Hydraulic engineering
Geosynthetics are used in all fields of hydraulic engineering to increase the quality and longevity of structures. Geosynthetic applications include filtration, sealing, protection, containment, separation, reinforcement as well as erosion control.

Geosynthetics can replace or complement conventional methods of construction, both offshore as well as in coastal areas. Acting as separation or filter layer, they protect dykes, dams and storm tide barrages. They are used in the foundation of groynes or breakwaters. Sand-filled bags and tubes are used in coastal constructions, e.g. for groynes or for sea bed stabilisation (scour protection).

Geosynthetic clay liners and geomembranes are used for sealing purposes in the construction of dykes, while needle-punched nonwoven filtergeotextiles prevent washout of fine particles and thus erosion of the construction.

Geosynthetics perform various functions in inland renovations, extensions and new constructions in flowing or static waters. Properly designed geotextiles ensure filter stability and erosion control, geosynthetic clay liners and geomembranes provide waterproofing, while geotextile containers and tubes stabilise the current flow and aid in scour protection.

The following chapters will illustrate and explain the different geosynthetic applications as well as methods used for design.
Geosynthetic functions

Filtration

In filtration applications such as hydraulic engineering and drainage systems, nonwoven geotextiles are used to retain soil particles while allowing the passage of liquids through the filter media. There are two aspects to filtration that should be evaluated when designing. The mechanical filter efficiency (does the fabric have sufficient soil retention capacity) and the hydraulic filter efficiency (does the water discharge without a hydraulic pressure build up). As with mineral filter layers, the geotextile thickness directly benefits the long-term mechanical and hydraulic efficiency of the filter.

Sealing

Acting as liquid and gas barriers, geomembranes have become a fundamental component in civil engineering, due to the heightened need for groundwater protection. High density polyethylene (HDPE) geomembranes, specifically those with a certification by government regulators and a thickness of more than 1.5mm, are most commonly used. Personnel from those companies that have been approved by the certifying agency, are employed to both deploy and weld the geomembranes where an area needs to be sealed. For sealing purposes in hydraulic engineering, road construction and environmental protection, HDPE geomembranes and geosynthetic clay liners are gaining use due to the importance of a quality liner.

Reinforcement

Geosynthetics are installed beneath or between soil layers to improve the mechanical properties of soil layers by absorbing the tensile forces and minimising deformation. Geotextiles, geogrids and composite synthetic materials are used in applications such as retaining structures according to the principles of "reinforced soil", slope stabilisation or for foundation reinforcement of earthen dams where the subsoil exhibits poor bearing capacity. The use of geosynthetics for reinforcement applications minimises expensive constructive measures and can reduce soil intermixing eliminating the need for additional soil layers.

Containment

Geosynthetic containment applications are those in which a textile in the form of a tube, bag or container, is used to encapsulate a construction material, such as soil or sand. They perform project-specific functions such as protection, filtration and separation. Nonwoven geotextiles as well as geocomposite products are the primary products for these applications due to their high elongation capacity.

Separation

As a separation layer, nonwoven geotextiles are used to prevent adjacent soil layers or fill materials from intermixing. Nonwoven geotextiles that exhibit a high elongation capacity are the materials of choice in most applications. The selection of a suitable product is dependent upon the base course grain size and the operational loads to be expected. The main use of separation nonwovens are road and railway construction, hydraulic and landfill engineering and sport fields.

Protection

Geomembranes, structures, coated materials as well as related construction elements must often be protected from potential mechanical damage. Without suitable protection damage may occur from sharp edged objects such as stones due to the unevenness of the subsoil or even by the cover material. Mechanically bonded needle-punched nonwovens as well as composite materials manufactured from polypropylene (PP) or HDPE are commonly used for protection layers. Specific to nonwoven geotextiles, the protection function is directly related to the thickness and mass per unit area, as a heavier and thicker nonwoven is more likely to provide better protection.

Erosion Control

Single-component geosynthetic layers and three-dimensional multi-component composite materials are used to prevent surface erosion. By preventing soil particles from being washed off slopes or channels, rapid vegetation is ensured when erosion control mats are used.
1 Filtration with Terrafix® (Dry installation)
2 Filtration with Terrafix® (Under water installation)
3 Filtration with Terrafix® sand mat (Under water installation)
4 Sealing with Bentofix® (Dry installation)
5 Sealing with Bentofix® (Under water installation)
6 Sealing with Carbofol®

- Filtration +
- Sealing +
- Separation +
- Protection +
7 Containment with Soft Rock
8 Terrafix® hydraulically filled tubes
9 Protection with Secutex®
10 Reinforcement with Secugrid®
11 Reinforcement with Combigrad®
12 Drainage with Secudrain®
Filtration with Terrafix® geotextiles

For decades, Terrafix® nonwoven geotextiles have been successfully used as three-dimensional filters in hydraulic engineering applications. They are employed between fine grained and coarse grained soils as well as scour protection projects to prevent dissimilar soils from intermixing thereby creating filter stability between two distinct soil sizes.

