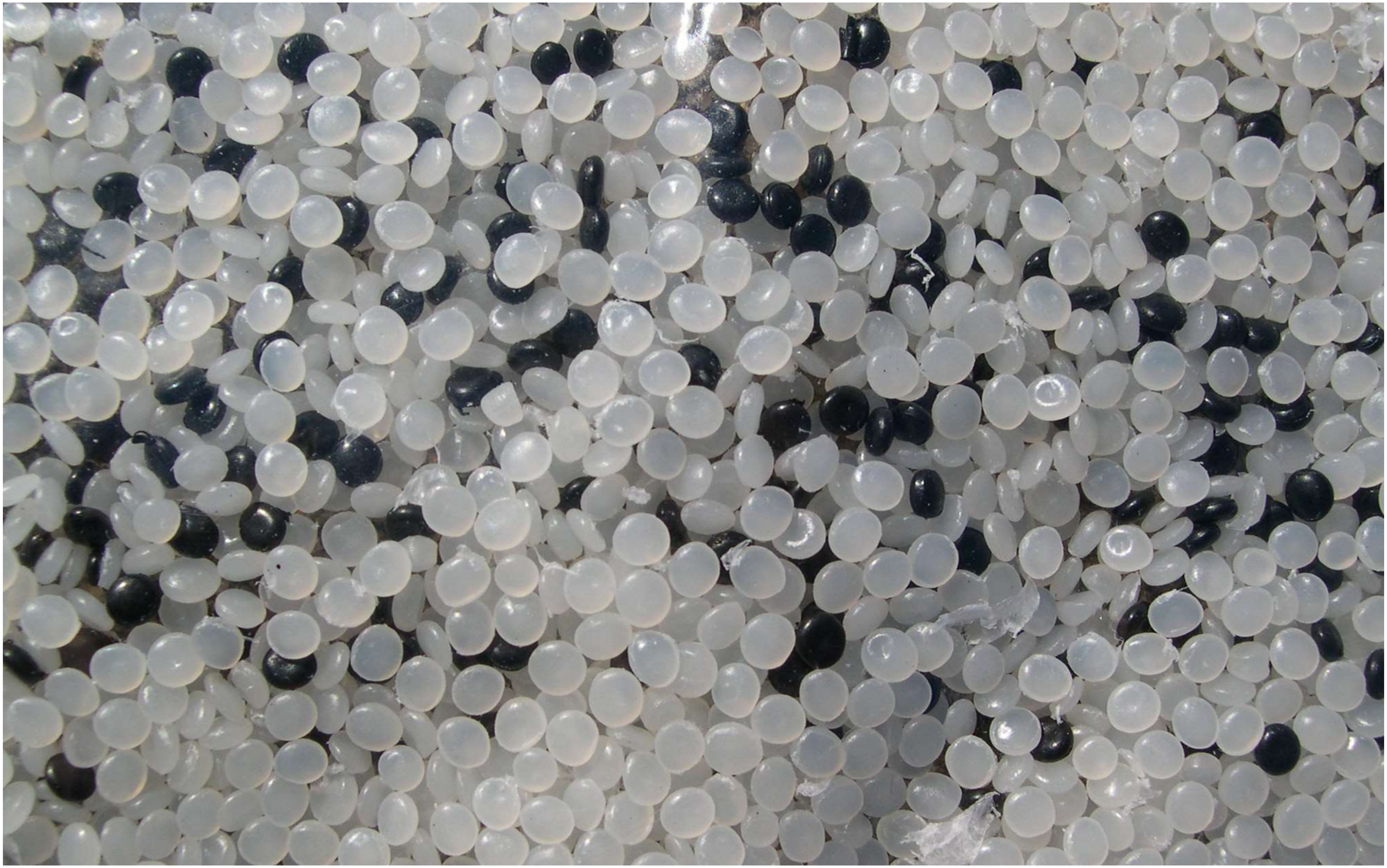
Additives



Carbon Black

Carrier Resin

master batch w/additives



The “Letdown”

Recycled-Reclaimed (No Post Consumer)

SI (METRIC) UNITS

Table 1(b) – High Density Polyethylene (HPDE) Geomembrane - Smooth

Properties	Test Method	Test Value							Testing Frequency (minimum)
		0.75 mm	1.00 mm	1.25 mm	1.50 mm	2.00 mm	2.50 mm	3.00 mm	
Thickness - mils (min. ave.) • lowest individual of 10 values	D5199	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	per roll
Density (min.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	90,000 kg
Tensile Properties *(1)* (min. ave.) • yield strength • break strength • yield elongation • break elongation	D 6693 Type IV	11 kN/m 20 kN/m 12% 700%	15 kN/m 27 kN/m 12% 700%	18 kN/m 33 kN/m 12% 700%	22 kN/m 40 kN/m 12% 700%	29 kN/m 53 kN/m 12% 700%	37 kN/m 67 kN/m 12% 700%	44 kN/m 80 kN/m 12% 700%	9,000 kg
Tear Resistance (min. ave.)	D 1004	93 N	125 N	156 N	187 N	249 N	311 N	374 N	20,000 kg
Puncture Resistance (min. ave.)	D 4833	240 N	320 N	400 N	480 N	640 N	800 N	960 N	20,000 kg
Stress Crack Resistance *(2)*	D 5397 (App.)	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	per GRI GM-10
Carbon Black Content - %	D 4218 *(3)*	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	9,000 kg
Carbon Black Dispersion	D 5596	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(5)* (a) Standard OIT — or — (b) High Pressure OIT	 D 3895 D 5885	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	90,000 kg
Oven Aging at 85°C *(5)*, *(6)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	per each formulation
UV Resistance *(7)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(9)*	 D 3895 D 5885	 N. R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	per each formulation

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction
Yield elongation is calculated using a gage length of 33 mm
Break elongation is calculated using a gage length of 50 mm
(2) The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.
(3) Other methods such as D 1603 (tube furnace) or D 6370 (TGA) are acceptable if an appropriate correlation to D 4218 (muffle furnace) can be established.
(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3
(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(6) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.
(7) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
(8) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(9) UV resistance is based on percent retained value regardless of the original HP-OIT value.

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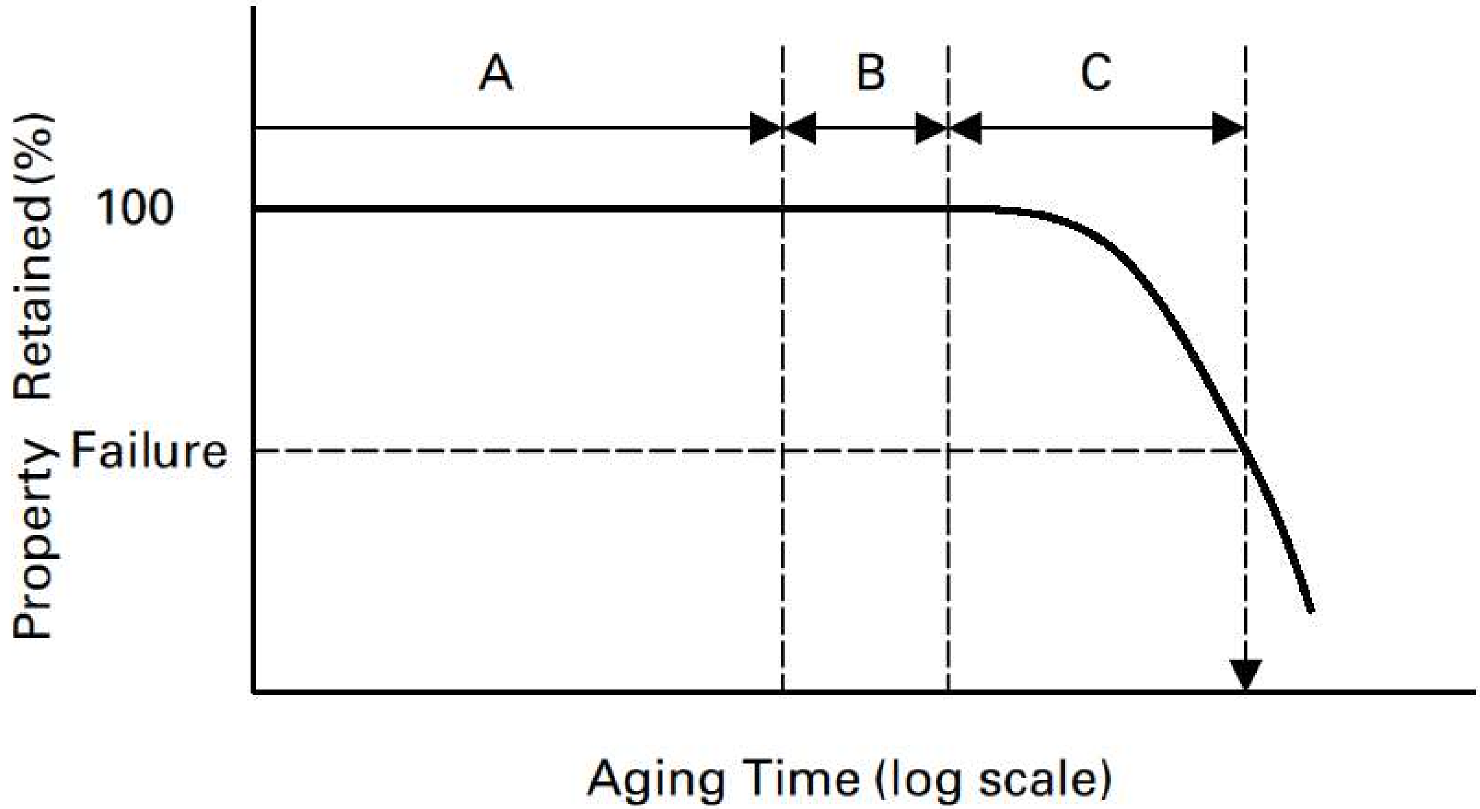
Incubated Property Behavior



