Geosynthetics in agricultural and aquacultural applications

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ABSTRACT: The continuously growing diversity of geosynthetic products allows for manifold usage also in agriculture and aquaculture. In many places and for many applications they take the place of traditional material, often leading to easier handling, higher robustness and greater cost effectiveness. The bandwidth of application is permanently increasing and new fields of applications are opened up. Geotextiles act as separators of materials, animals, fish and marine creatures, they provide shelter from wind, water, sun, dirt and animals, they control the interaction of water and soil, they allow for storage of all kind of things. Due to the diversity, only an overview can be given over possible applications, with the risk remaining to miss important individual solutions incorporating geosynthetics. Vice versa the examples should encourage to think about additional innovative use of geosynthetic in agriculture and aquaculture.

1 INTRODUCTION

Geosynthetics in agriculture and aquaculture comprise a very large scope of application, but are rarely discussed in international events. The large variety makes it difficult to give an overview without resulting in an endless list of uses. Therefore three large groups are chosen to give an impression to the applications without being lost in the diversity, namely geosynthetics (i) for weather shelter, (ii) for covers and envelops and (iii) for hydraulic applications in agriculture and aquaculture.

Geosynthetics can provide shelter from wind and sun, rain and extreme temperatures, applications that are of major importance in agriculture. Shelter is needed either to prevent generally any crop from being ruined or to allow for premium quality that is required today to sell the goods for a reasonable price on the market. (Whether the latter is really necessary or if we could allow for not so good looking but good tasting fruits and vegetables is another discussion not to be followed here.) Also all livestock need shelter, in some regions, depending on the climate, living without shelter would not be possible at all.

Geosynthetic envelops comprise all kind of covers, containers, shells and encasements. Containers are broadly treated in the discussion session on Geosynthetic Containers and will be touched here only to a minor extent. Envelops can be used as shelter from sun, rain, animals, natural enemies, thus being a fluent passage from shelter applications. Or they can retain dirt, odor, water. They can separate schools of fishes, flocks of birds, packs of animals. And they can contain fresh water or waste water, can be used as bags for all kind of material from sand to crops and more.

Hydraulic applications in agriculture and aquaculture are rather manifold in itself. Impermeable geosynthetics are used for linings of reservoirs, ponds, canals and dikes. Due to climatic changes, dikes become more and more important as shelter of the hinterland, and geosynthetic barriers, erosion protection and drains will contribute to well performing structures. Permeable fabric is found in a large variety of erosion protection measures from filters to artificial reefs. Also the use of capillary breaks is discussed whereas there is no wide-spread application.

There are promising new applications that might be of great help in agriculture and aquaculture. Examples are the absorption of pesticides and dewatering of slurries. For practical application a lot of research and testing is still needed. But such developments prove the comprehensive use of geosynthetics and the ongoing development of this material.

2 GENERAL REQUIREMENTS

Any geosynthetic product is predominantly designed for the final service state. But quite often the fabric goes through a long process until its final position is reached. As an example, geotextile bags and containers are manufactured, tailored to the desired size and shape, filled (in some cases with insufficient equipment), closed by sewing or stapling, loaded onto a transport unit and dropped in place. Then maybe armor rock is dumped upon. So very often the installation of a geosynthetic product and the accompanying construction steps incorporate the strongest load the product will meet during its lifetime.

In agricultural and aquacultural applications the installation stress is sometimes lower, but while the geosynthetic in other applications often is covered in its final position (and, as a result, protected), here the fabric often remains exposed during service life. So we have to ask for UV-resistance, heat and frost resistance, sufficient strength to bear wind induced forces, strength against biting animals and fishes or picking birds and much more. Generally, we have to ask for a high robustness. Robustness usually is provided by strength and mass. In most cases it is worth while to chose material with more than the required minimal robustness. Since geosynthetics are relatively inexpensive products, one shouldn't try to save money in the wrong place. A prolonged service live often compensates for the slightly higher price.

3 SHELTER FROM WIND AND SUN

3.1 *Lifestock and crop protection*

Within living memory, people have used animal skin and cloth as protection against the inclemencies of weather. Geosynthetics are the further development allowing for optimum solution for the manifold individual applications. One could argue whether shading cloth and wind protection are 'geo'-textiles. But there are no clear outlines, so some applications of geosynthetics are included even if there is no direct interaction of soil and fabric.

In many livestock buildings like cattle, pig and poultry houses, as well as in riding halls, special agricultural textiles are to be found to allow for wind protection and controlled ventilation (Figure 1). Usually polyethylene monofilaments are used which are sufficiently weathering resistant to ensure long service life. Wind protection systems are either fixed or movable to enable an opening for variable ventilation. There is a large variety of fabric available, typically in the range of 250 – 500 g/m² with 20 to 70 % open area. Often there is an antistatic finishing with the fabric and it can be manufactured flame retardant.

Figure 1. Animal stable wind protection and ventilation screens

As to riding areas, geotextiles additionally can play an important role for the stabilization of the riding surface. Geotextiles prevent the mixing of the layers and allow in outdoor areas for a good drainage. This avoids the formation of puddles and guarantees all year round usage of the arena.

