Intensified and Modified Wetland Designs

This paper summarizes recent developments in intensified and modified treatment wetland designs, with specific examples from France, the UK, and Germany.

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Abstract

This paper summarizes recent developments in intensified and modified treatment wetland designs, giving a brief overview of the current status of the technological advancements, with experiences from both the private consulting and research sectors. Current challenges are also discussed, such as optimizing treatment performance, and accurately estimating energy consumption. Finally, a summary of the discussion session is presented, which includes: global nitrogen cycling, the necessity for plants in intensified wetlands, and a surprisingly widespread observation of yellowing Phragmites in systems treating highly-nitrified effluents.

Introduction

Standard constructed wetland designs have been well-established for decades and successfully implemented throughout the world (Vymazal & Kröpfelová 2008; Kadlec & Wallace 2009) As the use of treatment wetlands has become more widespread, alternative designs have been developed in order to overcome the limitations of standard designs. Many of the advancements in treatment wetland design originate from consultants working in the private sector. Because economics and treatment efficiency are highly important in the private sector, modifications tend to be funded through the internal research and development efforts of private

Main outcomes of the session :

- There is overall interest in the mechanisms of nitrogen removal in intensified wetland systems.
  - Questions were raised about gaseous (N_2O) emissions from aerated wetlands, which is currently being investigated by Gabriela Dotro (Cranfield University, UK).
  - The extent that alternate nitrogen removal pathways, such as ANAMMOX, play a role in nitrogen removal in these systems is largely unknown.
- When using an industrial by-product as wetland media, with an anticipated end-use as a fertilizer (such as steel slag), care must be taken to ensure that it meets the allowable limits for soil application. This is important to characterize because slags vary greatly between producers.
  - A quick test that can be performed on large piles of slag should be developed, in order to ensure that all slag used in a wetland is suitable for soil application.
  - If the material is not suitable for soil application (due to metal content higher than what is allowed for agricultural reuse, for example) the slag could be repurposed for use in road construction.
- Yellowing Phragmites has been observed in many wetland treatment systems, typically in tertiary treatment wetlands, or wetlands with recirculation or active aeration. Observations from Canada, Denmark, France, Germany, and the UK, and other countries were reported.
  - For consultants, clients think yellowing plants look bad, even if the treatment system is performing well.
  - Reasons for yellowing may be due to iron deficiency and lack of preferred form of nitrogen (NH_4-N).
  - The use of other plants such as *Phalaris* and Iris, which might stay green under such conditions, is being investigated.
  - Further detail on this topic is presented in a separate report in this issue of SSP Journal.

companies and quickly implemented upon proof of concept (Nivala et al. 2013). One recurring theme in the development of intensified and modified treatment wetland designs is the overarching aim to improve subsurface oxygen availability – and thus, better removal of compounds such as ammonium nitrogen and carbonaceous compounds.

Current background / status

Common design modifications include the use of multi-stage or hybrid wetlands (Molle et al. 2008), recirculation (Gross et al. 2008; Troesch & Esser 2012, Prost-Boucle & Molle 2012), batch loading (Stein et al. 2003; Corzo et al. 2008) or tidal flow operation (Behrends 1999; Wu et al. 2011), and/or active aeration of the water column (Wallace 2001; Ouellet-Plamondon et al. 2006; Murphy & Cooper 2011). While most modifications involve some incremental increase in energy input to the treatment system, some modifications can be implemented without external energy inputs if the site topography is favourable (Austin & Nivala 2009). Another vein of intensified and modified wetland designs focusses on the use of active filter materials, which through their physico-chemical properties can increase removal of pollutants such as phosphorus (Molle et al. 2005; Vohla et al. 2011), ammonium (Austin 2006), and/or heavy metals (Sheoran & Sheoran 2006).

Experiences / examples

Experiences from Epur Nature (France), ARM (UK), and UFZ (Germany) were presented and at the workshop.