In the case of varying differences in water pressure (e.g. reversal of the direction groundwater flow) or turbulent stresses (e.g. impact of waves) nonwoven geotextiles can prevent soil displacement down the slope in the boundary layer.

Terrafix® nonwoven geotextiles exhibit an excellent abrasion resistance and filter properties, a high elongation capacity (ensuring resistance to installation damage) and a very good seam strength (if sewn together), thus outperforming products used for the same application, e.g. woven geotextiles.

Filtration

Terrafix® geotextiles are frequently used for filtration in dyke applications, on slopes and waterway beds for stabilisation as well as on associated applications such as dams, side ditches, etc. The Technical Delivery Conditions for geotextile filters, EU notification of 19.05.2003, describes in detail the minimum requirements for geotextiles - the geotextiles employed must exhibit the following characteristics: resistance to rotting, sea water and frost, be compatible with the environment, as well as remain flexible or be capable of elongation - which allows the geotextile to easily accommodate irregular or soft subsoil.

Geocomposite materials (consisting of several components) must be uniformly bonded over the entire surface area yet be distinguishable one from another.

The wide range of Terrafix® products offers numerous needle-punched nonwoven geotextiles complying with these basic requirements.

The properties presented in table 1 must also be fulfilled. Terrafix® geotextiles meet the material requirements in table 1 while addressing project-specific conditions and requirements such as the current velocity in the area of their application. Terrafix® nonwoven geotextiles are applied using standard deployment equipment and are covered with the specified revetment immediately after installation. Terrafix® 609 - with a minimum thickness of 4.5mm, is suitable for soil types 1 to 3 filter applications, while Terrafix® 813 with a minimum thickness of 6.0mm is suitable for soil types 1 to 4. Multiple-layered Terrafix® geocomposite materials (with a graduated...
geotextile opening size, AOS) are well suited to improve filtration effectiveness, especially in soils with high silt content and where significant hydrodynamic conditions exist. If the shear strength characteristics of the subgrade require improvement, Terrafix® coarse-fibre geocomposite materials are employed. Terrafix® sand mats are used for applications in strong currents as well as in deep water. These products are formed by mechanically encapsulating a uniform layer of sand ballast between two Terrafix® needle-punched nonwoven geotextile layers. This ballast layer facilitates underwater installation and prevents Terrafix® from forming folds by water movement.

Soft Rock are sand-filled tubes, bags or containers manufactured from needle-punched nonwoven geotextiles. They are used for erosion control to withstand extreme current velocities, in applications where scour holes must be filled quickly as well as for permanent stability. A particular advantage of Soft Rock products is that they can be quickly filled on site using existing sandy soils.

Manufactured with robust, needle-punched nonwoven geotextiles, Soft Rock sand containers easily accommodate local conditions but also perform well when subjected to tough site conditions. Terrafix® nonwoven geotextiles also exhibit a higher interface friction angle than woven geotextiles and can therefore be stacked to steeper angles with greater long-term stability.

Soil type test method
The German Federal Institute for Hydraulic Engineering (BAW) has developed soil type test methods to assess the suitability of a geotextile as a filter in navigation canals. The external dynamic and hydraulic filter stresses in waterways are simulated by:

a) the flow-through test method (quick drop and rise in the water level) and;

b) the turbulence test method (turbulent wave action, propeller stream, back flow).

The regulatory requirements for the filter effectiveness of a geotextile are described in table 1.

Conclusion
Terrafix® filter geotextiles are used when filter stability between two soil layers is absent or when hydrodynamic stresses may cause particle displacement. This condition is typically the case in slope and bed stabilisation for waterways as well as in dams, dykes or side ditches.

In the construction of revetments, robust Terrafix® geotextiles, designed for and capable of elongation, provide long-term stability for the revetment (e.g. riprap). Terrafix® sand mats or Soft Rock sand containers are used for erosion control when higher current velocities exist.
Sealing with Bentofix® geosynthetic clay liner

The installation of a sealing component in hydraulic engineering is possible both under dry conditions as well as underwater. In the case of a dry installation, conventional compacted clay liners (CCL) as well as Bentofix® geosynthetic clay liners (GCL) and Carbofol® geomembranes are commonly used. Dry installations have been carried out for decades; however, most recently state-of-the-art Bentofix® allows the underwater installation of liners on slopes and beds of waterways with fresh water.

Bentofix® BZ 13-B is a special bentonite composite lining system featuring a sand ballast layer that is integrally encapsulated by needle-punched nonwoven geotextiles. The sand layer performs several functions which includes ballasting this special Bentofix® GCL from floating when installed underwater - even where there are currents, or turbulences caused by ship propellers. Due to the needlepunching of the Bentofix® GCL, the sand layer also has the effect of providing a counter-pressure to the natural swelling properties of the bentonite, providing more uniform activation of this layer. Consequently, Bentofix® BZ 13-B can remain underwater without additional load or cover for longer periods of time - without loss of performance. During the subsequent placement of stone or other covering layer, this integrated sand ballast layer evenly distributes the load and prevents installation damage to the product.

Requirements
The maximum tensile strength of the GCL should be ≥ 10kN/m, and in general, should not be considered as a reinforcing layer in any slope stabilisation analysis.

