HOW TO BUILD A NATURAL SWIMMING POOL

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THE COMPLETE GUIDE TO HEALTHY SWIMMING AT HOME

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FOREWORD

It used to be that whenever we took a swim in a pool, private (always something of a luxury) or public, there would be that abrasive, aggressive reek of chlorine clinging to our bodies as we emerged and for some time afterwards. At school we used to go swimming on a Tuesday morning and the day became inescapably linked to the smell. Public safety made use of the potent biocide absolutely essential. More than that, it was public fear that made the absence of chlorine in a pool unthinkable. The link made between the well-publicized polio of American President Franklin Delano Roosevelt and bathing was one that hung over the 20th-century swimming pool like a threatening dark cloud. The penetrating reek of chlorine may have been unpleasant but it was a reassuring one. For some, however, the smell and the stinging eyes were all too much and public bathing became something to be avoided.

Then there were natural pools and rivers – so called "wild swimming". But the locations have always been few and far between and on a hot summer's day all too likely to be even more overcrowded than the public baths. And for many there were worries here too, at least for the nervous. Could your toes be nibbled by a pike? What do you do if you meet a mink swimming alongside you? What's that oozy slime you feel between your toes when your feet touch the bottom?

Times are changing however and we now have a natural alternative to the noxious but necessary chlorine. The natural swimming pool is part of a whole new range of technologies – reed bed sewage management and bioremediation in particular, and green roofs and living walls more generally – which aim to bring living, breathing nature into the processes we use to manage our lives on an increasingly crowded planet, and manage them far more sustainably.

Natural swimming pools, as Wolfram Kircher demonstrates, offer a way to get plants and micro-organisms (mostly the latter, but we tend to focus on the former as we can see them) to clean the water for us instead of horrible smelly chlorine or other chemicals. He shows in great detail how to construct and manage a variety of different types of pool, as well as how to think about the visual and aesthetic dimensions, all too important in such a design-conscious world.

Natural swimming pools took off in Austria some time ago using a technology which focused on a range of common water plants providing the necessary environment for micro-organisms that sweep from the water the nitrogen and phosphorus that can potentially feed pathogenic bacteria. Visiting Wolfram's own garden in a village in eastern Germany was a wonderful introduction to other possibilities, for example using the very special vegetation of low-nutrient acidic peat bogs. Visiting the university where he works, there are yet more examples of plant-based filtration and cleansing systems on display, such as one using a rock-garden-based planting. There are all sorts of possibilities. Hopefully this book will help get more of these living pools out there, so more of us can have the opportunity to enjoy the water and come out feeling and smelling fresh and unchlorinated!

Noel Kingsbury

AUTHORS' NOTE

In this revised edition published in 2025 a number of improvements and new developments have been incorporated including the latest guidance from the German Landscaping and Landscape Development Research Society (FLL), new products for the control of algae, appropriate fertilizers and updated photographs.

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Styles of natural swimming pools
Top a traditional formal pool is purified by a plant-free biological filter hidden under the wooden deck in the foreground.
Middle a formally designed natural pool with plants as the main purifier.
Bottom a naturalistic pool with extensive planted areas.

1
WHAT IS A NATURALLY FILTRATED SWIMMING POOL?

NATURAL VERSUS TRADITIONAL POOLS

Swimming pools are popular all over the world as a place to relax and cool off. Natural swimming pools offer a new way to swim in fresh water that has not been treated with chemicals. They integrate well into the garden, are gentle on the eyes and skin and benefit the garden ecosystem.

Only biological processes are used to purify the water so there are not the harmful side effects of conventional swimming pools, which are usually treated with chlorine, chlorine dioxide, mineral salts, organic biocides or ozone. These come at a cost, not only to the wallet but also to the user's health.

A natural swimming pool allows you to practice responsible water management too. In a well-balanced system, completely changing the water is neither necessary nor recommended. Only partial refilling is required from time to time to replace losses through evapotranspiration. By contrast, a traditional pool's entire body of water has to be replaced periodically because imported contaminants cannot be depleted or mineralized.

Natural swimming pools can take many forms and range from formal designs reminiscent of a traditional swimming pool to plant-dominated options which resemble a natural wetland.

Chemical treatment (especially preservatives and disinfection solutions) is not acceptable in natural pools because it reduces or disables the desired biological activity. (The "physical/chemical" cleansing mentioned right simply means special filter substrates which absorb certain ingredients or special fertilizers.) UV radiators are not desirable, because they kill all living organisms in the water. The use of an artificial seal to separate the body of water from the subsoil defines the difference between a natural pool and a naturally occurring body of water, which may of course also provide opportunities for swimming.

The German Landscaping and Landscape Development Research Society has published standards for private natural pools (FLL, 2017). It defines a natural pool as a "*pool system designed especially for swimming. It is sealed against the subsoil and comprises the swimming area and the regeneration area, and it has defined requirements in terms of water quality. The water is cleansed biologically and possibly also physically or physically/chemically...*".

Above left to right A natural pool can be a good alternative to the gym, is a popular play area for children, and shallow stream sections can replicate a "Kneipp Basin" which reactivates the blood circulation, improves the immune system and has a refreshing effect as you walk through it.

We use the term "natural pool" to describe all types of swimming facilities which meet the FLL guidelines. The recent Austrian guidelines "ÖNORM L1128-2013" use the term "Naturpool" (nature pool) only for oligotrophic, phosphorus-limited, artificially constructed, perennial water bodies, without inflow, without thermal stratification, used for swimming or bathing purposes, purified mainly by percolated filter bodies. So it covers only a small proportion of the pools in our broader definition. Types with mesotrophic water (higher nutrient concentration, p. 33) purified mainly by plankton development are called "Schwimmteich" (swimming ponds) in the Austrian guidelines. But in both Germany and Austria the spectrum of pools ranges from facilities without technical equipment (standing bodies of water) to intensive filtration by powerful pumps. In all cases, a division into two zones is typical: the swimming area provides sufficient depth and is free from vascular plants, and the regeneration area can feature a shallower water level and purification setups, mostly including vegetation. The regeneration area can be placed adjacent to the swimming area, forming one functional unit (in situ) or be separated in one or several ponds connected to the swimming zone by pipes (ex situ).

To distinguish between natural pools and normal garden ponds, it is worth clarifying that in most cases the latter are eutrophic standing bodies of water. Their main purpose is their ornamental value. A rich supply of nutrients encourages plant development and water clarity is of secondary importance.

Left The occasional canine paddle should not harm the water quality.
Right Natural pools can provide an unusual baptismal font, ice skating in winter or a plunge pool for the sauna, even in winter if a section is kept ice-free.

ADVANTAGES OF NATURAL POOLS

Conventional swimming pools are hard to combine attractively with a naturalistic garden design. They work better when integrated into a formal environment with hard landscaping or mown lawn. A "Mediterranean" design often provides a suitable theme. A natural swimming pool, however, integrates well with naturalistic planting or organic design.

A natural pool is often built into a constructed wetland area which enhances the ecological character of its environment. In summer it provides a cooler atmosphere. Artificially bedded out plants begin to interact with naturally establishing flora and fauna, creating a complex biotope which enriches the garden. The pool surrounds can also become a refuge for endangered plant species and animals.

A natural pool can play a part in rainwater management as a storage basin (Dunnett & Clayden, 2007) but, because it must have a relatively stable water level, its capacity as a water resource is limited. To avoid overtaxing the preflooder it is better to install a separate cistern or else construct an efficient drainage swale. However, a design which comprises two water bodies can provide an effective solution for rainwater storage: if a separate regeneration pond is located significantly lower than the swimming basin the water surface of the latter can be kept stable and the regeneration pond's level can rise and fall as it is fed by rainwater (p. 88).

Above left to right A well-designed natural pool is a peaceful recreational space, excellent for pond-dipping and a wildlife sanctuary where, with a little patience, even frogs can be tamed.

In 1954 much attention was given to the first "swimming pond" constructed by Gottfried Kern in Graz, Austria, an outstanding innovation at the time.

This conversion from traditional to natural pool was done in 1986 in Klosterneuburg, Austria. It is one of the first projects of the now international system provider Biotop (see case study 3).

2
THE DEVELOPMENT OF NATURAL POOLS

A LITTLE HISTORY

Austria is generally regarded as the first home of the natural swimming pool movement. In 1954 Gottfried Kern from Graz constructed a pond with the intention to use it for swimming, the first recorded natural swimming pool. However, in the USA around the same time a comparable but less well-known facility was built, as we shall see. Kern distinguished between a free-standing water zone and a regeneration area (Kern, 2014).

During the 1960s Kern's innovation was largely ignored as the wave of chemically treated swimming pools spilled over from America into Europe. But in tune with the wildlife garden movement in the 1970s, more and more enthusiastic amateurs and professionals especially in Austria, and followed by Germany and Switzerland, gave thought as to how best to establish ponds for bathing (Kufner, 2012). In 1983 the idea of locating a swimming pool in a natural pond was put into practice by Jochen Steinhard, a teacher from Hamburg. He created a natural pool very similar to today's with a vertically walled swimming part adjacent to a regeneration area, but free from artificial water movement (Steinhard, 1983). In the same year Werner Gamerith built a natural pool in his garden in Austria (Littlewood, 2005).

Of course, not all attempts to create a sustainable naturally purified pool worked, but they became increasingly reliable as professional companies began offering complete solutions for planning and construction. The first professional companies in Germany (re-natur) and Austria (Biotop, K. Sailer, R. Weixler, A. Kern etc.) began to offer natural pool implementations in the late 1980s (Kern, 2014), and within twenty years a complete new sector developed.

As natural pools have developed, so have the use of technical installations. The first systems by pioneers such as Richard Weixler comprised a big regeneration zone well stocked with submerged plants to provide

The natural pool in Pottenstein, North Bavaria, is one of the most beautiful public facilities in Germany.

clear water (Weixler, 2007). Gradually, a parallel approach emerged that trusted more in percolated filter areas than plants.

Originally the idea of enjoying nature while swimming promoted the development of natural pools but today there are more and more rectangular pools with vertical walls, which are almost indistinguishable from traditional chlorinated pools. Plants are no longer necessary if efficient substrate filters are used and supports to allow amphibians and other animals to escape are not required. One reason for this development may be the problem of achieving an acceptable level of plant growth in intensively filtered waters.

In 2005 about 5,000 private natural pools were estimated to exist in the German-speaking world, and the DGfnB (German Association for Natural Swimming Pools) estimates that now about 10,000 new private facilities are built here each year (Colditz, 2024).

FROM PRIVATE TO PUBLIC

Far-reaching legal regulations and technical guidelines had to be fulfilled to enable the step from private to public natural pools. The challenge was to ensure the absence of health hazards despite a heavy bio-burden resulting from a high volume of visitors. The first public natural pool, created by the Biotop company, was opened in Klosterneuburg, Austria, in 1991. By 2013 there were around 150 public swimming and bathing pond facilities in Germany alone, created by numerous different system providers.

The regeneration pond of a public natural pool is often completely separate and fenced off for safety. Proliferating algae, which are tolerated here, do not endanger the water quality of the swimming area just visible in the background (Legau, South Bavaria)

CONQUERING THE ENGLISH-SPEAKING WORLD

Michael Littlewood is said to have introduced the natural pool idea in the UK in 2000 (Littlewood, 2013). The first recorded facilities in the UK were constructed in 2001:

- designed by Littlewood at a private residence in Gloucestershire.
- at the RHS Hampton Court Flower Show in 2001, designed by Daniel Lloyd-Morgan and constructed by Anglo Aquatic Plant Co. Ltd., with Angelika Kern of Austria as consultant.
- a 250 m^2 pool near Cambridge including modern technologies for natural water purification was planned and constructed by Woodhouse Landscape Ltd.
- Today many UK companies work in cooperation with Austrian system provider Biotop. In 2015 the UK's first-ever public natural swimming pool was opened in King's Cross, London as a temporary installation.

In the USA the natural pool idea started much earlier than generally assumed. Around the same time as Gottfried Kern's swimming pond was built in Austria in the 1950s, the chemist Ken Andrews from Tennessee built a comparable pool in his garden, a pond with about 2,000 m^2 which even had an integrated biofilter. Michael Hilleary from Kansas was the first to commercially design and construct natural pools in North America. He remembers: "In 1996 I was researching the design of an Otter Exhibit and discovered the engineered biological filter principles. After seeing the otters frolic and play in the crystal-clear water we vowed to join them,

and build swimming pools/ponds for people". Based on research from the commercial aquarium and aqua-culture worlds, and reviving the ideas of the chemist from Tennessee, Michael's Total Habitat company began to build natural pools in 2000 (Hilleary, 2015; Total Habitat, 2012).

Other companies such as Waters Edge in Utah followed, and since 2013 several firms have promoted the natural pool idea mainly in cooperation with the German system provider Bionova®. In 2015 the first public facility in the USA opened: Webber Natural Swimming Pool in Minneapolis.

In 2011 the 6th international Congress for Natural Pools in Budweis, Czech Republic, became a forum of exchange of experiences between natural pool constructors from Australia, Israel, North America and South Africa (Wendebourg, 2011). Today natural pools are being created in many countries around the world. In most cases, specialized companies from Germany or Austria are involved.

NATURAL POOL ASSOCIATIONS

Professional organisations exist in Austria (Verband österreichischer Schwimmteichbauer, Germany (Deutsche Gesellschaft für naturnahe Badegewässer e.V.) and Switzerland (Schweizerischer Verband für naturnahe Badegewässer und Pflanzenkläranlagen). Related organizations in the UK, Italy, Spain/Portugal, the Czech Republic, and France followed.

In September 2009 the International Organization for Natural Bathing Waters (IOB) was set up on the occasion of the 5th International Swimming Pond Congress in Merano, Italy. The IOB is an umbrella organization which brings together all the national associations. The objectives of these organizations are to spread knowledge and promote the idea of pools with fully biological water purification and support the international development of relevant technologies and guidelines.

There are also independent associations for owners of swimming ponds, such as the General European Club for Natural Pools (Allgemeiner Schwimmteich Club = ASC). It aims to increase the amount of natural pools by defining quality standards.

SYSTEM PROVIDERS OR SELF-BUILD?

In Austria, Germany and Switzerland about one dozen companies can be counted as "System providers" (Thon & v. Giessen, 2007; Kufner, 2012). They have developed effective solutions for natural pools including filter techniques. Their enormous research budgets guarantee a pool that functions effectively.

Beside the necessary calculations and specifications, system providers supply landscaping companies with filter materials and technical equipment. Numerous components are patent-protected and copying is prohibited. Most system providers arrange specific courses to train their licensed landscapers in applying their methods. However, assistance through site visits are very unusual.

The natural pool expert G. Manzke (2014) warns that high expectations are created through professional companies marketing slogans such as "you can bath all year round in crystal-clear water without algae". Unfortunately information about preconditions for a particular construction type, demands in terms of the fill-up water quality and maintenance necessities are often scant. In order to prevent initial euphoria being followed by disappointment, you should examine and compare the commercially available systems carefully.

Most landscape designers outside the German-speaking world collaborate with system providers in Germany and Austria who in 2014 partnered with landscaping companies in numerous countries in Europe, the Middle East, America and Australia.

The trend within the German-speaking world, however, is for more and more landscape designers to offer complete planning, construction and customer support without ties to a system provider. There are numerous companies with great experience who build wonderful natural pools, and there are also of course some that lack the necessary limnological background knowledge.

It is also the case that many enthusiastic amateurs who use professional support for the design and planning of their filter equipment but build the pool themselves achieve very good results. For this reason we have created a cost estimate for natural pools not only for completely self-made or completely contracted solutions but also for hybrid options (p. 89).

This book aims to give the necessary background information to natural pool enthusiasts, so that they can examine contractors' proposals critically and make the right choice. Those who are keen to plan and construct their own natural pool will also find all the relevant information.

This pool combines lush perennial plantings with an organic shape. The bluish tone of the water is the result of hard water in a phosphorus limited system (Diss, Norfolk, UK).

3 BASIC CONSIDERATIONS FOR POOL WATER

When it comes to water quality, expectations are as diverse as their potential users. Some hardy souls might be willing to bathe in murky water, but most people have three key requirements:

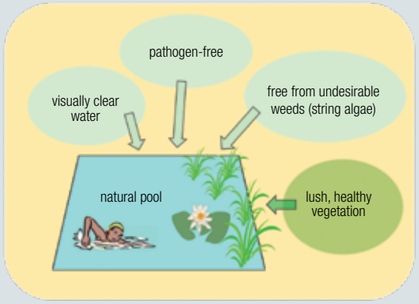
- The water should be visually clear
- It should be free from undesirable weeds (especially string algae)
- It should be free from pathogenic germs

For nature lovers, a fourth aim could be added:

- The pool should be surrounded by lush, healthy vegetation

Although a confusing diversity of pool types and filtering methods has developed, the essential principles derive from natural processes. In nature there is a wide range of water-dominated sites: from small tarns to huge lakes, from small springs to wide rivers, and rich carrs or fen woods to poor acidic bogs. It is important to understand their principal characteristics in terms of chemistry, physics and biology to guarantee a successful natural pool, since we want to use exactly these natural interactions to achieve clear, healthy water.

First let's look at some basic considerations which help explain the principal filtering methods for natural pools. For more detailed information on the physical, chemical and biological contexts, see chapter 9 (Maintenance).



Basic requirements of natural pools

BIOLOGICAL BASICS FOR WATER PURIFICATION

ALGAE: KNOW YOUR ENEMY

In most cases the appearance of algae is unwelcome. Though many algae are a sign of good water quality, they are seen as undesirable, aesthetically at least.

Above Stonewort (*Chara* spp.) in the clear water of a natural pool.
Below Viewed from above, filamentous algae may look ugly, but underwater they have a certain beauty.

Below Murky water in an algae production basin at Negev University, Israel. This plankton is produced as foodstuff for fish farming.

Algae can reproduce sexually, by producing zoospore-forming gametes, or asexually by cell division. Sources for algae are generally omnipresent. Whether they dominate the pool or stay within tolerable limits depends on environmental conditions. Natural enemies of algae are zooplankton, water snails and fish but fish are not recommended for natural pools (FLL, 2017).

The term "algae" covers a huge range of organisms. It is only the green algae subgroup which is considered undesirable. We will distinguish between three broad groups of green algae relevant to swimming ponds. The first group are welcome aquatic plants; the second and third are viewed as undesirable:

- **Stoneworts** The members of the algae family *Characeae* form attractive underwater mats on the ground. Thin rhizomes grow through the mud, sending slender stems with star-shaped leaf-whorls. If they become too pervasive, they can easily be weeded by hand.
- **Filamentous algae (or string algae)** form cotton-like clusters or blankets on the surface, mainly in shallow water. Some species can thrive even in very nutrient-poor water.
- **Planktonic green algae (floating algae)** create murky water if present in high concentrations.

A fourth group belongs only visually to green algae, as numerous species appear visually similar to floating ones:

- **Blue-green algae** (Cyanophyceae) are biologically classed as bacteria. Some species do resemble greenish slimy hazes on the water surface. In well-maintained natural swimming pools they are not a problem but becuase they are feared for their toxic excretions, they are covered on page 220.

LIVING WATER BALANCE: PROS AND CONS OF PLANKTON

Murky water is caused by plankton. In biologically active water, these tiny floating organisms are always present as zooplankton (tiny animals) and phytoplankton. The latter consist mainly of green algae which subsist on sunlight. They get eaten by numerous zooplankton species, such as water fleas (*Daphnia*) or copepods (*Cyclops*), so in a well-balanced body of water a self-regulating system develops over time.

Newly created ponds usually go through several phases: after a few days the initially clear water turns a murky green. This algal bloom is caused by an explosion of floating green algae. These first colonizers benefit from a good nutrient supply and a lack of natural enemies. After some weeks the emergence of enemies, particularly water fleas together with a diminishing nutrient supply, causes a decline of the planktonic algal population and the pond clears up. Over time a further switch of the balance may occur if a loss of algae reduces the population of their enemies: again a minor algal bloom can occur until water fleas, etc. cause a return to a stable, clear balance.

This procedure is not only seen in new ponds; each disturbance caused by installing new plants or any materials can provoke a nutrient peak and initiate the cycle. The same effect can be caused in winter and autumn by changing thermal conditions.

Even in very clear water a certain amount of planktonic algae is present. Besides green algae there are cyanobacteria, diatoms, bacteria and flagellates, amoeba, rotifers, etc; there are even tiny multicellular creatures such as roundworms, small crustaceans (*Cyclops*, *Daphnia*), watermites and tiny insect larvae.

These organisms play a major role in water filtering and the purification of natural pools. You cannot see planktonic organisms with the naked eye but their presence guarantees a much healthier swimming environment than chlorine or other chemicals. In standing and slow-moving water they absorb pollutants, pathogens and nutrients. These undesirable substances are sedimented with dead plankton on the base of the pool as a part of the organic mud which should be removed regularly with suction pond cleaners (p. 204).

BIOFILM: THE PURIFICATION FACTORY

The "overall underwater coat"

The surfaces of all underwater structures provide a habitat for microorganisms to grow. Submerged vascular plants, stones and substrates, wood constructions or the pond sealing itself are covered by an aggregate of microorganisms embedded within a matrix called "biofilm" (ÖNORM L 1128:2013). This is generated through the accumulation of microbial bacteria, algae, funguses, viruses, protozoa and tiny invertebrates. These microorganisms secrete Extra-cellular Polymeric Substances (EPS) and hydrogels, which form a mucus film that adheres to surfaces or boundary layer and feels slimy to the touch.

Dissolved nutrients, germs and pollutants provide nourishment for biofilm microorganisms. Their branch-like structure creates an enormous

Daphnia species

Copepods are tiny shrimp-like crustaceans, one of the most important zooplankton groups.

Bell animalcules are a component of the biofilm. They are fascinating when observed through a microscope.

adsorption surface. Even substances that cannot be degraded promptly can be trapped and processed later.

The speed and quality of biofilm formation are dependent on the substratum, water temperature, water ingredients (especially dissolved oxygen and nutrients) and the microorganisms present. Running water improves the nutrition of the biofilm significantly.

The development of a biofilm goes through four phases (Lemmer, Griebe, Flemming, 1996; Schmidt, 1994):

- The initial phase is the creation of a "**conditioning film**", which takes just a few minutes. This film consists of gauzy organic deposits and provides a bed for the first microorganisms.
- This leads to the second stage, the "**growth phase**". The colonizing microorganisms produce the mucus film explained above (EPS) which prevents its detachment from the stratum. After a sustainable EPS has developed, growth proceeds and more and more microbes settle, increasing the thickness of the biofilm. In this stage, sufficient nutrient and oxygen nourishment is important as the substratum's relevance declines. Particles transported by the passing water are absorbed and biodegraded.
- The third stage is the "**equilibrium phase**". Lower layers of the film become anaerobic. A high oxygen supply can slow but not stop this process.
- In the "**final phase of ageing**", parts of the biofilm die off and are removed from the matrix.

Beneficial biofilm in water filtration

The great purification power of the biofilm is the central component of special filter beds in natural swimming pools. The filters consist of layers with gravel in special sizes, depending on the particular system. The entire surface of the gravel aggregates provides an enormous substratum for biofilm development. Permanently percolating water ensures an effective uptake of nutrients, pollutants and pathogen germs.

Biofilm problems

Biofilm offers great advantages as a purification factory, but there are also challenges which need to be tackled:

- Only a developing biofilm can achieve efficient nutrient uptake. If the filter pores are blocked with microorganisms, severe dieback will occur. The filter loses its purification ability and the water will soon become murky again. Numerous natural pools of the first generation with percolated filter beds failed because of this. Modern filters provide a backwashing capability: the majority of the ageing microorganisms can be removed to clear the filter pores through a special setting of the plumbing valves. Subsequently a new biofilm will be generated (for technical solutions see p. 65).
- The slimy feel of underwater surfaces is only a minor problem, but if steps into the pool have a biofilm coating, the danger of slipping increases. The stronger the inflow towards surfaces, the more intensive the development of biofilm layers will be. So keep the flow within the swimming area low. Skimmers for cleaning the surface should either produce a low current or operate intermittently.
- Detached flakes from the ageing biofilm will float on the surface. If not removed with a skimmer or hand net, they will sink and accumulate in the mud layer. Degradation and mineralization of the mud can lead to algal problems and increased maintenance requirements. Microlayers of biofilm can also occur along the interface between water and air (Costerton et al. 1995) and form dull residue films. A mild surface current is enough to inhibit this unpleasant phenomenon.

Biofilm layer on a PVC liner.

Detached biofilm floating on the water.

PLANTS' ABILITY TO PURIFY WATER

Plants are an important factor for water purification. But do not lump together plant-based waste water filtration systems and natural pools. Constructed wetlands for waste water treatment create a significantly higher level of pollution and above all a higher nutrient level. In such a system, nitrogen-hungry plants will thrive optimally so that they can contribute significantly to the purification process. Natural pools on the other hand are characterized by very low nutrient levels and if not

sufficiently fed with nitrogen, plant growth may be too weak to play an adequate role in the purification process.

Generally plants in constructed wetlands have a kind of catalytic function for purification (Neemann, 2000). The direct uptake of nutrients is a comparatively small part of their contribution (Börner 1992). Most plant species, even on wet and flooded soil (Beck-Nielsen & Madsen, 2001), have a symbiosis with mycorrhizal fungi, exploiting a much greater area than the roots themselves through their mycelium. So even in an environment poor in nutrients, mycorrhiza-bound plants have access to all essential elements for feeding, especially phosphorus and nitrogen (Werner, 1987, Hilber, 1992). Mycorrhiza improve plants' ability to extract ions and decompose harmful contaminants. The latter is the result of particular enzyme systems catalyzing oxidative attacks into harmful cyclic organic compounds (Dobner & Holthuis, 2011). A final extraction of incorporated substances from the system only results if plant material is harvested and removed regularly.

Important for water purification is the phytoextraction of critical heavy metals such as cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni) or zinc (Zn). Such compounds cannot be eliminated with traditional technical filters. A small amount can be incorporated into plant material. The greatest amount is precipitated by sedimentation.

Some plants even excrete antiseptic compounds which kill harmful bacteria and numerous underwater species release allelopathic substances that suppress floating algae. String algae however are only reduced by plants if outcompeted by them.

Substrate filter beds percolated with water can be disturbed by clogging through small particles. This so-called "colmation" can be prevented by a planting with deep or intensively rooting helophytes. The roots keep the substrate permeable.

CHEMISTRY BASICS

THE IMPORTANCE OF NUTRIENTS

Green plants work like bio-factories producing organic material from water and nutrients by sunlight, as do green algae. To achieve visually clear water, it is important to reduce floating algae to a level where they do not affect visible water turbidity. The most environmentally friendly way to achieve this aim is by reducing nutrients. Shade also reduces algae, but most pool users would probably prefer swimming in a sunny place. It is worth locating at least a part of the pool in shady areas, though.

DISSOLVED OXYGEN

Oxygen is essential for the respiration of all organisms, microbes, animals and plants. It is responsible for nitrification (p. 31) and for the sedimentation of phosphorus, which is important to keep the pool clear.

The enrichment of water with oxygen occurs by dissolving from the atmosphere, photosynthesis of submerged plants, reduction of particular chemical compounds (nitrate and sulfate respiration) or the influx of oxygen-rich water.

How much oxygen can be dissolved depends on pressure and temperature. The dissolution capacity of all gases in natural waters is limited by their respective content in the atmosphere above: water of 10°C theoretically could absorb more than 50 mg/l of oxygen, but the low atmospheric counter-pressure of only 20% O_2 creates an oxygen sink. So in fact only 11 mg/l can be dissolved in the water. Locally the content of dissolved oxygen may be higher than physically possible in case of a very high photosynthesis rate under optimal conditions.

The presence of large amounts of organic matter and murky conditions decrease the oxygen concentration. At its most extreme the collapse of the entire body of water can be initiated when decomposing microorganisms

Fountains and waterfalls can increase the oxygen content of the water, but their main appeal is aesthetic.

Table 1 **Plant nutrition elements. Some further trace elements i.e. sodium (Na), selenium (Se), cobalt (Co), nickel (Ni) or silicon (Si) are essential only for certain specialized species**

Main elements for:	Nutrient element	Uptake by plants in form of
	Carbon (C)	Dissolved Carbon dioxide CO_2, Dissolved Hydrogen carbonate HCO_3^-
	Hydrogen (H)	H_2O
	Oxygen (O)	O_2
	Nitrogen (N)	Nitrate NO_3^-, Ammonium NH_4^+ Urea CH_4N_2O (mainly through green plant-surfaces)
	Sulphur (S)	Sulphate SO_4^{2-}
	Phosphorus (P)	Dihydrogen phosphate $H_2PO_4^-$ Hydrogen phosphate HPO_4^{2-} (Ortho phosphate $PO4^{3-}$ at high pH)
	Potassium (K)	K^+
	Calcium (Ca)	Ca^{2+}
	Magnesium (Mg)	Mg^{2+}
Trace elements, required in smaller amounts:		
	Iron (Fe)	Fe^{2+}, Fe(III)-chelate
	Manganese (Mn)	Mn^{2+}, Mn-chelate
	Boron (B)	HBO_3^{2-} , H_2BO^{3-}
	Zinc (Zn)	Zn^{2+}, Zn-chelate
	Copper (Cu)	Cu^{2+}, Cu-chelate
	Molybdenum (Mo)	MoO_4^{2-}
	Chlorine (Cl)	Cl^-

Table 2 **Solubility of gases in pure water (mg/l) in relation to temperature and under normal conditions of the atmosphere above**

	0°C	10°C	20°C	30°C	Atmosphere above (%)
O_2	14.5	11.1	8.9	7.2	20.1%
N_2	22.4	17.5	14.2	11.9	78.1%
CO_2	1.005	0.70	0.5	0.38	0.04%

Derived from Schwoerbel & Brendleberger, 2005

do not work adequately because of oxygen deficiency. Toxic substances can be released by anaerobic microbes.

A low oxygen concentration and declining redox potential affect the resolution of nutrients. If the sedimented mud on the ground is not removed regularly it can become anaerobic and initiate phosphorus resolution (p. 203).

Rising temperatures lead to lower oxygen concentrations, which can be a reason for deficiency problems in plants and animals. This can be tackled with water movement: streams, fountains and similar features increase the contact between water and air. Another possibility is injecting air through diffusers in the base of the pool but the real effect is generally overestimated. Artificial aeration may be worthwhile in hot summers, especially if run at night. However, in a well-designed natural pool, extra equipment for oxygen enrichment is not necessary. A sufficient proportion of underwater plants should guarantee maximal oxygen saturation at least throughout the period of use. In densely planted submerged vegetation, a supersaturation of oxygen can occur, which helpfully precipitates certain nutrients.

CARBON AND LIME

To understand how water can be kept clear, you need to know how carbon behaves in water.

Dissolved carbon compounds

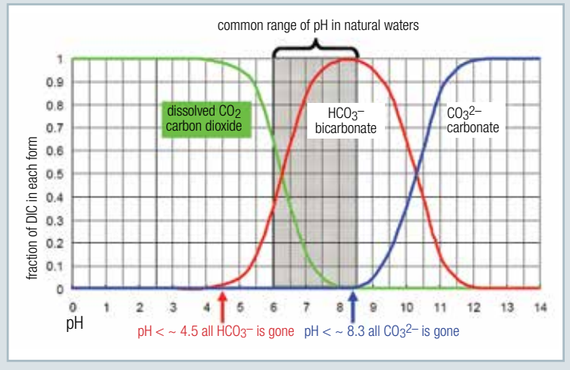
Carbon is the most important element of organic compounds. It is present in water bodies as dissolved organic carbon (DOC) and as dissolved inorganic carbon (DIC), which can be incorporated by plants. DOC is the sum of scarcely degradable compounds, often introduced droppings of wildlife or incompletely decomposed plant matter. Forms of DIC are carbon dioxide (CO_2), hydrogen carbonate or bicarbonate (HCO_3^-) and carbonate CO_3^{2-}. Carbon dioxide is transferred to the pool in rainwater, fill-up water, from organisms as an effect of their respiration or from soil respectively substrates.

In water, CO_2 is partly hydrated to carbonic acid:

$$CO_2 + H_2O \leftrightarrows H_2CO_3.$$

Further, the carbonic acid dissociates into H^+, HCO_3^- and CO_3^{2-}.

The relations of these forms to each other depend on the pH, as illustrated below.



Forms of DIC (dissolved inorganic carbon) in relation to the pH.
Derived from http://inside.mines.edu/~epoeter/_GW/19WaterChem3/WaterChem3pdf.pdf

Carbon nutrition of underwater plants

CO_2 is only present in significant amounts below pH 7. Between pH 6.5 and 10 the most important form of DIC is HCO_3^-. This is crucial for the growth of submerged plants. FLL (2017) recommends a pH for the fill-up water of natural pools of between 6 and 9. In practice most pools show a pH above 7 and most experts recommend a pH of 7.5–8.4 for pool water. The low amount of CO_2 in the water at this pH level requires submerged plants to adapt to take up carbon for photosynthesis: numerous aquatic species can use bicarbonate (hydrogen carbonate) as a carbon source.

Aquatic plants are categorized in three groups according to their C-assimilation (Ruttner, 1947) as follows:

- **Fontinalis type** These plants mainly take up dissolved CO_2. Besides the water moss *Fontinalis antipyretica* all submerged mosses are assumed to belong to this type as well as the stonewort *Nitella flexilis*. Vascular plants restricted to CO_2 are *Crassula helmsii*, *Berula erecta*, *Callitriche* spp., *Juncus bulbosus*, *Myriophyllum verticillatum*, *Potamogeton natans*, etc. (Maberly & Madsen, 1998; Newman & Raven, 1995; Allen & Spence, 1981).
- **Elodea type** These can use dissolved CO_2 as well as bicarbonate (HCO_3^-). CO_2 is incorporated about five times quicker than HCO_3^-. If CO_2 lacking, HCO_3^- can raise the pH up to 11. *Elodea*, *Ceratophyllum demersum*, *Myriophyllum spicatum*, *Potamogeton crispus*, *P. lucens*, *P. pectinatus* and *Vallisneria spiralis* belong to this type (Maberly & Madsen, 1998).
- **Scenedesmus type** The green alga *Scenedesmus* prefers to take up HCO_3^-. It is incorporated about 25 times better than CO_2 (Österlind, 1950). It is unclear if this holds true for all green algae.

Dissolved carbonates such as limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) are the most important factor for water hardness. Initially they are indissoluble, but in the presence of CO_2 they slowly form calcium hydrogen carbonate $Ca(HCO_3)_2$, which in turn can be dissociated into "bound carbon acid" HCO_3^- and Ca^{2+} (or Mg^{2+}):

$$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca(HCO_3)_2 \rightleftharpoons Ca^{2+} + 2\,HCO_3^-$$

In water containing lime these compounds form a "lime–carbonic acid balance". A depletion of CO_2 disturbs this balance and causes a decay of $Ca(HCO_3)_2$ into solid $CaCO_3$ (limestone) and CO_2 till the balance is restored. HCO_3^- buffers pH variation against OH^- as well as against H_3O^+:

$$HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O$$
$$HCO_3^- + H_3O^+ \rightarrow CO_2 + 2\,H_2O$$

If plants absorb HCO_3^- for photosynthesis, the incorporation of C into the produced organic matter can cause two effects:

1. A release of OH^-: $HCO_3^- \rightarrow CO_2 + OH^-$ ($\Rightarrow$ rising pH)
   ↳ photosynthesis
   the effect is a rising pH during the day, which drops down again at night, but can temporarily reach values of pH 11 (p. 209).
2. By fixing dissolved Ca^{2+} ions, lime layers can cover plants so that they develop a rough and greyish surface:
   $2\,HCO_3^- + Ca^{2+} \rightarrow CO_2 + H_2O + CaCO_3$ ($\Rightarrow$ lime solidification).
   ↳ photosynthesis

The solidification of lime is also performed by phytoplankton. This leads to a sedimentation of lime mud on the base of the pool. The subsequent withdrawal of lime by organisms is called biogenic decalcification. Biofilm flakes also form part of the lime mud after sinking.

Older parts of *Elodea canadensis* stalks covered in limescale as the result of biogenic decalcification.

Water hardness

Lime content (more precisely, dissolved alkaline earth metals) is quantified as "water hardness". Relevant hardening components are ions of calcium and magnesium whereby the generally low content of Mg is simplistically calculated as Ca. Traditionally it is indicated in "German hardness degrees": dH°

$$1\text{dH}° \triangleq 10\ \text{mg/l CaO} \triangleq 7.1\ \text{mg/l Ca}^{2+} \triangleq 18\ \text{mg/l CaCO}_3$$

In natural pools and drinking water, Ca occurs almost exclusively as calcium hydrogen carbonate, so these values must be seen as equivalents. The hardness of drinking water should be below 30 dH° (Schwoerbel & Brendleberger, 2005).

Today the common scientific practice is to quantify the hardness in millimoles of ions per litre of water (mmol/l), as used in the FLL guidelines (2011 & 2017). This means the concentration of calcium and magnesium ions per litre of water.

Table 3 **Water hardness classification of drinking water in Germany according to WRMG (2007); the classes in lighter type are additions from an older system (Baumhauer & Schmidt, 2008)**

Total hardness (GH):	mmol/l	dH°	Assessment
	< 1	< 5.6	Very soft
	< 1.5	< 8.4	Soft
	1.5 – 2,5	8.4 – 14	Medium-hard / medium
	> 2.5	> 14	Hard
	> 4	> 22.4	Very hard

From the Total Hardness (in German: "Gesamthärte" = GH) a "Temporary Hardness" and "Carbonate Hardness" (in German: "Karbonathärte" = KH) are distinguished. The KH quantifies the amount of calcium and magnesium ions per litre (mmol/l) with equivalent concentrations of carbonate, hydrogen carbonate or else hydroxide (OH^-) ions formed by their hydrolysis.

The non-carbonate hardness (NKH) describes the quality of calcium and magnesium ions with equivalents in other anions such as in sulphate (SO_4^{2-}) or chloride (Cl^-). **Carbonate Hardness (KH) + Non Carbonate Hardness (NKH) = Total Hardness (GH).**

In most water, the KH is identical with the Acid Binding Capacity (ABC), which correlates to the amount of hydrochloric acid (HCl) necessary for a complete transformation of all carbonate, hydrogen carbonate or hydroxide ions dissolved in 1 litre of water into H_2O and CO_2. In practice the degree of acidity up to pH 4.3 (acid capacity KS4.3) is used as a measure for ABC. This is a titrimetric determination of the amount of hydronium ions (protonated water: H_3O^+) needed to adjust a pH of 4.3 in a defined volume of water. Natural pool water should provide an acid capacity KS4.3 of at least 2 mmol/l (FLL, 2017). This provides a desirable stability of the pH: the water is well buffered against changes through acid deposition which mainly occurs by rain.

NITROGEN

Nitrogen (N) is the basic element for building proteins. It is essential for any plant growth and is absorbed as ammonium (NH_4^+) or nitrate (NO_3^-). Plants can utilize urea (CH_4N_2O), a simple organic compound, dissolved as complete molecule in the water – the most important nitrogen fertilizer for natural pools (p. 225).

Nitrogen is introduced into the water by the degradation of proteins from organic debris, by fertilizing or even through the air. Pure N_2-nitrogen can be dissolved in small amounts but is not usable by plants. The pool user's input of nitrogen is low; Schulz (1981) calculates hardly more than 3 g N daily per bather. Much more nitrogen can be introduced in the fill-up water. The German drinking water ordinance (TWV, 2001) allows nitrate (NO_3^-) values up to 50 mg/l. So does the German FLL guideline (FLL, 2017) for fill-up water in natural pools. If you have to add a great deal of nitrogen-rich mains water, this can cause over-fertilization: plants may thrive but the water looks murky as floating green algae can heavily reduce visibility.

However, in most natural pools the opposite happens: nitrogen turns out to be an inhibitor of plant growth. In a natural pool with enhanced technical equipment, the stratification of the water is very different from a natural body of stagnant water. In a lake, nutrients are concentrated in deeper zones but the water circulation in the nature pool pushes decomposition of nitrogen in particular. Most natural pools are rich in oxygen. In this aerobic environment nitrification takes place and dissolved ammonium (NH_4^+) is oxidized to nitrate (NO_3^-) by specific bacteria, e.g. *Nitrosomonas* and *Nitrobacter*, in two stages:

Step 1: *Nitrosomonas*: $2\,NH_4^+ + 3\,O_2 \rightarrow 2\,NO_2^- + 2\,H_2O + 4\,H^+$
exceeding >0.1mg/l nitrite (NO_2^-) is toxic for most organisms, but if no extraordinary disturbance exists, nitrite is very quickly transformed again:

Step 2: *Nitrobacter*: $2\,NO_2 + O_2 \rightarrow 2\,NO_3^-$
the resulting nitrate (NO_3^-) is easily absorbed by plants. It is the predominant form of dissolved nitrogen while ammonium is present in small amounts only.

But the N-transformation process continues: even in pools with good oxygen supply anaerobic zones exist, especially in the ground mud or between densely planted areas. Anaerobic conditions plus the presence of organic matter are the preconditions for denitrification: nitrate reduction by denitrifying bacteria. *Paracoccus*, *Thiobacillus*, *Pseudomonas* etc., divide NO_3^- according to the following simplified formula:

$$2\,C\ (\text{organic compound}) + 2\,NO_3 + 2H^+ \rightarrow N_2 + 2\,HCO_3^-$$

Most of the resulting nitrogen (N_2) escapes into the air. The effect of increasing the pH by fixing H^+-ions and setting free OH^- should not be overestimated because hydrogen carbonate usually buffers fluctuations.

Frequent vacuuming of the ground mud can reduce denitrification losses a little, but even in well-maintained pools denitrification causes weak plant growth (p. 227). The desired biofilm accumulation will also decline, which leads to reduced water purification rates. So it has become common practice to add urea to the water to mitigate this problem (p. 225).

TROPHIC LEVELS IN AQUATIC SYSTEMS

The overall nutrition of a body of water is defined by its trophic level. The term "trophic" describes the fixation rate of carbon (C) into organic compounds through the photosynthesis of plants.

Aquatic systems are classified in five types according to their nutrient supply as follows:

- **Oligotrophic** Weak C-production because of low nutrient availability. The development of phytoplankton is weak year-round. It is rich in species but poor in numbers/populations. The low plankton count affects visibility depths. The oxygen concentration is high even at the end of the winter and near the bottom of the pond.
- **Mesotrophic** More C-production than in oligotrophic water because of better nutrient availability. Moderate development of phytoplankton is possible, especially in spring. A degree of oxygen consumption can occur at lower depths. Limited algal blooms may periodically reduce the visibility depth.
- **Eutrophic** High C-production because of good nutrient availability. High phytoplankton concentration leads to significantly reduced visibility. The upper water layer is temporarily supersaturated with oxygen and at the end of summer there is often a lack of oxygen.
- **Polytrophic** Almost year-round high availability of nutrients. Phosphorus does not limit plankton production. Algal growth is strong and reduces visibility, which rarely exceeds 1 m. At deeper levels there is a permanent oxygen deficiency. The development of pathogen blue-green algae (*Cyanophyceae*) can make bathing impossible (p. 220).
- **Hypertrophic** Year round the nutrient availability is exceptionally high. Year round algal growth is very strong, resulting visibility of less than 0.3 m. At deeper levels there is a permanent oxygen deficiency. The development of pathogen blue-green algae can make bathing impossible (p. 220).

We can't directly correlate the trophic level with specific nutrient quantities because it may depend on one individual limiting factor.

The agronomist Carl Sprengel noted in 1828 that the production rate is limited by the particular growth factor being present in the smallest rate. The amount of all other elements is of low importance because the production output is defined by the minimum factor. The "father of fertilization", Justus von Liebig, illustrated this with what became known as "Liebig's barrel" or the law of the minimum: each barrel stave corresponds to the quantity available of a particular nutrient. The shortest stave determines how much water the barrel contains and this limiting factor determines the production rate. This simple rule is crucial not only for agriculture but also for keeping natural pools stable and clear. Besides hygienic impacts finding and adjusting a proper nutrient to limit algal growth is the most relevant strategy of all purification technologies which we will introduce in chapter 4.

When analysing natural bodies of water it is possible to arrive at an approximate estimate, as shown in the table on the next page. In practice often a single limiting nutrient may be responsible for the trophic level of a body of water. In view of modern natural pool filter systems, we have even added an "ultra-oligotrophic" level.

Liebig's Barrel

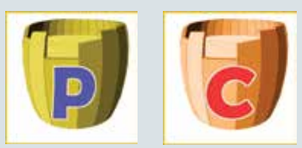
Table 4 **Water parameters for a range of trophic levels**

	Ultra-oligotrophic	Oligotrophic	Mesotrophic	Eutrophic	Polytrophic	Hypertrophic
$NO_3^- + NH_4^+$ (mg N/l)	< 1	< 1	1–2	> 2	>> 2	>> 2
P (mg P/l)	< 0.004	< 0.01	0.01–0.03	0.03–0.1	0.1–0.3	> 0.3
O_2 (mg/l)	> 8	> 8	6–8	2–4	< 4	<< 4
Visibility depth (m)	> 4	> 4	(1–) 2–4 (–10)	< 1–2 (–3)	< 0.3–1	< 0.3
Quantity of bacteria/ml	<< 100	< 100	~ 10.000	< 100,000	> 100,000	> 100,000

Derived and adapted from FLL, 2017, Frei, 2012, v.d.Weyer, 2014, Klee, 1990, Vollenweider and Kerekes, 1982, http://de.wikipedia.org/wiki/Trophiesystem

TWO OPTIONS FOR CLEAR WATER: PHOSPHORUS OR CARBON AS MINIMUM FACTORS

In practice there are numerous recipes for getting rid of algal turbidity, It is confusing to read in one source advice on adjusting the pH to around 8.3, while another suggests the water should be kept free from lime and reducing the pH would combat algae efficiently. To solve the mystery of clear water we have to distinguish between two possible strategies:



1. **Minimizing dissolved phosphorus**
2. **Minimizing absorbable carbon**

Most natural pools have no long-term problem with turbidity caused by planktonic algae. The overall nutrient level is usually at an oligotrophic to moderately mesotrophic level, so that algal bloom occurs only exceptionally. But string algae often cause problems. So eliminating this latter type is the main target of the two approaches below:

Phosphorus limitation

Phosphorus is seen as the most significant factor for algal growth. Phosphate limitation is part of the definition of natural pools purified by percolated filter bodies (Wesner, 2013; ÖNORM L 1128:2013). Even dissolved organic P-compounds must be quantified in the water as possible sources for phosphates absorbable by plants. In sum the total dissolved phosphorus (P_{tot}) should be analysed in the fill-up water. Furthermore many experts recommend testing the P-content even of the substrates and other relevant components of the natural pool.

The FLL guidelines (FLL, 2011 & 2017) set the recommended concentration of all dissolved phosphorus compounds **(P_{tot}) to a maximum of 0.01 mg/l** (= 10 µg/l) in intensively filtered NSP types (model 4, see p. 86). This is extremely low – and hard to measure. But to thrive algae need at least that P-concentration. Below 0.005 mg/l hardly any algae development is possible (Mostert & Grobbelaar 1987, Brunner 2005). For vegetation emphasized NSP types (models 1–3, see p. 83–6) a phosphorus concentration (Ptot) up to 0.03 mg/l is acceptable to ensure that ornamental plants will grow satisfactorily.

Mostly the water used for filling up the pool as well as to compensate for transpiration and evaporation losses contains more than the recommended limit of total P. To reduce phosphorus in the pool, special filter systems and treatments can be considered:

- **A high concentration of oxygen** promotes the sedimentation of P as oxidized insoluble compounds such as $FePO_4$ or $Ca_3(PO_4)_2$ (Upmeier, 2004). These substances are accumulated in the ground mud, which should be regularly vacuumed (see p. 203).
- **Moderately hard water and pH around 8** is required to achieve proper P sedimentation. For this purpose filter systems often are filled with carbonate gravel, such as lime ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$), which stabilizes water hardness and pH and promotes P-precipitation reactions, i.e.:
  $3\ CaCO_3 + 2\ H_3PO_4 \rightarrow 3\ H_2CO_3 + Ca_3(PO_4)_2$ (→ Sediment)
- **Special filters with iron(III) hydroxide oxide** ($FeO(OH)$) gravel can efficiently fix phosphorus: $FeO(OH)) + H_3PO_4 + FePO_4 + 2H_2O$ after some time the sorption capacity is used up and the filter medium needs to be replaced (p. 74).

To optimize the biological elimination of phosphorus, an anaerobic area plus an aerobic area is effective: microorganisms release phosphates as a stress reaction. This process generates energy, which is essential to survival, but it is linked to the presence of readily biodegradable organic matter. If an aerobic situation follows, the microbes take up previously released P again plus an additional P amount as "emergency storage". This process can run in the mud on the pool base and regularly vacuuming up the ground mud means effective phosphorus extraction.

The fill-up water should be analysed regularly. If the P content exceeds 0.035 mg/l P_{tot}, further steps can be discussed (p. 212; ÖNORM, 2013).

P-limited hardwater, oligotrophic lake in a former limestone quarry. The water is perfectly clear, free from visible algae and has an impressive bluish sheen.

Carbon limitation

Carbon absorbable by underwater plants (DIC) can be decreased by two methods:

- **Low pH** Between pH 4 and 8 the total amount of DIC increases with the pH, because HCO_3^- is soluble in much greater amounts than CO_2: the content of CO_2 in the atmosphere is only 0.04%. For this reason it is not possible to dissolve more than 0.5 to 1 mg/l CO_2 in water. Higher amounts are released from the water as gas to compensate for the extremely low counter-pressure of atmospheric carbon dioxide. Near the bottom of a pond the CO_2 level can be significantly higher if not compensated for by water movement. For this reason a reduction of the pH below 7 effects a reduction of DIC for the aquatic plants: many undesirable algae are affected by the lower carbon availability, and some very interesting ornamental underwater plants will thrive even better (Fontinalis type, pp. 28, 152).
- **Low hardness** the harder the water, the higher its hydrogen carbonate (HCO_3) content, which is absorbable by plants of the Elodea or the Scenedesmus types (p. 28-29), which include numerous species of green algae. To achieve a low hardness, the fill-up water should be very soft (carbonate hardness <5°dH).

Many common recipes for getting rid of algae aim at a C-limitation, but they may be contrary to achieving P-limitation:

- Using carbonate-free substrates and construction materials
- Using water with a low hardness or rain water
- Inserting acids or acidic reacting agents (e.g. raised bog peat) into the water.

A common recommendation for decreasing water hardness is to use substrates containing bog peat or other organic matter. They release high amounts of humin acid and fulvic acid. These DOCs will promote the desired C-limitation but lead to low visibility depths. The resulting brownish or yellowish colour of the water is not acceptable to most natural pool users.

Of course even if you choose C-limitation, it is worth trying to keep the phosphorus content as low as possible. But several P-reducing processes are negatively affected by soft water and low pH. Also the water's overall stability and its chemical properties are significantly less stable in soft water: pH fluctuations can be extreme and unintended influxes of nutrients may cause greater problems than in harder water, which provides a better buffer.

Which way to go?

Many recommendations for natural pools and garden ponds suggest elements of both P- and C-limitation. But the user should be aware that a simultaneous application of some methods may work against each other.

P-limitation is often recommended and in many cases is easier to achieve than C-limitation. Furthermore it guarantees a stable and well-buffered system. Organic matter degrades more efficiently in water with a certain degree of hardness, so the amount of sediment will be lower than in C-limited pools.

C-limitation can be kinder to skin because of its lower pH, though this claim is not unchallenged (Milstone, 2010). More significant is the importance of a low pH for plant enthusiasts with preference for bog plants in the marginal zones, especially insectivorous species such as sundews (*Drosera*) and pitcher plants (*Sarracenia*). Also several underwater plants will fail in water with pH above 7.5 or even 8.

The appropriateness of choosing C-limitation depends on the available fill-up water and the climatic situation:

The lower the hardness, the easier C-limitation will be. In cool climates, when the hardness of the fill-up water is below 5°dH(KH), C-limitation can be a natural choice, whereas a hardness above 10°dH(KH) and in hot regions with low rainfall, P-limitation is preferable. The high hardness of water containing lime provides a better buffer than water poor in lime, in which biogenic decalcification can raise the pH during the day up to over 10 till the evening. This can cause a release of nutrients which feed algae as well as growth depressions of submerged vascular plants. Warm water tends to show greater biogenic decalcification, raising the pH, and the increased transpiration losses demand more refilling, which again brings more HCO_3^-. Of course the fill-up water will also introduce phosphorus, but this can be intercepted with good filter equipment.

If you are lucky enough to live in an area with an oceanic climate, with cool summer temperatures and enough rainfall to store your fill-up water in a cistern, the C-limitation approach may be right for you. But do avoid lime throughout your system.

HYGIENE PARAMETERS

The word "hygiene" comes from Greek and means the "art of health". Critics of natural pools may argue that pathogenic germs can affect the swimmer. For conventional swimming pools, national and international directives,

Bog plants need a low pH. This water is soft enough to allow a spectacular marginal planting with insectivorous *Sarracenia flava* and numerous additional gems, but most plants from hard water are also able to thrive satisfactory, such as *Gladiolus imbricatus* on the left (see case study 7).

Underwater plants of the Fontinalis type such as *Hottonia palustris* will only thrive in low pH water.

guidelines and regulations exist to fix threshold values for amounts of bacteria per litre etc., such as the German DIN 19643 or the Directive 2006/7EC of the European Parliament and the Council (EU, 2006).

The chance of catching a disease due to contaminated water is greatly exaggerated. Infections can occur not only in a naturally purified pool but also by showering with mains water, in chemically treated facilities or even by shaking hands. According to Müller (2001, p. 314), the risk of certain infections – including *Dermatophytes*, *Legionellae*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* – is greater in a traditional public pool than in a natural one.

When comparing a natural swimming pool with a chemically treated one you should also consider that chlorine can increase asthma and allergy risks, especially for children and even the risk of getting cancer (Bernard et al., 2006; Sohn, 2010). Very regular exposure to chlorine may cause reproductive disorders and birth defects as well as quicker ageing of skin (Hahn, 2012).

Most pollutants in natural surface water derive from discharge of contaminated rainwater or communal sewage, from agricultural run-offs or dangerous substances from shipping, which of course do not affect constructed pools. Regardless of whether the purification method is chemical or natural, about 80% of all infections caused by pool water are of a less serious gastrointestinal variety. Self-healing respiratory diseases and inflammations of eyes, ears and skin can also occur (Müller, 2001). The greatest concentration of germs is found in summer due to higher temperatures and heavier use. To catch some infection from pool water is not of course solely determined by the presence of germs. Whether you are affected depends on the concentration of pathogens and their aggressiveness, on the amount of water swallowed and on your own constitution (p. 223).

CHEMICAL CRITERIA FOR FILL-UP WATER AND CONSTRUCTION MATERIAL

Though current filtering methods derived from nature are well developed and ingenious, it is necessary to adjust each particular pool construction to the available fill-up water quality. Beside the phosphorus content there also needs to be analysis of sulphur, hardness, total salt content etc. Recommended threshold values are listed opposite.

Table 5 **Recommendations for the chemical water quality**

Factor	Fill-up water	Pool water and pure water
Total phosphorus (P_{tot})	< 0.03 mg/l (if exceeded significantly it should go through a P-filter or an ex-situ regeneration pond) *	≤ 0.01 mg/l * (< 0.03 mg/l in pools without intensive filtering if a lower visible depth is acceptable)
Ammonium (NH_4^+)	≤ 0.5 mg/l	≤ 0.3 mg/l (pure water ³ 0.1 mg/l)
Nitrate (NO_3^-)	≤ 50.0 mg/l	≤ 30.0 mg/l (often intensive filtering causes N-deficiency)
Sulphur (SO_4^{2-})	≤ 40 mg/l	No specific recommendation
Iron (Fe^2+ / Fe^{3+})	≤ 0.2 mg/l	No specific recommendation
Manganese (Mg^{2+})	≤ 0.05 mg/l	No specific recommendation
Acid capacity $K_{S\,4,3}$ (related to carbonate hardness	≤ 2.0 mmol/l (KH ⌊ 5,6°dH) *	≤ 2.0 mmol/l (KH ⌊ 5,6°dH) *
Conductivity at 25°C	≤ 1000 µS/cm (may be higher if caused by temporary hardness and a decline below 1000 µS/cm can be expected within 6 weeks)	200 – 1000 µS/cm (< 400 µS/cm in C-limited pools)
Oxygen saturation	No specific recommendation	≤ 80%
pH	No specific recommendation	6.0 - 8.5 (short term up to 9,0 as an exception

* In C-limited waters $K_{S4,3}$/KH may be lower and a slightly higher P-level may be acceptable.

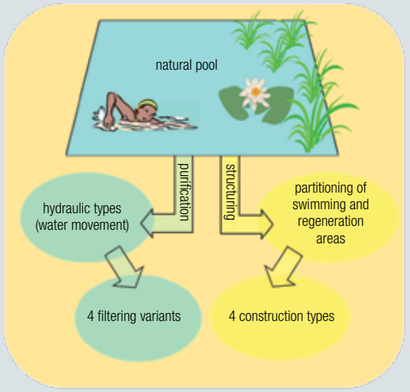
Derived from ÖNORM, 2013; Frei, 2012; FLL, 2011 and Baumhauer & Schmidt, 2008

Permanent contact with water can leach out harmful substances, so construction materials should not be selected on grounds of cost, durability or visual appeal alone. If you believe the gravel substrates or stones may contain a significant level of potentially dissoluble phosphorus, you should commission an analysis by a specialist laboratory. ÖNORM (2013) recommends that potentially dissolvable phosphorus content should not exceed 50 g per 100 m^3 pool water. This does not apply if all submerged materials provide less than 6 mg P per kg.

To keep the water clear, an adequate filter system must be implemented. These generally depend on plants and microorganisms, although some modern systems work with percolated substrate beds instead of plants.

4 FILTER SYSTEMS AND CONSTRUCTION TYPES

To describe the numerous variants of natural pools, we distinguish between: three hydraulic types of purification and, derived from this, four basic filtering variants. The partitioning possibilities of swimming and regeneration areas are the basis for four construction types.



Classification factors for natural pools.

RUNNING WATER AND STANDING WATER: HYDRAULIC POOL TYPES

In terms of limnological conditions, there are two main types:

- **Standing bodies of water** in nature come in the form of ponds or lakes. Ponds are shallow enough to be populated by green plants, while lakes provide deeper zones free from vascular plants.
- **Running-water types** are springs, streams and rivers.

The turbulence effect of the current causes a continuous substitution of warm layers by cooler ones. So standing water will reach higher temperatures than running water. Oxygen is also better incorporated in running water, but this is more the result of the cooler temperature than through turbulence increasing the interface between water and air (Jaksch, 2006). The carbon dioxide (CO_2) content can even be reduced by water movement: the very low content of only 0.04% CO_2 of the atmosphere causes a continuous sink, so that more carbon dioxide is given off by running water than dissolved into it.

In standing water the uptake of dissolved nutrients causes a contiguous depletion zone around plants' surfaces. Conversely, permanent water movement guarantees a constant nutrient supply around nutrient-absorbing parts of the plant. For this reason some plants from streams grow poorly in ponds without water movement.

In standing water, you will find sedimentation and areas due to sludge deposition, especially if there is little dissolved oxygen. These areas are described as anaerobic. In contrast, running water mostly creates aerobic conditions.

The limnological situation of natural pools can consequently be classified in three main hydraulic types (derived from ÖNORM L 1128, 2013; Jaksch, Wesner & Fuchs, 2013):

- Standing bodies of water
- Slow-running bodies of water (uneven hydraulic limnology) – mostly with a minor surface current
- Fast-running bodies of water

Table 6 **Three hydraulic types of natural pools**

Hydraulic type	Technical stimulus for water movement	Minimum percentage of regeneration zone compared to total pool surface
1: Standing bodies of water e.g. ponds and lakes	No technical support – only natural circulation, potentially promoted by thermal stratification	≤ 65%
2: Slow-running bodies of water e.g. river's lower courses	Skimmer → pump → influx through a stream or inlet at the pool wall or else through a planted regeneration area or a slowly percolated/intermittently working filter	≤ 50% (⌊ 30–40% if a percolated filter zone is used)
3: Fast-running bodies of water e.g. streams and river's upper courses	Skimmer → pump → percolated substrate filters; eventually supplemented by a specific vertical flow through inlets on the pool base	≤ 25% (³ 5–20% in professional systems)

Below left Standing water can accommodate lush vegetation but often clarity is limited as in this lake with *Nymphaea alba* in southern Sweden.
Centre Moderately clear water in slow-running Eglinton River, New Zealand. The brown vegetation at the back is a flowering group of *Myriophyllum triphyllum*.
Right Fast-running water with clear quality and a bluish hue in Erawan National Park, Thailand.

PURIFICATION FACTORS: FILTERING VARIANTS OF NATURAL POOLS

Four **operative factors** are responsible for water purification:

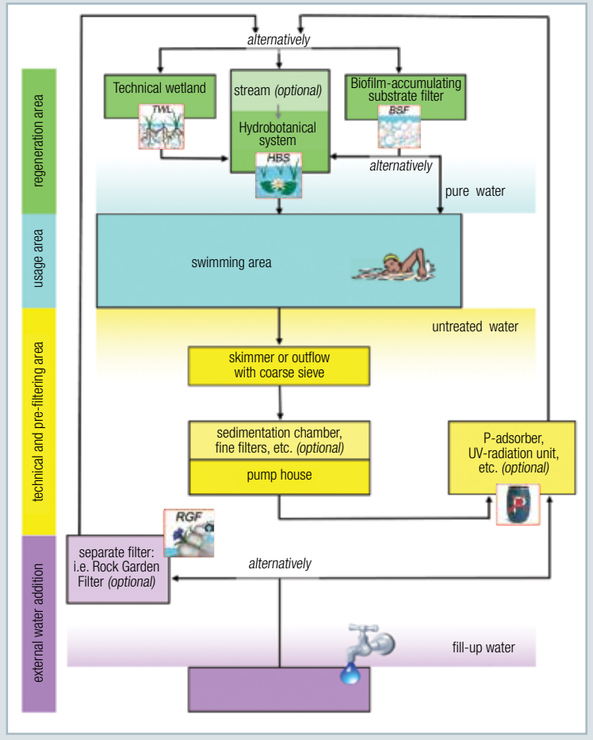
- Plants
- Plankton
- Biofilm
- Technical installations

Derived from these, we can distinguish between four filter types (terminology based on FLL, 2011) as follows:

- **Hydrobotanical Systems (HBS)** These use densely planted bodies of water as "regeneration areas"
- **Technical Wetlands (TWL)** Planted gravel or sand filter bodies, various possibilities of water level and percolation direction
- **Biofilm-accumulating Substrate Filter beds (BSF)** Without plants or with purely decorative planting
- **Additional filtering, pre-filtering and water treatment units** These include sieves, phosphorus adsorbers, aeration devices, UV radiation, etc., often integrated in the pump-house or in skimmer and overflow.

With the exception of the standing body of water type, natural pools are constructed as circulating systems: water is drawn from the swimming area through a skimmer or an overflow gutter through certain pre-filters (sieves etc.) into one or several regeneration areas where it is purified and returned to the swimming zone again (p. 44).

In principle TWL and BSF are most effective in reducing pathogenic germs but their phosphorus fixation is lower than in Hydrobotanical Systems. The latter provide effective phosphorus fixation but a lower reduction of microbes (FLL, 2011). For private facilities, filtering exclusively by Hydrobotanical Systems is sufficient if the planted area is big enough and the phosphorus influx is not too great. The best results can be achieved with a combination of different filter systems. In particular a TWL should always be combined with a densely planted HBS or with a BSF, because these eliminate phosphorus compounds much more efficiently.



Possible water circulation systems

HYDROBOTANICAL SYSTEMS (HBS)

Hydrobotanical Systems feature regeneration areas densely populated with hydrophytes (submerged and floating-leaved plants) or helophytes (wetland plants). Their impact on phosphorus elimination is calculated to be greater than in other systems: submerged vegetation is capable of removing up to 40% of dissolved phosphorus and helophytes up to 30%. The elimination of pathogenic germs however reaches only about 10% (FLL, 2011). For private pools, which experience far less use than public ones, Hydrobotanical Systems are very important. They also offer considerable potential for plant enthusiasts.

Table 7 **Filter types and their main purification factors**

	Description	Main purification factors	Maintenance requirements
Hydrobotanical System	Dense plantings in shallow water, slowly perfused or standstill conditions Flow rate < 0.2 m/hr	Plants, plankton	Trimming and harvesting submerged plants in summer, reeds/helophytes in autumn
Technical Wetland	Slowly, vertically or horizontally percolated sand or gravel filter beds, ± densely planted Percolation rate < 0.3 m/hr	Substrate, plants (helophytes) & microorganisms adjacent to roots and rhizomes	Trimming/mowing of plant sprouts in autumn; possible complete exchange after 10–15 years
Biofilm-accumulating Substrate Filter	Intensively, mainly vertically percolated gravel filter beds with high water permeability, planted only for decoration. Permanent water movement of 24 hr/day Percolation rate >> 0.5 m/hr	Biofilm	Regular backwashing
Additional filtering, pre-filtering or treatment units (examples)	Retention of dirt particles in sieves	Mechanical filtering / pre-filtering	Regular cleaning of the sieves
	Sedimentation of suspended matter	Sedimentation chamber	Regular removal of the sediment
	Special granulates to bind phosphorus	Chemical or physical binding capacity	Backwashing and regularly exchanging of the filter medium
	Aeration	Oxygen enrichment to promote aerobic microorganisms	Occasional checks
	Carbon dioxide enriched aeration	Soil air (richer in CO_2 than atmospheric air) increases locally the CO_2 content of the water – promotes submerged plants and shall diminish algal growth	Occasional checks
	Killing germs	UV-light intrinsically contradicts the natural pool philosophy	Occasional checks

Partly referring to ÖNORM, 2013 and FLL, 2011

Hydrobotanical System with water lilies and submerged plants. Underwater *Stratiotes aloides* and the small floating-leaved *Brasenia schreberi* have been shown to emit allelopathic substances which suppress other plants, chiefly algae and duckweed.

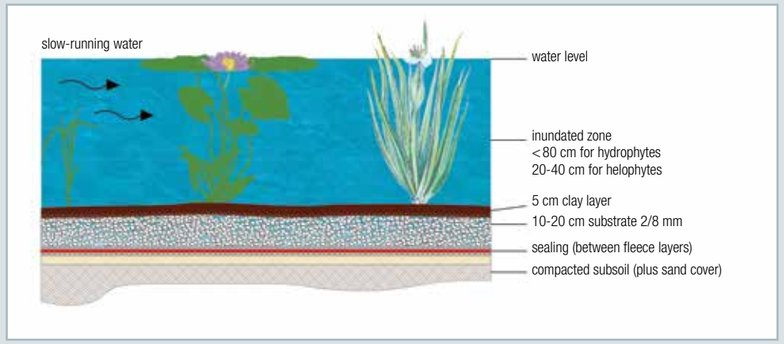
Above *Myriophyllum spicatum* can antagonize planktonic algae.
Below Hydrobotanical System with helophytes in Erlebnisgarten Schleitzer, Munich, Germany.

Plants for purification

Plants contribute to water purification especially in Hydrobotanical Systems in many ways:

- Plants with floating leaves such as water lilies cover some of the water surface and this shading effect keeps the water cooler and smothers algae.
- Free-floating and submerged macrophytes take all their nutrients out of the water and may compete with algae and phytoplankton (Gross, 2005).
- Submerged leaves and shoots produce oxygen, which promotes phosphorus precipitation (p. 35) and provides a supportive environment for pollutant-degrading microorganisms.
- The large surface of submerged plants provides a good substratum for the development of biofilm organisms (Brix, 1997).
- Numerous submerged macrophytes are assumed to release agents effective against algae (i.e. Jasser, 1995; Gross et al., 2007; Frei, 2008), such as *Ceratophyllum* spp., *Myriophyllum* spp., *Elodea* spp. and *Stratiotes aloides*. This trait's relevance for the purification of natural pools however is hard to quantify (Wyss, 2009). It seems to be only effective against planktonic algae, but does not significantly impact filamentous types.
- Reed-like helophytes from the shallow water zone develop a thicket of shoots. This creates a significant reduction of air and water movement, improving sedimentation. The shading of the water surface equalizes the temperature of the surrounding area and smothers algae (Brix 1997).
- Phytoextraction: some helophytes (such as *Schoenoplectus lacustris* and *Juncus fontanesii*) extract considerable amounts of heavy metals and organic pollutants (Oueslati, Haddad & Thayer, 1996; Ojo & Mashauri, 1996; Seidel, 1966).
- Antibiotics and diverse organic root excretions may kill pathogenic germs. This has been proved in the case of *Schoenoplectus lacustris*, *Iris pseudacorus*, *Mentha aquatica* and *Acorus calamus* (Seidel, 1966; Grathoff, 2009; Devi & Ganjewala, 2009; Bhuvaneswari, 2012).
- *Typha* and *Juncus* species are reported to release autotoxic compounds inhibiting seed germination of their own species but also affecting algae (Aliotta et al., 1990; Della Greca et al., 2001).

Of course achieving positive results depends on there being sufficient nutrition. Plants which show marked symptoms of deficiency contribute little to water purification (pp. 152, 225).



Section through a Hydrobotanical System (modified after FLL, 2011).

Table 8 **Effective filtering plants (submerged and floating-leaved) for Hydrobotanical Systems recommended for private pools in nemoral climates**

Species	Comments
Brasenia schreberi	Floating leaves, may fail in hard water
Ceratophyllum demersum & *C. submersum*	Submerged and rootless
Eleocharis acicularis	Underwater turf, may fail in hard water
Groenlandia densa	Submerged, proliferates with rhizomes in the ground
Hippuris vulgaris	Sprouts emerge above the water surface if planted in shallow water < 60 cm
Myriophyllum spicatum	Often establish spontaneously
Nymphaea Hybrids	Floating leaves, consider individual depth demands
Potamogeton crispus *Potamogeton perfoliatus*	Submerged, proliferating with rhizomes in the ground
Potamogeton lucens	Not for very nutrient-poor water
Stratiotes aloides	Their serrated leaves can scratch the bather's skin if they drift into the swimming area
Sagittaria graminea	Completely submerged in deep water
Vallisneria spiralis	Dense stands of vigorous, belt-shaped leaves

Iris pseudacorus plays an active role in hygiene by emitting antibiotic substances.

