**Geosynthetics Classification**

Geosynthetics can be broadly classified into categories based on method of manufacture. The current denominations and brief descriptions of geosynthetics are presented below.

**Geotextiles** are continuous sheets of woven, nonwoven, knitted or stitch-bonded fibres or yarns. The sheets are flexible and permeable and generally have the appearance of a fabric. Geotextiles are used for separation, filtration, drainage, reinforcement and erosion control applications.

**Geogrids** are geosynthetic materials that have an open grid-like appearance. The principal application for geogrids is the reinforcement of soil.

**Geonets** are open grid-like materials formed by two sets of coarse, parallel, extruded polymeric strands intersecting at a constant acute angle. The network forms a sheet with in-plane porosity that is used to carry relatively large fluid or gas flows.

**Geomembranes** are continuous flexible sheets manufactured from one or more synthetic materials. They are relatively impermeable and are used as liners for fluid or gas containment and as vapour barriers.

**Geocomposites** are geosynthetics made from a combination of two or more geosynthetic types. Examples include: geotextile-geonet; geotextile-geogrid; geonet-geomembrane; or a geosynthetic clay liner (GCL). Prefabricated geocomposite drains or prefabricated vertical drains (PVDs) are formed by a plastic drainage core surrounded by a geotextile filter.

**Geosynthetic clay liners (GCLs)** are geocomposites that are prefabricated with a bentonite clay layer typically incorporated between a top and bottom geotextile layer or...
bonded to a geomembrane or single layer of geotextile. Geotextile-encased GCLs are often stitched or needle-punched through the bentonite core to increase internal shear resistance. When hydrated they are effective as a barrier for liquid or gas and are commonly used in landfill liner applications often in conjunction with a geomembrane.

**Geopipes** are perforated or solid-wall polymeric pipes used for drainage of liquids or gas (including leachate or gas collection in landfill applications). In some cases the perforated pipe is wrapped with a geotextile filter.

**Geocells** are relatively thick, three-dimensional networks constructed from strips of polymeric sheet. The strips are joined together to form interconnected cells that are infilled with soil and sometimes concrete. In some cases 0.5 m to 1 m wide strips of polyolefin geogrids have been linked together with vertical polymeric rods used to form deep geocell layers called geomattresses.

**Geofoam** blocks or slabs are created by expansion of polystyrene foam to form a low-density network of closed, gas-filled cells. Geofoam is used for thermal insulation, as a lightweight fill or as a compressible vertical layer to reduce earth pressures against rigid walls.

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Geosynthetics include a variety of synthetic polymer materials that are specially fabricated to be used in geotechnical, geoenvironmental, hydraulic and transportation engineering applications. It is convenient to identify the primary function of a geosynthetic as being one of: separation, filtration, drainage, reinforcement, fluid/gas containment, or erosion control. In some cases the geosynthetic may serve dual functions.

**Separation:** The geosynthetic acts to separate two layers of soil that have different particle size distributions. For example, geotextiles are used to prevent road base materials from penetrating into soft underlying soft subgrade soils, thus maintaining design thickness and roadway integrity. Separators also help to prevent fine-grained subgrade soils from being pumped into permeable granular road bases.

**Filtration:** The geosynthetic acts similar to a sand filter by allowing water to move through the soil while retaining all upstream soil particles. For example, geotextiles are used to prevent soils from migrating into drainage aggregate or pipes while maintaining flow through the system. Geotextiles are also used below rip rap and other armour materials in coastal and river bank protection systems to prevent soil erosion.

**Drainage:** The geosynthetic acts as a drain to carry fluid flows through less permeable soils. For example, geotextiles are used to dissipate pore water pressures at the base of roadway embankments. For higher flows, geocomposite drains have been developed. These materials have been used as pavement edge drains, slope interceptor drains, and abutment and retaining wall drains. Prefabricated vertical drains (PVDs) have been used to accelerate consolidation of soft cohesive foundation soils below embankments and preload fills.

