Until well into the 20th century keeping feet dry meant compromising on comfort. Then new material developments and adaptations in construction changed this for all of us. Now consumers can enjoy outdoor pursuits in footwear that keep them both dry and comfortable, and the 21st century offers hope of even better things to come.

Waterproof barriers for footwear

In footwear, when water repellency is insufficient and water resistance is only temporary, waterproofing is the only completely impermeable solution. Waterproofing footwear is not a simple, singular process, not if you want to avoid 'boiling or dehydrating' your feet, as was the case before the breathable membrane was introduced by Gore-Tex in the 1970s. Waterproof footwear, as a somewhat imperfect product, has been around since the mid-1800s as a solid vulcanised boot, known in North America as the duck boot and in England as wellingtons or galoshes. Of course, 'somewhat waterproof' is an oxymoron, as a shoe or boot is either waterproof or it is not. In modern lightweight footwear, waterproof barriers are necessary at several stages of production to enhance the water resistance of the shoe or boot. Waterproof performance depends upon the type of breathable membrane barrier used, the materials protecting them, such as the seam sealant or tape, the critical adhesion of the sole to upper and the impermeability of the materials selected for the soling and upper. If cared for correctly, these waterproof barriers often last longer than the boots themselves.

While we're on the subject of defining waterproof footwear, there are various categories of footwear used on and around water for different purposes. Other than heat-sealed chest waders made of vulcanised rubber or flexible PVC, no other type of footwear can be made 'tall' enough to prevent water entering at the topline, albeit 6, 8, 10 inches (15.2cms, 20.3cms) or thigh high. Given water conditions deep enough or precipitation pouring down hard enough – water will find a way down to the feet. What we are

really discussing is effectively preventing water from penetrating from the ground up to the ankle. In certain sports and activities such as river rafting, surfing or rowing, the design and use of materials used in these forms of water activities is aimed at eliminating the anticipated water accumulation in the shoe as quickly as possible.

In designated waterproof footwear the outsole and midsole unit is the first line of defence. Vulcanised SBR or carbon rubber outsoles are still preferred to all other available soling compounds due to their combined characteristics of impenetrability to moisture, durability and traction. Vulcanised rubber can be used effectively as a water barrier in several forms.

1. *The Unit Outsole* – In a moulded unit form, either with heel or as a wedge, the vulcanised rubber unit can be adhered or stitched directly to welted midsoles in various thicknesses. Obviously, at the sacrifice of weight relief, the thicker the outsole and deeper the lugs, the more protection from ground water is provided.
2. *The Shell or Cup Sole* – Combining midsole with outsole, the rubber shell sole has the 'built-in' advantage of a high waterproof side wall (or foxing).
3. *The Built-Up Vulcanised Sole* – Prefabricated layers of rubber cut from a slab or sheet are used as cushioning or fillers as a midsole between the upper and outsole. A strip of rubber foxing is glued around the combined sole and upper, and then vulcanised into a single unit in an autoclave oven.
4. *The Direct Vulcanising Process* – Perfected almost fifty years ago, the process of extruding rubber as a sole unit directly onto a lasted shoe or boot and vulcanising it in a heated sole mould truly revolutionised the waterproofing construction of footwear. Along with a rubber sealant applied to the closed upper, the bonding processes between upper and sole offer a superb water barrier.
5. *Latest technology adheres vulcanised rubber to PU midsoles* – Bonding a pre-vulcanised rubber outsole to a polyurethane midsole, either in cement construction, or as a direct injection process, offers the maker of waterproof footwear the advantages of vulcanised outsole with a lightweight midsole. This process is now regarded as one hundred per cent reliable for waterproof footwear.
6. *PU, TPR and TPU Soling* – In high-density or blown form, if applied correctly, all "plastic" soling offers the maker a high degree of impermeability to water. These compounds do not, however, offer the wearer equal durability or traction to vulcanised rubber as an outsole.

Constructions used for waterproof footwear

Unless the construction method employed is of a one-piece upper and sole type, such as in all rubber vulcanised, heat-sealed PVC or the slush-moulded process, the sole must be bonded, adhered, stitched, tacked or riveted to the upper. Thus, the process of sealing the upper to the sole unit is critical in any waterproofing construction method.