A = Period during which depletion of antioxidants occurs

B = Induction time to onset of polymer degradation

C = Time to reach the failure level of degradation of a particular property

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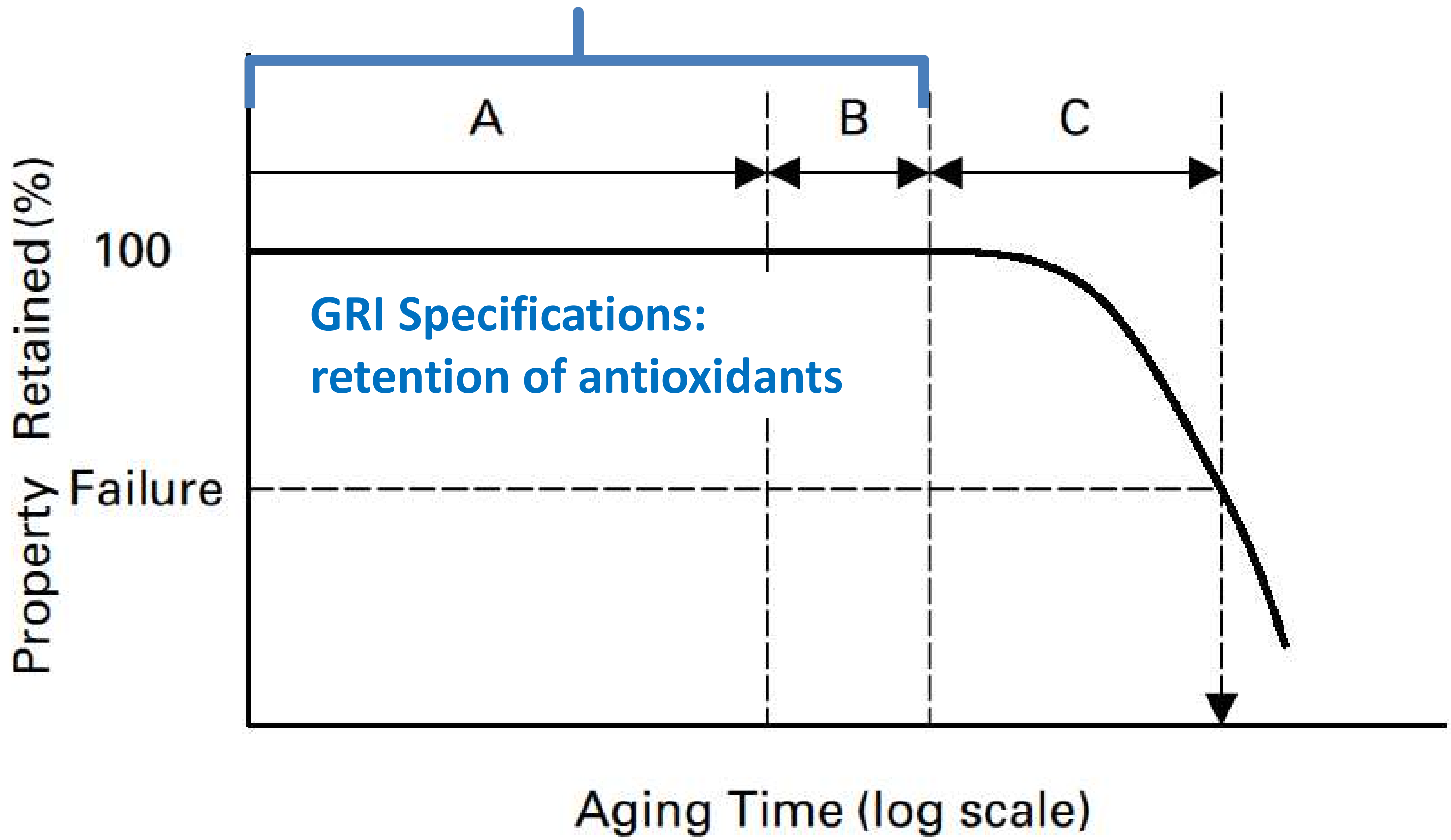

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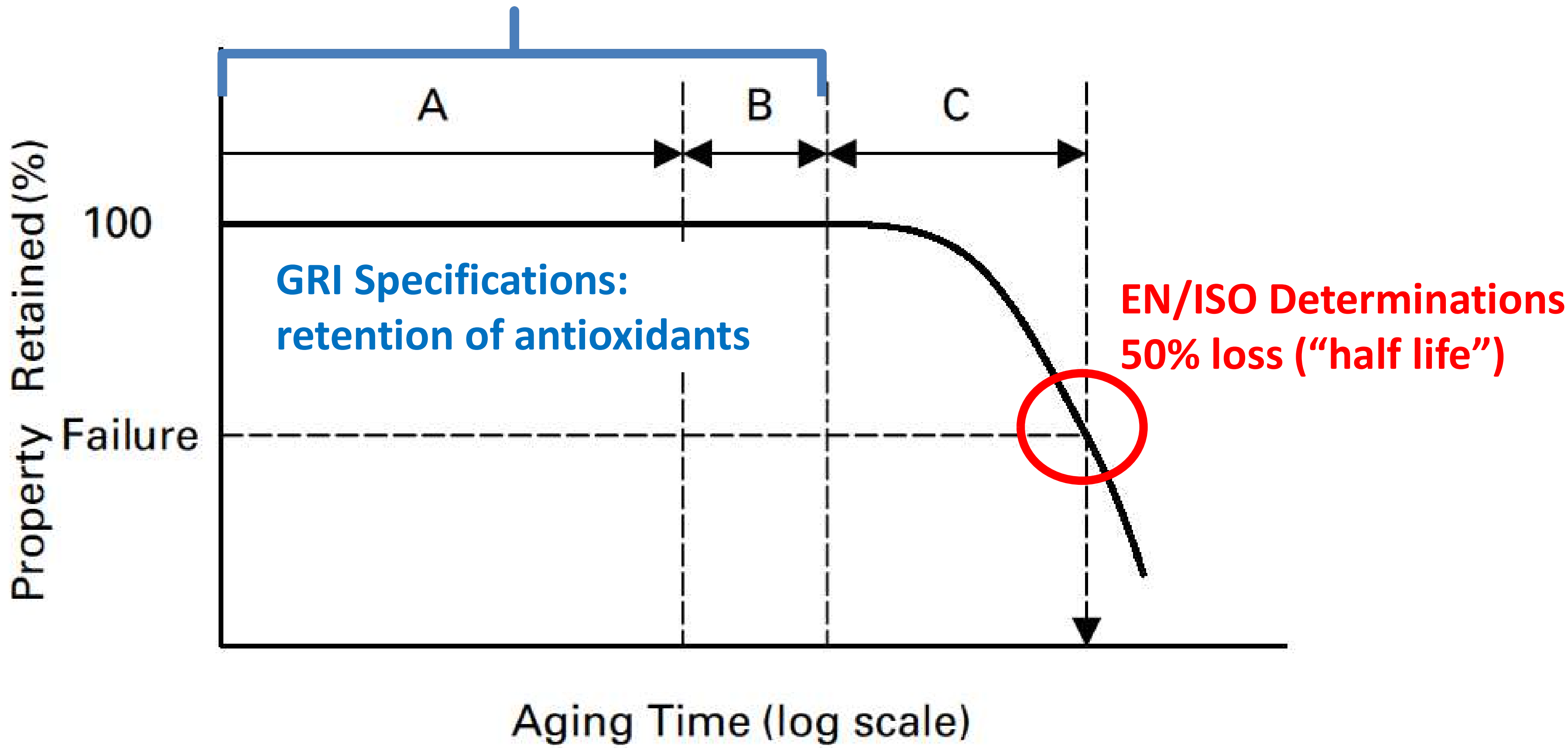

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Lifetime Prediction of HDPE at Elevated Field Temperatures (GSI)

Field Temperature		Stage "A" (yrs.)		Stage "B"	Stage "C" (yrs.)		Total
C (deg)	F (deg)	Std OIT	HP-OIT	(years)	Ref. 1	Ref. 2	Ave. Years
20	68	200	215	30	208	740	712
25	77	135	144	25	100	441	435
30	86	93	98	20	49	259	270
35	95	65	67	15	25	154	170
40	104	45	47	10	13	93	109
45	113	32	33	5	7	57	70

Notes: Stage "A" measured values from G. Hsuan research
Stage "B" estimated values from field samples
Stage "C" lit. values from Martin & Gardner[1] and Viebke[2]

