Silkeborg Municipality

October 1, 2009

Task E, 6th delivery: Status report (English) on the cost-effect ratio of the different treatment unit processes

Contract text to which the deliverable refers:

Evaluation of the cost-effect ratio of the different treatment unit processes (Action E11). The pollutant removal effect of the different treatment steps are compared to the capital cost of the step and to its running costs. The cost-effect for removal of particulate pollutants is expected best for the unit process 'sedimentation', while removal of dissolved and colloidal pollutants is expected best for the unit processes 'plant uptake' and 'absorption'.

Treatment efficiency of the wet basin, sand filters and sorption filters

In Table 1 the absolute removal of pollutants by the 3 wet ponds are listed. The absolute removal reflects a combination of the amount of wastewater entering the pond, the pollutant loads and the removal efficiencies. So are for example the low removals in Silkeborg not an expression of poor treatment efficiency but a combination of rather diluted stormwater runoff, a small catchment size and a very low hydrological reduction factor of the impermeable surfaces in the catchment. Similarly is the very high removal of copper in Odense an expression of very high copper loads in the catchment, and does as such not tell anything about the treatment efficiency of the pond.

Nevertheless, the numbers in Table 1 reflect the mass of pollutants retained for the investment costs of the respective ponds. The pond sizes for the sites Odense, Århus and Silkeborg are 1,990 m^3, 6,900 m^3 and 2,680 m^3, respectively. Comparing for example the pond size and copper removals of Odense and Silkeborg, it is evident that the “copper removal return” of the pond investment is more than 100 times better in Odense than in Silkeborg. Similar, if not as extreme, is valid for the other pollutants.

Table 1. Absolute annual removal of pollutants by the wet ponds. For The facility in Århus and Silkeborg, only data up till start of iron/aluminum addition are included.

	Odense	Århus	Silkeborg
Lead [g $year^{-1}$]	814	364	10.3
Cadmium [g $year^{-1}$]	2.4	4.2	0.5
Chromium [g $year^{-1}$]	237	297	13.4
Copper [g $year^{-1}$]	7,587	1,378	61
Mercury [g $year^{-1}$]	3.5	22.5	0.6
Nickel [g $year^{-1}$]	411	-1,065	92
Zinc [g $year^{-1}$]	3,805	13,786	241
16PAH [g $year^{-1}$]	8.9	38.5	
TSS [kg $year^{-1}$]	2,056	3,801	182
Total N [kg $year^{-1}$]	68	129	12
Total P [kg $year^{-1}$]	10.7	18.0	3.0
Ortho P [kg $year^{-1}$]	5.6	9.6	2.0
Oil and fat [kg $year^{-1}$]	93	29	n.d.
COD [kg $year^{-1}$]	1,338	3,790	n.d.

Similarly for the sand filters, the mass of pollutant removed is highly varying and much dependent on the actual load on the filters (Table 3). Not all water passed the sand filters as they turned out to have less capacity than envisioned in the design phase. The detainment in the filters is nevertheless calculated assuming that all water passed the filters in order to allow comparison with the wet ponds.

Of the 3 sorption technologies tested, only the fixed media filter showed a clear effect on the dissolved and colloidal pollutants (Table 2). This was partly due to this technology in fact allows stable and low discharge concentrations, but also because the loading on the facility coincidentally was very high. Had the pollutant loadings on the two other facilities been equally high, these technologies too might have proven an effect on the reduction of dissolved pollutants.

The “pollutant removal returns” of the investments in pond volume and sand filters, in terms of the cost of a certain pollutant mass removed, are strongly dependent on catchment characteristics. Seen from the perspective of the aquatic ecosystem, it is however irrelevant which mass was removed prior to discharge. What counts is the pollutant mass entering the ecosystem as well as the pattern with which it is discharged.

In other words, it is the pollutant load and the peak concentrations that are relevant and not pollutants retained. It is therefore more appropriate to look at the cost-benefit in terms of which levels of pollutant concentrations were achieved with the treatment technologies and whether problematic peak concentrations were avoided.