(a) Direct Vulcanised Process (described above)
(b) Built-up Vulcanised Process (described above)
(c) Cement Construction
(d) Direct Injection Process
(e) Welted Constructions

Whatever construction method is used to attach the sole to the upper in waterproofing footwear, a coating of sealant should be applied to the bottom of the lasted upper to seal the various materials above and below the featherline. In cement construction, a waterproof rubber 'apron' or foxing may be adhered around the upper, allowing the midsole wall or outsole unit to cover well above the featherline. With any of the direct attaching processes - PU or rubber, the sole is applied between the outsole and upper forming a sealed bond with the compatible upper material. Built-up vulcanising is sealed in an autoclave oven when the semi-cured rubber foxing is joined or 'melted' onto the upper. Welted constructions, such as Norwegian welt or Goodyear welt constructions, pose more of a challenge for the shoemaker. On the one hand, welted construction is the only waterproof sole attaching method that is readily repairable, making it still a very desirable as well as durable construction method. On the other hand, one cannot have a true welted construction without needle holes. In waterproofing footwear every stitch hole must be sealed to secure all stitched seams to prevent seepage. This is done by applying an adhesive sealant during the construction process.

Solid metal or plastic coated eyelets and shanks are preferred for use in shoes and boots that are constantly exposed to water. Polypropylene shanks are, of course, rustproof and lighter than metal. In certain sports shoes, such as golf and screw-in soccer studs, where receptacles are required to hold stud and spike fixtures, high density nylon and polypropylene male and female systems have been perfected in place of metal.

Today, at the heart of every successful waterproof boot or shoe is a breathable waterproof membrane inside liner which allows the foot to breathe and remain dry if correctly sealed. Polytetrafluoroethylene (PTFE) or more simply called Fluorocarbon Polymers, from which most breathable waterproof membranes are made, were discovered at DuPont in 1938 and began to have a commercial application in the 1950s as wiring insulation and as the Teflon brand name at DuPont. In 1969, Bob Gore discovered that PTFE could be stretched to form a strong, porous material that allowed vapours to pass through by osmosis but formed a barrier against water droplets. This discovery led to the introduction and patenting of Gore-Tex by the W.L. Gore Company in 1976 and as a waterproof bootie system in 1982. The waterproof membrane can be applied either as a lamination process, as developed by the Italian company Nextec

Major football brands all need to offer waterproof boots.
Packer Leather

srl of Varese, where a permeable waterproof membrane can be bonded to the back of leather or as an inside fabric bootie system as originated by Gore.

The Nextec product, named OutDry, turns the leather itself into an impenetrable barrier against water. OutDry is an extremely thin breathable resin membrane specifically developed to be waterproof and breathable with excellent moisture permeability properties. The membrane is flexible and elastic with excellent adhesion properties even under stress so as to easily bond to stretchable synthetic upper materials as well as lightweight leathers. Creating the patented laminating process employs a special hot melt adhesive system applied to the back of the leather, using technology provided by Nextec and equipment made to the company's specification. This Nextec lamination system enables the shoemaker to apply OutDry inside a fully stitched upper creating a totally waterproof upper requiring only the addition of a conventional lining and sealing tape. ASTM E96-BW testing with the OutDry membrane laminated to 1.2mm nappa leather show results of 4850 gr/m^2/24H compared to 3500 gr/m^2/24H for a conventional PTFE membrane.

OutDry membrane using Nextec technology promotes these features in waterproof footwear:

- Upper and not lining becomes waterproof.
- Combinations of upper materials are possible.
- Expensive taping is reduced to a minimum.
- Standard cement lasting can be used.
- More flexible and more comfortable shoes or boots are the result.
- Avoids entrapment of perspiration within the system which in cold conditions turns to ice.
- Eliminates dew condensation problem.

The process involves placing the stitched upper inside-out over a shaped form. The membrane, in either one or two cut shapes, with overlap allowances, is laid over the upper and the form enters the laminator. On completion of the cycle, the upper requires only one or two seams be sealed with heat-seal tape to complete the waterproof process. A conventional lining is then stitched round the throat and topline to complete the assembly.