Geosynthetic Installation
Containment Facilities

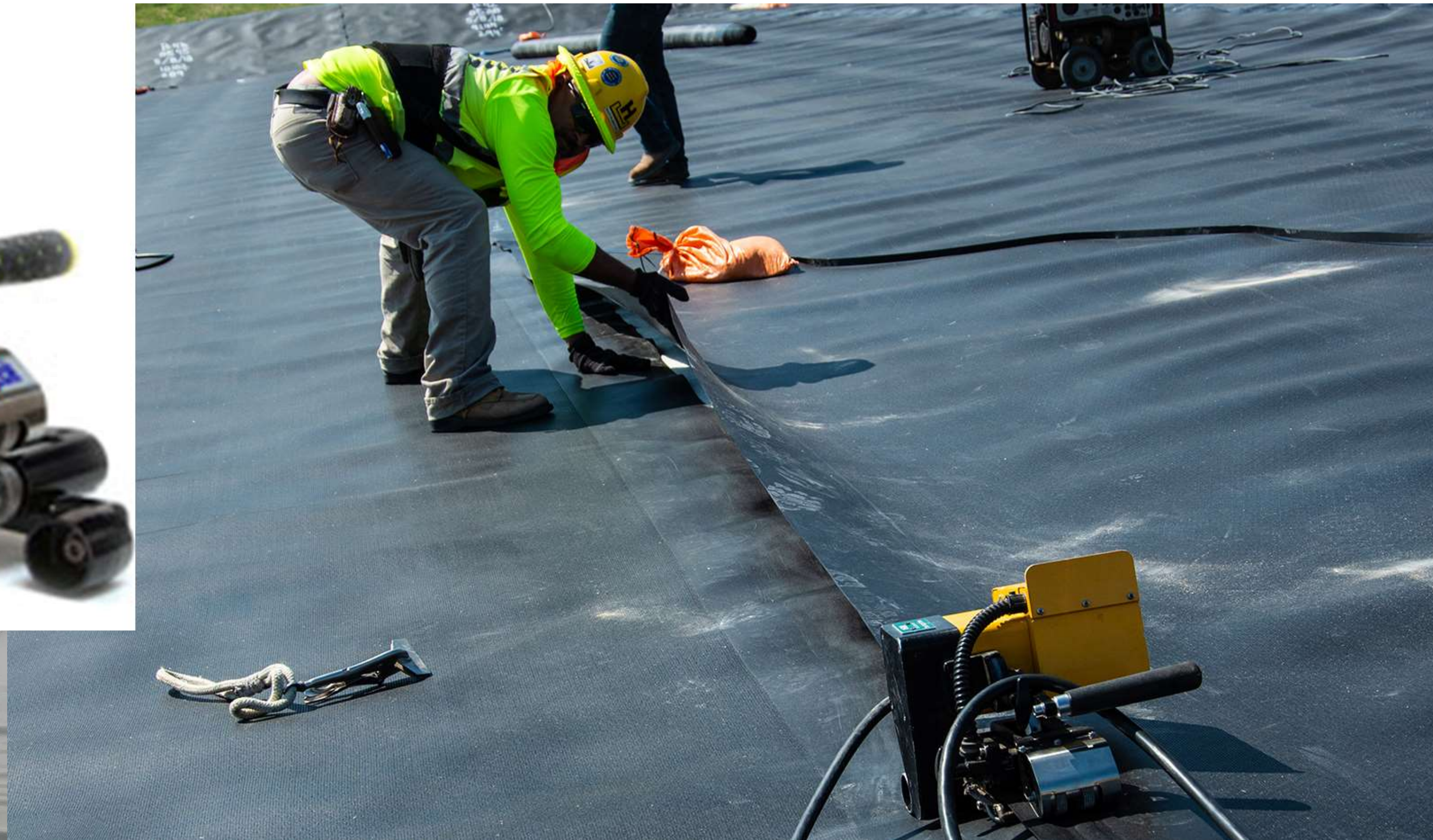
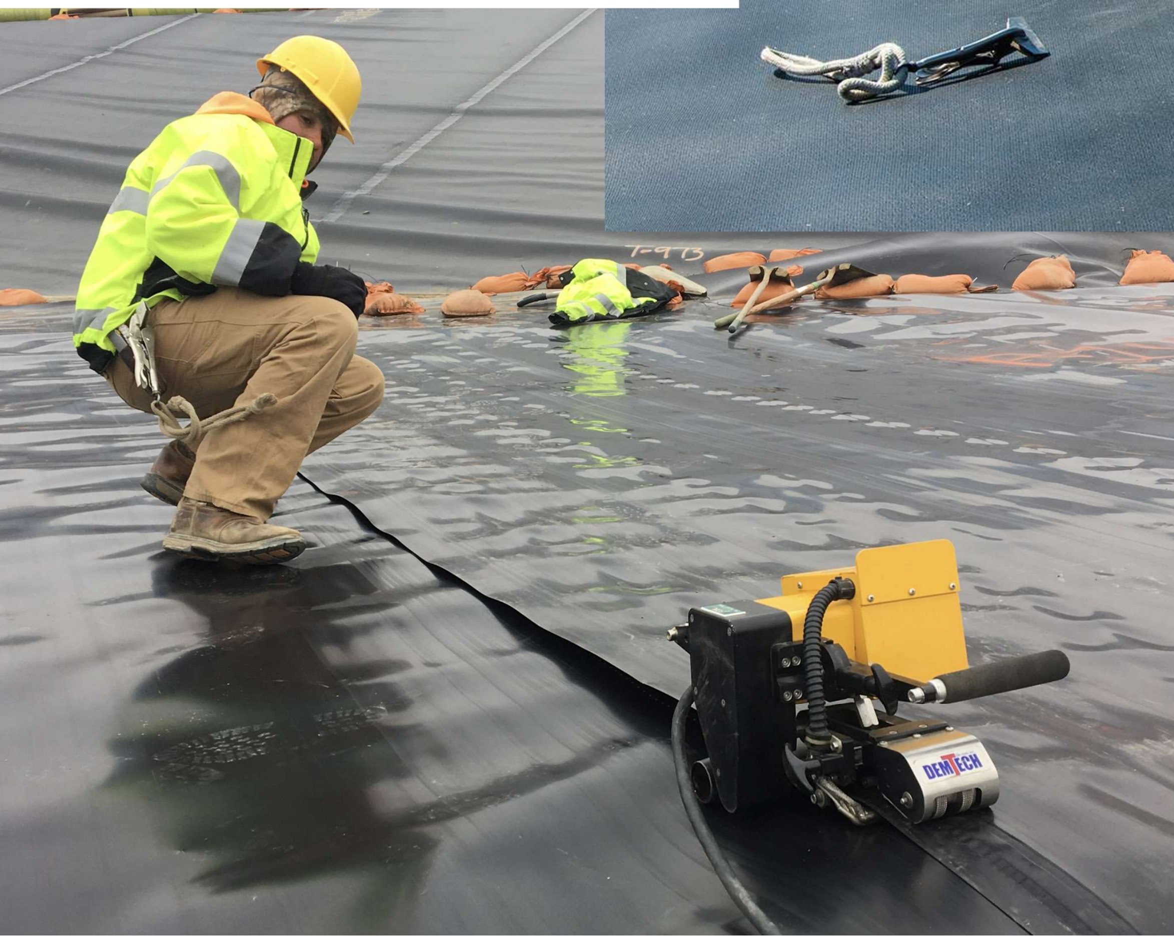

PENCO
V 3400
C 3000
B 6600
(SEE REVERSE)
POLYESTER
116
MADE IN CHINA

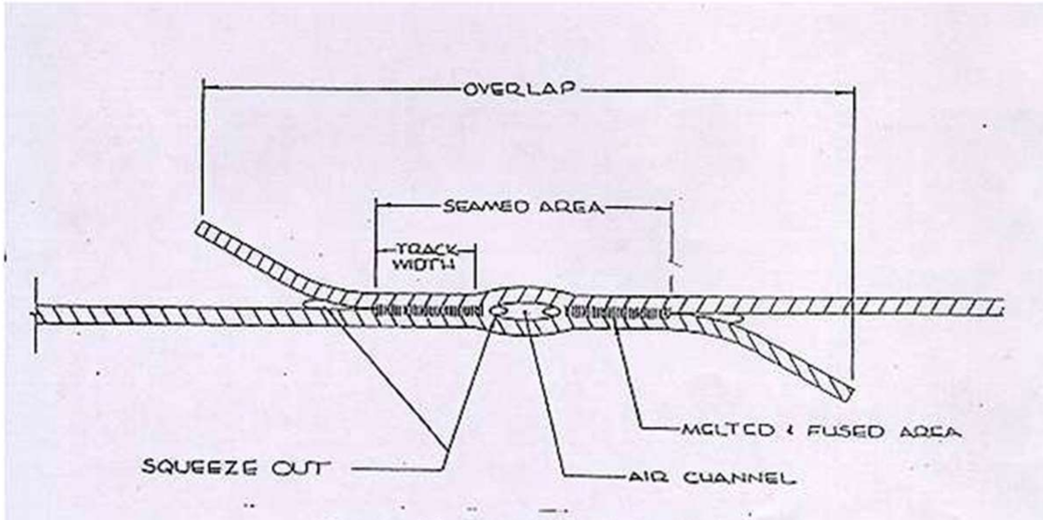

CARRY ON
SAFEWAY EE2-902 X 8 Ft
CHOKER 5000 V 6400
BASKET 12800 NYLON
FLAT
REFER TO INSPECTION CARE AND USE INSTRUCTIONS BEFORE USING.
INSPECT SLING FOR DAMAGE BEFORE USE.
DO NOT USE NEAR ACIDS OR BLEACHING AGENTS.
DO NOT CUT, OVERLOAD, OR EXPOSE TO TEMPERATURES ABOVE 194°F (90°C).
DISCARD WHEN RED CORE YARNS APPEAR.
FABRICATED IN U.S.A.

Installation: Seaming and Joining

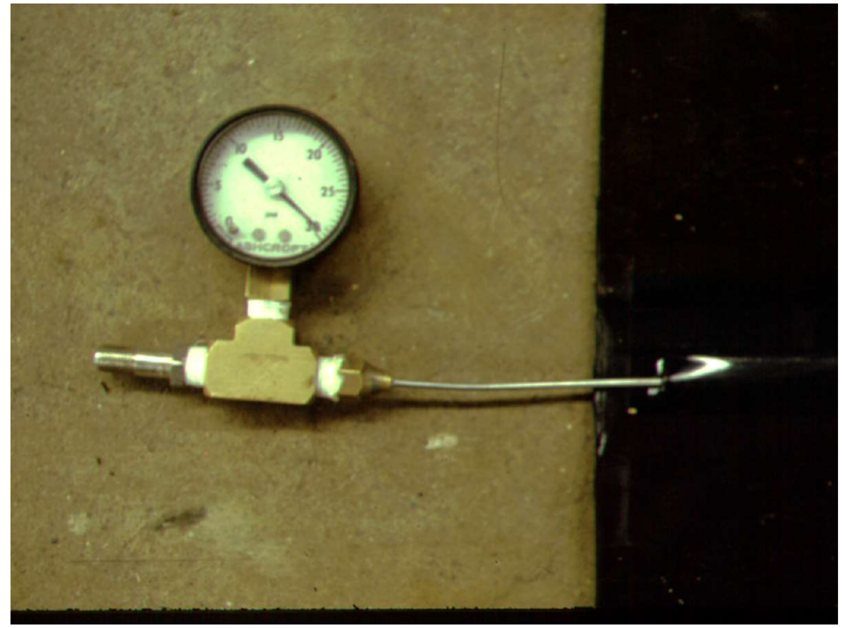
- details and penetrations are difficult
- work crews must be well trained
- equipment must be maintained
- overlap area must be **clean** and **dry** before seaming (holds for all GMs)
- Shingle overlaps down slope
- Seams up and down slopes

