LIFE-TREASURE

Treatment and re-use of urban stormwater runoff by innovative technologies for removal of pollutants

Advanced treatment of stormwater runoff

The Treasure Project

Rain water is clean water. But when it has been in contact with roads, buildings and other urban surfaces it becomes quite polluted.

Most often the rainwater that runs off from the surfaces of the city does not cause fish kills or similar direct toxic effects. Normally the effects are more circumspect: Reduced biodiversity and accumulation of pollutants in the food web.

But sometimes - when people or industries illicitly discharge toxic substances - stormwater can cause such direct effects on the environment:

Background

It seldom rains. But when it rains it pours. This makes the treatment of stormwater runoff somewhat of a technical challenge. At the same time, the runoff contains mostly inorganic pollutants - making it even harder to treat.

Existing technologies for treating stormwater runoff are only targeted at removing pollutants bound to particles. The dissolved pollutants are, on the other hand, not managed to a satisfactory degree.

Unfortunately, it is the dissolved pollutant fraction that is most mobile in the environment and which is most easy taken up by plants and animals.

It is therefore an environmental challenge to develop simple, robust, cost-effective and efficient technologies for removing dissolved pollutants from stormwater runoff.

Three Danish water companies and two Danish universities partnered to address the issue of advanced stormwater treatment. The partnership was supported by LIFE financial instrument of the European Community (LIFE06 ENV/DK/000229). The project ran from October 2006 to September 2009.

The purpose of the TREASURE project is to implement and demonstrate technologies that can efficiently reduce diffuse urban pollutant loads onto receiving waters. Focus is on the removal of phosphorous, a macronutrient largely responsible for eutrophication of lakes and inland costal waters, and on toxic substances (heavy metals and organic micropollutants).

As part of the project, 3 wet detention ponds for treating stormwater runoff have been constructed. The ponds are constructed with filtration and absorption units for enhanced removal of small particles and colloidal and soluble bound pollutants. In addition, the ponds are equipped for on-line monitoring of the treatment performance. The facilities are located in Odense, Silkeborg, and Århus, Denmark.

It is considered essential that the treatment facilities are constructed as natural and recreational elements in the form of semi-natural lakes that in a positive way contributes to an improved urban environment. Expectantly, the project will demonstrate how the simple and cheap treatment concept of a semi-natural lake extended with filtration and absorption is robust, and even for large storms following long droughts excellent treatment performance is maintained.