France

The standard French design for treating raw wastewater consists of a first stage of three alternately loaded, gravel-filled vertical flow beds and a second stage of two sand-filled vertical flow beds (Troesch and Esser, 2012). The system is capable of high levels of nitrification, is able to accept a relatively high hydraulic load, and also copes well with seasonal load variations. However, this standard design requires approximately 3 – 5 m^2/PE. Other challenges have been encountered as well, such as availability of a suitable sand substrate for the second stage beds. As a result, the standard French design is not always economically competitive. Recent work at Epur Nature (France) has investigated ways to decrease system footprint and improve ammonia removal at the same time. This has been achieved through the development of a single-stage recirculating wetland. Recirculation has proven to increase nitrification up to a recirculation rate of 100%. A decrease in nitrification was observed for recirculation rates higher than 100%.

A second design that has both unsaturated and saturated zones in one stage has also been developed in France (Figure 1). This approach includes a deeper bed depth, in order to "stack" the unsaturated zone (100 cm) on top of the saturated zone (40 – 60 cm deep). At the interface between the unsaturated and saturated zone are aeration pipes that facilitate transfer of oxygen to the subsurface. This "stacked" French design has shown high removal efficiencies for COD, BOD_5, and TKN. which makes it able to guarantee an outlet limit of 70 / 15 / 15 /25 mg/l of COD / BOD_5 / SS / KN respectively and reduces the global footprint.

A third design that has been developed by Epur Nature (France) consists of a first stage wetland followed by a trickling filter and settling zone. This combination of technologies has also resulted in high levels of treatment performance and reduced costs compared to the standard French design. Table 1 summarizes area requirements, costs, and outlet TKN concentrations for the standard French system compared to the "stacked" design and wetland-trickling filter combination design.

Investigations into phosphorus removal have also been conducted in France, specifically, the use of alternate media, such as apatite or slag. The use of a phosphorus-sorbing media offers an alternative to the classical approach, which involves the use of chemicals (FeCl), dosing and mixing devices, and sludge management.

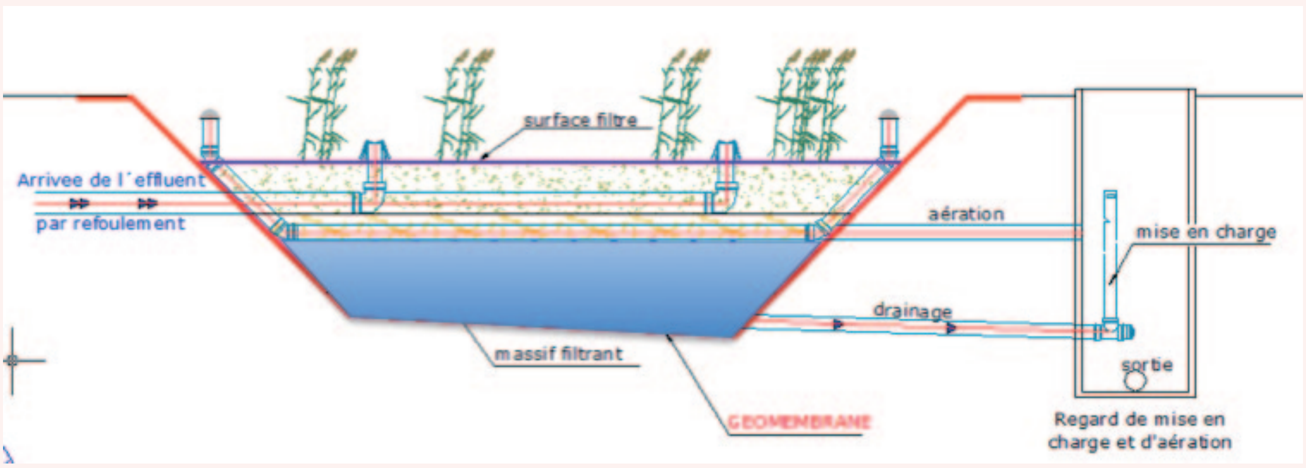

Figure 1: Modified French wetland design with unsaturated and saturated zones (Epur Nature).

