Improving the Performance of Canals with Geosynthetics
IGS Technical Committee on Hydraulics
November 15-17, 2021

Service life of Geosynthetics

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Expertise
Geosynthetics
Engineered Construction Materials

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Eric Blond

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Eric Blond is an independent consultant offering technical services to the geosynthetics and engineered construction material industries. His key expertise are soil filtration and drainage with geosynthetics; durability of geosynthetics and construction materials; geosynthetics lining materials and systems, and other applications of Geosynthetics.

Eric Blond is actively involved in several technical committees and Industry associations:

- ASTM D35 on Geosynthetics: Past-Chairman of subcommittee D35.02 on endurance properties of geosynthetics
- ISO TC221 on Geosynthetics: Chairman of the Canadian Mirror Committee, WG6-PG3 on Designing for Filtration
- IGS – International Geosynthetics Society: chairman of the Technical Committee on Hydraulics, council member (2010-2016)
- IGS-NA – North-American Chapter of the IGS: Secretary
- CGS – The Canadian Geotechnical Society: vice-President
- CCCME – Canadian Commission on Construction Material Evaluation: member of the commission
- CSA A123 on Bituminous roofing materials – member of the committee

Eric Blond is committed to education and introduction of geosynthetics technologies. He has authored more than 100 technical papers, conferences and courses. He is lecturer at Ecole Polytechnique de Montreal. He also offers custom trainings to engineering firms, and regularly contributes to pre-conference short courses and other training events.

He is a professional engineer, member of the OIQ (Quebec) and APEGA (Alberta). With more than 25 years of experience and projects conducted in Canada, the USA, South-America, Europe and the Middle-East, Eric Blond holds one of the most comprehensive independent expertise in geosynthetics and polymeric materials used in the construction industry.

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Service life versus Design Life

- A design life is a duration arbitrarily set for a project
- The design life depends on:
  - Predicted evolution of usage
  - Acceptable time until the next major reconstruction
  - Expected durability of major components of the structure
  - etc
- Design lives rarely exceed 100 to 120 years.

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Service life versus Design Life

In a canal, the waterproofing material can be:

- Exposed, on the soil or on top of a concrete base.
  The membrane is accessible and could (theoretically) be replaced periodically.
- Protected, e.g., by a concrete cover or a geosynthetic system.
  Replacing the geomembrane would require to rebuild the structure entirely.

The service life required for the waterproofing material depends on how it is used in the structure.

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Service life versus Design Life

The suitability for purpose of the material used to control seepage is defined considering:

* The ability to be waterproof in the context of the application
* The ability to retain its watertightness over time

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'Suitability for purpose' of different materials

Many products can be used to contain water.

Let's review:

* Steel
* Wood
* Concrete
* Geomembranes

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‘Suitability for purpose’ of different materials

Is **steel** a suitable material for canal lining?

* Steel is waterproof and used to contain liquid in several applications.
* Steel can be treated to last in humid environments.
* Steel can be welded to create large, continuous surfaces.

BUT

* Covering large surfaces would be very expensive!

Experiences were made in the 60’s, for erosion control (not for sealing)

Three men in a motorboat take water samples of the Cuyahoga River where the shore is lined with semi-submerged automobile wreckage in 1968 - Alfred Eisenstaedt/The LIFE Picture Collection/Getty Images
https://history.com/news/epa-earth-day-cleveland-cuyahoga-river-fire-clean-water-act

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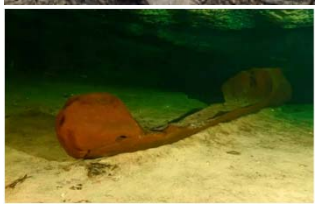
‘Suitability for purpose’ of different materials

Is **wood** a suitable material for canal lining?

* Wood is waterproof. Wood has been used to make boats for 1000 of years.
* Wood has been used to make water pipes and sewers.
* Different types of wood offer different resistances to water. When entirely submerged, wood can resist water for very long time.

BUT

* Wood is not a suitable material for canal lining because it would require too many assemblies.
* Wood is not a good material for canal lining for many other reasons.



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‘Suitability for purpose’ of different materials

Is **concrete** a suitable material for canal lining?

* Concrete is widely used for canal lining. But, is it a good product to prevent seepage?
* For concrete to preserve its watertightness:
  * It must not crack. Therefore, the concrete layer must be designed to resist reasonable soil settlement: it must be thick and reinforced. A thin layer of concrete will crack and will not preserve its watertightness.
  * It must not degrade over time. The formulation must be selected to resist permanent exposition to water.