Table 9 **Effective filtering helophytes (reed-forming plants) in Hydrobotanical Systems, recommended for private pools in nemoral climates**

Species	Comments
Caltha palustris	Only in shallow water, polyploide cultivars like 'Auenwald' tolerate 20 cm water level or more
Carex elata	Wide tussocks, may proliferate by seeding
Cyperus longus	Proliferate with rhizomes
Iris pseudacorus	Suffers in oligotrophic water
Lysimachia thyrsiflora	Proliferate with long rhizomes
Lythrum salicaria	Aggressive newcomer in North America
Mentha aquatica	Aromatic
Menyanthes trifoliata	Floating shoots
Schoenoplectus lacustris, S. tabernaemontani	Tough rhizomes
Typha laxmannii	Proliferate with rhizomes
Typha shuttleworthii	Proliferate moderately with rhizomes

The table above does not list extremely aggressive species. For example, the common reed (*Phragmites australis*) is very effective in promoting filtration, but is only suitable in large areas as monoplanting because of its competitiveness. A number of plants listed are competitive but short-lived or inconspicuous and these species are not listed.

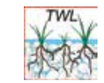
Construction advice

For Hydrobotanical Systems with submerged vegetation, a water depth of at least 80 cm is recommended (FLL, 2011), but shallower depths can work effectively, especially in private pools, if appropriate plant species are selected. Helophyte plantings should be in 20–40 cm of water. The higher temperature of shallower water can promote filamentous algae. The daily inflow rate of the flowing water should be around 5 m^3 per m^2 cross sectional area (FLL, 2011). In a linear system this means a water speed of 5 m/day or 200 l/hr.

Gravel of 1-8 mm grain size to a depth of 10–30 cm makes a suitable substratum. Mostly submerged plants do not need extra nutrition. But water lilies, lotuses and demanding reeds may suffer from deficiencies, mainly in nitrogen. A 5-cm clay cover is recommended to enable fertilizer tablets to be regularly inserted into the substrate and prevent nutrients from diffusing into the free water (see further tips p. 190).

Marginal wetland vegetation planted within the pool sealing but on non-flooded substrate surfaces is not an HBS. Its impact on water purification is only significant if the substrate is actively percolated (see below) and if there is enough water volume to allow sedimentation of P-compounds.

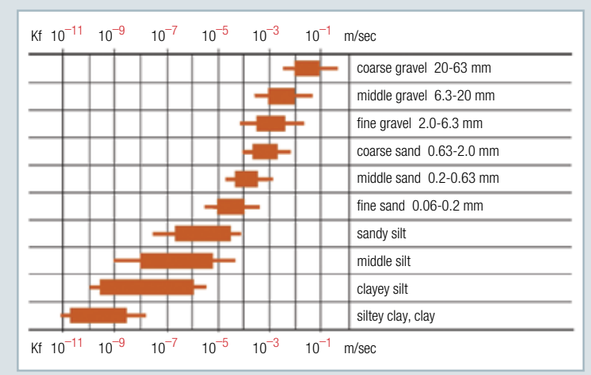
TECHNICAL WETLANDS (TWL)



Technical Wetlands are planted substrate-bound filter systems. The basic philosophy is derived from waste water treatment, where the term "Constructed Wetland" is more common. The substrate body of the Technical Wetlands can be vertically or horizontally percolated to purify pool water. Purification works through a combination of substrate and plant roots (FLL, 2011). Often this technology is used in separate regeneration basins in public pools. In private facilities it is a suitable filtration method for homemade construction along the edges of the main basin, surrounding or adjacent to the swimming area.

Substrates for TWLs

The substrate should be relatively fine-grained gravel to achieve slow percolation. The hydraulic conductivity (Kf-value) is recommended to be < 10^{-3} m/sec. in other words: the water can pass the root area at a maximum speed of 1 mm/sec or 3.6 m/h.



Permeability (Kf value) of different substrates (wide lines: main range, fine lines: acceptable range (DIN 4022; Pätzold, 2011).

Fine substrate can keep back even bacteria and tiny pollutants. Clogging is prevented by plant root growth. The contribution of plants is much lower than the impact of microorganisms and substrate, but their roots and rhizomes provide a suitable environment for microbes. In the rhizosphere a particular microbial community develops, which is beneficial for purification, nutrient incorporation and hygienization. Sand or fine gravel is used as a substrate. Opt for 1–8 mm gravel by preference and no coarser than 2–8 mm gravel. The chemical constitution of the substrate depends on the intended water quality: P-limitation is supported by carbonates (limestone or dolomite), C-limitation by silicates or any carbonate-free materials. Organic matter must not be mixed into the substrate; only layers clearly above water level may contain peat if demanded by its vegetation (bog plants at C-limitation).

Substrates should be stable in structure so that settlement is less than 5% after one year of operation.

Table 10 **Attributes of vertically percolated Technical Wetlands**

Thickness of filter layer	40–80 cm
Water inflow Qmax	3 $m^3/(m^2 \times day)$ = 125 $l/(m^2 \times h)$ ≙ 0.125 m/h
Grain size range in the filter	1–8 mm
Washable components in the substrate	< 5%
Hydraulic conductivity coefficient (kf-value)	$\leq 10^{-3}$ m/sec

Derived from FLL, 2011, partly adapted according to the authors' experiences

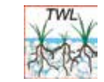
According to FLL (2011) an elimination of 85-90% of *Escherichia coli* can be calculated for Technical Wetlands, but practical experience suggests an elimination rate of over 99% is achievable (Bruns 2014). The phosphorus fixation is rated at only 20% by FLL (2011); P-compounds are more mineralized than eliminated. Basically TWLs are recommended for a pre-purification stage in conjunction with HBSs (ÖNORM 2013).

We can distinguish between several possibilities according to the flow direction of the percolating water and the water level in or above the filter:

- **Water level**
  Filter completely submerged / inundated
  Surface of the filter not flooded ("emersed filter"): low backwater level within the filter substrate / plants emersed (Helophytes)

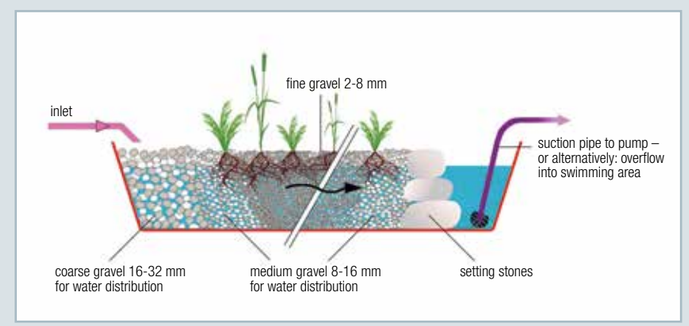
- **Direction of water flow in the root area**
  Vertically, bottom-up pumped through pressure-side drainage pipes
  Vertically, top-down pumped through suction-side drainage pipes. In separate basins the circulating water can be irrigated onto the substrate surface
  Horizontally, mainly applied in emersed/non-flooded systems

Horizontally percolated Technical Wetlands



In constructed wetlands for waste water treatment it is very common to draw the water horizontally through the filter bed (EPA, 2000), but occasionally this purification method is also used in public pools. The space requirements of horizontally percolated Technical Wetlands may be the reason why they are rarely found in private pools: a flow distance of at least 3–6 m needs to be provided (DWA, 2006; Baumhauer & Schmidt, 2008).

The water must pass through the filter bed slowly and an intermittent infeed is considered optimal. Disadvantages of this variant are the much lower influx of oxygen than in vertically percolated filters and the irregular water distribution (FLL 2008). So normally for private purposes a vertically percolated system is preferable.



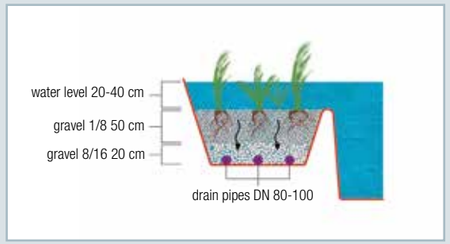
Above Technical Wetland with common reeds (*Phragmites australis*) to purify the water of a public pool near Hannover, Germany. From the swimming basin water is pumped into the ditch on the left and from here it moves slowly horizontally through the filter body. This space-hungry water treatment method is better suited to public facilities than private ones.

Left Section drawing through a horizontally percolated Technical Wetland, non-flooded.

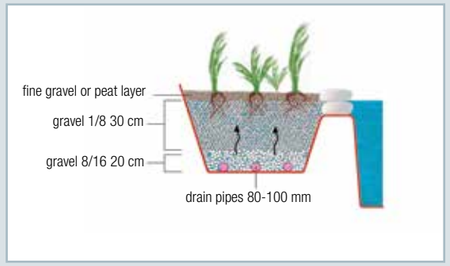
Vertically percolated Technical Wetlands (see case studies 5, 11, 12 & 14)

Technical Wetlands with vertical water movement can be flooded (submerged) or non-flooded. In practice, top-down percolation seems to be the most common method. The following images show sections through some variants:

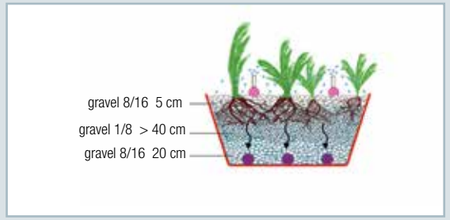
Vertically percolated Technical Wetland – option 1
In situ, flooded: water is drawn through the substrate via common drainage pipes (DN 80 or 100) and pumped into the adjacent swimming area. Alternatively, the water could be pumped from the swimming area into the drainage pipes and percolate upward through the substrate.



Vertically percolated Technical Wetland – option 2
In situ, non-flooded (plants emersed): marginal to the swimming area. Water is pumped upwards through the substrate via common drainage pipes (DN 80 or 100). The percolation is deflected horizontally towards the free body of water.



Vertically percolated Technical Wetland – option 3
Placed in an extra basin (ex situ) non-flooded (plants emersed) – water is irrigated onto the bed and runs through the substrate of sand or fine gravel by gravity. It is collected by drainage pipes on the ground and transported to the lowest point or to a collecting ditch from where it is pumped into the pool. If the bottom is constructed at a slight angle and its position is above the pool's surface, the water runs to its destination by gravity.



The plumbing of flooded top-down percolated TWLs can be constructed in a similar way to Biofilm-accumulating Substrate Filters (BSF) as explained later (p. 63). Water is pumped into or drawn out of the substrate through drainage pipes of 8–10 cm diameter (DN 80 or DN 100). If a wide area of the marginal zone or even the complete circumference is used as Technical Wetland, quite a few feeders to the pump should be connected along the evenly spaced drainage pipes to promote even water movement through the complete filter area (see case study 14). Technical Wetland purification is much less sensitive to percolation irregularities than Biofilm-accumulating Substrate Filters.

In practice it is often hard to differentiate between these two filter types.

Left Usually, perforated drainage pipes are laid in gravel to draw the water through the substrate top-down or pump it bottom-up.

Above The space between the edge of the pool (right) and the swimming area (left) is laid out with three lines of drainage pipes to draw water through the gravel, which subsequently will be filled onto the pipes (see case study 11). Here the pipes are provisionally fixed with bricks.

They are based on different purification factors, but are often combined to some degree in their implementation. Our clear distinction between the two might appear of academic importance only, but planting and maintenance requirements are different (p. 60). Case studies 11 and 14 show pools with filter zones which we characterized as Technical Wetlands, but even in these systems, where water is drawn through the filter gravel relatively slowly, a biofilm will occur – in practice the transitions between TWL and BSF can be fluid. Note the pipe-collecting chamber in case study 11, which can also be used as inspection shaft: if any clogging is noticed, a plumber's cleaning spiral can be inserted into the pipes.

Plants for Technical Wetlands

One main advantage of planting is to prevent clogging in filter bodies with fine structured substrates: small particles will prevent the water flowing through the narrow pores. The growth of plant roots and rhizomes will keep the substrate permeable (Frank, 2006).

Further benefits of planted filter bodies are provided by rhizodegradation: submerged plants' cell tissue is often sponge-like and the so-called *aerenchymae* provide intercellular spaces to promote the exchange of gases under water. So the direct environment of the submerged plant structures

Trial plots with sand filters.
Below left The plot without vegetation was clogged after a few weeks and the water overran the system.
Right The planted plot was still working perfectly after three years (Research station for Landscaping, Veitshöchheim, Germany; Kircher & Schönfeld, 2008).

Above A three-year-old common reed (*Phragmites australis*) root ball shows how intensively rhizomes and helophyte roots can reinforce their substrate.
Below Technical Wetlands can result in gorgeous wet meadows.

are better supplied with oxygen. This promotes microorganisms which suppress the development of toxic fermentation products (Vymazal et al., 1998; Börner, 1992; Knight, Kadlec & Ohlendorf, 1999). Only in planted constructed wetlands a decomposition of oils and fats has been experimentally confirmed (Flamisch, 1995; Reinhofer, Stuhlbacher & Grandi, 2007). Of course other effects of plants described for Hydrobotanical Systems (p. 46) are also evident in Technical Wetlands.

In Technical Wetlands separated from the swimming area (ex situ) swamp plants (helophytes) with strong growth of roots and rootstock (rhizomes) are favoured, mainly *Phragmites australis*, the common reed.

Table 11 **Helophytes with strong rhizomes recommended for Technical Wetlands that are separate from the pool's swimming area (ex situ)**

Carex acutiformis, C. acuta, C.riparia
Cyperus longus
Equisetum hyemale var. *robustum*
Phragmites australis
Schoenoplectus lacustris, S. tabernaemontani
Typha angustifolia, T. latifolia, T. laxmannii
Zizania caduciflora

When directly linked to the main pool basin, the use of plants with rampant rhizomes such as the above is not recommended; only *Cyperus longus* may be restrained enough to be acceptable. Spacious horizontally percolated TWLs can be integrated into an impressive overall design by establishing wet meadow forbs and grasses with compact growth such as *Filipendula* species, irises, *Eupatorium maculatum*, *Asclepias incarnata*, *Carex diandra* etc., all of which (except *Carex*) need a certain degree of nitrogen fertilization to guarantee lush growth. Appropriate vegetation for very poor water without much need of external nutrition can be designed with plants from poor lime fens. In a system with very soft water (targeting C-limitation) even plants from raised bogs like *Sphagnum* mosses and pitcher plants will be suitable for the site and look spectacular (pp. 151, 154).

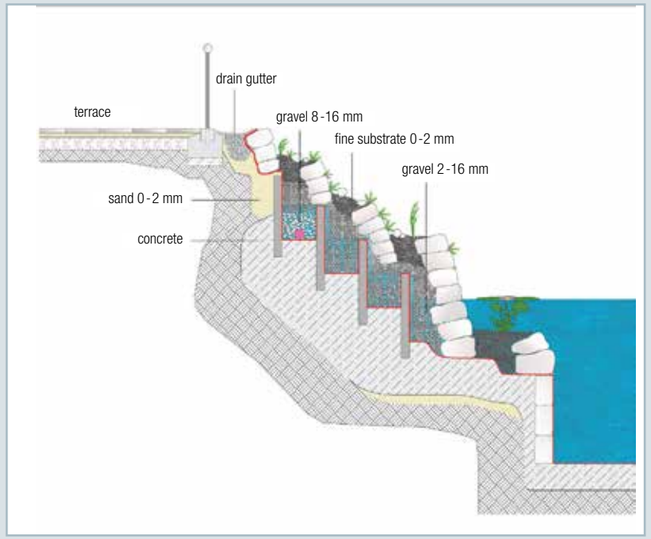
ROCK GARDENS AS TECHNICAL WETLANDS

Even sizeable Technical Wetlands will struggle to purify the whole pool if they are the only filtering element because of their low circulation rate. On the other hand you can create a beautiful setting for a pool with a dry stone wall or a rock garden constructed as a filter body.

These constructions can either be included in a circulation system where the pool water runs through the rock garden or to pretreat fill-up water to compensate for transpiration and evaporation losses. The hygienization effect will be very good, comparable with traditional TWL filters but the contribution to phosphorus elimination should not be overestimated. Nevertheless trials with sand filters to treat grey water showed a 34% decline of PO_4-phosphorus (Frank, 2005). These sand filters can be compared with RGFs without backwater (p. 56).

Rock Garden Filter (RGF) with backwater

In this set-up, terraces of several narrow basins filled with gravel form the substructure of a rock garden as shown below.



Section through the rock garden with embedded backwater basins which should provide 40-50 cm backwater depth.

Trial pool at Anhalt University, Germany

Above left Construction works in 2009 showing the substructure basins: a PVC-liner coats the concrete vessels. It is covered with a membrane (polypropylene fleece 900 g/m²) as protection against damage.

Right Filter gravel fills all the basins and in the upper one a pipe is installed before being covered with gravel.

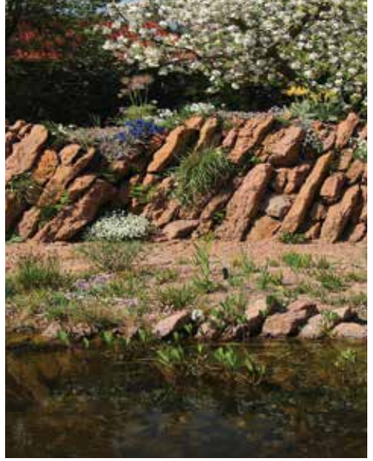
The basins' edges are horizontally levelled to distribute the percolating water equally along the complete width. This system should be permanently percolated throughout the complete frost-free period to provide a permanent oxygen supply for the vegetation, at least if alpines are used as they do not withstand anaerobic conditions. This purification variant was successfully tested at Anhalt University (Bernburg, Germany). Occupying only 20% of the total surface, it kept a 3 × 8 m pool clear and free from algae, but with a relatively strong percolation rate of about 400 l/hr and per m² base area of filter body. For a practical application we recommend a slower percolation (max. 300 l/hr/m² filter surface) and a bigger area (40% of total surface) or else additional filter zones from other types (HBS, BSF or other TWL types).

The photographs this page show the Rock Garden Filter at Anhalt University, Bernburg, which works as a permanently percolated system.

Rock Garden Filter (RGF) without backwater

Rock Garden Filters allow pretreatment of fill-up water within an attractive design. The water, trickling through the sand or gravel core of a rock garden even without embedded dams, feeds the crevice vegetation and becomes depleted in nutrients and germs.

Left On the filter gravel a setting of natural stones (rhyolite) among fine gravel (2–8 mm) forms a rock garden. Right *Leontopodium* cultivars



Naturalistic construction of a dry stone wall as "crevice garden" (see case study 7). Above left quarry rough rhyolite stone flags clad a pure sand body which works as filter for the fill-up water. Above right moisture-hungry alpines such as *Gentiana acaulis* cultivars and *Antennaria dioica* thrive and bloom without any problems.

Alpine plant enthusiasts can use a Rock Garden Filter to cultivate even difficult plants successfully: the mineral substrate is slowly percolated for a certain time each day. The water level in the pool can be kept stable by using a time switch. A rain/humidity sensor can switch off the system on rainy or cool, humid days. During frosty periods the water supply is, of course, switched off. Most plants prefer to be kept dryer through winter in any case. More information on design and plant selection is given in case study 7 along with a construction sketch (p. 256).

If located directly beside the swimming area, the low and irregular outflow rate of water at the base of the dry stone wall can create an area of unstable limnological conditions. Such a disturbed habitat provides an ideal environment for excessive string algae growth. It is worth inserting a zone of dense planting (HBS) between the filter wall and the swimming area, which smothers algae and promotes precipitation of washed-in mineralized phosphorus.

Sand filters are recommended to provide a lime ($CaCO_3$) content of 10–15 Vol.-% (MUNLV, 2003). In a phosphorus-limited system, up to 50% lime or dolomite gravel (2–8 mm) can be mixed into the substrate. Rock gardens for particular lime-hating plants (acidophytes), however, should contain quartz sand with a low proportion of fine particles (< 1 mm), the method of choice if you envisage C-limitation. An addition of 20% expanded slate (2–8 mm) may lift the pH initially, but after a while it tends to a moderately acid reaction.

Plants for Rock Garden Filters

It's not just alpines that are well-suited to percolated rock gardens; slow-growing fen and bog species as well as plants from water-bearing slopes or the banks of streams and waterfalls if appropriate in size and

Natural pool with dry stone wall as percolated filter. Pool water is distributed through a drip tube along the ridge and percolates through sand back into the basin. Along the foot of the wall the slowly released water provides good conditions for string algae to develop. This zone should be densely planted with helophytes or water lilies to work as a Hydrobotanical System that smothers the algae.

durability also enjoy the conditions. Rock gardens without backwater basins will be significantly dryer through winter, which was shown to be beneficial for most species in trials at Anhalt University (USDA zone 7b). The table opposite lists some recommendations derived from those trials. Plants for shady conditions are suited to north-facing slopes. Species recommended for sites on backwater basins will also thrive if used near the foot of rock gardens without embedded water storage vessels while plants for RGFs without backwater may also be suitable for substrates above barrages, if the planting site is at least 20 cm above water level.

BIOFILM-ACCUMULATING SUBSTRATE FILTERS

Currently most professionally built natural pools have an intensively percolated filter bed, which successfully oxidizes dissolved phosphorus (p. 35). The resulting compounds will be ligated within the filter. A sufficiently strong water movement in the filter allows biofilm organisms to develop on the filter grains' surfaces, efficiently removing them from the pool water. Advanced systems dispense with plants completely (see case study 10). To optimize phosphorus decline, consistent percolation for 24 hours a day is recommended, otherwise the biofilm organisms will be seriously harmed. The filter body must not contain anaerobic sections. The additional injection of air increases the effectiveness. Besides the need for permanent percolation, the most significant difference from certain types of Technical Wetlands is a markedly faster water flow through the filter substrate. To maintain a stable aerobic environment it is important to avoid areas of standing water. Table 13 shows relevant differences between Technical Wetlands and Biofilm-accumulating Substrate Filters.

BSF as fast-running water type

The water flow through the filter should be at least 1.5 m/hr, according to the Austrian guidelines (ÖNORM, 2013). Within the filter body the water is forced to run in curves around the substrate grains (as opposed to up or down). This circuitous route triples the speed between water molecules and inner substrate surfaces. Thus, to reach the required speed of 1.5 m/hr, an influx of just 0.5 m/hr is sufficient. According to trials at the University of Wädenswil, Switzerland (Frei, 2012), there is no clear upper limit for the percolation speed. Even more than 100 m/hr will increase the biofilm growth rate proportionally. These new insights may lead to smaller filters of the BSF type providing much faster percolation. The

Table 12 **Plants for Rock Garden Filters**

Species	RGF with backwater (or foot of RGF without backwater)	RGF without backwater (or > 20 cm above water level)	Requirements and habit
Allium angulosum	✓	✓	Sunny, upright tussocks
Armeria caespitosa		✓	Sunny, little cushions
Antennaria dioica cultivars		✓	Sunny, shallow mats
Arnica montana	✓	✓	Sunny/part shade/acidic
Asplenium (Phyllitis) scolopendrium		✓	Shade
Asplenium trichomanes		✓	Partly sunny/shady
Aster flaccidus		✓	Sunny, dense mats
Calluna vulgaris dwarf cultivars		✓	Sunny, acid
Caltha palustris var. *alba* & *C. p.* 'Multiplex'	✓	✓	Sunny/slight shade
Carex viridula	✓	✓	Sunny/part shade
Dactylorhiza Hybrids		✓	Sunny/part shade
Dryas octopetala, *D. o.* var. *tenella*		✓	Full sun, wide mats
Gentiana Acaulis Grp.		✓	Sunny, compact mats
Hakonechloa macra	✓	✓	Shady, overhanging grass
Hesperantha coccinea	✓	✓	Sunny, great autumn bloomer
Iris setosa subsp. *canadensis* 'Nana'	✓	✓	Sunny, compact tufts
Leontopodium stracheyi & *L. alpinum* cultivars		✓	Sunny, silvery cushions
Primula auricula		✓	Sunny/part shade
Primula frondosa	✓	✓	Sunny/part shade
Primula rosea	✓		Sunny/part shade
Salix helvetica		✓	Sunny, little shrub
Saxifraga cortusifolia var. *fortunei* cultivars		✓	Shade, slightly acid
Saxifraga oppositifolia 'Theoden'		✓	Cool sites, part shade
Tofieldia pusilla	✓	✓	Sunny/part shade
Trichophorum alpinum	✓		Sunny, slightly acid
Wulfenia x *schwarzii*	✓	✓	Shady, acid

Table 13 **Comparison of Technical Wetlands and Biofilm-accumulating Substrate Filters (hr = hour; d = day; m = metre; m² = square metre filter surface**

	Technical Wetlands	Biofilm-accumulating Substrate Filters
Hydraulic (limnological) type	slow running waters: lower courses of rivers	fast running waters: streams/creeks /upper courses of rivers
Objective	Elimination of pathogenic germs P-mineralization and moderate withdrawal by plants. Can be used in P- and C-limited water Oligo- to mesotrophic systems	Effective P-minimization Elimination of pathogen germs Requires and supports P-limitation Ultraoligo- to oligotrophic systems
Percolation rate	<~300 l/m²/hr <~0.3 m/hr	>> 500 l/m²/hr >> 0.5 m/hr (resulting in > 1.5 m/hr within the filter) Biofilm growth is proportional to speed of passing water (Frei 2012)
Percolation cycles	Can be intermittent for several hours per day (emersed TWLs) or permanent (inundated TWLs)	24 hr/d
Area of application	or	
Substrate recommendations	1–8 mm grain sizes or coarse sand (0.2-2mm) in emersed TWL or RGF	2–8 mm grain sizes or even coarser Should contain carbonates to stabilize the pH 5–20% of total surface
Minimum space requirements	30–50% of total surface (swimming area + regeneration area)	5–20% of total surface (swimming area + regeneration area) if optimally implemented
Oxygen supply	Small anaerobic areas are acceptable	Must be completely aerobic Additional aerification by air pump may support biofilm growth
Planting	Plants prevent clogging and support purification Hydrobotanical System should be added downstream	No plants necessary Plants from P-limited sites can be suitable but must not disturb even percolation
Plant growth	Moderate lack of nitrogen	Lack of nitrogen if not additionally fertilized lack of phosphorus may occur
Regular maintenance	Cutting back of helophytes in autumn to extract phosphorus and other nutrients	Backwashing the filter: slow percolation twice a year; quick percolation up to once a month or more

greatest challenge for this new generation of filters will be the implementation of proper backwashing devices. In most professional systems today, BSF technology is still laid out for not much more than 500 l/hr/m². However, many system providers produce a bespoke filter calculation for each project.

From Technical Wetland to Biofilm-accumulating Substrate Filter

A larger filter area fitted with drainage pipes for water distribution causes a declining percolation speed. Much lower flow rates than 0.5 m/hour will provide more P-mineralization than incorporation into the Biofilm. But even a bigger area fitted with drainage pipes gives very good results, though the purification effects may be based more on the Technical Wetland principles, which require a combination with thriving plantings and Hydrobotanical Systems for proper phosphorus immobilization. Many recent pools combine TWL and BSF features; case studies 11 and 14 show examples. As long as space is available, it is no problem to devote a correspondingly large area to a percolated filter. These "slow filters" should be combined with downstream Hydrobotanical Systems to complete the phosphorus fixation process. Furthermore, slow water movement may provide the possibility of targeting C-limitation (p. 38).

Filter substrates

Pure substrate filters concentrate on biofilm as the main purification resource. To promote optimal biofilm growth a very permeable substrate (kf > 10^{-3}) is required, which provides a microclimate with even water movement. We recommend using no substrate particles finer than 2 mm. Smaller grain sizes are suitable in Hydrobotanical Systems and Technical Wetlands, whereas coarser grit allows a stronger perfusion in the BSF.

The peripheral structure of the effective filter grains can be very diverse depending on the chosen material. Whereas the surface of pure stone gravel is relatively small, zeolites or special mineral wool products provide a much greater surface, which promotes microbial growth.

In general BSF should support phosphorus limitation. To achieve this the P-content of the substrate itself should not exceed 6 mg P/kg (ÖNORM, 2013). This can be analysed by digestion in hydrochloric acid (HCl). For the non-expert, it can be hard to check the relevant chemical

parameters. There are four options:

- Find a chemical lab which offers a proper service (make sure the method of analysis complies with ÖNORM (2013) or FLL (2017).
- Ask a professional landscaper dealing with natural pools to help.
- Buy professionally guaranteed substrates from an accredited supplier.
- Source the best material you can find. You should at least make sure that your gravel does not contain typical P-compounds (apatite).

Gravel with high quartz (SiO_2) content provides suitable quality, but to optimize P-fixation a certain proportion of carbonates is recommended. To achieve this, add at least 30% lime or dolomite chips to the filter substrate.

Example of sizing a BSF

If the swimming area measures 8 × 4 × 2.2 m, the wall and base surfaces add up to about 85 m². According to the calculation below right at least 4.25 m³ substrate is recommended to fill the BSF (85 ÷ 20 = 4.25). If 1 m deep, 5–6 m² will be sufficient for a proper filter, given appropriate fill-up water quality and remembering the lowest layer and the topping consists of a coarser grain size. This filter space can be reduced by special substrates as mentioned above. If the percolation rate is lower than 1.5 m/hr, the filter space should be increased or the BSF combined with TWL or HBS.

FLL-grain-size-surface table

particle size [mm]	total surface [m²/m³]
4–6	1400
4–8	1200
6–8	1000
8–12	700
8–16	600
12-16	500
16–22	350
16-32	300
22-32	250

Table 14 Attributes of substrate filters

Thickness of filter-effective layer	≤100 cm
Water inflow Qmax	>>500 l/m²/hr >>0.5 m/hr
Grain size range in the filter	2–16 mm
Washable components in the substrate	< 5%
Hydraulic conductivity coefficient (kf-value)	$>10^{-4}$ m/sec

Derived from FLL (2011), ÖNORM (2013) and practical experience

Sizing a BSF

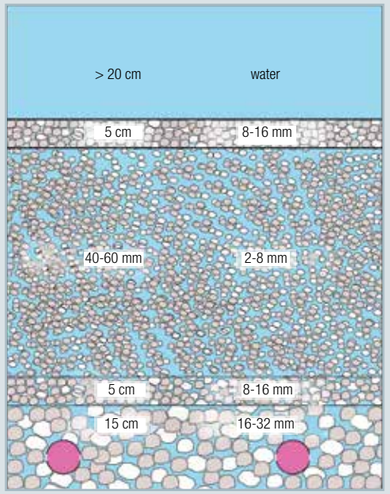
Biofilm coatings are undesirable on the surface of the wall and floor of the swimming area. But the sealing must not be treated with any biocide (FLL, 2017). Biofilm coatings can be avoided if the total surface of the substrate grains is at least 50 times greater than the total surface of the swimming area's walls, floor and other installations (ÖNORM 2013), if the percolation rate is adequate (p. 58).

If 1 m³ of 6–8mm gravel is calculated to provide a surface of about 1000 m² for biofilm development, the swimming area's total surface divided by 20 gives the necessary volume of filter substrate.

For proper biofilm development (see table left), the filter area must be calculated in relation to the suction power of the pump, so that the drawn off water amount does not drop below 500 l/m² filter area per hour. The depth of filter bodies should be at least 50 cm (FLL, 2011). The faster the water movement in an upward-percolated substrate bed, the thicker the substrate layer should be to prevent it from being destabilized by strong water pressure (p. 67). Particularly in BSF beds of 1 m or more, releasing air with an additional air pump into the upward-flowing water supports the biofilm (see case study 15).

Construction of a BSF

There are numerous ways of constructing the filter stratification. In all versions it is important to have a coarse-grained layer at the bottom as a water distribution zone and on top as a stabilization layer. Case study 15 (p. 290) shows an alternative method of providing even water distribution on the filter vessel's base. Above the distribution layer finer gravel is used to provide a large surface for biofilm to develop. Some professional pool system providers include special zeolite layers to provide best nutrient situation for biofilm accumulation. A very careful selection and layering of substrates is important to minimize the filter bed space requirements as shown in case study 10 (p. 268). However, if space is not limited,



Section through a BSF. If a very thick filter construction (> 80 cm depth) is chosen, a "second floor" of distribution pipes could be inserted at mid-height embedded again in a layer of coarser gravel to support proper backwashing.

Above left Construction of a small Biofilm-accumulating Substrate Filter (BSF) for upward percolation: in this 1.6 m wide filter bed, one distributing drainage pipe (DN 100) is sufficient. It will be embedded in a ground layer of coarse gravel (16–32 mm). The hard PVC connection provides maximally 45° angles to optimize the water flow. At the back a vertical PVC pipe is added as an inspection shaft to permit the removal of debris.
Above right The distribution plumbing for a spacious rectangular BSF. The central feeder pipe ensures even water distribution.

very effective purification results can be achieved even without inserting expensive zeolites or other extra materials.

By default, substrate filters are constructed completely submerged, 20–40 cm inundated. But this is not mandatory, as shown in case studies 5 and 10. The water is either pumped in from the bottom, streaming upwards ▲ (case studies 5, 9, 10, 16, 17) or drawn downwards ▼ (case studies 12, 13, 16). In both cases the water circulation must work 24 hours a day to guarantee optimal biofilm growth. Intermittent operation will cause dying back of the biofilm. Only during frosty periods and to prepare for backwashing should the pump be switched off. The withdrawal of phosphorus from the system is much more efficient than in Technical Wetland systems, provided the accumulated biofilm is removed regularly by backwashing the filter, as explained below.

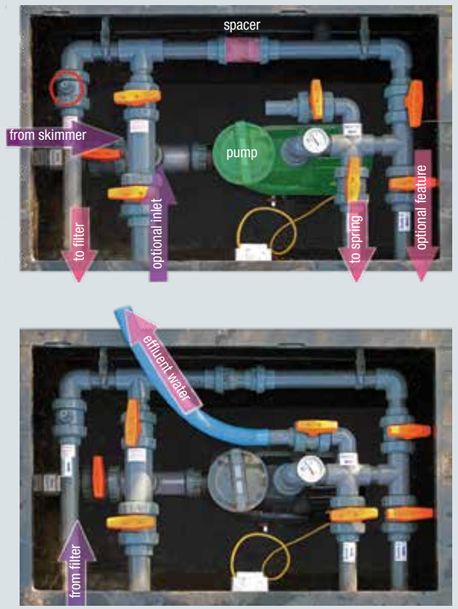
Pools with BSFs are defined as fast-running waters. Unlike Technical Wetlands, these filters must be percolated evenly without accommodating anaerobic spaces; the drainage pipes must distribute the water very evenly. To achieve this, you should not allocate too much space to the BSF. A smaller filter surface needs a less powerful pump to guarantee a percolation rate >500 l/m²/hr. If the filter is smaller than 4 m², one drainage pipe will be sufficient if connected centrally (photo above left). Bigger filters should be supplied by two or more well distributed feeders to or from the pump. Use drainage pipes with only 5 cm diameter (DN 50) to achieve even water distribution. In bottom-up percolated filters it may be more reliable to use non-permeable PVC pipes in which you can cut slots with an angle grinder. A few small holes on the upper surface help to release any air bubbles. If covered with a piece of liner, they will not lead to an "outburst" of the substrate layer as explained on page 67.

Left Instead of using drainage pipes, slots were cut in the outer ring of DN-50 pipes using an angle grinder. Before covering the pipes with substrate, the evenness of the water outflow at moderate pressure can be tested and, if necessary, more slots added.

Maintaining the biofilm in substrate filter beds

After several weeks, the biofilm will reach the final phase of ageing: particles die off and are flushed into the open pool area, making the water murky again (p.22). To prevent this, backwashing is required: the pump should be switched off for a week to kill the biofilm. Then, the direction of water flow in the distribution pipes should be reversed (photo below); instead of pumping water into the filter, it is drawn off and not removed into the pool but fed outside to trickle away or irrigate the garden. This discharged water will initially be brownish and murky or smell mouldy. As soon as it becomes clear and loses any unpleasant smell, the pump can be switched back to its original setting. The system will immediately return into its normal function and a new biofilm can begin to establish itself. The backwashing of the filter is recommended at least twice a year, in spring and autumn. An additional backwashing can be beneficial in mid summer. Very intensively percolated units, as described in case study 10, should be backwashed once every four to eight weeks.

When filling up with filter gravel, you should carefully align the horizontal strata layer by layer. In this filter bed the inflow is central to guarantee even distribution.



Plumbing in a Teichmeister® pump-house (BSF percolated bottom up)
Top Normal setting – the pressure water is split in two pipes, one feeding the BSF and one supplying an additional well. The circled valve balances the intended flow rate to the BSF. To adjust this adequately a flowmeter can be inserted in the detachable spacer marked in pink. Once adjusted, the handle is removed to avoid accidental changes.
Bottom Setting for backwashing – after switching off the pump for a week, the valves are reversed so that water is drawn from the filter and expelled.

Another way of removing dead biofilm is shown in case study 15. The pressure distribution pipe is inserted into a significantly wider pipe with a vertical connection protruding above the filter surface. Through this shaft the debris can be drawn off via a hose by an extra waste water pump.

The Floating Bed Reactor

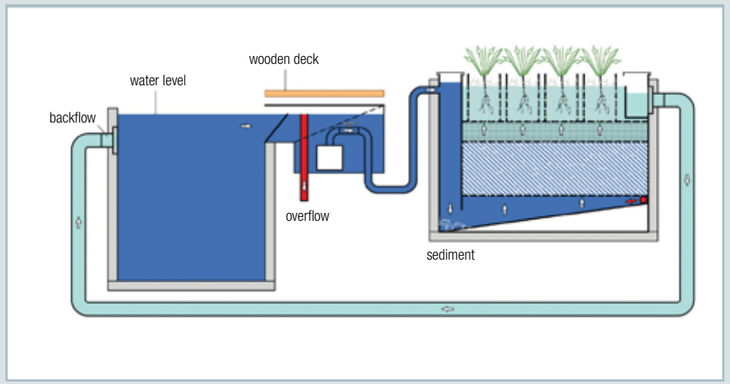
A further development is the Biofermenta Floating Bed Reactor, a floating layer of special lightweight substrate kept underwater by a grid. The water is distributed under the substrate and percolates at about 2m/hr through the substrate body. Once a year or, in case of larger nutrient influx, every other month during the swimming season, the pump is stopped for one week to provide backwashing: the biofilm dies back and is sedimented on the base. The inclined floor of the filter bed causes the debris to accumulate at the lowest point from where it can be vacuumed up. All the technical equipment, including the filter, can be covered by a deck. A planted Technical Wetland is recommended as part of the water circulation. In free-standing locations, the filter basin can also accommodate vegetation in special planters directly above the filter, as shown in the section drawing below (Kurzmann, 2015). In the UK the system is supplied by Clear Water Revival Ltd., Bristol.

BSF with top-down percolation

A top-down percolation system can be installed with similar plumbing to a bottom-up one. In case study 12 the drainage pipes were embedded under an artificial shingle beach, allowing access to the pool. The plumbing should be attached in the middle rather than at the end of the drainage pipe or several joints can be established at 3–6 m intervals to avoid inconsistent suction.

An advantage of top-down percolation is the simplified option for removing dead biofilm, which does not require extra adjustment of the pump plumbing. All that is needed is a branch pipe behind the pump along with a switching valve to divert the water out of the pool backflow. There are, however, two main disadvantages to top-down percolation:

- Cleaning the pool surface requires an extra water circulation system with a skimmer. In contrast, bottom-up percolation demands only one pump feeding the filter with water drawn from the pool surface via a skimmer. However, most pools with bottom-up filtration also have two water circulation facilities for additional water features (see case studies 5, 9, 10 and 16).
- Plant roots penetrate the drainage pipes much more easily if water soaks into them than being pumped out. This is more evident for slow-percolated filters (TWL) than for BSFs, which do not necessarily have to be planted. But in properly installed TWLs clogging of the drainage pipes rarely becomes so severe that the water circulation rate is significantly reduced and complete restoration is necessary.



Implementation of a SBR4 Biofermenta Floating Bed Reactor. The planters above the reactor have no connection to the filter substrate. (drawing: Biofermenta GmbH, A-Salzburg)

Planting and other risks

Plants do more harm than good on substrate filters as their roots and rhizomes may penetrate the filter body unevenly and disturb the uniform water flow. This can easily lead to areas lacking in oxygen and low redox potential. The biofilm will not work effectively and filtration will be insufficient. The worst-case scenario would be an outburst of the water through the substrate at one spot in the filter plane: if roots are growing through the complete filter body, the perfusion is greatly hindered. Over time pressure will concentrate onto the weakest point and break through the covering layers taking the filter gravel with it. This would require complete filter renovation. But such a disaster would only occur in filter constructions with very strong percolation and shallow depth. An inconsistent air release into the bottom of a BSF can also cause such a breach through the substrate layer, chiefly in shallow filter beds. Specialized system providers offer reliable artificial filter aeration solutions.

If plants with weak or shallow root systems are used at sufficient depth, the system will be reliable and durable.

A planting on intensively vertically percolated underwater filters must not send its roots very deep into the gravel bed. Monoplanting *Cyperus longus* provides even root penetration (Ellicar Gardens, UK).

Table 15 Plants for inundated BSF with shallow water (20–40 cm)

Species	Comments
Baldellia ranunculoides	Very small, only in combination with partner species
Calla palustris	For shady places, bright red but poisonous fruits in summer
Caltha palustris 'Auenwald'	Larger type of marsh marigold
Cyperus longus	Very competitive; as monoplanting
Mentha aquatica	For shallow water
Myosotis palustris	For shallow water
Nymphaea tetragona and dwarf *Nymphaea* cultivars	Prefer cool summer temperatures
Potamogeton perfoliatus	Maybe the best pondweed for P-limited waters
Sagittaria graminea	Partly and fully submerged leaves
Typha laxmannii	Very competitive; as monoplanting
Typha shuttleworthii	Moderately competitive; can be combined with clump-forming species

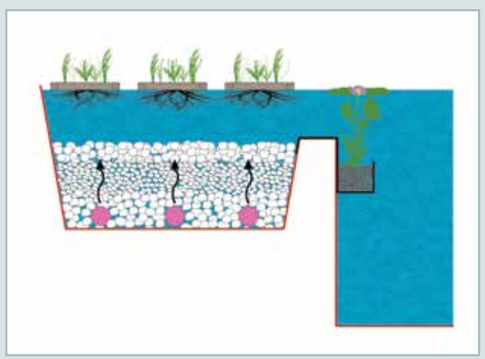
Floating islands to cover inundated BSFs

To enhance the appearance of an intensively percolated submerged filter in a naturalistic way, a fen vegetation can be established on floating islands above the filter bed. A minimum distance of 40 cm should be kept between the filter surface and the island. Once a year the roots growing out of the island's substrate can be cut and removed to prevent them penetrating the filter. To make this possible it is better to use a series of small islands fixed together with wire clamps rather than very large units.

Floating islands are available to buy, for example from BioHaven®. An easy way to make your own floating islands is to take a 5 cm thick sheet of hard polystyrene (rigid Styrofoam) as a baseplate. Smooth Styrofoam used for packaging is unsuitable because it soaks up water and will sink. Drill some holes in the plate and pull wicks of absorbent fabric (such as jute) through the openings, which should hang some centimetres into the water. A frame of wooden slats should protrude no more than 5 cm upwards to maintain the loosely filled-up substrate. A shallow layer of unfertilized peat or peat moss (*Sphagnum*) is sufficient if used on C-limited pools. However, Biofilm-accumulating Substrate Filters chiefly aim at P-limitation supported by hard, carbonate-enriched water. In this case 50% lime gravel (2-8 mm) can be mixed with the peat.

Table 16 Low-growing plant species for floating islands on BSFs (oligotrophic, P-limited, hard water)

Caltha palustris
Cardamine pratensis
Carex davalliana, *C. pulicaris*, *C. viridula*
Dactylorhiza hybrids (i.e. *Incarnata* Grp, *Praetermissa* Grp.)
Dianthus superbus
Epipactis palustris
Eriophorum latifolium
Gentiana asclepiadea
Iris setosa subsp. *canadensis*
Parnassia spp.
Schoenus ferrugineus, *S. nigricans*
Tofieldia calyculata
Zigadenus elegans



Section through a BSF covered with floating islands.

Above Floating island with fen vegetation for P-limited water.
Below Bog plants for C-limited water.

Below Floating islands should be easy to turn over to trim trailing roots once a year.

Wet meadow forbs and grasses provide an exciting alternative to monoplanting: plants such as *Liatris spicata*, *Zigadenus elegans* and *Allium cernuum* with moderate rooting power but beautiful blooms cover this percolated BSF in a trial pool at Anhalt University, Bernburg. The filter surface must protrude a few centimetres above water level.

Emersed (partly submerged) substrate filter beds

Trials at Anhalt University, Bernburg, showed that a substrate filter works reliably even if its surface protrudes a few centimetres above water level (Kircher, 2007; Thon, 2014). In effect, the vertical flow from the bottom up is diverted into a horizontal flow into the swimming area. (Case studies 5 and 15 show such systems.)

It is much easier to find suitable plants for this option, because bogs and fens provide a great diversity of species with shallow roots which tolerate nutrient-poor conditions. Plants from American wet prairies are welcome additions to enhance summer flowering.

ADDITIONAL FILTERING OR PRE-FILTERING UNITS

Besides the installation of one or several of the above-mentioned filter systems, a respectable number of mechanical, physical, biological and chemical filters can be added. Certainly mechanical pre-filtering is vital if any water movement is desired. Skimmer and underwater-pump chambers are usually equipped at least with coarse grids, sieves or filter mats, but also offer the possibility of adding special granulates.

Dry-installed pumps are mainly hidden in pump-houses; if these are spacious enough, some filter units can be accommodated there too (p. 120 & case study 12).

Case study 13 describes skimmer–pump combinations, including slice filters integrated in one multifunctional chamber by the swimming area.

Skimmers and mechanical filters

Irrespective of the chosen filtration type (generally a mechanical or at least physical purification is included into any water circulation) the water of the swimming zone passes a suction unit – the "skimmer" or an overflow gutter – to remove floating particles from the water surface before they sink. A coarse sieve traps larger particles such as leaves and insects. These pollutants can be detrimental to most pumps. Some skimmer variants also include an integrated fine filter to catch pollen, which can build up in large quantities in spring. These technical implementations just like sieves or filter systems relying on surface absorption have to be cleaned regularly so that the outflow is not blocked. Depending on the amount of dirt, this may be necessary one to three times a week. Current systems provide quick and easy-to-handle filter sieves so that the maintenance can be carried out in seconds. For safety, an integrated underwater suction device can be beneficial in case you forget to empty the sieve.

Skimmers must be flexible and functional over at least 15 cm fluctuations of water level (ÖNORM 2013). Skimmers and overflow units should be placed within easy reach for servicing. Choose the side of the swimming area to which pollutants drift according to the prevailing wind direction. Worldwide this tends to be the east side. In round shaped swimming areas, a circular water movement can be enforced by jets installed at a slight angle along the edges (see case studies 11 & 14). Here, one or several wall skimmers can be placed in any position. Ensure the skimmer has an adequate grid cover so that vertebrates do not become trapped. One skimmer per 30 m^2 of water surface should be used. Select a skimmer whose mouth provides 2 cm width per m^3 of hourly passing water (ÖNORM 2013). If not part of a permanent filter circulation the skimmer need not work round the clock. Two hours per day may be enough.

Table 17 **Devices to clean and pre-filter the water surface**

Device	Description	See case study No
Floating round skimmers	Most usual types, easy to install, accept a wide water level tolerance	9
Wall-integrated skimmers	To be flanged into liner/sealing, integrated preferably in walls of maximum thickness of 25 cm. Even available for inclined walls.	14, 17
Curved-slot filters	Can be added to skimmers. The slots measure only a fraction of a millimetre and trap even the finest particles. Essential part of the Biotop Curved Sieve Skimmer. The debris is washed down the sieve's surface and removed by an elaborate self-cleaning mechanism.	13
Overflow gutters	Skimmer-substitute if an ex-situ regeneration pond is located deeper than the pool. The water flows to the pond by gravity and is pumped back from there. Keeps the water level in the swimming basin stable.	16
Pure PVC pipe	Cheapest option for self-construction. A hard-plastic pipe ⌊DN 100 penetrates the sealing 40 cm below water surface (flanged through the liner). It is connected via a rectangular elbow with a further pipe section of the same width, which leads to the water surface at a slight angle. It can be turned up and down manually according to the water level. A suitable solution if connected with an underwater pump-house or as substitute for the overflow gutter in small pools.	7

Left The floating skimmer cleans the water surface of leaves, dust and pollen.
Right The floating cylinder can be removed to empty the sieve basket.

Left A firmly installed skimmer with a coarse sieve in its suction chamber. The mobile flap at the base of the opening will allow only the surface layer to be drawn inside.
Right Slot filter box to remove coarse algae, floating biofilm aggregates and other debris.

Left Overflow gutter at the eastern edge of a public pool in Egling an der Paar, Germany (Bionova® system). The water flows through a grid, which catches coarse pollutants and on through a buried pipe into the regeneration pond in the background.
Right A PVC pipe (DN100) substitutes for a skimmer. Finishing slightly below the water level, it cleans the surface of this pool. This may be sufficient if the user's expectations of water purity are not too high (case study 7).

Filter mats are often inserted into skimmer chambers or underwater pump housings. They are made from webbed polyester or nylon–polyester fibre blends and form a kind of three-dimensional sieve which keeps back debris without significantly damming the water flow.

Sand filter and AFM filter (Activated Filter Material)

Sand filters usually operate in traditional pools. A stainless steel or PVC filter vessel (cartridge filter) is filled with sand, which is intensively

Right The pre-chamber of a pump-house for an underwater pump is filled with three rows of brush filters, followed by a coarse filter mat (case study 7).
Far right Filter brushes can easily be removed and washed out.

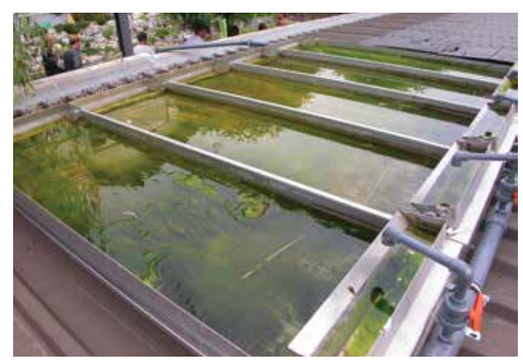
percolated by pool water. Even the finest particles can be eliminated. The vessel is regularly backwashed to remove debris.

AFM Filters are a further technological development of sand filters. Water is purified mechanically and due to the modified high surface of the AFM substrate (quartz and glass sand), this filter absorbs organics and small particles particularly effectively. In one hour 2–4 m^3 water can be purified.

The Algal Turf Scrubber

The Algal Turf Scrubber (ATS), an invention based on a US patent, is an unconventional mechanical filter designed to reduce string algae (Adey et al., 2011): water is pumped in a circulation line from the pool to shallow basins. A tip-over inlet creates intermittent torrents of passing water. Here filamentous algae thrive and form mats which regularly have to be removed to withdraw phosphorus (Brunner 2005; Graber 2007). Though this system has never gained widespread adoption, it demonstrates algae's favourite conditions: shallow, warm water, light exposure and irregular water movement. It follows from this that marginal pool and pond zones should either emerge slightly above water level or be inundated by at least 20 cm to avoid algae developing.

Above The filter mat's three-dimensional structure allows the water to flow almost unhindered, but catches even moderately fine pollutants.



Below left & right The Algal Turf Scrubber in a practical test, filtering water from a private natural pool in Switzerland (trials run by Zurich University of Applied Sciences, CH-Wädenswil).

Physical filters and treatments

A newer method of killing germs and algae in a circulating water system is to install a UV radiation unit in the pipe. If this is set up in the pump-house, it will be easy to maintain. You should be aware that a treatment with UV rays does not affect filamentous algae, only floating algae and all other plankton species, irrespective of whether they are harmful or beneficial. UV radiation might be a welcome tool for conventional pools, but it contradicts the idea of biological water purification in natural pools. Nor does it conform to the relevant guidelines (ÖNORM, 2013, FLL, 2011 & 2017) and trials with UV radiation have not given unambiguously positive results (Darga et al., 2008).

Ultrasonic frequency generators harm algae within the swimming area, again a questionable tool in the context of the natural pool philosophy. As these can easily be retrofitted, they are discussed in chapter 9 (p. 222).

Chemical filters and treatments

Chemical filters provide sorption of nutrients, which is important especially in the case of phosphorus. Sorption-capable materials are:

- Clays
- Iron-, manganese-, aluminium oxides and hydroxides
- Organic matter
- Activated carbon

Phosphorus reduction

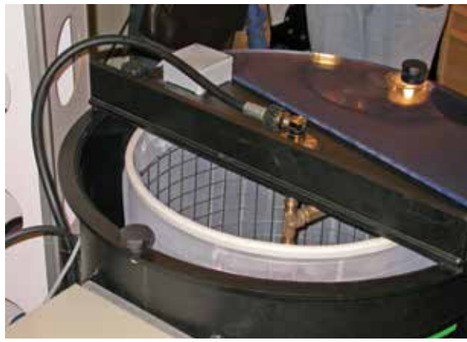
Additional phosphorus filtration systems mainly work with P-reduction granulates based on iron hydroxide oxide (FeO(OH)). Dissolved phosphorus is transformed into iron phosphate, which is fixed on the granulate surface. One kilogramme of iron hydroxide with a grain size of 2–4 mm (FerroSorp® Plus) can adsorb 8 to 10g of phosphate (manufacturer's information). In severely phosphorus-charged water, the adsorption may rise up to 25g (Schöpke et al., 2013). For a highly P-charged 100 m^3 pool, the application of 5kg iron hydroxide (2–4 mm) is recommended (Otto, 2014).

The necessity of using special phosphorus-adsorbing agents depends on the fill-up water quality. Some water suppliers put phosphorus in the municipal drinking water to prevent corrosion of the pipework. Locally, the mains water may contain 0.6–1.5 mg/l (ppm) of phosphorus. In this case a special P-filter is mandatory to fulfil the demands for low algal growth (p. 39; see case studies 12 and 13). Newer products (eg Phosfree) contain liquid lanthanum compounds that bind phosphates highly efficiently in low concentrations.

There are numerous products on the market, mainly in the form of separate complete filter bodies consisting mostly of a cylindrical housing, a sieve, an inlet with the filter granulate and connection equipment. A common product, a pressurized vessel, in different sizes with a six-way valve handle to give various water routing options, is structurally nearly identical to a sand filter for conventional swimming pools.

But you can also fill the granulate into permeable sacks and place them in an underwater pump's pre-chamber. The percolation speed should not exceed 50 m/hr for optimal P-reduction. An intermittent flow with retention periods of 30 minutes optimizes the adsorption process. Prior to application, the granulate should be washed out with a hose to remove fine abrasions, which could lead to the water turning reddish. To find out when the granulate should be replaced, regular analysis of dissolved phosphorus is recommended. But replacement should be carried out at least every spring.

Beside phosphorus adsorber granulates, zeolite filters are also sometimes recommended. Zeolites are minerals with a complex crystal lattice which can fix positively charged ions such as NH_4+, K+ or Ca_2+ but they are not effective at fixing phosphorus. Zeolites are mainly used as a beneficial growth medium for biofilm. Positively charged ions such as NH_4+, K+ or Ca_2+ fit into the lattice, zeolites are not effective to fix phosphorus. The main reason to advocate the use of zeolites is that they provide a beneficial growth medium for biofilm microbes.



Filter cylinders to be filled with iron hydroxide oxide granulate to fix phosphorus. The vessel can either be installed underground (above) or located in a sufficiently large pump-house.

Aeration systems

Particularly in pools which belong to the fast-running water type, overall oxygen saturation is important. But as explained on p. 27, the oxygen concentration can only marginally be improved by water movement or direct aeration. Oxygen saturation chiefly depends on the temperature or the content of biodegradable organic matter. Professional Biofilm-accumulating Substrate Filter technology is often equipped with aeration to feed in the percolating water with a proper oxygen supply, optimizing biofilm development. Special air pumps force air through jets or perforated pipes into the bottom-up percolated BSF. The system provider BioNova® works with a cylindrical filter vessel with a fine filtration fleece and special purification substrates. This unit is intensively aerated (see case study 18).

Aeration pipes laid along the swimming area's framing wall (private pool in Graz, Austria, designed by A. Kern).

Aeration jets can create extraordinary effects using gently ascending bubbles, which cause a pleasant tickling sensation on the skin.

CO2-enriched aeration

A special form of aeration is provided by the Biotop Carbonator, a patented invention by Biotop. Perforated pipes, which draw air from the ground, are laid underground outside the pool. This air provides a CO_2 concentration 10–300 times higher than atmospheric air, which contains only about 0.04% (Stange et al., 2011). During the day, when the pH value of the water rises, the carbonator leads this air through nutrient-binding granulated rock and is then distributed in the pool through aeration hoses or injector jets. The CO_2 acidification effect deteriorates the conditions for algae, while most submerged vascular plants are supported. Nutrients are bound and oxygen introduced into the water. The carbonator will support pools which aim at C-limitation. For P-limited systems with a certain hardness and high pH, there will be a local effect near the outlets. At a certain distance, the CO_2 is quickly transformed into HCO_3^- ions. (Case studies 12 and 13 show applications of the Biotop Carbonator.)

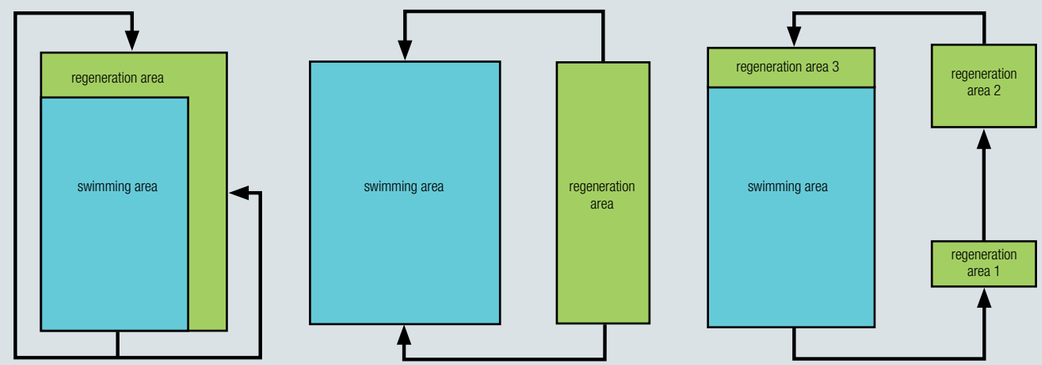
SINGLE OR MULTI-AREA:PARTITIONING OPTIONS FOR NATURAL POOLS

Filter zones can either be included in the same unit as the swimming area (**in situ**) or constructed as separated installation (**ex situ**). The latter option is common in public pools, where the regeneration basin is not accessible to visitors for safety reasons. Case studies 10, 16 and 17 show private facilities with the same partitioning. If the appearance of a traditional pool is sought, the purification installation needs to be separate.

Of course the filtering area can be partly outsourced and partly integrated into the same body of water as the swimming pool or comprise two or more separate regeneration basins (**in situ + ex situ**; see case studies 3, 8 and 18).

Pools with all compartments belonging to one body of water are "single-chamber systems". A "double-chamber system" means a separation into two basins and a purification cycle through more than two water bodies describes a "multi-chamber system".

In-situ and ex-situ variants of natural pools.



In situ: Regeneration area completely within the swimming area (single-chamber system)

Ex situ: Regeneration area completely outsourced (here: double-chamber system; the regeneration area could also comprise several bodies)

In situ + ex situ: Regeneration area partly outsourced (here: multiple-chamber system)

Above It may be distracting if the liner is directly visible along oblique edges of a swimming area.

Above Rounded boulders are loosely laid on the liner (protected by a tough fleece) in the swimming area (private pool, Canton of Bern, Switzerland.
Below Covering a previously built wall with a sealing is difficult and should be carried out by professionals to avoid folds and wrinkles. The slight folds in front will smooth themselves through water pressure.

SUPPORTING WALL ON OR UNDER SEALING: CONSTRUCTION TYPES OF NATURAL POOLS

The regeneration areas should be 50–150 cm deep, depending on the filtering system. It should be clearly divided from the swimming area, which should be at least 2 m deep (FLL, 2017). In practice, numerous naturally purified pools with lower depth work well, but if the bather's feet do not directly touch the base while swimming, sediment will not be stirred up. Furthermore, the temperature stratification is regarded as better for stable limnology. To optimize usability, the swimming zone should have steep walls, ideally built as a vertical casing. This saves space and offers the best bathing comfort without risk of injuries to hands or feet by kicking oblique surfaces. The transition to level ground can be rounded to improve the effectiveness of pool robots (see case study 17).

Generally at least a part of the regeneration area is included into the same basin as the swimming area. In these cases three basic construction types can be distinguished. A fourth variant runs parallel to the ex-situ partitioning:

- **No wall** (case studies 1, 6, 7, 14, 15 and 18)
  The edges of the swimming area are modelled into the ground with a slope of some degree and covered by the sealing. A covering of stones may be set on the slope to embellish its appearance.

- **Wall on sealing** (case studies 4, 6, 9 and 11)
  A vertical wall framing the swimming area is constructed on top of the sealing. Natural stone walls or timber constructions are commonly used. Larch or suitable hard wood types are very durable if kept permanently underwater (p. 114).
  Outside, a special substrate is used to fill the gap between sealing and wall, incorporating the filter systems or planting zones. If the resulting gap between wall and liner is filled with gravel, it will provide a long-term anaerobic space. If the filtration is based on the Hydrobotanical System or slowly percolated Technical Wetland principles, this is acceptable. If a Biofilm-accumulating Substrate Filter is desired, we recommend you fill the space from the bottom up to the beginning of the marginal regeneration zone with concrete and choose the construction type that follows.

- **Wall under sealing** (case studies 2, 3, 5, 8, 12 and 13)
  The vertical wall defining the swimming area is built with concrete, masonry or special plastic elements. Outside it, sand is filled up to the intended depth of the regeneration area and compressed. Finally the sealing is placed on top.
  If professionally constructed, the sealing can or even should be visible in the completed pool. Cleaning will be easier with a smooth-surfaced plastic liner than a stone or timber wall. Choosing an appropriate colour will deliver the desired water hue. As a further advantage, the regeneration zones do not include deep gaps behind the swimming area wall, which could create anaerobic spaces.

Above The swimming area is defined by a rectangular walled basin built onto the liner. The workspace around the wall is filled up with gravel. The advantage of this construction method is that ugly folds are covered up. For completely homemade facilities we recommend this method.

Above, both Private natural pool in South Tyrol, Italy: the swimming area is constructed as a separate pool and a percolated filter and planted stream for purification is completely outsourced.

- **Separate pool** (case studies 10, 16 and 17)
  This pool is built separately and the regeneration area completely outsourced. A rectangular pool without any marginal plantings offers the possibility of covering the surface with a protection roller when not in use. This is the easiest option for converting existing traditional pools into naturally purified ones: from the integrated skimmer the water will no longer be conventionally treated, but bypass through a filtration pool or chamber. In tropical regions where dangerous animals may be attracted by naturalistic planted pools, we recommend this construction type as it allows precise control of the swimming area (p. 198).

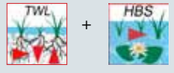
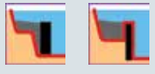
C-limited Swimming pond (model 1) in Lüchow, Germany. Underwater plants such as *Potamogeton perfoliatum* play an important role in the nutrient take-up and clear the environment of degrading microorganisms.

5
BASIC MODELS OF NATURAL POOLS

Combining the purification and construction options discussed in the previous chapter, we can distinguish four main types of design for a natural pool, or pool models (modified from FLL, 2006 & 2017, Frei, 2012 and ÖNORM, 2013). These four models are derived from their respective filtering and hydraulic types. The associated letters A to C indicate the partitioning type and extend the classification to 9 overall models. The following table lists the characteristics and recommended construction types for each model. The table and subsequent descriptions will help you find the most appropriate model for your individual requirements.

Often it is hard to distinguish between types 3 and 4 because the speed of the water drawn through the filter substrate may be quick but inconsistent or range across the threshold between the two recommended rates. But the faster the percolation, the more important it is to backwash the filter gravel regularly and arrange consistent water movement without anaerobic areas within the filter. So it is best to either choose a low percolation rate (→ Technical Wetland) plus appropriate planting, or construct a regeneration body which fulfils the criteria of a Biofilm-accumulating Substrate Filter.

Table 18 **Models of Natural Pools**

Hydraulic & filtration type + recommended construction types area (with reference to total surface area)	Partitioning type + recommended construction types **A** In situ: Regeneration area entirely within the swimming area (single-chamber system)	**B** In situ + ex situ: Regeneration area partly outsourced (double- or multiple-chamber system	**C** Ex situ: Regeneration area completely outsourced (double- or multiple-chamber system)
1: Standing bodies of water without technical installations only natural circulation ≤ 65% densely planted area	**1A** Single-area system 		
2: Bodies of water with surface flow water slowly flows through planting zone ≤ 50% densely planted area	**2A** Single-area system; Hydrobotanical System within the same water body 	**2B** Multiple-area system; Hydrobotanical System partly outsourced	Not recommended
3: Bodies of running water with Technical Wetland filtration + HBS  Percolation at moderate speed (<300 l/m²/hr) through planted filter bed ≤ 30–40% densely planted area on percolated substrate	**3A** Single-area system; planted filter within the same water body 	**3B** Multiple-area system; Regeneration area partly outsourced 	**3C** Multiple-area system; Regeneration area completely outsourced
4: Bodies of running water with Biofilm-accumulating Substrate Filter Controlled fast percolation (>> 500 l/m²/hr) through substrate filter ≤ 25% filter area (≤ 5–20% for professional systems); can be combined with TWL and HBS	**4A** Single-area system; filter within the same body of water	**4B** Multiple-area system; Regeneration area partly outsourced 	**4C** Multiple-area system; Regeneration area completely outsourced

SWIMMING POND

(SINGLE-AREA SYSTEM WITHOUT TECHNICAL INSTALLATIONS; SEE CASE STUDIES 1 & 6)

Swimming ponds have no technical equipment and are simply bodies of standing water. There is only minor water circulation caused by the natural warming of the water (thermal stratification). Anaerobic areas are accepted and the nutrient level may reach mesotrophic to moderately eutrophic levels, so its visual depth is lower than in intensively filtered waters. The pond can go through various phases of water clarity: murky conditions, etc. Murky conditions are likeliest in spring with rising temperatures, whereas in summer, when vegetation is well developed, the visual depth can reach two metres or more, providing the best conditions for swimming. We recommend building at least 30% of the swimming zone at least 2.5 m deep, so that accumulated mud is not stirred up by swimmers.

If the fill-up water with low hardness such as rainwater is available, C-limitation may be easier to achieve than P-limitation. Nevertheless it is desirable to keep the phosphorus content below 0.03mg P_{tot}/l on average (≙ about 0.1 mg phosphates/l). Purification is mainly carried out by plants and plankton. The latter activity promotes sedimentation. Together with introduced particles and pollutants (leaves, pollen, skin care products from bathers etc.) a certain amount of mud will accumulate on the base of the pool. This layer of dark-coloured debris is in keeping with how pools in this category are expected to look. To minimize the nutrient content, the mud has to be vacuumed up at least once a year and plants trimmed in early autumn.

The fill-up water can be fed in through a partially emersed "Technical Wetland", Rock Garden Filter (case study 7) or through certain chemical filters.

C-limited Swimming pond (model 1) in Lüchow, Germany. The border area is planted intensively as a Hydrobotanical System.

Assessment and recommendations

The swimming pond is the most cost-effective solution for nature-loving plant enthusiasts. It inevitably uses a naturalistic design and a lower visual depth must be accepted, but maintenance demands can be kept low. A great deal of space is necessary: FLL (2017) recommends at least 8 × 4 m for the swimming area or a diameter of at least 5 m. If only occasionally used to relax on hot summer days, this option can be very satisfactory.

This model 2A swimming pond in Linz, Austria, features a skimmer hidden under the wooden deck on the left. The slide in the background is made slippery with running water. Most of the water is released at the edge of the pond opposite the skimmer.

MODEL 2: SWIMMING POND WITH SURFACE FLOW (SEE CASE STUDIES 3, 7 & 8)

Water is drawn from the surface of the swimming area through a skimmer or an overflow gutter and returned through the mouth of a stream or some other water feature. The transition zone between moving and standing water does not provide long-term stability: spots of good oxygen supply vary with anaerobic locations – ruderal species such as string algae love such conditions. So a densely planted Hydrobotanical System should mediate between the point of running in water (running body of water, permanently providing aerobic conditions) and the swimming area (a more or less still body of water as in model 1). Plants should cover at least 50% of the total area.

The regeneration area can periodically be prone to algal mats developing, but if helophytes, floating-leaved and submerged plants provide adequate competition, the algae should not prove too troublesome and can be collected manually.

Purification factors, P-content and maintenance demands are comparable to model 1 pools, as is the possibility of C-limitation.

The pump capacity can be calculated on the basis of the recommendations for Hydrobotanical Systems (p. 48). If a cross-sectional area of 10 m width and 0.5 m depth (5 m^2) is effectively perfused, about 1 m^3 water per hour should be transported. A small conventional pump is sufficient for this (p. 117). The complete water volume should circulate about once every one to four days. The pump should either operate continuously or in cycles of less than 10 hours per day, targeting a well-balanced limnology of either slow-running or standing bodies of water.

Assessment and recommendations

This type of pool is easy to create as a homemade project. The space requirements are not much less than for model 1 pools. For a three or four person family, a total area of at least 100 m^2 is recommended for a model 2 pool. It is best to integrate it into a naturalistic overall design.

Model 2B swimming pond in Aschersleben, Germany. The very soft fill-up water (mains water with 5°dH GH) is a perfect base to promote C-limitation and cultivate cranberries (*Vaccinium macrocarpon*) within *Sphagnum* mosses in the marginal zone.

MODEL 3: BODY OF RUNNING WATER WITH TECHNICAL WETLAND FILTRATION

(SEE CASE STUDIES 11 & 14)

Technical Wetlands create a lower nutrient content and an advanced hygienization. The mineralizing effect of slow-percolated filters demands a downstream Hydrobotanical System to discharge phosphorus. Embedding a vast area with drainage pipes means reducing the flow rate proportionally. Partially anaerobic conditions are acceptable, so a highly consistent inflow from the distributing pipes is unnecessary.

Part-flooded (emersed) TWLs fed top-down by irrigating water onto the surface can run intermittently, for example in 30-minute cycles. Inundated TWLs should work permanently and the inevitable decrease in flow rate along the drainage pipes is much more acceptable than in BSFs of model 4 pools.

To percolate water bottom-up requires only one pump drawing off surface water from a skimmer and leading it into the filter's drainage pipes. For top-down percolation, an additional pump is necessary to run a skimmer at least two hours a day.