**Reinforcement:** The geosynthetic acts as a reinforcement element within a soil mass or in combination with the soil to produce a composite that has improved strength and deformation properties over the unreinforced soil. For example, geotextiles and geogrids are used to add tensile strength to a soil mass in order to create vertical or near-vertical changes in grade (reinforced soil walls).
Reinforcement enables embankments to be constructed over very soft foundations and to build embankment side slopes at steeper angles than would be possible with unreinforced soil. Geosynthetics (usually geogrids) have also been used to bridge over voids that may develop below load bearing granular layers (roads and railways) or below cover systems in landfill applications.

**Fluid/Gas (barrier) containment:** The geosynthetic acts as a relatively impermeable barrier to fluids or gases. For example, geomembranes, thin film geotextile composites, geosynthetic clay liners (GCLs) and field-coated geotextiles are used as fluid barriers to impede flow of liquid or gas. This function is also used in asphalt pavement overlays, encapsulation of swelling soils and waste containment.

**Erosion control:** The geosynthetic acts to reduce soil erosion caused by rainfall impact and surface water runoff. For example, temporary geosynthetic blankets and permanent lightweight geosynthetic mats are placed over the otherwise exposed soil surface on slopes. Geotextile silt fences are used to remove suspended particles from sediment-laden runoff water. Some erosion control mats are manufactured using biodegradable wood fibres.

Geotextiles are also used in other applications. For example, they are used for asphalt pavement reinforcement and as cushion layers to prevent puncture of geomembranes (by reducing point contact stresses) from stones in the adjacent soil, waste or drainage aggregate during installation and while in service. Geotextiles have been used as daily covers to prevent dispersal of loose waste by wind or birds at the working surface of municipal solid waste landfills. Geotextiles have also been used for flexible concrete formworks and for sandbags. Cylindrical geotubes are manufactured from double layers of geotextiles that are filled with hydraulic fill to create shoreline embankments or to dewater sludge.

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Geosynthetics can be effectively used as drains and filters in civil and environmental works in addition to or in substitution to traditional granular materials. Geosynthetics are easier to install in the field and often cost-effective in situations were granular materials available do not meet design specifications, are scarce or have their use restricted by environmental legislations.

Geosynthetics for drainage and filtration

Geotextiles and geocomposites for drainage are the types of geosynthetics used for drainage and filtration. These materials can be used in works such as retaining structures, embankments, erosion control, waste disposal areas, etc.

As a drain, a geosynthetic can be specified to attend hydraulic requirements that allow free flow of liquids or gases throughout or across its plane.
Geotextile filters have to attend criteria that assure that the base soil will be retained with unimpeded water flow. Available retention criteria establishes that

$$FOS \leq n D_s$$

where FOS is the geotextile filtration size, which is associated to pore and constriction sizes in the geotextile, $n$ is a number which depends on the criterion used and $D_s$ is a representative dimension of the base soil grains (usually $D_{85}$, which is the diameter for which 85% in weight of the soil particles are smaller than that diameter).

The filter has also to be considerably more permeable than the base soil throughout the project lifetime. Therefore, the permeability criterion for geotextiles establishes that

$$k_G \geq N k_s$$

where $k_G$ is the geotextile coefficient of permeability, $N$ is a number that depends on the project characteristics (typically varying between 10 and 100) and $k_s$ is the permeability coefficient of the base soil.

Clogging criteria require that the geotextile will not clog and are based on relations between geotextile filtration opening size and soil particle diameters that should be allowed to pipe through the geotextile. Performance filtration tests can also be carried out in the laboratory to evaluate the compatibility between a soil and a candidate geotextile filter.

If properly specified and installed, geosynthetics can provide cost-effective solutions for drainage and filtration in civil and environmental engineering works. Additional information on the use of geosynthetics in such applications and in other fields of geotechnical and geoenvironmental engineering can be found at www.geosyntheticssociety.org.


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Hydraulic structures comprise the geosynthetics market segment with arguably the largest growth opportunities. The term “hydraulic structures” includes dams and canals. Hydraulic structures interact with water, which can be one of the more destructive forces in the environment. Geosynthetics are often used to limit the interaction between the structure and water. Geosynthetics can increase the stability of the hydraulic structures.