The sealing layer used in Bentofix® consists powdered sodium bentonite with a hydraulic permeability of 2.0 × 10⁻¹¹ m/s. Bentofix® GCLs with single woven layers can be elongated up to 12% without an increase in permeability. Irregular or highly deformable subsoils, (where up to 30% elongation may occur), require Bentofix® styles that have needle-punched nonwoven geotextiles (one with a woven scrim reinforcement) incorporated on both sides.
Two special tests which simulate typical hydraulic stresses are the impact and the turbulence test. The impact test can be used to simulate the deployment of cover stones. That is, the impact energy of 1,200Nm corresponds to an impact stress which occurs when a stone of type III (according to EN 13383 LMB, 60kg) falls from 2m height under dry conditions. For underwater installations, dyke constructions or applications where the revetment is not placed directly on the Bentofix®, the impact requirements are considerably reduced. Bentofix® type BZ 13-B is commonly used for underwater installations to resist these loads without loss of performance. The turbulence test which simulates the dynamic wave action caused by a propeller stream shows that bentonite will not "wash out" from the Bentofix® under these conditions. This test approximates the stresses that could be expected during a 10-year span on most shipping routes.

Bentofix® is uniformly manufactured with direction-independent needlepunching (fibre reinforcement) over its entire surface area, with more than two million reinforcing fibres per square metre. Due to the surface structure of the needlepunched cover and carrier nonwoven geotextiles and the large internal as well as external friction angles, slope inclinations of 2.5 h : 1 v or greater are possible depending on the existing soil conditions and slope lengths. In poor soil conditions or on steeper slopes, Secugrid® geogrid can be used to further ensure slope stability.

Conclusion
Bentofix® has proven its performance worldwide in laboratory tests, field trials and in service, since it has been developed by NAUE in 1987. Bentofix® is suitable for sealing dykes and dams as well as flowing or turbulent inland waters. Standard or project-specific styles such as Bentofix® BZ 13-B, with the integral sand ballast material, can be employed for underwater installations.

For hydraulic engineering sealing purposes, there are physical properties that are also required for geosynthetic clay liners - not just low permeability. Bentofix® fulfills with these requirements by offering high impact resistance, erosion-stable encapsulation of the bentonite as well as high shear strength.
Coastal protection measures are designed to protect inland flooding and minimise the erosion of the coastline caused by the constant motion of the sea. Geosynthetics are used in various coastal protection applications such as filters in dykes and dams, for foundations under groynes and breakwaters, as well as by using geotextile containers as structural elements in groynes, seawalls, breakers or for bed and embankment stabilisation.

Stabilisation of dykes
Terrafix® needle-punched geotextiles are used to protect the coastline when used in the toe area of sea walls and dykes. They improve the construction efficiency if the sea currents cause surface erosion or unacceptable soil displacement. The three-dimensional, labyrinth-like pores and channels of Terrafix® nonwovens are not only similar to the soil structure itself, but, if correctly designed, also increase the stability of the revetment against impact stress caused by the motion of the sea. For coastal hydrodynamic forces and the typical fine to medium sands in these areas, the following simplified engineering approach can be used to determine the effective opening size $d_{50,W}$ of a filter geotextile when one is used below an open revetment:

$$d_{50,W} \approx d_{50}$$

The minimum thickness of the filter geotextile should be 4.5mm (please refer to chapter “Filtration”) in order to ensure the stability and permanency of the filter. Due to their extraordinary robustness, Terrafix® geotextiles with a mass of about 600g/m² are used below blocks or riprap.

A geotextile with a minimum mass per unit area of 600g/m² is necessary wherever type II (LMB 5/40) or III (LMB 10/60) armor rock with individual weights $\leq 60$kg are placed directly on Terrafix® geotextiles, or where concrete revetments for high-stress applications have been installed. Where individual stone weights exceed 60kg, Terrafix® geotextiles with yet a higher mass per unit area are recommended. In the case of low-stressed dykes, Terrafix® filter geotextiles with a minimum mass of 500g/m² and minimum thickness of 4.5mm serve to encapsulate and stabilise the sand core from erosion. When flooding occurs, they prevent washout of the sand and ensure the stability of the dyke. Top soil as well as concrete blocks can act as an effective cover layer over the geotextile.

Groynes, breakwaters and seawalls
In some cases, dykes alone are insufficient for coastal protection. Structures such as groynes, breakwaters and sea walls are used to prevent the erosion of coastal areas and directly influence the localised sea currents. Terrafix® sand mats provide stability as well as scour protection for these structures. Even in deeper waters, the underwater installation of Terrafix® B 813 is easy due to the integral sand ballast layer. Depending on the subsoil conditions, Terrafix® filter layers that are at least 4.5mm thick (for soil types 1 to 3) or 6.0mm thick (for soil type 4), ensure the filter stability of the fine grained subgrade. Secugrid® geogrids are used as additional reinforcing
elements where foundation failure is possible. The reinforcement measures required for transverse structures depend on the prevailing sea current stresses to which they are subjected. For low-current stresses, a Terrafix® needle-punched nonwoven geotextile or a Terrafix® sand mat can be placed on the sandy dam core and covered with riprap. For medium-current stresses, it is recommended that the dam core is reinforced with two or three layers of Soft Rock sand containers prior to installing the revetment. Groynes can be built entirely with Soft Rock sand containers, and if required, be covered with the appropriate revetment.