Table 1: Area requirements, costs and expected effluent concentrations for various French treatment wetland designs. Data for a 1000 PE capacity (1 PE= 150L/PE.d and 120 g COD/PE.d).

	Standard Design	Stacked Design	Wetland + Trickling Filter	Recirculating Design
Global Footprint (m^2/PE)	4 – 5	1.5 – 2	1.5 – 2.5	1.5 – 2.5
Investment Cost (€/PE)	450 – 550	350 – 380	370 – 400	300 – 350
Operating Cost (€/PE.year)	6 – 9	6.5	6.5	6
Energy Cost (€/PE.year)	0 – 0.3	0.3	0.5	0.3
TKN Effluent Concentration (mg/L)	10 – 20 (or less)	25	15	25
TN Effluent Concentration (mg/L)	-	50	-	-

United Kingdom

In the UK, one of the main drivers behind the development and implementation of intensified wetland systems is the increasingly strict discharge consents. Many community wastewater treatment systems (less than 10,000 PE) in the UK must meet an effluent ammonium-nitrogen concentration of less than 5 mg/L. In the next AMP phase (2015 – 2020), the number of additional treatment systems that will be subject to this limit will increase by nearly 30% (Pearce, 2012; Koodie et al, 2012). Many existing treatment works will struggle to meet these tighter consents. Population growth, increasing land costs, and the need to enhance existing assets have put a demand on the water industry to find appropriate effective solutions. Aerated wetland systems have been identified as a viable solution for both community wastewater treatment systems owned by the Water Companies, and privately owned wastewater treatment works in the UK, both as a retro-fit solution as well as new build systems. Aerated systems are deeper than conventional passive subsurface flow systems and therefore have a smaller footprint making them suitable for sites where the available land space is at a premium.

ARM Ltd has installed 32 systems in the UK over the last 3 years which vary in size from 10 m^2 to 2.1 ha. 53% of these have been retrofitted into existing constructed wetlands, thereby improving the treatment capability of the site whilst making use of the existing infrastructure. 87% of aerated systems were designed for sewage treatment which include secondary and tertiary treatment as final polishing to achieve < 5 mg/L of ammonia and one to treat effluent from a CSO. The systems designed to treat industrial effluents include a new build system to treat brewery effluent and a retrofit system to treat run off from airport winter deicing activities which have high levels of BOD, and ammonia and sulphide removal from landfill leachates (Figure 2).

Retrofitting aeration into an existing wetland can be implemented during a refurbishment. Gravel is removed from the bed and the airlines installed at the base of the bed before the gravel is replaced. On some sites such as the wetland at Mayfield Farm, the airlines can also be ploughed directly into the gravel (Figure 3). Figure 3 also shows photos from Hounslow, UK, where an aeration system is being retrofit into an existing treatment wetland.

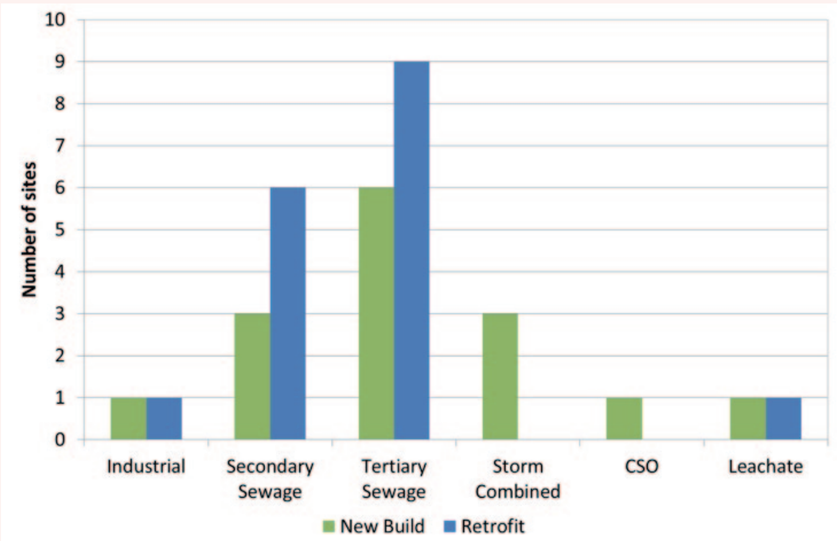

Figure 2. Number of aerated systems and associated effluent type installed in the UK (as of September 2013)

Figure 3: Retrofit of an aeration system into an existing treatment wetland at Mayfield Farm, UK.