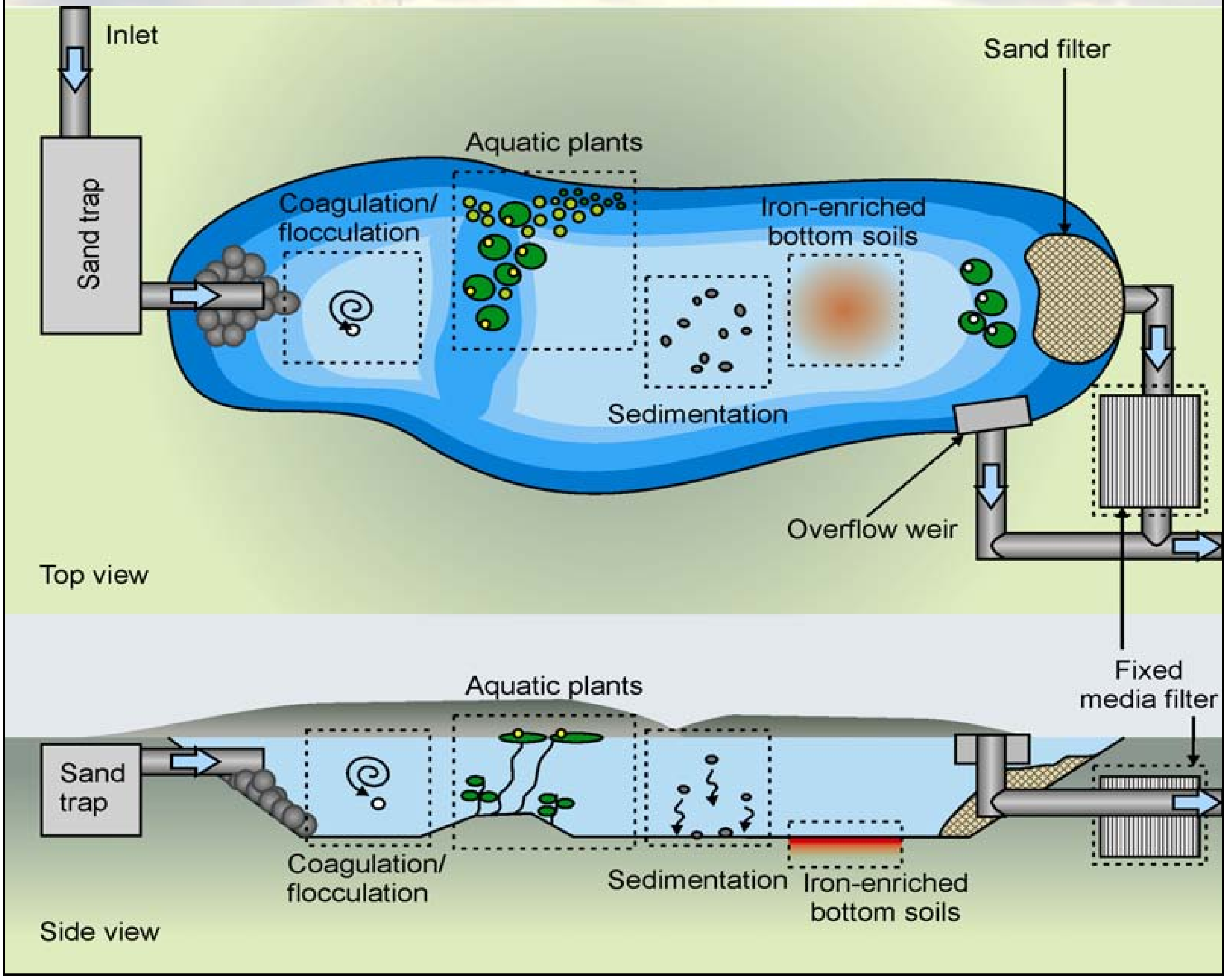
Technologies

The major principle for treatment of urban and highway runoff in wet detention ponds is sedimentation of suspended particles. However, several other processes occur to an unknown extend; i.e., plant uptake of dissolved pollutants, sorption of dissolved matter and colloids to surfaces, as well as flocculation of fine particles and colloids. The latter processes act on the dissolved and colloidal fraction of the stormwater pollutants, which are the most mobile in the aquatic environment and consequently possess the highest risk of causing adverse effects.

Each demonstration facility incorporates the unit operations of sedimentation, filtration and treatment by aquatic plants as mentioned above. In addition, the treatment is extended with one of the following technologies:

- sorption to iron-enriched bottom soil
- coagulation/flocculation by aluminium addition
- fixed media sorption

The image below illustrates the different technologies:



Technical facts

Sedimentation

Treatment of stormwater runoff by sedimentation relies on the fact that a significant part of the pollutants occurring in stormwater is associated with particles that can be settled out of the water column. In order to achieve good treatment efficiency, the suspended particles must therefore be able to settle out of the water column during the dry periods separating the rain events. Accordingly, the treatment efficiency is largely determined by the settling velocity of the particles and the hydraulic retention time of the pond. During large rain events, the runoff water flows through the pond resulting in low treatment efficiencies.

Aquatic plants

Emergent aquatic plants are often integrated in the design of wet detention ponds, but also where plants have not been actively included in the design, emergent as well as submerged plants tend to colonize a pond. The aquatic plants fulfil numerous purposes with respect to pollutant removal, and their combined effect is predominantly beneficial. In order to achieve good treatment efficiency, aquatic plants are therefore actively included in the design of the facilities. In addition, the aquatic plants can be actively integrated into the design of the pond thereby achieving an overall impression of the wet detention ponds of a natural aquatic habitat with a diverse flora and fauna.

Filtration

Filtration of the effluent from a wet detention pond in a fixed media filter - such as a sand filter - is an efficient method for retaining particles. During the filtration process, particles are deposited on the surface of the filter creating a filter cake. This filter cake will typically have a much lower hydraulic conductivity than the filter medium and therefore controls the overall hydraulic capacity of the filter.

Sorption to iron-enriched bottom soil

Investigations of the phosphorus cycle in shallow lakes have shown that high concentrations of iron in the bottom soil can efficiently control the concentration of dissolved phosphorus in the water column. The main mechanism responsible for these observations is adsorption of phosphate ions onto precipitated iron (oxy)hydroxides (primarily FeOOH and $Fe(OH)_3$) as illustrated in the image below. By deliberately blending e.g. ferric hydroxide into the bottom soil of wet detention ponds, the retention of phosphorus can be significantly enhanced. The retention of heavy metals may also be significantly enhanced, as several of these are strongly associated with iron (oxy)hydroxides.

Coagulation/flocculation by aluminium addition

The addition of aluminium salts has been practiced for restoration of eutrophic lakes in terms of phosphorous removal from the water column and immobilization of phosphorous in the lake sediments. Also for ponds, the addition of aluminium has been found effective. Addition of aluminum salts to the bulk water produces aluminum hydroxide ($Al(OH)_3$), which is highly insoluble and therefore precipitates forming relatively large settable flocs. Similar to the iron (oxy)hydroxide, the aluminum hydroxide flocs have a high sorption capacity for both phosphate and heavy metals.