For hydraulic structures, geosynthetics can be used to:

- Reduce or prevent water infiltration through the use of geomembranes
- Reduce or prevent bank erosion of canals through the use of geomembrane liners
- Provide drainage and/or filtration through the use of geotextiles and geonets
- Provide reinforcement for the structure’s foundation or the structure itself by using geogrids.

Geomembranes are practically impervious to water infiltration and are commonly used to create a hydraulic barrier on the upstream face of dams. The geomembranes can either be left exposed or covered up using materials such as concrete panels or rip-rap. The use of geomembranes has proven particularly useful in the retrofitting of ageing concrete dams. Exposure can shorten the life-span of the geomembrane due to UV-radiation degradation, but repairs can be made more easily than with covered geomembranes. Covered geomembranes can also be prone to damage, such as puncturing caused by the overlying and/or underlying materials. Geotextiles are often placed underneath, and sometimes over the geomembrane to protect the material from puncturing, serving as cushions to minimize stress concentrations.
Leakage through a geomembrane occurs mainly through defects at the seam joints, and puncture holes. Generally, the defects are minimized through CQA/CQC programs at the project site. However, leakage is inevitable especially as the geomembrane begins to age. To protect the structure, geonets or geonet/geotextile geocomposites are typically used as drainage behind the geomembrane. The leak water is collected and deposited downstream through a conduit in the dam or back into the reservoir.

The geosynthetic system is affixed to the dam facing by mechanical means, often through the use of anchor bolts and steel batten strips. Gaskets and sealants are used to waterproof the connections and joints. Dams with complicated geometries are more apt to have defects at the seams and joints.

The components of the geosynthetic system selected for use with a hydraulic structure are highly project- and site-specific. If properly specified and installed, geosynthetics can be cost-effective and prolong the service life of a hydraulic structure.

(*) Courtesy of the Geosynthetic Institute (GSI).

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Erosion is a natural process caused by the forces of water and wind. It is influenced by a number of factors, such as soil type, vegetation and landscape, and it can be accelerated by various activities that occur on a specific field installation. Uncontrolled erosion processes can cause major damages to existing structures and to the environment.

Geosynthetics can be used for erosion control in works such as:

- Slope Protection
- Channels
- Drainage Ditches
- Waterways
- Shoreline Protection
- Reclamation
- Re-vegetation
- Scour Protection
- Rockfall Netting
- Breakwaters
- Weirs
- Embankments

Depending on project and site characteristics, an erosion control work may involve the use of one or more geosynthetic products such as geotextiles, geomats, geonets, geogrids, etc.

Some examples of geosynthetics applications in erosion control works are presented as follows.
Slope erosion control

A slope protection work may need the use of geosynthetics, soil nailing, rock bolt or anchor to guarantee its stability. In some cases surface stability may be achieved by partially covering the slope face with a geotextile bag filled with cement paste. Complementary vegetation of the slope protects it from soil losses due to the actions of water or wind. Vegetation and geosynthetic mats can also be combined to protect the face of geosynthetic reinforced steep slopes against erosion.

Channel erosion control

Polymer or concrete blocks or panels and geosynthetics can be employed for the protection of channels, river banks and shore line slopes.

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Geosynthetics can be effectively used to reinforce unpaved roads and working platforms on soft soils. If well specified, a geosynthetic can have one or more of the following functions: separation, reinforcement and drainage. Geotextiles and geogrids are the most commonly used materials in such works.

Compared to the unreinforced unpaved road, the presence of geosynthetic reinforcement can provide the following benefits:

- Reduction of fill thickness;
- Separates aggregate from soft soil if a geotextile is used;
- Increases soft soil bearing capacity;
- Reduces fill lateral deformation;
- Generates a more favourable stress distribution;
- Widens the spreading of vertical stress increments;
- Reduces vertical deformation due to membrane effect;
- Increases the lifetime of the road;
- Requires less periodical maintenance;
- Reduces construction and operational costs of the road.