Geotextiles for shading treatment has been a specific response to the needs of flower and fruit cultivation as discussed for example by Hsieh et al. (2008). With such treatment, the length and number of new shoots could be reduced and the number of flowers and leaves increased significantly. Also higher chlorophyll content developed in the leaves of new shoots. In other applications, shading is used to reduce fruit growth: for example asparagus fields are covered by white membranes to reflect the sun and to retard the development of the asparagus spears. This measure is often used to avoid an oversupply during high season. On the other hand, black membranes are laid on the asparagus fields to attract the warmth of the sun in early spring to bring the crop onto the market as early as possible (Figure 2).

Figure 2. Asparagus fields with black (left) and white (right) cover

This way, geomembranes help to control the growth of crops which eases the work of the farmers and allows for longer harvest periods, avoiding an oversupply and the associated dramatic drop of prices.

3.2 *Road protection*

Wind protection is needed for roads, if the wind is prone to transport dust, sand or snow. Raised and air transported particles impede the view on the road, so windbreak fences are a must. When snow or sand blows and drifts on roadways or driveways, the end is often a reduction in driver safety, degradation of road quality, and significant removal costs for drifted material. Sufficient safety can only be achieved by keeping snow and sand cleared.

Such fences are designed to create snow and sand drifts rather than to prevent them – but in sufficient distance to the road. The drifting and settling of snow and sand behind and in front of a such a fence occurs because the wind speed on both the downwind and windward side is less than that on the far windward side, allowing material such as snow and sand to settle. This creates a pile both in front of and behind the fence. The sand will not drop on the barrier itself, otherwise it would soon be buried and becomes useless. In rural areas, snow fences are also used to create by purpose large snow drifts in basins for a ready supply of water in the spring.

Geosynthetic fences are lightweight and easy to transport and handle. Such fences will not rust, rot or corrode, and will never need painting. The fabric is UV stabilized to withstand sun exposure. The geosynthetic net or grid is attached on posts, typically 2.5 to 3 m apart and secured by support wires fixed on the ground (Figure 3).

Figure 3. Snow fence (Photo: Claude05)

4 GEOSYNTHETIC ENVELOPS

4.1 *Protecting agricultural goods*

Silo protection is an important demand in agriculture. Geosynthetic covers are in use for that purpose since 20 to 30 years. For easy handling, the weight is usually limited to 200 to 300 g/m² , for good weather resistance, polyethylene wovens are used that provide the required UV stability and resistance against acids and other chemicals and are highly tear resistant. The fabric also has to be resistant against picking birds, pawing cattle and game as well as against rain and hail. Geotextile bags or chains of bags can be used for fixation instead of old tires or a sand layer, which makes it easier to open and recover (Figure 4). For watertight covers there are special woven fabric or membranes available. High air ventilation combined with hydrophobic behavior can be achieved by special nonwovens.

To protect fruit from birds and insects, nonwoven bags have been successfully used while good light penetration is still provided. Concurrently a shelter against fruit rotting in the summer and freezing in the winter is provided (Hsieh et al. 2008).

Figure 4. Silo protection

4.2 *Glacier protection*

With global warming in central Europe the glaciers undergo accelerated melting, with probably adverse effects on hydrology and this way also on agriculture. A first try has been undertaken to "wrap the glaciers" as a protection against the glare of the sun. Nearly 25 acres of white nonwoven were applied to the Stubai glacier in the Austrian Alps (Figure 5). The patches were welded together along the edges. Sandbags were used to keep the covers in place. The ice melt is 2 to 4 m per year and it is hoped to preserve a certain snow cover by this method and by this to prevent ice melting. The optimum geotextile would be a fabric that reflects the sun, preserves the temperature of the snow and is permeable for air. Such a material is not available yet, but the first experience with the white nonwoven is promising.

Figure 5: Glacier cover (Photo: AlpS)

4.3 *Reservoir covers*

Often it is desirable to cover reservoirs and ponds, either to protect the liquid from pollution or evaporation or to protect the environment from odor. Floating covers from geosynthetic material could help to reach the desired function. An important example are potable water reservoirs to provide sufficient water all over the year. Wallace (2008) reports on two case histories that could be taken as models for other applications, discussing in detail the problem of the cover remaining in place, i.e. in close contact to the water surface. Both, a mechanically-tensioned cover system and a ballasted tensioning system for a 1.13-mm thick reinforced polypropylene geomembrane have been executed and good performance is reported for both.

4.4 *Casings in aquacultures*

Since the 1980s, aquaculture - the aquatic version of industrial agriculture - has been the fastest-growing supplier of fish worldwide. Some observers see aquaculture as an opportunity to take the pressure off wild fish stocks while addressing the growing imbalance between fish production and food requirements for an expanding world population. The vast majority of global aquaculture production, about 85 per cent, uses non-carnivorous fish species - such as tilapia and catfish - produced in land-based ponds for domestic markets. Such ponds are discussed in the section "hydraulic applications", being similar in construction to ponds for other purposes.

Marine aquacultures often are not confined like those in ponds but are installed nearshore using nets for boundaries. Two types of nets are used, namely cage nets and set nets. Cage nets are used to raise fish, set nets to catch fish by trapping them. With the latter method the fish retreat paths are blocked and the fish are guided into a sack at the rear side.