Model 3 natural pools can provide a much better visual depth than models 1 or 2. It is easier to ensure P-limitation with phosphorus concentrations below 0.01 mg P_{tot}/l (≙ about 0.03 mg phosphates/l). Given soft fill-up water and carbonate-free substrates and installations, C-limitation

Drainage pipes have been laid in three rows all along the marginal zone of this pool. They draw the circulating water through the root space functioning as a technical wetland (pool by The Swimming Pond Company, Bressingham, UK).

can also be targeted. Nitrogen fertilization may be advisable if the vegetation is unacceptably affected by denitrification.

Backwashing of mineralizing filters is less important than in BSFs of model 4 pools. So the maintenance can concentrate in harvesting biomass in autumn through cutting helophytes, removing dead and dying leaves from floating-leaved plants and reducing underwater plants. Vacuuming the base of the swimming area with a pool robot should be done more often, at least three times during summer or up to weekly.

Assessment and recommendations

This model is very widespread in self-made private pools of a more sophisticated type. The recommended minimum proportion for the filter area of 30% is generally exceeded in practice. The pump can be more energy-efficient and the evenness of the drainage pipe feed is less important than in model 4 pools. This is thus a proper solution for formal as well as for naturalistic designs: permanently crystal-clear water throughout the bathing season is possible.

MODEL 4: BODY OF RUNNING WATER WITH BIOFILM-ACCUMULATING SUBSTRATE FILTER (SEE CASE STUDIES 9, 10, 15 & 16; COMBINED WITH TWL: SEE CASE STUDIES 5, 12 & 17)

Pools of this type can provide perfectly clear water with a bluish hue even without any planting (see case study 10). The strong percolation rate of >>500 l/m²/hr guarantees an optimal development of biofilm within the filter body. The elimination of phosphorus and germs is very effective and nutrients decline to an oligotrophic level. Operating the pump all the time is important to keep the biofilm healthy. The circulation rate of the entire body of water can range from once to several times per day. Of course, in late autumn when the first severe frosts are expected, water circulation has to be stopped and dry-installed pumps usually have to be removed and stored in a frost-free place. Remember the need to backwash the filter regularly. This may be necessary two to three times per season or even once a month, depending on filter size, percolation intensity and pollution load.

These oligotrophic conditions produce lower mud accumulations because of reduced biological activity in the swimming area. At the same time, the very clear water may act as an added incentive to keep the ground clean. This can be done by using a pool robot once or twice a week.

The very clear water and the low sedimentation rate makes possible the construction of a swimming area shallower than in the previous types. Although a depth of 2 m is generally recommended, even water of 1.2 m is suitable for swimming.

Properly constructed and operated BSFs mean plants are not necessary. If planted, the growth will be very weak on the filter zone as well as additional marginal planting zones because of the low nutrient content. A well-adapted selection of suitable species or an adjusted fertilization can solve this problem.

Model 4 pools aim for P-limitation with a level of water hardness (pH around 8.3) which stablizes the chemical features. Special substrates in proper stratification as well as ingenious filter construction and feeding can allow even ultra-oligotrophic conditions (< 0.004 mg Ptot/l; Frei, 2012), often promoted by additional P-filters, P-binding agents, aeration etc. This is possible even with filter areas of less than 10% of the total pool size. To obtain such optimum conditions requires professional involvement. Numerous solutions have been patented and imitation is prohibited.

Fertilizing nitrogen in the form of urea is recommended more to feed the biofilm in the filter than to foster lush plant growth.

Model 4 pool in south Germany: the water is pumped bottom-up through the substrate filter in the foreground. Very clear water is provided at the expense of plant growth.

Assessment and recommendations:

Model 4 pools fulfil the highest water-quality demands and make possible the incorporation of a pool even in small gardens. A formal design fits well with crystal-clear water. For self-build, we recommend creating a bigger filter area than advertised by professional system suppliers. Plant enthusiasts should concentrate on chalk-loving vegetation (for example, lime fen plants – see pp. 69, 139). Combining Hydrobotanical Systems and Technical Wetlands is possible, but may require proper N-fertilizing.

Pools which also integrate special substrates or sophisticated aeration into the BSF could be considered as model 5 (Frei, 2012), but we decided to include these variants under model 4.

A sunken garden provides the option of including a water basin as part of a complete circulation system. Water from a pool in the upper garden area can flow via a waterfall into this basin to be pumped back. The water level in the pool is kept stable.

MULTIPLE AREA SYSTEMS

Of course, splitting the water body into two or more basins increases costs and space requirements. But it provides advantages:

- The planted basin can be cut back without messing up the swimming area with cuttings.
- In the swimming area vacuuming up the mud is easier and quicker.
- An extra regeneration pond can work as a storage basin if located deeper than the swimming basin: the water from the former is pumped up into the latter where it is led by gravity from an overflow edge back into the regeneration area. So a permanently stable level of the swimming pool is guaranteed. A lack of water affects only the level of the lower pond. So refilling water can be less frequent and in fairly humid climates it may be possible to use rain water alone even without an extra cistern (see case studies 3 and 16).
- The fill-up water can be added to the outsourced regeneration basin, so the new water is processed before entering the swimming area.

The inlet of the water into the swimming basin can create an area of inconsistent limnology, encouraging the emergence of string algae. If the water arrives via a stream, it should pass through a dense planting in the swimming part which smothers algae. If this is impossible, as in the case of a pure swimming basin without any plants (case studies 10, 16 and 17), it is better to insert the recirculation either submersed in at least 40 cm of water (case study 10) or through a vigorous waterfall (case studies 16 and 17). However, the turbulence of the latter case may promote algal biofilm layers on the pool wall near the waterfall. Another way of adding streams to natural pools at least visually is to construct them as "pondless water features", as in case study 18 (p. 301).

Table 19 Rough comparison between the 4 models of natural pools

Model	1 Bodies of standing water without technical installations	2 Bodies of water with surface flow	3 Bodies of running water with Technical Wetland filtration	4 Bodies of running water with Biofilm-accumulating Substrate Filter
Visual depth	▬▬▬

An infinity pool offers the opportunity to swim with a view.

6
A STEP-BY-STEP CONSTRUCTION GUIDE

Constructing a natural pool brings together a wide range of landscaping disciplines. Excavation is the obvious one, but you will also need sealing works, masonry, plumbing, planting and an understanding of limnology and water filtration to build a pool that will last. The hard landscaping of a pool requires various techniques that are essentially the same as those used to make a traditional garden pond. We recommend you consult specialist sources for detailed information on wooden decks, stone work in and around the water body, lighting etc. and in this chapter we will concentrate on the specific features of natural swimming pools.

Successful pool construction requires proper planning. We estimate that 80% of pool problems could be prevented by careful planning, which should include selecting a design style, choosing the best location in the garden, and working out pool size and filtration type. The amount of use the pool will get and the quality of the fill-up water also influence the choice of pool model and filter configuration.

Drawing sketches that include details and sections will help you determine construction materials and dimensions of the plumbing, substrates and other constituents.

Creating a natural pool has three stages:

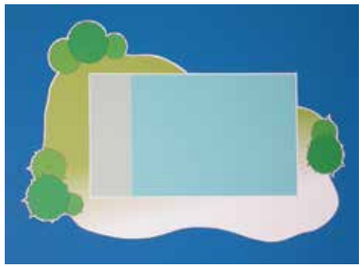
- Planning
- Choosing materials and technical equipment
- Practical construction work

PLANNING THE POOL

Professional landscape architects are used to drawing plans on paper or with a CAD program. DIY enthusiasts may find it simpler to plan directly on site but should at least draw a simple sketch of the pool. Your preliminary work should include five stages:

- **Draw a conceptual design** that determines the character, location, size and partitioning of the pool.

- **Assess water quality** as a precondition for the filtering equipment.
- **Choose a pool model and filtering equipment**.
- **Review legal considerations** and if necessary apply for building permission.
- **Finalize the design** in terms of concrete shape, depths and zoning as well as adjacent decks, paths, planting areas.



Conceptual design draft in formal style
Right The simple geometric lines of the pool are in tune with the paving and house façade and complement the upright form of the cypress grass (*Cyperus longus*) in the foreground.

Conceptual design draft in naturalistic style
Right From the wooden deck your gaze travels into the distance.

DESIGN CONCEPT

A fundamental decision has to be made between two main design types: the formal option, which has a clear geometric form and the naturalistic style, which employs more organic shapes. Your choice should enable the pool to integrate well into the overall garden design.

For the naturalistic option, site it at the lowest point in your garden to create the most natural impression. If this can't be achieved, then hide the slope with big rocks, tall plants, a mound or a wall.

An architectural design for a formal garden need not be sited at the garden's lowest point. In fact, a geometric pool raised above its surroundings can be impressive, particularly if it is defined by a sharp edge to make an infinity pool.

Aspect and light conditions are an important factor when choosing a location. A sunny site will raise the water temperature more quickly than a shady one. Cooler water and less sun radiation help avoid algae so it is best if at least part of the pool is in shade or semi-shade, particularly planted areas.

Further points to consider when siting a pool:

- The conditions of the subsurface determine how difficult the excavation will be and the equipment required.
- Find out if existing cables and pipes may interfere with excavation, and if so make sure there is an adequate safety distance between them and the pool site.
- If ground water seeps into the excavation from a higher level, it must be pumped out more or less permanently during construction work (see case study 6). It is best to insert a massive waterproof foundation and walling for the pool. A pond liner sealing can be inserted additionally to be on the safe side.
- Don't forget to check the view from indoors. A well-planned view from the house to the water feature affords year-round enjoyment.

Sizing and partitioning

The swimming area should cover at least 3 × 6m^2 with a depth of at least 1.8 m. A depth of 2 m or even 2.5 m will ensure less stirring up of the sediment. Depending on your pool model, sufficient space for the regeneration area also needs to be allocated. Of course smaller pools still provide enjoyment, but conditions will be less good for swimming unless they are supplemented by a counter-current system (see case study 10).

A naturalistic pool of model 1 or 2 should extend to at least 6 × 9 m or, better still, 8 × 11 m to allow enough room for the regeneration area.

Before you finalize your partitioning (siting of regeneration and swimming areas; p. 77) you should work out your pool model and filtering requirements by following the subsequent steps.

Sketch of a natural pool including adjacent garden areas.

ASSESS THE AVAILABLE WATER QUALITY

Keeping in mind P- or C-limitation as the two alternatives to prevent algae growth (p. 216), there are three possibilities for fill-up and refill water:

- **Water from a local well** is the most cost-effective source. Its quality will depend on individual geological and hydrological conditions. In limestone areas, hard water must be expected. It's possible too that certain nutrients will reach critical concentrations; bear in mind in particular the phosphorus content, which may require the use of a special P-filter (p. 74). In some regions, very high iron or manganese concentrations may result in a stubborn brown coating or deposit on all surfaces. In this case, using mains water or rainwater is preferable.
- **Mains water** is often hard and may have a pH that is too high for proper C-limitation, but is favourable to P-limitation. Problems with an over-concentration of phosphorus can be extreme when it is added to the local drinking water to reduce corrosion to plumbing. In the UK, the phosphorus content of mains water can rise above 2 mg P_{tot} per litre, 200 times more than the recommended quantity for P-limitation. In this case, a special phosphorus filter for pretreating the fill-up water is indispensable (p. 74; see case studies 11-13). Problems with too much nitrate or other elements are rare in most regions.
- **Rainwater** from a cistern guarantees low levels of phosphorus and other nutrients, low pH and soft water. This can work well if a carbon-limitation approach is envisaged. Near to industrial areas or big cities, pollution may cause problems. For P-limited pools, the hardness can be increased by proper filter substrates (pp. 50, 62).

A detailed chemical analysis of mains water can be requested from the supplier. Water from a well must be analysed by a qualified laboratory and we recommend this for rainwater collected near to industrial sites or big cities, too.

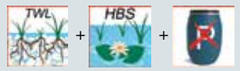
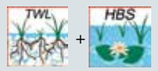
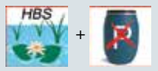
The most important chemical characteristics are pH value, water hardness and concentration of total dissolved phosphorus (P_{tot}). Additional information about other nutrients, especially nitrogen, may help determine likely plant growth and enable you to choose an appropriate planting theme. But keep in mind the more intensive the filtration technique, the quicker the nitrogen content will decline to a meso- or even oligotrophic level. Observe the threshold values listed on p. 39 to assess the results of the water analysis.

Tests on bacteriological contamination (p. 223) are indispensable in public pools but rare in private facilities. If the well is close to a farm with livestock or composting this is recommended.

CHOOSE THE RIGHT POOL MODEL AND FILTERING EQUIPMENT

In chapter 5 we introduced the four principal models of natural pools as well as filtering systems. Your final choice will depend on your expectations in terms of water quality, how you intend to use it, your design and planting vision, and desired maintenance level. The following table may help you make the right choice.

Table 21 Recommended minimum levels of filter equipment and regeneration zones required based on your expectations of water quality and phosphorus levels of fill-up water. If P_{tot} exceeds 0.5 mg/l an efficient phosphorus-filter is recommended in principle.

Desired clarity of the pool water	Fill-up water quality P_{tot} > 0.05 mg/l	Fill-up water quality* P_{tot} < 0.05 mg/l
Absolutely clear and mostly free from filamentous algae	Model 4 BSF >30% + P-filter Or: Model 3 TWL+HBS >40% + P-filter  	Model 4 BSF >25% Model 3 TWL+HBS >40%
Very clear but some filamentous algae in the marginal zones acceptable	Model 4 BSF >30% Or: Model 3 TWL+HBS >40%  Or: Model 2 HBS >60% + P-filter  	Model 3 TWL+HBS >30% Model 2 HBS >60%

Percentage value: share of regeneration area in total area

The advice in Table 21 must of course be adjusted in relation to the particular fill-up requirements of each pool. Less fill-up water will mean less phosphorus and a correspondingly smaller filter area. If the evapotranspiration rate is not too high, pre-treating the fill-up water, e.g. with a Rock Garden Filter, may be enough to achieve satisfactory water quality. If you

Table 21 continued

Desired clarity of the pool water	Fill-up water quality P_{tot} > 0.05 mg/l	Fill-up water quality* P_{tot} < 0.05 mg/l
Slight cloudiness acceptable (visual depth > 1.5 m)	Model 2 HBS >60% Or: Model 1 HBS >75% 	Model 2 HBS >50% Model 1 HBS > 60%
Moderate cloudiness acceptable (visual depth > 1 m)	Model 2 HBS >50% Or: Model 1 HBS >70% 	Model 2 HBS >40% Model 1: HBS>60%

Percentage value: share of regeneration area in total area

*relevant guidelines require a maximum of 0.035 mg/l in the fill-up water (Table 5, p. 39). We recommend these configurations to be sufficient to bring even 0.05 mg/l of P_{tot} down to the required level of 0.01 mg/l assuming average levels of refilling.

are unsure whether a P-filter unit is necessary, you should allow enough space in the pump-house to upgrade it later if needed.

Eventually you may want to extend the pool surrounds into a wetland theme that suits your garden. You may want to include additional ponds, streams or fountains, and these should be included in the planning process from the outset.

For precise dimensions of the regeneration area, the installed filter zones, and the partitioning (model A, B or C) follow the explanations in chapters 4 and 5.

Important considerations:

- Table 21 lists minimum sizes for the filtering/regeneration areas of DIY pools. To be safe, try to exceed the listed percentages.

- If a much reduced filter area is desired, choose a BSF technology. In this case we recommend you do not rely on your own calculations but engage a specialist or follow the guidelines of FLL (2017) at least to determine the filtration area including substrates, pump and plumbing.
- Consider not just the design value of planted filters but also their need to be exposed to light. An unplanted filter (BSF) can be hidden under a deck to make better use of available space.
- The location of the filter area (TWL and BSF) must be coordinated with space and position of the pump-house and its pipes and cables.
- To find out how many pumps are needed and how to configure the plumbing, make a decision not only on the filtering type but also the percolation direction for TWLs or BSFs (pp. 51, 66). You will also need to factor in any future installations of waterfalls, fountains, streams etc.
- Bottom drains are usual in traditional pools but we do not recommend them for natural pools. It is more reliable to regularly vacuum the floor of the swimming area with a pool robot or a special pump (p. 204).
- All models with a water current (models 2, 3 and 4) need one or more skimmers. At least one skimmer should be placed on the pool edge opposite the prevailing wind direction (mainly west–east). Wall-integrated skimmers are recommended primarily for swimming pools that are completely separate from the regeneration area (model C).
- Model B and C pools may be connected to regeneration ponds located below the swimming basin. In these cases, use an overflow gutter instead of a skimmer (see case study 16).
- Model 1 natural pools should provide an extensive planted regeneration area facing the prevailing wind direction (mainly west–east) to intercept floating pollutants.
- The next step is to choose the construction type.

REVIEW LEGAL REQUIREMENTS

In many countries large excavations, and ponds and pools in particular, are regulated by local construction law. Your local authority will be able to tell you about the building application process. Information about your intended source of fill-up water may be required. We recommend you gather the necessary information before finalizing the planning in order to pre-empt bureaucratic hurdles.

FINAL DESIGN

Now your sketches from step 1 can be completed. Once you have worked out the pool model and its regeneration requirements, you will be able to fix the depths of all zones. If you decide to insert a prefabricated basin (case study 10), the pool's design is largely fixed, but even here it makes sense to sketch out the location and related decks, paths, planting beds, pump-house etc.

Whatever your chosen sealing materials, you should next:

- Find a suitable place for an overflow at the deepest point of the liner's edge where surplus water (for example, after heavy rainfall) can seep away. This place should face away from buildings.
- Determine the depths of swimming area and regeneration areas. When calculating the latter, take into account the necessary depth of filtering or planting substrates and the desired water depth above the substrate surface.
- Decide if and where you want to add streams, waterfalls or other features.
- Include an appropriate network of paths to access and enjoy the pool, and permit maintenance.
- Locate the pump-house or chambers for filter equipment.
- Work out what light fittings (underwater spotlights etc.) you want and calculate the necessary cabling.

Decks, bridges and access to the pool

So that you can enjoy your pool without always getting wet, plan for at least one patio or deck directly adjacent to the water (see case studies 3–5, 8–12 and 14) or even a bridge which crosses the pool at a suitable position (case studies 6 and 7). For a family of four, make sure at least a 20 m^2 deck is available. Decks look attractive and provide an opportunity for poolside relaxation. Carefully consider their exposure to sun or shade and make sure it fits your personal preferences for sunbathing or relaxing.

A wooden deck can also cover the pump-house or even a non-planted filter zone (BSF). Locating a pool beside a terrace, path or deck allows you to hide the capillary barrier under stone flags, tiles or timber elements which can protrude a few centimetres above the water. Be aware, that protrusions of more than 10 cm directly above swimming areas can be dangerous for divers surfacing beneath them.

Not all users will be able to enter the swimming area by jumping from

Accessing the swimming area
Top row, left to right
Sandy beach; steps under the liner; concrete-fixed stone steps above the liner.
Bottom row, left to right
Stone steps interspersed with gravel; wooden steps; wooden ladder; stainless steel ladder.

CAUTION
All metal elements must be earthed. Don't use types of flooring that are slippery, sharp-edged or excessively rough. Even those that initially provide grip will soon be covered in a layer of biofilm and become extremely slippery. Materials such as wooden boards and mats that are prone to becoming slippery by accumulating biofilm layers should not be used on any surface which could be stepped on. Steps should be enclosed by walls or handrails so that there are no sharp edges.

the deck or leave it by pulling themselves out. Wooden or metal ladders can easily be fitted later, but steps must be planned in advance. It will of course reduce the swimming area and spacious steps should only be included if the facility provides adequate space for swimming. A clever solution for steps in a small pool is shown in case study 4. Large swimming areas can also accommodate a shallow beach zone for access.

Steps can be built using concrete, stone or even wooden coping. In a shallow planting zone you can use stone blocks laid in a gravel bed. Choose a material with a non-slip surface and for disabled and elderly users, fix a stainless steel handrail firmly in a concrete bed.

Ladders can easily be constructed from durable wood (p. 112). Consider how far the ladder goes into the water as it may interfere with swimming and increase the risk of accidents. The durability of stainless steel ladders, familiar from traditional pools, makes them a better option than wooden ones.

Before introducing stainless steel elements, clean them to remove phosphorus-containing polishing compounds.

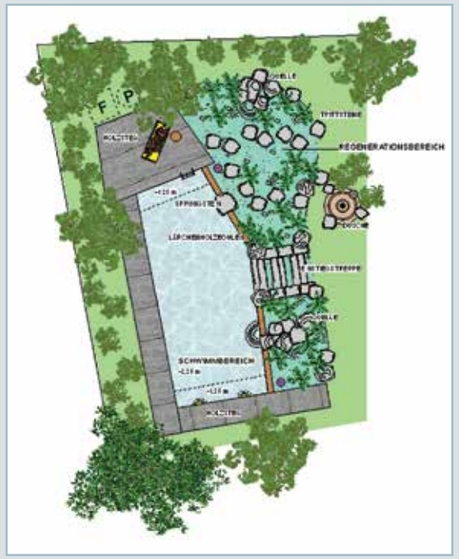
Final planning on site

Your sketches should be implemented directly on site. A flexible hosepipe can be used to outline the shape of your pool. Double-check the style, size and location with your design and the material lists. Check the site of the pool from different viewpoints in your garden and from your terrace, your windows and all other relevant points of interest. Don't hesitate to amend and improve the outline of your pool if necessary.

Once you are sure about the location and shape, insert wooden pegs to define the outline and water level. The spacing between these should not be more than 3 metres; curves may demand shorter distances. The marking out should be performed very accurately and identify the edge of the liner, the depth of the planting zones and the design of the surrounding garden space. Use a flexible hydrostatic hose balance or a surveyor's laser spirit level to determine and mark the water level of the pond onto the pegs – possibly consistently some centimetres higher than ground level – to make sure that the present topography allows an even water table. If the pegs withstand the excavation process they can be integrated in the alignment marking with a pond edge as shown and explained in photos (p. 107).

Once you have marked out the pool's shape and water level, use brightly coloured, highly visible spray paint to outline the shape (around the hose) on the ground.

Wooden deck with diving platform (demonstration pool, Woodhouse Landscaping Ltd., Cambridge, UK).



Design plans in formal style (left) and naturalistic style (above).
Design by N. Sobotta, D-Niedenstein.

MATERIALS

After marking out the pool, you should prepare a list of all the materials you will need. Filters, skimmers and substrates for regeneration areas were explained in chapter 4. Chapter 7 provides information on plants. In this section you will find information on sealing materials, stone, wood, pumps, pipes/plumbing and lighting technology. We concentrate on aspects that are specific to natural pools. Further reading on garden pond construction and garden features that use timber, stone, wood and lighting etc. will provide more ideas for constructing the pool environment; see the recommendations pages 304-310.

Installation of a prefabricated GRP basin: the wooden struts are necessary to prevent lateral distortion from the pressure of the concrete that fills the gap between excavation edge and pool wall.

The common formula to determine the necessary size of a liner is
Length = Length of the pool + 2 × depth + 1 m for the edge construction.
Width = Width of the pool + 2 × depth + 1 m

SEALING MATERIALS INCLUDING PROTECTION MEMBRANE AND EDGING

Sealing materials must have the following characteristics (Weixler, 2008):

- Impermeability to water, even along welding seams
- UV stability, frost resistance and longevity
- Root resistance
- Robustness for usage by swimmers and installation of boulders, decks, bridges etc.
- Freedom from harmful substances that could be released into the water

The tables (pp. 103-105) present tips to facilitate an appropriate choice for your pool sealing.

PVC liners are available in widths up to 8 m, EPDM up to 15 m. Several suppliers offer a made-to-measure service. The required size of the liner can be roughly estimated in advance if early ordering is necessary, but of course precise sizing is best determined during Step 3 of "Constructing a Natural Pool" (p. 127).

For the "wall on sealing" construction type, twice the depth of the adjacent regeneration areas must be added on top. But in this case a professional installer should be engaged and it may be best to leave the ordering of the liner to the specialist. However, if you order the liner before excavating the pool, your calculation should be generous enough to take all contingencies into account.

Table 22 **Main characteristics of different sealing materials**

Material	Characteristics and tips
PVC liner = polyvinyl chloride Case studies 1 and 3–6	• Most common material for natural pools • Suitable for all shapes and pool models • Requires a fleece underlay (specification: 500 g/m²) • Liner thickness should be at least 1.5 mm • Fabric reinforced types are very durable • Not totally UV resistant, should to be covered and sun protected • Available in individual shapes and varying colours (black, olive-green, bluish tones) • Bonded/welded joints should be used as little as possible; usually done with a hot-air gun • Heat-welding relatively easy • Cold-welding is possible with Tetrahydrofuran products: these use an invisible chemical, which is not healthy and environmentally harmful. Because of its gassy emissions it can only be used outdoors • Damage relatively easy to repair • Installation requires temperature of at least 10-15°C
EPDM = Ethylene Propylene Diene = Monomer (synthetic rubber) Case studies 9, 14, 15 and 17	• Very flexible and durable sealing • Generally considered ecologically harmless • Suitable for all shapes and pool models • Requires a fleece underlay (specification: 500 g/m²) • Liner thickness should be at least 1.2 mm • UV protection is less important • Can only be glued using a primer, special glue and adhesive tape • Long lifespan (40 years +) • Application is possible even at cool temperatures
TPO (≙ FPO) = Thermoplastic Polyolefines/ Flexible Polyolefines Case studies 12 and 13	• Very flexible and durable sealing • Originally developed as roofing membrane • Used in Europe in the 1980s and introduced in the US in 1992 • Very strong liner which is resistant to UV rays, ozone and chemicals • Can be heat-welded • Good for straight edges that are found on concrete rectangular swimming zones, giving a very nice finish; heavy duty • Less suitable for round-edged swimming zones as it is not elastic enough to fit corners and too rigid to fold, so you have to cut and weld overlaid pleats
Concrete Case studies 2, 16 and 17	• For formal shapes • Difficult to work with • Ice can cause it to rupture during severe frosts from ice expansion; an extensively planted marginal zone with shallow slopes may prevent this. • The wall should be at least 20 cm thick and reinforced with steel mesh • Use waterproof cement (hydraulic-, pozzolanic- or trass cements) to avoid lime leaching out. This can be improved by a supplementary specific sealant additive (p.111). • As a special construction in the case of high groundwater level, a water-resistant concrete vessel can be made to prevent water ingress. • A lean concrete is often used for constructing the frame of a swimming area above or under a plastic liner. In this case it has only to support stability and need not be waterproof

A short guide to welding PVC liners

Ideally, welding together the edges of the liner sheets should be done by a professional. For the untrained layperson it is best to order a prefabricated liner following the instructions in Step 3 of "Constructing a Natural Pool" (p. 127). In this book we can only provide a brief overview of welding techniques which will help you to decide if you feel able to undertake this task yourself.

There are three possibilities for welding PVC liners:

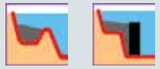
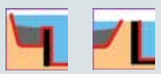
- Heat-welding with hot-air gun
- Cold-welding with solvent welding agent (Tetrahydrofuran)
- Adhesive bonding

In all cases a long, smooth, straight plank about 25 cm wide should be placed below the overlapping liner edges as abutment against which pressure can be applied. Rub the surfaces to be joined with a tissue dipped in PVC cleaner.

Heat-welding: Insert the tip of the hot-air gun between the surfaces of the overlapping liner edges and move it slowly along the seam so the two surfaces melt slightly. Immediately take a wooden or metal hand-roller

Above Heat-welding the PVC liner with hot-air gun and pressure roller.

Table 23 Comparison of sealing materials

	PVC Liner	EPDM	Pre-fabricated GRP basins	Concrete	Clay	Conclusion/tips
Handling for construction types “no wall” or “wall on sealing” 	Easy if pre-welded (folds may be covered with stones or other set-ups)	Easy, but welding requires experience	Not relevant	Not relevant	Recommended with limitations	For pools with “no wall” and “wall on sealing”, PVC and EPDM liners are the most common choices
Handling for construction type “wall under sealing” or “separate pool” 	Welding to ensure the liner fits closely to the basin should be performed by a specialist	Welding to ensure the liner fits closely to the basin should be performed by a specialist	Easy to manage with the correct building equipment	Specialist contractors required for separate swimming pools in formal shapes	Not recommended	Professional support is highly recommended for sealing
Tolerance to changing water level	Tolerant	Tolerant	Tolerant	Tolerant, maybe visually unsatisfactory	Not tolerant: desiccating sections will become cracked	Install a fixed overflow on one ledge
Time requirement for installation per 80 m³ pool	20–40 hrs	30–50 hrs	Fast: 8 hours (slow if GRP is applied on site)	40 hrs	40–50 hrs	Small pools can be built quickly using big prefabricated GRP basins
Tolerance of the sealing material to damage	Moderately sensitive: its flexibility and elasticity can withstand only minor pressure from sharp stones	Very good; flexibility and elasticity provides high tolerance	Tolerant and moderately flexible. Resistant to frost expansion. Possible damage from strong impact	Tolerant but inflexible. Eventually damage by frost	Damage can be fixed by replenishing the malleable clay	Most common materials for self-made private facilities is PVC, but currently also EPDM
Price per m² of a high quality material	£7.40-£9.30 (1.5 mm)	£12.60-£17.30 (1.5 mm)	£50 for basic configurations and £80-£100 for high end or custom designs	£65	£30-£50	Prices for liners which amount to 3–4 times the pool’s base area

(as used for wallpapering) and quickly roll it backwards and forwards, pressing the two liner surfaces against the plank and connecting them tightly. Adjust the hot-air gun precisely to achieve a proper degree of melting without blistering.

Cold-welding with the solvent-welding agent Tetrahydrofuran demands precautions as it is highly inflammable, harmful to health and caustic. Refrain from using it near an open flame, do not breathe in the gases and avoid contact with skin and eyes. Work only with small amounts of the agent in a small bowl, which of course must not be made of PVC. Apply the paste thinly with a flat brush onto the lower liner and let it dry for about 10 minutes. Then press the upper layer firmly onto the lower one. To increase contact, you can use an upper plank and clamp them. This will increase the quality of welding.

Adhesive bonding does not melt the liner surfaces together but joins them with an adhesive glue. We recommend "Innotec Adheasal" for repairing damage as it can even be used underwater and on less than perfectly clean surfaces.

Test the liner seams to make sure you have a strong bond: move your finger along them to locate any unevenness. If you do, these patches must be treated again, for example a layer of adhesive glue can be applied on top of the problem spots or you can weld a patch onto it. If possible, turn the liner to fix the underside of the seam too.

Above A solvent-welding agent is applied along the outer edge of the welded seam as additional security.

Above and right Avoid putting pipes through the liner as far as possible. If necessary, hard PVC pipes with flanges can be screwed or welded onto the liner.

Protection fleeces

To protect the liner from damage, a special fleece is used as an underlay. Disused carpets are also suitable, provided they are resistant to rotting and are environmentally friendly (see case study 14). Professional membranes are PES (Polyethersulfone) or PP (Polypropylene) fleeces with at least 150 g/m², ideally 300 g/m² or even 800 g/m² (the weight defines the material thickness). They are also suitable for covering the liner in setups that involve substrate, floor coverings, walls etc.

Edging of the pool

To fix and stabilize the liner at the edge of the pool, use either edging stones or special flexible plastic (PE) edge bandings. The former are set on a shallow concrete foundation with back support. The latter can be fixed on wooden pegs, which may rot after the liner is pulled over the banding, and secured with coarse gravel from outside. In formal pools in particular, the liner overlap can also be covered with stone flags or timber constructions. However you choose to finish the edge of a pool, make sure you include a capillary barrier to prevent water loss through absorption by the adjacent soil.

Above, both The PE pond edge is screwed onto wooden pegs which are driven into the ground 0.6–1 m apart. The edge is installed after the excavation and marks the correct heights and substitutes a batter board.

Above The alpine garden theme starts in the background rockery and is continued with rounded boulders into the natural pool. Continuity is achieved through the whole garden by the consistent appearance of the stone features (private pool, Canton of Bern, Switzerland).

Above A mortared natural stone wall encloses the swimming area.
Below This mortared limestone wall incorporates five water outlets. Several protruding stones make the waterfall splash impressively.

STONE AND GRAVEL CONSTRUCTIONS

Stone and gravel are the most important materials for pool design and construction.

As a general rule, avoid sharp edges in the swimming area and slippery surfaces that are shallow enough to be walked on. If you live in an area prone to frosts, use frost-proof materials. Porous and water-absorbent stones can easily be damaged by even light frosts.

All materials that are in permanent contact with the water must contain only very low levels of potentially dissoluble phosphorus. If C-limitation is your goal, do not use material that contains carbonate and try to use as few cement-based products as possible. By contrast, in P-limitation systems, carbonates are beneficial.

Natural stones

Unfortunately, building material from local quarries in developed countries is often much more expensive than imported natural stone. For a successful design, avoid combining different types of stone in one pool. Choose one stone for both the water body and adjacent garden spaces.

To minimize transfer of minerals into the water, select hard stone over soft. Very porous materials may be beneficial as substrate in Biofilm-accumulating Substrate Filters, but not as construction or design material. Water can easily leach substances from porous stone and slippery biofilm layers can grow on its surfaces.

Uses for natural stone in pools:

- **Walls** can enclose the swimming area in "wall on sealing" construction types. If constructed as a dry stone wall, the structural load-bearing capacity must be carefully considered. A rounded design as in case study 4 is a good solution. A mortared wall guarantees stability but note particular requirements for cement (p. 110).
- **Walls outside of the swimming area** work as dry stone constructions and can even have planted crevices if constructed for design effect only. Mortared walls can support diving boards, waterfalls, gargoyles, flower tubs and sculptures (see case studies 10 and 16).
- **Stone flags** can be used to cover the base of the swimming area or steps (see case studies 7, 12, 13 and 16). Polygonal flags must be laid in waterproof mortar (from pozzolanic-, trass- or hydraulic cement) or a grout bed to provide an even surface without risk of injury. Uniform rectangular flags can be set on a gravel bed (with 1–5 mm grain size).
- **Stepping stones through the regeneration areas** can be set on gravel beds if there is a stable foundation.
- **Block steps to enter the swimming area** must be safe to avoid accidents. It is best to use sawn stone steps with sufficient grip and even dimensions. Rough quarry stones may require a handrail.
- **Boulders** as design elements can be placed singly (for example, see case study 17), as a diving platform, or in groups to create naturalistic effects (case study 18).
- **Waterfalls and fountains** are often built into natural or semi-natural stone.
- **Gravel** can be broken or rounded. As substrate for planting, grain sizes of 1–8 mm are usual. Sizes of 1–32 mm are appropriate for filters

Left The transition from regeneration zone (left) to the swimming area can be bridged via heavy natural stones that have an evenly broken surface (see case study 1).
Right Millstones are popular to use as fountains.

Left Constructing steps down to the swimming area. Rhyolite polygonal flags are laid into trass cement mortar (case study 7).

Left These steps made of lightly processed natural stone blocks require special care from the user. A stainless steel handrail provides the necessary safety. The deeper areas of the swimming zone are enclosed by durable gravel-filled pond-sacks.

Above Rounded boulders allow for spot planting in basins.
Below Gravel and pebbles of various sizes add variety to the floor of a regeneration zone.

Pond-sacks are made of durable fleece. Once filled with gravel, close the opening by folding the overlapping fabric downward. Once positioned they are secured by their own weight.

(see chapter 4). As a floor surface, even larger sizes can be interesting for design purposes and are easier to maintain in terms of removing sediment

- **Filling material for pond-sacks** to stabilize the edges of regeneration zones can be coarse sand or gravel in grain sizes up to 8 mm (see case study 14).

Concrete stones

Invisible substructures that are not in contact with the pool water generally use concrete blocks. In "wall under sealing" constructions, concrete shuttering blocks are often used to define the swimming area.

Within the water body, natural stones are preferable because concrete leaches minerals into the water more readily.

STONE-BONDING AGENTS

Cement, which is the core ingredient of concrete or mortar, is the most commonly used bonding agent for any stone work.

Concrete is a mixture of cement, water and supporting additives (sand, gravel). Concrete with sand/gravel in a grain size of less than 4 mm is referred to as "cement mortar".

In natural pools, only high-quality concrete with the designation "C20/25" or higher should be used. The numbers 20/25 describe the pressure resistance after 28 days' setting. Concrete for high structural load-bearing capacity must not be mixed manually on site. If large amounts are required, for example to fill shuttering block walls (p. 126) or construct a floor, use concrete silos or order precast concrete daily from a ready-mix factory. Of course small amounts of mortar for binding natural stone constructions can be mixed at home in the ratio cement:sand (1–2 mm) = 1:3. Add water carefully while mixing until the consistency of creamy mashed potato is reached.

Concrete or cement mortar should be used carefully because it leaches lime and minerals. Even when mortar is used outside the pool but is in regular contact with water, problems with lime efflorescence on surfaces that are adjacent to the set mortar can occur.

To guarantee a firm set, all cement-bound features should be kept out of contact with permanent bodies of water for at least one, and ideally four weeks, until complete hardening is achieved. A firm set is also possible underwater, but lime efflorescence will increase.

During the building process, concrete surfaces should not dry out too quickly. For a good set, the right amount of water is necessary, so new concrete surfaces that are exposed to sunlight should be covered to reduce evaporation or sprayed with water, especially on hot summer days.

Several compounds, agents and coatings are recommended for use in natural pools:

- **Puzzolanic- or Trass cement** is a special product which contains volcanic "puzzolan- /trass-" powder. It should be used for all applications of concrete and mortar in and around natural pools instead of normal Portland cement because it because it has 30% less lime and prevents prevents lime efflorescence. It takes longer to set, but the stability, elasticity, resilience and weather-resistance exceeds normal Portland cement products.
- **Waterproof agents** such as Asolin DMK can be added to the concrete or mortar for underwater constructions. Even if the concrete is not intended to seal the pool, this agent is beneficial as it reduces leaching of lime or minerals into the water.
- **Waterproofing sealing slurries** are applied to the surface of underwater concrete constructions to prevent the leaching of lime or any minerals. Such a coating is particularly recommended for concrete floors or walls in the swimming area. Possible products are Schomburg-Aquafin or PCI-Barraseal®.
- **Special stone adhesives** can be effective for bonding stones, tiles or slabs to substructures, depending on the particular chemical character of the materials to be joined.
- **Epoxy resin adhesives** are an expensive solution for fixing stones or gravel on the sealing surface. Epoxy resin products need to be mixed with a hardening agent. Once mixed their applicability can range between 10 minutes and a few hours depending on the particular product, temperature and consistency. Contact with pool water must not happen before setting is complete, normally within 48 hours. Surfaces may need roughening or treating with a primer before applying the epoxy resin.

WOODEN CONSTRUCTIONS

Wooden decks, bridges and entrances look very attractive and inviting. They integrate well into both naturalistic and more formal designs. Wooden surfaces do not heat up strongly if exposed to sun and it is

Natural stone masonry with white lime efflorescence from the cement mortar.

The stones and gravel at this pond margin are fixed with epoxy resin, which provides a solid resilient bond without risk of lime leaching.

CAUTION

Take care that any chosen agents are certified for use in drinking water.

enjoyable to sit, lay or walk barefoot on them. But be aware that timber, if poorly finished, may provide risks in the form of splinters or slippery surfaces when wet.

Mostly solid timber is used, which is available in various durability grades. For outdoor construction, a wood moisture of 12–18% is considered optimal. A higher moisture level increases shrinkage and the risk of cracking.

Table 24 **Durability classes of diverse wood types. The "life expectancy" values are only rough guides. They refer to the highest "hazard class 4" (DIN 68800), for permanent contact with moist soil. In dry environments or completely submerged it will be much more durable.**

Durability class	Definition according to DIN EN 350-2	Life expectancy in nemoral climate	Life expectancy in tropical climate	Wood species
1	Very durable	>25 years	>15 years	Billinga, doussie, kambala, teak (Burma), robinia, cumaru, ipe, massaranduba (*Manilkara bidentata*)
2	Durable	15–25 years	10–15 years	Bongossi, cambala, sipo, bangkirai (*Shorea laevis*), plantation teak, low-quality robinia, western red cedar, European oak, plantation massaranduba
3	Moderately durable	10–15 years	5–10 years	Sapeli, sipo, bangkirai types, low-quality teak, walnut, European Douglas fir, European pine, larch
4	Less durable	5–10 years	2–5 years	Low-quality bangkirai, hemlock (*Tsuga*), fir (*Abies*, *Picea*)
5	Not durable	<5 years	<2 years	Beech, maple, European birch, ash, alder

Derived from Kay-Pannier, 2015 & Baumhauer & Schmidt, 2008

Purchase only tropical woods with **"FSC" label**, which guarantees their environmentally friendly origin.

- **Pressure-impregnated wood** is much more durable, but use it only out of the water and look out for potentially problematic ingredients such as boron salts (p. 210). Some tropical woods such as bangkirai exude harmful elements if it is not well-seasoned. Bangkirai also tends to black discoloration if it reacts with zinc-coated metals, so use stainless steel screws. But often it is not genuine *Shorea* wood which is traded as bangkirai, so in practice this brand name includes different species.
- **Wood Polymer Composites** (WPC) are a newer compound material made from wood powder, plastics and specific additives. Contrary to initial expectations, damage from UV radiation, moisture and fungi have been observed (Stark & Matuana, 2003). For constructions without permanent contact to water it may be a suitably durable material, but its visual appearance is more reminiscent of sterile plastic than living timber.

For all timber constructions above water level, consider the following wood protection measures (Baumhauer & Schmidt, 2008):

- A 1–1.5% falling gradient to the surface of decks and bridges allows rain water to run off quickly.
- End-grain faces and cutting edges should be properly sanded. If exposed to rain, a cover cap or annual treatment with a protective wax is recommended.
- Pre-drilling of screw holes and countersinking screw heads create smooth surfaces, which are less susceptible to decay.
- Boards of timber coverings must be laid with about 5 mm gaps between them to guarantee sufficient air circulation long term and prevent damage through swelling in damp periods. All timber constructions should allow some mm distance from adjacent elements, these are known as "shadow gaps".
- Insert spacers (plastic washers) between construction timber and supporting points of the substructure to prevent trapping moisture between close-fitting surfaces.

Boards with grooved surfaces may reduce the risk of slips and falls, but splinters form more easily and the grooves are more susceptible to decay. The recommended standard dimension for boards for decks and terraces is 140 mm wide and at least 25 mm thick. For the substructure, use beams of 45 × 50 (or 70) mm; for bridges, greater strength (100 × 100 mm) is necessary.

Bridgeheads and deck-supporting structures are usually placed on galvanized steel anchors fixed in concrete spot footings, to avoid any contact of the beam substructure with soil moisture. The board cladding is mounted at right angles onto the beam substructure. Depending on the thickness of the decking boards, the supporting beams should be placed parallel at a distance of 40–90 cm from each other (see table below); too widely spaced beams may cause spring-back when the decking boards are stepped on.

Above Wooden deck constructed from massaranduba boards and understructure beams, which are mounted on 120 × 120 mm main beams fixed on galvanized steel anchors. The anchors' regularly spaced foundations are poured in shuttering blocks as spot footings.
Left The boards are mounted with gaps of a few mm to allow expansion and contraction.

Table 25 **Recommended distances of substructure beams and screw sizes**

Thickness of the decking boards (mm)	Distance of substructure beams (cm)	Screw size (mm)
25	40–60	5×50 / 5×60
28	60–80	6×80 / 6×90
45	70–90	6×90 / 6×120
60	90–110	6×120 / 6×160

Baumhauer & Schmidt, 2008

Use two stainless steel screws for each joint between board and substructure beam. The screws' length must be at least twice the thickness of the boards in view of the measures for constructional wood protection listed above.

The substructure of decks protruding above the water can be cladded with boarding. If a diving board is placed on a deck or bridge, the foundation must be anchored particularly firmly to avoid any displacement through use.

CAUTION
Be careful with cantilevered constructions above the swimming area; they can cause danger if they are too close to the water level. If a diver surfaces directly under such a construction, it may inhibit breathing, which could trigger a panic reaction. Either keep an adequate distance between water surface and the construction above or make the area inaccessible, for example through vertical boarding.

Submerged wooden constructions

Particularly in underwater use, timber should not be treated with any potentially harmful compounds. Intrinsic tannic acids and other ingredients can also leach into the water, but without significant strain on the water quality, according to current knowledge (Baumhauer & Schmidt, 2008).

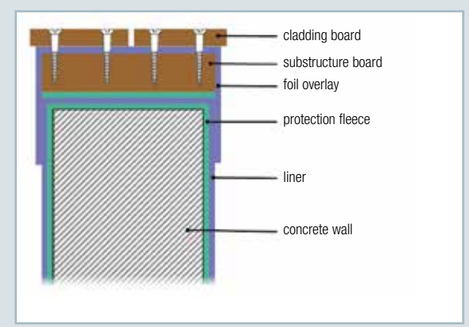
Timber parts just above water surface are the fastest to rot because of an oxygen–moisture ratio which is optimal for decomposing microorganisms. If you have wooden steps into the pool, test them regularly for resilience.

If the framework of the swimming area in a "wall on sealing" pool is built from timber, it will be much better protected from rotting, because it is completely and permanently submerged. Often larch is used for beams with a thickness of at least 14 cm. They last a very long time but in dry conditions they will acquire buoyancy. A proper way of anchoring the wooden framework is to brace it outward with posts embedded in the gravel of the adjacent filter or planting zones. After several weeks the structure will be saturated with water and no longer susceptible to buoyancy.

Above left Construction of a timber framework surrounding the swimming area. The larch beams are connected at an angle with vertically inserted hardwood dowels. An EPDM liner behind the framework will hold the substrate in the regeneration area; its pressure and interlocking into the gaps between beams stabilizes the timber wall sufficiently against buoyancy. This system was invented by the landscaping company Naturgarten-Martin Mikulitsch, Vienna, Austria (patent in Austria and Switzerland till 2008).
Above The deck protrudes above the water, supported by stainless steel posts, mounted on the timber wall of the swimming area. Wooden posts are prone to rotting in the transition between air and water (see case study 9).

Most tropical hardwoods are heavier than water, so there is no buoyancy problem, but their hardness makes them difficult to handle.

Covering swimming area walls in "wall-under-sealing" constructions with timber boards is very popular, as in case study 5. Often they are retained by boulders placed on the edges of the boards. Some constructors recommend fixing the boards onto a substructure which is screwed through the liner and sealing the holes created with generous amounts of adhesive bonding agent such as Innotec Adheasal. A less risky way is to fix a substructure board with a foil strip welded onto the liner as shown below. Now the cladding boards can be screwed above without any risk.



Fixing timber cladding onto an underwater wall.

Larch boards are fixed in accordance with the drawing. For additional stability, a heavy boulder is placed at the edge.

PUMPS AND PLUMBING

Regulating the water circulation and establishing the correct dimensions for pumps and pipes are vital to successfully managing a natural pool. Determine how many pumps are necessary to guarantee the effective operation of all filters, skimmers and additional features. The vast variety of possibilities may make consulting a specialist company worthwhile.

How many pumps?

In TWL- and BSF-systems (models 3 and 4) top-down percolation requires two pumps: one for drawing the water through the drainage pipes in the filter and returning it through jets, fountains or other devices; the second pump is required to clear the water surface via the skimmer (see case study 11–14). BSF systems require percolation to run continuously, whereas the skimmer need only run for a few hours per day.

Bottom-up percolation can be achieved with only one pump drawing the water directly from the skimmer to the filter (see case study 10). However, even in these cases a second pump may be desirable for operating additional water features or a counter-current swimming device. Our case studies show a representative spectrum of pump configurations.

Pump types

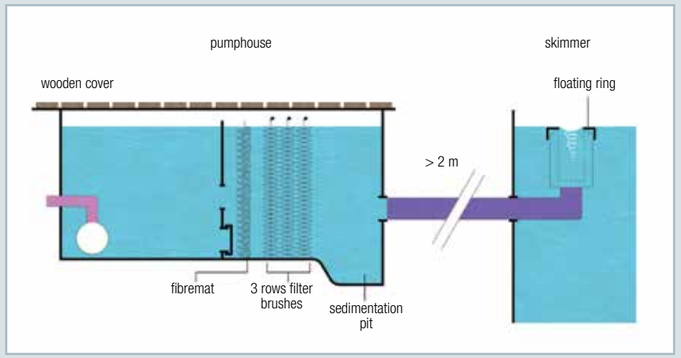
Underwater pumps need to be connected with a single pipe, the pressure line. They suck the surrounding water into the pump-house, which is replenished by pressureless flow.

Advantages of underwater pumps:

- They are much quieter than dry-installed pumps.
- The pump and the plumbing are located at a frost-free depth. So the pump can remain switched off in the pump-house during winter even in cool climates.
- The cooling of the pump by the surrounding water is more efficient than air-cooling.
- Generally they have lower energy requirements.
- The volume flow through the pressure pipe is infinitely variable by means of a valve which diverts surplus water into a bypass nozzle. It is easy to adjust using an extension.

Table 26 **Basic types of pumps for natural pools**

Pump type	Specifications	Used in case studies
Low-voltage underwater pumps which can be installed in the pool	12v; 50w; max. delivery head: 4 m, max. volume flow: 60–200 l/min.	2, 4, 12, 13
Underwater pumps which need to be installed in an external submerged pump-house	Pumps require 230v, 50w, max delivery head 3–5.5 m; max. volume flow 60–350 l/min. Factory-made cable length must be at least 10 m.	7, 11, 12
Dry-installed pumps in external pump-house	Max. delivery head 15–25 m, volume flow 150 l/min to 800 l/min. The pump with the best price/features can be chosen from the wide variety available	3, 5, 9, 15, 16
Variable-speed dry-installed pumps in external pump-house	Pump features that can be regulated according to the need of the skimmers, pool size and filter system. Max. delivery head 15–25 m; volume flow 150 l/min–800l/min	10, 14, 17
Solar underwater pumps for small fountains	Not suitable to run filters 17w, max. delivery head 3 m. Max. volume flow 25 l/min. Small fountains not higher than 60 cm spray. Different jets available	



Section through the underwater pump chamber and skimmer.

CAUTION

Pump chambers for underwater pumps must maintain a minimum distance of 2 m from the pool's body of water. Reducing or manipulating the cable of high-voltage underwater pumps must not be done: underwater short-circuits cause risk of death.

Right GRP pump-house for an underwater pump constructed on site by Kirchner Garten und Teich, Heidenrod. The pre-chamber in front is filled with brush filter and filter mat. The spacious chamber behind can optionally be used for sacks with phosphorus filter granulate, zeolite etc. The pump is located rear-right.

Calculating the pump configuration

Two parameters are relevant to calculate the configuration of a pump: Desired volume flow and effective delivery height.

- The **volume flow** indicates the amount of water which is transported in a certain time unit. A usual range to calculate the water flow drawn through a skimmer is around 6 m^3/hr (100 l/min). Pumps with 6–15 m^3/hr volume flow are often used to operate Technical Wetland or Biofilm-accumulating Substrate Filters. To adjust the filter percolation intensity, a valve is installed in the pump-house to divert surplus water into a bypass pipe (p. 65). This pipe can feed a water feature which aligns the water flow to the skimmer.
- The delivery head specifies the difference between the level of the water with the suction plumbing and the final outlet of the pressure pipe. This describes the pressure loss through gravity: one metre delivery head ≙ 0.1 bar.
- The pump curve (below) specifies each individual pump type, showing their dependence on volume flow and delivery head.

In addition to the pure difference in height, the pressure loss caused by the plumbing, including all curves and fittings, must also be considered. It can be expressed as an equivalent height to find out the "effective delivery head". To calculate this exactly, computer programs can be used, such as www.pressure-drop.com/Online-Calculator/.

Table 27 **Typical pressure loss table for a 20 m PVC pipe transporting a volume flow of 10m³/hr (166 l/min)**

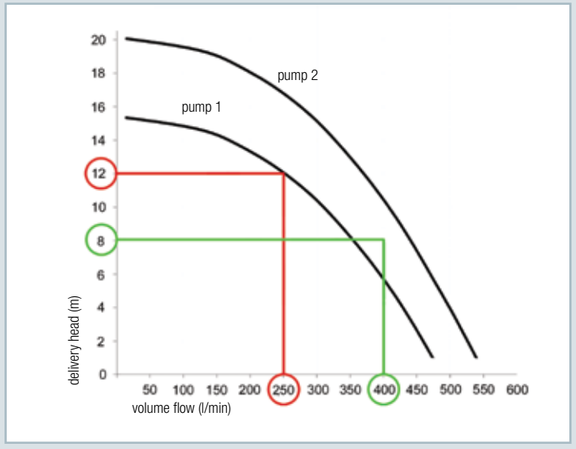
Inner width of the pipe (mm)	(inches)	Pressure loss (bar)	Equivalent delivery head (m)
25	1	2.84	28
40	1.5	0.26	2.6
50	2	0.09	0.9
63	2.5	0.03	0.3
90	3.5	0.005	0.05

Baumhauer & Schmidt, 2008

The pressure loss table above makes clear that pipes should be no thinner than 50 mm. A pipe width of > 50 mm means roughly 1 m equivalent delivery head for a 20 m pipe length. This value must be added to the delivery head in the pump curve to get a realistic resulting volume flow –see calculation example above.

The pressure loss of elbows, valves and any fittings can generally be estimated with an equivalent of 1 m delivery head (≙ 0.1 bar) for small facilities. For bigger pools, with many fittings integrated into the plumbing, a surplus of not more than 3 m (≙ 0,3 bar) is usual.

The pump curve (above) specifies each individual pump type, showing their dependence on volume flow and effective delivery head.



Typical pump curves. Following the red lines shows that pump 1 can transport 250 l/min at a delivery head of 12 m. Assuming that 400 l/min must be transported at a delivery head of 8 m, pump 1 will be overstrained, as explained by the green lines, but pump 2 is suitable.

Example to calculate roughly the effective delivery head of a pump

- A water flow of 10 m³/hr shall be guaranteed at an altitude difference of 4 m → existing altitude = 4 m
- Suction pipe plus pressure pipe length: 20 m; width 2 inches → pressure loss for pipe = 0.9 m → here rounded 1 m (for the existing 10 m length)
- Pressure loss for fittings (general value) = 3 m

Effective delivery head = existing altitude + pressure loss for pipe + general pressure loss for fittings = 4 m + 1 m + 3 m = 8 m

To find a pump which provides a sufficient volume flow you should work in the pump curve with the data "water flow = 10 m³/hr (=166 l/min)" and "delivery height = 8 m".

Operating streams and waterfalls

Streams should be designed with a slight gradient of not more than 6–8% to create an appealing current. Steeper gradients should be broken up by intermediary cascades.

As a general rule you can calculate per cm width of a stream-cascade a volume flow of at least 2 l/min to create an appealing appearance of the current. If a waterfall has a height greater than 50 cm, the volume flow should provide 3 l/min per cm width.

Spring heads or millstones which allow a moderate fountain effect should be fed with 1 l/min per cm width of the bore hole.

Waterfalls integrated into a stream at Fort Worth Botanical Garden, Texas.

Above A springhead can be visually enhanced by using a foaming aerator jet which draws air into the pipe mouth, creating the impression of a greater volume of water.

Above Prefabricated pump chamber for underground installation.

Left Will Murch (Ellicar Gardens, Gringley on the Hill, UK) entering a walk-in pump-house sunk under the wooden terrace.

Pump-houses for dry-installed pumps

Pumps, including all their technical components, are located in a separate unit, the pump-house or pump chamber, which is mostly located under a wooden deck. Only low-voltage underwater pumps are allowed to operate directly within the pool.

Technical components are: the pressure gauge, thermo-protection switch, suction and pressure pipes with various valves and wall bushings, time switches, sockets with integrated fuse, cables, drainage, aeration etc. If space allows, additional filter units such as mechanical sieves or phosphorus filters can also be integrated. All water circulation systems are controlled from here. In case study 12, a walk-in pump-house is shown, a masonry construction accessible through a timber flap in the deck. It is hidden from view by huge perennials.

Small homemade pump chambers are depicted in case studies 1 and 9.

Case study 13 and the examples left and above show variants of ready-made pump chambers for dry-installed pumps.

Using double pump chambers with two independent pumps seems to be a current trend. This can improve energy efficiency and flexibility of the pool.

Plumbing

The plumbing is usually configured with flexible PVC hoses of DN 50 or 63 (50 mm or 63 mm inner width). These hoses are connected to the pump through rigid PVC pipes. The internal plumbing of a pump-house should consist of rigid PVC pipes (p. 65).

Some suppliers offer special pipes for percolated Technical Wetlands and Biofilm-accumulating Substrate Filters but mostly in practice normal perforated drainage pipes DN 100 are used (pp. 53, 64). Suction pipes to the skimmer or underwater pump-house should be configured as rigid pipes (DN 100; KG-tubes) too.

Fittings to connect PVC pipes are available in diverse angular deflections, reductions, flanges to penetrate liners etc. These connections are usually glued with a PVC adhesive agent such as Tangit.

Pipes and hoses need to be cleaned, any grease removed and liquid PVC adhesive agent applied to both parts. Connections should be left to harden for at least 24 hours. They are very sensitive, especially during the first four hours.

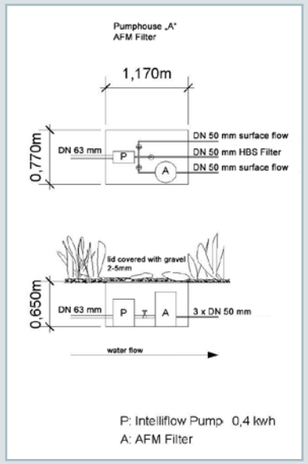
Flexible PVC hoses are embedded 40–60 cm deep in the ground. For this reason, in cold climates all water in pipes and pumps must be removed before winter with an air compressor to avoid frost damage.

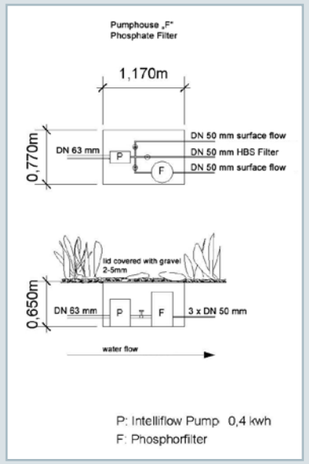
Jets

Jets as water inlets can be used to create a circular current in rounded pools (see case studies 11 and 14) to support the transfer of floating pollutants to skimmers or overflow gutters. There are stainless steel or PVC jets. According to the size, 5–7 m^3/hr water is required to run the jets properly. After removing all water from the pipes in preparation for winter, it is important to use a proper lid to close the inlets and make them waterproof.

Below PVC jet flanged into a liner. The foil surface is covered with gravel fixed with epoxy resin.

System layout and section through a pump-house including AFM Filter (p. 73): water is sucked through a 63 mm flexible hose. The pump (P) forces the water into three different outlet pipes with a diameter of 50 mm. The first pipe feeds the HBS, the second the additional water and the third the AFM filter (A).





System layout and section through a second pump-house: a phosphorus filter (F) is installed instead of an AFM Filter.

If you are looking for a massage effect from jets, they should provide 0.5–0.6 bar pressure. Consider where to use them: a ledge on which you can sit comfortably at the pool wall is the best place to enjoy this.

Jets for counter-current swimming systems (case study 10) need a very strong water flow of 25–75 m^3/hr (Baumhauer & Schmidt, 2008).

SKIMMERS AND EXTRA FILTER UNITS

Skimmers or overflow gutters are devices which remove floating pollutants such as dust, pollen, leaves, insects, suntan oil residue etc. from the water surface. They also ensure regular water circulation and prevent pollutants from sinking to the bottom and releasing undesirable nutrients. Introduced pathogenic germs remain for a time in the upper water layers and can also be captured through a surface suction system.

Skimmers operate on a pump's suction side, whereas overflow gutters are sited on the lowest section of the pool's edge where surface water runs out to a lower regeneration pond from which the water is pumped back into the pool.

Drawing water through ground drains is currently a feature of only a few systems. This disturbs the natural stratification and cleans only a small area around the outflow. It is much more reliable to clean the base of sediment with special vacuums or pool robots.

Prefabricated GRP pool with integrated underwater headlamp (Rivierapool®).

LIGHTING

Clever lighting of the garden around the pool as well as in the water itself can produce enchanting effects at night. Underwater spotlights installed 50–60 cm underwater also contribute to the safety of the swimmer. A simple but well-planned arrangement of a few lights can be enough to create a breathtaking atmosphere.

A variety of underwater lighting is available depending on the individual construction of the pool walls. They are designed for use in cool water; usage in other circumstances may lead to overheating. It is best to determine the underwater lighting as part of the planning process, although retrofitting is possible. Single-colour lighting in white to yellow spectral range suits naturalistic water gardens, whereas a more minimalist design may be visually enhanced through well-balanced multicoloured lighting schemes. Lamps with rotating colour wheels can create changing illumination or chromatic effects.

A special kind of underwater spotlight uses synthetic optical fibres. The light source is mounted out of the water and transmits the light through the fibres. They end at the inner surface of the wall or base of the swimming area and produce a starry sky effect from below. Of course it is much easier to install such a system in a "wall on sealing" construction type.

CONSTRUCTING THE NATURAL POOL

In the following, we presume that a pool of **model 3A** is being built:

- Sealing: PVC liner
- "Wall under sealing" construction
- Technical Wetland area percolated bottom-up
- Adjacent Hydrobotanical System with slow horizontal water flow

The photographs in this section show a project planned and constructed by Teich & Garten.

The case studies in chapter 10 describe a wide range of alternatives.

STEP 1: EXCAVATION WORKS

The pit for the pool must be excavated carefully, because it defines the pond's shape. Later modification can be difficult.

Before starting to dig you should consider the size and time requirements for your project. The charts below will help you design the workflow of the construction properly and order a suitable excavator.

Make sure the garden is accessible for the excavator. Decide if the excavation material is to be retained or removed. It can potentially be used for landscaping and to improve the overall design. Removing large amounts of soil can be expensive: in some countries the local authorities charges exorbitant fees for dumping.

A storage area near the site of the pool for construction materials (stones, gravel, substrate, etc.) needs to be allocated.

- Digging is labour-intensive, so pace yourself and get friends and family to help.
- We recommend excavating the basin to a depth of 2–3 m to provide an adequate volume of water.
- The topsoil should be removed and stored separately. The subsoil can be used to create a berm or the foundation of a mound etc.

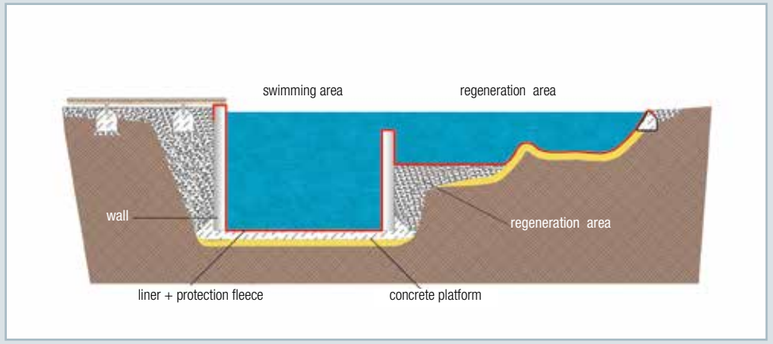
- Before excavating to the desired depth, a plain strip of at least 50 cm should be formed all around the pond edge to the height of the eventual water level as described in Step 3 (p. 127).
- While excavating the pond, all relevant heights of regeneration and swimming areas should be checked for consistency with the plan.
- Areas excavated to too great a depth have to be refilled with soil with adequate compaction to prevent creating unstable zones. If this is not possible, use crushed gravel (0–32 mm) for refilling.
- The swimming area should have vertical walls. Edges of this area, which correspond to the edge of the total basin, require an appropriately wider excavation along this line. After constructing the wall which frames the swimming area, the space between this wall and the edge of the excavation must be refilled with sand and compacted (step 2).
- Form raised banks along the edges of planting zones (HBS) to fix the substrate. Filter zones, which need a depth of more than 50 cm, are mostly installed just behind the wall of the swimming area. Bear in mind that covering the pool bed with sand will require digging out about 5 cm deeper.
- After the excavator has shaped the pond, the outline should be refinished with a shovel to get a level surface and a viable shape for the pool's different zones.
- Re-check all your measurements, including length and width of basin, plant shelf depth, and overall basin depth and correct if necessary.
- Remove any sharp objects from the excavated hole that may damage the liner.

Excavation works: to enable the digger to get out of the pit, a mound must be left which can later be removed from outside. On the left a vibrating plate is ready to compact the bottom of the hole.

Table 28 **Approximate values for excavating the pond with a digger**

Pool surface in m^2	Weight of the digger in tonnes (t)	Estimated time requirement in hours (hrs)
up to 50	4–7	3–7
50–80	7–10	5–8
80–120	10–14	7–9
120–150	15–17	8–10
150–200	18–20	8–12
200–550	20–24	10–14
250–300	24–27	12–16

Weixler, 2008



Section drawing through the excavation of a pool of model 3A plus subsequent constructions.

STEP 2: SUBCONSTRUCTIONS BELOW THE SEALING

If you want the base of the pool to be as clean as in a traditional chlorinated pool, the ground must be as level as possible. To achieve this, a 10 cm concrete layer of C12/15 should be poured onto compacted ground. Reinforcement is not necessary on stable, rocky ground. On unstable, sandy or even soggy ground 15 cm concrete with a simple steel reinforcement provides more security. The concrete layer must be spacious enough to allow the wall that frames the swimming area to be placed at its edges, as shown in the section drawing above. Reinforcement must be

surrounded by at least 2 cm of concrete to prevent cracks in the concrete layer due to rust of the steel.

If you are using the "wall on sealing" construction type, this framework should be built after the liner is laid in the pit (step 4) but a "wall under sealing" construction type demands the following work next:

- Measure out the precise course of the wall and build it along a horizontal line using a spirit level.
- Normal-weight concrete shuttering blocks are generally used. Place them layer by layer in overlapping masonry bond.
- Insert reinforcing steel rods of 8–12 mm width vertically through the continuous hollow spaces every 50 cm and fill them with concrete (C 20–25). The top layer should include horizontal steel rods wired together.
- Do not forget to include elements such as lighting, inlet jets or integrated skimmers and lay the necessary cables.
- The concrete must be allowed to set for at least one week. Then refill and compact sand or gravel into the outer gaps.

Constructing the framework of the swimming area. The ground within the masonry is covered with a concrete layer.

The entrance steps should be constructed next, if the liner is to be adjusted onto it.

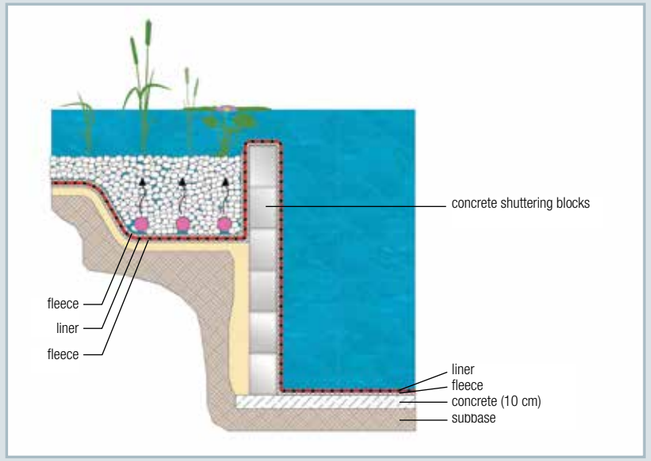
All constructions which transfer a very high load or a punctual pressure onto the liner should be supported by a concrete foundation below the sealing, which also must be built now. Precisely locate the envisaged spots for heavy boulders, load-bearing poles for wooden decks etc. and excavate a sufficient hole for filling in concrete C20/25 at least 20 cm thick. These local foundations must be covered with extra fleece layers (500g/m^2) for protection.

Consider whether any pipes or cables should be installed now, but if possible, locate them around the sealed area in case of future need for repair or modification.

STEP 3: UNDERLAY AND SEALING WORKS

Now the edge of the sealing should be defined with either edging stones or a plastic strip (p. 107) to indicate the maximum anticipated water level, adding a few additional centimetres to be on the safe side. Fixing the liner edges along this marginal structure, however, is the final step after the water is filled close to this height to avoid tension caused by the water pressure, which pulls the liner down to its final position.

When choosing the liner material, we already precalculated the necessary size to be able to order it in time. Now a precise calculation is possible by laying a measuring tape along the pit ensuring it is in contact with the surface at every point. Add 10% (at least 50 cm) on each side to the result to compensate for the increased demand caused by the water, which presses the liner tightly onto the pit and wall. Another metre should be added to the length and width to design a proper edging (50 cm along each edge).



Section through a natural pool showing the transitional area between the swimming zone and the TWL.

The size of the underlying protection fleece can be calculated similarly. A fleece should also be placed on top of the liner in places that will be covered by substrate or built up with installations such as walls. Now you can start the sealing procedure.

To guarantee a fold-free surface in the swimming area, we recommend delegating this work to a specialist company, who will also be able to offer a warranty for their work. This is even more important if lighting or other fittings need to be integrated into the liner.

Some advice for installing the liner yourself:

- Scatter up to 5 cm sand onto all surfaces of the pit (not on the concrete floor) to smooth out any remaining unevenness.
- Unfold the underlay fabric and place it in lengths into the excavated basin, starting from the deepest part. The lengths on the regeneration areas should overlap each other by at least 20 cm. Over the concrete floor the lengths may abutt to avoid unevenness on the base of the swimming area (not a problem if the surface is to be covered with stone flags). The lengths should be fixed together with a tough adhesive tape such as "Sicrall 60".
- Never stretch the fleece: it must cover the base and walls without tension.
- Cut the fleece tracks along the edges allowing enough of a protrusion, and protect it temporarily from slipping back into the pit with stones.
- Enlist some strong helpers to transport and unroll the extremely heavy 1.5 mm PVC liner.
- Place the liner on top of the underlay. If you ordered a prefabricated liner, be sure that the heavy foil roll is located in the right position. It is very difficult to move the liner once unfolded without disturbing the underlay.
- If you have to weld the liner, allow the tracks to overlap by at least 15 cm. PVC and EPDM linings should be smooth, clean and free from any tension.
- As with the underlay procedure, start at the bottom and unfold or unroll the liner upwards.
- Try to smooth out large folds. Under the regeneration areas, the liner should lie flat and fit tightly onto the substructure in all corners without twisting. Don't try to get it perfectly crease-free; you can hide the liner with rocks and substrates later, but be sure that at least the swimming area has a wrinkle-free base.

The liner is fitted and the margins are laid loosely above the pond edge, which is represented by the swimming area wall in the foreground and the edging stones around the regeneration areas to the sides and behind.