Table 2. Absolute annual removal of pollutants by the sorption facility in Odense

	Odense	Århus	Silkeborg
Lead [g year^{-1}]	-8,4	-27,0	-5,0
Cadmium [g year^{-1}]	0,7	-1,1	0,0
Chromium [g year^{-1}]	-3,7	-111,6	1,7
Copper [g year^{-1}]	1429,0	-77,0	17,0
Mercury [g year^{-1}]	1,3	2,5	0,1
Nickel [g year^{-1}]	31,1	341,0	479,2
Zinc [g year^{-1}]	1573,1	1139,4	-17,1
16PAH [g year^{-1}]	0,0	0,6	
TSS [kg year^{-1}]	727,1	177,3	20,9
Total N [kg year^{-1}]	15,5	-6,2	2,3
Total P [kg year^{-1}]	10,5	7,5	0,0
Ortho P [kg year^{-1}]	2,1	0,3	0,0
Oil and fat [kg year^{-1}]	2,9	5,4	0,6
COD [kg year^{-1}]	304,2		

Table 3. Absolute annual removal of pollutants by the sand filters, assuming that all water had passed the filters. For The facility in Århus and Silkeborg, only data up till start of iron/aluminum addition are included.

	Odense	Århus	Silkeborg
Lead [g year^{-1}]	422	16	18
Cadmium [g year^{-1}]	0.6	0.1	0.0
Chromium [g year^{-1}]	51	20	-6.7
Copper [g year^{-1}]	11,616	77	35
Mercury [g year^{-1}]	-0.6	-5.1	0.2
Nickel [g year^{-1}]	417	930	-902
Zinc [g year^{-1}]	16,211	2,310	961
16PAH [g year^{-1}]	7.3	2.2	0.4
TSS [kg year^{-1}]	175	275	7
Total N [kg year^{-1}]	61	13	20
Total P [kg year^{-1}]	-2.1	-6.2	0.1
Ortho P [kg year^{-1}]	0.5	-0.4	0.0
Oil and fat [kg year^{-1}]	10	64	6.6
COD [kg year^{-1}]	495	2661	408

Comparing all results, it is seen that in general a major removal of pollutant mass takes place in the wet basin and that a lesser fraction of the pollutant mass is removed by the other unit operations. The results confirm established knowledge that the major fraction of the pollutants listed in the tables are on particulate form and therefore subject to sedimentation as it occurs in a wet basin. The colloidal and soluble fractions contribute the smaller pollutant masses, but are also the most mobile in the aquatic environment and most hard to eliminate.

An important aspect when assessing the effect of the unit operations are there effect towards minimizing not only the average load, but also peak loads. In this respect both the sand filtration unit operation and the sorption unit operation has proven to be efficient.

An assessment of cost-effect ratio of the different unit operations should take this into account and a simple assessment of the type “price per mass pollutant removed” is not adequate when comparing treatment cost-effect ratios. Instead the different technologies removing colloidal and dissolved pollutants should be compared. At this state of the project, the data only allow comparison of sorption technologies for the fixed media technology, as sorption to bottom sediments and aluminum flocks in the water phase have not yet begun. Furthermore, as a fixed media sorption filter cannot exist without a sand filter or similar high-effective removal of fine particulates (due to clogging problems), a comparison between “sand filter” and “sand filter + fixed media sorption filter” is most appropriate.

It is furthermore irrelevant to compare the costs actually incurred in the Treasure-project, as the prototype nature of the treatment facility and the need for documentation of treatment performance have caused the by far largest part of the costs actually incurred. The comparisons of costs are consequently made by producing a cost estimate of a sand filter and a sand filter + sorption filter in a non-prototype full-scale version. The costs for special items like sorption media and vegetation are, however, taken from the costs incurred in the project.

Design example

Filters are designed as horizontal filters with a design flow rate of 1 L/s per 100 m^2 of filter, i.e. corresponding to preliminary results on the capacity of the filters in Odense with 20-40 cm overlying water pressure. The following two situations are compared

- A vegetated sand filter without build-in sorption filter, Figure 1
- A vegetated sand filter with build-in sorption filter, Figure 2