* **Concrete is not suitable to control seepage in canals**

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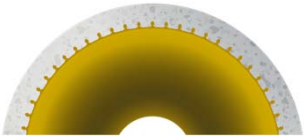
‘Suitability for purpose’ of different materials

Is **a geomembrane** a suitable materials for canal lining?

* Polymeric materials are widely used to contain liquid (e.g., plastic bottles).
  * PVC, HDPE, LLDPE and other geomembranes are watertight, can be assembled, are tolerant to small soil settlement, and are formulated to preserve their properties for very long durations.
* In fact, a PVC, HDPE or LLDPE liner is often incorporated to concrete structures to increase their durability.

BUT

* The geomembrane must offer a sufficient service life
  * Too thin, or badly formulated plastic films used in place of geomembranes will not offer a sufficient service life.



Photos AKS Lining Systems

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‘Suitability for purpose’ of different materials

In summary:

- Steel and wood are (obviously) NOT suitable for canal lining applications.
  - Despite they are waterproof and used to contain liquid in other applications
- Concrete is likely to crack and is therefore NOT suitable as a waterproofing material – unless a very strong, very thick layer is used. However, it may offer a protection for an underlying geomembrane.
- Geomembranes are suitable for use in canal lining applications if their service lives exceeds the design life of the structure.

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Geomembranes often used for canal lining

Type of geomembrane	Do they meet the required performance?
HDPE	Waterproof
LLDPE	Can be welded
PVC	Can be transported and installed
EPDM	Available and cheap
Butyl rubber	Easy to repair (most)
CSPE	Can resist small elongation
Bituminous	
Polypropylene	**HOW LONG DO THEY LAST??**

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Expected service life of geosynthetics?

Service life can be estimated:

* Based on field observation: performance of existing, similar structures
* Based on available science on material aging

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Noticeable projects with geosynthetics

* **Field experience with geosynthetics shows their ability to perform for >50 years**

Table 1 - Oldest Geomembrane Installations by Type of Geomembrane (after Scuero, 2005)

Type	Basic material	Abbreviation	Total exposed	Total covered	Oldest exposed	Oldest covered
Polymeric	Polyvinyl chloride	PVC-P	73	70	1974	1960 (Terzaghi Dam, Canada)
Polymeric	Polyolefin	LLDPE	0	28	-	1970 (Atbashinsk, Kirgizistan)
Polymeric	Polyolefin	HDPE	2	11	Not known	1978 (Bitburg, Germany)
Polymeric	Elastomeric	Polysobutylene IIR	5	4	1982	1959 (Contrada Sabetta, Italy)
Polymeric	Chlorosuflonated Polyethylene	CSPE	3	5	Not known	1981 (Kolnbrein Austria)
Polymeric	Polyolefin	PP	1	2	Not known	Not known
Polymeric	Chlorinated Polyethylene	CPE	0	3	-	1970 (Odiel-Perejil, Spain)
Bituminous	Oxidized bitumen	Prefabricated GM	7	10	1973 (Banegon, France)	1978
Bituminous	Polymer bitumen	SBS	0	1	-	1996

Oldest project: 62 years

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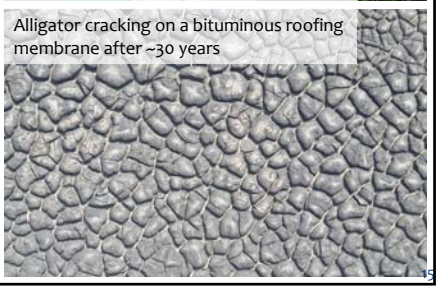
Importance of service conditions!

* Aqueduc and some man-made structures sealed with bitumen lasted for centuries. This is possible when the bitumen is entirely protected from oxygen and solvents.
* However, bituminous roofing products must be replaced periodically, typically every ~10 to 20 years.

This observation also applies to polymeric geomembranes: aging is faster when the geomembrane is exposed

Pont du Gard aqueduc, France
2000 years old, active for ~6 centuries
(with no maintenance)

Alligator cracking on a bituminous roofing membrane after ~30 years



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Importance of service conditions!

* Exposed geomembranes may also be exposed to unexpected stresses, vandalism and wildlife.
* **It is always better to cover a geomembrane:**
  * To increase its service life
  * To minimize its exposure to accidental damages

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Importance of service conditions!

Several solutions exist to cover a geomembrane.