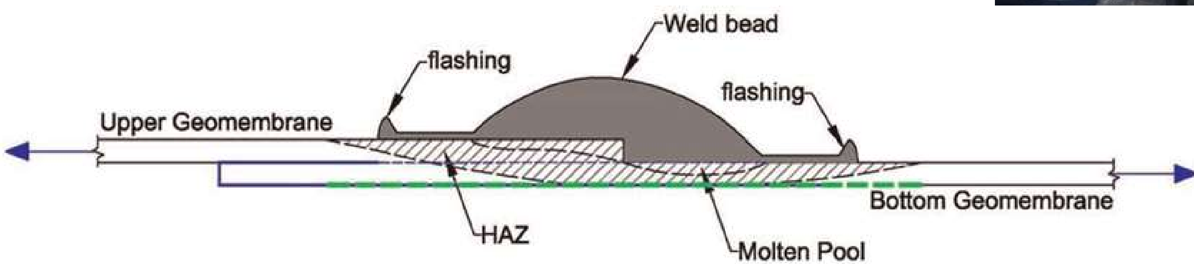

INGERSOLL-RAND

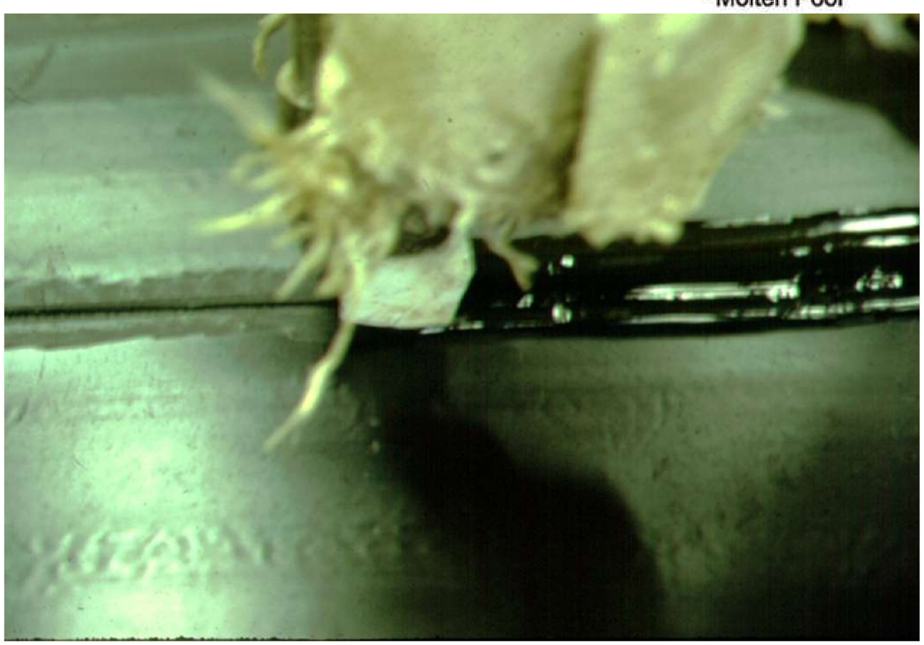

DEMTECH


DEMTECH

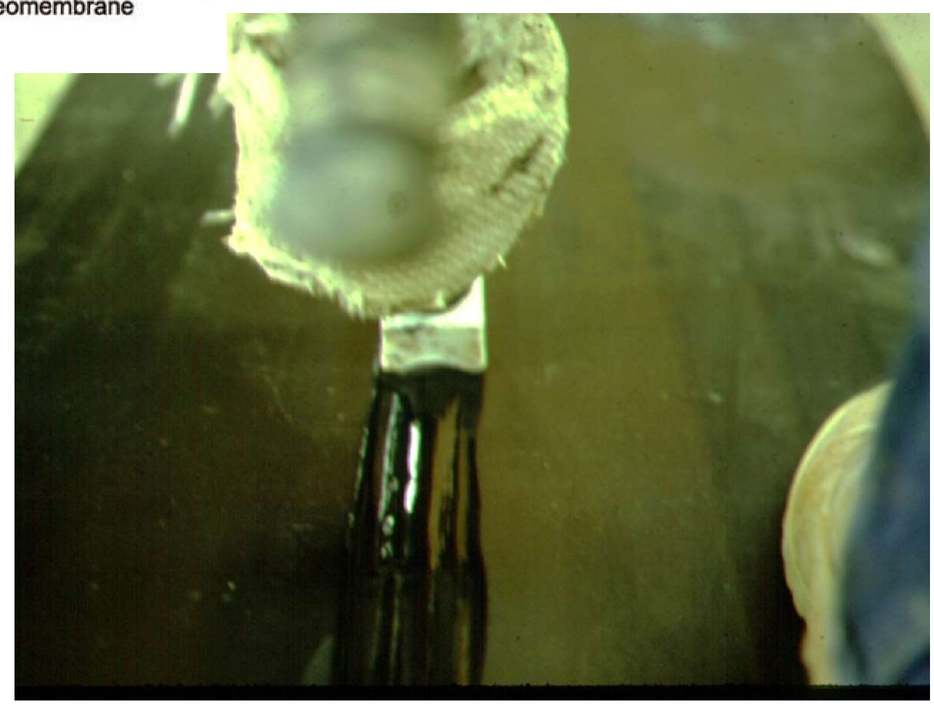



Cross section of a double track fusion weld.



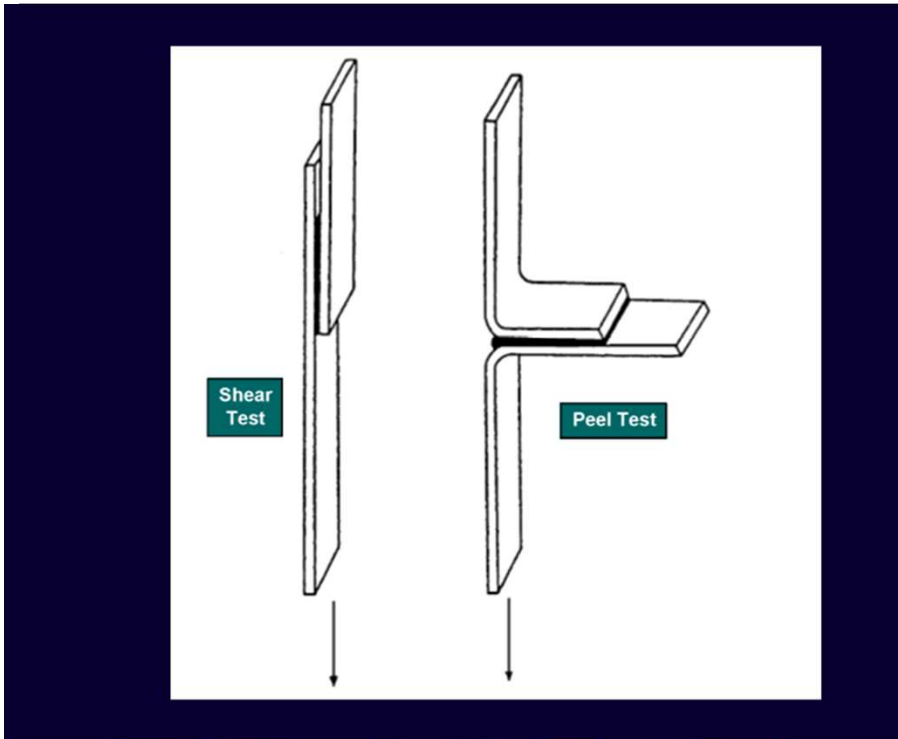

Weld bead
flashing
flashing
Upper Geomembrane
Bottom Geomembrane
HAZ
Molten Pool

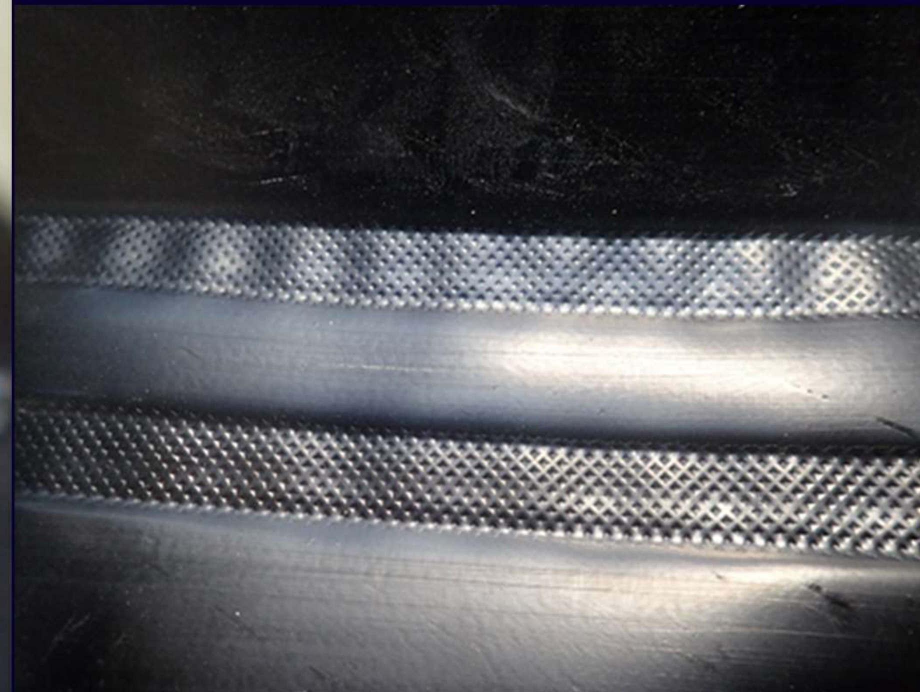


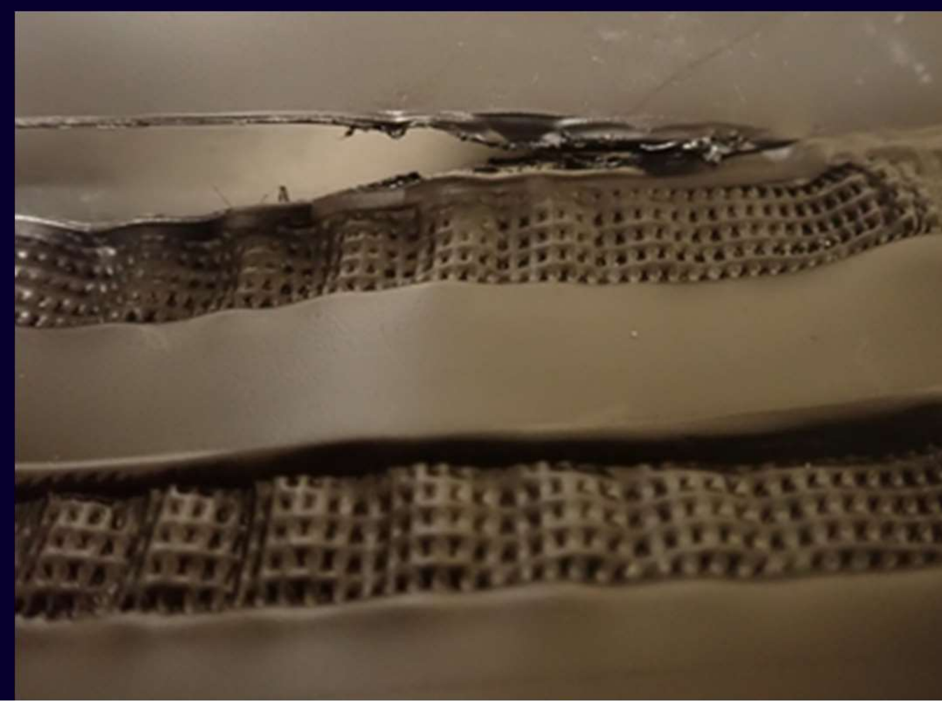



S-8
1052
S-2
1052


LET'S
DO
THIS.


Shear Test
Peel Test



Placement of GN and GC

- GNs should NOT be stored on ground due to vegetation / soil clogging
- GCs similar to GTs
- no equipment on underlying GSs
- joined using plastic ties or polymer braid
- QA plan must be specific
- GT must have generous overlap
- GT can be bonded to GN by hot air, hot wedge or hot knife (but needs care if GT is thin)

Geonet Installation

No. 1 concern is to protect against clogging and contamination through construction

Geonet Installation

Making sure there is net-net contact on butt seams

Geocomposite Installation

Continuous Sewn Seams

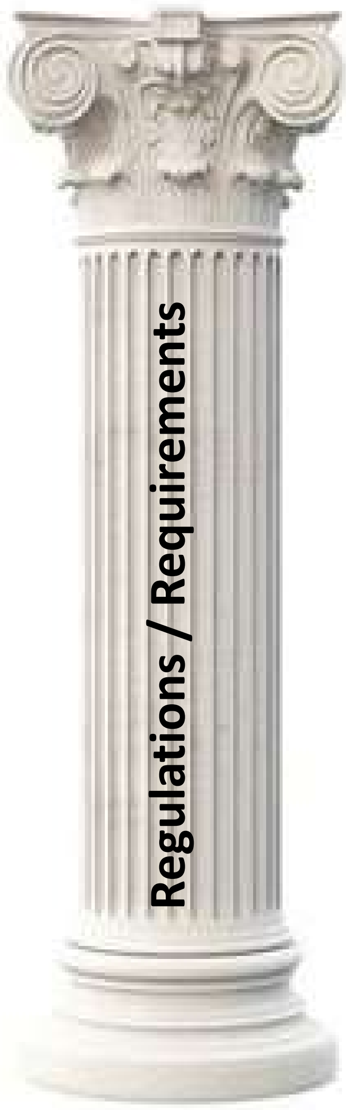
Pillars of Quality

Federal
Composite liner systems
Guidance for CQA

State regulations
Permitting
monitoring

Regulations / Requirements

Pillars of Quality



IGS
GSI
Geo-U
IAGI
ISO 17025

Education / Credentialing

Pillars of Quality

Quality Enforcement (QC/QA)