Soft Rock sand containers consist of needle-punched nonwoven geotextiles with a maximum tensile strength of $\geq 30\text{kN/m}$. Over 80% of the nonwoven geotextile strength is required for all seams. One of the remarkable features of Terrafix® is its robustness and elongation capacity. Soft Rock sand containers can be placed in their exact position and over granular terrain without a high risk of becoming damaged by using specific excavator grabs (“grippers”). When properly designed, even the dynamic impact of dumping does not reduce the performance of Terrafix Soft Rock® due to the flexibility of the Terrafix® nonwoven geotextile. Mussels, algae and other underwater life attach to the crimped fibres that are partially in a vertical position, so that the Soft Rock sand containers integrate quickly and easily into the sensitive sea ecosystem.

**Erosion control of the coast**

Storm tides can set the entire sea in motion, with its energy reaching the coastal breaker zone inducing erosion and morphological displacement. In such cases, Soft Rock sand containers used as artificial reefs serve as underwater breakers to reduce wave energy. Depending on the requirements, Soft Rock sand containers can have a volume of 1m³ to 250m³. Due to the high elongation capability needle-punched Terrafix® nonwoven geotextiles are used to handle the critical stress that can occur during the installation process. Soft Rock sand containers easily accommodate irregular surfaces.

Terrafix® nonwoven filter geotextiles are also used for the construction of artificial dunes. Using a unique wrap-around method, Terrafix® nonwoven geotextiles encapsulate a sand layer and are then planted with locally available bushes and grasses. Due to the high abrasion resistance and elongation capacity of Terrafix® nonwoven geotextiles, this construction technique provides excellent resistance to wave impact year after year - preventing erosion of the coastline (see figures 11 and 16).

**Conclusion**

Terrafix® system solutions allow the implementation of new and innovative coastal protection measures. Terrafix® needle-punched nonwoven geotextiles, sand mats and sand containers can be effectively employed in dykes, transverse structures, as well as breakers for erosion control. Placement of the robust and resistant Terrafix® products can be carried out under dry conditions, as well as from ships or underwater. Terrafix® products allow new approaches to coastal protection that are close to nature.
Flowing waters

Geosynthetics are used as filters, sealing elements as well as for scour protection in flowing waters. Natural construction materials are often found to be inadequate in performance without significant over-engineering - the use of geosynthetics is frequently required in support of natural systems for both performance and savings. Ecological aspects play an important role in hydraulic engineering as it is important to protect as well as preserve the natural flora and fauna habitat. Systems from NAUE offer ecological, technical as well as economic benefits together in a single solution.

Filtration

Terrafix® needle-punched nonwoven geotextiles significantly enhance system performance when two soil layers with dissimilar or non filter-stable grain structures are used as well as when a revetment is installed. Even where only hydrostatic loads are anticipated it is generally recommended to follow the requirements of the MAG (Instructions for the use of geotextile filters in waterways, Federal Institute for Hydraulic Engineering (BAW), Karlsruhe, Germany 1993). In filter applications for soil types 1 to 3, Terrafix® 609 with a minimum thickness of 4.5mm is well suited (for further details please refer to the chapter "Filtration", pages 6-7), whereas for soil types 1 to 4, Terrafix® 813 with a minimum thickness of 6.0mm would be appropriate. The installation instructions for different current velocities described in the chapter “Filtration” should be observed during common underwater installations. In the case of deeper water and higher current velocities, the use of Terrafix® sand mats or Soft Rock sand containers is recommended as they provide excellent stability.

The three-dimensional fibre structure of Terrafix® nonwoven geotextiles exhibit high elongation capacity and robustness. With these characteristics, they easily accommodate irregular or soft subgrades and are capable of withstanding installation loads when covered with stone, without loss of their filtration performance. The large effective pore space of the Terrafix® nonwoven geotextile structure offers an excellent environment for the establishment or continued propagation of local flora and fauna.

Protection from scouring

There is always a risk of scouring where current velocities are high. With turbulent currents typical of artificial structures...
such as bridge piers and ford foundations, the risk of scouring is particularly high. Soft Rock sand containers are an ideal solution to repair existing scoured cavities in river beds or other water channels. The containers can be filled with local sandy material under dry conditions and placed in the desired position with appropriate equipment. Using robust, needle-punched nonwoven geotextiles, Soft Rock sand containers easily accommodate and resist rough site conditions while preventing further scouring.

Groynes manufactured from Terrafix® sand containers are used to prevent scouring in river bends when constructed at right-angles to the river bank. If the subsoil is particularly soft, the ground can be stabilised with Terrafix® sand mats. The additional use of Secugrid® geogrids may be required in certain cases where substantial subgrade reinforcement is required. The wide range of Terrafix® geosynthetic products offer long lasting and economical solutions to resist natural destructive forces, regardless of the soil type or design of the revetment.

