



# New integrated utilisation of simulation and control software for an inexpensive and effective management of wastewater treatment plants

**LIFE98 ENV/L/000582 :**

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(prolongation of one year)  
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## \_ Introduction

An activated sludge wastewater treatment plant in Northern Luxembourg has been modernised by means of a detailed analysis of the treatment processes using modelling techniques and by the implementation of a model-based real time control. New strategies for a more efficient and economic management of the wastewater treatment plants (WWTP), as the one tested within the framework of the present project, are needed due to more stringent effluent criteria, imposed by the European legislation, and raising treatment costs.



## \_ Environmental problem

The project is related to the priorities set by the European Council directive 91/271/EEC, concerning urban wastewater treatment and the directive 2000/60/EC of the European parliament and the Council establishing a framework for Community action in the field of water. As observed for many biological WWTPs throughout Europe, the pilot plant's hydraulic capacity is exceeded and the wastewater treatment is not efficient, due to a lack of performance of the equipment and the processes. As a result the WWTPs effluents do not comply with *the strict emission limits* imposed by the European legislation. The negative impact of wastewater treatment is, however, not only limited to bad effluent quality, but is amplified by an *excessive consumption of energy and chemicals*.

From an economic point of view an optimisation of the treatment processes by reducing the consumption of natural resources leads to lower *treatment costs*. Furthermore, a better use of the existing treatment capacities at the WWTP allows to make the investments that are necessary to increase the overall quality of the water bodies in a more pertinent and efficient way.



## \_ Project objectifs

The lack of performance of a large number of existing WWTPs is due on one hand to infrastructure and equipment not allowing for the implementation of modern and effective treatment processes, and on the other hand to inefficient management rules and a lack of control of the processes. The management of the plants is often based on empirical and static rules that do not take into account the complexity and the dynamics of the biological treatment.

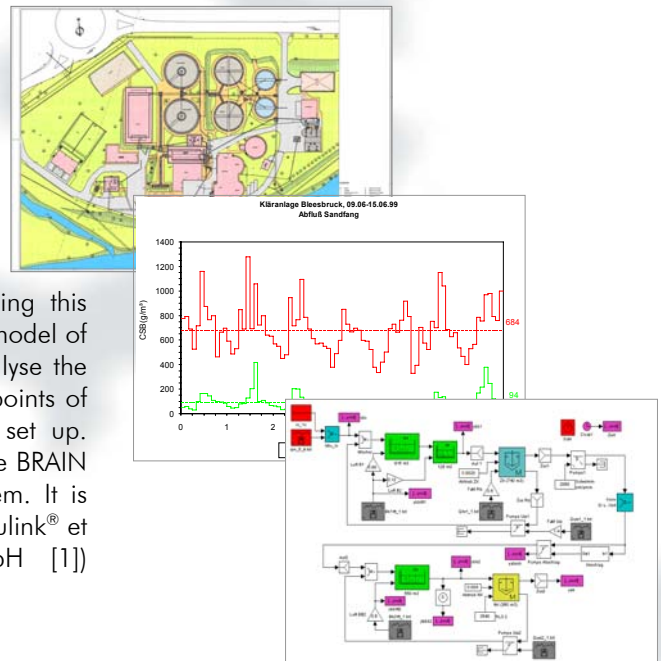


The project aims at demonstrating the validity of a real time management approach of WWTPs by the integrated use of simulation software, regulation and control equipment and on-line analytical sensors. The core of the system is a mathematical model of the STEP that has been used previously to analyse in detail the treatment facilities and to identify weak points of the processes. The informatics tools allow to increase the yield of the WWTP while reducing operating costs. Modification and upgrading scenarios can be developed and tested in a rational way via mathematical calculations.

## Technical aspects

The methodology for the optimised management of the wastewater treatment consists of an integrated use of simulation software, describing the biology of the processes, regulation and control equipment and on-line analytical sensors. It has been implemented in 3 steps :

1. Complete and updated overview of all processes, infrastructures, and existing control and regulation equipment. Characterisation of the efficiency of the treatment processes by means of analytical measurement campaigns. Using this information, a mathematical model of the WWTP that allows to analyse the processes and identify weak points of the wastewater treatment, is set up. The mathematical model is the BRAIN of the real time control system. It is implemented in a Matlab/Simulink® et SIMBA® (ifak system GmbH [1]) environment.