Quality Measures

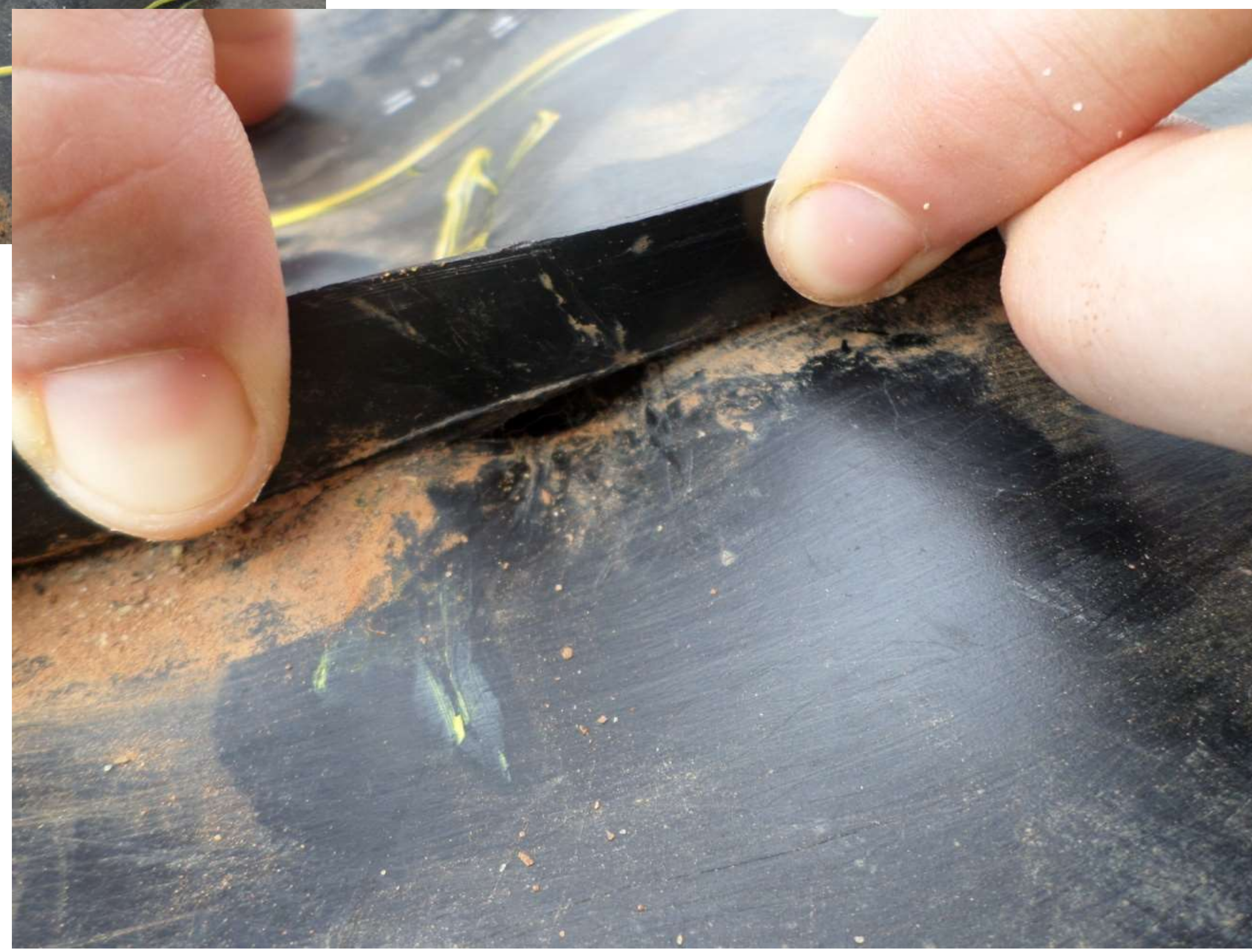
Quality Enforcement (QC/QA)

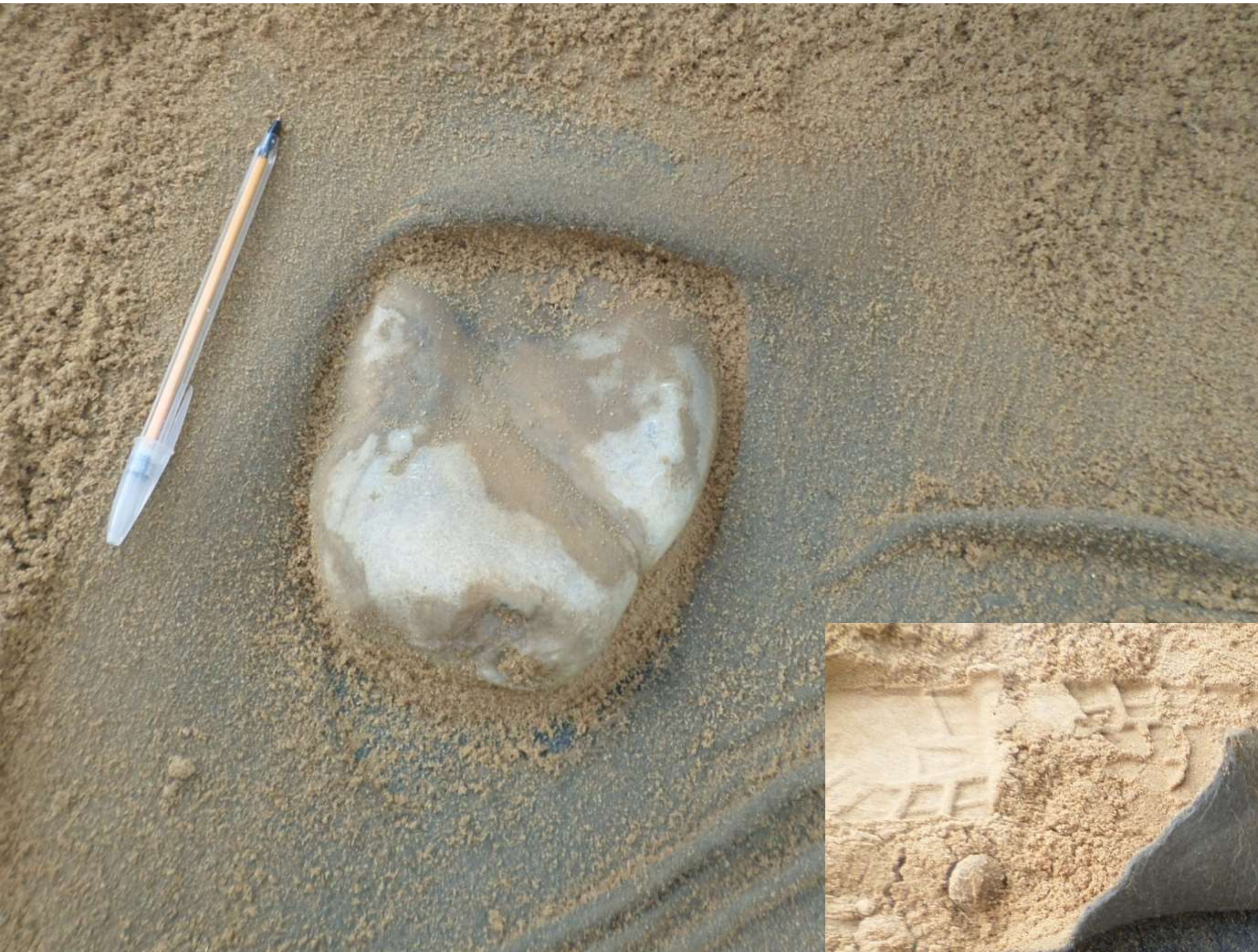
- Manufacturing Quality Control
- Manufacturing Quality Assurance (Verification Testing - EPA Guidance: 1/100,000 ft^2 of material)

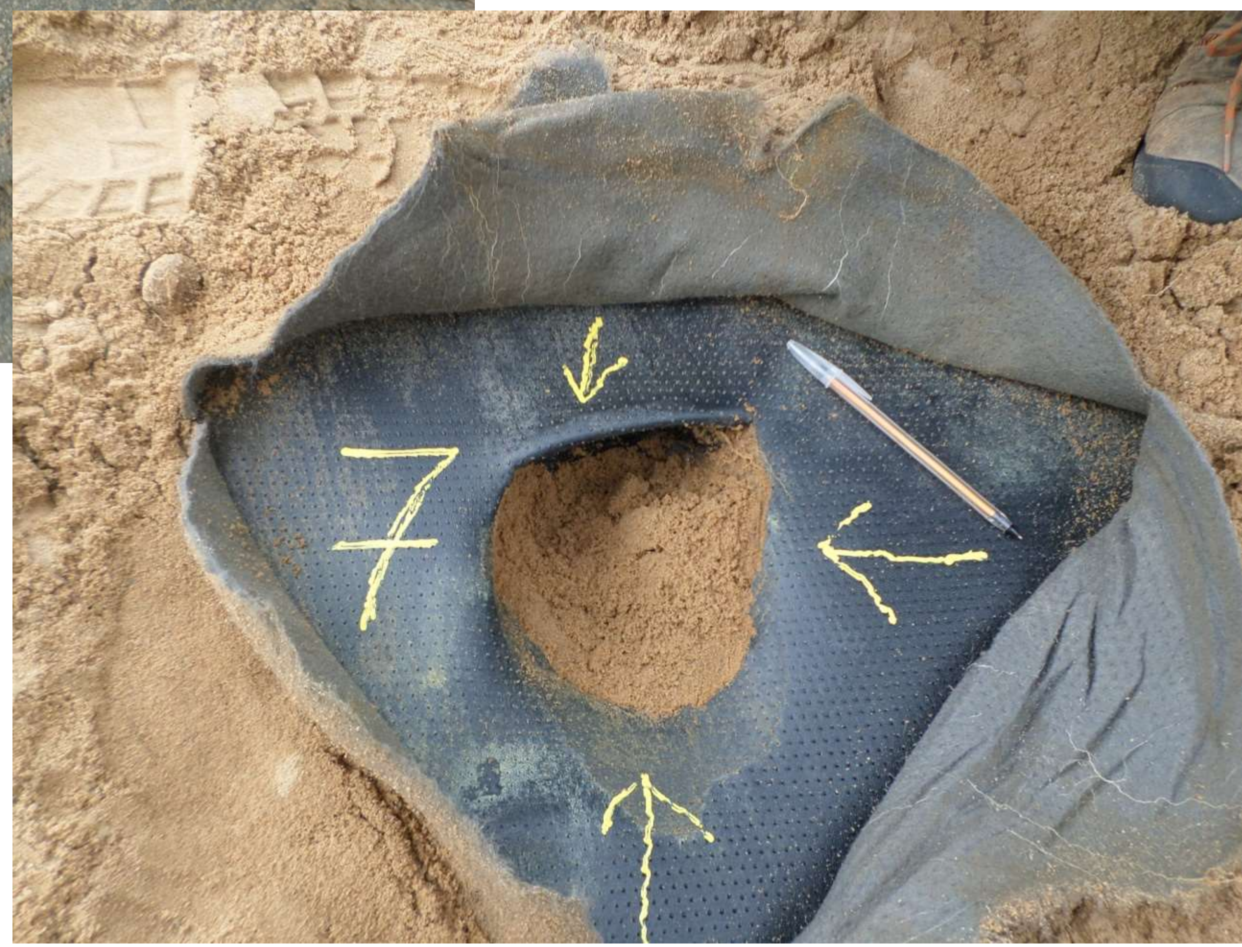
- Construction Quality Control
- Construction Quality Assurance (Monitoring / Inspection / **Electrical Leak Location**)

“All installed geomembrane liners should be subjected to electric leak location survey.”