Sealing
In some cases it is necessary to construct an artificial seal in flowing inland waters (fresh water). Bentofix® offers geosynthetic clay liner product variations that can be installed in both dry and wet conditions for this purpose (for further details please refer to the chapter "Sealing"). Dams and dyke seals may also be necessary to prevent protected areas from flooding. Since this work is usually carried out under dry conditions, Bentofix® as well as Carbofol® geomembranes - combined with Terrafix® or Secutex® protective nonwoven geotextiles, offer one of the industry's best lining solutions.

For slightly gravely-sands, needle-punched nonwoven geotextiles with a mass of 400g/m² can be used as a protective layer for the lining component, while nonwoven geotextiles with a mass of 1,200g/m² will work well for coarsely grained soils.

Conclusion
Terrafix® nonwoven geotextiles are effective filters for sub-grade erosion control on slopes as well as the base of flowing waters. Due to their robust nonwoven geotextile structure as well as the high elongation capacity and flexibility, they can resist difficult installation conditions while creating a favorable habitat for local flora and fauna. Bentofix® GCLs and Carbofol® geomembranes are used for sealing while Terrafix® or Secutex® nonwoven geotextiles protect the Carbofol® from undue damage from surrounding soils. Soft Rock sand containers protect against scouring in hydraulic structures, such as bridge foundations and piers. They are particularly well suited for the construction of groynes and thus, capable of preventing further scouring.
For centuries, water has been stored or transported in man-made canals and reservoirs to make it usable for transportation, as a source of energy, or for irrigation. A wide range of geosynthetic products can be used in order to create more efficient shipping routes, including those used for the construction or repair of canals and docks. Geosynthetics facilitate economical and ecological methods for the construction of retention reservoirs or barrages.

**Filtration**

When used for transportation hydraulic engineering, Terrafix® needle-punched nonwoven geotextiles can be used effectively below permeable revetments as a filter layer. They are selected and designed in accordance with the established technical guideline "Instructions for the use of geotextile filters in waterways" (MAG) of the Federal Institute of Hydraulic Engineering (BAW, Karlsruhe, Germany, 1993). Depending on the existing soil type and revetment, Terrafix® nonwoven geotextiles that are at least 4.5mm to 6.0mm thick are best suited to prevent erosion and soil displacement (please refer to chapter "Filtration"). Even under high hydrodynamic loads caused by rapid water level fluctuations or by the turbulence from ship propellers, Terrafix® nonwoven geotextiles maintain their mechanical properties and filter efficiency. Composite Terrafix® products which exhibit a coarse fibre layer can be effectively employed to stabilise the soil/filter boundary layer in soils with high single grain mobility, preventing particle displacement under the Terrafix® filter geotextile.

High mechanical stresses can occur during the installation process as well as from ship traffic. For this reason, the geotextile filters must exhibit adequate impact and abrasion resistance. Terrafix® geotextiles offer these properties and more! Their high elongation capacity and robustness allow them to easily accommodate irregular or soft subgrades while preventing damage to the nonwoven structure itself when covered with stone. The three-dimensional needle-punched structure of crimped fibres provides high abrasion characteristics and resistance to any movement of the revetment.

In fast flowing or turbulent waters caused by propeller wash, the general physical characteristics make the installation and positioning of a nonwoven geotextile an inexact science. However, the Terrafix® sand mat enables the filter geotextile to be placed quickly and accurately underwater due to the ballast of an encapsulated sand mass, providing simple permanent stability. Terrafix® offers filter stability against finely grained soils while sufficiently robust to resist damage from stone cover.

**Sealing**

In inland fresh water shipping routes where the water level is at an elevation higher than the natural groundwater level, artificial sealing is required to prevent the water from "draining" to the groundwater level. Bentofix® geosynthetic clay liners or Carbofol® geomembranes are well suited lining products for dry installations. When using geomembranes, Terrafix® or Secutex® needle-punched nonwoven geotextiles are recommended as a protective layer. Structured or textured Carbofol® geomembranes are available to effectively transfer shear forces on challenging slope designs. Regardless, project-specific direct shear tests should be performed to verify the required shear strength parameters in order to use them for calculating slope stability analysis.
When inland ship traffic cannot be interrupted, the under-water installation of Bentofix® BZ 13-B geosynthetic clay liner is recommended. It features a bentonite clay liner with an additional sand ballast layer and an encapsulating nonwoven geotextile. Due to our unique technology, this geotextile/liner composite is uniformly reinforced with direction-independent needle-punching over its entire surface area. With a mass per unit area of 8kg/m², the heavy, sand fill performs several functions: it facilitates the uniform swelling of the bentonite which ensures consistent hydraulic function throughout the entire GCL; it protects against impact stress during the installation of covering stones; and with the appropriate installation technology, it ensures precise positioning so that the Bentofix® BZ 13-B clay liner and sand ballast remain in a permanent, stable position even during shipping traffic. Bentofix® BZ 13-B is also uniformly impregnated with bentonite powder over its entire edge surface area to ensure the proper sealing performance in the overlaps.