A critical component of the design is to select an adequate solution considering available materials, workmanship, subgrade, cost, etc.

Rehabilitation of irrigation canal, west of Fayoum (photo from MWRI Facebook page)

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Field experience with geosynthetics

In summary, previous experience with the use of geomembranes in hydraulic applications has shown us that:

* The oldest geomembrane is more than 60 years old, and it is still performing.
* Service life depends on service conditions. Protected geosynthetics last much longer than exposed geosynthetics

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Service life of Geosynthetics

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Service life of a geomembrane

* The criteria to be considered to declare the 'end of life' of a geomembrane is when it leaks.

This end-of life can be reached:

- During construction (when detected on time, most leaks can be repaired) — **Survivability**
- When service conditions are beyond what the material can handle (improper design) — **Performance**
- When the material has lost its intrinsic properties and cracks under normal service conditions — **Durability**

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Service life of a geomembrane

Survivability	Performance	Durability
The material must resist construction stress	The material must resist to the stress it will be exposed to while in service	The material must preserve its properties over its entire service life
* Delivery and unrolling * Assembly into a continuous layer (welding) * Covering with subsequent material (concrete)	* Puncture by aggregates * Expanding and contracting joints of the concrete cover * Slope stability * …	* Canals = resist contact with potable water, oxygen * Other applications of geomembranes are often much more demanding!

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Service life of a geomembrane

Survivability	Performance	Durability
The material must resist construction stress	The material must resist to the stress it will be exposed to while in service	The material must preserve its properties over its entire service life

Installation — in service — Long-term performance

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Service life of a geomembrane

Survivability	Performance	Durability
The material must resist construction stress	The material must resist to the stress it will be exposed to while in service	The material must preserve its properties over its entire service life

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Designing for Survivability

Essentially based on field experience

Assessment of the ability of the geomembrane to survive involves a holistic approach to the construction process:

* Storage and handling
* Construction and installation technique
* Mechanical properties of the geomembrane
* Use of cushioning materials, such as geotextiles
* Design of the structure
* Quality assurance? Electrical Leak Location?

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Designing for Survivability

Improper storage and handling may affect the properties, hence the performance of the product

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Designing for Survivability

For canal lining:

* Minimum thickness 1.0 mm – may be increased to 1.5 mm under warm climate
  * Ease of welding is an essential criterion, may require a thicker product
* Minimizing the development of wrinkles caused by thermal expansion reduces the risk of accidental puncture
  * White-surfaced geomembranes

Survivability is closely related to construction practice

* Experienced installers!

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Service life of a lining product

Survivability	Performance	Durability
The material must resist construction stress	The material must resist to the stress it will be exposed to while in service	The material must preserve its properties over its entire service life

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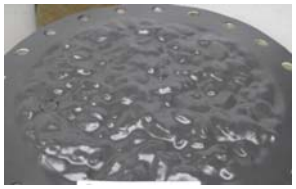
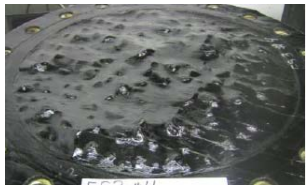
Designing for Performance

Example: puncture resistance

* ASTM D5514 to observe gravel / geomembrane interaction





Photos: CTT Group

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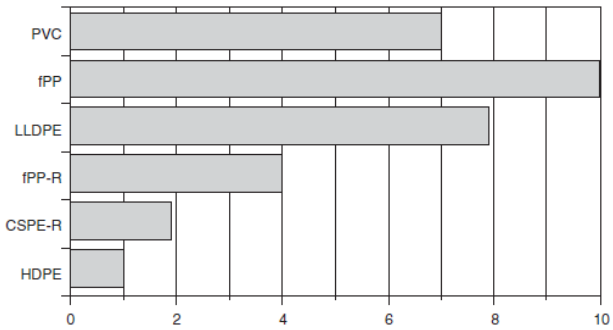
Designing for Performance

* Index property: Critical Cone Height (CCH)
* All geomembranes are not the same!