Typical degradation mechanisms in unreinforced unpaved roads on soft soils

Influence of geosynthetic reinforcement on unpaved road behaviour
As the depth of the ruts increase the deformed shape of the geosynthetic provides further reinforcement due to the membrane effect. The vertical component of the tensile force in the reinforcement reduces further vertical deformation of the fill.

Several researches in the literature have shown that in a reinforced road a given rut depth will be reached for a number of load repetitions (traffic intensity) larger than in the unreinforced case. This will yield to a greater life time and less periodical surface maintenance.

A draining reinforcement material will also accelerate soft soil consolidation, increasing its strength. Drainage of the soft soil can be achieved by using a geotextile, a geogrid and a geotextile or a geocomposite as reinforcement. The stabilisation of the top region of the soft foundation will be beneficial if the road is to be paved in the future reducing construction costs and minimising pavement deformations.

Design methods are available in the literature, including simple ones involving the use of charts for preliminary analyses. These methods require conventional soil and reinforcement parameters for design purposes under routine conditions. Some design charts have also been developed by some geosynthetics manufacturers specifically for preliminary design using their products.

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Roads and highway are of utmost importance to the development of any country. Due to systematic traffic of heavy vehicles, climate conditions and mechanical properties of the materials used in their constructions, highway pavements may last considerably less than expected.

In this sense, geosynthetics can be effectively used to:

- Reduce or avoid reflective cracking
- Work as a barrier to avoid pumping of soil fines
- Reduce asphalt cap thickness
- Reduce pavement thickness
- Increase the lifetime of the pavement.
The efficiency of the geosynthetics as reinforcement in a pavement can be estimated by the Efficiency Factor (E):

\[ E = \frac{N_r}{N_u} \]

- \( N_r \) = number of load repetitions up to failure for the reinforced pavement.
- \( N_u \) = number of load repetitions up to failure for the unreinforced pavement.

Available data in the literature present values of \( E \) as high as 16, which shows that considerable increases on the pavement lifetime can be achieved with the use of geosynthetic as reinforcement or separation. Field observations and research results confirm the improvements of pavement performance due to geosynthetic utilization.

![Graph showing the increase of pavement life time due to the use of geosynthetic reinforcement](image)

If properly specified and installed, geosynthetics can be cost-effective and improve the performance and durability of pavements. Additional information on the application of geosynthetics in pavements and other fields of geotechnical and geoenvironmental engineering can be found at [www.geosyntheticssociety.org](http://www.geosyntheticssociety.org).

(*) Courtesy of Dr. Lilian R. Rezende (University of Goias, Brazil).

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The construction of embankments on soft soils can be a challenging task. In this context, the use of geosynthetics to improve embankment stability is one of the most effective and well-tried forms of the soil reinforcement technique.

Typical unreinforced embankment failure and uses of geosynthetics as reinforcement.

In such problems, geosynthetics can be effectively used to

1) Reduce soft soils displacements due to low bearing capacity of soft soils;

2) Prevent overall failure of the embankment and soft foundation soil; and

3) Prevent sliding failure along the geosynthetics surface.

The stability level of a reinforced embankment on soft soil can be evaluated by the definition of safety factors ($F_s$):

- For overall stability
  \[ F_s = \frac{M_R + \Delta M_R}{M_D} \geq \text{typically } 1.2 \sim 1.3 \]
where $M_D$: soil driving moment  
$M_R$: soil resisting moment  
$\Delta M_R$: geosynthetic moment contribution against failure

- For stability against sliding failure  
  \[ F_s = \frac{P_R}{P_A} \geq \text{typically} 1.5 \]
  
  $P_A$: active thrust from the fill (from active earth pressures)  
  $P_R$: friction force along the fill-reinforcement interface

The efficiency of geosynthetics as reinforcements of embankments on soft soils can be visualized by the following figures.

In case of limited reinforcement effect, the so called “basal reinforced piled embankment” can be used. Prefabricated piles or improved soil piles can be employed.

If draining materials are used, geosynthetics can be properly specified to contribute to the acceleration of settlements due to soft soil consolidation.