**Protection**

Depending on the subgrade and the cover material, properly specified needle-punched protective nonwoven geotextiles such as Terrafix® or Secutex® both above and below the Carbofol® geomembrane will minimise the potential for damage from surrounding soils. For slightly gravelly-sand (≤ 30% gravel portion) or corresponding cover material, a needle-punched nonwoven geotextile with a mass per unit area of 400g/m² should be used. Coarser grained soils may require nonwovens exhibiting a mass per unit area of at least 1,200g/m².

**Erosion control**

On slopes with especially fine grained soils, heavy precipitation and wave impact may cause surface erosion. Significant erosion and rutting can occur if the slope is poorly vegetated. Geosynthetic erosion control mats are commonly used to address difficult, erosion-prone slope conditions. Secumat® erosion control mat can significantly reduce soil washout during heavy rainfalls - its three-dimensional, irregular labyrinth-like structure is designed to allow both fine grained and gravelly soils to fill the open convoluted structure. The irregular Secumat® structure holds the soil in position on steeper slopes and provides structural support to vegetation during the early stages of plant growth. The use of high quality propylene (PP) resins make Secumat® resistant to naturally occurring soil chemicals, soil microorganisms and UV-radiation. The Secumat® product range is also available with a needle-punched nonwoven geotextile attached to the bottom side. Installed with the three-dimensional mesh surface side-up, it will then perform two functions - soil separation as well as erosion control.

**Conclusion**

Robust Terrafix® geotextiles can be effectively employed under permeable revetments to provide filter stability to the subsoil. Bentofix® geosynthetic clay liners and Carbofol® geomembranes are ideal products for a myriad of sealing applications. Carbofol® must be installed under dry conditions and is protected against mechanical loads by Terrafix® or Secutex® nonwoven geotextiles. Conversely, Bentofix® can be installed under water - the integrated sand mat provides a controlling confining load during the swelling of the bentonite and protects the bentonite mat when it is covered with cover stones. In areas where wave impact occurs, Secumat® protects slopes from erosion during the early stages of plant growth.
Design  Cross-sections  Details

For dyke applications, geosynthetics perform important functions, such as long-term stability and waterproofing. Geosynthetics from NAUE have been used in these exacting applications for decades.

Reduction of the decrease in pore pressure
Load filters are placed downstream (air side) to improve stability and to reduce the seepage line in the case of flooding. By collecting water downstream, the filter reduces existing pore pressure in the dyke and prevents excess pore pressure build up, thus providing stability to the dyke. Terrafix® needle-punched nonwoven geotextiles fulfill the challenging filter stability requirements - they can be effectively employed as a filter layer between the dyke core and the filter as well as in the foundation of the dyke itself. Upstream (water side), Terrafix® geotextiles prevent permanent soil washout which could significantly reduce the dyke stability. The three-dimensional, labyrinth-like pore channels of Terrafix® provide excellent filter stability due to their similar structure to the soil. In addition, Terrafix® geotextiles are extremely robust due to their high elongation capacity allowing them to easily accommodate irregular or soft subsoil.

Sealing
For the repair or the new construction of a fresh water dyke, the 7mm thick Bentofix® geosynthetic clay liner is an economical alternative when compared to the typical 60cm thick compacted clay liner. When installed on the upstream surface, the high-swelling powdered sodium bentonite offers an excellent low permeability seal. Bentofix® is manufactured with direction independent needle punching, with more than two million fibres per square metre. Slope angles of 2.5 h : 1 v or greater are possible due to the surface structure of the needle-punched cover and carrier nonwovens as well as the large internal and external shear strength. In poor soil conditions or on steeper slopes, Secugrid® geogrids can be used to further ensure slope stability.

Due to their thin profile, Bentofix® clay liners consume less volume than compacted clay, and can require significantly less soil removal - especially in the case of dyke repair. The Bentofix® BFG 5000 also features a cover nonwoven geotextile that has been uniformly impregnated with a second layer of sodium bentonite powder over its entire surface area. The additional bentonite in the cover nonwoven geotextile can help the installation proceed more efficiently versus installations where the overlaps must be sealed with additional bentonite.

The cover and carrier geotextiles of Bentofix® geosynthetic clay liners protect the bentonite core while providing sufficient robustness for on-site handling. When high normal loads are anticipated, Bentofix® manufactured with nonwoven geotextiles exhibiting a mass per unit area of 300g/m² should be used.

Alternatively, 1.5mm thick Carbofol® HDPE geomembranes can be installed. Not only is placement simple, Carbofol® HDPE geomembranes are easy to weld due to the favorable Melt Flow Index of the resin.
Surface texturing is available to effectively transfer shear forces on slope locations. Regardless, project-specific direct shear tests should be performed to verify the required shear strength parameters of the confining soils and to calculate the stability.