- Fix the liner edges temporarily with stones or sand sacks. The completion of the edges will be done last (step 6).
- Apply an overlay of fleece to the regeneration areas and to the base of the swimming pool if it is to be paved with stone flags.

If no paving or masonry is being used above the base of the swimming area, water can be filled up close to the level of the deepest superstructures to fix the liner.

STEP 4: SUPERSTRUCTURES

Next, all features above the liner but inside the pool can be built:

- Staircases made of wood or stone (p. 100)
- Foundations for decks and bridges spanning the water. (The wooden structures themselves are added later.)
- Single boulders or other smaller stone arrangements can be placed on the substrates of filter and planting zones.
- In a "wall on sealing" construction the framework of the swimming area must also be added now.
- The floor of the swimming area can either be left as liner surface – if the material is tough enough – or you can lay stone flags onto a mortar bed (p. 108).

Heavy superstructures require protection of the liner with an extra fleece underlay (500 g/m^2). Foundations for boulders or pillars of bridges and wooden decks should provide a contact surface with a width of at least 50 cm with the liner to distribute the load.

Above Installing the pump chamber and pipework. The skimmer is installed (rear left), connected to the pump-house with a DN 100 pipe.
Above centre A planting zone for water lilies is integrated in the swimming area. The regeneration areas are filled with gravel covering the drainage pipes for the integrated Technical Wetland filtration. The round manhole cover in the foreground indicates the location of the pump-house. It will later be hidden under the wooden deck.

As building work progresses, the water level rises enticingly. The timber cladding of the swimming area is fixed with stones at the edges.

STEP 5: REGENERATION AREAS: PLANTING AND FILLING WITH WATER

As soon as the base of the swimming area is finished, you can start filling it with water to fix the liner. Stop filling when the water has almost reached the level of the next installation to be built.

The regeneration areas are filled with the substrate and the embedded pipework for filtering (see chapter 4). Planting is described in chapter 7. As soon as the deepest zone is planted you can turn on the water again and inundate the completed planting. Use a spray head to avoid damage to new vegetation.

Filling up with water should alternate with building the filter zones and putting in plants.

STEP 6: CONSTRUCTING THE CAPILLARY BARRIER AND TRIMMING THE LINER

The transition zone between the body of water and the adjacent garden space is called the "capillary barrier". It must be constructed carefully to separate the water from soil or absorbent substrates. Any section with contact causes water to be sucked out of the pool into the dryer garden soil or substrate. The influx of surface water from outside during heavy rainfall must be prevented to avoid nutrients and pollutants being washed in. This is crucial mainly if there are adjacent slopes above the pool.

In step 3 (p. 127) we recommended defining the edge of the pool with a plastic strip or edging stones. The margin of the pool edge should be raised 10 cm above the garden soil level and 5 cm above the maximum water level. Run-off rainwater must not discharge into the pool. To create a naturalistic appearance, this height differential can be leveled by filling around the edge with coarse gravel (> 32 mm grain size). The capillary barrier can also be concealed with plants, but over time the accumulation of leaves, roots, mosses and dirt will create a "wick effect" and draw water out of the pool. So check the functionality regularly, at least once a year.

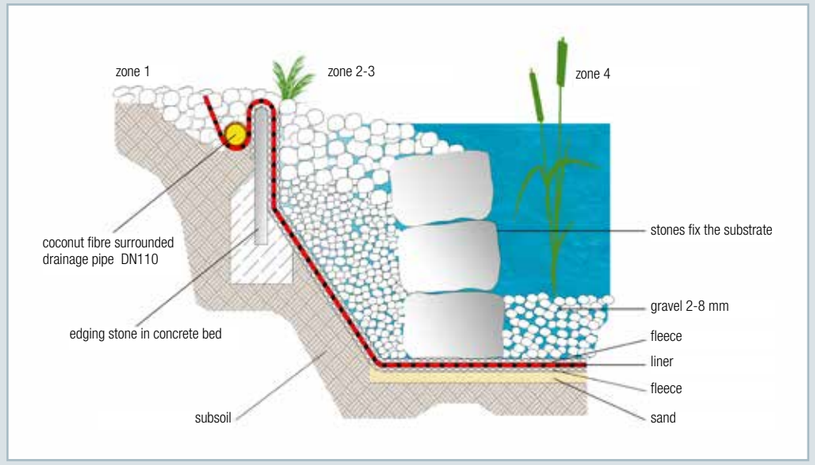
Along sections where the swimming area wall forms the pool edge, the liner can simply be folded over it and fixed, for example with an aluminium rail screwed in along the outer edge of the wall. A wall coping with timber (wooden deck) or stone flags will conceal the liner edge satisfactorily.

Be aware that the liner edges must not be fixed before the water level is brought near to its maximum height to avoid harmful tension in the liner.

A **drainage ditch** embedding a drainpipe will discharge surplus surface water during heavy rainfall. It must have a minimum incline of 3% and lead to a pre-flooder or an infiltration trench. We recommend installing a **controlled overflow** at one point of the edge. It should be away from the house or any buildings. Make this overflow about 20 cm wide and 5 cm deeper than the rest of the edge.

If adequate handling of surplus water after rainfall cannot be guaranteed, install an overflow gutter with a connection to a drainpipe as described above.

After completing the capillary barrier and drainage ditch, the protruding remnants of liner can be cut and removed. If possible, leave at least an extra 20 cm protrusion as a precaution. These liner strips can be concealed under gravel.



Possible edging of the regeneration zone with capillary barrier; the liner is folded over the edging stone and fixed with stones.

Finished! The capillary barrier is hidden with gravel around the regeneration areas and covered with the deck in the foreground.

Table 29 **Rules for ensuring safe use**

- The swimming area should be designed to avoid all risk of injury. Stone surfaces should be smooth and free from sharp edges.
- Materials prone to become slippery with biofilm layers, such as wooden boards or mats, are not recommended as flooring on steps or areas where people walk.
- The gradient of surfaces for walking should not exceed 3%.
- Steps should have walls or handles so that no sharp edges can cause accidents.
- A water depth of 40 cm or less can be deadly for small children if they fall in head first. The sudden shock can prevent them from reacting quickly enough.
- If you do not want to fence the pool, the best protection is a wide swamp zone around dangerous waters. Stepping onto soggy ground causes the child to be careful. A good option is to put an "aquatic incident alert system" in the pond: a sensor which floats on the water surface. As soon as it is submerged, an alarm sounds in the pool area. Of course it should be switched off at times when people are bathing and only switched on if the pool is not in use.
- Be sure you don't install any high-voltage electricity in the water body. Pump-houses with high-voltage underwater pumps must be located at least 2 m from the pool.

"Even in public pools complete safety cannot be achieved" (Weilandt, 2014)

Table 30 **Rules for ensuring sustainable pool construction**

- A suitable capillary barrier will avoid any influx of surface water and water loss by wicking.
- Streams and fountains constructed as separate bodies (water features) and plants with low transpiration rate reduce water loss by evapotranspiration.
- Aerobic conditions should be divided from anaerobic zones.
- Avoid materials rich in dissolvable carbonite and phosphorus in C-limited pools.
- Avoid materials rich in soluble phosphorus in P-limited pools. Carbonites are beneficial in such systems.
- Materials prone to weathering, especially wooden structures, should either be permanently underwater (enclosing and stabilizing the swimming area) or above the water level (wooden decks etc.).
- Heavy supporting structures (pillars of wooden decks etc.) inside the pond threaten the liner. A concrete foundation with extra layers of fleece under the liner will prevent damage.
- Under and above the liner, protection fleece should be used if sharp materials could cause damage.
- Mind the ground water level – a pool sealed with a plastic liner may be pushed in from the bottom if the ground water level rises.
- The water outlet/skimmer should be placed opposite to the wind direction, mostly at the east side of the pool.

Water lily *Nymphaea* 'Sunny Pink' is capable of covering large areas. Water lilies are beneficial in competing against algae and reducing phosphorus in the water.

7
PLANTING DESIGN IN AND AROUND NATURAL POOLS

LEARNING FROM NATURE

Plants can be used as versatile, living building materials. In addition to their ornamental function, they also fulfil numerous water purification tasks (see chapter 4). Depending on the pool model, hydraulic, fill-up water quality and maintenance, very diverse plant combinations can be incorporated. To enable healthy growth and optimal contribution to the water treatment, even in cases of lower care requirements, you should select species well suited to the conditions in or around your pool.

CLIMATE AND HARDINESS

This book focuses mainly on pools in nemoral (warm-temperate) climate zones, though some examples from subtropical or even tropical zone are included. Subtropical species can be hardy even in nemoral zones, if they originated at high altitudes.

Plants from boreal (cold-temperate) or even arctic areas are normally hardy in nemoral zones, but may have problems with hot summer temperatures. Numerous arctic plants can be found in the alpine zones of nemoral mountains. Many of these species are not very heat tolerant, but thrive if kept on permanently percolated gravel or sandy substrates – perfect plants for the Rock Garden Filter (p.55-59).

It is also important to differentiate between oceanic and continental influences: in oceanic areas, the temperature differences between summer and winter as well as between day and night are much lower than in continental ones. Within the nemoral zone, regions such as the British Isles, the extreme west of Scandinavia, France and the coastal parts of central Europe rarely experience severe frosts, whereas further east the continental influence increases extreme temperatures: the probability of frost damage grows as does summer heat and drought.

In nemoral-oceanic as well as in boreal or mountain climates, it is much easier to achieve C-limitation than in areas with warmer summers, because higher precipitation and lower transpiration promote soft water and low pH.

A proven tool for defining plants' winter hardiness is produced by the United States Department of Agriculture (USDA). A zone rating for each plant is given in the plant table (pp. 165-181). You can check the USDA zone of your own location by consulting the table on page 162.

ECOLOGICAL STRATEGIES AND COMPETITIVENESS

For successful low-maintenance planting, you need to combine species of similar competitiveness which are suited to the fertility of the site. Nature-rich sites can be planted with "**C-Strategists**": **competitive plants**, which produce dense cover. In shallow, flooded areas this will mean mainly reed-forming plants (see "species for mass planting" p. 146).

On the base of drained ponds or the disturbed soil surface of ditches and ploughed wetlands, "**R-Strategists**" are first to appear. These short lived, ruderal plants include *Lobelia siphilitica*, *Lychnis flos-cuculi*, *Mimulus luteus* and most *Bidens* and *Juncus* species (rushes), which germinate very quickly and form a loose first ground cover, often with a bright blooming effect for weeks. Later they will be out-competed by other species. In gardens and along the border of natural pools some can become noxious weeds and cause maintenance problems because of their enormous capacity to self-seed along path edges and even on tiny spots of bare soil between other plants. Only in very nutrient-poor conditions do R-strategists usually fail.

On sites poor in resources we find "**S-Strategists**": **Stress-tolerators**, which are mostly small and slow-growing, but often very long lived. If used on too productive sites they might grow even better, but you will have to struggle continuously against undesired weeds which tend more to be R- or C-Strategists, since they are more efficient in utilizing available resources. But S-strategists are suitable plants for intensively filtered natural pools, with their low nutrient level. Examples are wetland orchids (*Dactylorhiza* spec., *Habenaria* spec. etc.), pitcher plants (*Sarracenia* spec.), gentians or slow-growing, compact grasses (*Schoenus nigricans*, *Carex davalliana* etc.).

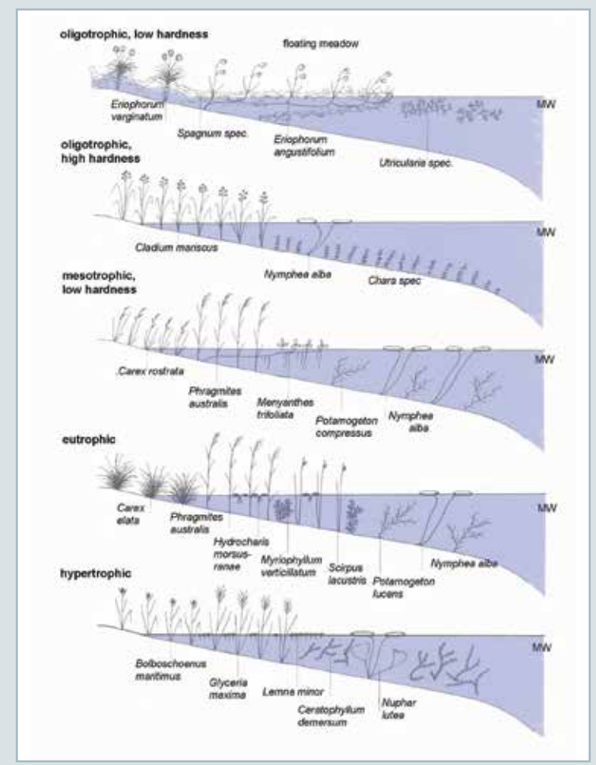
The vast majority of plant species can be situated somewhere between the three basic strategies: R, C and S. But knowing about the main characteristics helps create plantings with low maintenance demands that match the site.

NATURAL PLANT COMMUNITIES

We have already explained the relevant differences between flowing and standing water (p. 41). Natural pools of model 3 and 4 are running-water systems and type 1 represents a standing-water type. Type 2 (surface flow) is similar to a slow-flowing river system.

Flowing water has the most relevant effect on plants as it improves the availability of nutrients. Many species which typically grow in streams fail in still water or show symptoms of deficiency, mainly in nitrogen.

The zoning described refers mainly to still waters, because they account for the vast majority of relevant species.



Vegetation sequences in five types of Central European lakes (MW = middle water level; Kircher, 2004)

Veronica beccabunga thrives between coarse gravel in a stream in the Central Swiss Alps. Water flows permanently over its roots and promotes growth even though nutrient content is low.

Submerged zone

Fully submerged plants can live as hydrophytes, anchored with roots in the ground (*Potamogeton*, *Myriophyllum*), or as floating pleustophytes (*Ceratophyllum*, *Utricularia*). The pondweed *Potamogeton perfoliatus* can grow even in depths of 6 m. Under nutrient-poor conditions, carpet-forming stoneworts (*Chara* species) are typical, while eutrophic water is populated by stands of *Myriophyllum* or *Elodea* species. Water pressure and light intensity determine a plant's ability to grow in deep water. In an oligotrophic environment, submerged vegetation reaches deeper zones than in nutrient-rich waters: the low plankton content of the former improves the visual depth whereas the latter with its high concentration of floating algae can't easily be penetrated by light.

Floating-leaf community

In addition to submerged plants, rooted hydrophytes such as water lilies (*Nymphaea*) or *Nuphar* and floating pleustophytes are also present in this zone. The roots of the latter hang into the water without being fixed to the bottom (e.g. *Hydrocharis*). In eutrophic and hypertrophic water, *Lemna minor* or the tropical water hyacinth (*Eichhornia*) form dense carpets and shade out sunlight, so that submerged life is adversely influenced.

Emergent aquatic plant communities

Helophytes grow underwater or in saturated soil. Stems and leaves protrude above the water surface. *Schoenoplectus lacustris* can reach a depth of 3 m under water, whereas many *Carex* species or *Iris sibirica* settle in only temporarily flooded wet meadows. The most common emergent aquatic plant is the cosmopolitan *Phragmites australis*, the common reed, which forms extensive communities through its rampantly spreading rhizomes. In oligotrophic conditions with hard water, twig rushes (*Cladium mariscus*) are typical, and in eutrophic water *Butomus umbellatus*, *Iris pseudacorus* or *Typha angustifolia*, and in over-fertilized environments *Glyceria maxima* or *Bolboschoenus maritimus*.

Under oligotrophic or mesotrophic conditions, a very special kind of shore vegetation can develop: floating runners of *Eriophorum angustifolium*, *Potentilla palustris* or *Menyanthes trifoliata* proliferate on the water surface. They produce a dense floating net, which can be settled by other plants and eventually form a floating meadow ("Quaking Bog").

Carrs

Still bodies of water tend to silt up from the edges inwards with mud and peat, formed from partially mineralized plant matter. The sodden, periodically flooded edges of lakes are naturally settled by reeds (*Phragmites australis*) and tall sedges (e.g. *Carex elata*). This stage is followed by moisture-loving woody plants; in Central Europe this can include *Alnus glutinosa*, *Prunus padus* and several *Salix* species, which form a so-called "carr" (waterlogged, wooded terrain). Shade-tolerant helophytes, such as ferns, *Carex elongata* or *Calla palustris*, form ground-covering vegetation.

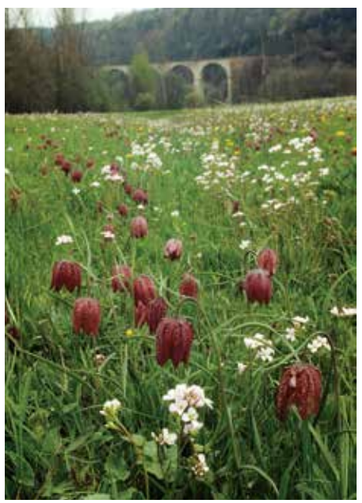
Left Hillside springwater fen in the Northern Limestone Alps, Germany. The blooming *Primula farinosa* is a typical carbonate indicator.
Right Providing a very similar appearance *Phlox glaberrima* subsp. *interior* grows on mesotrophic lime fen in Illinois State Park near Chicago.

Fens

In a very nutrient-poor environment a wood-free fen will develop naturally. In Central Europe such plant associations mostly result after carrs have been cleared. Long term they only can be preserved if mown once a year. Nutrients decline in tandem with denitrification processes in the anaerobic organic substrate. Autumn mowing has been practised since the middle ages to produce straw for farm animal bedding. Typical plant communities of wet straw meadows are low sedge swamps, formed by shallow growing *Carex* species, such as *Carex davalliana* or *C. flava*, along with attractive flowering perennials, even orchids (*Dactylorhiza*, *Habenaria* spp. etc.). Most plants from oligotrophic fens are very frugal in their phosphorus requirements (Wassen et. al., 2005; Duren & Pegtel, 2000), so lime-fen vegetation provides particularly suitable plants for the marginal zone of natural pools with P-limitation.

Above Acid bog in New Zealand (Key Summit). A colourful pattern of *Sphagnum* mosses and the endemic cushion plant *Oreophilus pectinatus* form a charming micro-landscape. Most plants from such oceanic origins can only be cultivated successfully in regions with mild winters and cool summers.

Above The pitcher plant (*Sarracenia purpurea*) grows in acid bogs of North America such as here in Volo Bog, Wisconsin. As a continental species it is easy to cultivate, given a sufficiently low pH.



Above In early spring *Fritillaria meleagris* and *Cardamine pratensis* bloom in a mesotrophic wet meadow (Sinntal, Germany) taking advantage of still low competition from surrounding grasses and forbs, which grow much taller in summer.
Right Moderately rich tall forb community at Mount Ibuki, Japan: dense vegetation pattern with *Veronicastrum sibiricum* subsp. *japonicum*, *Ligularia stenocephala* and *Lilium leichtlinii*.

Acidic bogs

Bogs differ from fens in terms of their pH value which is decisively below 7. The fens described earlier are fed mainly by mineral groundwater and surface water. In very humid areas the peat-accumulation mounts up, and over time the vegetation is fed more by precipitation water than by ground water. As this increases, a process of acidification and further nutrient depletion is achieved and an almost carbonate-free raised bog develops. The number of plant species declines and only well-adapted specialists remain. Typical peat mosses (*Sphagnum magellanicum*, *S. angustifolium* etc.) appear in attractive red and green carpets. In a nemoral climate an evenly distributed precipitation rate of ≥ 1000 mm is necessary to allow the development of a raised bog. *Sphagnum* mosses are able to exchange cations against oxonium ions (H_3O^+), promoting the acidification process. Extensive carpets of *Sphagnum* mosses cover the complete bog surface and grow constantly upwards while their lower parts die off. Being hardly mineralized they form very acidic bog peat.

Some *Sphagnum* species can occur and flourish to form fleecy carpets in groundwater-associated acidic bogs. The nutrient content is likely to be slightly higher than in raised bogs fed by precipitation only, so the vegetation can include species that are slightly more demanding in nutrients – a promising source for planting design in C-limited pools.

Tall forb communities (wet hay meadows and pastures)

When fertilized, former fens become productive enough to be mown several times a year or used as pastures. Meadows mown only two or three times a year offer an impressive amount of perennial species: *Bistorta officinalis*, *Trollius europaeus*, *Cardamine pratensis* or *Fritillaria meleagris* are some striking examples from Central Europe. Species from moderately fertilized wet meadows grow well on non-flooded Technical Wetlands.

Higher nutrient levels increase the frequency of mowing cycles and decrease species diversity. Plants from rich sites grow more rampantly than species from poor sites.

DEPTH ZONES FOR ARTIFICIAL PONDS AND NATURAL POOLS

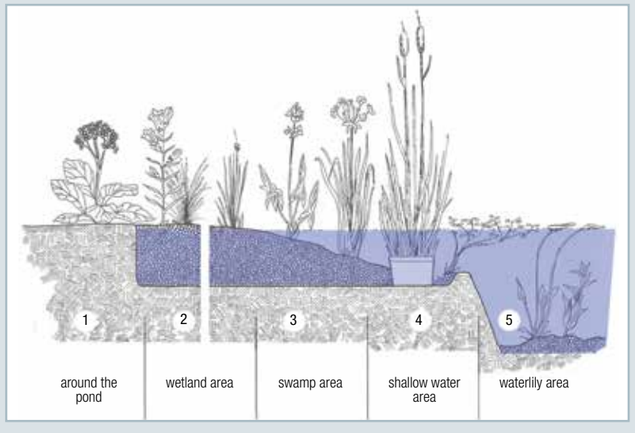
In manmade bodies of water, space is much more limited than in natural ones, so continuous transitions between the shore and the deepest zone are hard to achieve.

The **regeneration area** can be constructed more or less like a garden pond; it is simply shallow water area for helophytes marginal to the swimming area. To create a naturalistic bank requires a slope with a gradient of 1:3 or gentler. But in artificial ponds a steep drop in height is normally built in between the shallow and deep areas to save space, generally between 40 and 70 cm depth.

We can distinguish between five planting zones (derived from the model of the Association of German Perennial Nurseries (Bund deutscher Staudengärtner = BdS)):

- **Zone 1**: external edges adjacent to the pond or pool: normal soil without contact with the water. Plants should be chosen which suit the wetland character visually, but ecologically correspond to the conditions beyond the capillary barrier of the water feature.

- **Zone 2**: wetland area: permanent sodden soil, 5–15 cm above water level but not flooded. Here wet meadow perennials (tall forb communities, fens and bogs) can be established.
- **Zone 3**: swamp area: between about 5 cm above and 5 cm below water surface. Can tolerate the water level being a little deeper temporarily. This zone is suitable for emergent helophytes from the reed zone.
- **Zone 4**: shallow water area: a permanent water level of 5–40 cm is an ideal position for several part-submerged aquatic plants or small water lilies. We recommend keeping this area flooded to at least 20 cm because shallower water is particularly attractive to filamentous algae.
- **Zone 5**: water lily area: more than 70 cm deep. Most floating-leaved and submerged plants grow in this area.



Depth zones for plantings in and around artificial ponds (derived from BdS; Kircher 1996).

DESIGN CONSIDERATIONS FOR PLANTING NATURAL POOLS

DESIGN STYLE AND PLANTING THEMES

Natural pools can either be shaped in a formal or in a naturalistic style, depending on the environment. There is now a huge range of plants available, many of which are not very natural: variegated leaves, spiral-shaped shoots or the huge, colourful flowers of modern water lily hybrids will not harmonize with a naturalistic environment. However, as part of a formal design, these cultivars can be both convincing and appealing.

Wild plants and natural-looking cultivars are suitable for both formal and naturalistic pools and ponds. Formal design does not necessarily require a great diversity of plants. Sparing but well-balanced planting in and around the pool can create an elegant, sophisticated style. On the other hand only formal designs offer the possibility of arranging a great diversity of plant habitats in a small space. Geometric pools work well even when planted with completely different themes: a bogland can be separated from a water lily basin and a tall forb meadow by walls or a narrow path. Formal basins may accommodate any zoning arrangement; a swamp or shallow water area can be left out to allow water lilies to thrive even in a small garden.

If the planted area of a pool is smaller than about 50 m² and you want a diversity of species, hydrophytes and helophytes should be selected carefully. Many species behave very competitively, suppressing less vigorous ones.

Beside a general distinction between formal and naturalistic designs, we can choose between more sophisticated garden themes picking up cultural, historical or general aesthetic features. Designing gardens in particular colours, either monochromatic or featuring defined contrasts, is very popular. In the following table we list some possible garden themes. The proposed plants will thrive in a temperate climate.

Model planting concepts for five different themes are listed as an appendix to this chapter (p. 182).

The variegated bulrush (*Schoenoplectus tabernaemontani* 'Zebrinus') does not harmonize with a naturalistic design, but complements a formal environment.

Table 31 **Exemplary design themes for water gardens**

Theme	Design principles	Plant examples around the pool (Zone 1)	Plant examples in the water
"Garden of transparency"	Fine-textured plants and hazy clusters of flowers dominate the vegetation. As a contrast, some denser flowers and structures can be scattered in between.	*Albizia julibrissin* *Gaura lindheimeri* *Gypsophila paniculata* *Lespedeza thunbergii* *Limonium latifolium*	*Alisma laceolatum* *Cardamine pratensis* *Carex diandra* *Lysimachia quadriflora* *Myriophyllum aquaticum* *Schoenus nigricans*
"Garden of ascending motion"	Slim upright forms and parallel vertical structures define this garden. The plant arrangements can direct the observer's eye to tall architecture or sculptures.	*Calamagrostis × acutiflora* *Cupressus sempervirens* 'Stricta' *Eremurus robustus* *Kniphofia* Hybrids *Semiarundinaria fastigiata* *Trachycarpus fortunei*	*Butomus umbellatus* *Pontederia lanceolata* *Schoenoplectus lacustris* 'Albescens' *Scirpoides holoschoenus* *Typha laxmannii*
Cottage garden	Roses, ornamental perennials and annuals are informally arranged and combined with edible plants. The design principle emphasizes colour and texture rather than grandeur and formal structure.	*Alcea rosea* *Clematis viticella* cv. *Lavandula* spp. *Paeonia lactiflora* *Rosa* Hybrids (double-flowered shrub roses etc.)	*Caltha palustris* *Filipendula* spp. *Hibiscus moscheutos* *Liatris spicata* *Nymphaea* cultivars *Pontederia cordata*
Flowering meadow garden	Natural-looking forbs and grasses are combined to colourful effect. In the pool margins, artificial bog and fen meadows can be seen as prototypes if a sufficient diversity of species is used to guarantee a long and well-balanced flowering season. Rock gardens can be appropriate additions. The accompanying reeds and floating plant communities should not produce flowers that are too large or coarse-textured.	*Allium flavum* *Allium schoenoprasum* *Anthericum ramosum* *Carex montana* *Erica carnea* *Gladiolus illyricus* *Iris sintenisii* *Linum perenne* *Pinus mugo* cultivars *Schizachyrium scoparium* *Sedum kamtschaticum*	*Allium suaveolens* *Dactylorhiza* Hybrids *Erica tetralix* *Eriophorum latifolium* *Iris sibirica* (no Hybrids) *Ledum groenlandicum* *Liatris spicata* (low cultivars) *Lobelia sessilifolia* *Nymphaea tetragona* *Pogonia ophioglossoides* *Schoenus ferrugineus*
Damp woodland garden	Tall trees and shrubs surround naturalistic water features. Use big-leaved species in the foreground and fine-textured ones at the back, highlighting the perspective view and increasing the perception of depth. Funnel-shaped shrubs provide basal space for lush, shade-tolerant undergrowth, which evokes unspoilt, primordial nature.	*Alnus* species *Amelanchier laevis* *Carex pendula* *Catalpa bignonioides* *Hamamelis mollis* *Lysimachia clethroides* *Parrotia persica* 'Vanessa'	*Calla palustris* *Caltha palustris* *Carex appropinquata* *Iris pseudacorus* *Lysichiton* spp. *Lysimachia nummularia* *Nuphar advena*

Table 31 **continued**

Theme	Design principles	Plant examples around the pool (Zone 1)	Plant examples in the water
Mediterranean garden	Warm, mellow courtyards and walls in an architectural environment convey a Mediterranean style. A rectangular pool can be framed by column-like conifers or palms. A Provençal scent can be spread by lavender. Plants which are not hardy are cultivated in terracotta or timber tubs.	*Cupressus sempervirens* 'Stricta' *Juniperus virginiana* 'Sky Rocket' *Lavandula* spp. *Nerium oleander* *Rosmarinus officinalis* *Santolina chamaecyparissus* *Trachycarpus fortunei*	*Caltha palustris* *Cyperus longus* *Cyperus papyrus* *Mentha cervina* *Nelumba* Hybrids *Nymphaea* cultivars *Osmunda regalis* *Sagittaria* spp. *Typha shuttleworthii*
Tropical garden	Irrespective of the climate, a tropical garden should provide lush and sumptuous vegetation. Warm colours (yellow, orange, red) and big leaves should dominate. Rosette trees like palms or banana plants are ideal signifiers of the tropics. Of course you need a proper winter quarter for plants which are not hardy.	*Aralia elata* *Canna indica* *Kniphofia* Hybrids *Magnolia hypoleuca* *Musa basjoo* *Phormium tenax* *Phyllostachys vivax* *Strelitzia reginae* *Trachycarpus fortunei* *Zantedeschia aethiopica*	*Canna glauca* *Cyperus papyrus* *Hibiscus moscheutos* *Lysichiton americanus* *Nelumba* Hybrids *Nymphaea* cultivars *Osmunda regalis* *Pontederia lanceolata* *Thalia dealbata* *Typha shuttleworthii*

ARRANGING THE PLANTS

In a formal environment it is probably wise to arrange the planting in groups like in an ornamental border, whereas in naturalistic-themed gardens plants are interwoven with each other.

Group planting

In formal gardens, plants are often arranged in groups without considering their natural behaviour. This can look spectacular, but to the detriment of the sustainability of the planting scheme. A planting pattern in groups demands a static maintenance strategy: each group must be preserved in its condition. Neighbouring species of very similar growth behaviour and competitiveness may prove low maintenance, but if a rampant species is placed beside a much weaker one, the latter will soon be outcompeted. Regular attention may be required to replace weakened plants or cut back ones with exuberant growth. However, even in nature many reed-forming plants occur in groups of conspicuous size.

Cupressus sempervirens 'Stricta' is a typical element of a Mediterranean design.

Planting in groups can look exciting in water gardens, but demand regular attention to keep a well-balanced pattern (Wisley Gardens, UK).

Percolated substrate filter (BSF) with *Cyperus longus* as monoplanting. Only some *Lythrum salicaria* specimens can survive within the *Cyperus* thicket (trial pool at Anhalt University, Germany).

Mass planting

A lot of helophytes for zone 3–4 from mesotrophic or eutrophic sites are very competitive because of their rampant runners. In an average-sized garden, plants with a strong tendency to proliferate should be used in separate basins only. Some of these species are beneficial in Technical Wetland filters.

Table 32 **Reed-forming species with strong ability to compete, recommended only for mass planting**

Carex acutiformis, C. acuta, C. riparia, C. vesicaria
Cyperus longus
Eleocharis palustris
Equisetum – all species
Phragmites australis
Schoenoplectus lacustris, S. tabernaemontani
Sparganium americanum, S. emersum, S. erectum
Typha angustifolia, T. domingensis, T. latifolia, T. laxmannii
Zizania caduciflora

To achieve greater diversity, you can include either shade-tolerant ground coverers or species with a very early growing season: the reeds listed above start growing in late spring, so plants spreading and blooming in early spring and then dying back will not be suppressed by emerging reeds. Further partner plants can provide a visual enhancement for some years till the reeds have reached their full competitive power.

Planting in layers

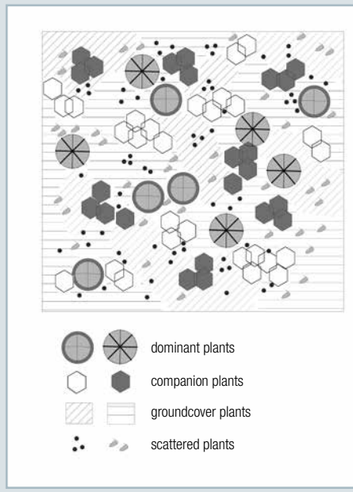
If you want a good diversity of species, another ordering principle needs to be found: to achieve a visually attractive arrangement, plants can form three clearly distinct layers. This approach of combining plants creates a natural-looking pattern. The tallest plants are used in low quantities, the shallowest in high ones to achieve a clearly defined relief in the planting. As long as the proportions between different species are well thought out, plants can be distributed more or less randomly. But take care that very tall plants are not used right in the foreground. Along paths, decks and terraces, low-growing species should be preferred.

In this planting style only shallow-rooting species should be allowed to proliferate with runners. Tall species should be clump-forming, stationary and long-lived.

The principle of layered planting can best be achieved in zones 1 to 3, as long as the vegetation grows significantly above the water level. In deep water, a combination of floating-leaved and submerged plants can similarly be arranged. Here floating-leaved species should be widely spaced and used sparingly, so that the water surface is not completely covered. The observer should always be able to sense the presence of water, which cannot be achieved if there is a thick layer of foliage. Only in a deliberately Hydrobotanical System is very dense vegetation desirable.

Table 33 **Planting partners to be scattered between rampantly growing reed species**

Shade-tolerant creepers can cover the ground over years:
• *Thelypteris palustris*
• *Lysimachia nummularia*
• *Equisetum scirpoides*
Bulbs/corms blooming in early spring use the period of low ground cover. With the emerging shoots of the developing reed plants their shoots die back and remain dormant underground till the following spring:
• *Anemone nemorosa*
• *Fritillaria meleagris*
• *Leucojum vernum* and *L. aestivum*
Clump-forming species can be added in the initial phase; they can enhance the visual quality for several years but will be suppressed or even outcompeted long term:
• *Caltha palustris* and *C. p.* 'Auenwald' (more vigorous growth)
• *Iris pseudacorus*
• *Lythrum salicaria*
Short-lived species (R-strategists) may be visually effective for one to three years, but afterwards they will occur only along the margins:
• *Myosotis palustris*
• *Lobelia siphylitica, L. fulgens*
• *Lychnis flos-cuculi* (if not inundated)



Recommended plant distribution in layers.

Layered planting in a regeneration zone: *Lythrum salicaria* is the dominant species, *Carex diandra* the companion species and *Thelypteris palustris* the ground cover species.

Scattered plants dominate this marginal fen planting: blossoms of *Dactylorhiza* orchids, *Tofieldia calyculata* and *Gladiolus imbricatus* between low sedges and *Trichophorum alpinum* (see case study 7).

Baldellia ranunculoides is a tiny and short-lived "filler plant" for oligotrophic and mesotrophic ponds. By self-seeding it reliably occupies bare spots in zones 3 and 4.

We structure plants into five **design categories** (adapted from Borchardt, 1996):

- **Dominant plants**: usually tall, clump-forming plants placed at an adequate distance from other solitary species to achieve the best visual effect. Planted densely, a meadow-like impression will be created. In this case there should not be too many different flower colours competing.
  Examples: *Iris pseudacorus*, *Carex pendula*, *Lysichiton americanus.*
- **Companion plants**: mostly semi-tall, cluster-forming plants, which should be planted in small groups or alongside dominant species.
  Examples: *Iris laevigata*, *Pontederia cordata*, *Carex diandra.*
- **Groundcover plants**: very shallow species should be distributed between or below plants of the categories above. In plantings aiming to achieve a well-balanced relief with clearly distinguishable layers, groundcover plants should account for over 50% of the total.
  Examples: *Veronica beccabunga*, *Lysimachia nummularia*, *Carex davalliana*, *Sphagnum* mosses in bog plantings.
- **Scattered plants**: In this category we find numerous important forbs with low space requirements and a limited period of visual effectiveness. They should be loosely distributed. This category includes bulbs and corms as well as plants with small rosettes and slim inflorescences that pierce through the vegetation.
  Examples: *Cardamine pratensis*, *Parnassia* spp., *Gladiolus imbricatus*, *Dactylorhiza* hybrids, *Leucojum aestivum.*
- **Filler plants**: short-lived species such as primroses and lobelias should not be used in big groups because after two or three years you may be left with an empty space. They should be added singly or in narrow belts, so that gaps which occur can be covered by adjacent plants. Bear in mind that short-lived plants sometimes seed themselves unpredictably, so particular attention should be paid to the selection of suitable species.
  Examples: *Primula japonica*, *Lobelia siphylitica*, *Mimulus cupreus*, *Myosotis palustris.*
  Examples with strong seeding: *Alisma* spp., *Mimulus luteus*, *Lychnis flos-cuculi*, *Juncus* spp., *Carex canescens.*

The suggestions for natural-looking plant compositions in the following pages are based on the plant categories above. If the plants are distributed randomly according to the listed proportions, sustainable scheme forming a visually enhanced naturalistic pattern will result (Kircher et al., 2011).

PLANT DENSITY

There is often uncertainty about proper planting distances and the required amounts of plants per square metre. The table below gives general suggestions for different groups of wetland and water plants.

The sample lists (pp. 183-189) also include plant quantities, which will help you to develop a sense of appropriate plant densities.

We recommend inserting submerged and non-rooted floating plants at a density of 3 to 5 per 10 m². If the environment is supportive, even a few individuals can quickly form a considerable population. So it is more sustainable to insert low quantities of a greater number of species than large quantities of a few.

Table 34 **Recommended planting densities**

Plant type	Plant density	Plant examples
Water lilies and rooted floating-leaved species: zones 4–5	1 per 3–6 m²	Vigorous plants: *Nymphaea* 'Gladstoniana', *N.* 'Escarbouclé', *Nuphar lutea*
	1 per 2–3 m²	Moderate growers: *Nymphaea* 'James Brydon', *N.* 'Rosennymphe', *Brasenia schreberi*
	1 per m²	Small plants: *Nelumbo nucifera, Nymphaea* 'Froebeli', *N.* 'Berthold' *Aponogeton distachyos*
	3–5 per m²	Dwarf plants: *Nymphaea tetragona, N.* 'Helvola' *Baldellia ranunculoides, Luronium natans*
Group planting: zones 3–4	2–4 per m² groups of > 2 m²	Rampant growers: *Carex elata, C. acuta, Phragmites australis*
	4–8 per m²	Moderate growers: *Pontederia cordata, Sagittaria* spp., *Carex appropinquata*
Mixed planting of wet meadow species without runners: zones 2–3	5–10 per m²	Mesotrophic wet meadow plants (tall forb communities): *Carex diandra, Filipendula ulmaria* 'Plena', *Liatris spicata*
10–20% dominant species 30% companion species 40–50% groundcover and filler species Plus additional scattered plants	10–15 per m²	Bog plants between *Sphagnum* carpets: *Andromeda polifolia, Eriophorum vaginatum, Sarracenia purpurea*
		Oligotrophic fen plants: *Carex viridula, Schoenus ferrugineus, Tofieldia calyculata*
		Bog plants without *Sphagnum* layer: *Arnica montana, Helonias bullata, Trichophorum alpinum*

Result of seeding between low grasses and companions: *Rhinanthus serotinus* enriches the marginal vegetation with light yellow flowers over a period of weeks.

Establishing plants by seeding?

Around the pool, outside the sealing (zone 1), seeded meadows can create beautiful vegetation, but we do not recommend relying on seeded vegetation in ponds and planted pools. In waterlogged or even inundated substrates (zones 2 & 3), germination is very unreliable. However, some specialized species can only be established by seeding between existing low-growing vegetation. As an annual for damp to wet soil the hemiparasitic greater yellow rattle (*Rhinanthus serotinus*) can only thrive on host plants, mainly low grasses. It makes a very attractive addition in fen plantings and can survive for a few years by self-seeding until it is outcompeted. Even more spectacular are the North American Indian paintbrush (*Castilleja*) species for damp meadows, such as *C. miniata* (see case study 7). Hummingbirds are required for pollination, so on other continents Indian paintbrushes cannot be expected to self-seed.

Several short-lived primulas as well as some "scattered plants" (*Parnassia* spp., *Cardamine pratensis*) can also be sown successfully into low-growing wetland vegetation. However, normally it is cheaper and easier to establish a few pot plants and wait for these to self-seed.

SEASONAL DEVELOPMENT

Plants provide different seasonal highlights depending on their growth cycle. Winter tends to last longer in wetlands than in drier garden areas. So it is important to include early spring bloomers in your planting scheme. Unlike sterile conventional pools, natural pools can stimulate pleasurable anticipation of the bathing season ahead as nature returns to life in spring.

Leucojum aestivum blooms in April between still dormant cobra lilies (*Darlingtonia*).

Table 35 **Spring plants for the pool margins**

Caltha palustris	Zone 2–3
Lysichiton americanus, L. camtschatcensis	Leaves appear after blooming and need much space, as does the root system: Zone 3
Primula rosea	Zone 2–3
Cardamine pratensis	Zone 1–2
Leucojum vernum	Zone 1–2
Fritillaria meleagris	Zone 1–2

The shoots of *Leucojum* and *Fritillaria* will die down soon after blooming and the plants spend summer and winter as dormant bulbs. *Caltha* and *Primula rosea* remain green through summer, but their leaves look rather unspectacular. So they should be complemented by summer- and autumn-flowering species. In contrast, *Lysichiton* spp. form leaf rosettes about 80 cm tall after blooming and need a great deal of space in summer.

Spring is the most difficult season in which to achieve an attractive visual effect. When combining plants for a year-round appeal, bear in mind the overall appearance of the intended species as well as their flowering season. Take care to hide plants after they've turned unsightly by positioning them next to partners which emerge later.

In nemoral zones, water lily leaves do not appear before late spring. Evergreen submerged plants such as *Stratiotes aloides* or *Fontinalis antipyretica* can provide a pleasing appearance in the absence of thriving water lilies. An interesting addition is South African Cape pondweed

Above In spring *Aponogeton distachyos* is one of the first spreading and blooming floating-leaved plants. With rising temperatures in summer it dies back and appears again in autumn. Through the frosty season it hibernates as a corm on the base of the pond.

Below left & right Glass-clear water but weak plant growth and yellow leaves are symptoms of nitrogen deficiency in this natural pool. Three years after completion much lusher vegetation should be expected.

(*Aponogeton distachyos*), which is only really visible in spring and autumn, outside the period when other floating-leaved plants attract attention.

PLANT SELECTION FOR SPECIFIC CONDITIONS

PLANTS FOR OLIGOTROPHIC POOLS

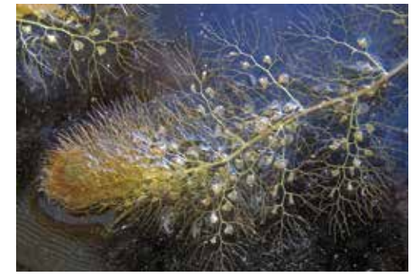
Experience from existing natural pools shows that many species of traditional aquatic plants do not grow satisfactorily in the oligotrophic water of pools with intensive filtering (Thon 2014, Kircher 2007) found mainly in pools of models 3 and 4. The desired P-limitation as well as C-limitation is accompanied by a similarly efficient process of denitrification.

Appropriate countermeasures are not only adding nitrogen fertilizer (p. 225), but also the use of well-adapted plant species.

The spectrum of submerged species which naturally occur in oligotrophic water as "S-strategists" is very limited. The small range of those plants is either not available in most nurseries or difficult to grow. Numerous species belong to the Fontinalis type and need free carbon dioxide for assimilation: *Crassula helmsii*, *Hottonia palustris* and most *Callitriche* species are recommendable only for soft-water pools, as found in C-limited systems.

In oligotrophic hard waters with P-limitation and a pH around 8 these species will not thrive. The species depicted opposite, bottom row have shown good results.

In P-limited water with nitrogen fertilization, some plants grow very well, but sometimes symptoms of phosphorus deficiency occur: the leaves



Aquatic plants for soft oligotrophic to mesotrophic water (C-limitation).
Left to right *Utricularia australis, Crassula helmsii* (classified as noxious neophyte in several countries outside Australia and New Zealand).

Left to right *Callitriche* sp., *Luronium natans.*

Aquatic plants for hard oligotrophic to mesotrophic water (P-limitation).
Left to right *Sagittaria graminea, Myriophyllum crispatum* (classified as noxious neophyte in several countries outside Southeast Asia and Australia).

Left to right *Potamogeton perfoliatus, Chara* sp.

Plants from oligo- to mesotrophic lime fens (including wet lime prairies) comprise numerous gems and provide flowers from spring to late autumn (P-limitation):
Top row, left to right
Early spring: *Fritillaria meleagris*
Late spring: *Iris sibirica* and *Eriophorum latifolium*
Early summer: *Epipactis palustris*
Bottom row, left to right
Mid-summer: *Liatris spicata* and *Allium cernuum* from North-American damp prairies
Late summer–early autumn: *Allium suaveolens*
Late autumn: *Parnassia glauca*

may be very dark green, but growth is restricted and leaves remain small. Good results under those conditions have been obtained with, for example, *Sagittaria latifolia*, *Menyanthes trifoliata*, *Lythrum salicaria*, *Scirpoides holoschoenus* and *Pontederia cordata* in zones 3–4.

A wide range of attractive plants with a low competitive ability is naturally offered for zone 2 of oligotrophic water: poor fen and bog vegetation provides a rich resource for creating diverse and exciting marginal meadows around pools. Case studies 7, 8 and 9 show projects with examples of planting schemes.

Sphagnum palustre has proved suitable in still water for creating a dense layer with *Sphagnum* moss along the marginal zone. If exposed to water movement, *Sphagnum squarrosum* has proved more reliable (Thon 2014).

In submerged zones some rooted floating-leaved plants from richer natural sites are suitable if there is a large substrate and some water movement. After an initial period of weaker growth, even water lilies or other floating-leaved plants may develop satisfactorily.

Acid bogs provide unusual plants for all seasons (C-limitation):
Top row, left to right
Early spring: *Rhododendron canadense* within *Andromeda polifolia*
Late spring: *Trichophorum alpinum*
Early summer: *Pogonia ophioglossoides* within *Sphagnum palustre*
Centre row, left to right
Mid-summer: *Eriophorum russeolum*
Summer–autumn: *Erica tetralix*
Autumn: *Aster nemoralis*

Left In the marginal area of the swimming zone troughs are integrated which provide a water volume of at least 100 l – a good place for water lilies to thrive.
Right Even 15 years after being planted in a trough, *Nymphaea* 'Chrysantha' is healthy and blooms throughout the summer.

PLANTED CHLORINE POOLS?

Swimming enthusiasts who are sceptical about completely naturally purified pools may consider combinations between traditional chlorination and additional plantings. Of course, the addition of any chlorine to a pool means that it can't be called a "natural pool" (FLL 2011 & 2017; ÖNORM 2013), but sometimes in warm climates, where there is a risk of

Iris spuria cultivars such as this one 'Dorothy Forster' resemble wetland irises but tolerate, or even prefer, dry soil.

waterborne diseases, some treatment with chlorine may be necessary. So it is legitimate to ask whether plants can thrive in such an environment.

In a trial by König et al. (1997) at Anhalt University 16 marsh and aquatic plants were tested in chlorinated water. Test basins were treated with chlorine tablets in a concentration that conformed to the manufacturer's instructions. At the end of the trial, eight species showed only insignificant growth reduction and still looked healthy: *Phragmites australis*, *Schoenoplectus tabernaemontani*, *Carex acutiformis*, *Aster tripolium* (biannual), *Bolboschoenus maritimus*, *Glyceria maxima*, *Iris halophila* and *Pontederia cordata*. *Typha latifolia* even showed a slightly better growth in the chlorinated pools than in the non-chlorinated comparison basin. Marked deficiencies were noted in *Zizania caduciflora*, *Iris pseudacorus* and *Mentha aquatica*. All the submerged and floating-leaved plants tested were unable to survive any chlorine content.

The trial ran for only 8 weeks, but suggests that combining a chlorinated pool with certain helophytes can be successful. They could be used as a Hydrobotanical System or a Technical Wetland planting, or simply as decorative marginal plants.

PLANTINGS AROUND THE POOL

Plantings in zone 1 can be arranged according to normal garden design principles. The edge of man-made water features often show a sharp boundary between a wet area within and a more or less dry area outside the sealing. Adjacent to the liner's capillary barrier, particularly of naturalistic pools, we recommend using drought-resistant species which resemble wetland plants. These can be lush-looking grasses or forbs with wide leaves, for example, species of the genera *Miscanthus, Hemerocallis, Telekia* or drought-resistant irises for nutrient-rich sites. On poor sites, bog or fen vegetation can be continued outside the sealing, for instance with small *Allium, Carex, Sesleria, Briza or Anthericum* species.

Some species will thrive in the pond as well as outside in normal garden soil – these are ideal plants to conceal unsightly capillary barriers and integrate naturalistic pools into their surroundings.

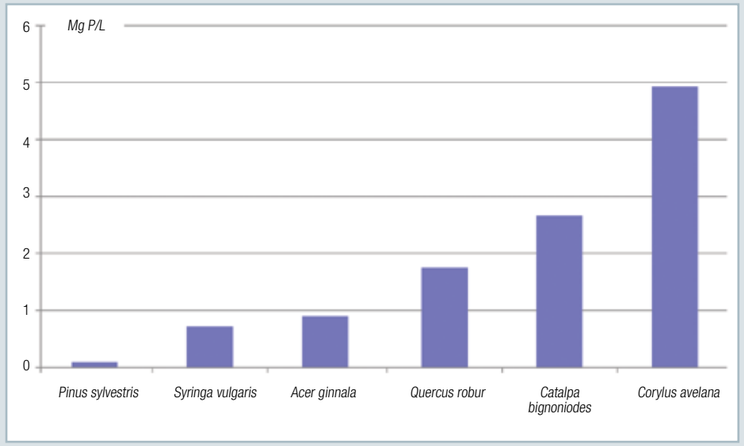
Woody plants around the pool

Partial shading by trees or tall shrubs is no problem; the accumulation of nutrients caused by leaves falling in autumn is generally overestimated. When selecting woody plants, you should choose species with a low

Plants which thrive sufficiently in waterlogged substrate of zone 2 or even 3 as well as in moderately dry soil outside of the pond sealing.
Top row, left to right
Euphorbia palustris, *Allium schoenoprasum* 'Forescate' (chive), *Carex pendula* (dry-tolerant in shade)
Bottom row, left to right
Liatris pycnostachya, *Lysimachia nummularia*

nutrient content in their foliage. The graph next page shows the phosphorus input of six woody species according to a trial at Anhalt University, Bernburg (Deichfuß et al, 2013). Hazel (*Corylus avellana*) and Indian bean (*Catalpa bignonioides*) are species with big, smooth leaves which should not be used near a pool. Conifers, by contrast (here, *Pinus sylvestris*), are characterized by a very low phosphorus input. Pine trees are particularly well suited to being used near water features, especially *Pinus sylvestris, P. banksiana* and *P. parviflora*.

Thirty grams of leaves of six woody plant species were soaked in 10 l of nutrient-poor tap water from October 2012 to May 2013 and stored outdoors protected from rainfall; evaporated water was refilled. The diagram shows the dissolved phosphorus (mg/l) which resulted at the end of the test (Deichfuß et al, 2013).



CAN PLANTS DAMAGE THE POOL?

Aggressive rhizomes or roots rarely cause problems. But they can grow into inexpertly welded joints with protruding seams and prise them apart. Pockets formed by too large folds create the possibility of roots and rhizomes penetrating the lining if they get caught in the fold and cannot escape laterally.

Table 36 **Plants with aggressive rhizomes or roots which may cause damage**

Helophytes: *Phragmites australis, Phalaris arundinacea, Cyperus longus, Zizania caduciflora, Schoenoplectus lacustris, Lythrum salicaria* (pointed tap roots), *Equisetum hyemale*
Terrestrial Plants which may penetrate the liner from outside: *Phyllostachys* spp. and other rhizomatous bamboos, *Prunus spinosa, Pyracantha coccinea, Hippophae rhamnoides, Elaeagnus commutata*

The species listed above not only risk damaging the sealing, but also tend to form extremely competitive clumps, overgrowing neighbouring plants (see p. 146).

PLANT EXAMPLES FOR USE WITHIN THE POOL

TABLE 37: LEGEND AND EXPLANATIONS

Sun/shade tolerance

Most plants prefer sunny sites, which means at least 3–4 hours of full sunlight between 9am and 3pm. Plants for shady or part-shaded sites are marked accordingly.

- Sunny sites
- Partly shady sites
- Shady sites

Mean Maximum height (cm) above substrate or water level

It is not easy to define a specific growth height for certain species as the size increases from spring to autumn. Flower clusters can be enormously tall but slim and transparent, while visually dominant leaf tufts may not reach even half their level. Therefore figures given are for the average maximum height in a suitable environment in our experience.

~ plant submerged

Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere

The coloured cells indicate the season with green foliage. Colour transitions describe variegated leaves. Flowers or visible fruits are depicted by appropriately coloured floral dots. The assigned seasons are derived from reference sources and own experiences in warm–temperate (nemoral) Central Europe (except purely tropical species). In warmer areas, blooming will occur earlier and the leafy cycle will be prolonged. In the nemoral zone of the southern hemisphere the sequence of months will be six months later. Inconspicuous flowers or fruits are not depicted.

Depth Zone

1 **Zone 1: around the pool**; outside of the sealing, without connection to the water body, "normal" garden soil; can be dry to moderately damp
2 **Zone 2: wetland area**; 5–15 cm above water level; permanently wet, but not flooded
3 **Zone 3: swamp area**; fluctuating between 5 cm above to 5 cm under water level
4 **Zone 4: shallow water area**; permanent water depth 5–40 cm
5 **Zone 5: water lily area**; minimum water depth 70 cm

Growth habit

When designing a sustainable planting scheme it is important to assess the competitive capacity of individual plants. Slim, tall species (often bulbs or corms) need partners that produce a certain amount of coverage, growing through the surrounding vegetation. Wide clump-forming plants can overgrow weaker neighbours. Plants with runners may develop into large groups or even single-species populations. Beside their ability to proliferate, their competitiveness depends on density and height.

- Plant body under water / mainly submerged
- Plant body mainly or partly submerged or with floating leaves
- Plant shoots emerge above water level

Submerged forbs, not fixed in the ground with roots	Forbs with floating, leaves not fixed in ground with roots	Forbs with floating, leaves fixed in the ground with roots	Forbs, grasses or shrubs with ± upright or creeping shoots/leaves, fixed in the ground with roots	
				Slim, vertical growth
				Compact clumps or rosettes
				Wide clumps/tussocks
				Very wide, dominant clumps/tussocks
				Low tendency to form runners or cushions
				Moderate runners
				Strong runners (rhizomes or stolons)
				Extremely rampant competitive runners
				Conspicuous propagation by self-seeding

– –	Short lifespan, often disappears after the first few years
–	Starts with solid presence, but declines over the years
±	Sustainably solid presence; does not become too competitive
+	Moderately spreading, but rarely too competitive
++	After a number of years outcompetes other plants
+++	Rampant growth, overgrows all weaker partners; hard to keep under control

Some species, mainly those without runners, produce a huge amount of seeds. If additionally competitive with vegetative sprouts (C-R-strategists) they can get out of hand and cause maintenance problems. The best countermeasure is regular removal of seedheads. Relevant species are marked by a dotted cell.

Estimated level of coexistence

During the first two years after construction, most planting schemes look well balanced. After this initial phase dense vegetation cover will develop and increasing competition between various species occurs. During this process, ruderals (R-Strategists) will partly disappear, though very competitive ones may overgrow their neighbours. Even in well-balanced, site-appropriate plantings some species are not able to form lasting populations without regular replanting. The stated coexistence levels are derived from the authors' experience in Central Europe and may vary according to region, site conditions and plant combinations.

Water hardness (for terrestrial plants: pH)

Numerous terrestrial plants are adapted to particular pH values. This roughly corresponds to the behaviour of aquatic plants in relation to water hardness.

Most terrestrial plants from acidic sites do not thrive on alkaline substrates or those containing lime/carbonate; usually the younger leaves get chlorotic–yellowish because of iron deficiency.

Aquatic plants suited to soft water often fail if used in hard-water environments and a lack of dissolved carbon dioxide can cause problems for submerged plants.

By contrast, unsatisfactory growth only exceptionally results if plants from alkaline/calcareous sites are cultivated on acid substrate or in moderately soft water. This means that plants for P-limited water generally also thrive in C-limited systems.

1	Only thrives in soft water (< 5° KH) or on acid ground (pH < 5.5)
2	Soft water advantageous; growth restrictions in hard water or alkaline soil
3	A wide range of water hardness or acidity accepted
4	Only thrives in hard water or alkaline soil (some lime content required)

Demands in nitrogen

Although only one of numerous nutrients, nitrogen is often used to indicate the overall trophic level. The system devised by Ellenberg (1992) shows the ecological optimum: the site conditions where a species occurs in nature under the influence of competing neighbouring plants. Respecting these natural facts in planned planting schemes will reduce maintenance demands. Plants from poor sites may thrive on rich substrates but they will easily be outcompeted by plants from rich origins, including weeds. Plants with a high Ellenberg nitrogen value however will soon show signs of nutrient deficiency and grow poorly or even disappear if used on significantly poorer sites.

The Ellenberg system may be too finely graded for application in planting design, so we have marked three main groups (1–3: poor sites; 4–6: moderate sites; 7–9: rich sites) in different shades of gray. Though we refer to Ellenberg, we adapted several items according to our experience of their behaviour in artificial ponds and estimated the nitrogen demands for species not listed in Ellenberg's indicative values.

1	Poorest nitrogen content (oligotrophic)
2	Intermediate level, between 1 and 3
3	Poor nitrogen content (oligo- to mesotrophic)
4	Intermediate level, between 3 and 5
5	Moderate nitrogen content (mesotrophic)
6	Intermediate level, between 5 and 7
7	High nitrogen content (eutrophic)
8	Intermediate level, between 7 and 9
9	Abundant nitrogen content (hypertrophic)

Proposed USDA hardiness zones (in cm water depth)

The USDA zones do not define the lowest temperature a species can survive, but they show regions in which it can be expected to withstand an average winter. The zones are not defined on average annual extreme minimums. So to be on the safe side, select species from one or even two half-zones lower than your area. We show the spectrum from coldest to warmest recommendable climate. If the range between coldest and warmest zone is very small, a good adaptation to oceanic areas can be surmised. In continental influenced climates, species with a wide range of USDA zones might be more reliable.

Zone	Average annual extreme minimum temperature °F	°C
1a	below –55	below –48.3
1b	–55 to –50	–48.2 to –45.6
2a	–50 to –45	–45.5 to –42.8
2b	–45 to –40	–42.7 to –40.0
3a	–40 to –35	–39.9 to –37.3
3b	–35 to –30	–37.3 to –34.5
4a	–30 to –25	–34.4 to –31.7
4b	–25 to –20	–31.6 to –28.9
5a	–20 to –15	–28.8 to –26.2
5b	–15 to –10	–26.1 to –23.4
6a	–10 to –5	–23.3 to –20.5
6b	– 5 to 0	–20.4 to –17.8
7a	0 to 5	–17.7 to –15.0

Zone	Average annual extreme minimum temperature °F	°C
7b	5 to 10	–14.9 to –12.3
8a	10 to 15	–12.2 to – 9.5
8b	15 to 20	–9.4 to –6.7
9a	20 to 25	–6.6 to –3.9
9b	25 to 30	–3.8 to –1.2
10a	30 to 35	–1.1 to 1.6
10b	35 to 40	1.7 to 4.4
11a	40 to 45	4.5 to 7.2
11b	45 to 50	7.3 to 10.0
12a	50 to 55	10.1 to 12.8
12b	55 to 60	12.9 to 15.6
13a	60 to 65	15.7 to 18.3
13b	65 to 70	18.4 to 21.1

Natural distribution

In contemporary planting design the natural distribution of species used has become a very important feature. As a countermeasure to the worldwide problem of alien species (neophytes) infiltrating native ecosystems, numerous ecologists recommend not using foreign species even in urban plantings. On the other hand, an aesthetically pleasing result often demands the inclusion of species from other continents. Whichever philosophy you prefer, please be very careful with using species marked as "invasive neophytes", which may upset the balance of your whole garden.

Region		Continent	
N-	North	Eu	Europe
S-	South	As	Asia
W-	West	Af	Africa
E-	East	Am	America
C-	Central	Au	Australia
cosm.	Cosmopolitan	NZ	New Zealand
red type	Introduced, not native	!	Invasive neophyte

Planting area

Although substrate filters (BSF) work independently of vegetation, they may be planted for ornamental purposes, ideally with shallow-rooting species. We indicate areas which are particularly suitable, but the spectrum is much wider.