Net cages are an offshore fishing net system with structural frames. There are two types of net cages, floating net cages and submersible net cages. The floating net cage is more popular and the costs of an installation are lower. However, the submersible net cage has better storm and weather resistibility, but needs more elaborated design and installation effort. Circular and rectangular net cages are available. The diameter of a net cage ranges from 10 to 40 meters. The typical submerge depth is 4 to 10 meters to reduce the impact of wave action, but allow for good control of the system.

For such cages, in most cases special polymer coated polyester net is used. It proved to be very strong and stable, but also flexible. Such nets are significantly stronger than conventional nylon nets. They need less maintenance and have fewer escapes than nylon nets. Nets are used with a mesh size of 5 and 50 mm. Tensile strength usually is 40 – 100 kN/m. The weight ranges from ca. 400 to 800 g/m², so no lead sinkers are needed.

While offshore aquaculture is beneficial in many cases, this is not the case when carnivorous species are farmed in open-net-cages (David Suzuki Foundation - www.davidsuzuki.org). Not being a problem of geosynthetics – they have proven to be a perfect material for such cages - it is a controversial fishing practice which has raised a number of environmental concerns. The problems associated with it include sea lice, pollution, drugs, escapes and net loss. The latter can be overcome by installing robust geosynthetics as described above and well monitored systems. But since the food supplied consists of industrial wastes, feed additives, etc., there is a possibility of parasites to develop. The remains from the food supply of this fish is discharged directly to the marine environment causing pollution. To overcome these shortcomings, closed tank technologies are developed recently which offer a major step forward in fish farming practices. Closed tanks have been demonstrated as technically feasible ways to grow salmon and are currently being tested to demonstrate commercial viability. There are several materials used for the tanks, e.g. concrete plus foam and fibreglass, but also geosynthetic material may offer suitable solutions for future development of this young technique. These systems eliminate: Solid waste to the marine environment, contamination of the area under the tanks, escapes from the rearing facility, marine mammal kills due to interactions with farmed fish and nets.

5 HYDRAULIC APPLICATIONS

5.1 *Capillary barriers*

With the increasing demand for water resources solutions are sought to prolong the access of water to plant roots and to decrease the water consumption. In many places assiduous efforts are made to enhance the effectiveness of irrigation and to inhibit the deep percolation of water, the latter with the additional advantage that also nutrients, salts and pesticides do not accumulate in deeper layers (McCartney & Allen 2008). This aim could be achieved by installing a barrier below the cultivated ground. The disadvantage of an impervious layer below the cultivated ground would be the drowning of the cultivated ground in case of extreme precipitation. Therefore the installation of a capillary barrier should be discussed, as for the application in landfill cover layers. Such a layer acts as an barrier in times of normal rainfall but allows for infiltration to deeper layers in case of heave rainfall. The installation of such barriers below cultivated ground would be extremely sophisticated, so it should be checked carefully if the benefit is worth the effort.

Using a geotextile as moisture controlling barriers may sound counter-intuitive, looking at the porosity and permeability of these materials, but the concept relies on the concept of a capillary barrier system which was originally conceived for two different soil layers, placed in separate layers. The material designated as the 'capillary block' would typically be a coarse grained pea gravel, which is placed below the 'capillary layer', which could be a clean fine sand for example. The pea gravel acts as a barrier to downward movement of water under unsaturated conditions as well as inhibiting upward movement of moisture by capillary action.

Capillarity causes suction, i.e. negative pore water pressure, due to the surface tension of the water. That behaviour is depending on the diameter of the pore channel. Once being filled, the capillary retains the water even if the pores below aren't saturated any more. Capillarity also causes different behaviour in drying and wetting that can be explained by an simple test: Approaching a water surface with a glass sphere shows that wetting takes place only if the glass sphere touches the water table. When removing the glass sphere from the water table, significant suction even at considerable distance of the sphere from the water surface develops – up to a certain distance, a water film remains from the water table around the sphere. Such effect develops during drying and wetting cycles in soils that can be measured resulting in a typical hysteresis in the relation of water content and suction force. The curve from wet to dry is known as water retention curve, i.e. the ability to retain water under an increasing applied suction. The reverse path is the wetting curve which shows low water content until very low or even zero suction is reached (Figure 6).

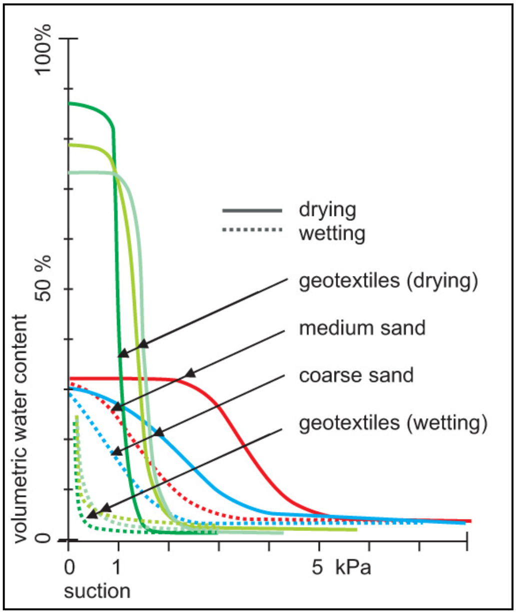

Figure 6. Drying and wetting curves of geotextiles and sand

Continuity requires that the suction must be the same on both sides of the interface between the capillary block and capillary layer and thus as long as both layers are not fully saturated, the capillary block layer has a hydraulic conductivity lower than that of the capillary layer. With certain boundary conditions, the capillary layer can become virtually fully saturated (with a small residual of suction) while the underlying gravely layer remains virtually dry, this way acting as a hydraulic barrier.