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Horizontal layers of geosynthetic reinforcement can be included with retaining wall backfills to provide a reinforced soil mass that acts as a gravity structure to resist the earth forces developed behind the reinforced zone. Reinforcement types are geogrid, woven geotextile and polyester strap. The local stability of the backfill at the front of the wall is assured by attaching the reinforcement to facing units constructed with polymeric, timber, concrete or metallic wire basket materials comprised of a variety of shapes. In North America it has been shown that reinforced soil walls can be constructed for up to 50% of the cost of conventional gravity wall structures.
Analysis and design calculations for reinforced soil walls are related to external, internal, facing and global mechanisms. Global modes refer to instability mechanisms that pass beyond the composite reinforced soil structure. These analyses are routinely handled using conventional slope stability methods of analysis.

Design modes for reinforced soil walls: a), b), c) external; d), e), f) internal; g), h), i) facing

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Layers of geosynthetic reinforcement are used to stabilize slopes against potential deep-seated failure using horizontal layers of primary reinforcement. The reinforced slope may be part of slope reinstatement and (or) to strengthen the sides of earth fill embankments. The reinforcement layers allow slope faces to be constructed at steeper angles than the unreinforced slope. It may be necessary to stabilize the face of the slope (particularly during fill placement and compaction) by using relatively short and more tightly spaced secondary reinforcement and (or) by wrapping the reinforcement layers at the face. In most cases the face of the slope must be protected against erosion. This may require geosynthetic materials including thin soil-infilled geocell materials or relatively lightweight geomeshes that are often used to temporarily anchor vegetation. The figure below shows that an interceptor drain may be required to eliminate seepage forces in the reinforced soil zone.

The location, number, length and strength of the primary reinforcement required to provide an adequate factor-of-safety against slope failure is determined using conventional limit-equilibrium methods of analysis modified to include the stabilizing forces available from the reinforcement. The designer may use a "method of slices" approach together with the assumption of a circular failure surface, composite failure surface, two-part wedge or a multiple wedge failure mechanism. The reinforcement layers are assumed to provide a restraining force at the point of intersection of each layer with the potential failure surface being analyzed. A solution for the factor-of-safety using the conventional Bishop’s Method of analysis can be carried out using the following equation:
\[ FS = \left( \frac{M_R}{M_D} \right)_{\text{unreinforced}} + \frac{\sum T_{\text{allow}} \times R_T \cos \alpha}{M_D} \]

where \( M_R \) and \( M_D \) are the resisting and driving moments for the unreinforced slope, respectively, \( \alpha \) is the angle of tensile force in the reinforcement with respect to the horizontal, and \( T_{\text{allow}} \) is the reinforcement maximum allowable tensile strength. Since geosynthetic reinforcement is extensible the designer can assume that the reinforcement force acts tangent to the failure surface in which case \( R_T \cos \alpha = R \). The potential failure surfaces must also include those passing partially through the reinforced soil mass and into the soil beyond the reinforced zone as well as those completely contained by the reinforced soil zone.

Example circular slip analysis of reinforced soil slope over stable foundation

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Geosynthetics are extensively used in the design of both base and cover liner systems of landfill facilities. This includes:

- **geogrids**, which can be used to reinforce slopes beneath the waste as well as to reinforce cover soils above geomembranes;
- **geonets**, which can be used for in-plane drainage;
- **geomembranes**, which are relatively impermeable sheets of polymeric formulations that can be used as a barrier to liquids, gases and/or vapors;
- **geocomposites**, which consist of two or more geosynthetics, can be used for separation, filtration or drainage;
- **geosynthetic clay liners** (GCLs), which are composite materials consisting of bentonite and geosynthetics that can be used as an infiltration/hydraulic barrier;
- **geopipes**, which can be used in landfill applications to facilitate collection and rapid drainage of the leachate to a sump and removal system;
- **geotextiles**, which can be used for filtration purpose or as cushion to protect the geomembrane from puncture.

The figure below illustrates the extensive multiple uses of geosynthetics in both the cover and the base liner systems of a modern landfill facility.