Depending on the requirements, needle-punched nonwoven geotextiles such as Terrafix® or Secutex® may be installed above and below the Carbofol® geomembranes for added protection. For slightly gravelly-sand (gravel portion ≤ 30%) protection nonwovens with a mass per unit area of 400g/m² should be used to protect the Carbofol® geomembrane. Coarser grained soils may require protection nonwovens, exhibiting a mass per unit area of 1,200g/m².

**Protection against rooting**

Roots from shrubs or trees can find their way into the downstream filter or into the body of the dyke - which may reduce the drainage performance of the filter or impact the permeability of dyke liner. The vertical placement of 1mm thick Carbofol® geomembranes ensures the effective protection against root penetration and long-term stability in critical areas. With a thickness of 2mm Carbofol® also provides long-term resistance to rodents.

**Erosion control**

On steep slopes, heavy rainfall may cause rutting or wash away young grass seed. Secumat® erosion control mats inhibit surface erosion and rutting by retaining the soil and seed in a convoluted three-dimensional structure. Secumat® is installed directly on the slope and filled with soil. Roots gradually intertwine with the three-dimensional structure of Secumat®, efficiently interlocking roots and the Secumat® with the surrounding soil.

**Conclusion**

Dykes are built for protection against flooding and must perform properly during this limited, yet demanding period. Terrafix® geotextiles are used upstream to prevent soil washout as well as downstream in the outflow area of the seepage lines to prevent erosion. With Terrafix geotextiles, the full drainage performance of the filter is maintained and the stability of the structure is ensured. Bentofix® geosynthetic clay liners and Carbofol® geomembranes are used extensively as sealing components while Terrafix® and Secutex® nonwoven geotextiles can effectively protect the Carbofol® from damage. Secugrid® geogrids further improve stability in the slope area while Secumat® or Carbofol® can provide erosion control and protection against root penetration. When you require complete system solutions for safe and stable dyke construction, think of the products available from NAUE - the natural choice.
Ecology plays an important role in the design of waterways, barrages, retention reservoirs, dykes and coastal protection measures. Tests for environmental compatibility and guidelines for landscape restoration are therefore specific components to be considered in planning new construction or extensions of existing waterways.

Preliminary planning is typically followed by an environmental compatibility study. This study includes an evaluation of the effects on all environmental aspects. From the cost-effective available options, the most compatible variant is then suggested.

The technical planning details a specific plan considering the environment, as well as economic aspects. If damage occurs, those that are impacted should be compensated by suitable measures.

Ultimately, the use of environmentally beneficial geosynthetics is recommended - products that protect natural resources and cause the minimum amount of emissions during transport and installation.

Protection of resources
Geosynthetics are used in hydraulic engineering as technical equivalents to conventional materials such as mineral liners. Bentofix® geosynthetic clay liners can be employed in lieu of compacted clay layers while Terrafix® filter geotextiles can replace granular filters - to conserve natural resources.

A 1cm thick Bentofix® sealing liner is technically equivalent to over 50cm of compacted clay and a 4.5 to 6mm thick Terrafix® filter geotextile can easily replace a 40cm thick aggregate filter.

Moreover, the use of geosynthetics generally requires less soil removal, transport and deposition.

Reduction of emissions
Ecological balance sheets developed by NAUE demonstrate the favourable energy balance of geosynthetics over natural construction materials. The use of Bentofix® GCLs requires only 2/3 of the energy required to compact a mineral clay layer under similar conditions to achieve comparable performance.

The transport of 33,000m² of Bentofix® GCL requires only eight truckloads while the transport of a corresponding amount of compacted mineral clay for a sealing layer 20cm thick requires approximately 550 truck loads (24t each)! Geosynthetics are the clear choice when aiming to reduce vehicle emissions!

Design close to nature
Geosynthetic construction methods can be integrated into almost any landscape. Numerous structures from the seventies and later illustrate the variety of design and vegetation options.

Extensive research shows that geosynthetics do not have a negative influence on the flora and fauna. To the contrary, they can offer nutrient and heat storage for plants and animals.
Quality assurance and control

...the continuous monitoring of raw materials, components, production and products

All incoming raw materials, fibres or components, needed for the production of our geosynthetics, are subject to a strict material analysis. Acceptance test certificates, submitted by the material suppliers, are reviewed and qualified in accordance with our product specific protocols.

During production of all geosynthetics, additional quality assurance measures are performed. To avoid a conflict of interest, the quality assurance staff is assigned to a separate and autonomous division from the production division.

After all quality assurance measures have been performed as defined in the quality assurance plan, an acceptance test certificate will be issued according to ISO 10204 when requested. Material will only be released once it has passed all quality reviews, checks and has all supporting documentation completed.

These quality assurance measures are conducted for all of our products according to the current standards and guidelines in effect at that time. This continuous manufacturing quality control guarantees product performance characteristics, and enables complete documentation from the raw material to the final product.

NAUE geosynthetics also undergo third party quality process checks that are typically performed twice a year (e.g. DIN 18200). Independent experts obtain test specimens from the different NAUE production facilities as well as from the various product inventories. The properties of the geosynthetic products are tested and documented in detail, including the notation of production processes, the type and extent of the manufacturing quality control and any other relevant observations.