For the capillary block layer, the hydraulic conductivity drops extremely rapidly as the suction is increased. That means, if water occupies only ca. 5% of the pore volume – mostly as a film on the grains – hydraulic conductivity is as low as of a perfect clay, although the hydraulic conductivity at zero suction (in the saturated state) may be extremely high. In contrast, over a large suction range, the capillary layer has a much higher hydraulic conductivity than the coarser capillary block layer, so water will percolate through the capillary layer and not penetrate into the capillary block. But it is essential that the interface of capillary layer and capillary block is inclined to allow the water in the capillary block to drain (Figure 7). If the capillary layer cannot drain and becomes nearly saturated, suction decreases and approaches zero, resulting in a breakthrough and leading to the collapse of the barrier function. In the case considered here that would be beneficial since the excess water volume would not oversaturate the cultivated ground but infiltrate in deeper layers.

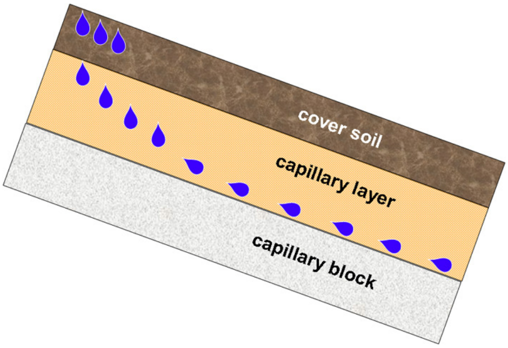

Figure 7. Capillary barrier schematic water flow

If we now consider a geotextile layer as capillary block, we have to look at the water retention and wetting curves of geotextiles. Due to the large pore volume of geotextiles, the water retention curves look quite different from those of soils. Only a suction slightly greater than 1kPa – which is rather low - is required to reduce the water content significantly. The wetting curves of geotextiles are remarkable, too, because it shows that the geotextile does not re-wet until the suction is virtually zero – maybe also a result of certain hydrophobia of the fibres (Figure 6). So it seems that there is a certain potential of thick nonwoven geotextiles being satisfactorily used in capillary barrier systems in the future, using them as a replacement for the pea gravel capillary block layer. This could be a particularly attractive option in countries such as Australia and South Africa where well rounded river gravel is not common and is expensive to source.

But there are some problems considering the realization in agriculture: As already mentioned, the placement of the capillary block has to be under the vegetated top soil, so it would be an option only for new artificially build up agricultural areas. Secondly the geotextile has to be thick enough to offer a sufficiently large pore space. This is impaired by compression of the geotextile and by soil particle intrusions – both reduce the pore space and reduce the capillary block quality. Thirdly, the system will function reliably only with sufficiently inclined layers which reduces the possible applications in agriculture.

5.2 *Erosion control - surface erosion*

Surface erosion develops when soil is exposed to wind and water and is in such a state that it can be transported. Loose and dry soil is susceptible to wind erosion while water erosion can affect every material, even rock – it is only a question of intensity of the water flow. Agriculture and aquaculture areas are affected in two respects: Loss of material (erosion of top soil or river banks) and deposition of (unwanted) material, resulting in pollution of ponds and waterways or spoiling farm land by the accretion of eroded soil.

Surface erosion may start with the first drop of water hitting the ground, followed by sheet erosion, which is a removal of soil from sloping land in thin layers. The next steps are rill erosion – gully erosion – channel erosion. As outlined in Table 1, Johnson et al. (2003) identify five types of water induced surface erosion and techniques for minimizing them respectively.

In general, surface erosion can be reduced by:

- slowing water velocity,
- dividing runoff into smaller quantities,
- allowing for water infiltration,
- providing mechanical or structural retention methods.

Table 1: Types of surface erosion

Type of Erosion	**Minimization Technique**
Raindrop splash (Raindrop impact of the raindrop dislodges soil, causing it be splashed into the air. The splash effect also increases compaction and destroys open soils structure.)	Stabilize the soil to prevent erosion. Mulch.
Sheet erosion (Transportation mechanism of soil loosened by raindrop splash, removal of soil from sloping land in thin layers. Dependent on soil type, depth and flow velocity.)	Minimize by diverting flow away from the slope.
Rill erosion (Occurs where sheetflow becomes concentrated in small, defined channels a few cm deep. Form of erosion in which most rainfall erosion occurs.)	Prevent by slope stabilization and diverting flow. Repair immediately with disking or tilling
Gully erosion (Concentrated flow in unrepaired rills.)	Requires extensive repair. Prevent by dispersing and diverting sheetflow.
Channel erosion (Occurs at bends and inconstrictive areas.)	Smooth bends, add riprap. Use of bendway weirs or bioengineering methods.

Erosion countermeasures should be installed as early as possible in the process of erosion, therefore the best solution is to avoid the initiation of erosion. If erosion has started already, measures have to be provided that hinder the increase of material transport, and if there is already a certain sediment flow, it should be guided not to result in detrimental effects. Tables 2 to 4 provide an overview over countermeasures according to the steps mentioned (Heibaum et al. 2006).