J.P. Giroud, Geosynthetics 2013 Panel Discussion

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V.T.OK

COURTESY HGI Geophysics

THE LAST SAFETY NET…

“Many problems have been found by ELL surveys that would never have been located any other way, and this is even with good installers and good CQA.”

Richard Thiel, 2012

The Truth About Leakage

- Environmental impacts ranges from negligible to severe
- Liquid depths in impoundments and ponds varies from extremely low to very high
- Landfill LCRS do not always function as designed.
- Summary: Site-specific, contaminant-specific, no “one size fits all” approach, no stringent federal guidance
- Only approximately 2% of geomembrane-lined facilities checked for leaks world-wide.

Current U.A. Regulations

- States requiring ELL:
  - New York – landfill expansions – primary and secondary geomembranes
  - California (several regions) – landfill expansions, waste lagoons
  - Wisconsin
  - Washington – waste water lagoons
  - North Carolina – landfill expansions
  - New Jersey
  - Ohio – landfill expansions

- States recommending ELL (site specific):
  - Florida, Illinois, Louisiana, Maryland, Maine, Missouri, Montana, Virginia, Wyoming

Electrical Leak Location

- Mature Technology
- Multiple Service Providers
- Standards: Bare Geomembrane
  - Water Puddle (ASTM D7002)
  - Water Lance (ASTM D7703)
  - Conductive Geomembrane Spark Testing (ASTM D7240)
  - Arc Testing (ASTM D7953)
- Covered Geomembrane (water or earth)
  - Dipole Method (ASTM D7007)
  - ASTM D8265 (dipole method typically used)
- Choice of method(s) includes many factors, many of which are site and project-specific.

Hole Statistics

- FOUND BY ELL
- 0.7 – 11 Holes per hectare (Rollins, Jacquelin, 1999)
- Up to 15 holes per hectare for leachate impoundments (Rollins, Jacquelin, 1999)
- Exposed geomembranes: 4 holes per hectare with CQA, 22 holes per hectare without CQA (Forget, 2005)
- Covered geomembranes: 0.5 holes/ha with CQA and bare survey, 16 holes/ha without CQA or bare survey (Forget, 2005)
- 73% damage occurs during cover soil placement, 24% occur during geomembrane installation, 2% occurs during post construction

Solmers Statistics

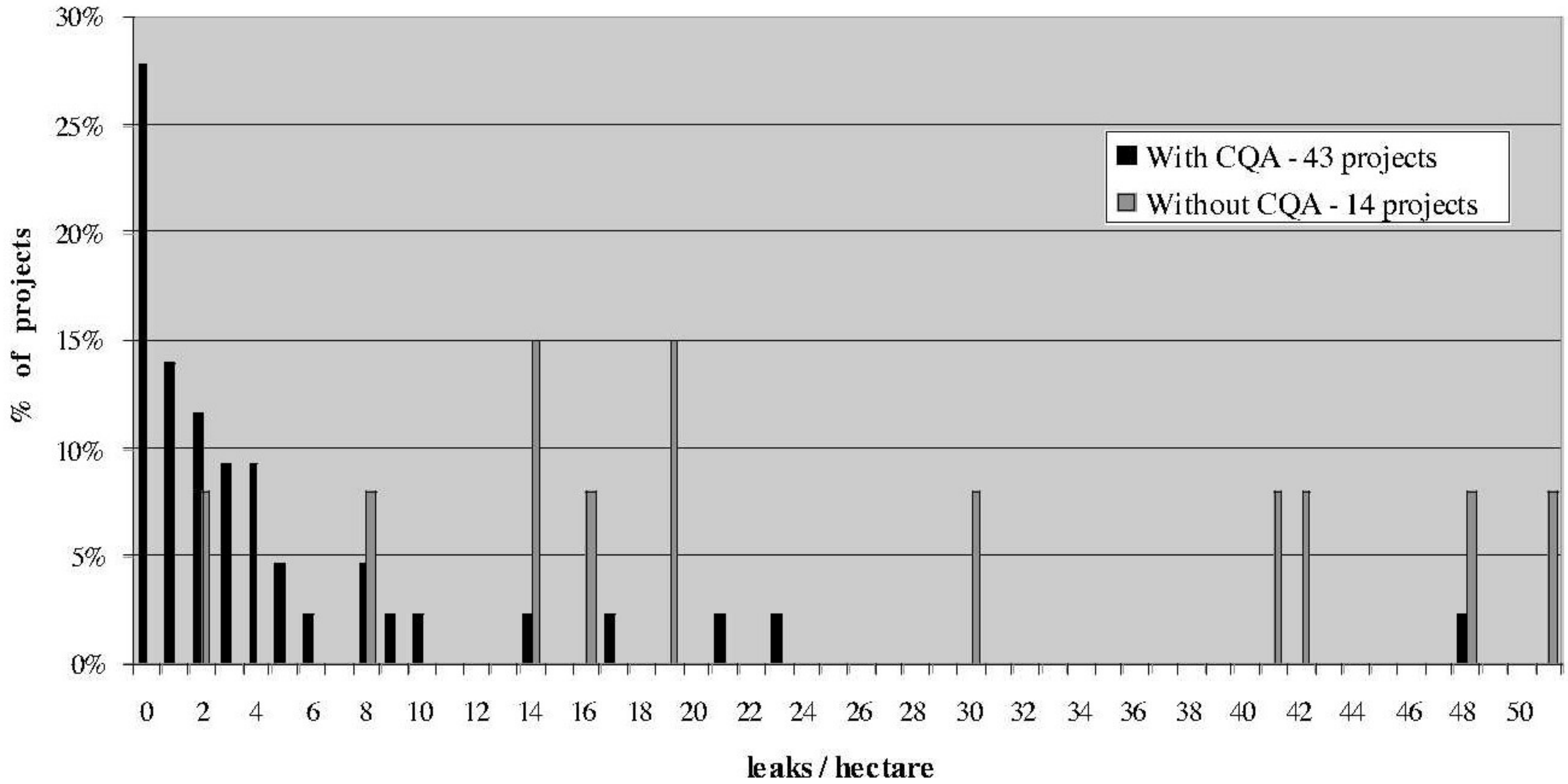


Figure 3. Leak Densities – With and Without a Rigorous CQA Program (Exposed Geomembranes).

- Forget et al., 2005; summary of 57 projects over 10 years

SOLMERS STATISTICS

- Forget et al., 2005; summary of 57 projects over 10 years

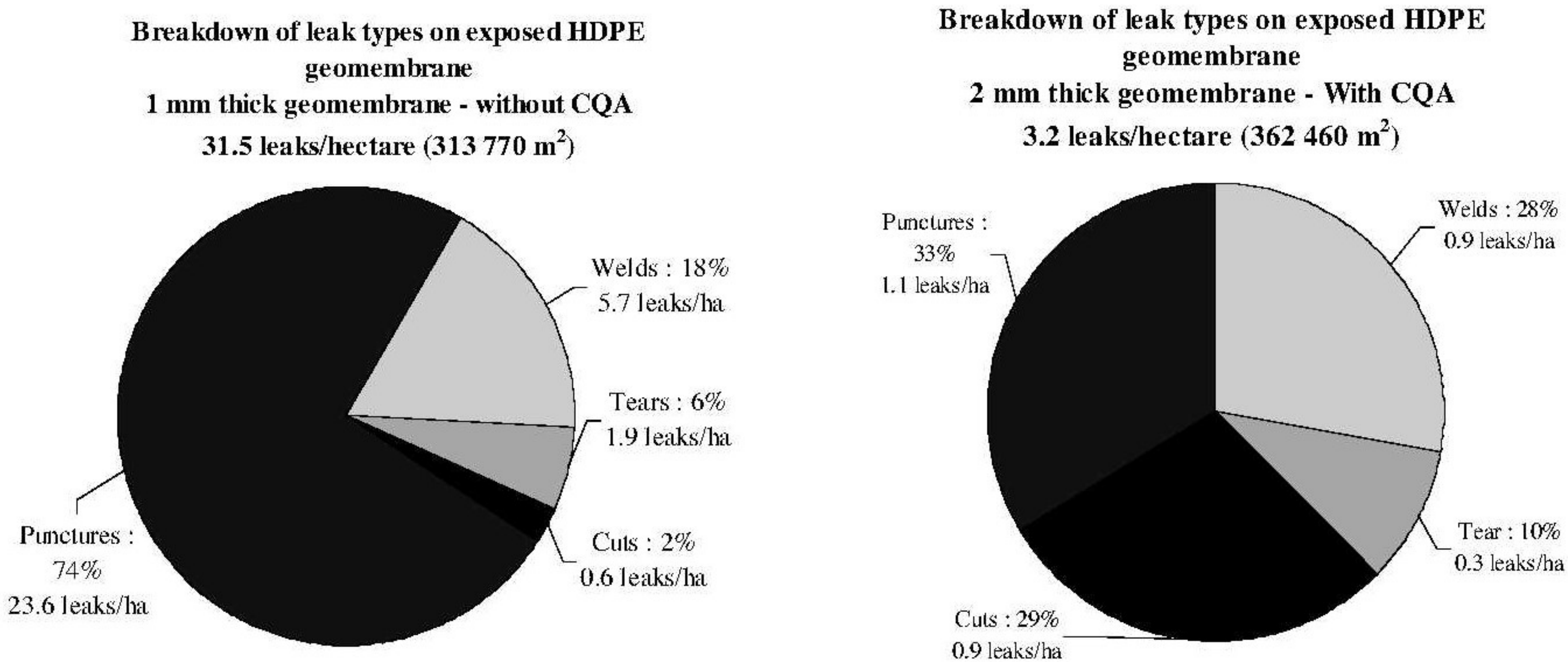


Figure 4. Breakdown of Leak Types (Exposed HDPE Geomembranes).