Project specific product properties

In special cases, independent experts are retained to test project specific product properties and to certify the test results. This testing is in addition to and completes the manufacturing quality control carried out on the raw materials as well as the finished products.

Quality Management According to ISO 9001

Since December 1994, the geosynthetics development, production, sales and geotechnical engineering divisions of NAUE GmbH & Co. KG have been certified according to ISO 9001. This certification is regularly validated by scheduled audits.

With the aid of this integrated quality management system, the requirements of the customer and/or the projects are understood and fulfilled. While we continually strive to improve the quality level of our existing products and services, a high quality foundation is guaranteed by our ISO 9001 standards.

Compulsory CE-marking

From 1st October 2002, CE-marking for geosynthetics was made compulsory (except for erosion control mats). The CE-marking certifies that a product corresponds to the product-specific European guidelines for specific applications and functions (separation, filtration, reinforcement, sealing, protection and drainage). NAUE has taken all necessary steps to put into effect the compulsory CE-marking.

Beginning on 1 July 2013 the basis for the compulsory CE-marking in EU countries is the new "Construction Products Regulation – CPR" (Regulation (EU) 305/2011). This new regulation requires that a "Declaration of Performance – DoP" must be issued for each supplied product and must be submitted to the customer if requested. With the DoP, the supplier ensures that geosynthetic product values are accurate and reliable and that a product may be used without further tests within the borders of the EU. In addition to the DoP, the CPR e.g. requires that the essential (harmonised) characteristics pursuant to application-related standards are noted on a label and attached to each geosynthetic roll along with the CE logo. NAUE has implemented these rules successfully since 1 July 2013.
Static puncture test (EN ISO 12236)

Direct shear device for the determination of friction coefficients (ISO 12957-1)

Determination of the strength and elongation properties of single fibres (EN ISO 5079)

Determination of the montmorillonite content of bentonite via the methylene-blue-adsorption (titration) method (VDG P69)

Tensile strength test on wide-width strips (EN ISO 10319)

Determination of the bonded peel strength of Bentofix® geosynthetic clay liners (ASTM 6496)

Tensile strength test on wide-width strips (EN ISO 10319)

Raw material identification according to the DSC method (EN ISO 11357)

Determination of water flow capacity in their plane (EN ISO 12958)

Tensile strength test of Secugrid® geogrids (EN ISO 10319)

Static puncture test (EN ISO 12236)

Tensile test on Carbofol® geomembranes (EN ISO 527)
The innovations of NAUE are leading the geosynthetic industry into the future. We offer project specific product development, geotechnical engineering support, and provide solutions to complicated challenges, simplifying your project.

**Carbofol®**

Carbofol® geomembranes are made with high density polyethylene (HDPE). They are available in different thicknesses as well as with different surfaces for all of your sealing tasks.

**Bentofix®**

Bentofix® is a needle-punched reinforced geosynthetic clay liner (GCL) that uses two geotextile layers to encapsulate a layer of natural sodium bentonite. The needle-punched fibres transmit shear forces through the bentonite core. It is used as a sealing barrier against liquids and gases in various civil and environmental applications.

**Secutex®**

Secutex® is a needle-punched staple fibre nonwoven geotextile (some types are additionally calendered) used for separation, filtration, protection and drainage. Secutex® can be used in many civil engineering applications such as hydraulic engineering, landfill engineering, road construction as well as tunneling.

**Secudrain®**

Secudrain® is a three-dimensional drainage system designed to discharge liquids and gases. It consists of a drainage core and one or more filter layers on the outer surfaces to protect the drainage core from clogging. All layers are uniformly bonded together to ensure high internal shear strength.

**Data  Facts  Figures**

---

[Graphs and charts showing data, facts, and figures related to the products discussed.]

---

22
NAUE has decades of experience in the development and production of high quality geosynthetics, offering complete geosynthetic solutions.

**Secumat®**

Secumat® is a three-dimensional erosion control mat consisting of a UV-stabilised labyrinth-like polymer core. Secumat® controls surface erosion by ensuring rapid vegetation growth on slopes while preventing soil erosion during heavy rains and water flows.

**Combigrid®**

Combigrid® is a firmly bonded composite of a high strength, low elongation Secugrid® and a needle-punched Secutex® nonwoven geotextile for soil stabilisation and filtration applications.

**Secugrid®**

Secugrid® is a geogrid made of flat extruded monolithic bars with welded junctions. It is used for soil reinforcement in earth works, road construction, segmented wall construction, landfill engineering and hydraulic engineering.

**Bentofix® X**

Bentofix® X is a needle-punched geosynthetic clay liner (GCL) with a firmly attached polyethylene coating to the woven side of the GCL. Bentofix® X is installed in sealing applications where gas permeation, root growth, desiccation, high water heads or chemical concerns need to be considered.
Further information on the subject geosynthetics are available through our website or from our:

- **Corporate brochure**

- **Application-related brochures:**
  - Civil engineering
  - Groundwater protection
  - Hydraulic engineering
  - Landfill engineering
  - Tunnel construction
  - Waterproofing manual

- **Application-related flyers and technical flyers with project-specific solutions**