Table 2: Countermeasures to prevent surface erosion

control measure	geosynthetic contribution
surface roughening (disking; tilling; slope checks)	confinement (netting) of check elements
mulching	netting, fixed on the ground, over mulch
soil retention blanket	natural, biodegradable or synthetic mats (nettings, wovens)
seeding and sodding (turf establishment)	

Table 3: Countermeasures to prevent accumulation of material transport

control measure	geosynthetic contribution
berm	
slope drain	geosynthetic tubing, geotextile filter
bale check	confinement (netting) of bales
silt fence	geotextile fabric
geotextile triangular dike	urethane foam elements in woven geotextile
riprap	geotextile filter below riprap layer
wattles	confinement (netting) of straw wattles

Table 4: Countermeasures to control sediment flow

control measure	geosynthetic contribution
bale checks	confinement (netting) of bales
silt fence	geotextile fabric
geotextile triangular dike	urethane foam elements in woven geotextile
riprap	geotextile filter below riprap layer
rock ditch checks	geotextile filter below rock
sandbag barrier	geosynthetic bag material
floating silt curtain	impermeable geosynthetic sheet
sediment trap	geotextile filter below structural elements geosynthetic bag material

Geotextile can help to realize erosion and sediment control measures. Silt fencing, sills, bales etc. help control soil loss at the sites (active measures), while radix and turf enforcement, grass protection meshes, etc. all contribute to longer-term erosion control and vegetation support (passive measures). If erosion control measures are installed temporarily, also natural fibres can be used. Such fibres will disintegrate after a certain time, but may remain strong enough until the final situation is reached, i.e. the vegetation forms the erosion protection cover.

Turf reinforcement is a widely accepted countermeasure to hinder the initiation of erosion of channels and slopes. In agriculture it is no application to safeguard farmland from erosion – here terracing is the best way to keep the top soil in place. But many other rural surfaces can be protected. Applications are found for roadside ditches, storm channels, slope protection. If turf reinforcement ceases to be an adequate erosion countermeasure, stronger systems like riprap or mattresses are needed. For turf reinforcement a number of systems is available, e.g. three-dimensional entangled webbings, open cells of a three-dimensional structure, woven fabric in manifold characteristics. The geosynthetic panels can be furnished with seeds and fertilizer to enhance plant growth which leads to an accelerated erosion resistance of the vegetative surface.

If erosion has started already, sediment control measures are needed to prevent transport of soil into nearby waterways or onto adjoining properties. Very useful elements are silt fences (Figure 8). If the eroded material is transported into waters or created by an construction site in the water, turbidity curtains (or floating silt curtains) help to reduce the sediment transport.

Figure 8: Silt fence (Photo: North Dakota Erosion Control Handbook)

A silt fence must accomplish its purpose to screen silt and sand particles from the runoff. It would be a misconception, to follow the concept of the geotextile to act as a filter. With the build up of sediments behind the fence it acts more as a barrier than a filter, even if in the beginning the trapped soil forms a secondary filter behind the geotextile. The fence reduces the flow velocity which leads to the creation of a pond of relatively still water behind it, acting as a sedimentation basin to collect the suspended soil from the runoff water. The silt fence should provide sufficient storage capacity for a typical storm event. If the suspension volume is completely unknown, overflow outlets should be installed to avoid fence overtopping.

Silt fences are composed of tough, durable, geotextiles attached to support posts. Laboratory tests such as the F^3 test (Sansone / Koerner 1992) can be used for the selection of a suitable geotextile. Tests using flumes can also be used for the study of the geotextile behaviour in silt fences. Compared to the F^3 test, the flume test subjects the geotextile to conditions closer to those expected in a silt fence in the field, but testing equipment and methodology are more complicated. Farias (2005) carried out large scale flume tests to evaluate the performances of some light and low cost non woven geotextiles as sediment barriers in silt fences. The use of light geotextiles in silt fences is particularly interesting because it reduces the costs of the structure. However, the geotextile has also to attend mechanical and survivability requirements for a satisfactory performance (Holtz et al. 1997).

The function of bale checks, geotextile triangular dikes or sandbag barriers is similar to that of silt fences, being more robust but usually of lesser height. Sandbags filled with very permeable fill and designed as a filter act in the beginning of the sedimentation process behind the barrier as a filter. But as with silt fences, the barrier function is predominant with increasing sedimentation. Sandbags barriers are less susceptible to overtopping if the size of the bag is chosen appropriately.

5.3 *Runoff control*

First flush collection systems are employed to capture and isolate the most polluted runoff. A broad range of pollutants can be found in this first runoff, the nature of which depends strongly on the land use and the activities carried out on the site. Pollutants can come from fallout, leakages, materials handling practices, chemicals, fertilizers and wastes. First flush is often observed if a high proportion of the catchment is impervious (such as paved surfaces and roads). It is desirable that runoff would be infiltrated into the ground on undeveloped surfaces, diverting the first flush through sand filters, median swales, or other treatment. These are difficult to install in urban areas due to space constraints.

Many materials entrained in runoff can be treated by physical separation methods such as screening, sedimentation and floatation, many treatment units have been developed for this purpose. However, suspended and dissolved organic components including pathogens in animal waste may also be of concern. It has been found that nonwoven geotextiles attract biomass and cause organic removal. Due to the fact that nonwoven geotextiles provide much higher surface area for microbial growth they perform better than wovens.