At the Gore laboratories in Elkton, Maryland all Gore-Tex fabrics are tested vigorously to survive frequent exposure to heat, dry cleaning chemicals, stains, spills, body perspiration, insect repellents, and detergents as well as abuse like flexing, abrasion and tearing. Throw in temperature fluctuation, humidity extremes and strong sunlight and it is easy to see why Gore takes its product guarantees seriously. To use the Gore-Tex hang tag, Gore insists on an exact production format be followed to ensure compliance to their waterproofing patent as well as independent testing of the finished boot or shoe.

Extensive waterproof testing at Gore laboratories includes the Mechanical Boot Flex Tester (left) and the Centrifugal Tester (right).

Gore-Tex

One of the tests performed on footwear is the Gore Mechanical Boot Flex Tester that flexes new footwear styles in a trough of water up to 500,000 times to ensure the product is waterproof. Another Gore test is the Whole Boot Breathability Tester that measures how much perspiration can escape from the shoe during use. The test assures the wearer that the tested footwear is designed to meet not only the shoe brands breathability performance standards, which may vary, but Gore's own standards. Gore also has a Centrifugal Tester that spins water-filled footwear at high speed. If pressurised water escapes from the shoe or boot, a leak is indicated – and corrected. Finally, the Gore Bootie Testing Machine, used inside the shoe factory, confirms that no seam-sealed Gore-Tex booties leak before going into production. A bootie is inflated underwater, and if bubbles indicate a leak, the bootie is redesigned, resealed and retested to assure dry feet inside the bootie even if the upper is not fully waterproofed.

Sympatex makes four different types of lightweight, 1/100th mm ultra-thin, non-porous polyester membranes that are totally waterproof, and highly breathable. Direct Laminate adheres to the reverse side of the outer material. It offers optimal transpiration because there are fewer layers. With direct laminates, every seam must be sealed with a special adhesive seam tape. Three-layer Laminate sandwiches the Sympatex membrane between the outer and lining materials. This variation is used in active sportswear and workwear. The other two Sympatex systems, Insert Laminate and Lining Laminate are more specific to garments and fashionable outerwear. In all four applications the unique non-porous construction creates an absolute wall against wetness, yet allows the same impenetrable barrier to transport perspiration, so the body can breathe too. Sympatex hails from Wuppertal, Germany and is widely used by a number of popular brands including, HI-TEC, Josef Seibel, Alpina and Dexter.

As part of the waterproofing process we need to consider the latest upper materials and sealing methods used to create the initial barrier between the foot and the elements.

Many man- made materials suitable for shoe uppers offer a high degree of waterproofness, amongst the obvious choices are vulcanised rubber sheeting, flexible PVC and neoprene. However, none of these materials breathe, which means that keeping the moisture out also means keeping the moisture in. With wicking, moisture control and phase change materials upper most on the shoemakers mind, there are alternatives and better choices for comfortable,

breathable waterproof footwear. Synthetics may be taking over in many product areas but for footwear, even waterproof footwear, leather is still the top choice.

Industry leaders such as Pittards, Prime and S.B. Foot view each shoe category's requirement as 'performance enhancing benefits' that add real value to modern leathers.

Oil and silicone tanned leathers offer water resistance but as more waterproofing fatliquors are added this tends to create an uncomfortable microclimate around the foot, with high temperatures and humidities. A better method is to combine water resistant leather with a polyester or PTFE breathable membrane, whereby a total water barrier can be achieved. For hunting and fishing boots adding a PU or PVC coating will successfully waterproof leather, but block the natural transpiration qualities at the same time. S.B. Foot in Red Wing, Minnesota adds waterproofing chemicals in the re-tanning process and a silicone top coating on its 2.0 – 2.2 mm Cammo waterproof leather to achieve the industry 20,000 Maeser flex test waterproofing standard. For children's footwear two of the leading manufacturers, Lorica with its Suable range of nubucks and Giardini with its Mycro Suede Hydro, both emphasise water-resistant features in their sythethic leather. Golf shoes worn in wet climates require a high degree of waterproofing. Ecco from Denmark, who entered the golf shoe market some years ago, have introduced a white 'Hydromax' side leather produced in the company's own tanneries with an increasing amount of colour being added using nubucks and oiled leathers, which are also treated as Hydromax. Hydromax is water resistant to eight hours on the Bally Penetrometer.