HBS	Hydrobotanical Systems
TWL	Technical Wetlands
BSF	Biofilm-accumulating Substrate Filters
RGF	Rock Garden Filters
Fen	Fen meadow, ± hard water
Bog	Bog garden, ± acid
TallForb meadows	Tall forb community, flowering
	Along streams
	Poisonous plant (this does not mean all other species are edible)

Plant type

m	Monoculture plant; plant in groups
d	Dominant plant
c	Companion plant
g	Ground cover plant
b	Bulb or scattered plant
s	Sowing between plantings possible

Planting theme

	East Asian gardens
	Gardens with tropical appearance
	Mediterranean gardens

Specifications derived and modified from Baumhauer, Schmidt & v.d. Weyer, 2014; Ellenberg, 1992; Erhardt et. Al., 2008; http://davesgarden.com/; Inst. f. Wasserwirtschaft (ed.), 1982; Kircher, 1996, 2004 & 2007; www.stauden-stade.de; Schwarzer, 2008, wikipedia; www.nympheion.de; www.seerosensorten.de; http://plants.usda.gov/

Table 37 **Plant species for natural pools**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	J F M A M J J A S O N D	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Acorus calamus Sweet Flag		100			3 4		++	3	7	4a - 9b	E-As, Eu, N-Am	HBS, TWL, m/c
Acorus calamus 'Variegatus' Variegated Sweet Flag		80			3 4		++	3	7	4a-9b	cultivar	HBS, TWL, m/c
Acorus gramineus Japanese Sweet Flag		30			(1) 2 3		+	3	6	7b-10	E-As	TWL, c/g
Acorus gramineus 'Argenteostriatus' Silver Japanese Sweet Flag		20			(1) 2 3		+	3	6	7b-10	cultivar	TWL, c/g
Acorus gramineus 'Ogon' Golden Japanese Sweet Flag		25			(1) 2 3		+	3	6	7b-10	cultivar	TWL, c/g
Acorus gramineus 'Pusillus' Golden Japanese Sweet Flag		10			(1) 2		+	3	6	7b-10	cultivar	TWL, g/c
Alisma lanceolatum Lanceleaf Water Plantain		90			3 4		++	3	6	5a-9a	Eur to C-As, N-Af, N-Am!, NZ!, Au!	HBS, c/b
Alisma plantago-aquatica subsp. *plantago-aquatica* European Water Plantain		90			3 4		++	3	8	5a-9a	Eur to C-As	HBS, c/b
Alisma subcordatum American Water Plantain		70			3 4		+	3	8	4a-9a	N-Am	HBS, c/b
Allium schoenoprasum Chive		40			1 2 (3)		++	3	2	3a-9b	Eu, As, N-Am	BSF, Fen, c/b
Allium suaveolens Sweet Scented Leek		50			1 2		++	3	2	4a-9b	C-Eu to E-Eu	BSF, Fen, c/b
Andromeda glaucophylla Blue-Leaved Bog Rosemary		40			2		+	1	2	2b-8b	N-Am	TWL, Bog, c
Andromeda polifolia Bog Rosemary		40			2		+	1	1	2b-8b	Eur to E-As, N-Am	TWL, Bog, c
Anemopsis californica Yerba Mansa, Lizard Tail		40			2 3		+	3	5 ?	7a-10	N-Am	TWL, c

Estimated level of coexistence: ++ inconspicuous flower heads, medicinal plant, but poisonous if ingested in quantity; ++ variegated leaves make it suitable for formal gardens; + evergreen leaves, inconspicuous flowers, good ground cover; + silvery variegated evergreen leaves; + golden variegated evergreen leaves; + evergreen dwarf form; ++ Inflorescences appear like "Baby's Breath" on most healthy *Alisma*, narrow leaves; ++ Inflorescences appear like "Baby's Breath", prone to Alisma Smut Fungus; + Inflorescences like "Baby's Breath", very prone to Alisma Smut Fungus, round leaves; ++ very dry resistant, prefers moving water if used in zone 2; ++ very dry resistant, but also thrives in damp soil, good for autumn effect; + low evergreen shrub with bluish leaves, grows between *Sphagnum* cushions; + low evergreen shrub leaves, grows between *Sphagnum* cushions; + bloom turns reddish when wilting, medicinal use against colds, stomach ulcers, etc

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit
Aponogeton distachyos Cape Pond Weed, Water Hawthorn		10	J F M A M J A S O N D	4 5	
Asclepias incarnata Swamp Milkweed		100		1 2	
Aster (Oclemena) nemoralis Bog Aster		30		2	
Bacopa monnieri Moneywort		10		3 4	
Baldellia ranunculoides Lesser Water Plantain		15		3 4	
Bistorta (Polygonum) officinalis European Bistort		70		1 2	
Brasenia schreberi Water Shield		5		4 5	
Butomus umbellatus Flowering Rush		130		3 4	
Calla palustris Bog Arum, Wild Calla		30		3 4	
Callitriche palustris agg Water Starwort		~ 5		4 (5)	
Caltha leptosepala Mountain Marsh Marigold		20		2 3	
Caltha natans Floating Marsh Marigold		~ 5		4 5	
Caltha palustris Kingcup, Marsh Marigold		30		1 2 3	
Caltha palustris 'Auenwald' Kingcup, Marsh Marigold		60		3 4	

Table 37 **continued**

Species or cultivar Common name	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Aponogeton distachyos Cape Pond Weed, Water Hawthorn	–	3	7	9a-11 (>60cm: 7)	S-Af	HBS, b
floating leaves in autumn and spring, flowers are prone to damage by water-snails						
Asclepias incarnata Swamp Milkweed	–	2-3	7	3a-8b	N-Am	TWL, TallForb, d
good cut flowers, fruits with silky haired seeds in late summer						
Aster (Oclemena) nemoralis Bog Aster	++	1	2	3a-8b	N-Am	TWL, Bog, c
likes to grow between *Sphagnum*, valuable for autumn flowering						
Bacopa monnieri Moneywort	+	2-3	4	8a-12	N-Am, C-Am, S-Am, E-As, S-Eu	HBS, TWL, BSF, g
submerse or ground cover plant						
Baldellia ranunculoides Lesser Water Plantain	–	3-4	1-2	7a-9a	Eu, W-As, N-Af	HBS, TWL, BSF, b/s
short-lived, but reliably self-seeding, subsp. *repens* forms runners!						
Bistorta (Polygonum) officinalis European Bistort	+	3	5	3a-8b	Eu to E-As	TWL, TallForb, c
forms groups by short runners, subsp. *carnea* is more compact and darker in bloom						
Brasenia schreberi Water Shield	++	2	5 ?	3a-10b	Am, As, Af, E-Au	HBS
can show annoying proliferation in warm climates. Emits allelopathic substances						
Butomus umbellatus Flowering Rush	+	3	7	5a-11	Eu, As, N-Am	HBS, TWL, BSF, m/c
runners are easy to reduce						
Calla palustris Bog Arum, Wild Calla	+	2	5	4a-8b	Eu to As, N-Am	HBS, TWL, g
red fruits in late summer. Older parts of the creeping rhizomes die back						
Callitriche palustris agg Water Starwort	–	2	4 ?	6a-9b	Eu, As, N-Am	HBS, TWL, g/c
floating leaf rosettes, submerged parts survive winter frost. Many similar species						
Caltha leptosepala Mountain Marsh Marigold	–	3	5 ?	3a-8b	N-Am	TWL, RGF, Fen, c
alpine dwarf Kingcup, prone to slug damage						
Caltha natans Floating Marsh Marigold	– –	2 ?	5 ?	2b-7a	N-Am, E-As	HBS
does not tolerate hot conditions						
Caltha palustris Kingcup, Marsh Marigold	++	3	4	3a-10	Eu, As, N-Am	TWL, Fen, c
diverse cultivars, 'Tyermannii', large-bloomed						
Caltha palustris 'Auenwald' Kingcup, Marsh Marigold	++	3	5	3a-10	cultivar	HBS, TWL, c
very tall cultivar, good between reed groups						

Table 37 **continued**

Species or cultivar Common name	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Caltha palustris 'Multiplex' Double Flowered Kingcup	–	3	5	3a-10	cultivar	RGF, c
compact, double-flowered cultivar, not for inundated situation						
Caltha palustris var. *alba* White Kingcup	–	3	5	3a-10	E-As	RGF, c
compact, white-flowered variety from Himalayas, not for inundated situation						
Canna flaccida Golden Canna	++	3	8	8b-11	N-Am	TWL, d
sprouts die off at frost, put in greenhouse in cold winters or store rhizomes cool & dry						
Canna glauca Water Canna	++	3	8	10-13	C-Am, S-Am	TWL, d
sprouts die off at frost, put in greenhouse in cold winters or store rhizomes cool & dry						
Canna x *generalis* Hybrid Canna various leaf & flower colours	++	3	8	10-13	cultivars	TWL, d
sprouts die off at frost, put in greenhouse in cold winters or store rhizomes cool & dry						
Cardamine pratensis Cuckoo Flower, Lady's Smock	++	3	3	3a-9b	Eu, As, N-Am	TWL, Fen, b
very good spring bloomer, shoots die back in summer						
Carex acuta (*C. gracilis*) Acute Sedge, Slender Sedge	+++	3	3	3b-9a	Eu, W-As, N-Af	HBS, TWL, m
rampant sedge with deciduous, narrow leaves						
Carex acutiformis Lesser Pond Sedge	+++	3	4	3b-9a	Eu, W-As, C-As, N-Af	HBS, TWL, m
rampant sedge with evergreen leaves, extremely competitive!						
Carex aurea Golden Sedge	+	3	4	3a-9	N-Am	TWL, BSF, Fen, c
drought tolerant, unusual bright fruit colour						
Carex davalliana Bath Sedge, Davall's Sedge	++	3-4	2	3b-9a	Eu, N-Am	TWL, BSF, Fen, c/g
low clumps with thread-like leaves, dioecious plant, males with yellow spring blooms						
Carex diandra Lesser Panicled Sedge	+++	3	3	3b-9a	Eu, As, N-Am	HBS, TWL, c
clumps with slender leaves, looks like a small *C. paniculata*, seeding may become annoying						
Carex elata Tufted Sedge	+++	3	4	4b-9b	Eu, W-As	HBS, TWL, d
big clumps with narrow, slightly overhanging leaves, trimming in June prevents seeding						
Carex elata 'Aurea' Bowles's Golden Sedge	++	3	4	5a-9b	cultivar	TWL, d
brighters shady spaces, best under trees, allow big distances between plants						
Carex flava subsp. *flava* Yellow Sedge	+	3-4	2	3b-9b	Eu, W-As, C-As, N-Af, N-Am	TWL, c
leaves and the nice starlike seedheads are light green, moderately seeding						

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Carex grayi Gray's Sedge		60		1 2 3		++	2-3	6	5a-9b	N-Am	TWL, d
tough upright clumps with dark green leaves and big starlike seedheads											
Carex muskingumensis Palm Sedge		60		1 2		++	3	6	3b-9a	N-Am	TWL, d
stalks with alternate overhanging leaves and dark terminal seedheads											
Carex paniculata Greater Tussock Sedge		70		3 4		+++	3	3	3b-9a	Eu, W-As	HBS, TWL, d
wide clumps with moderately narrow leaves. Can become very competitive by seeding											
Carex pendula Drooping Sedge		150		1 2 3		++	3	5	5a-9b	Eu, W-As	HBS, TWL, d
imposing broad-leaved clumps with widely overhanging spikes. Dry resistant in shade											
Carex pseudocyperus Cyperus Sedge		70		2 3 (4)		+	3	6	5a-9b	Eu, As, N-Af, N-Am	HBS, TWL, d/c
light-green-leaved clumps with overhanging spikes											
Carex riparia Great Pond Sedge		120		3 4		+++	3	3	5b-9b	Eu, W-As, C-As	HBS, TWL, m
rampant sedge with evergreen leaves, extremely competitive!											
Carex viridula Little Green Sedge, Little Yellow Sedge		20		2		+	3	2	3b-9a	Eu, As, N-Am	TWL, RGF, Fen, c/g
like a tiny *Carex flava*, highly recommended for low plantings											
Cephalanthus occidentalis Buttonbush		300 (500)		2 3		+	3	7	5a-10b	N-Am, C-Am	TWL, Shrub, d
tolerates coppicing in spring to reduce the transpiration loss											
Ceratophyllum demersum & *C. submersum* Coontail, Hornwort		~		5		++	3-4	8	5b-9b	Eu, W-As, N-Af	HBS, c, g
overwintering as hibernation buds sink down onto the ground											
Chara aspera Coarse Stonewort		~		4 5		–	4	1	3b-9a	Eu to C-As, N-Am, N-Af	HBS, g
forms submerged lawns which may appear spontaneously, sometimes short-lived											
Chara globularis (syn. *C. fragilis*) Stonewort		~		4 5		–	3-4	3	3b-11	± cosm.	HBS, g
forms submerged lawns which may appear spontaneously, sometimes short-lived											
Chara vulgaris Stonewort		~		4 5		–	3-4	4	4b-11	± cosm.	HBS, g
forms submerged lawns which may appear spontaneously, sometimes short-lived											
Chondropetalum tectorum Thatching Reed		200		(1) 2 3		+	2-3	6	9a-11	S-Af	HBS, TWL, BSF, d
ornamental South African grass with dense growth, appearing like a horsetail species											

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Chrysosplenium oppositifolium var. *rosulare* Golden Saxifrage		10		(1) 2		+	3	5	5a-9b	Eu	TWL, RGF, g
slow-growing groundcover, nice beside waterfalls											
Crassula helmsii (*C. recurva*) Australian Swamp Stonecrop		5		(3) 4 5		++	2	5	7a-10	S-Au, NZ, W-Eu/, Eu	HBS, BSF, g
submerged lawns, as aggressive Neophyte trading is prohibited in UK!											
Colocasia esculenta Taro/, Elephant Ear		120		1 2 3		++	3	7	8a-13	S-As, tropical	TWL, d, m
rhizomes must be cooked to be edible, numerous cultivars with colourful leaves											
Cyperus alternifolius (syn. *C. involucratus*) Umbrella Papyrus		120		3 4		+++	3	8	8b-13	E-Af-Isles	HBS, TWL, d, m
can form dense reedbeds, bent-over stems can form new plants											
Cyperus haspan Dwarf Papyrus, Galingale		80		2 3		+	3	7	8b-11	N-Am	TWL, c
fine textured foliage, bent-over stems can form new plants											
Cyperus longus subsp. *longus* Sweet Galingale		120		3 4		+++	3	5	7a-11	Eu, As, Af, W-Au	HBS, TWL, BSF, m
rampant grower, long-leaved inflorescences form thickets after some years											
Cyperus papyrus Papyrus		250 (500)		3 4		++	3	8	9a-13	S-Eu, SW-As, Af	HBS, TWL, m, d
in cooler climate as tub plant with very light, frost free overwintering											
Cyperus prolifer (syn. *C. papyrus* 'Nana') Dwarf Papyrus		150		3 4		++	3	8	8b-13	S-Af	HBS, TWL, m, c
in cooler climate grow as pot plant with very light, frost-free overwintering											
Dactylorhiza Hybrids Garden Orchid		45		1 2		+	3	3	5a-9a	Eu, W-As, N-As	TWL, RGF, Fen, b
will propagate by seeding if set between low- growing companion plants											
Darlingtonia californica Cobra Lily		40 (80)		2 (3)		+	1-2	3	(7b)-9a	N-Am	TWL, Bog, c
best along streams, where the root system is kept cool											
Drosera anglica English Sundew		15		2		–	1	2	4a-6b	Eu, N-As, N-Am	TWL, Bog, b
grow on wet peat or *Sphagnum* cushions, short-lived but self-seeding											
Drosera binata Forked Sundew		35		2		–	1	4	7b-9b	Au, NZ	TWL, RGF, Bog, c
best grown on wet peat											
Drosera rotundifolia Round Leaved Sundew		10		2		–	1	1	3b-9a	Eu, As, N-Am	TWL, Bog, b
grow on wet peat or *Sphagnum* cushions, short-lived but self-seeding											

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Dulichium arundinaceum Threeway Sedge		60	J F M A M J J A S O N D	2 3		+++	2-3	6	5a-11	N-Am	HBS, TWL, m
						forms dense thickets					
Eichhornia crassipes Water Hyacinth		20		4 5		+++	3	8	10-13	C-Am, S-Am, S-As!, Afl!, Au!	HBS
						feared Neophyte in the tropics, suitable as annual plant outside of the tropics					
Eleocharis acicularis Needle Spikerush		15		3 4 5		++	2-3	3	3-9	cosm.	HBS, TWL, g
						evergreen underwater lawns, emersed leaves die down at frost					
Eleocharis dulcis Water Chestnut		120		2 3 4		++	3	7	9b-13	Af, S-As, Au	HBS, TWL, m
						edible corms at the end of rhizomes, but good yields only near equator					
Eleocharis maculosa Spikerush		40		2 3 4		++	3	6	9a-12	C-Am, S-Am	TWL, g
						can form lawns					
Eleocharis palustris Common Spikerush		40		3 4		++	3	6	2-9b	Eu, As, N-Am	HBS, TWL, m
						rampant grower, can form a ground cover between taller C-strategists					
Elodea canadensis & E. nuttallii American Waterweed		~		4 5		+++	3	6	2b-9b	N-Am, Eu!, As!, Au!, Afl!, NZ	HBS
						not recommended outside North America, can smother weaker water lilies					
Epipactis palustris Marsh Helleborine		50		2 3		++	3-4	2	6a-9a	Eu, W-As, C-As	TWL, Fen, c
						in fen meadow plantings sometimes too competitive - remove seedheads					
Epipactis 'Sabine' Hybrid Helleborine		60		1 2 3		++	3	2	7a-9b	Eu, W-As, C-As	TWL, Fen, c
						in fen meadow plantings sometimes too competitive					
Equisetum hyemale var. robustum Rough Horsetail		150		(1) 2 3 4		+++	3	6	3a-11	N-Am, C-Am	TWL, m
						very invasive, competing out partner plants, but impressively prehistoric-looking					
Equisetum scirpoides Dwarf Horsetail		15		2 3		+++	2-3	2	2a-9b	N-Eu, N-As, N-Am,	TWL, g
						though very shallow it can become invasive and out-compete partner plants!					
Equisetum variegatum Variegated Horsetail		30		2		+++	3	2	1-8b	Eu, W-As, N-As, N-Am	TWL, g
						can become invasive and out-compete partner plants!					
Erica tetralix Cross-leaved Heath		35		2		+	1-2	2	6a-8b	Eu	TWL, RGF, Bog, c
						very long-blooming season; also white and dark pink cultivars, prune back in spring					
Eriophorum angustifolium Common Cotton Grass		60		2 3		+++	2	2	3b-7b	Eu, As, N-Am	TWL, BSF, m
						very competitive; in warm areas poor in blooming					

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Eriophorum latifolium Broad Leaved Cotton Grass		70	J F M A M J J A S O N D	2 3		±	3	3	4a - 9a	Eu, As	TWL, BSF, Fen, d/c
						very slender shoots with cotton balls waving in the wind					
Eriophorum russeolum Red Cotton Grass		50		2 3		+	1	3	4a-8b	N-Am, N-Eu, N-As	TWL, Bog, c/b
						orange cotton balls, very slender, never too competitive					
Eriophorum vaginatum Tussock Cotton Grass		60		2 3		+	1	1	1b-9b	Eu, As, N-Am	TWL, Bog, d
						tough tussocks, plant wide distances apart in bog gardens					
Eutrochium (Eupatorium) maculatum Spotted Joe-Pye Weed		170		1 2		+	3	8	3a-8b	N-Am	TWL, TallForb, d
						amazing autumn bloomer, cultivars: Gateway > 2m tall, 'Atropurpureum': dark blooms					
Euphorbia palustris Marsh Spurge		90		1 2 3		+	3	6	5a-9b	Eu, W-As	TWL, TallForb, d
						tolerates dry and wet soil, bright autumn colour, very long-lived					
Filipendula palmata (syn. *F. digitata*) 'Kahome' Siberian Meadowsweet		60		1 2		+	2-3	6	2b-8b	cultivar (E-As)	TWL, TallForb, c
						dwarf form of the Siberian Meadowsweet, pretty summer bloomer					
Filipendula rubra 'Venusta' Queen of the Prairie		150		1 2 3		+	2-3	7	3a-8b	cultivar (N-Am)	TWL, TallForb, d
						elegant tall and space-demanding summer bloomer					
Filipendula ulmaria 'Plena' Double Flowered Meadowsweet		120		1 2 3		+	3	5	3a-9a	cultivar (Eu, As)	TWL, TallForb, d
						pretty double flowers, sterile; the single-flowered species can disseminate invasively					
Fritillaria meleagris Checkered Lily		35		1 2		+	3	5	4a-8b	Eu	TWL, Fen, b
						egg-shaped bells in white or with chessboard pattern on very slim stalks					
Gentiana pneumonanthe Marsh Gentian		30		1 2		–	2-3	3	4a-8b	Eu, W-As, N-As	TWL, RGF, Fen, b
						slim leaves and shoots, nice summer bloomer but low competitive species					
Glyceria maxima 'Variegata' Striped Manna Grass		90		3 4		+++	3	9	4b-9b	cultivar (Eu)	TWL, m
						recommended only with proper N-fertilizing for monoplanting or in wide groups					
Gratiola officinalis Hedgehyssop		40		(1) 2 3		±	2	5	6a-9a	Eu, W-As, C-As	TWL, c, g
						dense cushions, not very strong in competition					
Groenlandia densa Frog's Lettuce		~		4 5		+	3-4	5	6b-9a	Eu, W-As, C-As, N-Af	HBS
						interesting submerse plant with leaves in two rows					
Hakonechloa macra Japanese Forest Grass		40		1 2		+	3	5	5b-9b	E-As	RGF, c, g
						attractive overhanging leaves; variegated leaved cultivars; perfect along shady edges					

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit
			J F M A M J J A S O N D		
Helonias bullata Swamp Pink		45		2	
Hibiscus moscheutos subsp. *palustris* Swamp Mallow		120		1 2	
Hippuris vulgaris Mare's Tail		30		4 5	
Hottonia palustris Water Violet		~ 30		4 5	
Houttuynia cordata Houttuynia		40		1 2 3	
Hydrocharis morsus-ranae		10		4 5	
Iris Ensata-Grp. Japanese Flag		80		1 2	
Iris laevigata Rabbit-Ear Iris		80		1 2 3 (4)	
Iris - Grp. 'Black Gamecock' Dark Louisiana Iris		80		1 2 3	
Iris pseudacorus Yellow Flag		120 (180)		(1) 2 3 4	
Iris setosa Beachhead Iris		60		1 2 (3)	
Iris setosa subsp. *canadensis* 'Nana' Canada Beachhead Iris		30		1 2	
Iris sibirica		100		1 2	
Iris versicolor Blue Flag		60		2 3	

Species or cultivar Common name	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Helonias bullata Swamp Pink	–	1-2	5	4a-9b	N-Am	TWL, RGL, Bog, b
		evergreen leaf rosettes; can be suppressed by competitive neighbours				
Hibiscus moscheutos subsp. *palustris* Swamp Mallow	±	2-3	9	5b-10b	N-Am	TWL, TallForb, d
		cultivars with huge flowers (white, pink or red) prefer slightly drier sites				
Hippuris vulgaris Mare's Tail	++	3-4	5	3a-8b	Eu, As, N-Am	HBS, m, g
		best use submersed in 50 to 80 cm depth				
Hottonia palustris Water Violet	+	2	5	5a-10b	Eu	HBS, c, g
		submersed or floating leaved, inflorescences emerge above the water				
Houttuynia cordata Houttuynia	++	3	6	5a-11	E-As	TWL, m, g
		low growing creeper, 'Tricolor' (= Chamaeleon') is variegated leaved				
Hydrocharis morsus-ranae	++	3	6	5a-9b	Eu, W-As, N-Af, N-Am!	HBS
		forms loose carpets on the water surface; good between reeds and in shade				
Iris Ensata-Grp. Japanese Flag	–	2-3	8	5a-9b	cultivars (E-As)	TWL, TallForb, d, c
		typical for Japanese Gardens, cultivars with huge flowers				
Iris laevigata Rabbit-Ear Iris	±	2-3	7	5a-9b	E-As	TWL, TallForb, c
		long blooming season, repeat blooms till late summer, cultivars in white & spotted				
Iris - Grp. 'Black Gamecock' Dark Louisiana Iris	–	2-3	7	5a-10b	cultivar	TWL, TallForb, d, c
		very dark violet bloom, for "mystical" gardens				
Iris pseudacorus Yellow Flag	++	3	7	3b-9b	Eu, W-As, C-As, N-Af	HBS, TWL, TallForb, d
		expansive growth, very competitive on fertile sites; cultivars with light or double blooms				
Iris setosa Beachhead Iris	+	2-3	5	3a-8b	N-Am, E-As	TWL, Fen, d, c
		prefers cool climate, not too damp, tolerates dryness				
Iris setosa subsp. *canadensis* 'Nana' Canada Beachhead Iris	±	2-3	4	1-8b	N-Am	TWL, RGF, Fen, c, b
		probably the smallest viable iris for pond margins, protect from competitive neighbours				
Iris sibirica	++	3	3	3b-9a	Eu, N-As	TWL, BSF, Fen, d
		slim growth; numerous hybrids which demand richer but less damp sites				
Iris versicolor Blue Flag	+	3	6	4a-8b	N-Am, W-Eu	TWL, BSF, TallForb, c
		long blooming season, inflorescences with numerous flowers				

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit
			J F M A M J J A S O N D		
Iris x *robusta* 'Gerald Darby' Siberian-Louisiana Iris		80		2 3	
Juncus effusus Soft Rush		70		1 2 3	
Juncus effusus 'Spiralis' Corkscrew Rush		40		1 2 3	
Juncus ensifolius Swordleaf Rush		40 (70)		1 2	
Juncus filiformis 'Spiralis Nana' (syn. 'Curly Wurly') Dwarf Corkscrew Rush		25		2 3	
Juncus inflexus Blue Rush		70		1 2	
Lagarosiphon major (*Elodea crispa*) Oxygen Weed, African Elodea		~		4 5	
Ledum groenlandicum Labrador Tea		70		2	
Leucojum aestivum Summer Snowflake		45		1 2 3	
Liatris spicata Dense Blazing Star		100		1 2	
Lobelia cardinalis Cardinal Flower		80		(1) 2 3	
Lobelia sessilifolia Asian Lobelia		90		2 3	
Lobelia siphilitica Great Blue Lobelia		60		(1) 2 3	
Lysichiton americanus Yellow Skunk Cabbage		70		2 3	

Species or cultivar Common name	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Iris x *robusta* 'Gerald Darby' Siberian-Louisiana Iris	+	2-3	7	4a - 9b	cultivar (N-Am)	TWL, TallForb, d, c
		forms tough clumps, intense coloured flowers				
Juncus effusus Soft Rush	++	2-3	4	4a-10b	Eu, W-As	TWL, d, c
		evergreen grass with limited ornamental value, invasively self-seeding				
Juncus effusus 'Spiralis' Corkscrew Rush	+	2-3	4	4a-10b	cultivar (Eu, W-As)	TWL, c
		evergreen shoots are corkscrew-like				
Juncus ensifolius Swordleaf Rush	++	3	6	4a-10b	N-Am, N-Eu	TWL, BSF, c, m
		nice ball-shaped seedheads, but self-seeding can be noxious				
Juncus filiformis 'Spiralis Nana' (syn. 'Curly Wurly') Dwarf Corkscrew Rush	±	2-3	3	5b-10a	cultivar (Eu, N-As, N-Am)	TWL, RGF, c
		evergreen shoots are corkscrew-like				
Juncus inflexus Blue Rush	++	3-4	4	4b-10b	Eu, W-As, C-As	TWL, BSF, d, c
		bluish-green grass with limited ornamental value, invasively self-seeding				
Lagarosiphon major (*Elodea crispa*) Oxygen Weed, African Elodea	+++	3	6	8a-11	S-Af, W-Eu!, Am!, Au!, NZ!	HBS
		USA: prohibited in some states (Neophyte outside South Africa!)				
Ledum groenlandicum Labrador Tea	+	1	2	1-8a	N-Am	TWL, Bog, Shrub, d
		compact shrub, after 15 years about 1 m^2-sized. 'Compactum' is smaller				
Leucojum aestivum Summer Snowflake	+	3	6	4a-9b	Eu, W-As	TWL, b
		bulb to use between tall forb meadows or loose reed plantings				
Liatris spicata Dense Blazing Star	+	3	5	3a-10b	N-Am	TWL, BSF, Fen, TallForb, d, c
		slim summer bloomer from damp prairies, also in white. Dwarf-cultivars prefer it dryer				
Lobelia cardinalis Cardinal Flower	– –	3	7	3a-9b	N-Am, C-Am	TWL, TallForb, d, b
		basic leaf rosettes stay green over winter. Short-lived. Cultivars for annual bedding				
Lobelia sessilifolia Asian Lobelia	+	2	4	5b-9b	E-As	TWL, Bog, TallForb, d
		long-lived species with vertical inflorescences and red leaves in autumn				
Lobelia siphilitica Great Blue Lobelia	+	3	6	4a-9b	N-Am	TWL, s
		short-lived species, but reliably self-seeding; winter-green rosettes				
Lysichiton americanus Yellow Skunk Cabbage	+	2-3	8	5a-8b	N-Am, Eu!	TWL, d, m
		30 cm tall yellow inflorescences before massive leaf rosettes appear				

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit
			J F M A M J J A S O N D		
Lysichiton camtschatcense White Skunk Cabbage	◒	70	✽ ✽	2 3	
Lysimachia nummularia Moneywort	◒ ●	5	✽ ✽	1 2 3	
Lysimachia thyrsiflora Tufted Loosestrife	◔ ◒	50	✽ ✽	1 2	
Lysimachia vulgaris Common Loosestrife	◔ ◒	120	✽ ✽ ✽	1 2	
Lythrum salicaria Purple Loosestrife	◔ ◒	120 (150)	✽ ✽ ✽	1 2 3 4	
Marsilea schelpiana Cutleaf Water Clover	◔ ◒	20		2 3 4	
Marsilea quadrifolia European Water Clover	◒ ●	25		2 3 4	
Mentha aquatica Water Mint	◔ ◒	80	✽ ✽ ✽	2 3 4	
Mentha cervina (Preslia c.) Water Spearmint	◔ ◒	40	✽ ✽ ✽	(1) 2 3	
Menyanthes trifoliata Bog Bean	◔ ◒	30	✽ ✽	2 3 4	
Mimulus guttatus Common Monkey Flower	◔ ◒	40	✽ ✽ ✽ ✽	1 2 3	
Mimulus ringens Allegheny Monkey Flower	◔ ◒	80	✽ ✽ ✽	2 3 4	
Myosotis scorpioides (= M. palustris) Water Forget-Me-Not	◔ ◒	40	✽ ✽ ✽ ✽	1 2 3	
Myriophyllum alterniflorum Alternateflower Watermilfoil	◔ ◒	~ 5		4 5	

Species or cultivar Common name	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Lysichiton camtschatcense White Skunk Cabbage	+	2-3	8	5a-9b	E-As	TWL, d, m
30 cm tall yellow inflorescences before massive leaf rosettes appear						
Lysimachia nummularia Moneywort	++	3	5	3a-9a	Eu, W-As, N-Am!	TWL, BSF, g
conceals ugly edges of the liner, the creeping shoots can grow into deeper water						
Lysimachia thyrsiflora Tufted Loosestrife	+++	2-3	3	3a-9a	Eu, As, N-Am	HBS, TWL, BSF, m
don't underestimate the spreading ability of its rhizomes; slim sprouts appear all around						
Lysimachia vulgaris Common Loosestrife	++	3	5	4b-9b	Eu, As, N-Am	TWL, TallForb, m
nice autumn bloomer, but very long rhizomes result in multiple shoots!						
Lythrum salicaria Purple Loosestrife	++	3	5	3a-9b	Eu, As, N-Am!	HBS, TWL, TallForb, d
on poor sites only 50 cm tall. Agressive Neophyte in USA! Prune back seedheads						
Marsilea schelpiana Cutleaf Water Clover	++	3	6	7b-11b	Af	HBS, TWL, g
lawn-forming fern with clover-like leaves with finely cut texture						
Marsilea quadrifolia European Water Clover	++	3	6	6a-9a	Eu, As, N-Am!	HBS, TWL, g
lawn-forming fern with clover-like leaves, emersed or floating						
Mentha aquatica Water Mint	++	3	5	4b-11	Eu, W-As, N-Af	HBS, TWL, BSF, TallForb, c
aromatic scent if touched, essential oils with antiseptic effect! Can grow between reeds						
Mentha cervina (Preslia c.) Water Spearmint	+	2-3	5	7a-9b	S-Eu, N-Af	TWL, BSF, c, g
narrow leaves with aromatic scent if touched, essential oils with antiseptic effect!						
Menyanthes trifoliata Bog Bean	++	2-3	3	4a-9b	Eu, As, N-Am	HBS, TWL, BSF, Fen, c
long shoots float over the water surface						
Mimulus guttatus Common Monkey Flower	++	3	6	6a-9b	S-Am, Eu!	TWL, s, c
short-lived, but strongly self-seeding. Hybrids with spotted flowers are less aggressive						
Mimulus ringens Allegheny Monkey Flower	–	3	7	4b-9b	N-Am	HBS, TWL, TallForb, d
long-lived species, moderately spreading by rhizomes, slim stalks						
Myosotis scorpioides (= M. palustris) Water Forget-Me-Not	–	3	5	3a-9a	Eu	TWL, BSF, TallForb, c, s
cutting back inflorescences after blooming prolonges lifespan; 'Alba' blooms white						
Myriophyllum alterniflorum Alternateflower Watermilfoil	+	2	3	2b-8a	Eu, As, N-Am	HBS
prefers floating in soft water; emersed, inconspicuous inflorescences						

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit
			J F M A M J J A S O N D		
Myriophyllum aquaticum (syn. *M. brasiliense*) Parrot Feather	◔ ◒	20		4 5	
Myriophyllum crispatum Upright Watermilfoil	◔ ◒	15	✽ ✽ ✽	4 5	
Myriophyllum hippuroides Western Watermilfoil	◔ ◒	10		4 5	
Myriophyllum spicatum Eurasian Watermilfoil	◔ ◒	5		4 5	
Myriophyllum verticillatum Whorled Watermilfoil	◔ ◒	10		4 5	
Nelumbo lutea Yellow Lotus	◔	120 (180)	✽ ✽ ✽	4 (5)	
Nelumbo nucifera cultivars in red to white Sacred Water Lily, Lotus	◔	120 (180)	✽ ✽ ✽ ✽ ✽ ✽	4 (5)	
Nitella flexilis Flexible Stonewort	◔ ◒	~		4 5	
Nuphar advena Erect Spatterdock	◔ ◒	80	✽ ✽ ✽ ✽	4 5	
Nuphar lutea Southern Spatterdock, Yellow Pond Lily	◔ ●	30	✽ ✽ ✽	5	
Nuphar pumila Little Pond Lily	◔ ◒	10	✽ ✽ ✽	4 5	
Nymphaea 'Aurora' Semi-Dwarf Water Lily	◔ ◒	10	✽ ✽ ✽	4	
Nymphaea 'Candidissima' Water Lily	◔ ◒	10	✽ ✽ ✽ ✽	(4) 5	

Species or cultivar Common name	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Myriophyllum aquaticum (syn. *M. brasiliense*) Parrot Feather	++	3	7	7b-12a	S-Am, S-Eu!	HBS, BSF, g
shoots partly submersed and partly floating; can overwinter between reeds in frosty climate						
Myriophyllum crispatum Upright Watermilfoil	++	3	6	8a-10a	Au	HBS
shoots mainly submersed, slim emersed inflorescences						
Myriophyllum hippuroides Western Watermilfoil	++	3	7	7a-11b	N-Am	HBS, BSF
shoots partly submersed and partly floating; can overwinter between reeds in frosty climate						
Myriophyllum spicatum Eurasian Watermilfoil	++	3-4	6	5b-10b	Eu, As, N-Am, Af	HBS
appears often spontaneously, emersed, inconspicuous inflorescences						
Myriophyllum verticillatum Whorled Watermilfoil	+	3-4	8	5b-10b	Eu, As, Am	HBS
shoots mainly submersed, slim emersed inflorescences						
Nelumbo lutea Yellow Lotus	++	3	8	7a-11	N-Am, C-Am	HBS, d, m
tolerates cooler temperature than *N. nucifera*; can be evergreen in very warm areas						
Nelumbo nucifera cultivars in red to white Sacred Water Lily, Lotus	++	3	9	8a-13	S-As, C-As, Au	HBS, d, m
hardy till zone 4 with long warm summers and if rhizomes don't freeze - then deciduous foliage						
Nitella flexilis Flexible Stonewort	+	2	1	4-9b	Eu, As, Am	HBS
makes submersed delicate mats in soft water						
Nuphar advena Erect Spatterdock	++	3	6	3b-10b	N-Am, C-Am	HBS, m, d
tough, emersed leaves provide tropical appearance, small round flowers						
Nuphar lutea Southern Spatterdock, Yellow Pond Lily	+++	3	6	3b-11	Eu, W-As, C-As, N-Am, N-Af	HBS, m
strong grower, recommended only for huge ponds if water lilies don't thrive sufficiently						
Nuphar pumila Little Pond Lily	++	3	2	2a-8b	N-Eu, C-Eu, N-As, C-As	HBS, m, c
weaker in growth than *N. lutea*. Similar to the North American *N. microphylla*						
Nymphaea 'Aurora' Semi-Dwarf Water Lily	+	3	5	4a-11	cultivar	HBS
bowl-shaped flowers, good for shallow water or in troughs; 20-50 cm water depth						
Nymphaea 'Candidissima' Water Lily	++	3	5	4a-11	cultivar	HBS
robust cultivar with bowl-shaped flowers best in 40-80 cm water depth						

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Nymphaea 'Charles de Meurville' Water Lily		10	J F M A M J J A S O N D	5		++	3	6	4a-11	cultivar	HBS
huge bowl-shaped flowers, pale pink to red 70-100 cm water depth											
Nymphaea 'Chrysantha' Semi-Dwarf Water Lily		10		4 (5)		+	3	5	4a-11	cultivar	HBS
bowl-shaped flowers, good for shallow water or in troughs; 20-50 cm water depth											
Nymphaea 'Escarboucle' Water Lily		10		4 (5)		+	3	6	3a-10b	cultivar	HBS
big stellate-shaped flowers, rich-flowering; 70-120 cm water depth, slow growing											
Nymphaea 'Froebeli' Semi-Dwarf Water Lily		10		4		+	3	5	4a-11	cultivar	HBS
cup-shaped flowers, good for shallow water or in troughs; 30-50 cm water depth											
Nymphaea 'Gladstoniana' Water Lily		15		5		+++	3	6	3a-11	cultivar	HBS
huge bowl-shaped flowers, strong grower, needs 80 -150 cm water depth!											
Nymphaea 'Hal Miller' Water Lily		10		5		++	3	5	4a-11	cultivar	HBS
huge stellate shaped creamy-white flowers, 50-90 cm water depth											
Nymphaea 'James Brydon' Water Lily		10		4 (5)		++	3	6	3a-10b	cultivar	HBS
round bowl-shaped flowers, very rich-flowering; 40-70 cm water depth											
Nymphaea 'Joey Tomocik' Water Lily		10		5		++	3	6	4a-11	cultivar	HBS
stellate shaped flowers, most robust hardy yellow cultivar; 40-80 cm water depth											
Nymphaea 'Panama Pacific' Tropical Water Lily		20		4 (5)		++	3	7	8b-12	cultivar	HBS
deep water, bearing new plants at leaf blade's base! One of the best tropical water lilies											
Nymphaea 'Perry's Baby Red' Dwarf Water Lily		5		4		±	3	5	4a-9b	cultivar	HBS
compact round flowers, for shallow water or water-troughs; 30-50 cm depth											
Nymphaea 'Perry's Vivviparous Pink' Water Lily		10		5		+	3	6	5a-11	cultivar	HBS
stellate flowers, can bear young plants at the receptaculum; 40-80 cm water depth											
Nymphaea 'Star of Siam' Tropical Lily		20		4 (5)		++	3	7	9a-12	cultivar	HBS
tropical cultivar with semi-double violet blue flowers; sweet fragrance! Dark mottled leaves											
Nymphaea 'White Sultan' Water Lily		10		5		++	3	6	5a-11	cultivar	HBS
bowl-shaped white flowers, 40-80 cm water depth											
Nymphaea tetragona Dwarf Water Lily		5		4		–	2-3	4	6a-8b	N-Eu, N-As, E-As, N-Am	HBS
tiny plant, prefers cool water, can slightly propagate by self-seeding											

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Nymphoides peltata Floating Heart		5	J F M A M J J A S O N D	5		+++	3-4	7	5a-11	Eu, As, N-Am!	HBS
can cover big areas of the water surface, banned in some US states as invasive weed!											
Onoclea sensibilis Sensitive Fern		70		(1) 2 3		++	3	7	4a-8b	N-Am, E-As	TWL, BSF, c, g
ornamental pinnatisect leaves appear along long runners											
Orontium aquaticum Golden Club		25		(3) 4		±	3	7	5a-10b	N-Am	HBS, TWL, c
blueish leaf rosettes with slim upright flower cobs; floating leaves if planted deep enough											
Osmunda regalis Royal Fern		120		1 2		+	2-3	5	2b-10b	Eu, N-Am	TWL, d
tropical looking fern, forming dark, spore-bearing fronds at the tip of matured leaves											
Peltandra virginica Arrow Arum		70		3 4		±	3	6	5a-9b	N-Am	HBS, TWL, d, c
clump forming perennial appearing similar to Sagittaria, but not proliferating											
Persicaria amphibia (*Polygonum amphibium*) Water Smartweed		10 (40)		2 3 4 5		+++	3	5	5a-9b	Eu, As, N-Am, N-Af, S-Af	HBS, m, g
floating leaves if planted in deep water, upright flower cobs											
Phalaris arundinacea 'Picta' Ribbon Grass		120		1 2 3		+++	3	7	3b-9a	cultivar (cosm.)	TWL, m
variegated leaf form of the Canary Grass, very competitive even on moderately dry soil											
Phragmites australis Common Reed		200		3 4		+++	3	6	4a-10b	cosm.	HBS, TWL, m
roots and rhizomes proliferate rampantly; use only in separated regeneration ponds											
Pilularia globulifera Pillwort		~ (15)		4		+	2	3	6a-9a	Eu	HBS, g
submerged lawns. Similar species in North America: *Pilularia americana*											
Pistia stratiotes Water Lettuce		10		4 5		+++	3	8	10-13	cosm. (tropical)	HBS
floating rosettes of velvety-hairy leaves, inconspicuous white inflorescences											
Pontederia cordata Pickerel Weed		70		3 4		++	3	7	5b-10a	N-Am	HBS, TWL, c
good blooming if sufficiently fed. Hardy even in Zone 3 if planted deep enough											
Pontederia cordata var. *lancifolia* (syn. *P. lanceolata*) Tall Pickerel Weed		120		4 5		+	3	7	6a-11	N-Am	HBS, TWL, d, c
Inflorescences lighter blue than *P. cordata*; hardy in cold areas if planted 50-70 cm deep											
Potamogeton crispus Curly Leaf Pondweed		~		5		++	3	5	5b-11	Eu, As, N-Af, Au, N-Am!	HBS
undulate leaves with reddish veins; can grow rampantly. Banned in some US states!											

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Potamogeton lucens Shining Pondweed		~ (5)		5		++	3	6	2-11	Eu, W-Af	HBS
Potamogeton natans Floating Pondweed		10		4 5		+++	3	6	2-10	N-Am	HBS
Potamogeton perfoliatus Perfoliate Pondweed		~		5		++	3	5	4b-10a	Eu, As, N-Am	HBS
Potentilla (Comarum) palustris Marsh Fivefinger		60		3 4		++	2	2	2a-8b	Eu, As, N-Am	HBS, TWL, c, g
Primula x bullesiana Candelabra Primrose		50		1 2 3		–	3	7	5a-8b	cultivar	TWL, c, b
Primula florindae Tibetan Primrose		60		1 2 3		–	3	7	3a-9b	E-As	TWL, TallForb, c, b
Primula frondosa Birds-Eye Primrose		15		2 3		±	2-3	3	4a-8b	E-Eu	TWL, RGF, Fen, b, c
Primula poissonii Candelabra Primrose		60		2 3		–	2-3	6	5b-8b	E-As	TWL, c, b
Primula rosea Himalayan Meadow Primrose		20		(1) 2 3		±	3	5	5a-8b	E-C-As	TWL, RGF, c, b
Ranunculus peltatus Water-Crowfoot		~ (5)		5		– –	3	6	4a-8a	Eu, W-As, N-Af, NZ!	HBS
Ranunculus flammula Lesser Spearwort		40		3 4		±	2-3	3	2b-8b	Eu, N-W-As, N-Am	HBS, TWL, BSF, c
Ranunculus lingua 'Grandiflorus' Greater Spearwort		90		3 4		+++	3	7	4a-9a	Eu, W-As, N-As	HBS, TWL, m
Rhynchospora (Dichromena) colorata Star Grass		70		2 3		+	3	6	8b-11	N-Am	TWL, c
Sagittaria graminea Grassy Arrowhead		~ 40		4 (5)		++	3	5	5a-9b	C-As, C-Am, Au	HBS, m, c

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere	Depth zone	Growth habit	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
Sagittaria latifolia Broadleaf Arrowhead		70		4		++	3	7	4a-11	N-Am, C-Am, Eu!	HBS, m
Sagittaria sagittifolia Common Arrowhead		60		4		+	3	6	6a-11	Eu, As	HBS, m,c
Sarracenia flava Yellow Pitcher Plant, Trumpets		80		2 3		–	1	4	8b-10b	N-Am	TWL, Bog, d, c
Sarracenia x catesbaei Hybrid Pitcher Plant		50		2 3		±	1-2	4	5b-10b	cultivars (N-Am)	TWL, Bog, c
Sarracenia purpurea Common Pitcher Plant		25		2 3		+	1-2	3	4b-9b	N-Am	TWL, Bog, c
Saururus cernuus Lizard's Tail		70		3 4		++	3	6	5a-11	N-Am	HBS, TWL, m
Schoenoplectus (Scirpus) lacustris Lakeshore Bulrush		180		4 5		+++	3	6	4a-9b	Eu, W-As, C-As, N-Af	HBS, TWL, m
Schoenoplectus lacustris 'Albescens' Variegated Bulrush		130		4 (5)		++	3	6	4a-9b	cultivar	HBS, TWL, m, d
Schoenoplectus (Scirpus) tabernaemontani Soft-Stem Bulrush		150		4		++	4	6	4a-9b	Eu, W-As, N-As, N-Am	HBS, TWL, m, d
Schoenoplectus tabernaemontani 'Zebrinus' Zebra Rush		110		4		++	4	6	4a-9b	cultivar (Eu, As, N-Am)	HBS, TWL, m, d
Schoenus ferrugineus Brown Bogrush		40		2 3		±	3	2	5b-10	Eu	TWL, BSF, Fen, c
Schoenus nigricans Black Bogrush		60		2 3		+	4	3	6a-11	Eu, W-As, C-As, N-Am, Af	TWL, BSF, Fen, d
Scirpoides holoschoenus (syn. *Holoschoenus romanus*) Round-headed Clubrush		90		1 2 3 (4)		+	3	7	6b-10	Eu, As, N-Af	TWL, BSF, d

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere												Depth zone	Growth habit	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
			J	F	M	A	M	J	J	A	S	O	N	D								
Sparganium americanum American Bur-Reed		100													(3) 4 (5)		+++	3	6	5a-11	N-E-Am	HBS, TWL, m
																	submersed to floating leaves and upright erect shoots with green, star-shaped seedheads					
Sparganium emersum (simplex) European Bur-Reed		70													(3) 4 (5)		++	3	7	3a-8b	Eu, As, N-Am	HBS, TWL, m
																	in deep water only floating ribbon-like leaves, upright emersed shoots in shallow water					
Sparganium erectum (racemosum) Erect Bur-Reed		130													(3) 4 (5)		+++	3	7	5a-9b	Eu, W-As, N-Af, N-Am!	HBS, TWL, m
																	submersed to floating leaves and upright erect shoots; prohibited in some US states!					
Sphagnum palustre Peat Moss		15													2 3		+	1	2	4-8	Eu, Am, Au, NZ	Bog, g
																	fast grower, flat cushions which can be grown through by bog-species such as cranberry					
Sphagnum squarrosum Peat Moss		10													2 3		+	1-2	2	4-8	Eu, As, N-Am, N-Af, NZ	TWL, Bog, g
																	fast grower tolerant of water movement. Best results on percolated substrates!					
Stratiotes aloides Water Soldier, Water Pineapple		~ 15													5		++	3	5	5a-11	Eu, W-As	HBS, m
																	rosettes submersed in hard water; they emerge partly in summer in soft water					
Symplocarpus foetidus Skunk Cabbage, Polecat Weed		70													2 3		±	3	8	4b-8b	N-Am, E-As	TWL, d, c
																	winter bloomer: flower cobs 20 cm tall followed by tough leaf rosettes					
Thalia dealbata Blue Canna		180													4		+	3	8	8a-12	N-Am	HBS, TWL, d
																	may be hardy even in Zone 6 if hot summers allow ripening of plant tissue					
Thelypteris palustris Marsh Fern		50													2 3 (4)		+++	3	5	3b-8b	Eu, As, N-Am, Af, NZ	HBS, TWL, BSF, g
																	pinnate-leaved fern with very rampant runners which can float above the water surface					
Trichophorum alpinum Alpine Bulrush		25													2 (3)		±	2	2	2-8b	Eu, N-As, N-Am	TWL, Bog, c
																	small, delicate grass with decorative woolly seedheads, do not plant between *Sphagnum*					
Typha angustifolia Narrowleaf Cattail		240													3 4 (5)		+++	3	7	3a-9a	Eu, As, N-Am, Au	HBS, TWL, m
																	rampant grower, only suitable in separate regeneration ponds, light-brown cobs					
Typha latifolia Broadleaf Cattail		200													3 4		+++	3	7	3a-11	Eu, As, N-Am	HBS, TWL, m
																	rampant grower which can appear spontaneously, dark cobs					
Typha laxmannii Graceful Cattail		130													3 4		+++	3	6	3a-10b	Eu, As	HBS, TWL, BSF, m
																	similar to *T. angustifolia*, but much smaller; forms dense reeds					
Typha minima Dwarf Cattail		50													3 4		++	4	5	3a-10b	Eu, As	HBS, TWL, m, c
																	smallest cattail species; egg-shaped cobs appear early and disperse by summer					

Table 37 **continued**

Species or cultivar Common name	Sun/shade tolerance	Mean maximum height (cm) above substrate or water level	Blooming month & colour, period of green foliage in nemoral zone of the northern hemisphere												Depth zone	Growth habit	Estimated level of coexistence	Water hardness (for terrestrials: pH)	Demands in nitrogen	Proposed USDA hardiness zones (in cm water depth)	Natural distribution	Planting area, plant type, themes
			J	F	M	A	M	J	J	A	S	O	N	D								
Typha shuttleworthii Shuttleworth's Cattail		130													3 4		++	3	6	4-10	Eu, W-As	HBS, TWL, m
																	loose reeds, dark cobs which turn to grey; a bit less competitive than other tall typhas					
Utricularia australis Bladderwort		~ 10													4 5		+	2-3	3	4-9	Eu, As, Af, Au	HBS
																	tender submersed insectivorous plant with "hunting bladders"; emersed yellow flowers					
Vaccinium macrocarpon Cranberry		15													2		++	1	6	2b-8b	N-Am	TWL, Bog, g
																	grows well between *Sphagnum*; reduce runners, when harvesting the berries					
Veronica beccabunga European Brooklime, Cow Cress		30													3 4		–	3	6	5a-11	Eu, W-As, C-As, N-Af, E-Af	HBS, TWL, BSF
																	prefers running water, but often short-lived or vagrant along streams					
Zantedeschia aethiopica Calla Lily, Arum Lily		110													1 2 3		+	2	8	8a-12	S-Af	TWL, TallForb, d, m
																	evergreen if kept moist and warm, leaves die back in cold temperatures and drought					
Zigadenus (Anticlea) elegans Elegant Camas		70													1 2		+	3	4	4b-9b	N-Am	TWL, BSF, Fen, d, b
																	pretty summer bloomer for fen meadows, inside or outside the capillary barrier					
Zizania latifolia (caduciflora) Manchurian Wild Rice															3 4		+++	3	7	6-11	As, NZ!	HBS, TWL, m
																	very rampant grower, used as vegetable in Asia. Import into the USA prohibited!					

SAMPLE PLANTING CONCEPTS FOR DIFFERENT THEMES

The following suggestions introduce plantings particularly rich in species. By leaving out strongly proliferating plants, a natural dynamic begins to evolve. However, in most cases after about 10 years a complete restoration of a planting scheme can be helpful to get rid of thickets. This is also necessary if roots penetrate the drainage pipes of top-down percolated Technical Wetlands and significantly reduce the water circulation rate.

Plantings dominated by rampant species must be arranged in groups of at least five plants per species simply grouped together. Allow very competitive species at least 3 m² per group.

The following examples follow the concept of "randomly mixed plantings" (Kircher et al., 2011), which refrains from strict visual planting plans. Itemized by the design categories "dominant plants", "companion plants", "ground coverers", "scattered plants" and "fillers", we list respective species/cultivars plus required amounts for zones 1 to 5. Submerged and floating-leaved species are listed separately. To provide transitions, several plants are used in two or even three adjacent belts.

WHITE GARDEN

An aura of tranquillity is provided by a reduced palette of colours. Limiting the design to white flowers plus silvery or variegated leaves communicates a kind of sacred purity, best suited to formal gardens.

The listed plant combination is suitable in USDA zones 6b to 8b. It requires at least mesotrophic water. In an oligotrophic pool of model 3 and 4, modest urea nutrition is recommended to permit sufficient plant growth. Some species such as *Pontederias* and *Acorus* may demand extra nutrition (p. 226).

Suitable surrounding trees and shrubs (zone 1): *Davidia involucrata*, *Sorbus koehneana* (white fruit, for acidic soil), *Amelanchier lamarckii* 'Ballerina', *Cornus* 'Eddie's White Wonder', *Spiraea arguta.*

Table 38 **White garden plant list**

Plant category & species		Plant quantity per 10 m² of each zone				
		Zone 1	Zone 2	Zone3	Zone 4	Zone 5
Dominant plants	*Aconogonon* 'Johanniswolke'	1				
	Calamagrostis × acutiflora 'Overdam'	5				
	Liatris spicata 'Floristan White'	8	5			
	Asclepias incarnata 'Ice Ballet'		5			
	Ageratina (Eupatorium) rugosum		3			
	Typha latifolia 'Variegata' (best in troughs)			3	3	
	Schoenoplectus tabernaemontani 'Zebrinus'				5	
Companion plants	*Aster divaricatus*	12				
	Achillea ptarmica 'Schneeball'	10				
	Carex diandra		10	10		
	Iris laevigata 'Alba'			15		
	Pontederia cordata 'Alba'			5	10	
	Acorus calamus 'Variegatus'				5	
	Sagittaria trifolia 'Plena'				10	
Ground coverers	*Bergenia* 'Silberlicht'	15				
	Brunnera macrophylla 'Jack Frost'	10				
	Carex conica 'Snowline'	15				
	Carex flava		20			
	Caltha palustris var. *alba*		25			
	Acorus gramineus 'Variegatus'		5	10		
	Gratiola officinalis			10		
	Menyanthes trifoliata			10	5	
Scattered plants	*Anemone blanda* 'White Splendor'	50				
	Lilium candidum	20				
	Cardamine pratensis		15			
	Leucojum aestivum		30			
Fillers	*Ajuga reptans* 'Alba'	20				
	Aquilegia chrysantha 'Silver Queen'	15				
	Myosotis palustris 'Alba'		5	15		
	Alisma lanceolata				8	
Submerse and floating leaved species	*Sagittaria graminea*			3	5	5
	Nymphaea tetragona				8	
	Ranunculus aquatilis				5	5
	Hydrocharis morsus-ranae				5	5
	Potamogeton perfoliatus				5	5
	Nymphaea 'Gonnère'					2
	Aponogeton distachyos					5
	Stratiotes aloides					5

TROPICAL GARDEN

The sumptuous vegetation of a tropical garden – big, lush and intensively green leaves, warm colours of flowers, fruits and even leaves in yellow, orange and red – can be provided by plants from any USDA zones. Blue and violet tones are added as complementary colours. Try to include rosette trees or huge grasses as well as ferns and pinnate-leaved plants to emphasize the tropical theme. Companion species should be planted in groups.

The following list suggests a planting scheme for USDA zone 9b to 11. Most species need proper protection in winter if used in cooler regions. A closely related planting scheme is described in case study 17.

Table 39 **Tropical garden plant list**

Plant category & species		Plant quantity per 10 m² of each zone				
		Zone 1	Zone 2	Zone3	Zone 4	Zone 5
Dominant plants	*Costus comosus*	3				
	Asclepias curassavica	3				
	Canna × generalis 'Tropicanna'	3				
	Canna glauca		3	3		
	Cyperus alternifolius		3	3		
	Colocasia esculenta 'Fontanesii'		2	2		
	Cyperus papyrus		1	1	1	
	Thalia dealbata			2	2	
Companion plants	*Hemerocallis* × 'Mond'	20				
	Ruellia brittoniana	3				
	Tulbaghia violacea	15	5			
	Zantedeschia aethiopica	6	6	6		
	Dichromena colorata		15	10		
	Cyperus haspan		10	6		
	Pontederia lanceolata				6	
	Nelumbo nucifera				2	
Ground coverers	*Liriope muscari* (in shade of tall plants)	30				
	Dichondra repens	10				
	Acorus gramineus cultivars		5	15		
	Eleocharis maculosa		3	10		
	Bacopa monnieri			10	5	
	Marsilea schelpiana			5	5	
Submerse and floating leaved species	*Myriophyllum aquaticum*				3	
	Nymphaea 'Red Flare'				3	
	Nymphaea 'Mrs George H. Pring'					1
	Vallisneria tortifolia					10
	Elodea crispa					5

In oligotrophic and even mesotrophic water, most species demand extra nutrition.

Suitable trees, shrubs or tree-like perennials (zone 1): *Phoenix reclinata, Musa basjoo, Strelitzia nicolai, Spathodea campanulata*, *Cordyline australis, Bambusa tuldoides* 'Ventricosa', *Hibiscus rosa-sinensis*.

FLOWERING LIME FEN MEADOWS

Even in gardens with restricted space, forbs and grasses can be combined to create colourful meadows if species with moderate and slender growth are used. The pool margins can accommodate lime fen gems with rockeries or even RGFs with alpines planted nearby.

This is an exciting solution for naturalistic as well as for formal pools with P-limitation, mainly model 3 and 4 (see case studies 7, 8 and 9).

The listed plant combination is suitable in USDA zones 5b to 8a for oligotrophic hard water.

Some species such as *Iris sibirica, Peltandra* or water lilies may demand extra nitrogen.

Suitable trees and shrubs (zone 1): *Pinus* species with short needles, *Acer griseum*, *Taxus × media* 'Hillii' (male type, no seeds!), *Hamamelis mollis*, *Viburnum farreri*, *Lonicera × purpusii*.

Table 40 **Flowering lime fen meadows plant list: see pages 186 & 187**

ACIDIC BOG GARDEN

The overall appearance of this garden is similar to the lime fen meadow above, but can be established on acid substrate or in water with a low hardness. Fill-up water should be rainwater or very soft mains water (<< 8°dH KH). An artificial peat moss carpet can cover the marginal pool area, accommodating insectivorous plants, orchids and a variety of ericaceous shrubs. The listed plant combination is suitable in USDA zones 7b to 9a in oceanic climates with cool summers. A combination with lime fen species from the list above is possible. Zone 1 species need sufficient moisture even outside the water.

The water should be oligo- to mesotrophic, but *Sarracenias*, *Helonias* and some further species benefit from additional fertilization.

Suitable surrounding trees and shrubs (zone 1): *Pinus banksiana*, *Styrax japonica*, fine-textured Rhododendrons, *Pieris japonica*. Do not include coarse-textured/big-leaved plants. A heather garden is a perfect addition to this theme.

Table 41 **Acidic Bog Garden plant list: see page 188**

Table 40 Flowering lime fen meadows plant list

Plant category & species		Plant quantity per 10 m² of each zone				
		Zone 1	Zone 2	Zone3	Zone 4	Zone 5
Dominant plants	*Iris spuria*	3				
	Aster 'Pink Star'	3				
	Pennisetum orientale 'Tall Tails'	3				
	Liatris spicata	5	5			
	Filipendula ulmaria 'Plena'		3	2		
	Iris sibirica (pure species, not hybridized)		5	3		
	Schoenus nigricans		3	5		
	Carex elata (remove seedheads in June)			2	5	
	Lythrum salicaria (NOT in USA, Canada)			3	2	
	Typha shuttleworthii				2	
Companion plants	*Anthericum ramosum*	15				
	Geranium 'Sirak'	10				
	Gentiana asclepiadea		8			
	Gentiana pneumonanthe		15			
	Tofieldia calyculata		25			
	Iris setosa subsp. *canadensis* 'Nana'		10			
	Phlox glaberrima subsp. *interior*		8			
	Epipactis palustris		3			
	Eriophorum latifolium		12	10		
	Schoenus ferrugineus		5	10		
	Caltha palustris			10		
	Peltandra virginica			3	8	
Ground coverers	*Geranium cantabrigiense* 'St. Ola'	15				
	Carex caryophyllea 'The Beatles'	15				
	Alchemilla faeroensis (close to capillary barrier)	15	20			
	Carex serotina		20			
	Carex davalliana		5			
	Menyanthes trifoliata			5	10	
Scattered plants	*Narcissus triandrus* 'Hawera'	80				
	Dactylorhiza Hybrids	5	10			
	Gladiolus imbricatus	20	20			
	Allium angulosum	10	25			
	Allium suaveolens		15			
	Cardamine pratensis		10			
	Parnassia palustris		20			

Table 40 continued

Plant category & species		Plant quantity per 10 m² of each zone				
		Zone 1	Zone 2	Zone3	Zone 4	Zone 5
Fillers	*Primula veris*	20				
	Lychnis flos-cuculi	10	10			
	Myosotis palustris			10		
	Baldellia ranunculoides			5	10	
	Alisma lanceolatum				10	
Submerse and floating leaved species	*Nymphaea* 'Perry's Baby Red'				3	
	Nymphaea 'Berthold'				3	
	Myriophyllum spicatum (mostly appears spontaneously)			5	5	
	Myriophyllum crispatum				5	5
	Potamogeton perfoliatus				5	5
	Sagittaria graminea				5	3
	Nymphaea 'Rosennymphe'					2
	Chara vulgaris					5

SHADY GARDEN

Table 42 Shady Garden plant list: see page 189

Parts of a pool and its surroundings can be shaded by tall trees or buildings. A moderately dark environment should not be too rich in species. Leaf and plant shapes are more important than a great diversity of colourful flowers. Cultivars with yellow foliage tend to burn if grown in full sunlight, but in shady areas they brighten the appearance and improve contrasts.

The listed plant combination is suitable in USDA zones 7a to 9a for mesotrophic, moderately soft water. The soil in zone 1 is assumed to be slightly acid and provide a certain degree of moisture.

Some species such as *Symplocarpus foetidus* and *Lysichiton* spp. may require extra nitrogen.

Suitable surrounding trees and shrubs (zone 1): rhododendrons (if the pH is above 6, choose plants grafted on lime resistant rootstocks, named "INKARHO"), *Ilex × meservae*, *Lonicera × purpusii*, *Hamamelis mollis*, *Stewartia pseudocamellia*.

Table 41 Acidic Bog Garden plant list

Plant category & species		Plant quantity per 10 m² of each zone				
		Zone 1	Zone 2	Zone3	Zone 4	Zone 5
Dominant plants	*Molinia caerulea* 'Edith Dudszus'	5				
	Gentiana makinoi 'Royal Blue'	5				
	Zigadenus elegans	8	3			
	Rhododendron canadense		3			
	Ledum groenlandicum		2	1		
	Eriophorum vaginatum		3	3		
	Lobelia sessilifolia		3	5		
	Sarracenia flava		5	3		
Companion plants	*Arnica montana* (not between *Sphagnum*)	20	10			
	Bletilla striata	3	8			
	Andromeda polifolia		3			
	Kalmia polifolia		5			
	Erica tetralix		10			
	Aster nemoralis		15			
	Darlingtonia californica		5			
	Sarracenia Hybrids		5			
	Sarracenia purpurea		5	5		
	Eriophorum russeolum			8		
	Peltandra virginica			5	10	
Ground coverers	*Calluna vulgaris* cultivars	30				
	Erica vagans cultivars	25				
	Alchemilla faeroensis (close to capillary barrier)	15	10			
	Vaccinium macrocarpum		5			
	Sphagnum palustre etc.		20	20		
	Trichophorum alpinum (not between *Sphagnum*)		15	10		
Scattered plants	*Erythronium* 'Pagode'	15				
	Pogonia ophioglossoides		15			
	Drosera binata		8			
	Helonias bullata (not between *Sphagnum*)		15	8		
Fillers	*Lychnis viscaria* 'Plena'	8				
	Pinguicula grandiflora (lime tolerant; not between *Sphagnum*)		10			
	Primula rosea (not between *Sphagnum*)		10	10		
	Drosera anglica		10			
	Viola palustris		5			
Submerse and floating leaved species	*Crassula helmsii*			5	5	5
	Pilularia globulifera				5	
	Nymphaea tetragona				5	
	Nymphaea 'Froebelli'				2	
	Nymphaea 'Candidissima'				1	
	Brasenia schreberi				3	2
	Aponogeton distachyos					3
	Utricularia australis					5

Table 42 Shady Garden plant list

Plant category & species		Plant quantity per 10 m² of each zone				
		Zone 1	Zone 2	Zone3	Zone 4	Zone 5
Dominant plants	*Molinia arundinacea* 'Karl Foerster'	2				
	Astilbe chinensis var. *taquetii* 'Purpurlanze'	5				
	Cimicifuga ramosa	3				
	Osmunda regalis		1	2		
	Lysichiton camtschatcense		3	3		
	Iris pseudacorus 'Bastardii'			3	3	
Companion plants	*Iris foetidissima*	10				
	Bergenia 'Herbstblüte'	5				
	Hosta 'Fortunei Aurea'	5				
	Symplocarpus foetidus		5	5		
	Carex elata 'Aurea'		3	5		
	Dryopteris cristata		5	5		
	Carex appropinquata		10	8		
	Caltha palustris 'Auenwald'			5	5	
Ground coverers	*Omphalodes verna*	20				
	Waldsteinia geoides 'Leuchtkäfer'	12				
	Lysimachia nummularia 'Aurea' (close to capillary barrier)	15	10			
	Chrysosplenium oppositifolium var. *rosulare*		10			
	Houttuynia cordata 'Chameleon'		5	5		
	Calla palustris			5	5	
Scattered plants	*Galanthus nivalis*	30				
	Adonis amurensis hort.	10				
	Lilium hansonii	10				
	Leucojum vernum	30	50			
Fillers	*Primula elatior*	20				
	Aquilegia caerulea	5				
	Primula poissonii		10			
	Primula × bullesiana		8	8		
	Lobelia cardinalis		10	10		
Submerse and floating leaved species	*Hottonia palustris*				5	
	Fontinalis antipyretica				3	3
	Hydrocharis morsus-ranae				5	5
	Brasenia schreberi					3
	Nuphar angustifolia					2
	Ceratophyllum submersum					5

PLANTING TECHNIQUES

PREPARING THE PLANTING AREA

Except for non-rooted submerged and floating species, all plants need a substrate layer in which to fix their shoots. For the vast majority of species a thickness of 10–20 cm substrate is sufficient for healthy growth. Only some very deep-rooting helophytes need at least 30 cm, mainly representatives of the genera *Canna*, *Lysichiton, Orontium* and *Symplocarpus*. These deep rooters should not be planted on BSFs. For vigorous water lilies and lotuses we also recommend deep and spacious substrate beds to support their healthy development even in water with low nutrient levels. Lotuses in particular need extra fertilization.

Substrates must be free of organic matter. For bog or fen plants in pools which provide C-limitation (mainly models 1 or 2, and possibly 3) organic particles (peat) are allowed in zone 2 and 3, above or even slightly below water level.

If not used in model 4 pools, species which require nutrients such as the above can be planted on beds on a 5–10 cm sublayer of clay or silt to improve the chemical buffering of the water quality around the roots. This layer should be covered with the essential substrate, mainly 10–20 cm gravel of 1–8 or 2–8 mm grain size.

To allow regular fertilization with tablets, especially if they contain phosphorus, cover the substrate in zones 3 to 5 with a 5 cm top layer of clay (ÖNORM, 2013; Wesner, 2014). This is important to separate the nutrient-enriched substrate water from free-flowing water. This is only possible in plantings outside of percolated filter areas (TWL and BSF), but recommended for HBS. Of course the clay as well as all substrate materials must be free from soluble phosphorus. The best tactic is to put down the clay after siting the plants, allowing for the thickness of the clay layer.

The carbonate (lime) content of all materials depends on the limitation strategy being used.

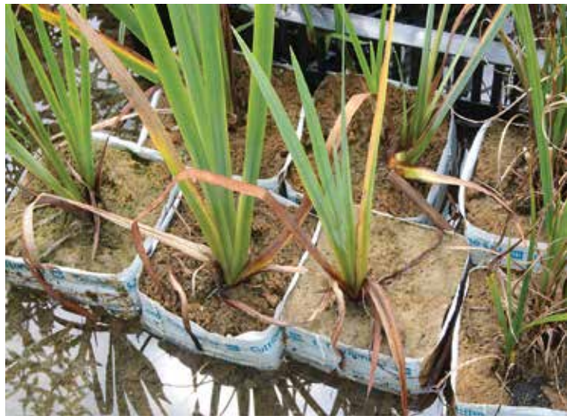
Some experts even use pure loam or clay for the entire planting bed. Covering the clay layer with coarse gravel or pebbles is often recommended, but it may cause problems by partly sinking into the clay and making maintenance difficult. Vacuuming up organic debris will be easier from a pure clay surface. A gravel layer directly on a clay body also affects aerobic conditions within close proximity to an anaerobic environment, which can stimulate phosphate releases (Woodhouse, 2014).

Scattered on the gravel, substrate clay pellets ("Nymulat") or clay chips are a suitable cover to separate fertilized substrates from the pool water. Once soaked with water they form a dense layer.

PLANT MATERIAL

Special water-plant nurseries offer cultivated plants in pots. For use in natural pools the plants should be cultivated in nutrient-poor media. Heavily fertilized and quick-growing helophytes and hydrophytes cause too much phosphorus influx through their root bales and the cell tissue is not tough enough to tolerate a sudden switch to oligotrophic conditions. The pot substrate should be purely mineral. If the growing medium is based on peat or any organic matter, we recommend carefully removing the substrate at least partly and planting bare rooted.

Of course plants must be free from pests, diseases and weeds. Water lilies and other plants for zones 4 and 5 should be checked for waterweed (*Elodea*), which can choke small water lilies and other sensitive species.



Production of *Cyperus longus* left and *Iris pseudacorus* right in rockwool substrate, a kind of hydroculture which is particularly beneficial for plants destined for nutrient-poor pools and meets the demands of ÖNORM 2013 (Nursery A. Kern, Graz, Austria).

PLANTING SEASON

The usual seasons for planting in zone 1 are spring and autumn in the nemoral zone. As long as there is adequate irrigation, you can plant perennials and shrubs with potted bales throughout the summer. In subtropical regions, winter or the beginning of rainy seasons are suitable planting periods.

Within the water itself, there are temperature requirements to observe so that roots can grow and fix in the substrate. A suitable period in nemoral climates is from late April to July. Only quick-rooting species

should be planted later to avoid winter damage. Late-planted specimens in zones 2 and 3 can be harmed by ice pressure pushing them above the substrate. Vigorous species may survive that, but must be pressed back into the substrate in spring. In warmer climates the planting season is proportionately longer of course.

Seeded vegetation in zone 1 should be applied in autumn because numerous species need at least four weeks with cool temperatures (<4°C) to trigger germination.

PLANTING PROCEDURE

Plants are usually sold in pots or containers; these should be removed before planting, except biodegradable ones. The latter should only be used in zones 1 and 2 because of their organic content. They should be partly opened down the side before planting to encourage root growth. Remove organic particles from the roots if using in zones 3 to 5. It is advisable to remove at least the top 2 cm layer of the substrate to get rid of hidden weeds.

The root ball of most plants should be inserted in the substrate to the same depth as their pot. Water lilies grow with a horizontal rhizome, which must not be dug in too deep. It should stay shallow enough to be visible. If it can't be adequately fixed, place some big pebbles on the rhizome.

We recommend planting while you are filling the pond with water: when a bed is saturated, stop the water flow temporarily till all plants of this layer have been put in place.

In beds with a clay cover, after planting all spots with a breach in the clay layer must be closed again. Or, as recommended above, plant before creating the clay layer.

In acid bog plantings, *Sphagnum* mosses can be used as ground cover by pressing them flat onto the wet substrate. A capillary that draws water from the substrate into the mosses is necessary for *Sphagnum* to grow.

Non-rooted floating and submerged plants can simply be placed in the water in the desired places. If such plants have to be stored for a certain time, put them into a bucket of water and leave it in a shady place.

Submerged species which produce roots should be pressed into the substrate with their base or fixed with a stone. This will help *Myriophyllum* and *Potamogeton* spp., *Ranunculus peltatus*, *Hottonia*s or *Crassula helmsii* establish themselves.

If rampant growers with long rhizomes are to be combined with clump-forming, compact species, it is worth placing them in big containers or baskets. Their size can be controlled more easily but often after three years the new shoots appear malnourished and crowded together. It is best to take the plant out of its vessel and divide it into fist-sized chunks of which only a small number should be replanted in the container. Planting bags made of coconut fibre or other biodegradable material are sometimes favoured, though their lifespan is, of course, limited.

Left Submerged water plants are sometimes sold in transparent packaging. To store them, open the boxes and place them in the shade to prevent overheating, which can prove fatal.

Below left Planting a water lily in a plastic basket: place the rhizome in a corner and point its growing tip towards the centre to provide the greatest potential for growth before it breaches the confines of the basket.
Below right Baskets can't keep water lilies from proliferating with rhizomes, but they can make it easier to reduce the plant by cutting rhizomes which grow through the basket mesh.

Dragonfly top and pairing damselflies bottom depositing eggs in the water.

8
ANIMALS IN THE POOL?

Without any human intervention, a natural pool will quickly attract animals, proof that it is a living biotope. Mesotrophic water attracts animals more than oligotrophic because it offers richer food resources. Formally designed pools often have steep sides, so remember to install supports to help vertebrates get out.

UNINVITED GUESTS

Soon after filling the pool, the first microbic animals (zooplankton) propagate because their predators have not yet arrived: cyclops and water fleas dance in the water like tiny bubbles, feeding mainly on floating algae.

Numerous water insects and other arthropods follow: pond skaters walk across the surface thanks to their hydrophobic feet, great diving beetles make their rounds like tiny submarines and whirligig beetles tumble over the water. Later dragonfly larvae go hunting with their fascinating extendible mouth pliers.

However, if you prefer bathing without any creatures around, choose a model 3C or 4C pool as shown in case studies 10, 16 and 17, ideally with a non-transparent cover for periods when not in use. We recommend this for pools in tropical regions which are potentially at risk from bilharzia or other dangerous water-borne diseases (see p. 200).

Water snails are often introduced as eggs attached to aquatic plants. Most species are harmless or even beneficial to the vegetation because they graze on algal coatings from submerged surfaces. However in the tropics snails play a role in bilharzia transmission.

Common amphibians found in and around natural pools are frogs, toads and newts of various species. They should not be deliberately introduced, but local regulations relating to nature conservation must be complied with. Usually indigenous species quickly populate the pool without any human help.

Most toads visit the water only to reproduce. The females place their

The freshwater snail (*Lymnaea stagnalis*) is a very common part of most ponds and pools in nemoral climate. From top Adult snail on a glass plate; clutches of eggs on the underside of a water lily leaf; leaves and flowers of *Aponogeton distachyos* damaged by *Lymnaea* snails.

Top row After a few years or even within the first season, pond frogs (*Pelophylax esculentus*) will move in. Males produce loud croaking with their vocal sacks through the breeding season from late spring till summer; with some patience, amphibians can become accustomed to the human hand, as did this rare moorfrog (*Rana arvalis*), found in Europe and Western Asia.
Right Frogspawn among submerged plants in shallow water.
Bottom row Cute guy with a grumpy face: the Texas toad (*Anaxyrus speciosus*) is a common guest in the southern USA and northern Mexico; tadpoles of the European toad (*Bufo bufo*) grazing on algae on a stone.

spawn in long strings among aquatic plants. In contrast, frog spawn occurs in clumps. When tadpoles hatch, they will prove efficient algae eaters.

Occasionally mammals such as mice or hedgehogs may come to the pool to drink. Steep walls into the pool can become a deadly trap for them, so if there is no shallow planted zone by the swimming area, a wooden board at a gentle angle or a planted floating island (p. 69) can help animals get to land.

INVITED GUESTS

The question of whether it is acceptable to put fish in the pool is a common one. The relevant guidelines (FLL, 2017, ÖNORM 2013) categorically rule this out because fish excrement would introduce nutrients into the system and reduce beneficial zooplankton organisms. Any fish will decrease the population not only of insects but also amphibians. In practice however numerous pool owners keep fish, mostly Japanese koi carp. Case studies 8 and 14 describe pools with koi. The water in case study 8 was moderately hazy with a visual depth of about 1.5 m, which is fine for the owner, but may not be for more demanding users. This model 2 pool is filtered only by a Hydrobotanical System sparsely planted with submersed species. In contrast, the pool in case study 14 belongs to model 3 and provides an extensive percolated Technical Wetland. Here, in spite of the presence of the koi, the water appeared completely clear. If you intend to keep fish, you should opt for a model 3 or even 4 pool.

Bear in mind the following tips for koi keeping:

- Feed the fish sparingly to prevent nutrient enrichment by increased defecation and mineralization of unconsumed food.
- One 30 cm koi needs at least 1 m^3 water volume. In a pool where people swim they need significantly more.
- Koi are shoaling fish, so purchase at least four of them.
- Koi churn up the ground, which can cause turbidity, but if the base of the swimming area is regularly cleaned the fish will move back into planted regeneration areas.
- If the fish gasp for air at the surface, the oxygen concentration should be checked, as oxygen enrichment may be necessary. This symptom is usually a sign of overfeeding and occurs in tandem with emergent floating algae.

Koi carp (*Cyprinus carpio*) breeds come in various colours and patterns including orange, white, black and golden-yellow.

As an alternative to keeping fish in the swimming area, we suggest giving them their own space in a separate regeneration pond (models B and C) of more than 10 m^2 and at least partly > 80 cm depth, which guarantees a frost-free area of retreat in cold winters. In shallower water, an ice preventer can be useful. Never crack an ice layer by force. This causes needless stress to the fish as well as to other animals hibernating underwater.

The best visual quality is provided by fish species which clearly contrast with the dark base. Beside light-coloured koi types, this may include goldfish (*Carrassius auratus*) and golden orfe (*Leuciscus idus*). The latter often appear at the surface to catch insects and as a predatory species it does not whirl up sediment from the bottom. In contrast, omnivorous goldfish like to churn up the ground, which can cause turbidity. Considerably greater problems however must be expected from grass carp (*Ctenopharyngodon idella*), tench (*Tinca tinca*) or other species which are greedy herbivores. The small sunbleak (*Leucaspius delineatus*) can reproduce rapidly and populate the pool with thousands of individuals.

The presence of a fish population requires careful consideration of nitrogen fertilization. They can lift the nitrate and ammonium content significantly, so that fertilization must be reduced or even ceased. An occasional water exchange can also be practical and is recommended by numerous fish breeders.

Of course even more animals can be kept in a pool, but they will all dis-

turb the natural ecological balance in some way. Freshwater mussels are well known for their effective water filtration. But introduce them only in a completely separate regeneration pond, unless you want to encounter them on the base of the swimming area. Terrapins and lobster have very special requirements and can escape by land. Establishing these special creatures demands a lot of specialist knowledge and it is doubtful if a natural pool is a suitable home for them.

The backswimmer (*Notonecta* spec.) is called the "water bee" in Germany because of its painful sting, but if left undisturbed is generally harmless.

UNDESIRABLE GUESTS

Lymnaea snails can cause damage by feeding on tender plants. Aquatic snails can also transmit "Swimmer's Itch" or even dangerous tropical diseases, though only in combination with water birds (see below).