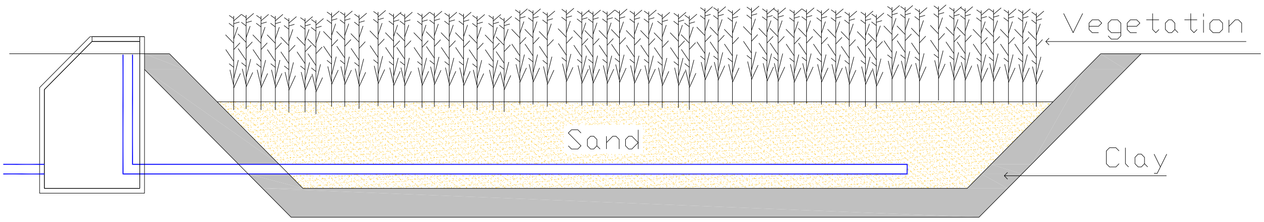

Figure 1. Construction of a vegetated sand filter. The magnitude of the sand layer is 0.9 m.

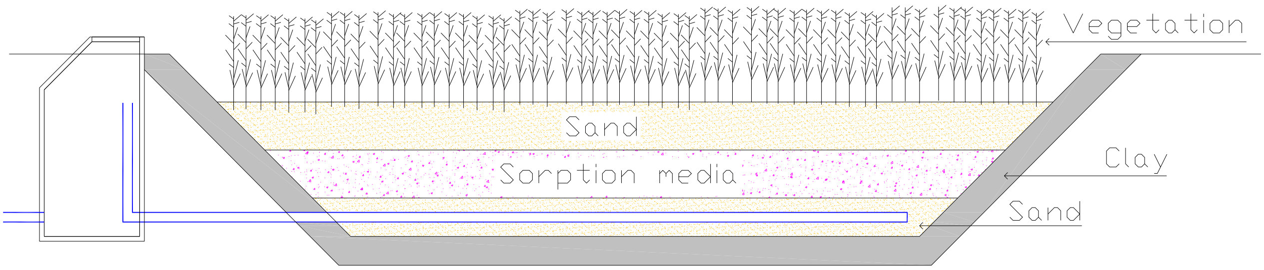

Figure 2. Construction of a vegetated combined sand filter / sorption filter. The magnitude of the top sand layer is 0.5 m, the magnitude of the sorption media is 0.5 m, and the magnitude of the lower sand layer (drain layer) is 0.4 m.

Comparing the total costs incurred by the sand filter with and without sorption filter (Table 4), it is seen that the combined sand filter / sorption filter costs approximately 20% more than building the sand filter without sorption media. The costs are only tentative and will of course depend on local conditions, materials used, transport costs of sorption media, and etceteras. Due to the high variability of the data, a quantification of the benefit in terms of removed pollutant masses are difficult, but as can be read from the table, the technology removes many pollutants to below the detection limit. Furthermore, the sorption technology is a very effective protection against pollutant peaks. Such pollutant peaks are typically acute toxic to the aquatic environment and protection against such peaks are therefore of great importance. All in all, the demonstration has shown that a combination of wet sedimentation pond, sand filter and sorption filter is a cost-effective approach to significantly reduce the pollutant load on the environment and at the same time effectively protecting the aquatic environment against pulses of toxic pollutants.

In this example, the filter is design for a flow of 25 L/s, i.e. corresponding to a catchment of 25 ha (Table 4).

Table 4. Cost estimate of two filter types designed for a flow of 25 L/s

	Unit price	Combined Sand /sorption filter	Costs of construction	Sand filter without sorption filter	Costs of construction
Vegetation	200 kr/m^2	2,500 m^2	500,000 kr	2,500 m^2	500,000 kr
Soil work, removal of soil	50 kr/m^3	5,900 m^3	295,000 kr	4,500 m^3	225,000 kr
Sand, top layer	150 kr/m^3	1,250 m^3	187,500 kr	1,250 m^3	187,500 kr
Sorption media (Skellsand)	230 kr/m^3	1,250 m^3	287,500 kr		
Sand, drain layer	200 kr/m^3	1,000 m^3	200,000 kr	1,000 m^3	200,000 kr
Clay membrane, 0.3 m thick	30 kr/m^2	2,700 m^2	81,000 kr	2,700 m^2	81,000 kr
Inlet structure (kr/piece)	450,000	1 piece	450,000 kr	1 piece	450,000 kr
Outlet structure (kr/piece)	185,000	1 piece	185,000 kr	1 piece	185,000 kr
Design and supervision		25% of cost	546,500 kr	25% of cost	457,125 kr
Total costs			2,732,500 kr		2,285,625 kr