**Multiple uses of geosynthetics in landfill design.**

The base liner system illustrated in the figure above is a double composite liner system. It includes a **geomembrane/GCL** composite as the primary liner system and a
*geomembrane/compacted clay liner* composite as the secondary liner system. The leak detection system, located between the primary and secondary liners, is a *geotextile/geonet composite*. The leachate collection system overlying the primary liner on the bottom of the liner system consists of gravel with a network of perforated *geopipes*. A *geotextile* protection layer beneath the gravel provides a cushion to protect the primary *geomembrane* from puncture by stones in the overlying gravel. The leachate collection system overlying the primary liner on the side slopes of the liner system is a *geocomposite* sheet drain (*geotextile/geonet composite*) merging into the gravel on the base. A *geotextile* filter covers the entire footprint of the landfill and prevents clogging of the leachate collection and removal system. The groundwater level may be controlled at the bottom of the landfill by gradient control drains built using *geotextile* filters. Also, the foundation soil below the bottom of the landfill may be stabilized as shown in the figure using randomly distributed *fiber reinforcements*, while the steep side soil slopes beneath the liner are reinforced using *geogrids*.

The cover system of the landfill illustrated in the figure contains a composite *geomembrane/GCL* barrier layer. The drainage layer overlying the geomembrane is a *geocomposite sheet drain* (*composite geotextile/geonet*). In addition, the soil cover system includes *geogrid, geotextile, or geocell* reinforcements below the infiltration barrier system. This layer of reinforcements may be used to minimize the strains that could be induced in the barrier layers by differential settlements of the refuse or by a future vertical expansion of the landfill. In addition, the cover system could include a *geogrid* or *geotextile* reinforcement above the infiltration barrier to provide stability to the vegetative cover soil. *Fiber reinforcement* may also be used for stabilization of the steep portion of the vegetative cover soil. A *geocomposite erosion* control system above the vegetative cover soil is indicated in the figure and provides protection against sheet and gully erosion. The use of *geotextiles* as filters in groundwater and leachate extraction wells is also illustrated in the figure. Finally, the figure shows the use of an *HDPE vertical barrier* system and a geocomposite interceptor drain along the perimeter of the landfill facility.

Although not all of the components shown in the figure would be necessarily needed at any one landfill facility, the figure illustrates the many geosynthetic applications that can be considered in landfill design.

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### About the IGS

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Geosynthetics are used in various applications in waste water facilities. The most common use is in lagoons operating with anaerobic and aerobic processes. Other applications include enhanced evaporation of wastewater and sludge dewatering by permeable geotextile geotubes.

**Anaerobic Lagoons with Covers**

When wastewater with a reasonably high organic load is kept in a lagoon for several days an active anaerobic sludge accumulates at the bottom of the lagoon. In an uncovered lagoon the anaerobic digestion activity takes place at the base of the lagoon and the activity near the surface tends to be more aerobic.

These lagoons can be covered with a geomembrane floating cover to:

(a) enhance the anaerobic digestion activity by the exclusion of air (oxygen)
(b) enable the harvesting of gas (especially methane) which can be used as a fuel
(c) reduce the effect of odour from the anaerobic activity

Generally these lagoons will take wastewater with BOD of 400 to 5000 kg/cum and the output effluent will have the BOD reduced by 90 to 95%. Detention time is normally 4 –7 days. The anaerobic process is largely self propelled and the only mechanical input is that required to feed wastewater to the lagoon and force its exit at an overflow outlet. There may be a need for systems to deal with excessive accumulations of sludge (base) and scum (surface under cover) but this will depend on the nature of the wastewater and the dynamics of the system.

**Aerobic (Aerated) Lagoons**

Aerated systems use either surface aerators or diffuser systems to introduce air into the wastewater and this results in consumption of the organic content of the wastewater which is mostly released as carbon dioxide.

These aerobic systems require considerable mechanical input to operate the aeration system and further work may be needed to remove excess sludge from the base from time to time. Typically these systems take wastewater with BOD in the order of 500 to 1500
kg/cum and the output effluent will have the BOD reduced by around 90%. Detention time is normally 4–7 days.