Backswimmer bugs or water scorpions can sting painfully but only if intensively disturbed by bathers. In tropical America, relatives of these arthropods reach impressive sizes and their sting is correspondingly more painful.

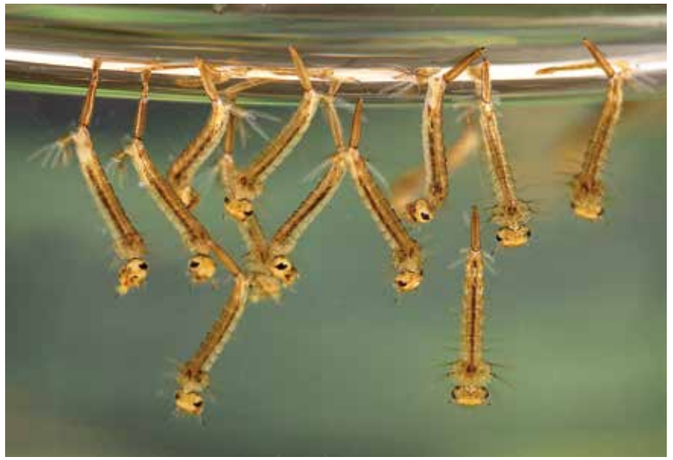
Undesirable guests also include pests on plants. Some significant ones are listed in the next chapter.

The European ring snake is completely harmless to humans but loves to hunt frogs.

REPELLENT REPTILES?

In Central Europe ring snakes are occasionally encountered in pools with naturalistic designs. This is a completely harmless species, except for the unpleasant smell it gives off when startled. Dangerous water snakes do occur, mainly in regions with warmer summers than in Central Europe and with natural wetlands.

In the Southeast USA the pit viper (*Agkistrodon piscivorus*) can find its way into a pool surrounded by lush vegetation, as can snapping turtles and even alligators. In Africa or Southeast Asia cobras or in tropical America and Asia boas or pythons may occasionally appear in a pool. Potentially dangerous encounters are very unlikely in formal pools without plants or in dry areas without surrounding natural wetlands. If you live in an area where these reptiles are indigenous, you should choose a pool with a completely separate regeneration area (model C), as shown in case studies 10, 16 and 17. The probability of finding dangerous reptiles in a natural pool of model C is no greater than in a conventional, chlorinated pool (Richter, 2015).



Mosquito (*Culex*) larvae in standing water. They are hanging under the water surface and breathing air through a tube.

MOSQUITO INFESTATION?

Prospective natural pool owners often ask if their pool may become a breeding ground for mosquitos. In a nemoral or subtropical climate, most species of mosquito do not transmit diseases, but the sting of adult females causes itching and painful skin irritation.

Mosquito larvae can live in all kinds of standing water, particularly puddles or rainwater cisterns, where they can develop safe from natural enemies. But in well-constructed natural pools and garden ponds a considerable number of predators guarantee that mosquitos do not become a significant problem. Dragonfly larvae, backswimmers, predatory water beetles and newts all do a very good job in keeping the water mosquito-free.

In tropical climates *Anopheles* and *Stegomyia* mosquitos are dangerous, because they can transmit malaria or yellow fever. Here particular caution should be exercised, while bearing in mind that in at-risk regions these disease vectors will also be present in the general environment.

SWIMMER'S ITCH

If after bathing the skin reacts with an unpleasant itching and shows locally delimited red wheals, an attack of cercaria dermatitis may be the reason. Cercaria are a stage in the life cycle of so-called trematodes, which burrow into the bather's skin, causing an allergic reaction. For

Symptoms of swimmer's itch.

humans this is painful but normally not dangerous. The trematode species *Trichobilharzia ocellata* is a parasite found in the intestinal tract of waterfowl. The trematode's eggs are excreted by birds into the water, where small larvae, the miracidias, hatch out. They then search for water snails as intermediate hosts. The miracides propagate inside the snail and become infectious cercaria. At temperatures above 24°C they are released into the water. To fulfill their reproductive cycle, the cercaria need find a waterfowl and reach its intestinal tract. Other animals or humans may accidentally become hosts. The parasite dies soon after its attack.

Trying to collect water snail as a preventive measure against cercaria is like tilting at windmills: in a natural pool they are omnipresent. But water birds should be kept away, not only as cercaria vectors but also as potential carriers of pathogenic germs in general. If they persistently appear at the pool, an effective countermeasure is crisscrossing nylon strings above the pool surface for a while. They can be high enough to allow bathing but will stop birds landing.

Ducks should be discouraged in natural pools: they pollute the water with excrement and are possible vectors of cercarial dermatitis.
Right Hard to see, but an effective defence against waterfowl: nylon strings stretched across a fish pond. This construction need only be a temporary measure in spring – after a few weeks it can be dismantled.

BILHARZIA IN THE TROPICS

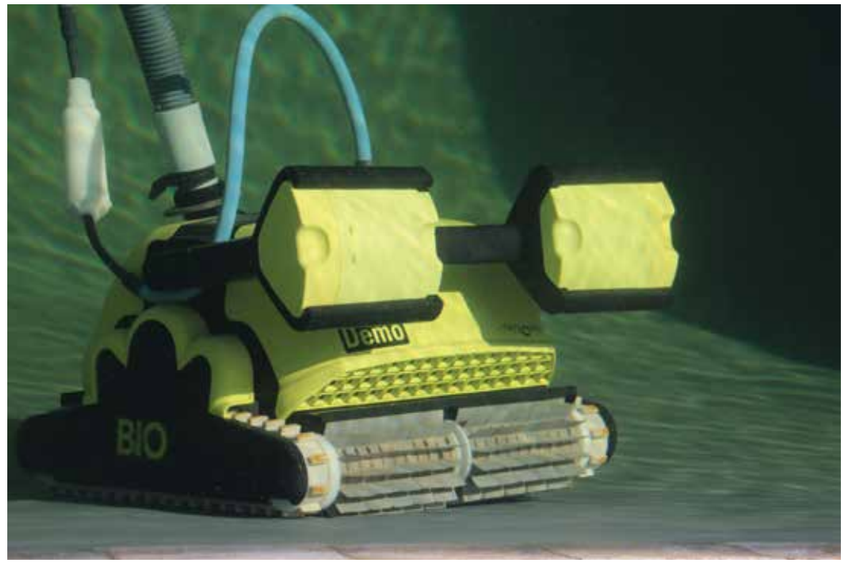
Much more dangerous than swimmer's itch is a closely related pathogen: schistosomiasis or bilharzia, a tropical disease caused by the trematode *Schistosoma*. Several species of *Schistosoma* are known to damage the human liver, bladder and intestinal tract. Here humans and certain animals are not only accidental hosts but serve as ideal environment for the cercaria. In the human body they develop to adult trematodes; their eggs are excreted with the stool or urine. If they get into water, the larvae (miracidias) can hatch out and attack water snails as intermediate hosts. As described above for *Trichobilharzia* the snails release the pathogen as cercaria. In tropical and warm subtropical climates, schistosomasis is widespread in natural water, especially in Africa, East Asia and South America. Artificial pools in the city landscape should be checked regularly and warm-blooded animals, which are potential carriers of trematode eggs, must be kept out of the water.

CAUTION

Where there is a risk of schistosomasis or other dangerous tropical animal- and water-borne diseases and your pool is non-chlorinated, we strongly recommend the following:

- The pool must be of the limnological "running water" type and provide an intensive filtering system (model 3 or 4).
- The regeneration areas must be completely separate (model 3C or 4C) and the swimming area should comprise a rectangular basin with vertical walls (as in case studies 10, 16 and 17).
- When not in use, the swimming pool must be covered with a non-transparent protection sheet.
- The regeneration areas must not create flooded spaces. Technical Wetlands as well as Biofilm-accumulating Substrate Filters should have emersed surfaces.

Though located in nemoral climate, case study 10 fulfils all these preconditions.



Some pool robots such as the Maytronics Dolphin are able to clean vertical walls.

9 MAINTENANCE

The focus in maintaining natural pools is on supporting appropriate water quality, keeping the swimming area clean, managing plants and filters and regularly servicing equipment. Measures also need to be taken to keep the water level stable.

If you have a contract with a professional landscaping company, we recommend including a general inspection of the pool at least once a year in the contract.

As general standards for using natural pools, the ÖNORM (2013) lists:

- Regeneration areas of model 3 and 4 pools as well as plantings in all pool types should not be entered by bathers, except where accessible by special wooden constructions, stepping stones etc.
- Sharp-edged items must not be brought into or used in areas with unprotected liner surfaces.
- Sun lotion and oils do not harm natural pools, but taking a shower before bathing is recommended.
- Before using the pool for ice-skating in winter, make sure that the ice is stable. In areas of moving water the ice is generally thinner. Installations must also be protected from damage.

CLEANING CONSTRUCTED ELEMENTS IN THE SWIMMING AREA

Slippery biofilm coverings may occur on all smooth surfaces. Mud produced by sinking debris and sedimented compounds may also accumulate on the bottom.

REMOVING COATINGS AND SEDIMENTS

Mud and biofilm layers should be removed regularly to get rid of nutrients and enhance the smooth operation of the system. In particular,

Hydrofoil brush for cleaning pool walls.

Working with a suction funnel.

CAUTION
Before starting any manual operation in the water of an inundated pump-house, unplug the pump from the power supply.

inspect steps and other entrance points, platforms and all installations, which must be safe to step on with bare feet.

The common way to remove film from the wall or mud from the bottom is to use a special brush on an extendable rod. It can be a challenge applying sufficient pressure when cleaning the pool wall from the side. Using a special brush with "hydrofoil" or "flipper" design such as the Wall Whale can help channel your efforts. Another option is to use a motor scrubber, which saves effort but costs much more.

After brushing, detached particles will create some murkiness till they sink back to the bottom. Vacuum up the sediment as soon as the water is visibly clear again with a suction pond or pool cleaner. Use a suction funnel attached to an extendable rod connected via a hose to an extra pump, usually fixed on a trolley. By default the hose is a 50 mm wide spiral tube.

The suction funnel is a handy tool even for cleaning pebbles or gravel layers in planted areas: small stones are disturbed (but not removed) in order to collect fine particles between them.

There are four ways of drawing the debris from the ground:

- The easiest is to use a **"pure" suction pond cleaner** consisting of a pump with expiration hose, which discards everything into the garden. As long as the quality of fill-up water is sufficiently high, pumping out a moderate amount of water and replacing it with new fill-up water about once a month will not harm the pool's stability. Good results have been achieved with impeller pumps such as the Tapir 10,000 or 12,000 (see case study 9).
- Using a **suction pond cleaner with integrated collection tank** for highly concentrated mud allows the purified water to flow back into the pool. It has the disadvantage of having to regularly empty the tank, which may create an enormous workload. We only recommend this option if the quality of the fill-up water is unacceptable.
- If there is an **underwater pump** in your pump-house with a prechamber for mechanical filtration beside the pool (minimum safety distance: 2 m) it can be used for removing the mud. Provided with a skimmer or an extra port which allows to connect the suction hose with the pump-house, the mud can be drawn into the prechamber, where it is retained by the mechanical filter (p. 117). If a grid basket or a net lines the prechamber, the mud can be removed by emptying this unit regularly. As in option 2, the refilling water will still be murky and should be released into the planted regeneration area. We rate this method as suitable for model 2 pools only (see case study 7).
- The most labour-saving option is a **pool robot**. If the floor is even, the robot is able to move straight over the ground. When it reaches an edge, it changes direction at random, so the complete floor is covered after several hours. The robot sucks all debris into an internal tank. If used once or twice a week in an average pool, the tank needs be emptied only once after each operation. Most devices even work on vertical walls so that all surfaces of the swimming area can be treated. However, use on walls is not recommended if any adjacent submerged regeneration area provides a seamless transition to the swimming area. The robot may stray into the regeneration area and cause problems with plants and substrate (see case studies 5, 9, 13 and 17).

On p. 312 we list examples of producers and distributors for cleaning tools, suction pond cleaners and robots. A German comparison between seven suction cleaners for private natural pools in 2014 was won by Oase Pondovac 4. In tests of pool robots Zodiak Vortex and Maytronic Dolphin products were recommended.

PREVENTING LEAF ACCUMULATION IN AUTUMN

If tall trees and shrubs grow near the pool, a cover net should be stretched over the water surface in autumn. If this is not possible, even a 1 m fence with a mesh size of less than 3 cm installed against the prevailing wind direction keeps away most leaves. Remove this protection only when the trees have shed most of their leaves and you have swept them up.

Above Cover net over a pond to protect it from leaves. Left Even a simple fence around the pool prevents leaves from being blown in.

CONTROLLING THE WATER LEVEL

In hot summers a natural pool can lose more than 5 mm water per day through direct evaporation and the transpiration of plants, even in a nemoral climate. This can increase to over 1 cm per day in hot regions. The evapotranspiration loss is boosted by a marginal zone planted with large-leaved species and through features such as streams, waterfalls and fountains.

To get the best use out of your natural pool, you should try to minimize fluctuations in the water level. Even in relatively humid areas, it can be necessary to top up the water during warm periods. Water can be replaced either manually with a hose or via a mechanical or electrical water-level control (see case study 17).

To assess the quality of the refill water, refer to p. 38.

Mechanical water level regulator: the floating golden ball locks and unlocks the valve which releases fill-up water.

REDUCING TRANSPIRATION AND EVAPORATION

Reducing the need for refilling means decreasing the phosphorus input, especially if the water available is less than ideal. Not creating streams, waterfalls, fountains etc. reduces the transpiration loss significantly: less refill water is needed and the phosphorus input is reduced. If you do not want to sacrifice these features entirely, consider running them for only part of the day to limit water loss. Another option is locating streams and waterworks in separate basins, adjacent to but unconnected with the pool, as shown in case study 18.

A further factor influencing water consumption is the presence of plants with large leaves. Trials at Anhalt University showed that marginal plantings with small species from oligotrophic fens are not only best adapted to phosphorus-limited waters but also the lowest evaporators (Thon, 2014). In contrast, very high evaporation must be accepted for *Sphagnum* moss carpets.

In pools with a completely outsourced regeneration zone (model 3C and 4C) the swimming area can be rectangular, which enables the installation of a mechanical cover to reduce transpiration.

CONTROLLING THE CAPILLARY BARRIER

As explained in chapter 6 (p. 130), it is very important to extend the liner's edge a little bit above the adjacent soil surface to prevent a wicking effect, which would continuously draw water out of the pool. This capillary barrier can be hidden by coarse pebbles, stone flags, wooden decks, overhanging ground-covering plants or the like. Over time, fine particles, dead plant matter, ant activity or ingrowing mosses may render the blocking of water loss ineffective. Check the sealing's edges once a year and remove all water-drawing plant parts and debris.

DAMAGE TO THE LINER

A professionally constructed sealing will suffer damage only in cases of gross carelessness. Of course, liners made of PVC, PE, EPDM or other plastic materials must not come into contact with sharp or pointed objects. The risk of plants damaging the liner is often overestimated (potentially problematic species are listed on p. 158).

Holes in the liner of regeneration areas often go unnoticed because fine particles in the substrate inside or the soil outside may seal the holes tightly enough to limit water loss. Locating holes which significantly reduce the water level can be difficult. It is best to wait till the water level stops dropping and then carefully investigate the sealing along the water's edge. Minor perforations can be closed with a polymer-based adhesive sealant (such as Innotec Adheasal). It can be used even on wet surfaces or underwater to fix patches onto the damaged sealing.

MAINTAINING WATER QUALITY

In chapter 3 basics of water filtration in natural pools were explained and we listed parameters for pool and top-up water (p. 38). The following sections contain additional important information about pool water maintenance.

TEMPERATURE

Natural standing water has a typical thermal stratification profile. In most natural pools this is not evident because of its low depth and the degree of water circulation. However, in temperate climates with frosty winters a certain degree of stratification does occur throughout the cold period. Pumps are switched off to prevent technical defects. In spring, after the ice layer has melted, a certain circulation in the cool water causes redissolved nutrients from the ground mud to be distributed. This can produce an algae bloom or turbidity from increased plankton growth.

In model 1 or 2 pools with no or only minor water movement, some degree of thermal stratification may develop through the summer. Redissolved nutrients stay mainly near the bottom and the water becomes very clear again. In autumn natural water circulation resumes and a level of turbidity similar to that seen in spring will recur.

Some pathogenic germs increase their propagation rate with rising temperatures. So according to FLL (2011), the long-term water temperature should not exceed 25°C though temperatures of no more than 28°C can be tolerated for up to five days. Many hygiene experts state that even higher temperatures will not cause serious health risks – otherwise constructing natural pools could not be recommended in tropical climates.

Some very hardy bathers like to swim even when it is frosty, but this can only be recommended if you follow a proper training programme. A thin layer of ice can easily be removed manually. To keep a small entrance area defrosted even through harsh winter periods, you should create a water current with an extra pump which permanently circulates warmer water layers upward to prevent freezing.

Ice swimming strengthens the immune system but should only be practised as part of an accredited physical training programme.

CHEMICAL PARAMETERS

pH levels

Daily pH fluctuations are caused by the photosynthesis of submerged plants, especially planktonic algae. Permanently fluctuating pH stresses aquatic organisms. Under very alkaline conditions (high pH, >>8.5) the availability of nutrients deteriorates and toxic ammoniac can occur. On the other hand nitrous acid (HNO_2) and carbonic acid might increase at a very low pH, though this is rare in natural pools.

Several experts recommend a high pH up to 8.4 for natural pools (Wesner, 2013), but this is problematic for submerged aquatic plants which belong to the "Fontinalis-Type" (see chapter 3, p. 28).

Oxygen

Oxygen is necessary to break down organic and inorganic carbon compounds. The pollution level of aquatic systems is quantified by the biological oxygen demand (BOD) and the chemical oxygen demand (COD). In natural pools pollutants should be present in such low levels that BOD and COD analyses are meaningless. However, the degradation of sediments on the ground is only effective if enough dissolved oxygen is present. The level of oxygen saturation in natural pools recommended by FLL (2011) is 80–120%. (An oversaturation of O_2 (> 100%) can occur i.e. in dense submerged plant stands as an effect of the assimilation).

Electrical conductivity (EC)

The electrical conductivity is an easy way of expressing the overall salt content of water. It is measured in µS/cm or as an older unit in mho (1 µS = 10-6 mho). Taking a reading with a conductivity meter is very easy, but has to be adjusted according to the temperature. Modern devices do this automatically.

The EC value should not be misunderstood as an explicit indicator of specific nutrients or dissolved ions. However, in nutrient-poor waters, the EC can be a gauge of water hardness. 1 dH° corresponds to 33 µS/cm, provided that no ions are present except hardening salts.

Rainwater may provide a conductivity of 30–60 µS/cm, while drinking water can range from about 100–1000 µS/cm; the threshold value of 2000 µS/cm should not be exceeded (TWV, 2001). The recommendation for natural pools is 200–1000 µS/cm at 25°C (FLL, 2011). If the reading is higher than 1000 to maximally 1500 µS/cm, the water should undergo

more detailed analysis. Pollution of the water by preservatives from wooden decks often produces high electrical conductivity because of high boron salts content. Though boron is listed as an essential trace element, it can be ecologically questionable, though its harmfulness is often overestimated (Peylo, 2000).

Nitrite problems

Nitrite can be dangerous to the pool ecology if it exceeds a concentration of 0.1 mg/l water. In a water body with anaerobic areas and a pH above 8.8, nitrite decomposition is strongly inhibited. If a large supply of ammonium is present, microbially produced nitrite can cause problems. In new ponds and pools this can be the case, especially if a lot of concrete was used underwater, as this greatly raises the pH. As a countermeasure, Jaksch, Wesner & Fuchs (2013) recommend placing a big block of "dry ice" in the water (frozen CO_2; caution: use protective gloves and eyewear because of its low temperature). This treatment will be much more effective than an application of acids, because they will be buffered by the water hardness.

Another reason for nitrite problems can be the use of tropical timber (mainly lapacho) for wooden decks and other structures above the water. Rain can also leach nitrite into the pool.

Phosphorus

A single gram of phosphorus can build up to a 100 kg algae mass (Frank, 2008). You can calculate about 70–100 mg input of phosphorus per bather into the water (FLL, 2011; Schulz, 1981). This amount would lift 7–10 m^3 of P-free water to the threshold value of 0.01 mg p/l. However, in a moderately used private pool, the main phosphorus input will not be from bathers but by aerosols washed into the pond by rain, deposition of dust and organic matter (pollen, leaves) and top-up water. In many countries it is common practice of the mains water providers to add phosphate to prevent the pipes from clogging through incrustation by certain ingredients. German drinking water regulations (TWV, 2001) allow up to 6.7 mg/l phosphate, more than 600 times the recommended value from FLL. In the UK high P-concentrations in the mains water are even more common than in Germany. From this point of view the use of rainwater for filling the pool is preferable to mains water, or special phosphate filters should be installed to pretreat the water (p. 74).

Algae seem to take up predominantly orthophosphate (PO_4^{3-}) or hydrogen phosphate (HPO_4^{2-}). But more forms of phosphorus can be absorbed, such as pyrophosphate ($P_2O_7^{4-}$) or organic bound phospholipides and even detergents from washing agents with phosphate content, if hydrolyzed by specific enzymes (Fogg, 1973). Even polyphosphates with limited chain lengths are usable. Organic P-compounds can be utilized via phosphatase enzymes, mainly located at the periphery of algal cells (Kuenzler & Perras, 1965).

A properly filtrated pool will provide the desired phosphorus limitation to guarantee visually algae-free water. The lower the phosphorus concentration, the weaker the growth of annoying algae.

Table 43 Sources of dissolved phosphorus influx
Deposition of air pollutions (dust, pollen etc.)
Excrement of animals and bathers. Fish lead to a significantly increased P-level, depending of the intensity of feeding (see case studies 8 and 14)
Substrates and installation components, if they contain soluble P-compounds
Decomposition of dead particles of submerged plants, animals and plankton
Resolution of P from the sediment under anaerobic conditions
P-enriched surface water from nearby plants can flow into the pool if not prevented by a capillary barrier
Influx of P with the fill-up water, if P-enriched mains water is used

Table 44 Measures against phosphorus influx
Reduce the loss of water with a well-constructed capillary barrier
Features such as streams, waterfalls, fountains which exceed evapotranspiration losses should be included sparingly
Submerged plants incorporate P
Use of low P fill-up water (< 0.035 mg/l Ptot). In areas far from industry, rainwater may be better than mains
Refrain from using fertilizers that contain P and substrates with a high P content
Bathers should make sure not to release P-rich substances into the pool: especially drinks like Cola can contain significant amounts of P. Hygiene products used for skin care should be phosphorus-free

Table 45 **Measures to eliminate phosphorus from the water**

Measures	Recommended for targeted limitation	
High oxygen concentration, hard water and pH around 8–8.4 promote the sedimentation of P as oxidized insoluble compounds such as $FePO_4$ or $Ca_3(PO_4)_2$ (Upmeier, 2004). These substances accumulate in the ground mud and should be vacuumed up regularly.	✓	
Harvesting biomass: cut back submerged plants in late summer and trim new shoots of helophytes in autumn before their phosphorus is translocated into roots and rhizomes. Remove the rubbish: it is ideal for composting. Leave some reed shoots till early spring as an overwintering refuge for animals	✓	✓
BSF biofilm (model 4 pools) guarantees good P-removal. Regular backwashing prevents overpopulation: if the biofilm layers have reached a certain thickness, they begin to die off. Without backwashing, the phosphorus reduction will stop after a time and P will be redissolved.	✓	
Special filters with iron- or aluminium hydroxides or sulphates can fix dissolved phosphorus, for example as FePO4 or as AlPO4. The effect on the pH has to be checked and if necessary adjusted. Setting up this equipment should be done by an expert.	✓	(✓)
4 g slaked lime ($Ca(OH)_2$) can eliminate about 1 g P, precipitating as $Ca_3(PO_4)_2$ sediment. In pools the application of 3 g slaked lime per m³ is recommended if short-term P-elimination is deemed necessary. Note that the pH will be increased by this process. Slaked lime should only be used in extraordinary cases and applied by professionals.	✓	X
Special shallow basins remote from the swimming zone can be constructed as "traps" for filamentous algae, such as the Algal Turf Scrubber.	✓	✓
Lanthanum chloride (eg Phosfree) fixes dissolved phosphorus very efficiently. A slightly excessive P content can be significantly reduced with just 1 litre of lanthanum solution per 100 m³ of water.		

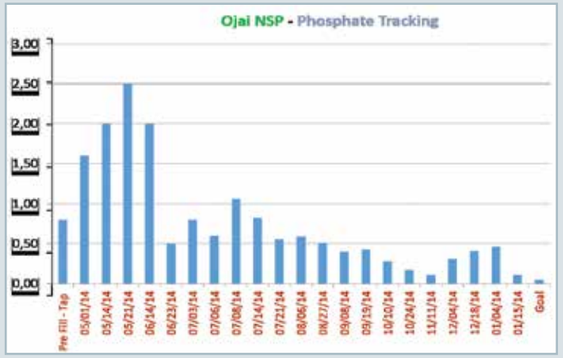
MEASURING AND ASSESSING PHYSICAL AND CHEMICAL PARAMETERS

Regularly checking relevant chemical data about the pool water according to table 5 (p. 39) is mandatory only for public pools. In private pools occasional testing is recommended to provide more security and efficiency for further maintenance activities. Three tests per year (April, June, September) are sufficient.

Conductivity, pH, oxygen saturation and water hardness are relatively easy to measure with electronic devices or simple analysis kits with indicator solutions or sticks. Suppliers are listed on page 313.

Nitrate, nitrite and phosphate tests are included in most analysis kits too. The values are very approximate, but adequate for checking nitrate and nitrite. Phosphorus however should be analysed more accurately. Conventional devices are not able to measure total dissolved phosphorus, only orthophosphate (PO_4^{3-}). The necessary fine determination of concentrations in 0.01 mg/l steps is not possible for most non-professional instruments. If you want to find out the actual P_{tot} concentration in your pool, you must send a water sample to a specialist laboratory. A hand-held Low Range Photometer can be used as a semi-professional solution. It measures PO_4^{3-} to an accuracy of 0.01 mg/l. To transform the results into pure P-content divide the displayed values by 3 – but all other P-compounds are unrecorded, which limits the relevance of the results.

Measuring with a conductivity meter.



Phosphate monitoring of the pool water in case study 17 in Ojai, CA (Becker, 2015). After inaugurating the pool in May 2014, a peak up to 2.5 mg/l PO_4^{3-} was measured, which was reduced drastically by November and January. Intermediate peaks show effects of events such as "many dogs enjoying the pool" and a discharge of P-enriched irrigation water

Differences between analysis results and recommended values do not necessarily indicate problems. If the pool has been well planned and has adequately proportioned regeneration and filter areas, you may not encounter problems with algae, murkiness or germs. Surplus nutrients will be removed by a lush, well-balanced vegetation (Hydrobotanical System). Also remember that many parameters show pronounced fluctuations between day and night.

ALGAE CONTROL

Chapter 3 provided a brief overview on the main types of algae. In the following section we discuss the troublesome ones in more detail and recommend measures to prevent and control them.

STRING ALGAE

Water net (*Hydrodictyon reticulatum*)

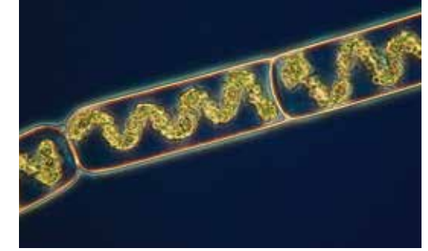
Some string (or filamentous) algae species can thrive even in very nutrient-poor waters. They produce cell threads which proliferate by division or branching and potentially huge mats result. These mats can fragment into smaller pieces, which form new colonies. Their assimilation has a strong impact on the pH of the water. During the day it can reach 10 or even 11. In the evening nutrient availability changes, and at night the pH declines again, potentially causing stress to organisms.

Water net (*Hydrodictyon reticulatum* and related species) is a very particular type of filamentous algae, which can be found in nutrient-rich, but clear waters in the subtropics and tropics. Its cell threads grow in honeycomb-like meshes but in well-managed natural pools it is rare.

Important for low-nutrient natural pools are filamentous green algae from two orders:

- **Zygnematales**: the best-known representative is *Spirogyra*, named after its spiral chloroplasts. The annoying *Zygnema* and *Mougeotia* species can thrive even in very low-nutrient concentrations. They often occur jointly in natural pools, forming unpleasant mats in layers near the surface. Their slippery threads are tender and break easily. It is very hard to completely remove their colonies from the water. In trying to pull them out, a large amount of thread bundles remain in the water.
- **Cladophorales**: the most common genus of this group is *Cladophora*. Its branched cell threads feel coarse because of lime coatings, the result of biogenic decalcification. They prefer water with a certain P-concentration and need any firm surface structure to adhere to with rhizoids, from where the mats start to develop. The coarse threads are much easier to remove manually from the water than Zygnematales algae. Of course *Cladophora* mat will leave some remnants even after removal, so regular checks are required. Mats turn a light yellowish green when they mature. At this stage the threads lose their stability and it is hard to remove bigger units because they easily fragment when touched.

Even in water with low-nutrient concentrations, mats of slippery *Zygnema* and *Mougeotia* algae can occur.



Top row Mats develop even between rosettes of the water soldier (*Stratiotes aloides*), its allelopathic excretions hardly affect string algae. The spiral chloroplasts of *Spirogyra* spp. under the microscope. String Algae mats often start to grow from the base of a pond. On reaching the upper water layers, it begins to spread sideways.
Bottom row Between the numerous shoots of mare's tail (*Hippuris vulgaris*), *Cladophora* algae thrive, creating an unattractive appearance. Types of "planktonic green algae": left cluster of *Scenedesmus*, right *Euglena* cells.

PLANKTONIC GREEN ALGAE (FLOATING ALGAE)

This algae group consists of single-celled species (e.g. *Chlamydomonas*, *Chlorella*), cell associations (*Eudorina*, *Gonium*) or multi-celled complexes (*Volvox*). Species of the genus *Scenedesmus* can occur single-celled or in little cell clusters.

In chapter 3 we explained the development of algal blooms. Water fleas and other zooplankton organisms are natural antagonists and keep the water clear if the nutrient level is not too high. An algal bloom can be a result of unbalanced water quality. The concentration of algae is low near the surface if fully exposed to sunlight, because the light intensity exceeds the appropriate value for the algae's photosynthesis. It increases downward to the area of optimal light intensity and then declines quickly towards the bottom. Floating algae are a part of the plankton responsible for greenish murky water if the nutrient level increases suddenly.

In pools with modern filter systems, floating algae rarely cause problems. Though always present to some extent, they should not greatly affect visibility.

METHODS OF ALGAE CONTROL

To what extent do filamentous algae belong in a natural pool? The Swiss algae expert Andreas Graber writes: "in a natural pool without algae I feel uncomfortable for there must be some poison in the water" (Graber 2007). Our aim can only be to keep the algae level low.

As a rule, the warmer the water temperature and the higher the light intensity, nutrient level and pH value, the better algae will thrive. Other reasons for algae problems can be: frequently changing the pool water, improper maintenance, high demand for refill water and the use of substrates with a high organic content.

Algae control by water movement?

In general, green algae – both filamentous and floating species – are indicators of ecological instability. Running water with a good oxygen supply generally guarantees low filamentous algae growth, as in such conditions it is not easy for cell threads to fix themselves onto firm surfaces. Still water with lower oxygen content and low redox potential are often free from string algae too. But they are encountered in areas with variable hydraulic conditions such as the mouths of streams and areas with slow-moving water. For these zones, provide a well thought out planting scheme to compete against algae or ensure the overall construction guarantees a separation of the flowing water from the still water (see case study 18).

Algae control by hardness and pH? – the C-limitation approach

There are two different strategies in case of pH/hardness and algae appearance. Some experts prefer a high pH of 8.4 (Wesner, 2013) to promote optimal biofilm development and guarantee a well-buffered system overall. Others recommend a low pH to get rid of algae.

In chapter 3 we explained the two alternatives for clear water: P-limitation and C-limitation. Controlling algae by means of low pH (soft water) is compatible with the C-limitation approach.

In trials conducted by Moss (1973), three *Zygnema* species achieved their best growth rates at pH of about 7.5–9. Two species showed low growth rates or even stagnation below pH 7. A high lime content, which causes high water hardness, seems to be beneficial for particularly annoying species, especially filamentous ones, notably of the Scenedesmus type (p. 29).

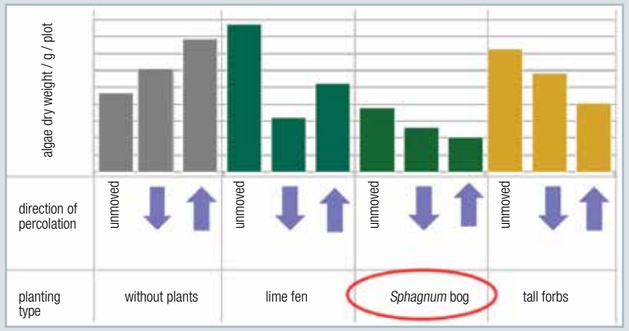
But the acidity of water is stabilized (buffered) by its dissolved substances, especially the hardening salts (p. 30). If active acidification measures are implemented, a significant effect on the pH cannot be expected, but water hardness can be reduced. The same reaction can be found if bog plants dominate the marginal vegetation, including thriving peat moss carpets (*Sphagnum* spp.). These mosses have special cells for the uptake of cations (NH_4^+, Ca^{2+}, Mg^{2+}, K^+ etc.), which they exchange for oxonium (= hydroxonium) ions (H_3O^+). But even in moderately hard water, it is not the pH that will decline but the level of hardness. In fact, we may even see a slightly raised pH as a result of biogenic decalcification in water with reduced buffering capacity. However, in trials by Kircher & Schönfeld (2008) and Thon (2013), filters planted with *Sphagnum palustre* and *S. squarrosum* resulted in a significantly reduced algae stock in the surrounding water.

In soft water and at low pH, the amount of dissolved carbon tends to be very low, so it might be an effect of C-limitation that is responsible for the reduced algal growth.

Lime chippings near the pond shore provide a perfect spot for filamentous algae to develop if not limited by a sufficiently low P-content.

Algae control by phosphorus minimization? – the P-limitation approach

The Redfield ratio is often quoted as a basis for interpreting nutrient ratios in a pool: according to Redfield (1934) nitrogen and phosphorus are found in a proportion of 16:1 (7:1 by weight) in marine plankton organisms, which holds good in freshwater conditions too. A ratio lower than 10:1 indicates nitrogen limitation, a ratio above 17:1 phosphorus limitation. Theoretically,



Left Dry weight of filamentous algae in basins fitted with 12 different planted filter variants: amongst three percolation directions and four planting types the bottom-up percolated filter planted with *Sphagnum* effected the lowest algal growth (Thon, 2013).

Trials at Anhalt University, Bernburg, Germany
Below left Trial plots simulate natural pools with TWL-filter bodies.
Right *Sphagnum* bog plot with *Sarracenia purpurea* and *Eriophorum vaginatum* between *Sphagnum squarrosum*; the surrounding water is visually free of filamentous algae.

moderate nitrogen fertilization could cause this P-limitation and help get rid of algae. However, the nutrient content of phytoplankton varies according to species, season and environmental conditions (Eckholm, 2008). The absolute value of these nutrients of course is crucial too: if dissolved inorganic P exceeds 0.025 mg/l and dissolved inorganic N exceeds 0.14 mg/l, neither P nor N may be limiting (Nixdorf et al, 12013). These levels are so low, that it seems nearly impossible to control algae by the N:P ratio alone.

The best way of reducing phosphorus is to achieve a sufficient hardness and a pH of 8 – 8.4. According to Jaksch et al (2013), it is either the minimization of phosphorus or of dissolved carbon that prevents algal emergence. So check the recommendations for C- or P-limitation given in chapter 3.

Algae control by competition?

Dense planting in appropriate zones provides strong competition for algae by competing for space and nutrients. Remember that many submerged plants, especially *Potamogeton* and the aggressive Elodeas, increase pH values through intensive biogenic decalcification (p. 29).

Cutting dense leaves and shoots back helps remove nutrients. Mowing and removal of plant material in autumn prevents decomposition and the release of nutrients into the water.

In model 2 and 3 pools, we recommend including special water-calming zones, especially behind the mouths of streams, around waterfalls and similar features and the swimming area, where the growth of filamentous algae is to be expected. A dense planting of these buffer zones will compete with the algae. Algae mats here will not attract attention and can occasionally be removed from the water manually.

Eliminating string algae

The most natural approach to controlling these "green cotton pads" is removing them by hand. Some algae have the ability to take up excessive phosphorus under certain conditions. Thus harvesting filamentous algae from the pool can lead to a significant P-reduction.

All other methods in Table 47 on page 221 may disturb the system and should be used carefully. Methods marked with question mark are particular problematic. The algae may be killed effectively, but a lot of beneficial organisms, including algae antagonists, can be affected too. If dead algae cannot be removed from the system after a certain period,

Table 46 **Measures to prevent algae problems applicable for P- or C-limited water**

	Recommended for limitation type	
Preventative control of filamentous algae		
Support phosphorus sedimentation by using hard water, aerobic conditions and pH 8.4	✓	X
Refrain from using substrates, stones and installations rich in easily soluble phosphate.	✓	(✓)
Consider measures against phosphorus influx (p. 211)	✓	✓
Prefer water with low hardness. Rainwater not only provides low hardness but also low nutrient concentration	X	✓
Avoid substrates, stones and installations rich in easily soluble carbonate, in particular no concrete or mortar surfaces should be in contact with the water. If concrete/mortar is absolutely necessary, hydraulic cement with a waterproofing additive (e.g. Asolin-DMK; see p. 111)	X	✓
Planted percolated carbonate-free sand and gravel filter systems will release water with an increased CO_2 concentration, because of the respiration of microorganisms, roots and rhizomes.	(✓)	✓
Marginal vegetation with bog plants, enhancing *Sphagnum* mosses may reduce the emergence of algae.		✓
Raise the CO_2 concentration with the Biotop Carbonator (p. 76).	(✓)	✓
A certain fertilization with nitrogen (i.e. urea) moves the N:P ratio to a comparatively lower P-presence. This is mainly recommended for model 3 and 4 pools, which often show N-deficiency, to feed plants as well as biofilm (p. 225).	✓	✓
Avoid zones with inconsistent water flow.	✓	✓
Densely planted regeneration areas compete with and smother algae.	✓	✓
Prevent accumulation of leaves, bird droppings etc. in the pool. In autumn a net cover over the pool helps keep out leaves. Even a 1 m high fence can prevent most leaves from being blown into the water.	✓	✓
A partly shaded location of the pool reduces light intensity and lowers the temperature. This worsens the conditions for algae to thrive. Shading between 11:00 am and 2:00 pm is most effective.	✓	✓
An adequate stock of water snails should be tolerated because they graze algae coatings on submerged surfaces.	✓	✓
Avoid or reduce areas with a water depth of less than 20 cm. The higher temperature in shallow water means less oxygen and increasing redox potential of phosphorus compounds that promotes algae. Try to build steep marginal edges and place the vegetation frame either in the water surface area (wet meadow) or deeper than 20 cm. Failing that, increase the planting density to create shady areas.	✓	✓

Above Buffer zone between a stream mouth (foreground of image) and the swimming area of a private natural pool (case study 7)
Below Submerged plants and water lilies (*Nymphaea* 'James Brydon') absorb nutrients and smother algae.

Above Stoneworts (*Chara* spp.) form a pretty carpet above the water level.

Above The most sustainable method to get rid of filamentous algae is removing it regularly by hand. A coarse outdoor broom has proved very successful for this task. Even slimy Zygnematales algae can be picked up by turning the bristles upward and then shaking it out into a wheelbarrow.

the problem may re-emerge worse than before. Chemical treatments must be applied regularly to work long term. Suddenly stopping a certain treatment will lead to disturbance and promote greater algal growth. The application of copper containing algaecides can even lead to a selection of algae-ecotypes producing phytochelatines as a form of self-protection. The German guidelines (FLL 2011 & 2017; ÖNORM L 1128:2013) outlaw chemical algae control in natural pools.

Some companies, especially those which target keepers of koi and other fish, distribute "special remedies" against string algae. They may be advertised as completely harmless to any organisms except algae, but if the active ingredients are kept secret you should be restrained in their use.

STONEWORTS – DESIRABLE ORNAMENTAL ALGAE

Some 300 Characeae species occur in two main genera: *Chara* and *Nitella*, in addition to which there are *Nitellopsis* and *Tolypella*. Most *Chara* species prefer hard water, whereas *Nitella* like soft. All species need clear water and can even thrive at low nutrient concentrations.

Sometimes stoneworts are sold in plastic boxes in garden centres or nurseries. Such specimens are not recommended, because each species is adapted to specific water conditions. Nonetheless stoneworts often appear spontaneously through introduced spores or cuttings, so their presence in a pool may simply be a matter of patience. If stonewort populations get out of hand, they are easy to remove manually.

BLUE-GREEN ALGAE (CYANOPHYTES OR CYANOBACTERIA) – A POISONING RISK?

This group are not algae in a botanical sense as they are more closely related to bacteria. Like bacteria they have no real cell nucleus, but like algae they depend on light to photosynthesize. Some species produce the eponymous blue-green colour (Phycobilines). These pigments allow the Cyanophytes to use more spectral ranges than plants. Compared with green algae their growth rate is quicker in low light condition; at high light intensities it is slower (Hunter, 1998). So murky water strengthens their competitive advantage over green algae. This effect can be further enhanced by a high phosphorus concentration (Steinberg et al., 2000).

Harmful blue-green algae species occur almost exclusively in eutrophic or hypertrophic water with a lack of oxygen. We do not know of any

Table 47 **Measures to eliminate algae**

Measures		Recommended for targeted limitation
The best method is to regularly scoop up string algae mats with a net, rake, broom or special tool such as the Algae Witch:	✓	✓
Barley straw is a "secret remedy" of garden pond enthusiasts: some species of algae are not killed by it, but further algal development is blocked. 20 g straw per m³ water should be effective. First existing algae mats should be removed manually. The straw should then be loosely packed in wide-meshed sacks and placed in the water. It will be most effective in well-oxygenated areas, e.g. on percolated filter beds. Add the straw in late winter and remove it after a time as it releases organic matter and nutrients into the water when it decomposes. However, its real effectiveness is still uncertain (Lembi, 2002).		✓
Acidifying the water with peat from raised bogs (without fertilizer, lime or other additives). Acidifying the water with peat from raised bogs (without fertilizer, lime or other additives) will not directly reduce the pH but soften the water: 1 kg (dry weight; correlates to 3–4 l) of a proper peat per m³ water will reduce the water hardness by about 1 dH° (KH). Apply the peat following the same method as for barley straw above. Note that the water can go a dark brownish colour from dissolved organic compounds, which some users may not like.		✓
If only hard mains water is available as fill-up water, storing it for a time in a cistern can cause lime sedimentation and reduce its hardness.		✓
Inserting an ion exchanger in the water pipe is effective in reducing the hardness, but the hardening ions may be substituted by Sodium (Na+), which can be harmful to plants.	X	✓?
As a pretreatment of the fill-up water, the addition of oxalic acid ($C_2H_2O_4$) should be mentioned: 22.5 g oxalic acid per m³ water will reduce the water hardness by 1 dH° (KH). Calcium is precipitated in tiny crystals of calcium oxalate and sinks to the ground, where it can be discharged or vacuumed up.		✓
Dinatriumperoxydicarbonate is the active substance in the products Peroxyd (Tripond) and Peroxydal® (PerProdukte). This white powder can be scattered in low amounts onto filamentous algae mats which grow in deeper water and are difficult to access by hand. A strong oxidation reaction kills the algae and makes them rise to the surface, where they can easily be removed. The pH should not be above 8.5. Allow 20–50 g per m³ water.	✓?	✓?
Lanthanum chloride (eg Phosfree) fixes dissolved phosphorus very efficiently, see p. 212.	✓	✓?

Table 47 continues on page 222

Possibly harmful blue-green algae create a slimy layer on the water surface of a polytrophic lake.

Ultrasonic frequency generator at the edge of the swimming area.

Table 47 **continued**

Measures	Recommended for targeted limitation	
A more recent innovation is to use ultrasonic frequency generators in the pool. The algae's cell walls will be disrupted but vascular plants are not affected. Damaged planktonic algae may sink to the bottom, so regularly vacuuming the mud is recommended. The sound waves are virtually undetectable by the human ear, but we recommend switching the device off when bathers are in the pool. Unfortunately results with this technology are not too encouraging.	✓?	✓?
Using a colour compound which filters out spectral ranges essential to algae. Unfortunately the resulting colour looks very unnatural and the compound has to be regularly refilled. For example Aquashade® was proven effective against filamentous algae (Camberato & Lopez, 2010).	✓?	✓?
Algaecides such as copper sulphate or chlorine may be successful but affect the whole ecosystem. And even these "wrecking bars" may be unreliable: in carbonate-rich waters, copper sulphate does not fulfill its role effectively; some algae types are chlorine-resistant (Baumhauer & Schmidt, 2008).	?	?

case where a natural pool was affected. A good supply of oxygen and low nutrient concentrations should guarantee their absence.

A mass development of Cyanobacteria can affect the water quality significantly and make it unsuitable for bathing. A few species produce a variety of toxins, antibiotics, hormones, allelopathic substances etc. The optimal temperature for blue-green algae is 25°C, so in a nemoral climate a mass development ("Cyanophyte bloom") can happen especially in summer and early autumn (Zeck, 2001; Mur et al., 1999). Though Cyanobacteria have an enhanced capacity to absorb and store phosphorus, a mass development at P-concentrations below 0.03 mg P_{tot}/l is unlikely (Chorus et al., 1992).

On the other hand the appearance of Cyanobacteria has to be carefully checked in natural ponds, especially in the countryside. If the emergence of Cyanophytes is proven, bathing is usually prohibited because toxins can cause symptoms such as nausea, vomiting, diarrhoea, respiratory diseases, earaches, and eye and skin irritations. In the long term, even liver damage and cancer can result (Sommer, 1996; MUGV, 2013). As a rule of thumb, you should not bathe if the visibility is less than the distance from the sole of your foot to your knee (MUGV, 2013). Various organizations quantify the maximum limit of cyanobacteria as 15,000–20,000 cells/ml; at higher concentrations the water should be avoided (WHO, 1998).

In natural pools an unpleasant-smelling oily haze on the surface of murky water betray the presence of Cyanophytes. The colours of the outbreak range between violet, blue-green, purple, brown-red and olive. Cyanophytes occur as single cells, filaments or colonies, but the range of forms is very diverse: Jaksch (2006) describes that normally unbranched cell threads can develop to dense, dark green to blackish mats, overgrowing water plants and green algae. Within ageing systems, gas bubbles can appear and support the mats on the water surface, resembling some filamentous green algae (*Zygnematales*).

Not all Cyanophytes are harmful. Some species fix atmospheric nitrogen and transfer it into compounds usable by animals and plants (an important factor for plant nutrition in rice fields). In oligotrophic pools, small gelatinous balls can occur on submerged structures. These so-called "pond plums" are also formed by harmless Cyanophytes.

HYGIENE CONTROL

Assessing pathogenic germs

Among the huge diversity of pathogenic species, a manageable group of representative microorganisms have been chosen as indicators of hygienic safety. These "index germs" play a diagnostic role and should be analysed regularly in public pools (FLL, 2011). Faecal streptococci (*Enterococcus faecalis*, *Escherichia coli* or *Salmonella* spec.) are defined as being characteristic of intestinal pathogens. Exogenous agents are represented, for example, by *Legionella pneumophila*, *Mycobacterium* spp., *Pseudomonas aeruginosa* and *Staphylococcus aureus* (Baumhauer & Schmidt, 2008). Being part of the human intestinal flora and excreted with the stool, most of these germs can be seen as indicators of faecal contamination. But pollution by waterfowl excrement is much more critical than any human input, so water birds must be kept away from natural pools.

In samples of the pool water the so-called "colony-forming units" (CFU) in a defined amount of water are analysed: on an artificial culture medium a particular amount of colonies can be identified after some time. Each colony is a result of either a single bacterium or possibly of several contiguous ones.

Table 48 **Maximum values for sanitary microbiological parameters of pool water**

Parameter	Measurement	Maximum value
Escherichia coli	CFU/100 ml	≤ 100
Enterococci	CFU/100 ml	≤ 50
Pseudomonas aeruginosa	CFU/100 ml	≤ 10
Legionella	in 100 ml	Below limit of detection

FLL, 2011

The most common indicator germ worldwide is *Escherichia coli*. Additionally Intestinal Enterococci, *Pseudomonas aeruginosa* and sometimes *Legionella* are used for assessing the hygienic safety of pool water (FLL, 2011). *Pseudomonas aeruginosa* is added to the indicator germs because in natural pools it can propagate in biological purification filter pipes (Feuerpfeil & Lopez-Pila, 2011; Bruns, 2014). More detailed information about critical pathogens, including those found in warmer climates, can be found in the Australian Drinking Water Guidelines (Australian Government, 2013, p. 274f.).

Of course the microbiological parameters can only be determined by a professional laboratory. This is recommended weekly for public pools by FLL (2011). For private pools, official analysis is unusual unless there are grounds for suspicion.

Preventative measures

If built and used appropriately, worrying levels of germs are very unlikely in private natural pools.

Remember to take a shower before entering a pool, leave out dirty tools and toys and keep an eye on small children so you are able to lift them out "in case of emergency". Infants and small children do not only introduce more germs than adults; they are also more susceptible to infection. For younger members, it may be better to install a separate small paddle pond with no connection to the natural pool and change the water completely on a regular basis.

As mentioned on p. 46, some pathogens can be eliminated by the excretions of some plants and by plankton. So a densely planted regeneration zone (Hydrobotanical System) promotes good hygiene. But the biggest impact on eliminating pathogens comes from percolated filters (TWL, RGF, BSF).

Chemical disinfection treatments should not be applied as they risk harming beneficial organisms and the biological balance. The guidelines of the FLL (2011 & 2017) and ÖNORM L 1128 (2013) forbid disinfecting chemicals. Working exclusively with natural purification processes guarantees freedom from problems with skin or eye irritations and allergic reactions to chemicals. And bathers enjoy clear water with a pleasant smell.

MAINTAINING PLANTINGS

By the second vegetation period after construction the plants should be thriving. In model 1 and 2 pools, plants which grow in flooded zones often thrive long term. In wetland zones (zone 2) which are placed within the liner but not flooded, after three to five years the plants may begin to weaken because nutrients from the water do not diffuse quickly enough to the roots. In contrast, zone 2 plantings on percolated substrates of a Technical Wetland (model 3) provide permanent nutrition for vegetation. Finally, the Biofilm-accumulating Substrate Filters of model 4 pools are so efficient in nutrient withdrawal that some fertilization is often necessary.

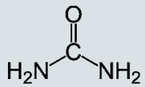
FERTILIZING

If significant growth depressions are noticeable, proper fertilization should be considered. The aim of P-limited pools to reduce the phosphorus concentration to an extremely low level is often accompanied by an undesirable loss of dissolved nitrogen, mainly through denitrification (p. 32).

In winter-cold climates (USDA zones 1–9) all fertilizing activities must be carried out between spring and mid-summer. Do not apply nitrogen after the end of July, because a nutrient boost will delay the development of hibernation buds and weaken plants' frost resistance.

Fertilizing the complete body of water

For **model 4 pools** with Biofilm-accumulating Substrate Filters some experts recommend adding 3 g potassium nitrate (KNO_3) and 3 g magnesium nitrate ($Mg(NO_3)_2$) per m^3 water volume in April at the start of the vegetation period. Furthermore from April till July 8–10 g urea



Urea: structural chemical formula. Below Scattering the granules in the pool.

per m^3 should be added monthly. Urea is the most important fertilizer for natural pool water, not just because of its low cost but also because even in relatively high concentrations it is better tolerated by the pond biology than ammonium and nitrate salts. It does not harm bathers; urea is also an ingredient of skin-care products.

Besides plant nutrition, high N-input promotes biofilm development. In any case increasing the nitrogen level influences the N:P ratio to the disadvantage of phosphorus. According to the Redfield formula (p. 217), this will impede algae growth. But the high concentration refers to a "traditional" plant range with N-demanding species such as *Cyperus longus*, *Typha* spp., most irises, *Sagittaria latifolia* etc.

If BSFs are combined with plants from oligotrophic lime fens (p. 154), the amounts recommended above can be sharply reduced. Potassium and magnesium nitrate will not be required and urea may be applied as 2–5 g per m^3 three times annually (early April, mid-May, late June). The specific amount should be determined according to the plant's vigour and health.

For **model 3 pools** fertilizing activities should not exceed the level of 2–5 g per m^3 urea three times a year as above. Using vegetation from oligotrophic fens or even bog plants will mean that fertilizer should be applied only to individual plants which need additional nutrients (see below).

In **model 1 and 2 pools** you generally should determine fertilizing needs with reference to any growth deficiencies. If vegetation is growing in nutrient-poor water but interspersed with demanding plants such as water lilies, lotuses or cannas, applying fertilizer to specific plants is better than increasing the nutrient content of the entire pool.

Fertilizing individual plants or planting zones

Inundated plants in zones 3 to 5, apart from percolated filters, should be set into substrates covered with 5 cm clay to protect root systems from the free-flowing water (p. 190). All demanding species in these areas can be fertilized with **nutrient tablets**, inserted at least 5 cm deep into the substrate, even if they contain some phosphorus. Of course the fertilizers should be nitrogen rich, because this is the deficiency you are seeking to remedy. Aquatic plant fertilizers are phosphorus-rich, so choose a product with a low P-content or mix it with pure N-fertilizer.

One suitable product is Osmocote Exact Tablet 5-6M, which has a nutrient composition of: 14:8:11:2 (14% nitrogen : 8% P_2O_5-phosphorus : 11% K_2O-potassium : 2% MgO-magnesium) + trace elements.

To get pure nitrogen into the substrate **hoof-and-horn** chippings can be used. They contain about 16% N plus only 1% P. This organic substance is insoluble in water but slowly mineralized, releasing nitrogen mainly as ammonium. To apply, take a small handful and wrap it in a piece of toilet tissue, which quickly disintegrates in water, and place it in the substrate. Or you can fill an ice cube tray with hoof-and-horn chippings, add water almost to the brim and put it into the freezer overnight. The resulting ice cubes can be used as nitrogen fertilizer tablets. To calculate the exact nutrient content, weigh the dry chippings before soaking. For one water lily with leaf cover of about 1 m diameter, we recommend 4 × 7.5 g Osmocote Exact tablets, plus 50 g hoof and horn as homemade tablets. Other options for a nitrogen enhanced fertilization through the substrate are sheepwool pellets (N:P:K = 9-12: <0.5: 2-5) or the synthetic products such as Floranid Eagle (N:P:K:Mg =17:0:16:2).

Even some plants which we recommend for oligotrophic lime fen or acidic bog mixtures such as sarracenias and darlingtonias should be individually fertilized each spring. A handful of hoof-and-horn chippings per adult plant applied in early spring supports its healthy growth. Blueberry shrubs (*Vaccinium corymbosum* hybrids) cultivated between bog plants should be fertilized with three handfuls of hoof-and-horn chippings.

Zone 2 plantings, apart from percolated areas, can be sprayed with a 1% urea solution in spring (1 l per m^2). If the summer growth is unsatisfactory, repeat this in May and possibly also in June. This solution is also suitable for spraying onto leaves of water lilies and other floating-leaved plants or helophytes when nitrogen deficiency symptoms are apparent.

Iron fertilization

Iron deficiencies occur chiefly in plants adapted to acidic sites or else to soft water if used on sites with high pH or in hard water. In the plant table on pp. 165-181 we showed water hardness (for terrestrials: pH). Species with values of 1 or 2 are potentially susceptible to iron deficiency. If the

Above left Nitrogen deficiency symptoms in a water lily; and centre a *Pontederia cordata* in which growth is significantly reduced and leaves remain small and yellow. Above right Nitrogen fertilizing with frozen hoof-and-horn tablets.

Above Iron deficiency symptoms in *Menyanthes trifoliata*: it's mainly the younger leaves that are affected by yellow discoloration. The veins are still green. Below Iron chelate fertilizer Fe-EDDHA stains the water strongly. It is effectively absorbed through roots as well as green leaves.

Table 49 **Interpreting the most important nutrient deficiency symptoms**

Deficiency	Typical symptoms
N (nitrogen)	Pale, yellowish leaves, discoloration starts in the older plant parts
	Small growth, short sprouts
	Late budding out, early ending of the growth period
	Small flowers (emergency blossom) or no flowers (*Butomus*)
	Small fruits and underdeveloped seeds
P (phosphorus)	Dark leaf colour, sometimes partly bluish-green or violet
	Stunted growth
	Enrichment of Anthocyanines causes unnatural red to violet discoloration
	Leaves smaller or thinner, slim stalks. Sometimes stiff growth with tips showing downwards.
	Reduced blossom intensity, flowers smaller and malformed
	Small fruits and underdeveloped seeds
Fe (iron)	Pale, yellowish leaves
	Discoloration starts at the youngest plant parts (growing tips).
	The leaf veins stay green, often sharply delimited from the yellow blade.
Mg (magnesium)	Can appear similar to iron deficiency, but starting at the oldest parts.
	Yellowish to pale spots on the leaves, sometimes with violet discoloration near the tips. Leaf veins stay green.

site conditions can't be adapted to the plant's demands, fertilization with a soluble but chemically stable form of iron helps. The most efficient compound is Fe-EDDHA, an organic chelate with 6% Fe, sold under the brand names Basafer®-Plus or Sequestrene®. 15 g Fe-EDDHA per 10 l water can be irrigated even onto sensitive plants two to three times during the growing season (in spring, early summer and mid-summer). The intense red colour limits the application to submerged plantings.

Annoying weeds which often seed on soggy and shallowly flooded soil (zones 2 and 3). Left to right *Epilobium* sp. (fruiting), *Ranunculus sceleratus*, *Alopecurus aequalis*.

WEEDING

Weeds can sprout in pond and pools, limiting the growth of desirable plants. If suitable plants are chosen for the site in the first place, weeds are only a problem in the initial phase until plants form dense cover and are able to compete. Through time, seedlings of plants which do not match the intended vegetation pattern should be removed, including their roots and rhizomes. To prevent disturbing the substrate stratification, use slim weeder blades only and pull up the weeds carefully.

Helophytes, which tend to R-strategy, can behave like weeds if their self-seeding becomes aggressive. Problematic species are marked in Table 37 with a densely dotted "growth habit" box. Cutting back fruiting shoots or removing inflorescences after wilting helps prevent uncontrolled propagation.

Plants with rampant rhizomes are indicated in Table 37. If such species have outcompeted all partner plants, it is generally impossible to get rid of them without completely digging up the affected areas. Use these strong competitors only in very large pools or, even better, exclusively in separate regeneration ponds.

Inundated zones 3 to 5 are not greatly endangered by "green invaders", while wet, but non-flooded substrate surfaces provide very good conditions for seeds to germinate. In zones 1 and 2 a mulch layer of coarse gravel (8–16 mm) keeps the surface dry and inhibits weed germination. But such coarse grain sizes are only recommended for tall forbs or tough reeds such as irises, *Typha* or *Lysichiton*, and not between sensitive fen or bog plantings.

Above Blooming sneezewort (*Achillea ptarmica*) under pressure from invasive, woody, small reed stalks (*Calamagrostis epigejos*) – in zone 2 possibly the most dangerous invader with rampantly proliferating rhizomes.

Above *Carex elata* is a clump-forming grass which flowers in April. To prevent its propagation the complete leaf crown including flower clusters can be trimmed and removed in early June. Two weeks later new leaves sprout but it rarely blooms again.

Young *Alisma* plants showing smut fungus symptoms on a nitrogen-poor site.

Rust spots on *Carex pseudocyperus*.

Marginal pool planting in late summer: the leaves of *Caltha palustris* are affected by powdery mildew which coats them white till they die off in necrotic brown.

PESTS AND DISEASES

Plants with small, yellowish leaves and restricted growth are mostly a result of nutrient deficiencies. Selecting species appropriate to the water quality is the best method of preventing growth problems, even if caused by pests or diseases. Phytopathogenic fungi, bacteria and bugs rarely cause lasting damage in well fed (but not overfertilized) plants. Remove damaged plant parts and feed appropriately. Weakened flowering plants can be strengthened by removing flower or seed heads.

As a natural preventive treatment spraying extracts of horsetail (*Equisetum* spp.) or diluted milk onto particularly sensitive plants is sometimes recommended to strengthen resilience. Chemical pesticides are not allowed in natural pools, not even pyrethrum products.

In the following we list some important pests and diseases as well as countermeasures.

Smut fungus in water plantain (*Alisma* spp.)

Round, dark spots, often with yellow fringes occur on the leaves. They increase in size till finally the whole leaf turns brown and dies. The fungal disease chiefly affects plants lacking nitrogen and only in their flowering or fruiting phase. *Alisma lanceolatum* shows the least vulnerability while *A. subcordatum* seems to be particularly at risk. Normally even completely defoliated plants sprout again after being fertilized or else the following spring.

Rust fungus in *Carex pseudocyperus*

Rust fungus also mainly attacks underfed plants. It looks particularly nasty on cyperus sedge (*Carex pseudocyperus*), which shows long brown spots along yellowish leaves.

Powdery mildew on broad-leaved perennials

Unlike most fungal diseases, powdery mildew prefers warm temperatures and dry air. Mealy coverings on young shoots, leaves and buds of helophytes with broad, soft leaves appear mainly in late summer. In advanced stage the affected tissue dies off and looks brown. Susceptible species are *Caltha palustris* or *Filipendula*, if kept too dry. The following spring the plants sprout normally again. Calthas should be combined with taller, late-sprouting plants such as typhas or pontederias which will hide their unpleasant summer appearance without competing with their bright spring bloom.

Rhizome rot in water lilies

Some susceptible water lily cultivars can be affected by a still-mysterious fungal disease. The leaves turn increasingly yellow and finally die off. The best prevention is to avoid injuring rhizomes of young plants, which allows the fungus to enter the cell tissues. Older, well-established and healthy stands can be reduced without great risk of infections. Several yellow, orange and red flowering cultivars are particularly prone to rhizome rot, e.g. 'Marliacea Chromatella', 'Sioux' and 'Attraction'.

Brown China-mark (*Elophila nymphaeata*)

The most dreaded pest for water lilies and many floating-leaved species is a small moth, the Brown China-mark. On summer evenings with temperatures above 10°C the brown-white patterned adults can be seen near waters with host vegetation. They lay tiny eggs on floating leaves. Soon after hatching the caterpillars eat from the leaves and after a while cut oval pieces out of the leaf blades. Spinning two pieces together, they construct a "boat" or quiver in which the larva hides. Protected from enemies, it continues feeding from leaves and builds a new quiver when the old one becomes too small. Larvae hibernate in submerged petioles or stalks of helophytes. In late spring they pupate in their final quiver. About two weeks later the young moths hatch out. In nemoral climates the Brown China-mark produces two generations per year.

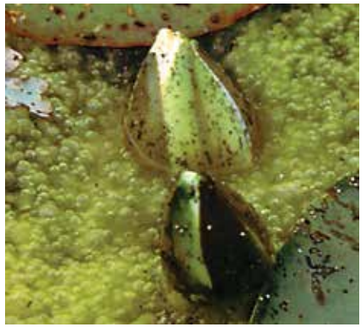
Combatting the moths or caterpillars with chemical insecticides in a natural pool is not possible and the caterpillars are protected against chemicals in their quivers. If you notice "leafboats", remove them from the water manually and also check the underside of leaves. Some songbirds and bats hunt the moths.

In nurseries a biological product was successfully tested: *Bacillus thuringiensis* (BT), a bacterium which affects the caterpillars' intestinal tract. It is available as Safer Brand Caterpillar Killer or Bonide 803 Thuricide BT Insect Killer. Aquatic plant gardeners recommend spraying suspended BT as soon as the first quivers are observed and repeating the application two weeks later (Kircher, 1996).

Water lily aphid (*Rhopalosiphum nymphaeae*)

The water lily aphid is the most common leaf louse in aquatic biotopes. The tiny insect can cover leaves and flower buds of water lilies and soft submerged parts of other aquatic plants with masses of black dots. It hibernates on stone-fruit trees.

Brown China-mark quiver on the underside of a water lily leaf and an open quiver with caterpillar inside.



Water lily aphids prefer to reproduce on young buds and leaves of various aquatic plants. Unfavorable conditions such as string algal competition increases their emergence.

Water lily beetle in various stages of development: adults, larvae and eggs as well as typical feeding traces.

Above Trimming a wetland planting in zone 2 with a lawnmower. This is least disruptive after the first frosty nights in autumn.
Below After mowing, mosses can easily be raked out of the vegetation cover to support the seeding of the desired fen plants. *Sphagnum* cushions should be left untouched or cleaned with a leaf blower.

Affected plant parts can be wiped off or the aphids hosed down with cold water. Potassium soap products can be a good way of reducing the infestation. But it also significantly reduces the surface tension of the water, which harms several organisms such as pond skaters. So such products must only be applied directly onto the aphid populations to minimize run-off into the water.

Water lily beetle (*Galerucella nymphaeae*)

Distinctive feeding patterns on the upper surface of water lily leaves reveal the presence of the water lily beetle. The adults overwinter among pond-shore helophytes. In early summer they fix packets of eggs onto the leaves. The hatched larvae eat there until they pupate. They look similar to ladybird larvae, firmly adhering to the leaf blade and are difficult to flush off by spraying water.

To control them, we recommend measures similar to aphid control: manually wiping off or careful use of potassium soap products.

TRIMMING PLANTS AND RENEWING PLANT STANDS

Irrespective of the pool model, submerged helophyte stalks and leaves should be cut down or mown each autumn to remove nutrients.

Removing leaves of mature water lilies and other floating-leaved plants from the water just before dying off in autumn prevents their sinking to the ground and releasing nutrients through being mineralized. In model 1 and 2 pools, every three to five years this measure can be combined with scooping out mud layers, which works best if you wade carefully into the plant stands using your hands and remove the upper organic cover on the substrate.

Leaves of water lilies planted less than three years ago and autumn-developing leaves of *Aponogeton distachyos* should be left till their foliage recovers independently. Young floating plants such as *Hydrocharis*, *Salvinia* or *Stratiotes* can have their populations reduced by withdrawing surplus parts or rosettes, but be careful not to eradicate complete stands.

Submerged clumps of *Crassula helmsii*, *Elodea* spp., *Potamogeton* spp. or other proliferating species can be harvested periodically throughout the growing season whenever deemed necessary.

Over time, certain plant species may become dominant and their proliferation get out of hand. Completely excavating vegetation stands and inserting new plants may then become necessary. The best time for this is late spring to early summer. Water lilies and other valuable species can be divided into pieces, which should be larger than fist-sized for direct replanting. As a protective measure for water creatures do not renew more than 50% of a regeneration area at a time. The remainder can be tackled the following year. Take care to restore the substrate layers, which are covered with clay to protect fertilizer from the pool water, adequately again.

Left Mowing sedge with a hand sickle.
Helophytes in shallow water (zones 3 and 4) should not be mown below the water surface to allow penetration of gasses through the stalk remnants.
Centre A clever method for inaccessible areas is to use a shovel with a sharpened blade as a "mower" to scrape away all shoots protruding above a tough ice sheet in winter.
Right Sharpened garden tools such as hoes, scythes or this Japanese sickle fixed on a long rod are useful tools for mowing floating leaves, even under water.

WINTER PROTECTION

The plant table (pp. 165-181) lists USDA-hardiness zones as a guide for climate-specific plantings. Species of one or even two levels above the USDA zone of the pool site can be used if adequate winter protection is given. Evergreen plants such as *Sarracenia*, *Darlingtonia* or *Erica* are prone to frost damage by desiccation: if the root area is frozen the transpiring leaves can't equalize the water loss adequately. Removing these plants during frosty periods is the best remedy. Plug conifer twigs into the substrate south of the endangered plants or cover them with a protective polyethylene fleece. In snow-prone regions it should be stabilized by spacers (boxes, twigs, tough wire bows etc.) to prevent pressure damage.

CAUTION
For model 3 and 4 pools: in Technical Wetland and Biofilm-accumulating Substrate Filters, a radical and substantial renovation of plantings can make it necessary to also reconstruct the complete substrate stratification.

Natural pool in winter: the bog planting with several evergreen gems is protected by fleece and conifer twigs – stabilized against snow pressure with boxes underneath.

MAINTAINING FILTER BODIES

Hydrobotanical Systems are substantially planted for water filtration, so all relevant maintenance work is explained above.

Technical Wetlands must be carefully checked for the water flow rate through the drainage pipes. If a significant reduction is noticed, clogging by invading roots is the likely cause. A plumber's cleaning spiral may solve the problem but long-term the clogging may return with increasing

frequency. A sustainable solution entails completely renovating the TWL area, although in practice this is rarely necessary.

Biofilm-accumulating Substrate Filters should be kept free of vegetation or planted with shallow-rooting plants only to prevent clogged plumbing. Biofilm-accumulating filters need consistent water percolation 24 hours a day. Depending on the amount of nutrients to cope with and the percolation rate, the biofilm must be removed from the system before reaching the stage of partially dying off (p. 22). This must be managed by periodic backwashing (p. 65). We definitely recommend carrying this out in spring before starting the pump and in autumn at the end of the season. Additionally, in pools which are heavily used with a BSF as only filtration unit (case study 10), backwashing may be necessary once or even twice a month – but with a clever installation of pump and plumbing, this measure will not be too time-consuming.

SERVICING TECHNICAL INSTALLATIONS

It is not necessary to explain all the necessary maintenance work on technical equipment in this book, because each item will come with its own servicing instructions, which should be observed carefully. But don't neglect the following regular tasks:

Skimmers and mechanical filters: soaked-in pollutants must be cleaned regularly. If necessary, replace filtering units as specified by the manufacturer.

Pumps should be prepared for the winter break: either removed from the pump-house or at least protected from frost damage. Most pumps require an annual service to remove deposits from moving parts.

Phosphorus filters need periodic replacement of the adsorbent granulate. Either use a regular water analysis or carefully monitor algae to determine the right time to do this.