Yaman and Korkut (2008) propose a "Geotextile Baffle Contact System (GBCS)" to remove and degrade pollutants from first flush of stormwater runoff, being a rectangular tank where thick nonwoven geotextiles are vertically suspended and closely packed, providing a sinuous sequence of channels with pervious walls. The geotextile panels serve as biofilm attachment media. So the pollutants are removed by multiple mechanisms: filtration through the porous geotextile, adsorption onto the geotextile surfaces, and sedimentation in the elongated channel pathway. Enclosed organic material is degraded by biomass growing in the porous geotextiles.

The authors report that the suspended solids and microorganisms were captured by filtration. A biomass morphology developed within the nonwoven geotextile structure without clogging it, and grew to emerge on the surface. This allowed contact between the biomass and substrate by both internal filtration and surface adsorption. Space requirement is low since most of nonwoven geotextiles have more than 90% porosity which doubles the gravel porosity used e.g. in trickling filters.

5.4 *Floating curtain*

A floating silt curtain (also called turbidity curtain) is mostly used to keep suspended sediments in a restricted area of at least, in flowing water, downstream off the water surface, forcing the particles to the river bottom. It is attached to an anchored floating device on the water surface, reaching down to the specified length, being kept in more or less vertical position (depending on the flow velocity) by ballast chains or bars (Figure 9).

Figure 9. Silt curtain (Photo: Layfield)

A silt curtain minimizes turbidity migration but cannot prevent it. Only short periods of turbidity are with nearly no harm to flora and fauna in rivers and lakes. As soon as turbidity is persisting for a longer time, plants in water and aquacultural life is endangered. Even with silt curtains installed there remains still the problem that particles settling to the bottom can suffocate creatures living on the water bottom and it can fill spaces in the bottom which is used by certain species for shelter and breeding.

To obstruct the majority of suspended particles, for example from aquacultures, such a curtain (also called turbidity screen) must block off any suspended particles that create turbidity. This can be achieved by leading the curtain to the bottom or by building a cage with a bottom made from similar fabric as the curtain. To allow for water exchange, the fabric must be designed according to filtration guidelines, which is complicated by the fact, that most guidelines are written for unidirectional flow like the flow toward a drain. In open water the local flow may change direction, e.g. induced by waves. So often only tests will give adequate answers for proper design. The above mentioned F^3-test considers the retention capacity of a fabric, but only when loaded unidirectional. Bidirectional flow is advantageous since it may remove clogged material. (Bidirectional flow through a filter in an soil covered system is much more complex.) On the other hand, as a consequence of the fact that deposited material can be removed, no secondary filter can develop. So the opening size of the geotextile has to be chosen such that also the finer suspender particles are retained, resulting in rather low numbers, and therefore vice versa reducing the water exchange and increasing the risk of blinding. Summarizing these facts, on has to come to the conclusion that designing such a geotextile protection for cultures in water is very sensible and needs a lot of effort and experience.

5.5 *Bank protection*

Even though bank protection seems not to be closely connected to agriculture and aquaculture, such protection measures may become of vital importance if farmland and aquafarming infrastructure are threatened by land loss due to scouring or unwanted accretion of water transported soil. Rivers often create new channels after severe flooding, so the loss is twofold: the new riverbed has destroyed farmland and the old riverbed can be used as farmland only after extensive effort. So it is essential to force the river back into the old bed after the flooding. An outstanding example has been built in Bangladesh (Oberhagemann and Sharif-Al-Kamal 2004, and Oberhagemann et al. 2006).

In Bangladesh there are shortages of local aggregate for concrete and no suitable rock for riprap. But there are resources as sand and labour. Driven by the urgent need to protect two large irrigation schemes where the conventional type of riverbank protection was not economically feasible, a new path was followed using sand-filled geotextile bags. With traditional riverbank protection works, failures were observed within a few years after construction. So a flexible approach was required, taking into account the variable river environment. Since low cost solutions were sought, sand-filled geotextile bags were chosen as protective elements, being much cheaper than commonly used concrete blocks, quarried rock or boulders and taking advantage of available inexpensive labour and locally attainable sand (Figure 10).

Figure 10: Riverbank protection by geosynthetic containers (Photo: Oberhagemann)

With riverbank protection using geotextile bags, three main loads beyond the normal use are associated: ultra violet radiation above water, wave action, abrasive forces due to sediment and bedload transport. To cope with these loads, the fabric has to be chosen carefully. Details are reported in Heibaum et al. (2008).

Generally, abrasion is an issue in all applications where the geotextile is not protected by an additional layer or armour. When testing a fabric for abrasion resistance, the load in situ should be met as well as possible, which is rather difficult for wind or flow induces abrasion processes. The "sliding block method" for geotextiles takes into account only a loading that simulates the sliding of a solid mass over a fabric, representative e.g. for carpets or seat covers. The contact of moving soil particles and geotextile is different! The soil particles roll, tumble or rock on and over the fabric. BAW developed an abrasion test for hydraulic application (RPG 1994), that approximates best the abrasive load induced by hydraulic processes and my be used also for wind abrasion. In this test, a mixture of stone chippings and water passes over geotextile samples installed in a rotating drum. The standard test comprises two abrasion phases of 40,000 revolutions each. The drum speed is set at 16 rpm and the direction of rotation is reversed every 5,000 revolutions. The tensile strength and, if filter function is an issue, the opening size after abrasion is tested. tensile strength should not decrease below 75 to 80% of the required value, opening size should not be enlarged more than 0,01 mm (if fine sand and silt has to be retaned).