ARM Ltd.'s pilot system at Rugeley, UK and the full scale system at Wolseley Bridge have been monitored for the past 3 years and provide first insights into how quickly aerated wetlands achieve high levels of nitrification from the date of commission (start-up) (Figure 4). Results from their investigation indicate that nitrification is reached at approximately 4 weeks for a summer start-up and 6 weeks for a winter start. Water temperatures for the Period of Record (POR) for Wolseley was 17.6 – 21.6˚C and for Rugeley 5.4 – 12.7˚C. Further studies on this pilot system aim to optimise aeration in order to increase TN removal capabilities and to characterize how aerated systems respond if the air pump is turned off; and how quickly the system recovers when the air supply is restored.

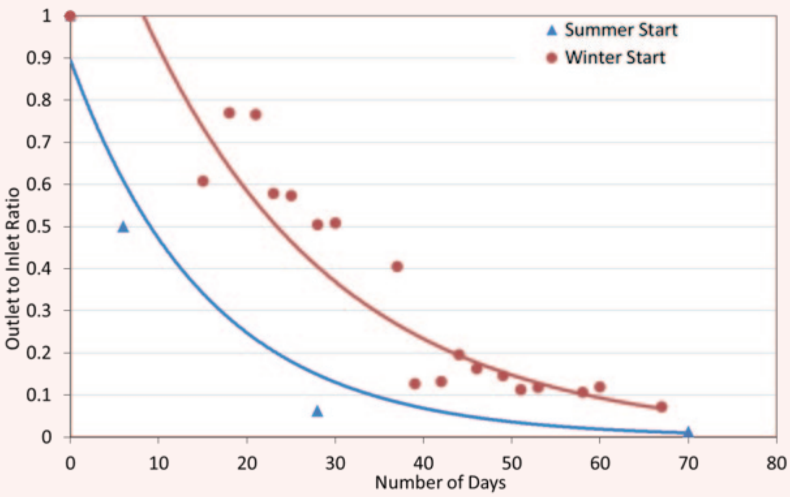

Figure 4: Outlet to inlet ammonium concentration ratios during the start-up phase for two aerated wetland systems in the UK (ARM, Ltd).

Germany

Located approximately 50 km northeast of Leipzig, Germany, the UFZ Ecotechnology Research Facility at Langenreichenbach contains traditional and innovative treatment wetland designs in order to compare the relative merits of various systems in terms of treatment performance and nutrient cycling, the role of plants, water use efficiency, and energy efficiency.

The research facility is unique in the fact that it is located adjacent to the wastewater treatment plant for the nearby villages, enabling all of the pilot-scale systems to receive the same domestic wastewater. The wastewater has no industrial inputs. Raw wastewater for the research site receives primary treatment in a large septic tank before being dosed to the wetland systems. Details of the 15 individual pilot-scale systems are given in Table 2.

Table 2: Details for the 15 pilot-scale treatment systems at Langenreichenbach, Germany (adapted from Nivala et al. 2013).