Table 50 **Maintenance work by season**

		Model			
Season	Measures	1	2	3	4
Spring	Remove winter protection, fleeces etc.	✓	✓	✓	✓
	Reinstall pump and clean filter devices		✓	✓	✓
	Renew batteries of time switches		✓	✓	✓
	Clean swimming area walls from biofilm covers	✓	✓	✓	✓
	Backwash BSF				✓
	Vacuum up mud from the swimming area	✓	✓	✓	✓
	Check the capillary barrier	✓	✓	✓	✓
	Fertilize plants as required	(✓)	(✓)	✓	✓
	Remove mud from the ground of Hydrobotanical Systems (not annual)	✓	✓	(✓)	
Regularly throughout bathing season	Clean swimming area walls from biofilm covers	✓	✓	✓	✓
	Vacuum up mud from the swimming area	(✓)	(✓)	✓	✓
	Backwash BSF				✓
	Refill water	✓	✓	✓	X
	Control P-filter		(✓)	✓	✓
	Clean mechanical filters of skimmers, pump-house etc		✓	✓	✓
	Weed control	✓	✓	✓	✓
	Remove fruiting shoots of potentially rampant plants	✓	✓	✓	✓
Autumn	Cutting back helophytes and dying leaves of water lilies, etc	✓	✓	✓	✓
	Clean swimming area walls from biofilm covers	✓	✓	✓	✓
	Backwash BSF				✓
	Vacuum up mud from the swimming area	✓	✓	✓	✓
	Install leaf protection net or fence	✓	✓	✓	✓
	Clean mechanical filters of skimmers, pump chambers etc		✓	✓	✓
	Protect pumps from frost or remove them and store in frost-free place		✓	✓	✓
	Remove plants which are not hardy for appropriate overwintering	✓	✓	✓	✓
	Weed control	✓	✓	✓	✓
	Remove fruiting shoots of potentially rampant plants	✓	✓	✓	✓
Winter	Protect sensitive plants with fleece, conifer twigs etc. before the frost season	✓	✓	✓	✓
	Remove leaf protection net or fence	✓	✓	✓	✓
	Service technical equipment stored indoor (e.g. unclog pumps)		✓	✓	✓
	Plan any enhancements of your pool for next season	✓	✓	✓	✓

Stainless steel steps extending from a wooden platform make an inviting entry point to this naturalistic pool.

10 CASE STUDIES

This section features natural pools in use in Austria, Germany, the UK and the USA that are built for a range of climates and needs. The table below reveals their individual characteristics at a glance.

		Case study number																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Design style	Architectural		✓	✓	✓	✓			✓	✓	✓			✓	✓		✓	✓	✓
	Naturalistic	✓		✓		✓		✓	✓	✓		✓	✓			✓		✓	✓
Model	1	✓	✓				✓												
	2	✓	✓	✓				✓	✓										
	3											✓			✓				
	4				✓	✓				✓	✓		✓	✓		✓	✓	✓	✓
	A	✓		✓	✓	✓	✓				✓	✓	✓		✓				
	B			✓	✓														
	C (separate pool)										✓						✓	✓	
Construction type	No wall	✓					✓	✓							✓	✓			✓
	Wall on sealing				✓		✓			✓		✓							
	Wall under sealing	✓			✓			✓				✓	✓						
Conversion pool			✓	✓															
P-filter											✓		✓	✓			✓	✓	✓
Aeration/carbonator													✓	✓		✓	✓	✓	✓
Koi carp									✓						✓				
USDA zone		8	8	8	8	8	8	7	7	7	8	8	8	8	8	5	7	9	6

AUSTRIA

Austria, the country where natural pools originated, provides a vast range of possibilities in design and filtering techniques. It began with rudimentarily equipped natural swimming ponds, but today exemplifies a very high level of sophistication. Numerous professional construction companies and system providers are based in Austria, including several which are active internationally.

In our case studies we mainly focus on older pools, which show that even simple constructions can produce very satisfactory results. Two conversions from traditional swimming pools into naturally purified ones carried out in the 1980s are still in use today. We have concentrated on examples near Vienna and Graz.

Case Study 1 A view over lush water lilies onto the vast swimming area.

CASE STUDY 1
SWIMMING POND, NEAR GRAZ

Location and design principles

The 3,000 m² garden on the outskirts of Graz is surrounded by flowery meadows in a hilly landscape. A swimming pond with a total surface of 300 m² was constructed in the southern part of the garden. The residential house 25 m north of the pond is surrounded with plantings of varying degrees of formality, while the pond area has a more organic and naturalistic feel. A mixed border forms a divide between the two parts of the garden.

Partitioning and purification methods

The pond provides a huge swimming area, framed by a marginal shallow water zone densely covered in helophytes. The sloping ground militates against vertical walls around the swimming area, so the substructure consists of only compacted loam covered with a thick protection fleece and then a PVC liner.

On the southern side, a path made of large stone blocks leads across the pond dividing the swimming part from a small regeneration area with rich vegetation in 20–130 cm of water. Near the wooden deck on the northern side, water is drawn through a skimmer and brought into regeneration area. We would define this facility as model 1-2 because the pump is used only occasionally.

Case Study 1 **General data**	
Mean annual precipitation* (Graz University)	819 mm, mainly in the warm season
USDA zone	8a
Pool sealing	PVC liner, 2 mm
Substrate for plantings	Max. 20 cm thick cover of nutrient-poor loam
Maximum depth of swimming area	2.4 m; visual depth: 1.5 m
Water circulation rate	The pump works only occasionally
Dry-installed pump	Espa Iris 750M, lifting height: 0.5 m, ~200 l/min

*Mean annual precipitation (1990–2014) data for all case studies from www.weatherbase.com.

CASE STUDY 1

Model 1-2A

Designed and constructed in 1998 by the owner in cooperation with a local job creation company

Planting design

The pond is divided from the rest of the garden by a path of natural stone flags. Beyond it, ornamental perennials and shrubs such as hydrangeas and *Potentilla fruticosa* provide a sense of lush verdance. Inside the pool sealing, a much more naturalistic effect is created with wild herbaceous plants, dominated by spikerush (*Eleocharis palustris*), growing along a narrow margin to a depth of 20–40 cm. The limited development of most other species indicates the water has a low nutrient content. However, white and pink water lilies grow well, planted in a depth of 100–140 cm in spacious troughs.

In the regeneration area a dense network of helophytes, floating-leaved and submerged species creates very clear water. Nutrition is promoted by occasional water movement.

Case Study 1	Important plants (+ : vital growth; ++ : rampant growth; – weak growth, moderate deficiency symptoms; – – : strong deficiency symptoms)
Zone 1: perennials around the pool	*Hemerocallis* cultivars, *Verbena bonariensis*, *Gaura lindheimeri*, *Bistorta amplexicaulis*
Zones 3–5: regeneration area	*Lythrum salicaria* (–), *Carex pseudocyperus* (–), *Scirpus sylvaticus* (–), *Acorus calamus* (–), *Typha laxmannii* (+), *Sagittaria latifolia*, *Schoenoplectus lacustris*, *Menyanthes trifoliata* (+), *Nymphoides peltata* (–), *Potamogeton lucens* (+), *Utricularia* sp.
Zones 1–2: margins of swimming area	*Mimulus luteus*, *Briza media*, *Sarracenia purpurea* (+), *Lythrum salicaria*, *Carex acuta* (–), *Acorus calamus* (–), *Eleocharis palustris* (++)
Zones 4–5: water lily and reed area	*Juncus articulatus* (as a weed), *Lysimachia thyrsiflora*, *Menyanthes trifoliata* (+), *Nymphaea* cultivars (+)

Maintenance

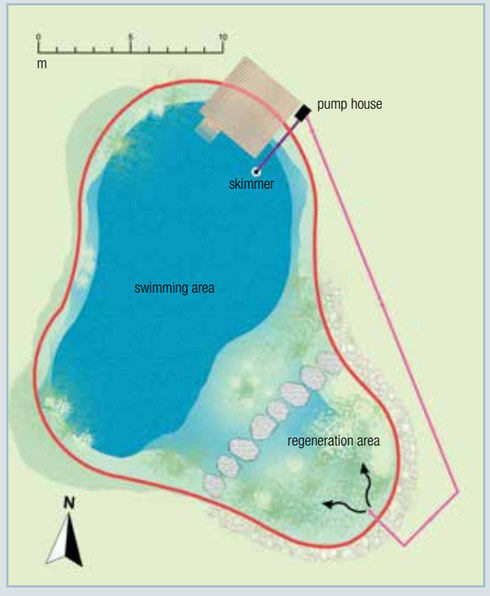
Rainfall is sufficient here to keep the water level stable and guarantee a low nutrient level. In spring, dead parts of reed-like plants are cut and removed. Vacuuming up the mud happens once a year with a Hartl HW 300 vacuum pump. To date, no fertilizers have been used.

Assessment and recommendations

A pond with such a vast bathing area does not necessarily need a vertical wall to separate the swimming area from the planted zones.

Being fed only by rainwater, the pond tends to be a carbon-minimized system. Wild ducks introduced topmouth gudgeons (*Pseudoraspora parva*), which bred rapidly and seem to be responsible for slightly murky water. Catching the fish periodically helps mitigate this. However, there are no problem with filamentous algae and the owners say: "When we are swimming, the water feels marvellously soft and it smells great".

The marginal *Eleocharis* populations look rather uniform; adding swamp plants from nutrient-poor bogs and fens would increase the diversity and attractiveness, but would require raising the substrate layer slightly above the water level.



The pump is used only occasionally to stimulate water circulation. It is hidden in a box beside the deck.

Sketch of the pool and its surroundings.

CASE STUDY 2

Model 1-2B

Designed and constructed in 1988 by Fricke Gründächer und Gartengestaltung, Weidling

CASE STUDY 2
POOL CONVERSION, VIENNA

Location and design principles

A traditional rectangular swimming pool (4 × 8 m) was constructed in a Vienna suburb in the 1960s. To reduce maintenance demands, it was converted into a swimming pond in 1988. Its geometric shape echoes the Bauhaus style of the house.

Partitioning and purification methods

The conversion method is both very simple and rather unusual: the filter zone, conceived as a Hydrobotanical System, is completely integrated into the concrete basin. A wooden construction forms a trough 1.2–1.5 m wide and 80 cm deep, filled with loamy substrate and covered with gravel (8–16 mm), so that there is an effective water depth of 20–50 cm above the substrate.

An additional filter element was added as a stream bed, sealed with a PVC liner and running parallel to the regeneration zone. It is filled with rough pebbles but free from vegetation. The underwater 24v pump can safely be included into the swimming area. The stream is only occasionally activated as the water quality is sufficiently clear.

Planting design

Though the pool is shadowed by a tall spruce and other trees, lush reed plants and dwarf water lilies have flourished in the wooden trough for 25 years. Helophytes used consist chiefly of *Iris pseudacorus*, *Lysimachia thyrsiflora*, *Acorus calamus*, *Caltha palustris* and *Lythrum salicaria*.

Maintenance

Cleaning is done periodically by a pool robot. Helophyte shoots are cut and removed in autumn or early spring. No fertilizer has ever been applied. The concrete construction is strong enough to withstand normal winter frosts.

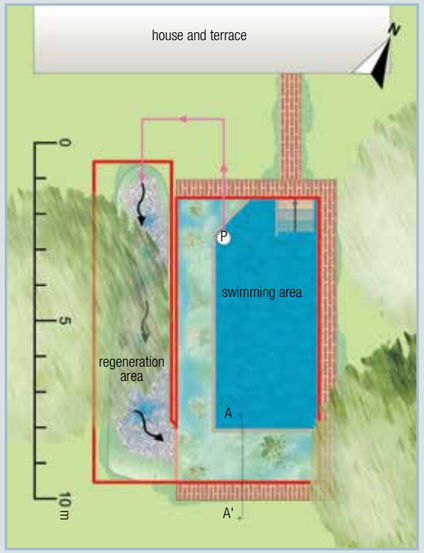
Assessment and recommendations

This is a simple project which produced a successful solution. The water is clear enough for the bottom to be visible. The strong shading does not cause problems, apart from an increased accumulation of leaves and needles. The light brownish hue of the water suggests the presence of humic acids as a result of organic input. In combination with the local water quality, this may result a in C-limitation hostile to algae growth.

Along its margins the stream bed could be planted with some shade-tolerant helophytes, which would require some fine-grained substrate between the pebbles and regular use of the pump. Recommended species: *Acorus gramineus*, *Caltha palustris*, *Primula japonica*, *Symplocarpus foetidus*, *Lysimachia nummularia*, *Calla palustris*, *Carex elata* 'Aurea'

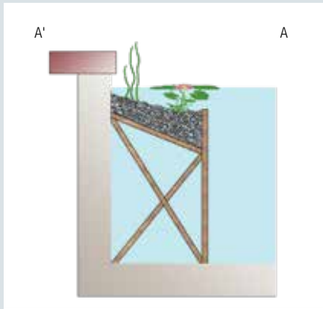
Case Study 2 **General data**	
Mean annual precipitation (Vienna, Hohe Warte)	620 mm
USDA zone	8a, slightly continental influenced
Pool sealing	Reinforced concrete wall 30 cm thick, stream: PVC liner, 1 mm
Depth of swimming area	1.5–1.8 m
Water circulation rate	Pump runs only occasionally
Underwater pump	OASE UWP 75 (75 l/min), 24v (old model, equivalent to OASE Aquamax 6000, 12-v)
Cost of conversion (incl. stream)	~ € 8,000

The regeneration zone is completely integrated within the former pool, which still provides the overall framework.



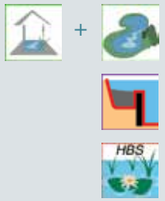
Sketch of the pool and surroundings.

Section through the planted larch wood construction. The side facing the swimming area is fully boarded to prevent accidents.



CASE STUDY 3

Model 2B



Designed and constructed in 1986 by P. Petrich and J. Fricke, Klosterneuburg

The rectangular pool marries well with the architecture of the house behind. Stalks of *Schoenoplectus tabernaemontani* form a transparent curtain framing the water.

CASE STUDY 3
CONVERTED ARCHITECTURAL POOL WITH NATURALISTIC REGENERATION POND, KLOSTERNEUBURG

Location and design principles

This rectangular swimming pool made of fibreglass-reinforced polyester resin was built on the rural outskirts of Vienna in the 1960s. In 1986 the upper 40 cm of two walls was removed. A PVC liner was fitted into the complete pool and led out to form an adjacent shallow regeneration zone. The result was one of the world's first natural pools.

Partitioning and purification methods

The regeneration area was filled with poor loam and covered with gravel. Dense planting works as a Hydrobotanical System. Two aeration nozzles provide oxygen enrichment. Through an overflow the water reaches a stream, which meanders about 20 m down to a separate regeneration pond with lush vegetation. From here it is pumped back to a well stone at the edge of the pool.

Case Study 3 **General data**	
Mean annual precipitation	644 mm
USDA zone	8a, slightly continental influenced
Pool sealing	PVC liner, 1.5 mm
Depth of swimming area	2 m
Water circulation rate	c. 1× complete volume/day
Dry-installed pump	Pump chamber beside the regeneration pond: Speck Badu L 11, output of 11 m³/hr reduced to about 5–6 m³/hr at a lifting height of ~3 m
Cost of conversion (incl. regeneration pond and stream)	~ € 40,000

Planting design

The clear water is proof of low nutrient content, so plant growth is weak. The weeping willow at the east side of the regeneration pond shades the vegetation in the morning. *Potamogeton crispus* formerly thrived underwater here, but disappeared after about 10 years.

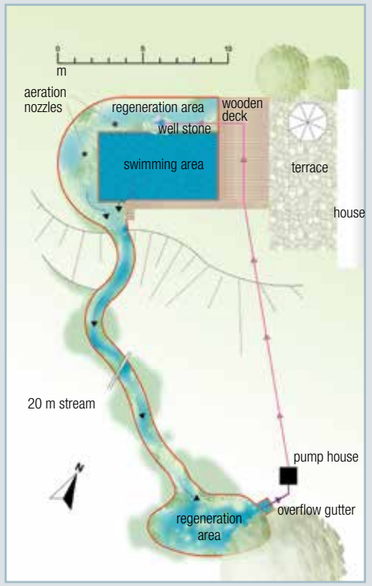
Maintenance

Regular vacuuming by a pool robot keeps the swimming area tidy. Helophyte shoots are cut and removed in autumn. Along the stream and the separate pond the capillary barrier has to be checked occasionally so that proliferating vegetation can be reduced to prevent water loss through wicking. No fertilization to date.

Assessment and recommendations

This pool has been working well for over 30 years. The water is clear and the bottom visible. A slight brownish hue is acceptable. It is the result of organic input from willow leaves and other trees nearby.

Case Study 3 **Important plants**	
Zone 3–4: regeneration zone around swimming area	*Schoenoplectus tabernaemontani*, *Iris pseudacorus*, *Lythrum salicaria*, *Typha laxmannii*, *Lysimachia thyrsiflora*, *Epilobium hirsutum* (introduced as weed?), dwarf *Nymphaea* cultivars
Zone 4: separate regeneration pond	*Pontederia cordata*, *Hippuris vulgaris*, *Cyperus longus*, *Lysimachia vulgaris*
Zone 5: separate regeneration pond	*Ceratophyllum submersum*, *Nymphaea* cultivars, *Potamogeton natans*, *Stratiotes aloides*, *Hippuris vulgaris*

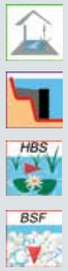


Sketch of the pool and its surroundings.

Below left A wooden walkway covers the original edge of the pool. In the lefthand corner the water leaves the pool, flowing over a step into the stream.
Below right The outsourced pond at the base of the slope is densely covered with water lilies as well as filamentous algae, no problem as long as they do not invade the swimming pool.

CASE STUDY 4

Model 4A



Designed by D.I. Christine Haas, constructed in 2002 by Fricke Gründächer und Gartengestaltung, Weidling

An oval pool is easy to fit into a wide variety of gardens. In the background the swimming area opens to the regeneration planting.

CASE STUDY 4
ARCHITECTURAL POOL, NEAR VIENNA

Location and design principles

A formal design makes sense when space is limited: a small garden on a sloping site in a Vienna suburb was transformed into a water and pool garden. An oval pool, accessible via a wooden deck, was created in front of a dry stone wall. Two mature apple trees in the background were protected from building work. One tree breaks through an opening in the wooden platform and provides shade.

Partitioning and purification methods

The PVC liner was laid out in a 10 × 8 m hole. The swimming area was integrated with a rounded enclosure wall constructed with volcanic tufa blocks. On the northern side the gap between wall and liner was used as substrate filter: in a filling of 50% crushed bricks (2–11 mm) and 50% round gravel (4–16 mm) a perforated drainage pipe (DN 50) was laid horizontally at a depth of 50 cm. A pump permanently draws water through the gravel bed into this pipe and then into a regeneration zone on the east side. A second circulation system transports water from a skimmer under the western deck to the southern regeneration area.

Case Study 4 **General data**	
Mean annual precipitation (Vienna, Hohe Warte)	620 mm
USDA zone	8a, slightly continental influenced
Pool sealing	PVC liner, 1.5 mm
Depth of swimming area	2 m
Water circulation rate	c. 1× complete volume/day
Underwater pump for substrate filter	OASE UWP 75 (75 l/min), 24v, working 24 hrs/day
Underwater pump for skimmer	OASE Aquamax 6000, 12v (100 l/min), working 12 hrs/day
Cost	~ € 40,000

Planting design

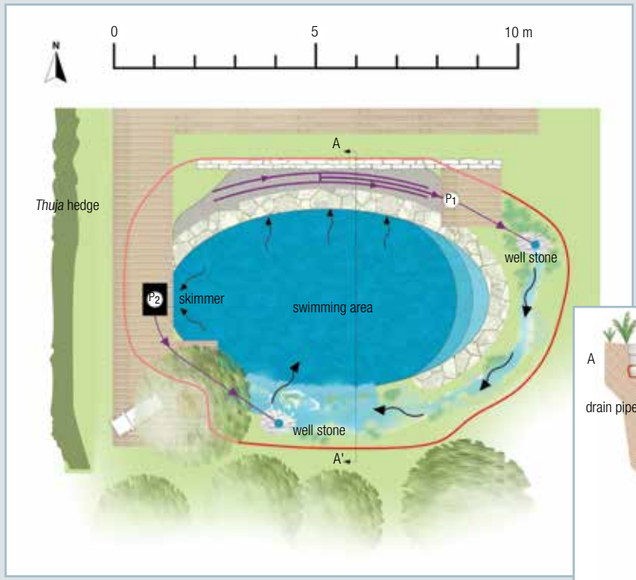
Plant growth is moderately good. Some minor chlorosis symptoms indicate a low trophic status, but running water promotes nutrient absorption. All the plants live in shallow water (10–50 cm): *Typha laxmannii*, *Iris pseudacorus*, *Schoenoplectus tabernaemontanus*, *Lysimachia thyrsiflora*, *Pontederia cordata* and dwarf water lilies are the most significant species.

Maintenance

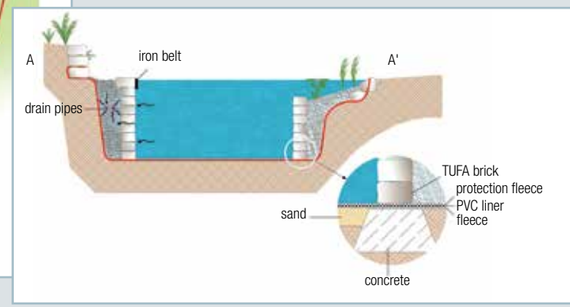
A pool robot cleans the bottom frequently. Porous tufa stones provide a surface for slippery biofilm layers to develop, so the pool wall has to be brushed regularly. Occasionally biofilm flakes float on the surface and need to be removed with a hand net. Regular cutting of dead plant material is a task for early winter. No fertilizer applied to date.

Assessment and recommendations

A rounded shape presents many advantages: the swimming area can be constructed without mortar as a solid vault construction, curved steps can



Sketch of the pool and surroundings.



Section through the pool.

At the eastern end rectangular stones form steps into the pool. The surrounding polygonal flags are fixed by a steel belt circling the whole swimming area.

The swimming zone is framed by a steep wall of volcanic tufa blocks. Overlapping wooden walkways form a wide flight of stairs leading to the house.

easily be integrated and swimming in circles makes best use of limited space.

The porous tufa does however make increased maintenance demands. It allows good percolation of water into the substrate filter, but even with solid stones, a sufficient amount of water could pass the wall if their edges were rounded or slightly irregularly crushed to leave spaces within the gaps.

The filter systems guarantee crystal clear water. The problem with flakes of detached biofilm could be solved by the addition of a sponge filter between the skimmer and the regeneration area which could be retrofitted.

The filter surface could be planted with proper fen plants as a suitable addition to the dry stone wall behind.

CASE STUDY 5
ARCHITECTURAL POOL WITH NATURALISTIC REGENERATION AREA, GRAZ

Location and design principles

The 120 m² pool enhances a level garden plot on the outskirts of Graz. The rectangular swimming area to the west straddles a more naturalistic eastern regeneration area. The swimming area is accessed by a classic stainless steel pool ladder.

Partitioning and purification methods

Purification relies on two planted substrate filters:

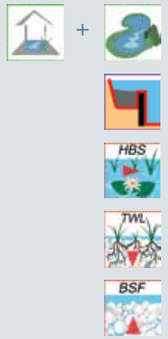
- A 10 m² strip along the western margin of the swimming area is filled with 45 cm round gravel (8–16 mm) which contains limestone. At the bottom of this bed a drainage pipe removes water and transports it to three nozzles on the northern wall. The top-down percolation speed of about 0.35 m/hr is relatively low, so that it can be classed as "slow filter", which does not create much biofilm, but filters according to the Technical Wetland principle.
- An 8 m² gravel filter is percolated bottom-up in the south-eastern edge of the regeneration zone: filled 1 m deep with gravel in various grain sizes, water is pumped from the ground through a drainage pipe arranged in a spiral. Here about 1–1.5 m³ per m²/hr runs through the filter (≙ 1–1.5 m/hr), so that a biofilm can grow on the gravel surfaces. The filter ends some centimetres above the water level, so a surface stream is formed, which falls in a small cascade into the regeneration area, a Hydrobotanical System.

A dry-installed pump draws water from the first filter bed and a skimmer at the north-east edge of the swimming area and feeds the second filter. An amount of 60–70 l/min is pumped through the three nozzles at the west side of the swimming area. They create a surface current in the direction of the skimmer, supporting the removal of floating pollutants.

In a corner of the regeneration area a waterfall has been created as an additional feature with its own circulation system. It is regulated by an extra pump, which is switched on only occasionally.

CASE STUDY 5

Model 4A



Planned and constructed in 2008 by Angelika Kern, Graz

A view from southeast over the regeneration zone.

Case Study 5 General data	
Mean annual precipitation	870 mm, mainly in the warm season
USDA zone	8a
Pool sealing	PVC liner, 1.5 mm
Dimension of swimming area	40 m²; 2.2 m deep
Dimension of regeneration area	48 m² HBS 0.8–1 m deep 15 m² HBS 0–0.4 m deep 10 m² TWL 8 m² BSF
Water circulation rate	2–3 × complete volume per day
Dry-installed pump 1	Oase Aquamax Eco Premium 16000, 220–240v, 145w, Output max. 266 l/min (1)
Dry-installed pump 2: only occasionally used for the waterfall	Oase Aquamax Eco Premium 8000, 220-240v, 65 Output max. 133 l/min (1)

The western end of the swimming zone: inviting, perfectly clear water.

Planting design

The whole garden is dominated by orange, yellow and white tones. The intensive gravel filtering points to a phosphorus-limited system. Despite regular nitrogen fertilization, *Pontederia*, *Lythrum* and some irises appear dark green but restrained in size, typical symptoms of slight phosphorus deficiency. The deep part of the regeneration area is mainly covered with water lilies. Initially *Chara* spp. and *Potamogeton lucens* were planted there, but presumably because of phosphorus limitation as well as regular mud extraction, they have largely disappeared over the years.

Case Study 5 Important plants (+ : vital growth; ++: rampant growth; – weak growth, moderate deficiency symptoms; – – : strong deficiency symptoms)	
Zone 2: substrate filter surface	*Iris laevigata*, *Iris pseudacorus* (+), *Lythrum salicaria*, *Typha laxmannii* (– –)
Zone 4: regeneration area	*Sagittaria latifolia* (++), *Pontederia cordata* (–), *Menyanthes trifoliata* (+), *Iris pseudacorus* (+), *Acorus calamus* 'Variegatus' (–), *Lythrum salicaria* (+), *Orontium aquaticum*, *Typha laxmannii* (– –)
Zone 5: regeneration area	*Nymphaea* 'Hermine' (white), *N.* 'Marliacea Chromatella' (yellow), *N.* Sioux' (orange), *N.* 'Amabilis' (light pink)

Maintenance

The Sopra Premium Cleaner robot regularly cleans the base of the swimming area. Biofilm development on the pool walls is low, but occasionally the coverings are loosened with a brush and removed by the robot. Each spring before restarting the pumps, filter 2 (BSF) is backwashed to remove organic debris of dead biofilm remnants.

In autumn the helophyte shoots are cut and removed. From April to August 1.2 kg urea is added to the water monthly to compensate for the lack of nitrogen.

Assessment and recommendations

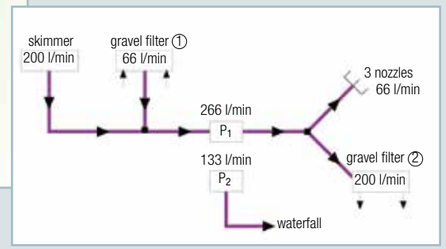
The complete pool system is perfectly integrated into the garden. The clear water proves that the filter dimensions were well calculated. The bottom-up percolated substrate filter could be even more efficient if additional aeration jets were installed on the base.

The weak growth of some water lilies could perhaps be improved by additional substrate to increase space for root development and fertilization. Possible additions to the regeneration zone could be *Sagittaria graminea*, *Stratiotes aloides* and *Baldellia ranunculoides*. We recommend using plants from oligotrophic lime fens on the bottom-up filter such as *Schoenus nigricans*, *Epipactis palustris*, *Allium suaveolens*, *Eriophorum latifolium*, *Tofieldia calyculata*, etc.

Along the edge of the second filter, water runs into the regeneration area.

The waterfall in the northern inlet of the regeneration is used according to the owner's whim.

Concept sketch of pool and plumbing.



Layout of pumps and pipe distribution.

GERMANY

Natural pools were built in Germany during the 1980s, since when an enormous variety of construction types and filter variants has been produced. As in neighbouring Austria there is a range of professional construction companies and system providers who operate nationally and internationally.

Here we focus especially on pools which have had significant input from their owners and have lower technical demands but outstanding planting design. We also feature an example of the new approach to building biologically purified pools without plants.

Case study 7. A wooden bridge crosses this large pool dividing the swimming area from the regeneration zone.

CASE STUDY 6
NATURAL POOL AT A COMMUNITY CENTRE NEAR LÜCHOW, LOWER SAXONY

Location and design principles

The swimming pond is part of the property belonging to the community centre of a small village which can be hired for events. The pond at the back of the garden has become a visual attraction. To provide proper balance between the pond and the huge garden, it was designed as a big naturalistic body of water, 23m wide and 40 m long.

The greatest construction challenge was coping with a groundwater level just 80 cm below the surface. About 15% of the building costs were devoted to temporarily lowering the groundwater table. To be able to excavate the swimming area and insert the liner at a depth of 220–260 cm, temporary wells had to be installed 3 m apart to pump out the water.

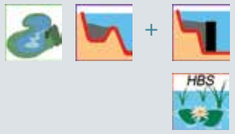
Partitioning and purification methods

The 850 m² pond is a rounded rectangle and is purified solely by plants. A spacious regeneration area 1.5–5 m wide surrounds the swimming zone. Covering not even 50% of the total pond surface, it is smaller than recommended in relevant guidelines (FLL, 2017). The local water is very poor in nutrients and soft enough to provide a degree of C-minimization and no phosphorus oversupply. On the north side a transition to the swimming area is created by a steep dry stone wall. Along the other three sides a sharp angle was modeled from the marginal berm's edge down to the deep central part. This edge is banked by a strip of stones in two to three layers to keep the substrate within the planting area. Water loss is automatically redressed by an irrigation system.

Case Study 6 General data	
Mean annual precipitation (Lüchow)	560 mm
USDA zone	8a
Pool sealing	PVC, 1.5 mm
Dimension of swimming area	~ 450 m², 2–2.5 m deep
Dimension of regeneration area	~ 400 m², 0–100 cm deep

CASE STUDY 6

Model 1



Designed and constructed in 2008 by Markus Sitzer, Trebel/Vasenthien

The huge pond blends with the natural surroundings and provides marginal zones spacious enough for even rampant helophytes.

Planting design

Marginal planting works as a hydrobotanical system without active percolation. The water depth goes from 0 cm to 60 cm and in places to 100 cm. A shallow substrate layer of poor loamy unwashed sand (0–2 mm grain size) is sufficient to support lush vegetation of helophytes and water lilies. A submerged carpet of *Potamogeton lucens* covers the ground.

Case Study 6 **Important plants with healthy growth**	
Zones 3–4	*Lythrum salicaria*, *Caltha palustris*, *Butomus umbellatus*, *Cyperus longus*, *Saururus cernuus*, *Mentha aquatica*, *Mimulus luteus*, *Iris pseudacorus*
Zones 4–5: helophytes	*Butomus umbellatus*, *Pontederia lanceolata*, *Schoenoplectus lacustris*, *Typha latifolia* (spontaneously)
Zone 4–5: submerged and floating-leaved species	*Nymphaea* cultivars, *Potamogeton lucens*, *Hydrocharis morsus-ranae*, *Myriophyllum spicatum* (spontaneously)

Maintenance

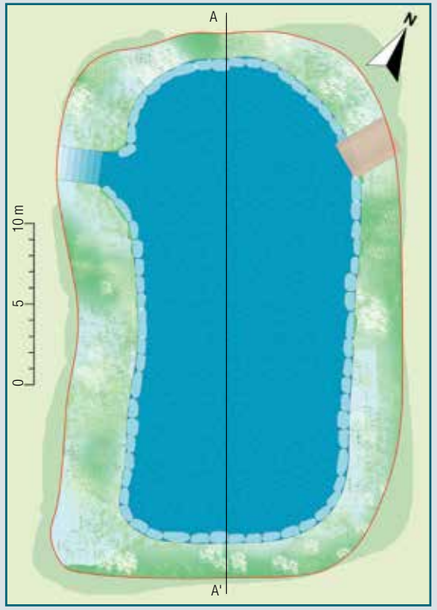
It is vital that public ponds do not have high maintenance requirements. This pool has proved successful in that regard. Trimming and harvesting helophyte vegetation once a year in October requires less time than repeatedly mowing an average lawn. A certain accumulation of mud on the bottom of the swimming area is tolerated.

Assessment and recommendations

The pond is used only occasionally, so pollution by bathers is very low. The visual depth is about 1.5 m and thread algae occur only between the marginal helophytes. A slightly brownish hue reveals the presence of humic acids as result of the soft water and organic sediment.

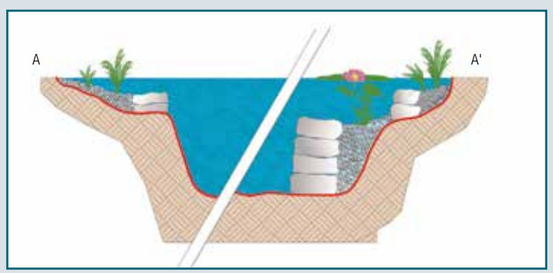
The overall plant growth is very lush, so nitrogen supply must be adequate. *Typha latifolia* has spontaneously established itself and behaves invasively. It will not be possible to get rid of it completely but a reduction of shoots in summer every few years might help to keep the vegetation pattern in balance. Silt and mud accumulation should be removed annually. An occasional check and cleaning of the capillary barrier would reduce water loss and the need for refilling.

Saururus cernuus, or lizard's tail, has established a considerable population in the shallows.



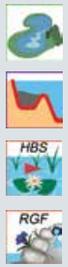
Sketch of the pond.

Section through the pond.



CASE STUDY 7

Model 2A



Planned and constructed in 1997 by W. Kircher

Sealing construction supported by landscaping company Bollerhey, Fuldatal

Pump chamber construction by Kirchner Garten und Teich, Heidenrod

CASE STUDY 7
NATURAL BOG AND FEN POOL, STASSFURT, SAXONY-ANHALT

Location and design principles

The 2000 m² garden is located in a development that dates from the 1990s. An even layer of 60–80 cm fertile loam and Black Soil (Tschernosem) covers shell limestone. The owners, plant enthusiasts with four children, began constructing the garden in 1995, as a largely self-build project. In 1997 the pool was constructed with two aims: providing a refreshing environment through the hot summer and assembling a large diversity of plants. An organic shape was chosen for the 130 m² pool. A wooden bridge crosses the pool, dividing the swimming area from the regeneration part. As a transition between the naturalistic pool and a formal vegetable garden, a wooden pergola extends along the eastern edge of the water.

Partitioning and purification methods

Because the owners had a new-born baby, a 2-m wide entrance area with only 40 cm of water was built, accessible via two stone steps.

The facility can be subdivided into four main parts:

- **Swimming area**: beyond the steps the swimming area is only 120–135 cm deep. Above the liner a protection fleece was laid, bearing a layer of rhyolite stone flags. The marginal zone is filled with lime-free grit (2-8 mm) and planted with fen and bog vegetation.
- **Regeneration area**: this runs from 10 cm above to 100 cm below water level. It is densely planted with helophytes, water lilies and submerged species operating as a Hydrobotanical System.
- **Raised wetland bed**: west of the regeneration area, a swamp bed was added in 2006. Framed by rhyolite stones, it is slightly raised and filled with carbon-free gravel (0–8 mm) and covered with a 5 cm layer of acid *Sphagnum* peat as substrate for heather vegetation and bog plants.
- **Rock garden filter**: a double dry stone wall stretches along the complete northern front of the swimming area like a parapet. Designed as a crevice garden (Zvolanek, 2006) filled with lime-free sand, it was added in 2011 to pretreat the fill-up water. Via a dripline laid along the ridge, water percolates through the sand body. For the dripline, NetafimTM Techline EZ with a 30 cm distance between drop points was chosen. It releases 2.3 l water per hour per drop point, in total about 80 l/hr.

An underwater pump is installed in a flooded chamber under the wooden deck behind the bridge. Through a 10 cm wide PVC pipe ending at the east side of the swimming area, water soaks by gravity into the pump-house, where it is drawn through a rough brush filter and a filter mat and then pumped via a 50 mm pipe to the well stone. After the first frosts the pump is switched off till late March, but left in the chamber.

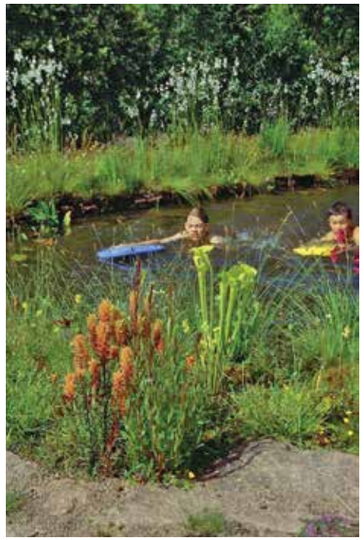
A stream with a very slight incline crosses a paved driveway. Here the PVC liner is substructured by a reinforced concrete bed; thick fleece layers above and below the liner provide protection. Flat stones were fixed onto the fleece with trass cement mortar so that cars can cross the stream.

From the stream the water reaches the regeneration zone. Its narrow shape accelerates the water movement through the Hydrobotanical System.

The planting on the raised wetland bed is irrigated by a second underwater pump, also placed into the pump-house. It transports water into a drip pipe running along this bed. The pressure of the 40w pump is too weak for the narrow dripping outlets, so a few additional 1 mm wide holes were pierced in the pipe. This pump works 3–5 hrs each day from spring to autumn – too little to really categorize it as a Technical Wetland.

The stream, extensive marginal plantings and the water surface itself promote transpiration losses of up to 10 mm on hot summer days. To keep the water level stable, fill-up water from a cistern is pumped into the drip pipe of the rock garden filter's ridge (see part 4 above). About 80 l water per hour percolates through the construction and is led into the pool via the adjacent path's sub-base and the swimming area's marginal

Case Study 7 General data	
Mean annual precipitation (Diebzig)	463 mm
USDA zone	7b, slightly continental influenced
Pool sealing	PVC liner, 1.5 mm
Ground cover of swimming area	Polygonal rhyolite stone flags
Depth of swimming area	max. 1.35 m, irregular ground surface, curved upwards towards the edges
Water circulation rate	c. 1× complete volume/day (operating12 hrs/day)
Underwater pump	Oase Aquamax 1.000, 110w, lifting height 0.6 m
Cost	~ €4,000 (completely self-built)



Above 2001: a view from the western edge. In the marginal zone an Indian paintbrush (*Castilleja miniata*) was sown between low sedges. The pitcher plant *Sarracenia flava* thrives in an acid peat layer above rhyolite grit.
Below 2004: A view from the south over the regeneration zone with the stonework of the stream in front.

planting zone. In spring and autumn a timer switches on the water influx for two hours; in summer that shifts to four hours or longer, if the weather demands it.

Planting design

There is a huge diversity of species in this design. The rock garden filter has proved a perfect home for a collection of alpines. Water lilies in the regeneration part are lush and fast-growing because of a suitable substrate layer: 10 cm loam plus 10 cm lime-free grit (2–8 mm) cover the whole base.

The plant ranges of tall forb, fen and bog communities have been selected to guarantee constant flowering from March till October. During July, North American wet prairie forbs such as *Liatris spicata*, *Lysimachia quadriflora* and *Zigadenus elegans* fill the flowering gap left by European species.

In the dry region of Staßfurt with its calcareous soil, the cultivation of blueberries (*Vaccinium corymbosum* hybrids) is not normally successful. But in the wetland zone of this pond, four shrubs thrive, providing a good harvest every year.

The bog areas are dominated by peat mosses: at water level *Sphagnum squarrosum* thrives; some centimetres above, mainly *S. palustre* and some *S. magellanicum* etc. grow well. Between the mosses, carnivorous plants emerge (*Darlingtonia californica*, *Sarracenia* spp.). In June the pink flowers of *Pogonia ophioglossoides* provide a special highlight, as does *Aster nemoralis* in autumn. Both have rhizomes that grow through loose peat and *Sphagnum* layers. In winter cranberries can be harvested. They sit alongside the slender shoots of the *Vaccinium macrocarpon* plants.

Maintenance

To enable bog plants to thrive, soft water is required (C-limitation). Fill-up water is provided by a pressure-vessel pump from the cistern. It is mostly rainwater, but sometimes during summer it is supplemented with mains water (12°dH total hardness).

In spring some plants are individually fertilized with urea: all pitcher plants and the blueberries are irrigated with a solution of 10 g urea plus 1 teaspoonful citric acid per 10 l can. About 2 l per plant (5 l for blueberries) is poured onto the root plates.

Removing the mud in the swimming area is carried out once or twice a year using a steel broom to loosen the sediment and biofilm layers from the bottom. The following day, after the dislodged particles have settled, a 10 cm wide suction hose is inserted into the opening of the skimmer pipe. This makes it easy to absorb all the loose particles.

Between late autumn and early spring all helophyte shoots are cut back and removed. At the same time the overwintering cranberries can be harvested and their long runners reduced. In the regeneration area about every two years water lily rhizomes and other proliferating plants are partly reduced and some mud is removed by hand.

From December to March the Rock Garden Filter is covered with a thin fleece to save evergreen and sensitive plants from frost damage. The

Case Study 7 Important plants

Zone 1: trees and shrubs around the pool	*Acer griseum*, *Cornus kousa*, *Pinus banksiana*, *Quercus libani*
Zone 1: behind the pool, under the pergola	*Clematis viticella* cv., *Actinidia kolomicta*, *Anemone japonica* cv., *Hosta* spp., *Carex pendula*, *Astrantia carniolica* 'Rubra', *Cimicifuga simplex*, *Euphorbia palustris*, *Amsonia tabernaemontani*
Zone 2: Technical Wetland, wet meadow with bog character	*Vaccinium corymbosum* 'Blue Crop', *Vaccinium macrocarpon*, *Andromeda polyfolia*, *Ledum groenlandicum*, *Rhododendron canadense*, *Sphagnum palustre*, *Pogonia ophioglossoides*, *Eriophorum russeolum*, *Sarracenia purpurea* and Hybrids
Zone 2: margin around swimming area, wet meadow with fen character	*Carex davalliana*, *Eriophorum latifolium*, *Schoenus nigricans*, *Allium angulosum*, *Allium suaveolens*, *Liatris spicata*, *Dactylorhiza* Hybrids, *Epipactis palustris*, *Parnassia glauca*
Zone 2–3: regeneration area, wet meadow with tall forbs	*Lythrum salicaria*, *Carex diandra*, *Filipendula ulmaria* 'Plena', *Lysimachia quadriflora*, *Dryopteris cristata*, *Caltha palustris*, *Cardamine pratense*, *Lobelia sessilifolia*
Zone 4: regeneration area, shallow water	*Nymphaea* 'Chrysantha', *Nymphaea* 'Perry's Baby Red', *Typha shuttleworthii*, *Peltandra virginica*, *Sagittaria graminea*, *Baldellia ranunculoides*, *Pontederia cordata*
Zone 5: regeneration area, deep water	*Nymphaea* 'James Brydon', *Stratiotes aloides*, *Potamogeton lucens*, *Ceratophyllum submersum*, *Utricularia australis*, *Pontederia lanceolata*
Sunny rock garden filter	*Antennaria dioica* cv., *Leontopodium stracheyi*, *Carex baldensis*, *Primula auricula*, *Trichophorum alpinum*, *Gentiana acaulis* Grp., *Androsace sarmentosa*, *Dryas octopetala* 'Minor'
Shady rock garden filter	*Pleione limprichtii*, *Saxifraga fortunei* cv., *Saxifraga oppositifolia*, *Pinguicula grandiflora*, *Wulfenia carinthiaca*, *Hakonechloa macra*, *Primula clusiana*, *Asplenium trichomanes*

Impressions from spring to autumn from the same viewpoint. Above left to right *Ledum groenlandicum* announces spring; *Dianthus superbus* and *Dactylorhiza* hybrids are in full bloom in June.
Below *Allium suaveolens* takes over in September, its slim shoots and leaves are almost invisible before the flowers appear.

water inflow is switched off from November till March. If long frosty periods are forecast, pitcher plants are protected with fleece and conifer twigs. However, *Sarracenia purpurea* is hardy everywhere in Central Europe without any protection.

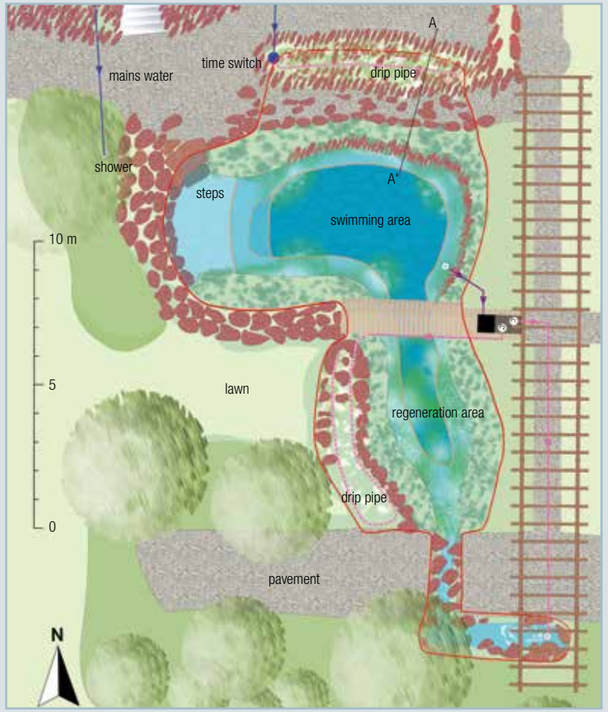
Assessment and recommendations

During the first 15 years the pool was used frequently by the whole family and their friends. Now only the father of the household uses it regularly, so the visual quality of the water and vegetation plays a more important role than during the early years.

In retrospect, the shallow entrance area wasn't necessary. To prevent the risk of small children drowning, a wide swamp zone with waterlogged soil is more effective. For a relaxed swim the pool could be a little deeper and its side walls steeper.

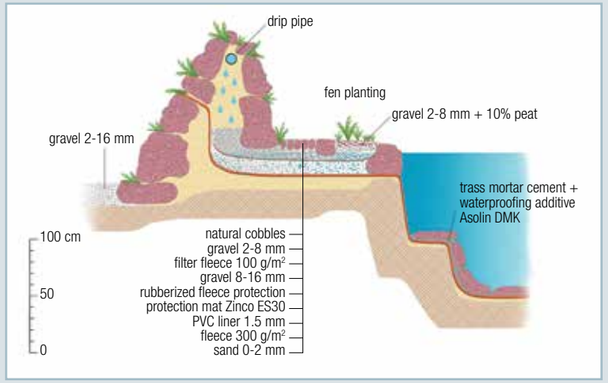
Carex paniculata as well as related sedges should not have been used; they seed so vigorously in the margins of the regeneration zone that they need to be cut down twice a year to stop them outcompeting other plants. The majority of the other plants established well and efforts to keep the water soft were successful. A lot of species from acidic sites still thrive well.

For more pictures of this pool, see page 37, 57 (above), 148, 150, 219.



Sketch of the pool and its surroundings.

Section through the Rock Garden Filter.

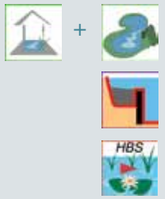


Above Bathing behind orchids (*Dactylorhiza* hybrids)
Below North of the swimming zone a rock garden filter was built in 2014. The fill-up water percolates through sand. After passing the path's permeable subbaseand marginal fen planting it reaches the pool.

Below Vacuuming up mud from the base of the swimming area.

CASE STUDY 8

Model 2B



Planned and constructed in 1988 by the owner

Renovation of pool and stream in 2003 by sealing with fibreglass-reinforced polyester resin (GRP) constructed by Kirchner Garten und Teich, Heidenrod

CASE STUDY 8
ALPINE LANDSCAPE POOL, NEAR ERLANGEN, BAVARIA

Location and design principles

This pool is located in a small village near Erlangen in Northern Bavaria, where the soil is sandy and slightly acid. A couple with a great interest in plants created an extraordinary garden with some exceptional features. The even surface was remodeled to make an alpine and wetland landscape with a backdrop of pine trees and mainly evergreen shrubs. Amid a rockery with countless exquisite alpines, two springs create narrow streams; they meet before they reach the rectangular pool framed by planted dry stone walls, a winter garden and a wooden deck. The pool is also home to a couple of koi.

Partitioning and purification methods

The rectangular swimming pool has marginal zones with bog vegetation. The plants have been placed in shallow troughs which are part of the fibreglass (GRP) sealing. On-site GRP construction of this sort should be carried out by specialists.

From the pool area an underwater pump brings the water to the two springs at distances of 15 and 20 m. The upper stream passes through a pond, which is a tough concrete construction. The stream sealing is also made from GRP which is firmly bonded to the concrete body with innotec adhesive. A second, smaller pond is formed with GRP some metres lower. The vegetation in streams, ponds and the marginal zone of the pool works as a Hydrobotanical System.

Case Study 8 General data	
Mean annual precipitation (Nuremberg)	610 mm
USDA zone	7b, slightly continental influenced
Pool sealing	Fibreglass-reinforced polyester resin (GRP), laminated on-site in 6 layers of fibreglass mats; 12 layers at the capillary border line
Depth of swimming area	2 m
Water circulation rate	c. 1× complete volume/day
Underwater pump	Output c. 2 m³/hr at a lifting height of 1.5 m

Planting design

With a backdrop of evergreen pines (*Pinus sylvestris*), rhododendrons and deciduous shrubs and small trees a stunning miniature landscape was created. Mainly plants from bogs and poor fens have been used in the streams and along the marginal pool and pond zones. Their fine texture and low growth makes them perfect partners for the alpines in the adjacent rockeries. The ponds' inner zones, however, have very few plants.

In many places along the streams and regeneration ponds the capillary barrier has been overgrown by *Sphagnum* moss cushions and various ground cover plants. This makes possible a very natural transition from the bog and fen vegetation to the adjacent garden landscape. Water loss through suction above the edges of the sealing is accepted because of very soft, nutrient-poor refill water.

Case Study 8 Important plants	
Zone 2: bog plants around swimming area	*Sphagnum* spp., *Carex appropinquata*, *Andromeda polyfolia*, *Pogonia ophioglossoides*, *Eriophorum vaginatum*, *Sarracenia purpurea* and Hybrids
Zone 2: regeneration pond and stream with fen and bog plants	*Carex davalliana*, *Carex viridula*, *Eriophorum latifolium*, *Dactylorhiza* Garden Hybrids, *Parnassia palustris*, *Gladiolus imbricatus*

Above, both The whole garden has an amazing diversity of alpine, bog and fen specimens.

The swimming area is framed by a conservatory, wooden deck and planted dry stone walls.

Above Dry stone wall and marginal bog planting on shallow GRP troughs in 2006 left and 2014 centre.
Above right Construction of the regeneration stream and pond system: rounded stones have been placed on mortar supports above the GRP liner. The block stones on the left define the edge of the connected concrete pond.

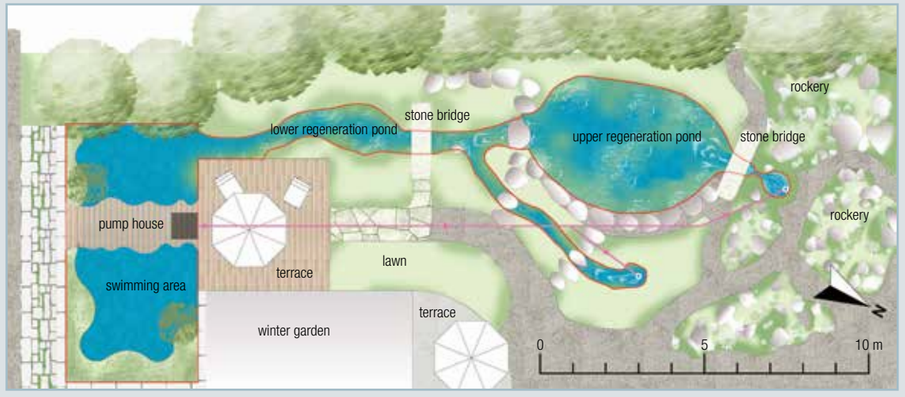
Maintenance

To replace evapotranspiration losses, soft mains water is added as well as rainwater, so a C-minimization can be aimed for, which ensures clear water and a low algae stock.

The mud in the swimming area and the ponds is removed manually with a hand net on a telescopic rod. Grasses along the marginal zone are cut in early spring and *Sphagnum* cushions may be reduced every three to four years.

Assessment and recommendations

The swimming area is very small. The vegetation in the deeper zones of the regeneration ponds would do better if slightly irrigated with urea (5 g/m^3 monthly from April to July). The water provides a visual depth of about 1.5 m, despite the presence of huge koi, which are fed daily. The water is poor in lime and seems to be carbon minimized, so the underwater flora (including algae) is poor, but the bog plants in the marginal zones are thriving.



Sketch of the pool and surroundings.

CASE STUDY 9
ARCHITECTURAL-NATURALISTIC POOL, NEAR ASCHERSLEBEN

Location and design principles

The pool is in the 1000 m^2 garden of a young family with three children who live at the edge of a village in the rain shadow of the Harz Mountains. Here, a completely self-built natural pool was planned and constructed between early 2010 and mid 2011.

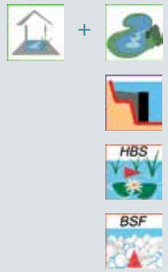
Partitioning and purification methods

The regeneration area surrounds the swimming part. This planted belt is only interrupted by a wooden deck in the south-eastern corner and the wide entrance steps adjacent to the house terrace. The swimming area is framed by larch timber walls made of 10 × 20 cm beams built on the sealing. A round skimmer on the east side of the pool within the regeneration area draws water to the pump, which is dry-installed in the pump-house. The water is pumped through a 63 mm wide conduit to the western regeneration area. Here there is a 6 m^2 filter bed: a system of distribution pipes

Case Study 9 **General data**	
Mean annual precipitation (Halle/Saale)	490 mm
USDA zone	7b, continental influenced
Pool sealing	EPDM liner, 1.5 mm
Ground cover of swimming area	Granite stone flags, 30 × 30 cm, set onto trass (hydraulic) mortar above a fleece (800 g/m²) which protects the liner
Size of swimming area	32 m²; 1.2–1.6 m deep
Size of regeneration area	44 m², 0–60 cm deep
Water circulation rate	~ 1 × complete volume in 1–2 days
Dry-installed pump for fountain and wall jets, also for backwashing the filter bed, run only occasionally	Speck Bettar 12 with pre-filter, 450w, output max. 200 l/min
Dry-installed pump: skimmer to filter bed and stream running continuously	Messner Eco Tec 2 15000, 105w, output max. 245 l/min, also suitable as underwater pump

CASE STUDY 9

Model 4A



Designed and built by the owner (2010–11), in consultation with A. Thon and W. Kircher

In 2013, two years after the pool's first use, planting zones and the wooden deck are still being developed, a typical situation if busy owners are carrying out a project themselves.

(sliced 100 mm PVC tubes) has been embedded horizontally into a 25 cm layer of gravel (16–32 mm grain size) and covered first with a layer of 8–16 mm gravel, then a 2–8 mm one. Each layer is 20–30 cm thick. Finally, a shallow cover of rough gravel fixes the fine fraction. The filter bed is inundated to 20–30 cm. The bottom-up percolation rate is adjusted to 1–1.5 m/hr, so a biofilm can develop. Excess pumped water is transported through 50 mm wide pipes to the stream beside the southern wooden deck.

A second pump draws water from the bottom drain and feeds two jets in the western wall of the swimming zone. This pump is switched on only when people are bathing.

Planting design

The regeneration zone is planted with three water lilies in 40–80 cm deep areas beside the filter pipe system. In a narrow marginal strip, fine gravel substrate (2–8 mm) protrudes slightly above the water, providing a home for bog and fen meadow plants.

An additional bog area was created in the north-western corner in 2013. It is a separate basin, sealed with an EPDM liner and filled with perforated water tanks in acid peat. The water level matches that of the pool thanks to a U-shaped pipe leading from there deep into the bog bed. As long as the pipe is completely filled with water it maintains an equal water level on both sides.

Maintenance

For cleaning the base and walls of the swimming area, the impeller pump Tapir 10,000 is used about every four weeks throughout the bathing season. Additional fittings are a telescopic rod with a brush or a suction funnel and hoses. Since spring 2015 a pool robot Zodiak Vortex 3 has occasionally been used.

Trimming helophyte shoots is done in autumn or early spring. During the first two years of use, the water was very clear. Later, some filamentous algae appeared in the regeneration areas. Though this was not seen as particularly troublesome, the owner decided to test an unusual chemical agent in 2014, Aquaforte Alg-Stop, which achieved completely algae-free water, but also a marked increase in the phosphorus content. If this agent is not administered regularly, the high P-level encourages greater algae development than before.

Assessment and recommendations

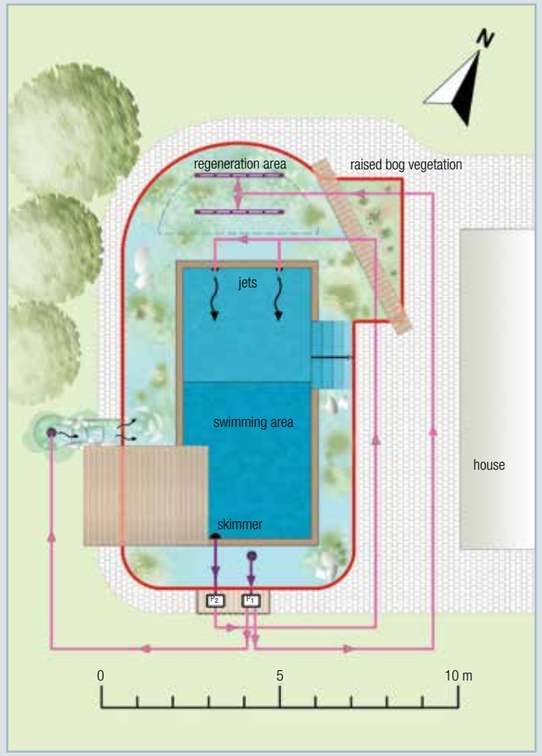
The pool offers a perfect place for cooling off on hot summer days and plenty of possibilities for experimenting with rare and interesting plants. The unusual chemical algae treatment has not so far caused problems with the plants. We assume, though, that sensitive bog vegetation might suffer from long-term application.

The Biofilm-accumulating Filter bed seems to work satisfactorily. However, an addition of an air pump distributing oxygen under the gravel layers has increased its effectiveness.

The very soft mains water which is used for refilling (< 5°dH) provides a promising basis for C-limitation. An addition of more submerged plants in the shallow water zone would help compete against the algae.

In 2014 bog vegetation and the fen meadow in the background were already showing healthy development.

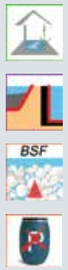
A disused water tank is turned into a pump-house, hidden under the path. The seemingly complicated plumbing allows the use of the robust Speck Bettar 12 pump (right) for backwashing the filter bed.



Sketch of pool and plumbing.

CASE STUDY 10

Model 4C



Design and construction 2012 by Baumann Gärten & Freiräume GmbH, Griesheim. Filter methods and dimensioning: Teichmeister® System, distributed by Balena GmbH, Gemmingen

CASE STUDY 10
ARCHITECTURAL GRP POOL, STOCKSTADT, NEAR FRANKFURT-AM-MAIN

Location and design principles

In the course of reconstructing and integrating a building, a pool was included in a small garden in the densely populated area around Frankfurt where land prices are exorbitant and plots tiny. A prefabricated fibreglass-reinforced polyester resin (GRP) pool was chosen to save space and construction time. The basin is a modified model from Balena GmbH, which was adapted according to the contractor's design. Its rectangular shape was in keeping with the formal design of this garden. On the east side, a smaller basin for koi was added as an independent pond unconnected to the main pool. The characteristic features are light flagstone surfaces, gravel beds exclusively planted with grasses, expressive sculptures and Corten steel elements.

Partitioning and purification methods

The GRP basin measures 7.5 × 32 m. Steps, water inlets, skimmer and lights were prefabricated and ready to use as soon as the basin was in position. The pool edges are covered with rectangular flagstones. Beside the southern edge the filter vessel is embedded in the soil. It rises about 40 cm above the ground, clad in Corten steel plates, which have a rusty patina. The adjacent wooden deck hides the pump-house. All three components

Case Study 10 General data	
Mean annual precipitation (Darmstadt)	652 mm
USDA zone	8a
Pool sealing	Prefabricated GRP basin
Dimension of swimming area	~ 24 m², 1.45 m deep
Dimension of BSF	~ 3 m²
Water circulation rate	~ 2 × complete volume per day
2 dry-installed pumps (one for filter, one for jets)	2 Pentair Intelliflo® set to 120w (filter) 500w (jets, occasional operation)

2012: the prefabricated GRP pool is sunk into the prepared site. After adjustments and pipe and cable assembly, the outer spaces are backfilled with concrete to stabilize its walls.

2013: a flagstone coping conceals the edges of the pool basin. Straight lines and rectangular shapes define a sophisticated formal design.

(pool, filter vessel and pump-house) belong to a complete package supplied by Balena GmbH. Two water circulation systems are installed, both starting at the skimmer, which is integrated into the pool's eastern edge:

- A 120w pump brings water to perforated PVC spiral hoses at the bottom of the 1.5 m deep filter vessel. Twenty-four hours a day around 500 l water per m²/hr percolate upward through a mixture of several gravel types including zeolites.
- A more powerful second pump (500w) is used to feed jets at the western side. They work as a counter-current swimming system, running only during bathing activity and not longer than 2–3 hrs per day.

The pump-house also accommodates a phosphate-filter with iron hydroxide to pretreat the refill water.

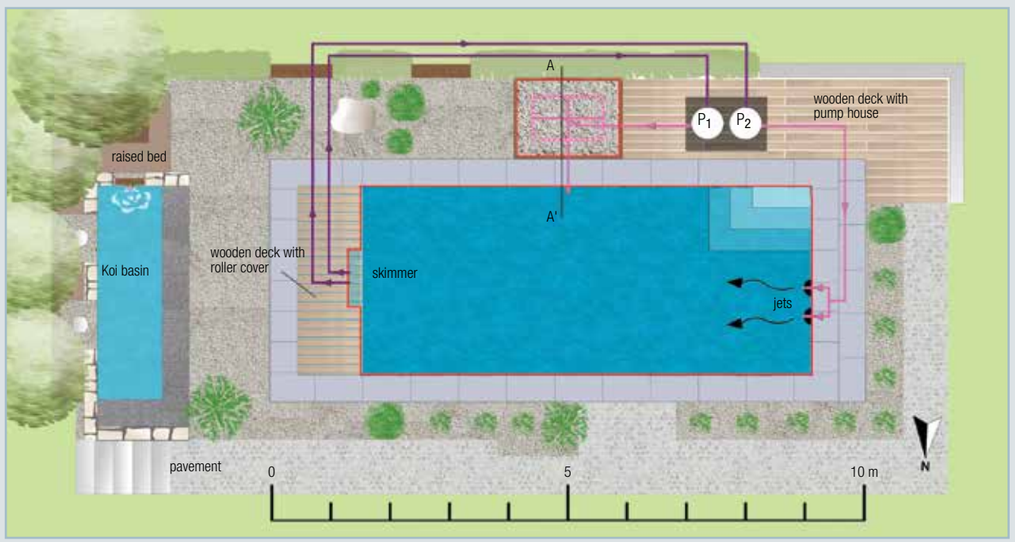
Planting design

Planting the filter bed is possible but not necessary. The owner has put some *Cyperus longus* plants on the filter, which provide a good visual balance to grasses used in the gravel beds around the pool: *Molinia caerulea*, *Pennisetum alopecuroides* and *Imperata cylindrica* 'Red Baron' are planted in lines among coarse gravel mulch, highlighting a minimalist design together with two *Buxus* bowls and *Nandina domestica* shrubs. A trimmed evergreen hedge of *Photinia* 'Red Robin' frames the garden to the southern border.

Maintenance

A roller cover is moved above the pool at night and during periods when it is not being used. It slows down cooling of the pool and reduces any input of unwanted pollutants, such as dust, leaves and pollen. Debris accumulation is consequently very low but a pool robot is nevertheless used to clean the pool.

Substrate filters of this type must be backwashed once every one to two months depending on how much the pool is used. The iron hydroxide filling of the P-filter must be replaced if saturated. Regular checks of the phosphorus content in the water indicates when to do this. Using the roller cover helps reduce water evaporation loss and the need of refilling with potentially P-enriched mains water.

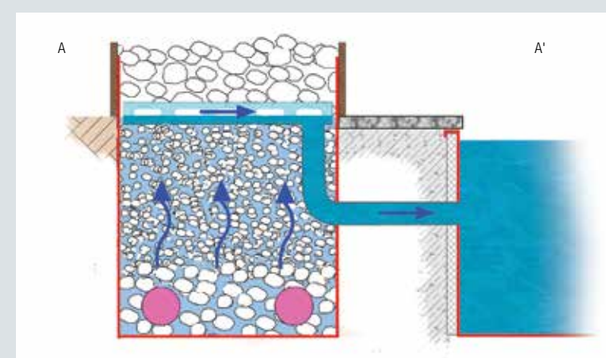


Concept sketch of pool and plumbing.

Assessment and recommendations

The pool combined a very short construction schedule and ready-to use functionality. The surface of the biofilm-accumulating substrate filter comprises not much more than 10% of the total water body and functions well. The composition of the filter gravel results from extensive research by Balena GmbH. Reliance on such small filters can only be recommended if the system is guaranteed by a reliable professional supplier.

The filter bed can be seen as a challenge for planting design: certainly only a few traditional water garden species are able to grow in the low-nutrient water. But plant enthusiasts could design the filter bed as a diverse lime fen meadow comprising *Dactylorhiza* orchids, *Iris sibirica*, broad-leaved cotton grass, etc. as shown in case studies 7 and 8.



Section through the BSF.

UNITED KINGDOM

The natural pool movement in the United Kingdom started with the new millennium. Our three case studies belong to the "running-water type" with percolated filter areas. Pure "standing water" bodies or systems with only surface flow seem uncommon due to most users' expectation of perfectly clear water.

Two of the three projects were based on the Biotop Natural Pool concept: a local landscaping company designed and constructed the complete facility using the methodology, support and some construction elements from the Austrian Biotop company.

A great problem in the UK is the addition of phosphate to the mains water, which serves as a corrosion inhibitor. If this P-enriched water is all that is available for refilling, a special phosphorus filter is highly recommended.

Case study 13. A formal octagonal pool set in a historic estate integrates well with the house and garden.

CASE STUDY 11
NATURALISTIC POOL, NEAR BRESSINGHAM, NORFOLK

Location and design principles

The setting is a huge garden in a landscape of pastures and open woodlands. The generous timber house is designed in a lovely American country style and surrounded by abundant perennial plantings. The 120 m² swimming pond is accessed via a 10 m wooden walkway. It has an organic shape and forms a beautiful foreground to the surrounding grassland, which is dotted with picturesque oak trees.

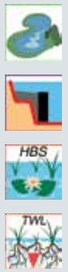
Partitioning and purification methods

The liner is protected by fleece membrane above and below. The swimming area was defined on top by a steel-reinforced concrete floor surrounded by a curved framing wall of mortared rectangular stones. In the gap between concrete wall and liner, three 10 cm wide drainage pipes were laid parallel under 30 cm coarse gravel covered with 35 cm of porous slag material (Lytag, grain size 4–14 mm). Finally this layer was topped with gravel up to 20 mm grain size. The resulting filter area was flooded to a maximum depth of 20 cm.

Case Study 11 General data	
Mean annual precipitation (Diss)	620 mm
USDA zone	8b, oceanic influenced climate
Pool sealing	Alkorplan lining membrane (1.5 mm) sandwiched between 2 (2 mm) geo-textile membranes
Dimension of swimming area	~ 50 m²; max. 1.5 m deep
Dimension of Technical Wetland, areas including tubs of water lilies	~ 70 m²; 0.1–0.5 m water level (water lilies > 50 cm)
Water circulation rate	~ 1 × complete volume per day
Underwater pump (filter drains & jets)	Oase Aquamax Eco Premium 4000 40w, Output ~ 60 l/min
Underwater pump (skimmer – springhead feature; not permanently running)	LOWARA DOC 3 250w; Output ~120 l/min

CASE STUDY 11

Model 3A



Designed and constructed in 2013 by The Swimming Pond Company Ltd, Bressingham, Diss, Norfolk

Purple loosestrife, cypress grass and cattail enhance the naturalistic impact and charm of the swimming pond.

The water is drawn through the filter material into the three pipes, which meet in one connection shaft leading to the drainage pump, placed in a flooded pump-house beside the pool. The relatively low percolation speed means the filter system can be classified as a Technical Wetland. The water is pumped back into the swimming area through four jets in the wall. The angle of the jets means they create a slight circulation of the water.

A second pump-house is connected with the skimmer at the east side of the pool. This water is brought to the springhead feature at the north-western edge.

Planting design

The pool is mainly surrounded by lawn, with a strip of blue flowering catmint (*Nepeta* × *faassenii*) along the edge of the wooden deck.

Tall forbs and reed-like grasses dominate the marginal planting of the pool above the filter areas. Seven tubs, 75 cm deep and 90 cm wide, have been inserted in the filter medium. They are filled with 30 cm of clay soil and planted with water lilies. The resulting water level measures at least 50 cm, depending on the particular cultivar.

Case Study 11 **Important plants**	
Zone 3–4: well developed after one year	*Typha gracilis*, *Cyperus longus*, *Equisetum hyemale* var. *robustum*, *Lythrum salicaria*, *Caltha palustris*, *Myosotis palustris*, *Pontederia cordata*, *Iris pseudacorus*, *Iris* 'Black Gamecock'
Zone 3–4: weak development after one year	*Ranunculus lingua* 'Grandiflora', *Orontium aquaticum*, *Nasturtium aquaticum*, *Ranunculus aquatilis* (completely disappeared)
Zone 4–5: water lilies	*Nymphaea* 'White Sultan', *N.* 'Virginalis', *N.* 'Charles de Meurville', *N.* 'Marliacea Chromatella'

Maintenance

The swimming area is regularly cleaned with the Blagdon 'Pond Monsta' pond vacuum. In autumn the emergent plants are cut back. In the first two years there has been no fertilization.