Hole Statistics Updated*

- Projects tend to have either no or few holes or many holes (depending on construction/ CQA practices, i.e. function of "mistakes")
- Applying simple average of all cases not descriptive of "most likely" number of holes
- Statistics from 50 ELL projects 2016-2018 for projects in North America in HDPE with CQA in place (typical "high quality" installation).
  - Average: 0.3 leaks/ha (0.74 leaks per acre)

*Gilson-Beck (2019). "Controlling leakage through installed geomembranes using electrical leak location", *Geotextiles and Geomembranes* 47, 697-710.

Geosynthetics contribute to sustainable Infrastructure

INTERNATIONAL GEOSYNTHETICS SOCIETY

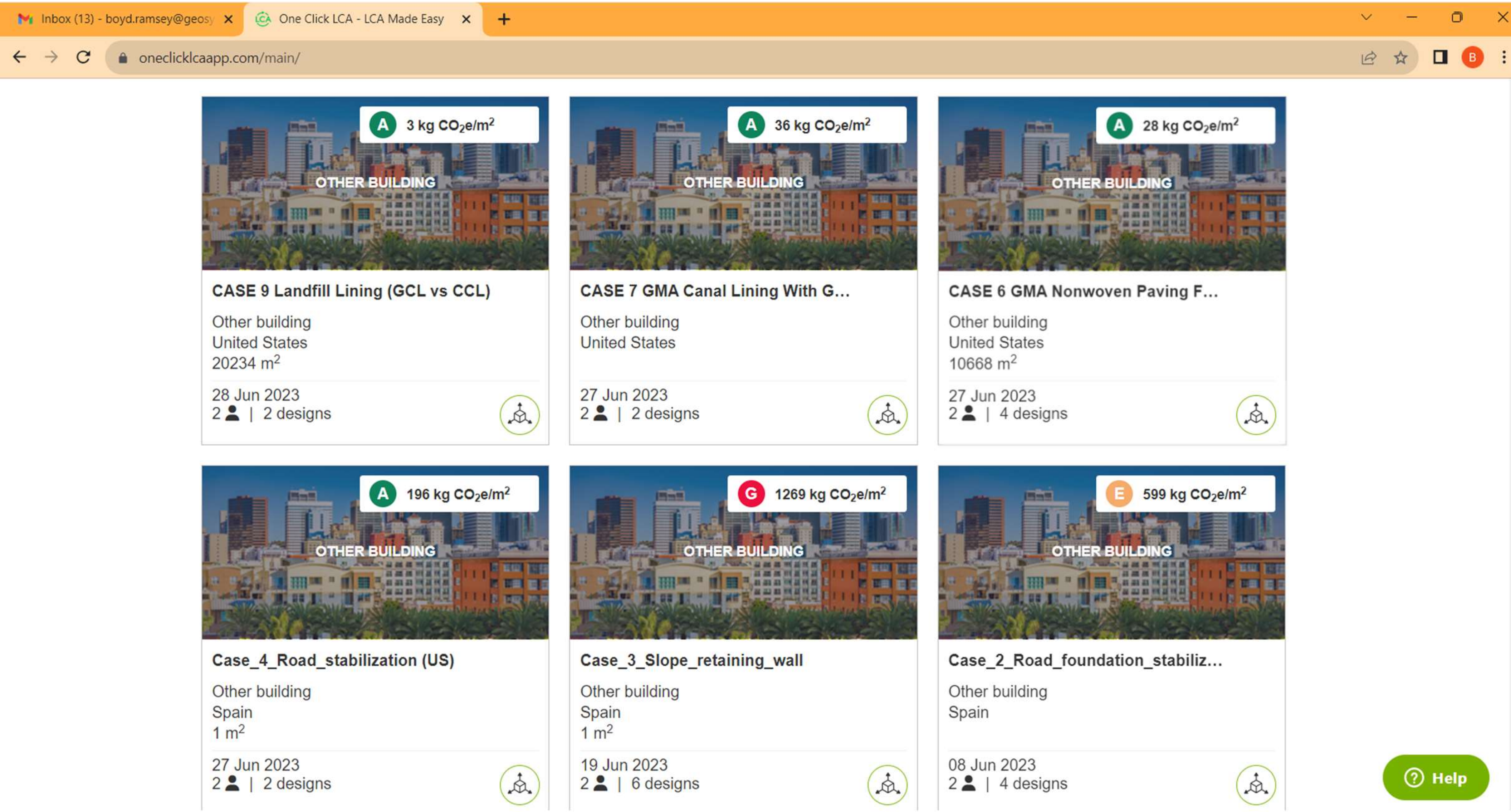
Environmental Sustainability Calculations

One Click LCA

- IGS Calculator Partner IGS
- Harvests product EPD and carbon footprints
- Supports software and sustainability education

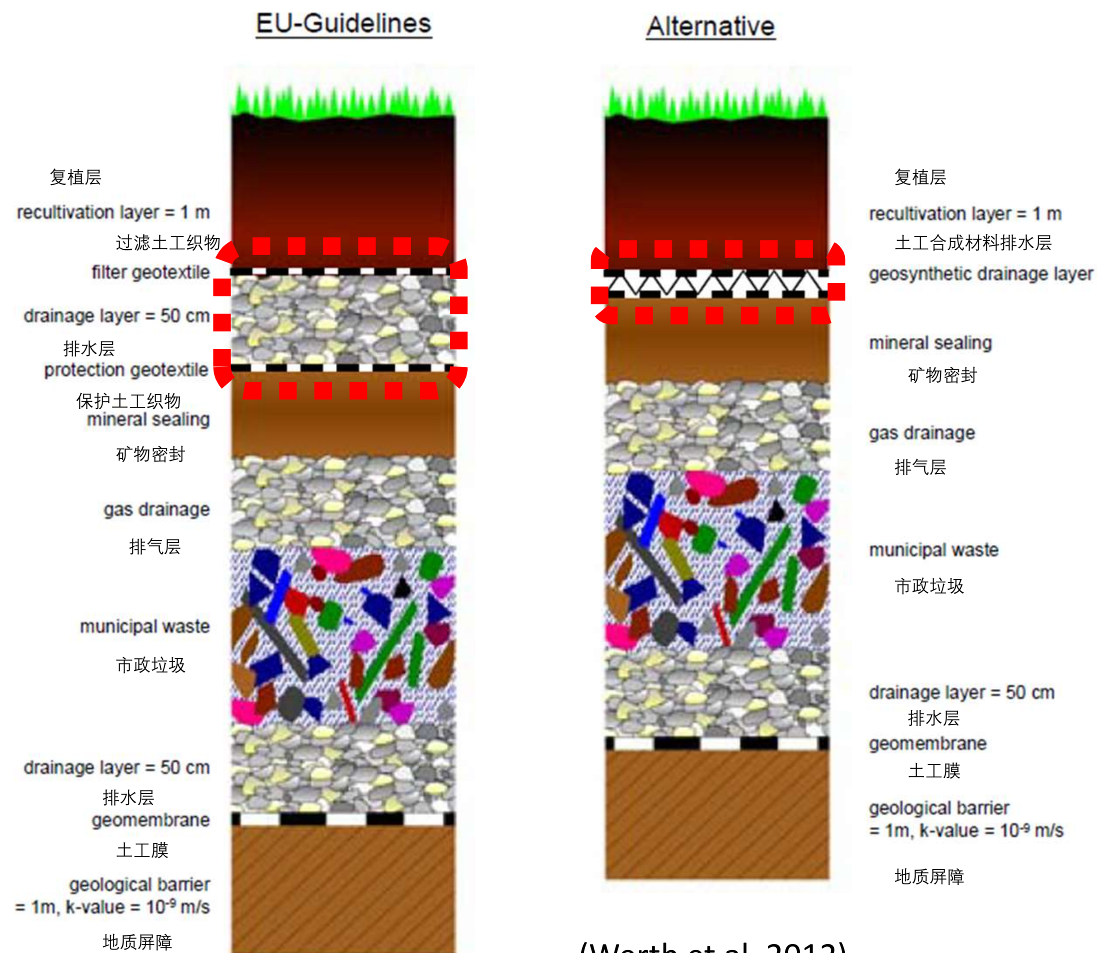
Overview

- Provide geosynthetic common templates
- Give access to life cycle assessment tools (the more the merrier!).
- Facilitate (and encourage!) the creation of EPD.
- So far, focus on **environmental** (sustainability) calculations
- Demo for idealized, geosynthetic-based scenarios (so called IGS templates)


Inbox (13) - boyd.ramsey@geosy
One Click LCA - LCA Made Easy
oneclicklcaapp.com/main/
A 3 kg CO2e/m2
OTHER BUILDING
CASE 9 Landfill Lining (GCL vs CCL)
Other building
United States
20234 m2
28 Jun 2023
2 | 2 designs
A 36 kg CO2e/m2
OTHER BUILDING
CASE 7 GMA Canal Lining With G...
Other building
United States
27 Jun 2023
2 | 2 designs
A 28 kg CO2e/m2
OTHER BUILDING
CASE 6 GMA Nonwoven Paving F...
Other building
United States
10668 m2
27 Jun 2023
2 | 4 designs
A 196 kg CO2e/m2
OTHER BUILDING
Case_4_Road_stabilization (US)
Other building
Spain
1 m2
27 Jun 2023
2 | 2 designs
G 1269 kg CO2e/m2
OTHER BUILDING
Case_3_Slope_retaining_wall
Other building
Spain
1 m2
19 Jun 2023
2 | 6 designs
E 599 kg CO2e/m2
OTHER BUILDING
Case_2_Road_foundation_stabiliz...
Other building
Spain
08 Jun 2023
2 | 4 designs
Help