System Abbreviation[1]	System Type	Effective Depth (m)	Saturation Status	Main Media	Surface Area (m^2)	Inflow (L/d)
Horizontal Flow						
H25, H25p	HF	0.25	Saturated	8 – 16 mm gravel	5.6	100
H50, H50p	HF	0.50	Saturated	8 – 16 mm gravel	5.6	200
Vertical Flow						
VS1, VS1p	VF	0.85	Unsaturated	1 – 3 mm sand	6.2	600
VS2, VS2p	VF	0.85	Unsaturated	1 – 3 mm sand	6.2	600
VG, VGp	VF	0.85	Unsaturated	4 – 8 mm gravel	6.2	590
Intensified						
VA, VAp	VF + Aeration	0.85	Saturated	8 – 16 mm gravel	6.2	590
HA, HAp	VF + Aeration	1.00	Saturated	8 – 16 mm gravel	5.6	730
R	Reciprocating	0.85	Alternating	8 – 16 mm gravel	13.2	1770

[1]Systems planted with P. australis are denoted with "p" in the system abbreviation; other systems are unplanted.

First results from Langenreichenbach provide insight into the treatment performance of the 15 individual treatment systems. Results for common wastewater parameters ($CBOD_5$, TSS, TOC, TN, NH_4-N, NOx-N) are summarized in Nivala et al. (2013) and E. coli results are provided in Headley et al. (Headley et al. 2013). Of particular interest is the observed E. coli removal in the horizontal flow beds with aeration (HA), which showed upwards of 4.5 log10 unit E. coli removal at a hydraulic retention time of 2.9 days (Figure 6).

Current research at the research facility in Langenreichenbach is now focused on assessing and optimizing the energy efficiency of the various designs, and aiming to further improve removal of priority contaminants such as total nitrogen and E. coli. Additional research into the microbiological community function and structure in standard and intensified treatment wetlands is currently underway.

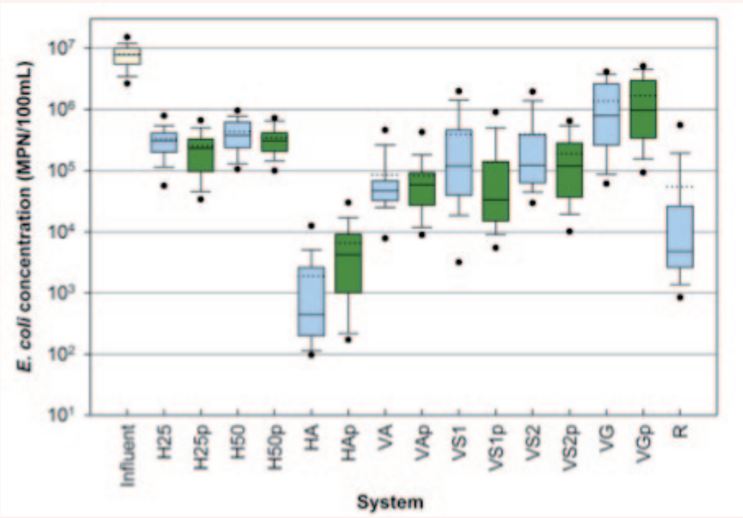

Figure 6: Box and whisker plot showing effluent E. coli concentrations from each treatment system (Headley et al. 2013).

Summary of the discussion

Main topics discussed and questions raised include:

- How do intensified / modified systems compare to other conventional wastewater treatment technologies (cost, footprint, etc.)?
- How efficiently are emerging pollutants and organic compounds removed in intensified/ modified wetlands (compared to standard designs)?
- To what extent to alternate nitrogen pathways (e.g. Anammox) play a role in nitrogen removal in intensified / modified treatment wetland sytsems?
- Denitrification in aerated wetland systems
  - Can increased denitrification be achieved through different aeration techniques and/or different orientation of the air distribution lines in the bed?
  - Can recirculation in aerated systems improve TN removal?
  - What can be done in the case of stoichiometric carbon limitation?
- Longevity of aerated wetland systems
  - How is sludge handled over the long term?
  - Does aerating a wetland bed help maintain hydraulic conductivity?

- What mechanism is responsible for high levels of E. coli removal in the horiziontal flow aerated wetlands at Langenreichenbach?
  - It is suspected that microbial predation plays a key role (Headley et al. 2013), but further research on this topic is only in the beginning stages.
- Bacterial shifts in aerated wetlands
  - How does a system react if the aeration is turned off?
  - How long does it take for the system to recover?

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