Waterproof leather from 'Down Under'

Packer Leather has been active developing waterproof bovine for both military and the outdoor footwear markets. Military waterproof bovine has been produced as 2.2mm nubuck that meets the minimum 20,000 Maeser flex standard for waterproof footwear with less than ten per cent water uptake after three days of manufacture. The Packer unique cross-linking tanning method continues to be developed to improve water resistance, with maximum figures achieved after eight weeks. Packer tests its waterproof leather up to 300,000 Maeser flexes with less than five per cent water uptake. In addition this leather has a new integral technology that enables it to dry out more quickly if subjected to water over extended wear periods. This special leather, called Defender Mark 1 has been exclusively tested and used in high humidity zones by the Australian Armed Forces.

Packer Leather in Australia has been developing waterproof leathers for a variety of products.

Packer Leather

Packer has also developed a military waterproof kangaroo - a 1.2mm nubuck or suede leather, which has a minimum of 20,000 Maeser flexes and less than ten per cent water uptake after three days of manufacture. The kangaroo leather process uses the same technology as the military bovine. The obvious added advantage of the kangaroo leather, called Kombat, comes from its superior strength, and is preferred for 'Special Ops Forces' around the world for lightweight stealth type boots. It is also available in a non-stretch version for special components in military footwear to maintain its original size and fitting throughout the life of the boot.

The stalwart leather substitute materials have long been PVC and PU coated fabrics. However, with the advent of the 'breathable membrane' era, other woven and non-woven materials can now be reliably waterproofed. 1,000 denier Cordura nylon in a camouflage pattern is used extensively in hunting boots as an upper component reinforced with leather overlays. The Viking Elk model for example uses a 1,000 denier Cordura with the ultimate 100% waterproof Gore-Tex liner. Itasa brand produces a 19-inch (48.26cms) Expedition Snake Protective Boot in heavy duty Cordura uppers using AquaPlus waterproof, breathable membrane with double padded pigskin collar. Giardini, of Italy haves introduced its Mycro upper material, which is claimed to have a three dimensional fibre structure similar to natural leather. It is more flexible and durable than natural leather; waterproof yet permeable while being only one third of leather's weight. Permair leather, produced by Porvair has passed the EU standard EN344 which includes hydrolysis resistance and high breathability as well as having high durability and abrasion resistance, excellent cold crack and flex resistance, waterproofness and a wipe-clean finish.

One unfilled needle hole ruins the effect

As impermeable as all materials, components and membranes may be - one unsealed thread hole or one oversized eyelet can become a water porthole. A good waterproof shoe should start with a sensible seam (and decorative stitch) free design. For sealing, Sagitta has a special adhesive applicator using a patented adhesive for waterproofing upper seams, applying the adhesive both under and over the lap seam in one unique operation. Seam tape is an (alternative) essential component in the waterproofing process. Tongue design and detailing is an important feature in securing the final waterproofed product. Bellows tongue design using an impenetrable PU or PVC material aids in keeping the elements out. Likewise, a correctly designed, well padded collar snugly fit to the leg without being restricting, makes water penetration less likely to occur.

Lining materials finish the job

Lining materials must be chosen carefully; for summer sports, whether they involve submerging the foot in water or not, the lining used in footwear needs to keep the foot cool, as well as dry. For cold weather activities, the foot needs warmth and dryness. The role of a high tech lining in waterproof footwear is to help keep moisture out while at the same time allowing the foot to breathe, thus eliminating odour and perspiration build up inside the shoe. CoolMax, Cambrelle, Dri-Lex and the like when backed with a sealed waterproof membrane will achieve this goal. There is also a Dri-Lex version with a waterproof membrane.