Scheirs, 2009

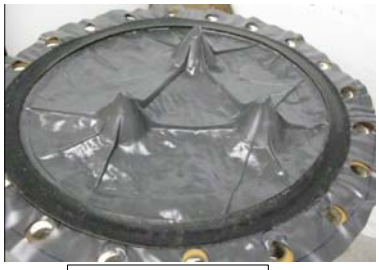


Photo: CTT Group

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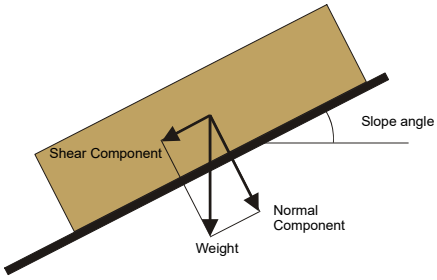
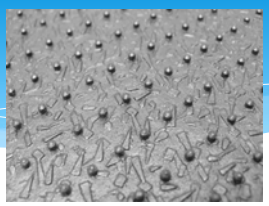
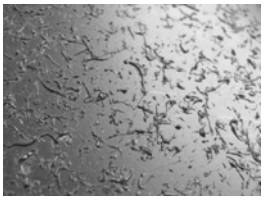
Designing for Performance

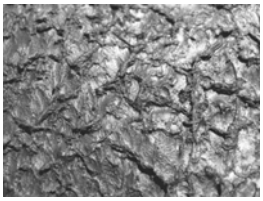
Several other design considerations

* Interface friction properties
* Surface erosion
* Elongation over crack
* …









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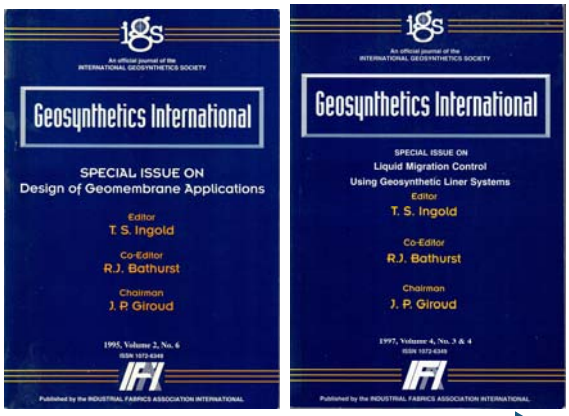
Designing for Performance

Design methods for the safe design of geomembrane lining have been published

- 1995, Volume 2, N°6: Special issue on Design of Geomembranes Applications
- 1997, Volume 4, N°3 and N°4: Special issue on Liquid Migration Control Using Geosynthetic Liner Systems

Full texts of 'Geosynthetics International' (and 'Geotextiles and Geomembranes') are accessible to regular members of the IGS



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Service life of a lining product

Survivability	Performance	Durability
The material must resist construction stress	The material must resist to the stress it will be exposed to while in service	The material must preserve its properties over its entire service life

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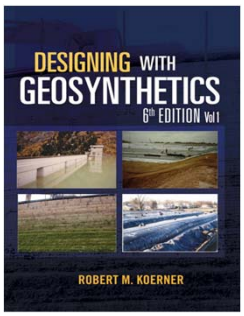
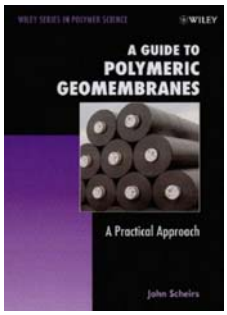
Designing for Durability = long-term performance

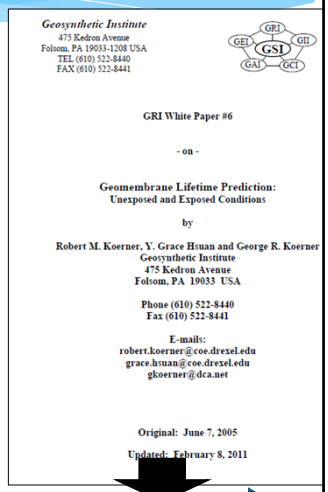
Since the 1950's, a lot of literature on the performance of 'plastics' was published

Tests methods and design methods were developed for geomembranes as well

* ASTM D35
* ISO TC221
* CEN TC189







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GRI White Paper #6

- on -

Geomembrane Lifetime Prediction:
Unexposed and Exposed Conditions

by

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Original: June 7, 2005

Updated: February 8, 2011

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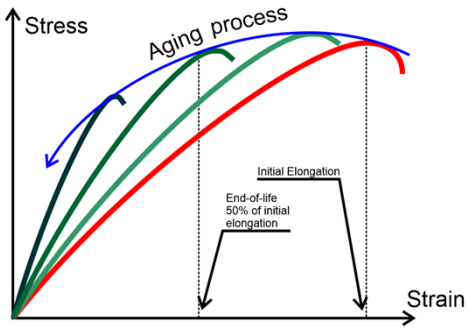
Designing for Durability = long-term performance

A lifetime can be predicted based on the degradation mechanisms of the geomembrane, which depends on the type of polymer and the environment:

* Temperature
* Chemical environment
* Exposure to UV
* Stress
* …



The typical end-of-life considered is a reduction of 50% of a relevant property, such as the elongation at break for a product which function is to remain waterproof.