Fixed media sorption

Various pollutants may effectively be removed by adsorption in a fixed media filter. Which pollutants are retained by such a filter depends largely on the chemical composition and structure of the sorption media. For example, materials containing calcite ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) like marble, limestone, dolomite rock and different types of shells from marine organisms have proven efficient in removing especially phosphorus. Similarly, various organic materials and materials containing iron or aluminium oxides provide efficient absorption of heavy metals. Prior to filtration in a fixed media filter, the concentration of particles in the runoff water should be reduced e.g. by sand filtration.

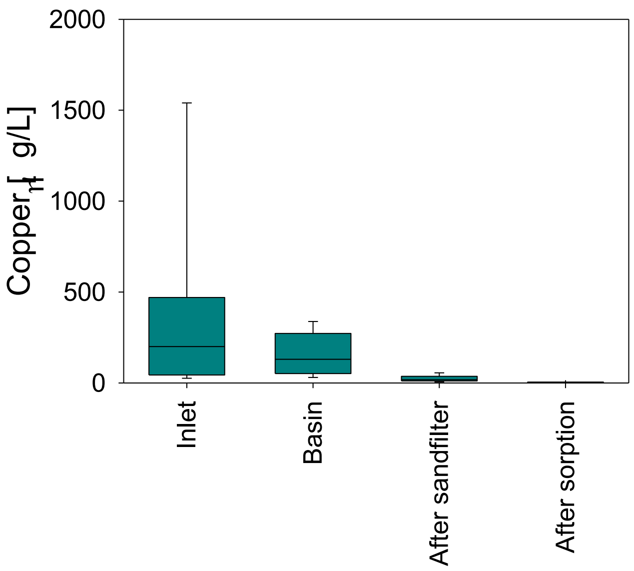
Results

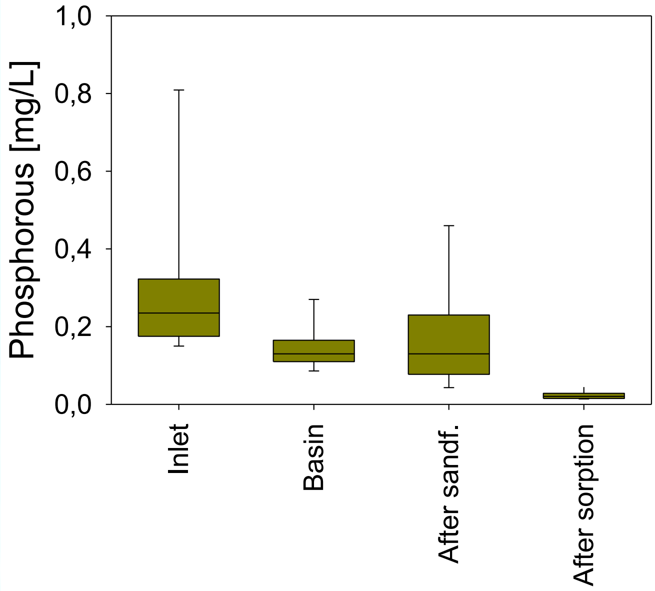
The treatment train consisting of a wet retention pond, a sand filter and a fixed media sorption filter was the most efficient technology for reducing a broad range of dissolved and colloidal pollutants in the stormwater runoff. The two other technologies were also effective towards some pollutants, but only their effect against phosphorous could be proven. Sand filters effectively polished the runoff water. Plants contributed marginally to the cleaning processes, but were important for ensuring integration of the facilities as recreational elements of the urban environment.