**Combined Anaerobic and Aerobic Lagoons**

Many wastewater plants make use of anaerobic and aerobic systems as a combined or two part process. This can be readily achieved in one lagoon using a specially designed geomembrane floating cover. These combined systems have a capacity to take wastewater with BOD of 5000 kg/cum and to achieve an output effluent less than 100 kg/cum. Total detention times would be in the order of 10 days although some systems use final ‘polishing’ lagoons or grass filtration/irrigation. These combined systems have the capability for the gas to be used on-site to provide power which can be used for the aeration energy input.

**Applications for Geosynthetics**

The applications for geosynthetics in these lagoon systems are essentially associated with the liner system and with the floating cover system but there are many variations that may be chosen according to circumstances.

(a) Liner Systems: geosynthetic clay liners with soil or concrete covers or geomembranes can be properly specified for liner systems.

(b) Cover Systems: Cover designs may vary with factors such as the intended operation of the cover with respect to effluent levels, gas collection and associated factors, as well as the construction restrictions which may limit the cover design options.

(c) Enhanced Evaporation: a typical dark geomembrane with shallow wastewater over it will see the wastewater temperature rise with solar radiation creating an enhanced capacity for evaporation. This is used in wastewater disposal and for salt and mineral extraction processes. A floating cover over the wastewater will prevent growth of waste volume in the wet season as well as enabling fresh water to be gathered from the cover.

(d) Sludge Dewatering: geotubes were initially developed as a construction tool enabling the use of dredged sands to build groynes and the like. These filtration properties can also be used to take sludges with high water content and rapidly dry them to a solid state which allows truck transport without dripping.

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Agricultural use of geosynthetics is one of the fastest growing market segments worldwide. The earliest geosynthetics applications were for on farm use and some of the earliest specifications were directed at agricultural use of pond linings. These early uses included the lining of ditches to help save valuable water as well as the lining of farm ponds and water harvesting catchments in the arid regions of the world. Today, there is a wide variety of applications ranging from covered and uncovered ditch linings and ponds to protection of the groundwater and surface waters that are being polluted by animal waste. The use of geosynthetics and in particular geomembranes on the farm has come a long way and has grown significantly in recent years, especially with more stringent governmental legislation as well as public awareness through programs such as those developed by the USDA/NRCS, U.S. EPA and governmental agencies in other countries.

CONTAINMENT AS A REQUIREMENT
Potable water sources are becoming more and more scarce and water is becoming more costly. The requirement to provide a barrier against high rates of water seepage loss is already a reality in many more areas than just the arid and semiarid regions of the world. And, just as water is important to conserve, it is even more important to environmentally protect surface and groundwater sources from pollution due to animal waste and the air we breathe from noxious gases and odors. Again, containment with a reliable time proven method is a requirement, not just an option due to recently enacted environmental legislation in many parts of the world.

Geosynthetics will provide a reliable cost effective alternative to traditional compacted soil and clay liners that provide much less in seepage control, are highly variable in quality and may not be acceptable for design and regulatory compliance. Although geomembranes are the primary type for use as a barrier or odor control cover, other geosynthetics are used in conjunction with geomembranes and include geotextiles, geocomposites, and geonets.

ANIMAL WASTE LAGOON LINERS
Animal waste lagoons contribute to the pollution of ground and surface waters worldwide. To control waste seepage, compacted earth linings as well as geosynthetics are utilized. However, with the increasing concern over pollution and governmental legislation, the use of geosynthetics has been increasing very rapidly. In particular, exposed geomembranes, geomembranes with soil cover and GCL’s with soil cover are currently being used. In addition, geotextiles and geonet composites are utilized for protection / gas transmission.
ANIMAL WASTE ODOR CONTROL COVERS
A growing number of scientists and public health officials have traced a variety of health problems to vast amounts of concentrated animal waste which emit toxic gases such as hydrogen sulfide and ammonia. Odor control covers can be a low cost geomembrane or coated fabric or they can be a more expensive engineered floating geocomposite cover system dependent on the design and criticality of the containment.