Hydraulic structures made from geosynthetic bags or containers also can help to shield aquacultures from harmful hydraulic loads like large waves and high currents. Such structures are reclamation dikes, groins, breakwaters and artificial reefs. Fine Australian examples are presented by Hornsey et al. (2002), an overview over artificial reefs is given by Hsuan (2008).

5.6 *Impervious linings*

5.6.1 *Polymeric and bituminous membranes*

Impervious lining is traditionally done by clay, later also by concrete. Since more than 40 years, geomembranes are used to achieve watertightness of hydraulic structures. About 20 years later, geosynthetic clay liners were added to the group of lining materials and are meanwhile established as well.

Geomembranes are very widely used for lining ponds with a large variety of uses: irrigation, runoff retention (Figure 11), drinking water, energy production, aquaculture, leisure activities, fire-fighting, artificial snow production. The structures concerned have widely varying sizes, ranging from irrigation ponds for a single farm to very large ponds mainly for energy production, but often for multiple purpose.

Figure 11: Runoff retention basin with membrane lining

Membranes are manufactured from several polymers, e.g. the Afourer pumping station (Morocco) which is located in highly permeable limestone zones was sealed using a PVC membrane of a thickness of 1.5 mm over a total surface area of around 330 000 m². The designer chose to protect this geomembrane by a covering structure, because the lifetime of the geomembrane is considerably increased, the protection against the wind would have required large anchorage systems for this type of basin, and the protection against vandalism and passing animals (Fayoux et al. 2006). Another example uses an EPDM (ethylene-propylene-diene monomer) geomembrane (2 mm) to line the upper pond of the Yambaru pumped storage power plant (Japan) located on the edge of the Pacific Ocean and using seawater (Takimoto et al. 2002). Since the geomembrane is not covered, it is carefully anchored to concrete blocks installed before the granular sub-base.

The two examples illustrate beside the use of different polymers the difficult choice: "covered or exposed" geomembrane. The advantages of an exposed geomembrane are: costs are generally lower (although the cost of an elaborate anchorage system should not be underestimated), quicker and easier installation, no risk of damaging the geomembrane by installing a cover layer, easy visual inspection and repairs, shorter intervention times (important in rehabilitation operations); the disadvantages are: lower durability of the exposed geomembrane, risk of mechanical damage by vandalism, floating objects, falling objects, ice, mechanical effects of wind and waves and need for a more resistant sub-base. Covered geomembranes are protected against the external factors mentioned above, thus providing greater durability. On the other hand, there is a risks of puncturing the geomembrane when installing the cover layer, access to the geomembrane in case of a leak (detection and repair) is difficult and the costs are generally higher.

Geomembranes are also widely used in canals, whether for the transport of water (irrigation, drinking water, electricity production) or for navigation. Geomembranes are used for new structures and in the rehabilitation of old structures. They have certain advantages compared to older solutions like clay and concrete. ICID (International Commission on Irrigation and Drainage, 2004) reports an a growing use of geomembranes in irrigation channels. It is suggested that geomembranes should be covered because irrigation channels cannot be protected from access by the public or animals, and require maintenance operations (removal of sediment, for example).

Strobl et al. (2002) present a comparison between the traditional sealing methods (cement and asphalt concrete) and polymeric and bituminous geomembranes in the rehabilitation of water transport canals for hydroelectric power production. The main advantages of geomembranes are: time savings on installation, lower costs, no decrease in the size of the canal (thickness of the geomembrane compared with that of a layer of concrete), smoother surface (of the uncovered membrane) allowing for higher flow rates (Figure 12). Guidelines have been published by the Technical University of Munich (2006).

Figure 12. HDPE-lining of inflow canal of hydroelectric power plant

Some problems were observed when using geomembranes for ponds and canals of modest dimensions . This seems to be linked to the fact that for modest structures it is the financial factor, unfortunately, that often becomes dominating (ICID 2004). Another difference between small and large works is that often less experienced people are concerned by small projects even though technical questions are similar. It is important to stress that the designer must approach the system as a whole in all cases. Good performance depends just as much on the subbase, covering layers, anchoring systems etc. as on the geomembrane itself.

5.6.2 *Geosynthetic clay liners*

Geosynthetic Clay Liners (GCL) have been installed in many applications, predominantly in landfill and road construction (including runways). In hydraulic application it can be found as lining (initial or repair) of irrigation and retention ponds, irrigation canals and dikes (or levees). With these applications the GCL is placed in the dry. The usual installation guidelines require that the bentonite must not have any contact to water until the system of lining and protection is completed.

When installing a GCL, the overlap needs special treatment. Usually bentonite powder is spread in the overlap and the seam is sealed with bentonite paste. Such after-treatment is not possible when the GCL is to be placed in the wet, e.g. in a canal that cannot be closed and emptied. Then a lot more aspects have to be taken into account. On the other hand GCL is the only geosynthetic material that can be installed as an impervious liner under water, since welding or other joining of membranes is impossible in the wet. In 2009, a first attempt has been made in the Isar intake channel to achieve an impervious overlap under water with a HDPE membrane. This was realized by covering the joint of two structured membranes by a layer of impervious underwater concrete (Heerten 2009).