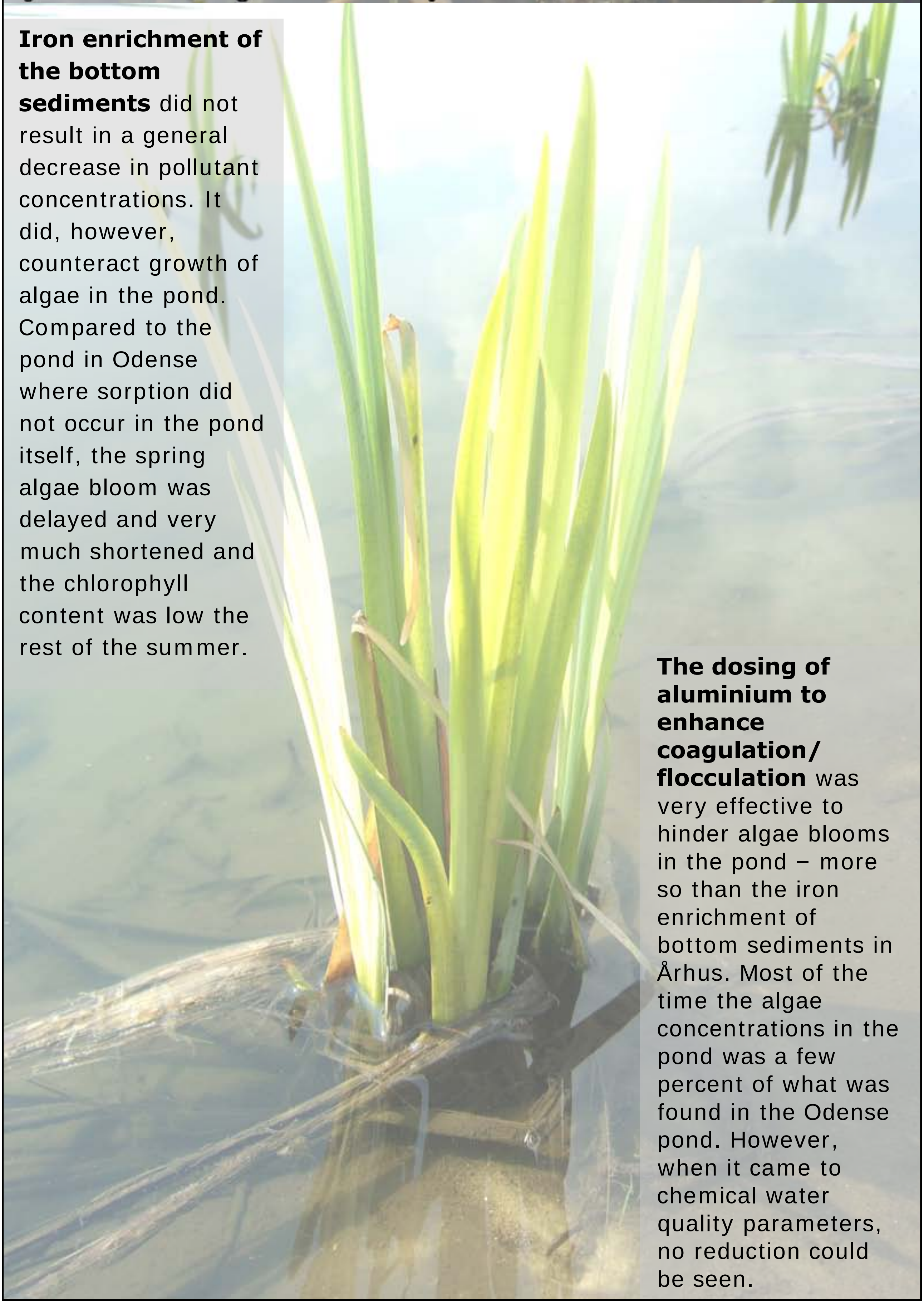
Fixed-media sorption

The fixed-media sorption technology proved very efficient to manage the high loads of dissolved heavy metals from the catchment in Odense. This technology allowed very low outlet concentrations, which were independent of the inlet concentrations to the filters. For all measured pollutants, the outlet concentration was consistently below the respective receiving water quality criteria. This was the case even for copper, where the inlet concentration at times was several hundred times the water quality criteria.

As examples, the results for copper and phosphorous are presented. Copper was reduced from an average of 310 µg/L down to 4 µg/L, corresponding to an overall removal rate of 99%. Phosphorous was reduced from 0.27 to 0.025 mg/L, corresponding to an overall removal rate of 91%.







Iron enrichment of the bottom sediments did not result in a general decrease in pollutant concentrations. It did, however, counteract growth of algae in the pond. Compared to the pond in Odense where sorption did not occur in the pond itself, the spring algae bloom was delayed and very much shortened and the chlorophyll content was low the rest of the summer.

The dosing of aluminium to enhance coagulation/ flocculation was very effective to hinder algae blooms in the pond – more so than the iron enrichment of bottom sediments in Århus. Most of the time the algae concentrations in the pond was a few percent of what was found in the Odense pond. However, when it came to chemical water quality parameters, no reduction could be seen.

Economical and environmental costs-benefits

The prime environmental benefit of the technologies is a protection of the environment against the vast majority of pollutants present in stormwater runoff. Especially the fixed media sorption filter is effective for this purpose, and does, furthermore, present an effective barrier against many illicit discharges.

The addition of a coagulant/ floculant like aluminium presents an effective protection against phosphorous which in many cases is crucial when fighting eutrophication of urban and natural waters.

The costs of protecting the environment against the pollutants in stormwater runoff is mainly associated with construction and operation of the facilities. The management of the concentrated waste products from the treatment process does also constitute both economical and environmental costs. However, compared to the environmental benefits obtained, the induced costs are deemed marginal.

Transferability of results

The demonstrated technologies for advanced treatment of stormwater runoff are not restricted to a single urban context, region or climate. The technology can also be applied for related purposes such as treating drinking water polluted with for example arsenic or heavy metals. Another application is treatment of phosphorous polluted surface waters.

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