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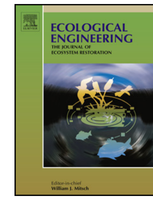

Modelling constructed wetlands: Scopes and aims – a comparative review

Daniel Meyer [a,b,e,f,*], Florent Chazarenc [b], Dominique Claveau-Mallet [c], Ulrich Dittmer [d], Nicolas Forquet [a], Pascal Molle [a], Ania Morvannou [a,e], Tamás Pálfy [a,e,f], Alain Petitjean [a], Anacleto Rizzo [g], Roger Samsó Campà [a,h], Miklas Scholz [i], Audrey Soric [j], Günter Langergraber [f]

[a] IRSTEA, Freshwater Systems, Ecology and Pollution Research Unit, 5 rue de la Doua, CS70077, F-69626 Villeurbanne Cedex, France
[b] L'UNAM Université, Ecole des Mines de Nantes, CNRS, GEPEA UMR 6144, 4, rue Alfred Kastler. B.P. 20722 F-44307 Nantes, France
[c] Polytechnique Montreal, Department of Civil, Geological and Mining Engineering, H3C 3A7 Montreal, Quebec, Canada
[d] ISWA, Institute for Sanitary Engineering, Water Quality and Solid Waste Management, University of Stuttgart, Bandtaele 2, D-70569 Stuttgart, Germany
[e] Epur Nature SAS, ZAC des Balarucs, 153 Avenue Mare'chal Leclerc, F-84510 Caumont sur Durance, France
[f] Institute for Sanitary Engineering and Water Pollution Control, University of Natural Resources and Life Sciences, Vienna (BOKU), Muthgasse 18, A-1190 Vienna, Austria
[g] Department of Environment, Land and Infrastructure Engineering (DIATI), Politecnico di Torino, Corso Duca degli Abruzzi, 24-10129 Turin, Italy
[h] GEMMA – Group of Environmental Engineering and Microbiology, Department of Hydraulic, Maritime and Environmental Engineering, Universitat Politècnica de Catalunya-BarcelonaTech, c/Jordi Girona, 1–3, Building D1, E-08034 Barcelona, Spain
[i] Civil Engineering Research Group, The University of Salford, School of Computing, Science and Engineering, Newton Building, Salford, Greater Manchester M5 4WT, UK
[j] Aix-Marseille University, CNRS, Centrale Marseille, M2P2 UMR 7340, F-13451 Aix en Provence, France

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ABSTRACT

During the last two decades a couple of models were developed for constructed wetlands with differing purposes. Meanwhile the usage of this kind of tool is generally accepted, but the misuse of the models still confirms the skepticism. Generally some groups of models can be distinguished: on one hand mechanistic models try to display the complex and diffuse interaction of occurring processes, on the other hand the same kind of models are used to investigate single processes. New kinds of 'simplified' approaches – well appreciated by engineers – try to display system performances without going to deep into details. All types of models are valuable – some more for scientific usage, others more for engineering. The given summary tries to support potential users in taking the right choice in model selection. Big differences can be found in the model availabilities. Whereas some of the compared software packages are purchasable without limitation, some others are only accessible on their platform level, and some can be seen as exclusive property. From the experience of the authors it can be summarized, that research groups starting modelling/simulation studies should be encouraged to use the given knowledge before starting from scratch again.

1. Introduction

Over the last two decades, an abundant literature has been published to present the modelling efforts performed to simulate the main bio–geo–chemical processes occurring in constructed wetlands (CWs). CWs can be built according to numerous designs – mostly linked to the flow, which can be saturated/unsaturated, vertical/horizontal, surface/subsurface, and all the possible combinations (See the latest nomenclature in Fonder and Headley, 2013).

In CW systems, pollutants are treated by a combination of physical, chemical and biological processes. The biological removal

* Corresponding author. Tel.: +49 170 52 777 03.
E-mail addresses: daniel.meyer@irstea.fr (D. Meyer), lorent.chazarenc@emn.fr (F. Chazarenc), dominique.claveau-mallet@polymtl.ca (D. Claveau-Mallet), ullrich.dittmer@iswa.uni-stuttgart.de (U. Dittmer), nicolas.forquet@irstea.fr (N. Forquet), pascal.molle@irstea.fr (P. Molle), ania.morvannou@epurnature.fr (A. Morvannou), tamas-gabor.palfy@irstea.fr (T. Pálfy), alain.petitjean@irstea.fr (A. Petitjean), anacleto.rizzo@polito.it (A. Rizzo), roger.samso-campa@upc.edu (R. Samsó Campà), m.scholz@salford.ac.uk (M. Scholz), audrey.soric@centrale.marseille.fr (A. Soric), guenter.langergraber@boku.ac.at (G. Langergraber).

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of each category of pollutant is typically associated with a specific microbial functional group. Pioneering modelling research works have employed circumstantial evidence (black box approach) to compute these basic assumptions into models mostly for domestic wastewater. Then mechanistic models have been developed trying to consider the hydrodynamic and the biodegradation processes occurring in CW systems at the same time for a larger range of sources of wastewater (industrial, diffuse, surface runoffs . . .)