Case 1 - Landfill drainage layer

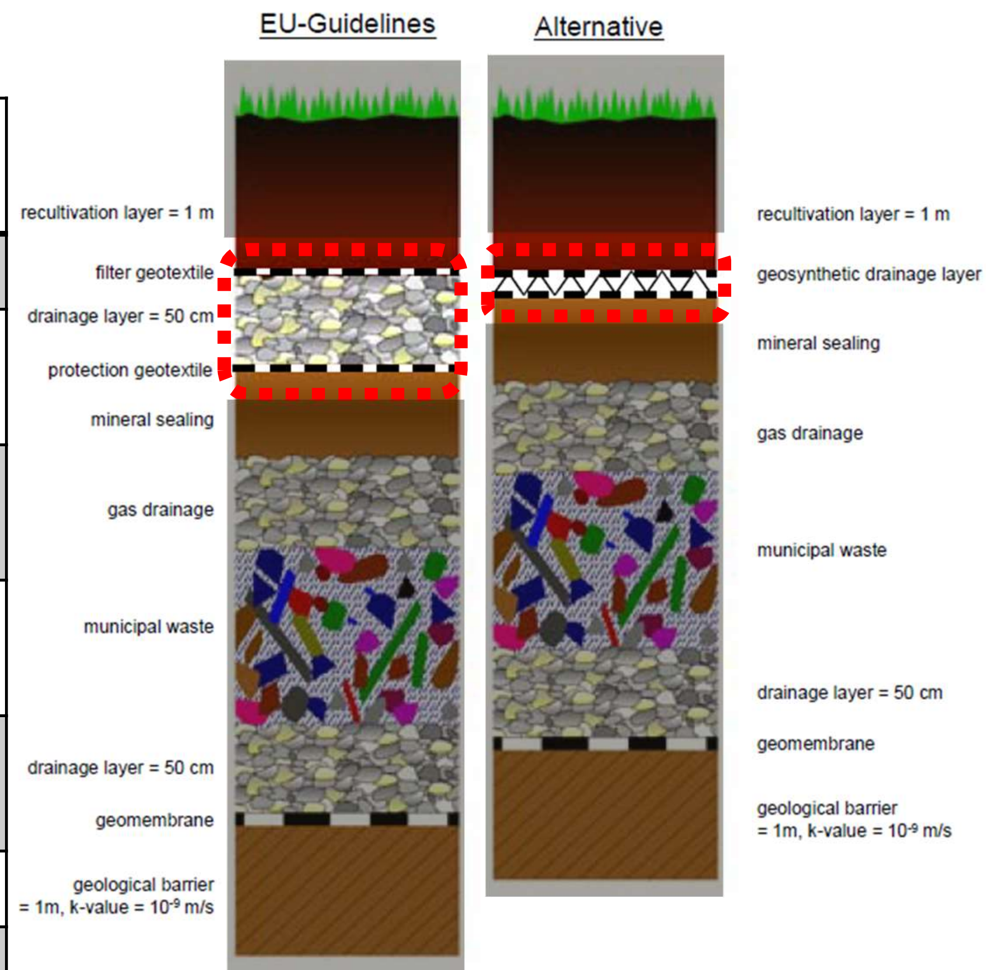
- Comparison of drainage systems over a waste landfill site.
- Function: Provide a proper drainage layer in a landfill cap of a waste landfill site by discharging infiltrating rainwater from the surface.
- Functional unit: Construction and disposal of 1 m^2 surface area drainage layer with a hydraulic conductivity of 1 mm/s or more and 100 years of service life.



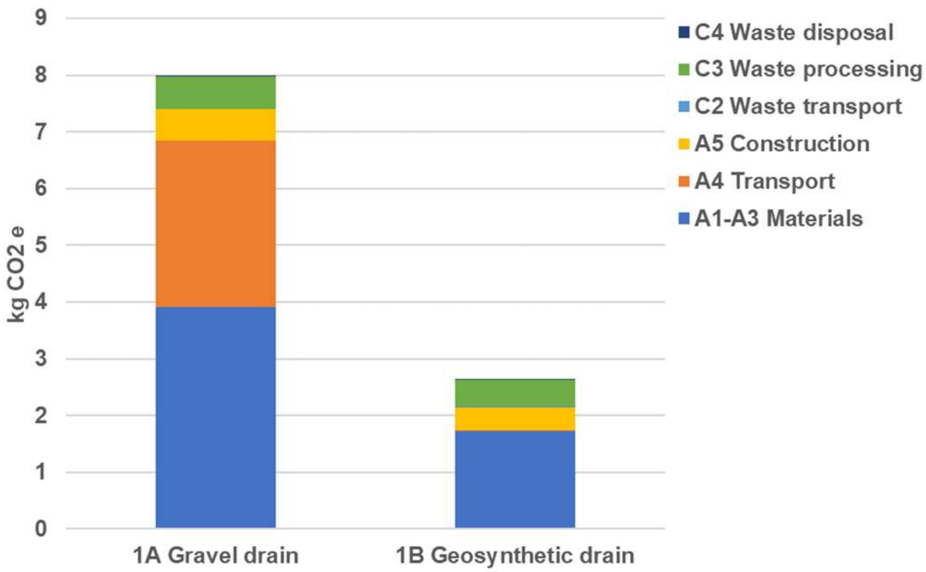
(Werth et al. 2012)

Case 1 - Inventory

Item	Unit	Case 1A	Case 1B
Gravel	t/m^2	0.90	-
Geosynthetic filter layer	m^2/m^2	1	-
Geosynthetic protection layer	m^2/m^2	1	-
Geosynthetic drainage core	m^2/m^2	-	1
Diesel used in building machines	MJ/m^2	4.5	3.8
Transport, lorry	tkm/m^2	45.1	0.2
Transport, freight, rail	tkm/m^2	0.1	0.3

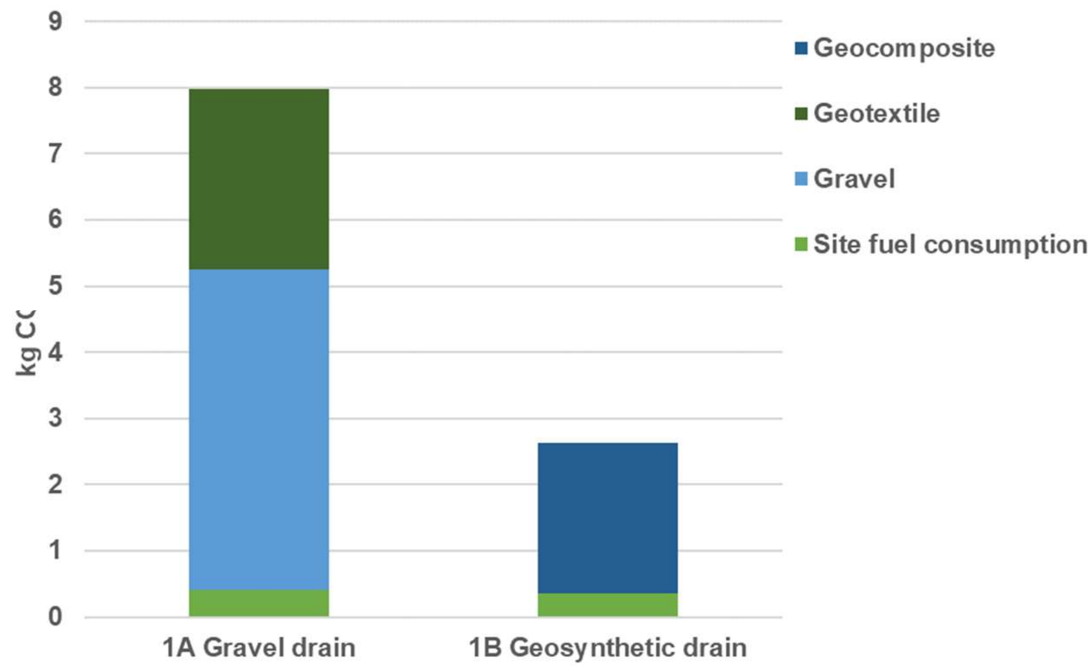


Case 1 – Results



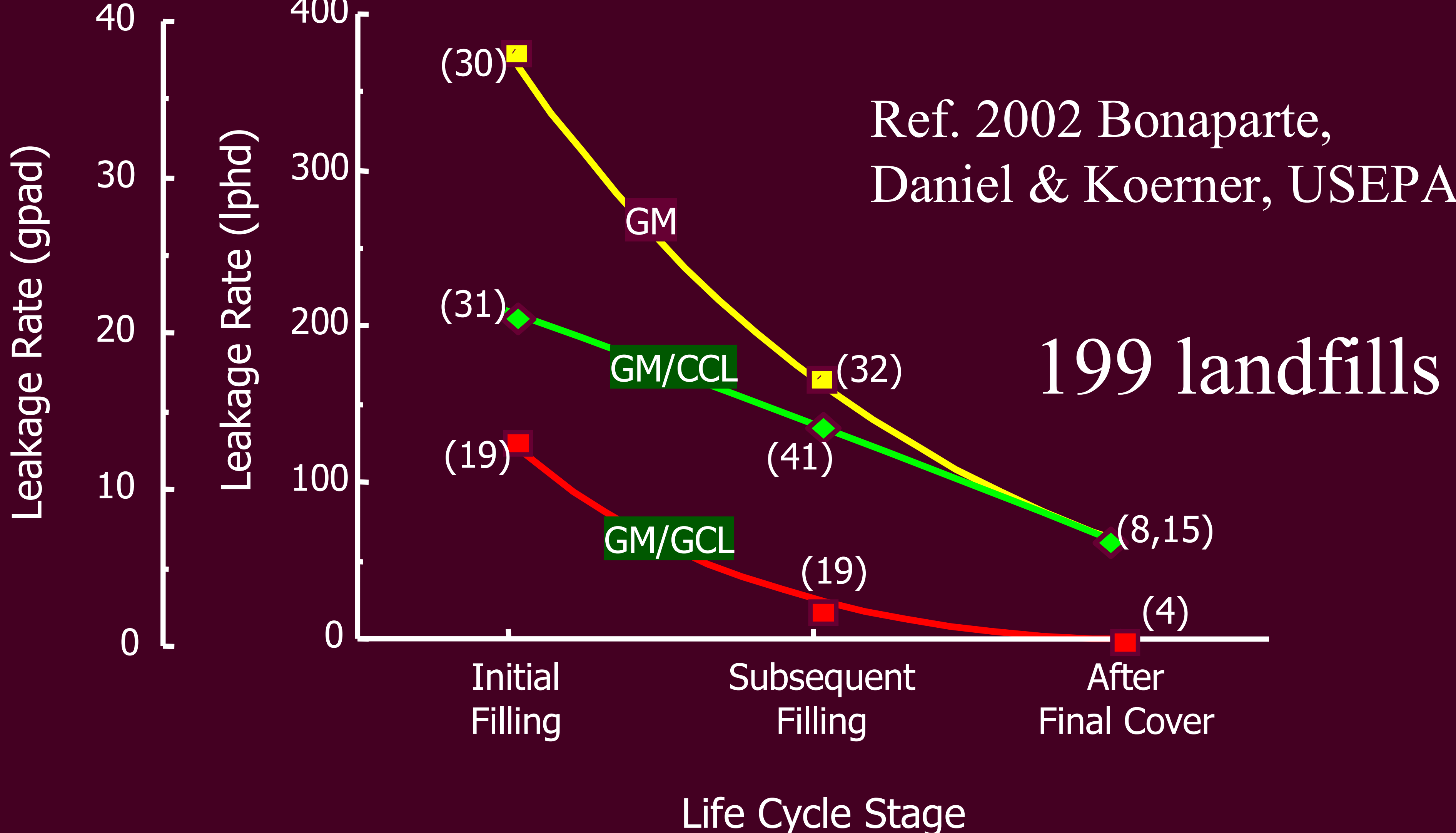
- 67% of reduction in kg CO2 e when using a solution based on geosynthetics

Case	kg CO2 e (per 1 m^2 of drain)
1A Gravel drain	7.28
1B Geosynthetic drain	2.63



Pillars of Quality

Average Primary Leakage Rates



Thank you !!!

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