Assessment and recommendations

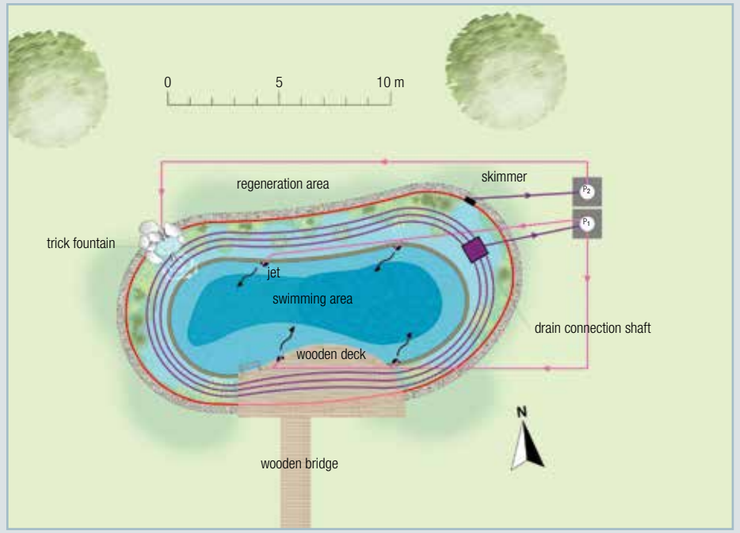
The water is glass clear and the owners are very happy with their pool. However, the shallow areas outside the swimming zone are partly covered with filamentous algae. An analysis of the local tap water revealed a phosphorus content of 6.6 mg P/l, 600 times the FLL recommendation for natural pools. A very similar pool nearby fed with the same fill-up water showed a P concentration of 0.56 mg/l in the pool water. So a substantial reduction of dissolved phosphorus can be effected by plants and filtration processes, but it still is too high. A denser covering of the marginal areas with helophytes and submerged species would help reduce algae development. A phosphorus filter was deliberately not installed to keep the technology level low, but it is likely that complete elimination of the algae problem could only be achieved by treating the fill-up water in this way.

The alternative approach to get rid of filamentous algae, the C-limitation by achieving soft water, is not recommended here because the concrete surfaces will always increase the hardness of the water. (Case study 14 shows a project with comparable filter technique where C-limitation was successful.)

Above The springhead feature in the background redirects the filter water into the pool again. While the walls and base of the swimming zone are clean, the marginal shallow water areas are covered in filamentous algae.
Below The view from the wooden deck over the pool and the parkland beyond.

We assume a monthly addition of urea (at least 5 g/m^3 water) from April to August would support the development of part-submerged and floating-leaved plants as well as reducing the competitive impact of filamentous algae. The springhead feature was requested by the customer. It makes the adjacent pond water move intermittently, which also promotes filamentous algae, so water lilies nearby should be encouraged to compete. Injecting fertilizer tablets in spring into the clay substrate may stimulate their growth even more effectively than urea treatment because it supplies nutrients directly to the roots.

A step-by-step illustrated account of the building of a similar pool is available on the website of 'The Swimming Pond Company'.



Concept sketch of pool and plumbing.

CASE STUDY 12
ELLICAR GARDENS NATURAL SWIMMING POOL, GRINGLEY-ON-THE-HILL, NOTTINGHAMSHIRE

Location and design principles

The 2-ha Ellicar Gardens are home to a professional horticulturalist and garden designer couple and their five children. Design and construction of the gardens began from scratch in 2010 with the aim of attracting and sustaining a rich diversity of wildlife. Visitors have much to enjoy with traditional perennials alongside swathes of wildflowers and contemporary planting patterns with new perennials and grasses. Ellicar Gardens provide various workshops and their own special school garden. At the heart of the gardens is the huge natural swimming pool, which opens onto a wide gravel beach at its northwest edge. Around the pool are several wooden jetties and decks, lovely places to sit and relax beside the water and enjoy the sumptuous perennial plantings that frame this beautiful pool.

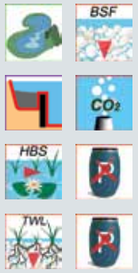
Enjoying the water lilies in the regeneration zone.

Partitioning and purification methods

The 300 m^2 pool stretches over a length of 25 m from west to east. The spacious swimming area of 120 m^2 can be accessed from the western beach or from curved stone steps at the northern side. The eastern edge is defined by a huge wooden deck. The southern marginal zone and the beach area

CASE STUDY 12

Model 4A



Designed by Sarah Murch, constructed in 2010 by Natural Pools UK Sarah & Will Murch

Filter methods and dimensions based on the Austrian Biotop system

Above The filter zone opens onto an inviting shingle beach. It operates not only as access to the water but also as substrate filter bed.
Below The skimmer is hidden under a cover in the wooden deck.

to the west accommodate filter zones (Technical Wetlands) where water is drawn through perforated pipes embedded 50 cm deep in filter gravel. The pumps and technical equipment are placed in a spacious pump-house hidden between tall perennials in the adjacent pool-side garden. There are two different water circulation systems:

- **Gravity system**: the water from the southern Technical Wetland is drawn through a pipe flanged into the liner and then into the pump-house. Here gravity causes it to flow into a round vessel from which a submerged pump transports it back to the swimming area via two jets and two millstones, which are arranged as gently bubbling fountains set just above the water level. This pump runs for just 8 hours during the day to reduce electricity costs and prevent trapping nocturnal animals.
- A skimmer has been fitted under the wooden deck to keep the pool surface clean. It is also a part of the gravity system channeling water to the vessel in the pump-house.
- **Beach filter**: the water is drawn through the western beach filter by a second pump, which leads it through an in-line P-filter, a 500 l pressurized vessel (Biotop Phostec) and then back into the pool via a 50 mm pipe. The percolation rate through the beach filter is close to 500 l/m²/hr, so moderate biofilm development can be expected. This pump works permanently from spring to autumn.

The high phosphorus concentration of the fill-up water (mainly mains water) is adequately reduced by a second Phostec filter in an extra chamber hidden among tall perennials.

Case Study 12 General data	
Mean annual precipitation (Finningley)	575 mm
USDA zone	8b, oceanic influenced climate
Pool sealing	TPO liner, 1.2 mm thick, heat-welded
Mains water parameters (used as fill-up water)	20.675 °dH, ~ 1 mg P/l in average, 17 – 25 mg NO_3/l ~ 140 mg SO_4/l, pH 7.5–7.7
Dimension of swimming area	150 m²; max. 2.75 m deep
Dimension of regeneration areas (Hydrobotanical System)	80 m²; 60–80 cm water level
Dimension of Technical Wetland areas	70 m²; 10–40 cm water level
Water circulation rate	~ 1 × complete volume per day
Pump 1: underwater pump running 8 hrs/day	Oase Aquamax Expert 30000 220-240v, 650w; Output max. 500 l/min
Pump 2: for beach filter running 24 hrs/day	Oase Aquamax Eco premium 6000 12v, 50w; Output max. 100 l/min

This view of the pump-house shows the PVC vessel with the underwater pump. The phosphorus filter can be seen in the opening rear right.

The pool also has a carbonator from Biotop: a perforated pipe buried 1m below the surface in the garden draws air from the soil using a compressor. The soil air is much richer in carbon dioxide than the atmosphere. It is pumped into the pool through 5 outlets in the regeneration zones through a perforated membrane to create fine bubbles. This local enrichment with carbon dioxide may help support the growth of submerged plants and suppress filamentous algae.

Planting design

The adjacent perennial planting is characterized by tall forbs, mainly flowering from mid-summer to autumn. Tough grasses placed among them create structure and interest throughout winter.

Aquatic plants are thriving without being too vigorous. The tall reed-forming grasses in the filter areas provide screening and a fantastic backdrop to various beautiful flowering water lilies in the regeneration beds, which also work as Hydrobotanical Systems. The filter areas contain gravel (1–4 mm grain size) inundated to a depth of 10–40 cm. These work as filter beds percolated top-down. The water lily areas are 60–80 cm deep and planted in extra zones where clay is used as a substrate.

Case Study 12 Important plants (+ : vital growth, ++: rampant growth, – weak growth, moderate deficiency symptoms, – – : strong deficiency symptoms)	
Perennial plantings surrounding the pool (outside the liner)	*Eutrochium maculatum*, *Persicaria amplexicaulis*, *Helenium cultivars*, *Helianthus microcephalus*, *Aster (Symphiotrichum)* cultivars, *Monarda* cultivars, *Iris sibirica* cultivars, *Lythrum virgatum*, *Miscanthus* cultivars, *Panicum virgatum*, *Calamagrostis* × *acutiflora*, *Deschampsia* cultivars
Zone 2–3: substrate filter surface	*Cyperus longus* (+), *Typha laxmannii* (+), *Carex riparia* (++, much too strongly proliferating), *Iris pseudacorus*, *Ranunculus flammula*
Zone 2–3: regeneration area (Hydrobotanical System, clay substrate)	*Acorus calamus*, *Alisma plantago–aquatica*, *Butomus umbellatus*, *Caltha palustris* var. *alba*, *Carex elata* 'Aurea', *Dichromena colorata*, *Equisetum hyemale*, *Geum rivale*, *Iris ensata*, *Iris pseudacorus*, *Iris laevigata*, *Iris louisiana* 'Gamecock', *Lobelia cardinalis*, *Lychnis flos–cuculi* 'Alba', *Lysimachula nummularia*, *Lythrum salicaria*, *Mentha aquatica*, *Menyanthes trifoliata*, *Myostis palustris*, *Nasturtium aquaticum*, *Persicaria amphibia*, *Pontederia cordata*, *Ranunculus lingua*, *Veronica beccabunga*, *Zantedeschia aethiopica*

Maintenance

England's maritime climate with its higher humidity causes much lower evapotranspiration than in Central Europe. Less than 10 cm of mains water had to be added to this pool in 2014 (less than 30 m^3 in total). Its high phosphorus content is reduced by the P-filters, which have to be backwashed regularly. Refilling the filter medium is deemed necessary only once in four years.

To feed the plants the water is fertilized monthly with 10 g/m^3 urea from April to August. In spring the water lilies are fed with Osmocote tablets, 3 × 7.5 g per plant, inserted deep into the clay substrate.

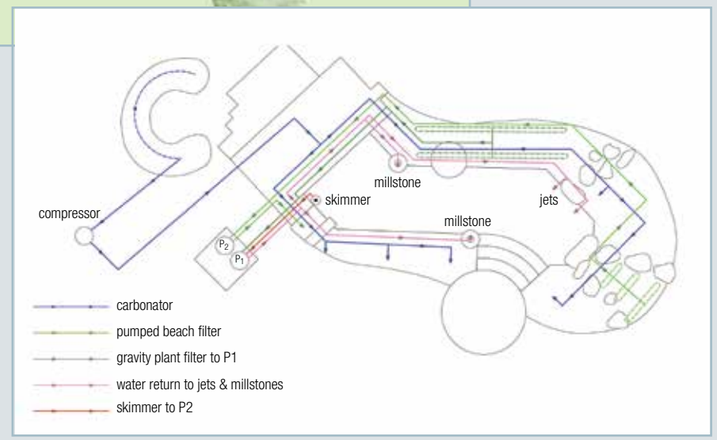
The surface biofilm on the swimming zone is brushed and vacuumed four or five times during the swimming season with a Liverani Flexible Impeller pump. Reed-forming plants and tall marginals are cut back in late autumn.

Assessment and recommendations

The wonderful water landscape is perfectly integrated into the beautiful garden. The pool and adjacent plantings meld together in a harmonious whole.

The high P-content in the fill-up water prompted the owners to use two Phostec filters. Even potentially mineralized phosphorus within the pool water can be removed by inserting one such filter into the circulation of the second pump.

Drawing water off by gravity through the filter bed is a clever and a relatively easy way to move it. It seems unlikely that the carbonator is strictly necessary. The owners find the noise of the compressor irritating and would prefer to use one of the water circulation pumps and inject the air into the pressure pipe using the Venturi principle.

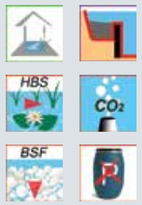


Concept sketch of the pool.

Pool plumbing.

CASE STUDY 13

Model 4A



Designed and constructed in 2013 by Will Woodhouse, Weston Colville, Cambridge, UK

Filter methods and dimensions based on the Austrian Biotop system

CASE STUDY 13
FORMAL POOL, NEAR LETCHWORTH, HERTFORDSHIRE

Location and design principles

It is a great challenge to develop a garden in an estate with historic architecture: this 1.2 ha property is characterized by an ensemble of protected Listed Buildings from the eighteenth century, one of them Grade 1. The historic buildings authority agreed to the integration of a formal octagonal pool into the garden.

The pool's eastern side faces the house and provides a generous flight of steps for accessing the swimming area. The elegant appearance is enhanced by light limestone flags covering the surrounding path, walls which frame the swimming area and the four platforms between the regeneration zones.

Partitioning and purification methods

The entire basin measures 136 m², of which 50% belongs to the central swimming area. It is framed by four planted zones of 17 m² each. The two western-facing ones work as Technical Wetland filters: through a 50 cm bed filled with dolomite chips (2–6 mm) water is drawn top-down by a drainage pipe system. About 400 l/m²/hr pass through the filter. The water runs back to the pool through two 5 cm pipes at the edges of the filter zones.

The eastern planted areas provide 50-cm layers of clay as planting substrate for submerged species and water lilies which work as a Hydrobotanical System. The three skimmer–pump combinations at the southern, western and northern edge keep the surface clean and bring the water back into the swimming area through four jets.

An air distribution pipe, the Biotop Carbonator, has been sited on the surface of both water lily beds: air from an underground pipe outside of the pool is pumped into the water.

Case Study 13 General data	
Mean annual precipitation (Potton)	530 mm
USDA zone	8a, maritime climate
Pool sealing	20 cm concrete shell with topcoat of thermoplastic polyolefin (TPO)
Well water parameters (mainly used as fill-up water)	9 °dH (total hardness), 0.023 mg P/l 46 mg NO3/l, pH 7.35
Dimension of swimming area	68 m²; 1.1–2.5 m deep
Dimension of regeneration areas (Hydrobotanical System)	34 m²; 1.1 m water level
Dimension of Technical Wetland areas	34 m²; 0.15–0.45 m water level
Water circulation rate	~ 2 × complete volume per day
3 underwater pumps in Biotop skimmer/pump chambers (S, W & N sides)	Oase AquaMax Eco Premium 12000 / 12v; 100w Output per pump max. 200 l/min

The formal pool is separated from the wooded pasture beyond by a trimmed hedge.

Planting design

A symmetrical hedge forms an architectural backdrop along the western side of the pool, separating the garden from the pastureland beyond. The pool's immediate surroundings are lawn, so the water plants provide an enhanced design focus. Within the first year all reed-forming plants in the filter zone developed into impressively lush clusters. *Typha laxmannii*

Case Study 13 **Important plants**	
Zone 2: substrate filter surface on dolomite gravel	*Typha laxmannii, Carex riparia, Cyperus longus, Iris pseudacorus, Iris laevigata*
Zone 4: regeneration area on clay substrate	*Nymphaea* 'Hal Miller', *Potamogeton nodosus, Lagarosiphon major* (= *Elodea crispa*)

Reed-forming plants in the Technical Wetland zone are arranged in groups, appropriate to the overall formal design.

has reached a height of over 2 m and several specimen of *Iris laevigata* are distributed along the margins.

In the deeper regeneration zone, which works as a Hydrobotanical System, clay was used as substrate for water lilies and submerged *Lagarosiphon major* (African elodea).

Maintenance

A Biotop pool robot keeps the base of the swimming area clean. Other maintenance work is contracted out to the construction company, including a twice-yearly service: cutting back all emerging plants in autumn and cleaning in spring.

The water lilies are fed with slow-release fertilizer tablets in spring (e.g. Miracle Gro® 15-5-10). Urea is applied according to an assessment of plant growth. Due to the high nitrate content of the fill-up water, it has so far only been necessary once.

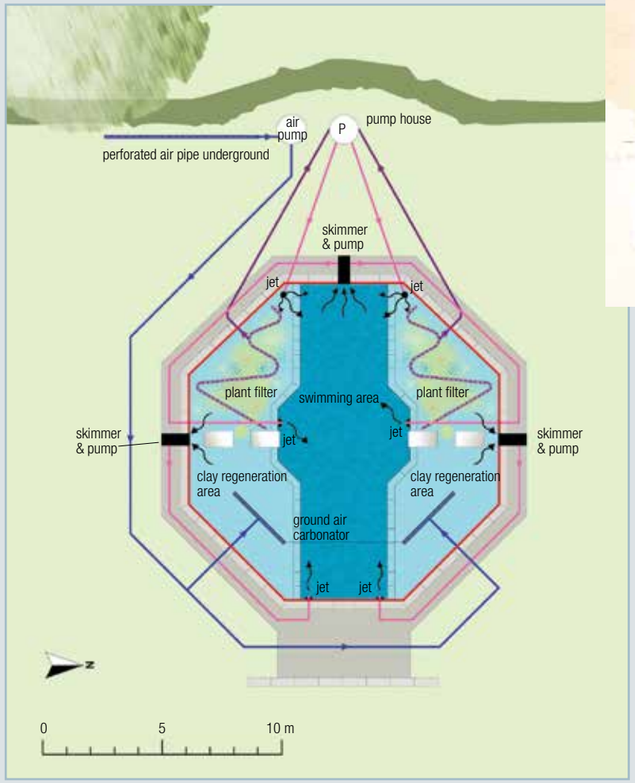
Assessment and recommendations

After the first year of living with their pond, the owners are very satisfied with the well-integrated design and the perfectly clear water, and the ingenious filtering system promises long-term satisfaction.

The very low phosphorus content suggests a simpler technical set-up would be sufficient. But the system as installed will be able to cope with all possible variations in water types and environmental changes such as torrential rainfall, agricultural fertilizer contamination, sudden changes in the fill-up water quality, and even the over-filling of the pool. The constructor's experience from 13 years of building natural pools resulted in the present layout. The phosphorus filter system is only turned on if algae or critical water analysis values indicate it is necessary. In other pools of similar size the contractor has used only two skimmers, but here, anticipating pollution from leaves from surrounding trees, a third has been installed.

The vegetation cover in the hydrobotanical areas was not very dense when we visited because the owners wanted the planting to be kept simple. The carbonation effect will soon encourage the growth of the oxygen weed (*Lagarosphon major*) and it is expected that the low P level as well as the hard water will allow stonewort carpets (*Chara* spp.) to establish themselves spontaneously.

Flagstone platforms for diving.



Concept sketch of pool and plumbing.

Combining skimmer and pump-house is an effective solution for construction and maintenance purposes.

UNITED STATES OF AMERICA

Swimming pools have a long tradition in the USA, especially in regions with hot summers, but the idea of purifying the water entirely through natural processes was brought over from Europe only a few years ago. At the same time, though little noticed in Europe, there was a parallel process in the US initiated by pioneers such as Michael Hilleary, the founder of the Total Habitat company, based near Kansas City, KS. Michael originally designed wildlife enclosures for zoos and in 2000 adopted the same principles of biological filtration from aquariums and aquaculture facilities to develop swimming pools (Hilleary, 2015). Other companies followed suit, such as Waters Edge in Utah, which began in 2006 with its own constructions and later adopted the German BioNova® system.

None of our five examples was more than two years old when described. Three projects were based on the BioNova® system, currently very widely used for natural pools in the USA.

For non-specialists confident of their building skills, case study 14 may be of particular interest as it shows a relatively easy project executed as a joint venture between the owner and the Total Habitat company.

As in the UK, we found only fairly intensively technically equipped model 3 and 4 pools in the USA. It seems as if the easier and more cost-effective model 1 and 2 pools are regarded as less reliable.

CASE STUDY 14
FORMAL POOL, NEAR DENTON, TEXAS

Location and design principles

North of the Dallas–Fort Worth agglomeration there is a rural area with open woodland and pastures. The solitary house and garden of a nature-loving couple blends well into this landscape. After the children left home, the owners decided to create a chemical-free pool. Cost-effectiveness was important but so too was ensuring clear water. Total Habitat was chosen as contractor to plan the construction and technical installations while the owners played a major role in carrying out the work. A simple circular shape and mid-range technical equipment kept the costs in check.

Partitioning and purification methods

The circular swimming area is surrounded by a 2.5 m wide filter bed regeneration zone. Instead of a massive wall, a steep slope leads from the 2 m deep swimming area up to the regeneration zone. At its edge the filter substrate is separated from the swimming zone by a wall made of six layers of gravel-filled pond-sacks.

Two skimmers mounted at the north and east sides draw off surface water, which is brought to a cascade-like stream mouth at the east side.

CASE STUDY 14

Model 3A

Design and construction by the owner in 2013 with consultancy from Total Habitat Design & Fabrication Group, Bonner Springs, Kansas

Simple shape and effective purification: in a circular pond it is easy to achieve even distribution of well-oxygenated water.

Above The marginal regeneration zone is fixed by six layers of sand-filled durable pond-sacks. They also constitute the framing wall of the swimming area.
Below Keeping fish in a swimming pool is not recommended by most experts, but here they have not so far affected the water quality.

Case Study 14 General data	
Mean annual precipitation (Denton)	885 mm
USDA zone	8a, continental influenced climate with hot summers
Pool sealing	EPDM liner, protected from the subsoil by old carpets
Dimension of swimming area	~ 70 m²; in the central area, 2 m deep, becoming slightly shallower towards the edges
Dimension of Technical Wetland areas including tubs with water lilies	~ 70 m²; surface about 10 cm above to 20 cm below water level, mean substrate depth ~ 1m
Water circulation rate	~ 2–4 × complete volume per day (depending on pump setting)
2 dry-installed pumps (one for filter drains & jets; one for skimmers & waterfall)	Pentair Intelliflo® variable speed; 8 possible settings, 150 to >2500w; up to 300 l/min

The bottom of the regeneration area comprises five rows of drainage pipes (100 mm width ADS 4-in, corrugated HDPE plastic, coated with a geotextile fabric) covered with about 80 cm lime-free gravel. The water is drawn through the gravel bed by a pump with maximal 250 l/m²/hr. Six jets located along the edge of the swimming zone pump the water back into the system, creating a circulating current which supports a high oxygen content.

Planting design

The project was only completed in 2013, so the planting is still developing. The owners love trying out plant species at different water levels. Several *Iris* species, *Typha minima*, *Myriophyllum aquaticum*, *Hibiscus coccineus* and *Mentha aquatica* are already established. A ground cover layer of *Bacopa monnieri* is particularly noteworthy. Some single specimen of *Canna* × *generalis* and *Cyperus alternifolius* have been tried to see if they are hardy; they survived their first winter.

Maintenance

Top-up water is provided by a nearby well. To clean the swimming area the owners use the Oase Pondovac 4 vacuum which is very reliable.

About every three months proliferating plants are cut back and any string algae removed. Moderate problems with the latter occurred in summer 2014 when temperatures reached around 40°C.

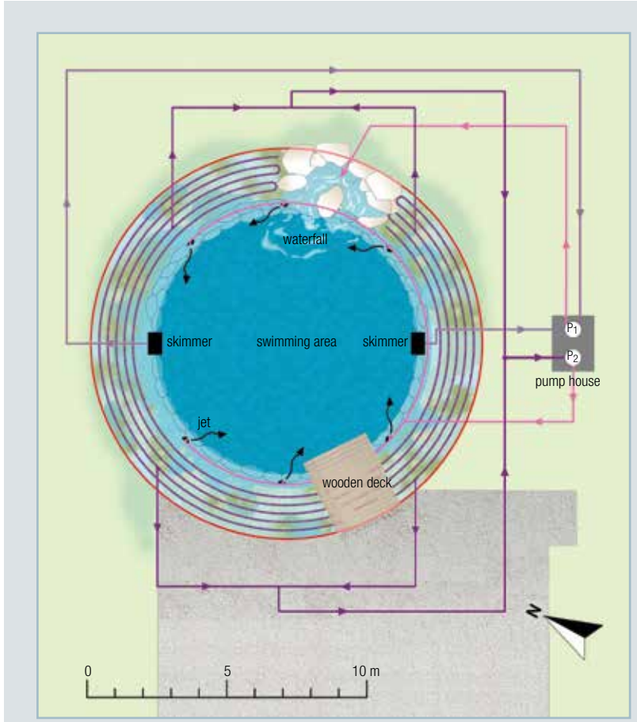
Assessment and recommendations

Though some goldfish and koi carp live in the pool, the water looks perfectly clear. Construction and installation were kept relatively simple so that they could be carried out by reasonably skilled non-specialists with some input from professional landscapers.

The percolation rate of 0.25 m/hr is too low to count it as a Biofilm-accumulating Substrate Filter, but according to the investigations of Total Habitat, it creates a "massive biofilm" (Hilleary, 2015). In any case, the purification results are entirely convincing. The filter construction is very similar to that of case study 11, but in contrast to that, the local water quality and omission of concrete and any features containing lime makes a C-limited system possible.

The owners clearly like lush, luxuriant plants such as hibiscus, canna and cypress grasses. If nitrogen deficiencies occur in the future, specific fertilization may be necessary. Total Habitat recommends inserting fertilizer into water lily root balls to encourage extra flowering.

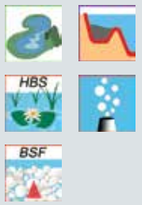
Above The waterfall at the east side is a very shallow feature but appears effective because of its width.
Below The brahmi plant (*Bacopa monnieri*) creates dense ground cover in the wetland area and also sends its shoots into the shallow water.



Concept sketch of pool and plumbing. Four equidistant connections from the drainage pipes to the pump feeders promote equalized percolation through the whole filter area. The seemingly complicated plumbing guarantees equal suction rates from each connection point.

CASE STUDY 15

Model 4A



Design and construction by Waters Edge, 2013

CASE STUDY 15
NATURALISTIC POOL, NEAR PARK CITY, UTAH

Location and design principles

The mountains of northern Utah are dominated by mixed open woodland. In this beautiful landscape a weekend property among subalpine firs and quaking aspens is used as a place to recharge during the summer holidays by a young family with children. The owners wanted a water feature to enhance the experience of primordial nature and they wanted to site it at the foot of a wooded, north-facing slope. The landscaping company Waters Edge, renowned particularly for naturalistic stone settings, created a spacious stream and pond blending into the surrounding wilderness as if it had been created by nature itself. This effect is emphasized by huge stones and boulders: rugged in appearance, but artfully arranged.

Partitioning and purification methods

Viewed from the north edge in front of the slope, the pond starts with a shingle beach zone, transitioning into a shallow shelf about 7 × 8 m – a perfect place for children to play. It leads abruptly to a circular swimming area, about 9 m in diameter and 2 m deep. Through three skimmers the water is drawn off by a pump and pumped into the filter bed at the east edge of the pond. The filter area measures about 7 × 5 m and is percolated bottom-up. The percolation speed of more than 1.5 m/hr supports strong biofilm development. An aeration pump supplies the filter with oxygen released into the drainage pipe. Some of the air is conducted to the bottom of the pool, from where it bubbles up.

A powerful second pump runs the stream. Water must be pumped about 2.5 m higher, from where it burbles downward, forming waterfalls, cascades and splashing points. Due to its high energy consumption, this is used only when the owners are present. Purification by the filter bed alone is sufficient to keep the water clean.

The waterfall in the background looks natural but is in fact man-made. It enters a deep pond with clear water and the whole design melts into the environment as if it were part of landscape.

Case Study 15 General data	
Mean annual precipitation (Park City)	544 mm; driest period from July to September
USDA zone	5b, rather hot summers
Pool sealing	Reinforced EPDM liner, 1.3 mm
Dimension of swimming area	~ 80 m²; in the central area 2 m deep, becoming slightly shallower outwards
Dimension of the shallow water bathing area	~ 60 m²; maximum depth 1 m
Dimension of percolated filter bed	~ 30 m²; partly covered with rocks
Dimension of the stream	~ 15 m long and 3 m wide; starting ~ 2.5 m above pond surface
Water circulation rate through filter bed	~ 4 × complete volume per day
Dry-installed pump running stream plus waterfall	Speck 21-80 /33G, 3000w (4 HP), Output ~1300 l/min (360 GPM) at 3 m lift height
Dry-installed pump for substrate filter bed	Speck 21-80 /33, operating at ~ 350w (½ HP), output ~ 950 l/min (251 GPM)

Planting design

The whole water feature is surrounded by primordial woodland. One year after completion, the low-growing shrubs and perennials which had been planted (spiraeas, day lilies, irises and grasses) had not yet completely integrated the aquatic landscape with its natural surroundings.

Case Study 15 **Important plants**	
Zone 3: filter bed planted with species native to Utah	*Carex nebrascensis*, *Carex rostrata*, *Juncus arcticus*, *Myosotis palustris*, *Mimulus ringens*
Zone 3–4: marginal zone of the pond	*Iris pseudacorus*, *Acorus calamus* 'Variegatus', *Butomus umbellatus*, *Sagittaria latifolia*
Zone 4–5: water lilies	*Nymphaea* – diverse cultivars

Water lilies are distributed along the pond margins at a depth of at least 20 cm. Around the top shelf area of the pond, diverse helophytes have been planted, tough enough to withstand Northern Utah's harsh winters. The surface of the filter area has been covered with a vegetation mat providing a dense planting of native grasses and forbs. Unfortunately the owners did not start the pump for two weeks, so the mat became dry and only a few plants survived. Those survivors include Arctic rush, Nebraska sedge and beaked sedge as well as some water forget-me-not; in time they will form a dense covering. The stream bed is kept free of vegetation so that irregular use of the pump does not harm any plants.

Maintenance

The first frosts can occur at this altitude in October, so the pumps are switched off from early autumn till April. The whole property is used only for a few weeks in summer, so there is not much chance of pollution except by leaves of aspens, which have not caused significant problems yet. Vacuuming the mud from the base of the bathing area once a year in spring, which is done by Waters Edge, and then backwashing of the filter bed have proved sufficient. In autumn the filter baskets in the skimmer chambers should be cleaned of soaked-in foliage weekly. We expect the marginal plants and water lilies to need some urea nutrition in future.

Below left The bottom-up percolated filter area was covered with a vegetation mat before going into operation so some plants failed to establish, but the remaining ones will develop into a dense stand.
Below right Like a real mountain creek, the stream ripples down in lively cascades. Only the bare soil of the adjacent beds, which are not yet completely planted, reveals that it is manmade.

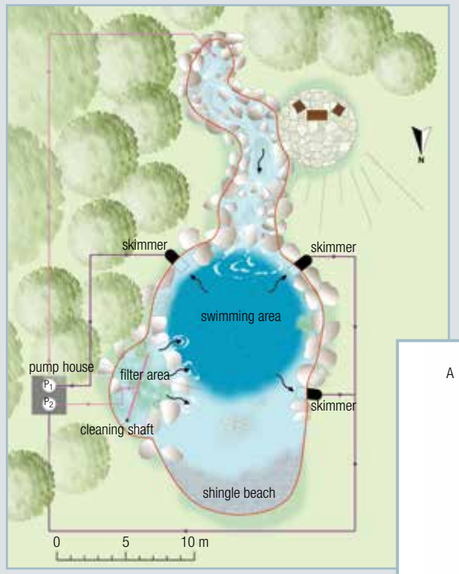
Assessment and recommendations

The pool and its surroundings fit perfectly into the environment and enhance the property aesthetically in return for low maintenance demands.

Locating the mouth of a stream directly in the swimming area is not generally recommended as it creates an area of inconsistent water movement, which can promote filamentous algae growth. Here the partial shading by nearby trees and the short periods of operation mitigate these disadvantages.

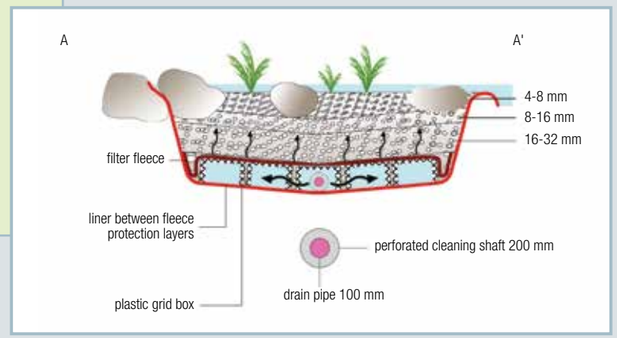
Although the filter bed is filled with lime-free gravel, it produces very clear water. Limestone is recommended for effective phosphorus reduction, but this pool is located in a region with slightly acid site conditions and may approach a C-limitation as the algae supressing factor.

A rustic wooden seating area reflects the naturalistic overall design.



Concept sketch of pool and plumbing

Section through the filter bed. The drainage pipe which releases the water is located within a wider pipe, which can be accessed by a vacuum pump for backwashing the system. The plastic grid boxes are placed upside down along the bottom to distribute the water current and allow equal percolation through the gravel.



CASE STUDY 16

Model 4C

Planned and constructed in 2013 by Richard Story, Lenoir, North Carolina, finished in 2014

Filter methods and dimensions based on the BioNova® system

CASE STUDY 16
FORMAL POOL, NEAR LENOIR, NORTH CAROLINA

Location and design principles

A wonderful picturesque landscape in the hills around Lenoir with its rich diversity of deciduous woodland is the home of professional landscaper Richard Story. In front of his house he has designed a formal pool with biological purification. A rectangular terrace provides the setting for the architectural swimming basin, which is completely free from any plants. The regeneration pond is located about 25 m away between huge trees. Though functionally complete when we visited in November 2014, the surrounding design and more naturalistic planting continued in 2015.

Partitioning and purification methods

The swimming area is situated 2.5 m above the regeneration pond, so gravity means the water passes through two overflow gutters at the pool's edges into the treatment area. From here, it goes through a separate cylindrical chamber with fine filter (fleece membrane) plus aeration (see case study 17), a typical BioNova® component. Then the water flows to the regeneration pond, passing three filter zones, each one measuring around 12 m^2:

- **First substrate filter bed**: The eastern chamber is filled with gravel in layers of various grain sizes. A drainage pipe (100 mm: ADS 4-in, corrugated HDPE plastic) meanders along the bottom, pushing the water upwards.
- **Hydrobotanical System**: in the centre of the pond there is a narrow, densely planted zone in about 1 m water.
- **Second substrate filter bed**: this is constructed like the first, but the water is drawn downwards.

The percolation rate through the substrate filter beds is more than 1 m/hr, an effective flow for generating a beneficial biofilm. The substrate beds are framed by walls of hollow gravel-filled blocks, dividing them from the hydrobotanical area. A pipe of 76 mm diameter guarantees low pressure loss.

The fill-up water comes from the property's own well and contains around 0.06 mg phosphorus per litre. It is led through a phosphorus filter with iron hydroxide into the regeneration pond. A big advantage of the location of this pond below the swimming part is that water losses only influence the regeneration basin, while the pool itself provides a permanently stable water level.

The swimming area viewed from the house – it presents a formal design accentuated by the open chimney on the north-east side.

Case Study 16 General data	
Mean annual precipitation	1242 mm
USDA zone	7b, summer temperatures can rise above 38°C
Pool sealing	Waterproof plaster on concrete. A reinforced PVC protection layer has been welded onto the surfaces
Sealing of the regeneration pond	EPDM liner between protection membranes
Dimension of swimming area	~ 55 m^2; max. 2.7 m deep, getting shallower towards the steps at the southwestern edge
Dimension of regeneration pond	~ 35 m^2; ~ 1 m deep: 1/3 substrate filter bed percolated 1/3 Hydrobotanical System 1/3 substrate filter bed percolated
Water circulation rate	~ 2 × complete volume per day
2 dry-installed pumps (feeding two waterfall columns each)	Speck S90 2 HP Single Speed Pool Pump (S90-IV); 1500w (2HP) Output ~ 200 l/min
Air pump for the fine filter chamber	Supreme (Danner) ASP04280 AP-100 Air Pump, 100w

Planting design

The pool is completely free from plants, but the terrace is surrounded by groups of ground-covering shrubs and trees.

Light shade is cast on the regeneration zone by some huge trees, which are far enough from the swimming area not to cause problems with fallen leaves. The shallow water areas above the filter granulate are planted with various irises, *Myriophyllum aquaticum*, *Houttuynia cordata* and some

Above Four water-spouts are located on the north and south sides of the pool.
Below At the centre of the north-eastern and the south-eastern edge two BioNova® overflow gutters take the water to the regeneration area.

Hibiscus moscheutos. The hydrobotanical area features *Ceratophyllum* species and some water lilies, which will soon cover its surface.

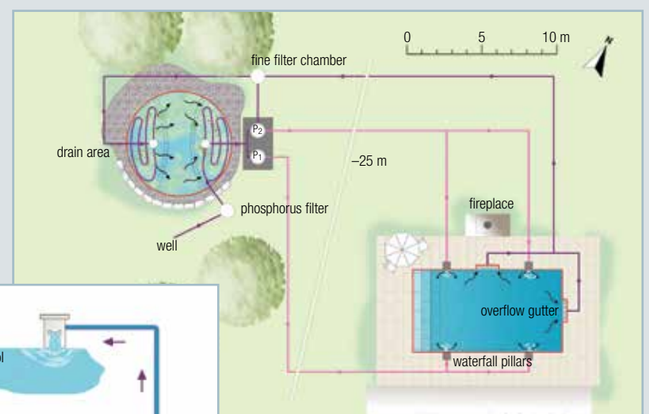
Maintenance

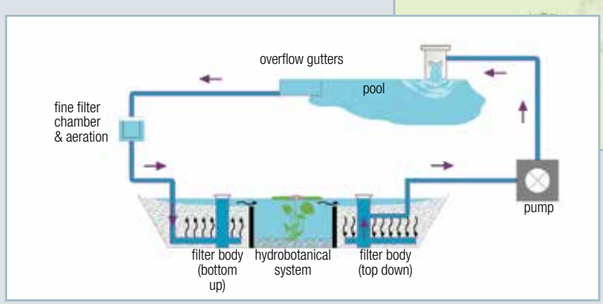
The swimming area is regularly cleaned with a pool robot. In the first year of operation no fertilizer was used. To keep nitrogen-hungry species such as *Hibiscus moscheutos* alive, it may be necessary to add nitrogen. Backwashing the filter areas should be carried out twice a year. Refilling the iron hydroxide granules should not be necessary in the first four years of operation.

Assessment and recommendations

The crystal-clear water in the swimming basin is very inviting. The P-content is below 0.02 mg/l and the permanent water movement provides a good overall oxygen content. The very low phosphorus content of the fill-up water would presumably provide excellent pool water even without the P-filter, especially given the high rainfall.

The routine use of the pool robot guarantees a clean pool. When we visited in November 2014, the regeneration pond was ready for hibernation and most plants looked bare and dormant, but planting more helophytes in subsequent years should create enough vegetation cover.





Concept sketch of pool and plumbing.

Scheme of water circulation.

CASE STUDY 17
FORMAL POOL, OJAI, CALIFORNIA

Location and design principles

The small town of Ojai is a tourist centre in the very warm, dry climate close to Southern California's Los Padres national forest. A considerable estate in this region was recently acquired by a couple with a young daughter. The climate makes a pool almost a necessity here for much of the year, but the young family wanted to find a chemical-free option.

Local California BioNova® contractor Troy Becker introduced them to the vision of a natural pool with a rectangular swimming area with a "Baja Bench", a shallow inundated platform for chilled sunbathing, set in a naturalistic landscape with a pond and waterfall which help purify the pool water. Rounded stones and boulders already on the site were reused to build the slope.

Troy Becker's original construction design was enhanced and documented for a TV production, *Animal Planet's Pool Master*. Host Anthony Archer-Wills wanted to make the natural pool idea better known and added a large natural-looking spring and stream to the design.

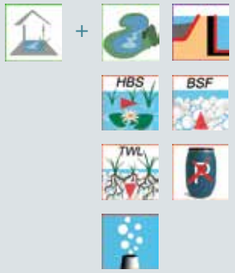
Partitioning and purification methods

The swimming pool measures 5.5m × 13.7 m. The water from the swimming basin is soaked through three skimmers hidden under the perimeter coping made of naturally cut stone slabs. The water goes through a conventional cartridge pool-cleaning filter for three hours a day. Then a time-controlled valve sends the water through the BioNova® fine filter to a regeneration pond on the western slope, about 3 m above the pool basin's water level. This pond has a 1 m gravel filter which contains lime and is percolated bottom-up; it leads the water into a stream running diagonally downwards to a second pond. Now it partly percolates top-down through a filter bed and partly flows over a boulder which creates a small cascade. Both branches meet in a small basin adjacent to the swimming pool into which the purified water runs back via a canal under the paved path and coping.

The percolation rate can be varied up to 220 l/min (13 m^3/hr) depending on the amount of water fed over the cascade boulder. The current within the filter body can be lower than recommended for biofilm-accumulating systems and may be classed as a Technical Wetland. The upper

CASE STUDY 17

Model 4C



Constructed in spring 2014 by California BioNova® – The Pool Reinvented™ (Troy Becker and Laurence Nicklin), design and stone work by Anthony Archer-Wills

Filter methods and dimensions based on the BioNova® system

Above The rectangular pool in front of the house at first glance looks like a traditional one. If the owners are away, an automated cover moves over its surface.
Above right By the north side of the swimming pool is a regeneration area. The surrounding areas have not yet been planted. The purified water runs over a waterfall into a small pool and from there under the flagstone pavement through a slot (foreground right) into the swimming pool.

pond with its smaller surface, however, is percolated strongly enough to fulfill the substrate filter (BSF) criteria.

The complete system is laid out with pipes of at least 70–100 mm diameter, so that the pressure and volume flow are reduced only inconspicuously. The variable pumps mean the regeneration area can operate with an energy requirement of less than 100W.

The fill-up water comes from a nearby well and passes through a phosphorus filter with iron hydroxide on its way to the lower regeneration pond. Refilling is electronically controlled by a sensor in the swimming basin.

Planting design

The pool has no plants but even within the first year the regeneration ponds provided lush, well-developed vegetation with a tropical feel. Tough groups of the dwarf papyrus (*Cyperus prolifer* = *C. papyrus* 'Nana'), surrounded 2 m *Canna* × *generalis* specimens, which bloom from summer to late autumn. *Myriophyllum aquaticum*, *Marsilea schelpiana* and *Typha minima* are low-growing species with runners and will create ground cover in the marginal and shallow water area. Among these dominant plants, some individuals of moderately compact species like *Acorus gramineus*, (variegated form), *Cyperus haspan* and the South African grass *Chondropetalum tectorum* provide accents. A lotus plant in the deeper water of the lower pond is still establishing itself.

Case Study 17 General data	
Mean annual precipitation	397 mm, almost no rain from May to October
USDA zone	9b, Mediterranean climate with hot summers
Pool sealing	Waterproof plaster on 22 cm thick gunite (shotcrete)
Sealing of the regeneration pond	Thoroseal® coating on reinforced concrete
Dimension of swimming basin	~ 75 m²; 1.4–2.1 m deep
Dimension of filtering area in upper regeneration pond	~ 20 m²; ~ 1.2 m deep: substrate filter bed percolated 0–20 cm deep
Dimension of filtering area in lower regeneration pond	~ 30 m²; ~ 1.2 m deep: substrate filter bed percolated 0–30 cm deep
Water circulation rate	~ 2 × complete volume per day
3 dry-installed pumps (two for regeneration zones and stream, one one for the pool robot, working 3 hours a day)	Jandy® JEP 2.0 + variable speed pump motor controller Max. 2.7 HP (2000w) here set to 50w Output at least ~ 220 l/min (60 GPM) at 3 m lift height
Air pump for the fine filter chamber	Danner ASP04260 AP-60 Air Pump, 59w

In the upper pond an effective backdrop is provided by the eye-catching leaves of the tarot plant (*Colocasia esculenta*). Along the stream a few *Eleocharis maculosa* grasses are scattered between boulders and pebbles.

Maintenance

The emergence of algae in the swimming area is suppressed not only by water filtration but also by the use of a non-transparent automatic pool cover when it is not in use. The cover rides over the area where water is exchanged from the cascading waterfall via a 5 cm high and 45 cm wide copper overflow tray under the path and coping.

A pool robot works 3–4 hrs daily under the pool cover. The base's rounded edges allow the robot to climb the walls and clean the vertical surfaces too. The robot is a prototype from Maytronics, which the owners and the construction company have found very effective.

The subtropical plants produce a high amount of biomass which need regular cutting back. Several species will not die down in winter due to the mild climate. The plant stock should be checked about three times a year (spring, summer, autumn) to remove rampant shoots and dead matter. From time to time it might be necessary to remove bigger aggregates

Above The view above the regeneration pond dominated by cypress grasses, *Canna* x *generalis* and *Colocasia esculenta*, creates an impression of tropical lushness.
Below Perfect relaxation on hot days is provided by the "Baja Bench", a shallow platform with room for a parasol and sunbeds.

of rhizomatous species such as *Typha minima* or *Colocasia esculenta*. The streambed has to be carefully monitored to stop pushy plants from damming the water. In future, fertilization may be required.

California BioNova® checks the water quality regularly. The PO_4-phosphorus content is analysed with a Mi412 Phosphate Low-RangePhotometer".

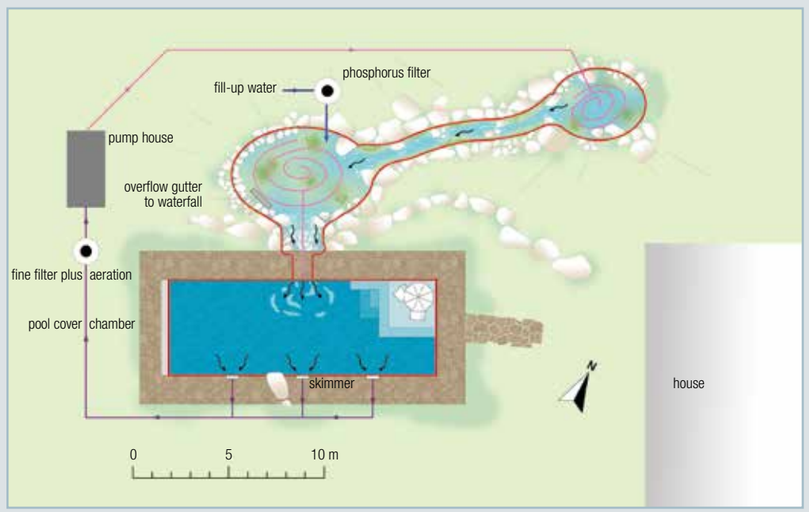
Assessment and recommendations

The construction process was filmed for a TV documentary and various articles appeared in magazines and newspapers (e.g. Colby, 2014). For this reason high-quality professional equipment was used.

A thin green algae layer on the stone surface under the final cascade is accepted as a natural process by the users. Occasional filamentous algae in the regeneration ponds is also tolerated.

Due to the very dry summers, the design of the garden areas adjacent to the pool and regeneration areas demand an irrigation system to continue the wetland vegetation theme around the pool.

Top To stabilize the water level in a pool which is situated lower than the regeneration area, a sensor is installed in the mouth of a skimmer. It manages the influx of fill-up water via the upper regeneration pond.
Above The cylindrical fine filter with central aeration is a typical part of the BioNova® System. Water passes through it before entering the pump and regeneration ponds.



Concept sketch of pool and plumbing.

CASE STUDY 18
NATURALISTIC POND AND POOL, NEAR PROVO, UTAH

Location and design principles

The mountains in Northern Utah are characterized by dry forests and grassland. The house on this extraordinary property is built from limestone and fits perfectly into the surrounding landscape. Although the basalt blocks used in the construction of the huge pond are not native to the region, they seem in tune with the limestone architecture thanks to their similar grey tones.

In order to offer business guests a choice, a traditional chlorinated pool was created as well as a spacious swimming area within a naturally purified pond.

The pool in front is conventionally chlorinated and not connected with the natural purification system. The waterfall in the background is a separate system.

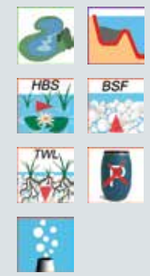
Partitioning and purification methods

Like case studies 16 and 17, this project is based on BioNova® technology, so we can omit detailed descriptions of water purification. Furthermore, the very large dimensions of the waterfalls puts the project beyond the scope of normal domestic pools.

The main house is connected to an annex by a bridge that crosses the pond and divides it in two. The southern one is used for swimming. From the east side a stunning group of huge cascades highlights an impressive basalt rockery and feeds a stream which runs westwards towards the edge of the pool. It is a subtle illusion that the stream seems to enter the swimming basin under a stone bridge – but it is in fact a separate water feature completely distinct from the pool with its own liner.

CASE STUDY 18

Model 4B



Planned and constructed in 2014 by Waters Edge, Park City, Utah

Filter methods and dimensioning based on the BioNova® system

Case Study 18 General data	
Mean annual precipitation	513 mm; driest period from June to August
USDA zone	6a, continental influenced climate
Pool sealing	shotcrete (gunite) and reinforced 1.5 mm (60 mil) EPDM liner
Dimension of swimming area	335 m², max. 3 m deep
Dimension of regeneration areas (hydrobotanical system + percolated filter areas)	370 m², max. 1.5 m deep

Case Study 18 Important plants	Compact in growth or moderately running	Rampant growers for big groups
Zone 2–3: wetland and swampy areas	*Caltha palustris, Iris versicolor* 'Deep Rose', *Iris × louisiana* 'Black Gamecock', *Juncus* 'Goldstrike', *Juncus effusus* 'Spiralis', *Acorus gramineus* 'Ogon', *Myosotis palustris, Houttuynia cordata*	*Phalaris* 'Feesey', *Equisetum scirpoides Equisetum hyemale, Typha minima*
Zone 4: shallow water areas	*Peltandra virginica, Pontederia cordata, Thalia dealbata* (requires warmth),	*Acorus calamus* 'Variegatus', *Sagittaria latifolia, Typha latifolia* 'Variegata', *Typha laxmannii*
Zone 4–5: water lilies	*Nymphaea* 'Attraction' (red), 'Texas Dawn' (light yellow), 'Perry's Double White', 'Mayla' (bright pink), 'Barbara Dobbins' (light orange), 'Colorado' (light salmon)	

Water from the northern regeneration pond, however, is pumped back into the swimming area via a waterfall. Here the impact of the water influx is strong enough to prevent an algal problem.

Under the bridge which connects the two buildings another system of waterfalls leads the swimming pool water down to the regeneration pond 1.5 m below. Here it soaks through a gravel filtering area and is brought to the source of the stream.

Planting design

The plants in the shallow water zones are mostly arranged in groups. The table above names the most common species used. *Thalia dealbata* should be particularly highlighted: this attractive helophyte is native to the southern USA but has been proven hardy in cooler regions if planted deep enough and if long, warm summers allow the plant to mature enough to survive even harsh winters.

Above left The water features are surrounded by huge stone blocks that blend into the landscape.
Centre The separate stream springs from a rockery constructed from huge boulders.
Right Picturesque waterfalls provide a visual and acoustic delight. The stone arrangements continue deep into the glass-clear water.

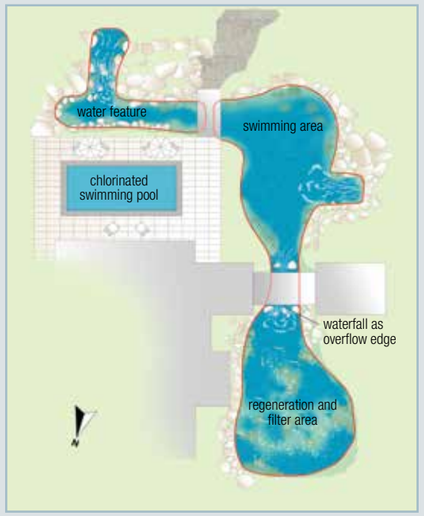
Maintenance

Water features of this complexity demand professional servicing by a reliable landscaper. The optimized filter technique means that the need to remove debris is low, but trimming plants, fertilizing, filter-backwashing, wintering/maintaining equipment, etc. should all be scheduled.

Assessment and recommendations

The integration of the complete garden into the surrounding mountain landscapes as well as into the architecture makes this project a jewel of contemporary garden design.

Below The white rain lily is pretty for warmer zones. Some bulbs were cultivated in pots and scattered around the marginal areas as annuals.



Concept sketch of the natural pool and ponds including the traditional chlorinated pool.

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www.poolroboter-test.de

www.pressure-drop.com/Online-Calculator

www.safetyturtle.com

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www.teichschlammsauger-test.de

www.victoria-adventure.org/more_than_links_images/angelika_kern/page1.html

www.weatherbase.com

NATURAL POOL ASSOCIATIONS

Association for Swimming Ponds and Natural Swimming Pools (ASPNSP), USA: www.aspnsp.org

Austrian association for natural pool constructors: www.schwimmteich.co.at

The British Association for Natural Swimming Pools (BANSP): www.bansp.org

German association for natural pools: www.dgfnb.de

International Organization for natural bathing waters (IOB) – provides addresses from national associations worldwide: www.iob-ev.eu/cms/iob/en

Swiss association for natural swimming pools and constructed wetlands: www.svbp.org

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Weixler, R., 2011: *Garden Pools and Swimming Ponds Design, Construction, and Landscape*. Schiffer Publishing, 192 pp.

SUPPLIERS

Companies highly skilled in natural pool construction and active internationally

Austria, Germany & Switzerland

Balena GmbH www.balena-gmbh.de, provide the Teichmeister® system; international partners in many European countries, Australia, South Africa, Turkey

Bionova: www.bionova.de; www.bionovanaturalpools.com, International partners in many European countries, Algeria, Egypt, South Africa, Bahrain, Israel, Jordan, Lebanon, Qatar, Saudi Arabia, United Arab Emirates, Canada, Uruguay, USA, India, Philippines, Australia, Mauritius

Biotop Landschaftsgestaltung GmbH.: www.swimming-teich.com www.biotop-natural-pool.com International partners in many European countries, Australia, New Zealand, Canada, USA, Israel

Biotop-Kern: www.biotop-kern.at enquiries to office@biotop-kern.at

blueBase GmbH: www.bluebase5.com/en International partners in Germany, Austria, Switzerland, Slovenia, Italy, Czech Republic, UK & Ireland

Fricke Gründächer und Gartengestaltung, Weidling: www.fricke.at

Kirchner Garten+Teich GmbH (on-site construction of GRP pools, Japanese gardens): www.kirchner-gartenteich.de

Naturgarten Landschaftsbau KG: www.naturgarten.at

Polyplan: www.polyplan-gmbh.de/cms/polyplan/en

Renatur: www.re-natur.de/schwimmteiche.html Website only in German, but also internationally active (e.g. Turkey, Czech Republic, Italy, Spain, South Africa)

Teich&Garten: www.teichundgarten.de Has carried out pool projects in Germany, Italy, Spain, Portugal, Tunisia, Canada

Teichmeister® www.teichmeister.de see Balena GmbH

Joint website for various companies: www.naturpool-schwimmteich.de

United Kingdom

Anglo Swimming Ponds: www.angloswimmingponds.co.uk

Clear Water Revival: www.clear-water-revival.com

Ellicar Gardens natural pool design and consultation by Will and Sarah Murch: www.ellicargardens.co.uk

Five Valleys Natural Pools: www.fivevalleysnaturalpools.co.uk

Gartenart Swimming Ponds: www.gartenart.co.uk

Michael Littlewood (landscape designer and author): www.ecodesignscape.co.uk

Natural pool and swimming pond construction company: www.naturalpoolsuk.com

Poolscape: www.poolscape.co.uk

The Swimming Pond Company (Paul Mercer): www.theswimmingpondcompany.co.uk

Woodhouse Natural Pools Ltd.: www.naturalswimmingpools.com

United States of America

BioNatural® Swimming Pools: www.bioswimpools.com

Bionova North America: www.bionovanaturalpools.com

California Bionova: www.californiabionova.com

R. Story Development Inc.: www.rstorylandscaping.com

Total Habitat: www.totalhabitat.com

Waters Edge (Bionova system): www.utahwatersedge.com

Contacts for other countries can be explored via www.iob-ev.eu/cms/iob/en

Filter techniques and substrates

Biofermenta GmbH: www.biofermenta.com (Floating Bed Reactors SBR4 and successor model SBR2)

Biotop: www.biotop-natural-pool.com/system_bogensieb-skimmer.html (Biotop Curved Sieve Skimmer)

www.drydenaquapools.com/swimming-pool-products/swimming-pools-afm-active-filter-media (AFM filters)

VIRITEC Ltd. & Co. KG: www.naturepool.eu

www.lytag.com/applications/green-roofs (Lytag - light-weight substrate)

www.teich-center.de (Nymulat clay pellets)

www.waterco.com.au/component/virtuemart/category/56/pool-&-spa-products/filters/sand/media-filters (Sand filters)

www.zodiacpoolsystems.com/Products/Filters.aspx

General pool and pond material and maintenance equipment

store.aquaticbiologists.com

www.bradshawsdirect.co.uk

www.naturagart.com

www.teich.de

www.oase-livingwater.com

www.onlinepoolstore.co.uk

www.manzke-schwimmteiche.de

www.re-natur.de/online-shop

www.thepondoutlet.com

www.wallwhale.com

www.motorscrubbers.com

www.der-saubere-teich.de/en

www.poolgear.com

www.thepondoutlet.com/home/tpo/multilist_392/algae_witch.html

Sealing materials, prefabricated basins and fleeces

usa.sarnafil.sika.com

www.rivierapool.com

www.teichmeister.de/de/BalenaPool.html

www.re-natur.de/online-shop/vmchk/schwimmteiche/teichrand-undteichsaecke/teichsaecke-aus-geotextil.html

www.goetzloff.at/techtex_en/Produkte/showArticle.php?nr=7&cat=Geotextiles

www.thoroproducts.com

Sealing additives

www.schomburg.com/de/en

www.pci-augsburg.eu/en

www.innotecworld.com/products/sealants-glues.php?productid=29

Drainage, drip, and other pipes and flanges

www.fraenkische.com/index_en.html (Strabusil®; DN100)

Netafim irrigation Inc.: www.netafimusa.com/landscape/products/techline-ez-tech (driplines)

Aeration technology

store.aquaticbiologists.com

www.biotop-natural-pool.com/system_carbonator.html

Pumps, pool cleaners and robots

dolphinpoolrobot.com/en

speck-pumps.com/en/badu

www.zodiac-innovation.com/; www.zodiacpoolsystems.com/Products/Pumps

www.pentairpool.com/sections/pumps-42.htm

www.hartl-pumpe.at

www.oase-livingwater.com/; http://store.oase-usa.com

www.sopra.de/en

www.lowara.com

www.blagdonforcehybrid.co.uk/BlagdonPondMonsta.aspx; www.youtube.com/watch?v=lrzNXg2fKok

www.castlepumps.com/pumps/pump/liverani-flexible-impeller-pump

Floating Islands

store.aquaticbiologists.com

www.oekon-vegetationstechnik.de/oekon/Schwimmende_Roehrichtinseln.html

www.floatingislandinternational.com (BioHaven®)

www.floatingislandswest.com/customer-guide/buy-an-island

www.bradshawsdirect.co.uk/freedom-ponds-island-scapes-decorative-pond-islands

Plants

www.angloaquatic.co.uk

www.aquascapesunlimited.com

www.floridaaquatic.com

www.nymphaion.de/en

www.seerosensorten.de

www.watergardenparadise.com.au

www.watersidenursery.co.uk

Fertilizer

www.compo-expert.com (Fe-fertilizer Basafer®-Plus)

www.interhort.com/products/105033_osmocote_plus_tablet_56mth_7-5gm.php (Osmocote Exact Tablets)

www3.syngenta.com (Fe-fertilizer Sequestrene®)

www.swimming-teich.com/shop/product_info.php?cPath=21&products_id=46

Pesticides

www.bonide.com (Bonide 803 Thuricide BT Insect Killer)

www.saferbrand.com (Safer Brand Caterpillar Killer)

Testing water quality

www.jbl.de/en

www.lamotte.com/en/drinking-water

www.milwaukeeinst.com/site/products/products-by-parameters/phosphate

www.pce-instruments.com/english

Water additives

(remember the natural pool philosophy!):

www.koitec24.de

www.lavaris-lake.de/en

www.peroxyd.de

www.tripond.de/en

www.weitz-wasserwelt.de (choose “English”)

Wool pellets

www.krpelletco.com

GLOSSARY

(* Indicates a separate entry in the Glossary)

ABC (acid binding capacity): amount of a 0.1 mmol/l HCl which is needed to titrate 100 ml water to pH 4.3. ABC value × 2.8 ≙ °dH KH (*carbonate hardness).

Acidophyte: plant species which needs acid substrate to grow adequately.

Aerenchyma: cell tissue of marsh and aquatic plants with air-filled intercellular spaces.

Aerobic: well supplied with oxygen, providing oxidizing conditions.

Anaerobic: undersupplied with oxygen, providing reducing conditions.

Archeophyte: not originally native plant species, introduced before 1500 AD. Forms populations without deliberate human intervention.

Berm: ± horizontally levelled space or interrupting a slope or embankment; often used as a track or planting ground.

Biogenic decalcification: crystallization and precipitation of calcium carbonate ($CaCO_3$) as a result of photosynthetic consumption of CO_2 or HCO_3^- as a carbon source for submerged aquatic plants.

Boreal climate: cold-temperate or subarctic climate, defined by vegetation period ~4 months (>5°C); generally from 50° to 70° northern latitude; natural vegetation mainly coniferous forests, merging polewards into tundra.

BSF: Biofilm-accumulating Substrate Filter.

C-Strategist: Competitor: plant with strong competition power. Long-lived and sometimes rampantly proliferating with its shoots.

Carbonate hardness (KH): concentration of dissolved Ca^{2+} and Mg^{2+} with an equivalent concentration of HCO_3^- - ions. Measured in °dH or mmol/l (1°dH ≙ 5.6 mmol Ca^{2+}/l).

Carbonator ("Biotop Carbonator"): aeration system for ponds, which injects CO_2-enriched soil air into the water body. The increased CO_2-content reduces algae emergence (patent of Biotop company).

Carr: wet woodland on soggy peat, can be periodically flooded; climax community of silted-up lakes.

Colmation: clogging of filter bodies by fine particles.

Diaspore: dispersal units like seeds, fruits, spores or detached, regenerative shoot particles.

EC (electrical conductivity): measure of the salt content of water.

Emersed filter: not completely inundated filter body; its surface is located above water level.

EPDM: ethylene propylene diene monomer, a very elastic synthetic rubber material for liners

Extra-cellular Polymeric Substances (EPS): secretions of microorganisms, which effect their mutual binding together in a biofilm.

Eutrophic: site condition, which provides a high production rate of organic matter; mostly water with a high nutrient level.

Evapotranspiration: sum of evaporation (water loss by vaporizing from soil or water surfaces) and transpiration (water loss from vegetation surface).

FLL: German Landscaping and Landscape Development Research Society (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.).

GH: *total hardness.

GRP: fibreglass-reinforced polyester plastic.

Hardiness zone: classification system referring to the winter hardiness of plants (*USDA zone).

HBS: Hydrobotanical System.

Helophyte: plant, which grows in marshy ground with submerged regeneration buds. Shoots emerge above the water level.

Hydrophyte: aquatic plant with floating leaves or growing completely submerged.

Hygrophyte: plant which grows on damp sites, but without permanent excess water in the root area.

Hypertrophic: site conditions which provide an excessively high production rate of organic matter; mostly water with an abnormally high nutrient level.

Inflorescence: plant shoot, which develops accumulations of flowers, sometimes in dense concentration, which appears like a conspicuous single bloom (e.g. plant family Asteraceae).

KH: *Carbonate hardness.

Koi: species of carp (*Cyprinus carpio*), often exhibiting spectacular colour patterns.

Lanthanum: a rare earth element, which is used for binding phosphorus compounds in water. It can be applied as lanthanum chloride. The resulting insoluble lanthanum phosphate is sedimented.

Mesotrophic: site conditions, which provide a moderate production rate of organic matter; mostly waters with a medium nutrient level.

Mycorrhiza: symbiosis between specialized fungi and roots of certain *vascular plants. The fungi improve the plant's uptake of nutrients and water.

Nemoral climate: warm-temperate climate, mean temperature of the warmest month > 20°C; yearly mean temperature < 20°C. Natural vegetation mainly deciduous mixed forests; in continental areas coniferous forests or steppes.

Neophyte: not originally native plant species, introduced after 1500 AD. Forms populations without deliberate human intervention. Some neophytes are invasive and cause severe problems in nature conservation.

NKH: *non-carbonate hardness.

Non-carbonate hardness (NKH): concentration of dissolved Ca^{2+} and Mg^{2+} with an equivalent concentration of other ions than the ones responsible for *KH, e.g. SO_4^{2-}, Cl^-, NO_3^-.

Oligotrophic: site conditions which provide a low production rate of organic matter; mostly nutrient-poor waters.

pH value: measure for the acidity or alkalinity of water. Defined as negative decimal logarithm of hydrogen ion (H^+) activity. pH<7 ≙ acidic; pH >7 ≙ alkaline; pH=7 ≙ neutral.

Phosphorus (P): essential element as energy currency, in DNA and RNA (genetic information) and in membranes. Considered particularly relevant in terms of hygiene and algae growth.

Phytoextraction: extraction of dangerous elements or compounds, mainly heavy metals, from soil or water by plants.

Pinnatisect: deeply cut leaves not separated into leaflets.

Plankton: tiny organisms of diverse groups, which are unable to swim against a current. Microscopic algae are zooplankton, which are mainly responsible for the visual depth of a water body.

Pleustophyte: *hydrophyte, which floats in the water during the vegetation period, not fixed in the ground.

P_{tot} : total *phosphorus – sum of phosphorus in all compounds.

PVC: polyvinyl chloride, a common plastic material for liners, pipes and jets.

Redox potential: describes the ratio between chemically oxidized and reduced compounds. It can range between +800 mV (strongly oxidizing) and -300 mV (strongly reducing – poor degradation of organic matter).

RGF: Rock Garden Filter.

R-Strategist: ruderal plant which establishes itself quickly on disturbed sites. Short-lived but quick flowering and producing enormous amounts of *diaspores. Some R-strategists can become annoying weeds.

Rhizodegradation: degradation of contaminants in the *rhizosphere (= phyto-stimulation).

Rhizome: stem axis (runner) which grows underground.

Rhizosphere: substrate area surrounding the plants' roots.

Rhyolite: siliceous volcanic rock, often reddish and coarse crystalline. Lime-free material.

sp. : species (singular)

spp.: species (plural)

S-Strategist: stress tolerating plant; long-lived but slow growing. Often with hard leaves or compact growth. Well adapted to deficiency of certain growth factors such as nutrients but soon outcompeted on rich sites by *C-strategists.

Subtropical climate: climate with yearly mean temperature > 20°C; mild winters, minimally 0 to -10°C. Generally from 23.5° to 40° northern/southern latitude; natural vegetation evergreen sclerophyll forests, steppes or even deserts, depending on rainfall patterns.

Technical Wetland: water treatment by percolating through a planted filter bed. Purification mainly by substrate plus microbes in the *rhizosphere.

Temperate climate: *boreal climate + *nemoral climate.

Total hardness (GH): sum of *carbonate hardness and *non-carbonate hardness.

Tschernosem: *soil type rich in organic matter ("Black Soil"), typical of continental climate regions.

Trophic levels: level of site-productivity depending on the nutrient supply.

Tropical climate: climate with year-round >20°C monthly mean. Generally 23.5° northern to 23.5° southern latitude.

TWL: *Technical Wetland.

USDA zone: *Hardiness zone.

Vascular plant: plants with specialized vascular bundles to transport water and nutrients; comprising seed plants, ferns and lycopods.

Zeolite: crystalline aluminosilicates with a microporous structure. Some zeolites can fix special ions. The enormous inner surface promotes biofilm colonization.

USEFUL INFORMATION

Climate belts – derived from the Köppen-system

	Distribution	Monthly mean temperature	Description	Vegetation and plant examples
Arctic and Antarctic	Poles to arctic/ antarctic circles (66.6° latitude)	year-round < +10°C	summer very short and cool	Tree-free zone, dominated by dwarf shrubs *Betula nana*, *Phyllodoce caerulea*
Boreal (cold-temperate)	Northern hemisphere only	1-4 months +10°C to +20°C 8-11 months < +10°C	Short summers 1-3 months Winters very cold regular frost < –20°C	Coniferous forest (Taiga) *Picea abies* *Pinus sylvestris*
Nemoral (warm-temperate)	Northern hemisphere only	< 4 months > +20°C 4-12 months +10°C to +20°C < 4 months < +10°C	Winters cold, regular frost < –10 °C	Broad-leaved deciduous forests to open woodland, steppe, desert
Subtropics: Meridional Zone (northern hemisphere) Austral Zone (southern hemisphere)	ca. 40° to 23.5°	4-11 months > +20°C 1-8 months +10°C to +20°C	yearly average > +20 °C mild winters, coldest temperature 0 to –10 °C	Evergreen sclerophyll forest, dry shrubland, steppe or desert
Tropical Zone	23.5° to equator	year-round > +20°C	no frost, rarely < +5 °C No thermal seasons	Tropical rainforest to open forest, dry shrubland

Conversions

To Convert Temperature:	
°C = 5/9 × (°F –32)	
°F = (9/5 × °C) + 32	

To Convert Length:	Multiply by
Kilometres to miles	0.62
Metres to yards	1.09
Metres to feet	3.28
Centimetres to inches	0.39
Millimetres to inches	0.04

To Convert Area:	Multiply by
Square centimeters to square inches	0.155
Square metres to square feet	10.8
Square metres to square yards	1.2
Hectares to acres	2.5
Square kilometres to square miles	0.386

To Convert Weight:	Multiply by
Grams to ounces	0.035
Kilograms to pounds	2.20

DN drain pipe numbers refer to the diameter of the inside of the pipe. A DN 100 drain pipe has an inside diameter of 100 mm.

General Legend

Nutrient limitations:

- Carbon limitation
- Phosphorus limitation

Filter Techniques:

- Direction of water percolation
- Hydrobotanical system
- Technical Wetland
- Biofilm-accumulating Substrate Filter
- Rock garden filter
- Aeration
- Carbon-dioxide-enriched aeration
- Phosphorus filter

Plumbing:

- Suction pipe
- Pressure pipe
- Jet

Construction/framing of swimming area:

- Edge of the sealing material/capillary border
- No wall
- Wall on top of sealing material
- Wall beneath sealing material
- Pool separate from regeneration pond

Design Style:

- Formal design
- Naturalistic design

Symbols in formulae:

⇄	balance reaction
↳	transferred to
≙	equivalent to

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Zigadenus (*Anticlea*, elegant camas) 69, 181, 188, 258
Zizania (Manchurian wild rice) 54, 146, 156, 158, 181
Zygnematales (algae) **214**, 216, **220**, 223

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Front cover The natural pool at Ellicar Gardens. (Designed by Sarah Murch and built by Natural Pools UK)

Back cover A beautiful, naturalistic pool set in the heart of the English countryside. (Designed and built by Gartenart Swimming Ponds)

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