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Designing for Durability = long-term performance

Examples of degradation mechanisms:	Applicable to:
* **Oxidation – UV or thermal**	**All**
* Molecular chain reorganization (stress-cracking)	HDPE
* Molecular chain scission	All (in harsh environment)
* Reticulation	EPDM
* Loss of volatile matter	PVC
* Loss of plasticizers	PVC
* Dehydrochlorination	CSPE, PVC
* Segregation, loss of light-weight components	Bitumen

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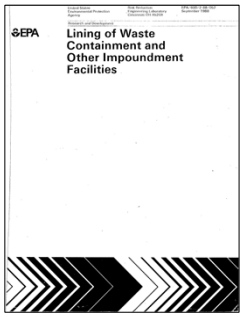
Designing for Durability = long-term performance

For **Polyethylene:**

* Oxidation – UV or thermal
* Molecular chain reorganization / stress-cracking (HDPE)
* Chemical dissolution (in harsh chemical environments)


Siting, design, operation and rehabilitation of landfills

Contents


EPA

Lining of Waste Containment and Other Impoundment Facilities

The most abundant literature available on aging of geomembranes is focusing on the use of polyethylene in waste containment facilities

HDPE geomembranes are prescribed for waste containment facilities in several countries

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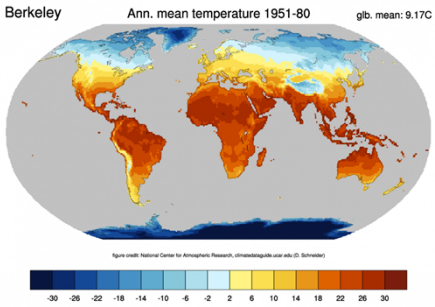
Designing for Durability = long-term performance

For **Polyethylene:**

* **Oxidation – UV or heat-induced**
* Molecular chain reorganization / stress-cracking (HDPE)
* Chemical dissolution (in harsh chemical environments)

PE geomembranes are formulated to resist oxidation
The rate of oxidation depends on the temperature
Therefore, the lifetime prediction depends on:

* The application
* The location on earth



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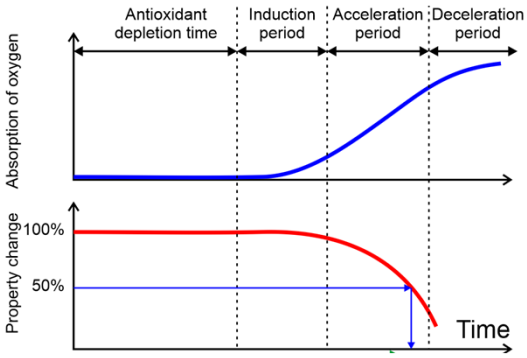
Designing for Durability = long-term performance

Oxidation process for geomembranes:

Property change is not linear. Polyethylene preserves ~100% of its initial properties until antioxidant are completely depleted.

* Mechanical properties are not reliable to project end of life!
* OIT – an indicator of the effectiveness of antioxidants – is used instead to detect the end of the antioxidant depletion time.



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Lifetime prediction for HDPE geomembranes in Covered applications

Lifetime prediction for typical **HDPE geomembrane**

The lifetime prediction depends on the temperature

Table 2 - Lifetime prediction of HDPE (nonexposed) at various field temperatures

In Service Temperature (°C)	Stage "A" (years)			Stage "B" (years)	Stage "C" (years)	Total Prediction* (years)
	Standard OIT	High Press. OIT	Average OIT			
20	200	215	208	30	208	446
25	135	144	140	25	100	265
30	95	98	97	20	49	166
35	65	67	66	15	25	106
40	45	47	46	10	13	69

*Total = Stage A (average) + Stage B + Stage C

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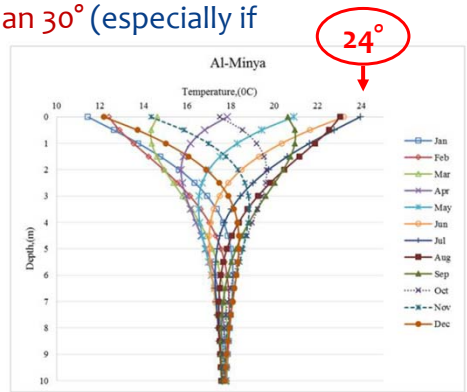
Lifetime prediction for HDPE geomembranes in Covered applications

The temperature of the soil can be considered to know the temperature of the geomembrane. This temperature is typically lower than 30° (especially if the geomembrane is covered).