The need for CW models can be summarized as follow:

- Describing the phenomena ongoing in a CW system (e.g., water flow, adsorption, O_2 transfer).
- Using models as a tool to compare 2 similar systems and their behavior under different conditions (e.g., effect of loading characteristics, effect of plant species, effect of season, etc.).
- Predicting the performances of a given system (e.g., developing design recommendations).
- Answering "what if?" questions (e.g., over or under loads, etc.).
- Performing system control (especially in case of system intensification like the use of artificial aeration, recycling etc.).

In this context an increasing number of publications dealing with CW modelling has been observed over the last 3 years (2011–2013) as it represents more than 38% of the number of papers ever published containing the words "constructed/treatment wetland" and "model/modelling" in the title (Science Direct research engine).

Among the most cited review papers, most of the most common modelling approaches of CWs treating domestic wastewater, including biokinetic models and process models, have been reported in Rousseau et al., 2004; Marsili-Libelli and Checchi, (2005); Langergraber (2008); Langergraber et al. (2009) and more recently Kumar and Zhao (2011).

Although the previous review efforts were performed to establish a non-exhaustive list of all the modelling approaches successfully developed (including their main results), this review paper aims at describing a sort of guideline to help users to choose the most appropriated modelling approach adapted to their needs at different levels: the level of knowledge of the process considered, the complexity associated to the model and its spatial resolution, and the resources necessary to the usage of the reviewed models.

In 2013, in the frame of the 5th International Symposium on Wetland Pollutant Dynamics and Control, WETPOL 2013, a wide range of recent simulation and modelling studies were presented. Most of the concepts initially applied to CWs for pre-treated domestic wastewater have been developed, adapted and applied to more and more case studies including for (raw) domestic wastewater, combined sewer overflows (CSOs) and intensified CWs. All publications from the WETPOL conference dealing with modelling and simulation were selected for this review, and all main authors contributed to this paper.

The concepts selected in this paper mostly deal with three main approaches that can be ranked as follows:

a Biokinetic models: the most advanced models using saturated water flow are those developed by Rousseau (2005) and Langergraber et al. (2009), both considering bio-kinetic models that are based on the IWA Activated Sludge Models (ASMs) (Henze et al., 2000). For modelling vertical flow CWs with intermittent loading, transient variably-saturated flow models are required. These systems are highly dynamic, adding requirements to the complexity of the overall system. The most advanced reaction models are implemented in the Wetland Module of the HYDRUS software package (Langergraber and Šimůnek, 2005), based again on the mathematical formulation of the ASMs (Henze et al., 2000).

b Process dedicated models, which rely on simple kinetics employed to model a single process related to the degradation/transfer of one compound or one family of compound (e.g., COD, NTK, O_2 etc.).

c Design support models such as GPS-X, enabling to model the system according to an initial Residence Time Distribution analysis; or RSF_Sim for the specific context of combined sewer overflow treatment.

Table 1
Reviewed modelling and simulation studies overview.

Contributing modelling/simulation study	Model used	Water flow	Biochemical processes		Additional processes	Dimension
			Species considered	Reactions		
Pálfy and Langergraber, 2013	HYDRUS/CW2D	Saturated and unsaturated (Richards eq.)	12, incl. forms of COD, N and P	9		2D
Morvannou et al., 2014	HYDRUS/CW2D	Saturated and unsaturated (Richards eq.)	12, incl. forms of COD, N and P	9	Ammonium adsorption	2D
Pálfy and Langergraber, 2014	HYDRUS/CWM1	Saturated and unsaturated (Richards eq.)	16, incl. forms of COD, N and S	17	Heat transfer and root effects	2D
Rizzo et al., 2014	HYDRUS/CWM1	Saturated and unsaturated (Richards eq.)	16, incl. forms of COD, N and S	17	Ammonium adsorption	2D
Samsó and García, 2013a,b; Samsó and García, 2013a,b	BIO_PORE (COMSOL Multiphysics™)	Saturated (Darcy + adapting water table level)	18, incl. forms of COD, N and S	17	Root effects	2D
Petitjean et al., 2012 Forquet et al., 2009a,b	Diph_M (MATLAB)	Unsaturated (two-phase flow)	forms of COD, NH4-N, oxygen	5		1D
Morvannou et al., 2013	Dual-porosity model (DPM) in HYDRUS-1D	Saturated, unsaturated and preferential (Richards eq. + dual porosity)	0	0	Non-reactive tracer transport	1D
Claveau-Mallet et al., 2012, 2014	PHREEQC P-hydroslag	Saturated	post treatment, no biochemical model	0	4 inorganic reactions	1D
Sani et al., 2013	Wang-Scholz-Model (COMSOL)	Vertical-flow wetlands with uniform water flow	no biochemical model	0	Clogging processes (particle setting)	1D
Zeng et al., 2013a,b	RTD/GPS-X	Tanks in series with recycle and dead volumes under variable water content	12, incl. forms of COD, N (only soluble)	11	Interaction with biofilm growth	2D
Meyer and Dittmer, 2015	RSF_Sim	Tanks in series with variable water content	no biochemical model	0	transport, filtration, adsorption, degradation	1D, 1.5D in future?