To avoid any aftercare of the seam, the overlap is manufactured as a bentonite- impregnated nonwoven (top fabric of the lower GCL) and a woven (base fabric of the upper GCL) – or another bentonite-impregnated nonwoven. This way, no transmission flow in the overlap is possible. Pilot installations have been done in German navigation canals (Fleischer / Heibaum 2002). For agricultural and aquacultural canals and ponds, installation can be done usually in the dry. But there might be exceptions like the rehabilitation of a drinking water canal in the Ukraine (Figure 13). This canal cannot be closed being the only water supply for the Donez Basin. To repair the leaking concrete lining, a new impervious layer was needed, but with limited thickness only, not to reduce significantly the channel's cross section. The solution chosen was to place a GCL upon the existing surface (under water) and to build a protection layer from prefabricated concrete slabs with spacers to hold them with a gap above the GCL and then to fill the gap with pumped concrete.

Special aspects for the use of GCL have to be considered: GCL provide a flexibility to guarantee that no leakage or weakening will develop due to deformations of the subsoil, this way being similar to polymeric membranes. There has to be a sufficient resistance against impact forces. When armour is dropped upon the GCL, the liner must not be impaired. This is not a question of damage to the geotextile which can be chosen with sufficient strength, but the bentonite will be locally displaced, leading to spots of increased permeability. An additional protection layer is necessary in the zone of fluctuating water level because GCL are not resistant against plant roots.

Particular care is necessary during the placement of the GCL as to the overlaps. No granular material at all must remain in between two overlapping GCL sheets. The overlapping technique should guarantee imperviousness from the very beginning, even for placement in the dry, since in the wet no after-treatment is possible like in dry conditions. But even if the GCL is installed in dry conditions like in dikes, walking on the GCL for after-treatment of the overlaps isn't favourable to the lining.

Figure 13: GCL-liner below concrete protection for potable water canal, Ukraina (Photo: Naue)

6 OUTLOOK

The applications of geosynthetics in general and in agriculture and aquaculture are increasing and the development of materials and fabric will increasingly go on. Dennis (2008) is expecting rather flexible material, impervious or pervious depending on the state of strain, products that thicken depending on the use, colour changing and fragrance-emitting, in any case multi-functional, ending up in a "tropospherosynthetic". Even if this are dreams, Dennis argues concurrently that in other sciences the development we experience today was not anticipated, so why not with geosynthetics. To foster this development, he requires as a general demand to enhance overall quality by increasing both, design and performance. This request can't be but supported in every respect.

An example for an important step forward is the introduction of EVOH (ethylene vinyl alcohol) to geosynthetics (Kolbasuk 2008). Originating from food application, it can help to increase the barrier function against solvents and gases. Compared to LDPE, the permeability of oxygen is 1000 times lower. This could be rather valuable for silage covers. Silage is put into storage immediately after being harvested and compacted. It should be stored in such a manner that infiltration of air is prevented, to allow for fermentation, that will use quickly the existent oxygen. This way the nutritional value is much higher than with dried crops. Due to the moisture content, any entry of oxygen could spoil the silage. Polyethylene, which is usually applied as silage cover, still allows for permeating of oxygen, so at least an outer layer of silage can be spoiled. A polyethylene cover laminated with a EVOH layer in between, would reduce the oxygen entry significantly and this way the risk of spoiled silage.

Another promising application is reported by Boutron et al. (2009). The authors performed a study on the retention of pesticides in the environment, especially in agricultural ditches and wetlands. In order to investigate the possible use of geotextiles for the retention of pesticides in agricultural watersheds, studies of the adsorption and desorption of three widely used pesticides namely diuron, isoproturon and azoxystrobin, were performed. The three most promising fibres appear to be polyamide, jute, and hemp, with adsorption percentages ranging from 35% to 80% at equilibrium for the three studied pesticides. Adsorption kinetics are relatively fast, which suggests that these geotextile fibres could retain significant amounts of pesticides even for the short contact time conditions which are typically encountered in flowing ditches or wetlands.

Adsorption data are compared with those previously obtained for natural substrates (dead leaves and sediments) typical of agricultural watersheds. Adsorption for geotextile fibres is much better than that for sediments, but is lower than that for dead leaves. However, they could offer an interesting alternative to the addition of plant matter to ditches or the introduction of wetlands to retain pesticides thanks to their improved mechanical properties and greater resistance to water flow. Adsorption potentials could thus be significantly improved by developing new geotextiles containing a mix of fibres with different physico-chemical natures to trap a larger range of pesticides. Such geotextiles might need to be developed specifically for pesticide retention purposes.

The developments observed indicate "a progress in silence". Many new applications have been tested secretly and are one day surprisingly available on the market. Maybe it would be better to side the introduction of new fabric or new geosynthetic systems by some rumor in technical periodicals to make sure that the engineers and designers of structures incorporating geosynthetics have access to the latest developments. Maybe we should think of spreading our findings not only among the insider community but try to approach the users. That seems to be extremely important considering geosynthetics in agricultural and aquacultural applications since these applications often are not part of typical civil engineering planning processes. This application area should therefore considered more often in international conventions dealing with geosynthetics.

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