Therefore, the predicted lifetime for a HDPE geomembrane can be considered to exceed 166 years.

In Service Temperature (°C)	Total Prediction* (years)
20	446
25	265
30	166
35	106
40	69



Temperature data from A.A. Serageldin et Al: Soil Temperature Profile for some New Cities in Egypt: Experimental Results and Mathematical Model

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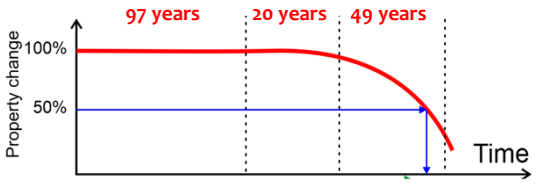
Lifetime prediction for HDPE geomembranes in Covered applications

For hydraulic applications where a HDPE geomembrane is covered:

a lifetime significantly greater than a typical design life of 100 years is a reasonable assumption.

During approximately 2/3 of the predicted lifetime, the mechanical properties do not change.

This prediction applies to a HDPE geomembrane formulated to comply to the specification GRI GM13. Compliant products are available from numerous suppliers.



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Lifetime prediction for other geomembranes in Covered applications

- LLDPE degrades faster than HDPE geomembranes. Achieving similar service lives as HDPE can be achieved with better stabilization packages and by using thicker products.
- The rate of degradation of PVC depends on the type of plasticizer. There are very significant differences in performance between different grades of PVC geomembranes!
- EPDM geomembranes contain up to 40% of carbon black and are therefore very stable. The oldest geomembrane in service (1959) is a predecessor of EPDM
- Bituminous geomembranes piggy-back on the historical use of bitumen as a sealing product in covered applications.

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Lifetime of geomembranes in EXPOSED applications

Every type of geomembrane is sensitive to UV and weathering.

An exposed geomembrane is subject to vandalism, accidental damage, wildlife…

It is always better to protect geomembranes!

* Nevertheless, the Geosynthetic Institute is conducting a very long-term assessment of the performance of geomembranes using laboratory exposure.

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Lifetime of geomembranes in EXPOSED applications

HDPE, EPDM, and high-performing grades of flexible polypropylene and PVC geomembranes have predicted lifetimes **in excess of 30 years** – with tests still ongoing

These results are supported with the performance on actual projects monitored:

* PVC (1974)
* Butyl (1982)
* Bituminous (1973)

Table 6 – Exposed lifetime prediction results of selected geomembranes to date (2011)

Type	Specification	Prediction Lifetime in a Dry and Arid Climate
HDPE	GRI-GM13	> 36 years (ongoing)
LLDPE	GRI-GM17	≃ 36 years (halflife)
EPDM	GRI-GM21	> 27 years (ongoing)
fPP-2	GRI-GM18	≃ 30 years (halflife)
fPP-3	GRI-GM18	> 27 years (ongoing)
PVC-N.A.	(see FGI)	≃ 18 years (halflife)
PVC-Eur.	proprietary	> 32 years (ongoing)

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Final remarks (1/2)

Geomembranes are more suitable than concrete to act as a sealing material.

Geomembranes are in fact **the most suitable materials for sealing canals**.

Geomembranes should be protected against accidental degradation, vandalism, exposition to UV and excessive heat. Concrete, concrete slabs, or other protection materials (geosynthetics) can be used for that purpose.

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Final remarks (2/2)

A PROTECTED geomembrane can offer a service life **in excess of 100 years**

To offer such a performance, the geomembrane must be adequately formulated:

* with adequately selected antioxidants for all polymeric geomembranes
* With plasticizers for PVC

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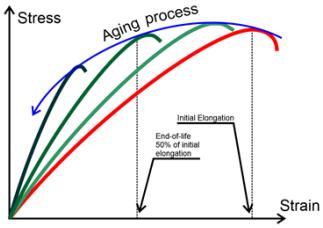
Questions?



Expertise
Geosynthetics
Engineered Construction Materials

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