WATER CONVEYANCE
Geosynthetics and most notably geomembranes have been used for decades in preserving and transporting clean water for on farm use. The conveyance of water in ditches, laterals and main canals for delivery to crops is as common as on farm water storage tanks and ponds. However, water is becoming more and more scarce and more costly especially with the drought conditions in many parts of the World. Seepage loss in canals and ditches can approach 30 to 50% but loss of valuable water can be eliminated with the use of geomembranes as lining systems. Both soil covered and exposed geomembranes are used extensively in the lining of both new and old canals that require rehabilitation. In addition, old cracked concrete lined canals have lost their effectiveness over the years and are being replaced or repaired with geomembranes. Water conveyance systems utilize other geosynthetics in conjunction with geomembranes such as protection geotextiles, geocomposites and geogrids.

WATER CONTAINMENT
Water containment in ponds and concrete tanks for on farm use is just as important as water conveyance in that seepage and loss of valuable water should be minimized, especially for remote ponds and tanks. Soil covered geomembranes and GCL’s are used for the construction of new or the rehabilitation of old ponds. Exposed geomembranes are used to re-line old stock water concrete tanks or to line new prefabricated storage tanks.

ANAEROBIC DIGESTERS
Anaerobic digesters are used to rapidly decompose animal waste in a controlled environment thus allowing the recovery and use of methane-rich low Btu biogas. Biogas is used to fuel combined heat and power (CHP) generators that produce on farm electricity, process heat and domestic hot water. They are also a viable method of waste management due to the fact that both bottom lining systems as described above and flexible cover systems are used. With every digester constructed, geosynthetics are used to either line the anaerobic lagoon or cover the lagoon for collection of biogas. The number of operating digesters is rapidly increasing worldwide as government funding is becoming available for farm installations.

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Geosynthetics may perform the following functions in new track construction or rehabilitation: separation of materials with different particle size distributions, filtration, drainage and soil reinforcement. In railroad construction, geosynthetics may be installed within or beneath the ballast or subballast layers.

Emphasis will be given here to the use of geosynthetics within and beneath ballast and/or subballast layers. Geosynthetics that are commonly used in this application are geotextiles, geogrids, geocomposites and geocells.

**Separation:** Geosynthetics (geotextiles) may be used to separate layers of the track support structure with different particle sizes and properties. The passage of trains on the rail causes movement of the track ties. As a result, fines from the subgrade may be pumped upward into the granular layers, reducing the strength and the drainage capacity of these layers. Furthermore, geosynthetics can reduce the penetration of granular particles into a soft subgrade, thereby maintaining the thickness and integrity of the granular layers and increasing track life time. To provide this function, the geosynthetic must be resistant to concentrated stresses (tear, puncture and burst) and have aperture sizes compatible with the particle sizes of the material to be retained.
Reinforcement: Geosynthetics (geotextiles, geogrids and geocells) installed over unstable subgrades may eliminate the necessity to replace this soil, increasing the load bearing capacity of the system due to better stress distribution. When installed within the ballast or subballast layers, geosynthetics may help to reduce settlements associated with the lateral spreading of the ballast and subballast materials. The main geosynthetic characteristics that must be considered for this function are the interaction between geosynthetic-soil/ballast, resistance to mechanical damage, tensile stiffness modulus and tensile strength.

Filtration: The flow of water from the subgrade into the overlying granular layers may carry fines from the subgrade. This can occur because of the increase in stress levels in the subgrade due to the passage of trains. In this case, a geotextile can act as a filter, allowing the water to pass freely while the subgrade solid particles are retained. To fulfill this role, the geotextile must have adequate permeability and retention properties, and be resistant to clogging.

Drainage: Good drainage is critically important to avoid track deterioration due to the action of the water originating from precipitation onto the track or pumped from the subgrade into the ballast layers. A drainage geocomposite installed at relevant points in the track structure can provide cross-track drainage, preventing the accumulation of water. In this application the geocomposite must have adequate large discharge capacity and be resistant to mechanical damage.

If properly specified and installed, geosynthetics can improve the performance of railroads by increasing their life time and time between maintenance cycles.

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