2. Installation of analytical on-line sensors and modernisation of the technical equipment of the WWTP to allow a real time control of the processes. With the analytical on-line sensor for nutrients (COD – Chemical Oxygen Demand,  $\text{NH}_4$ ,  $\text{NO}_3$ ,  $\text{PO}_4$ ) a continuous monitoring of the biological treatment is possible. The sensors are the EYES of the system that must provide at any moment a correct view of the WWTP and its processes. Rigorous maintenance procedures, laboratory control measurements and advanced mathematical tools have been implemented to monitor de good functioning of the sensors and to supply substitution values in case of erroneous experimental data.

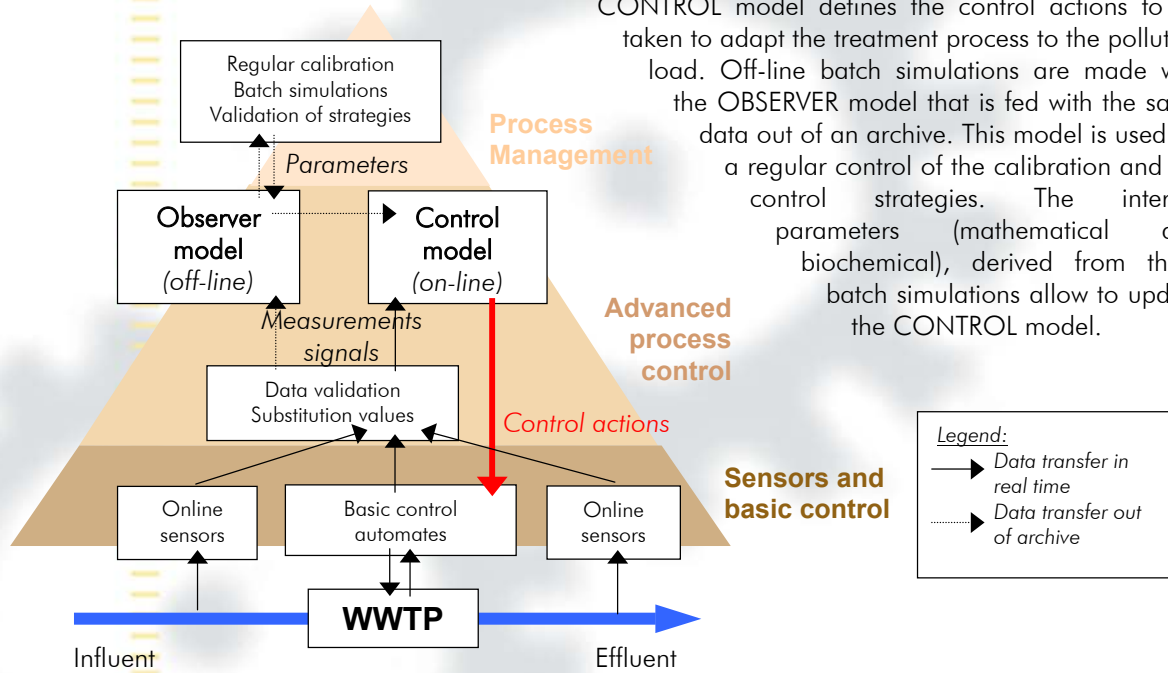
3. Interface between the simulation software and the control and regulation software of the WWTP. This step allows the integration of the online simulation into the daily management of the STEP, leading to a better efficiency of the treatment processes. The scheme below shows the control concept, based on online simulations as it has been developed in the present project (adapted from ifak [1]). Included in the scheme is the representation of the control hierarchy of the wastewater treatment processes, as defined by Olsson et Newell [2], to show the hierarchical levels at which the control actions take place as well as the time scale at which the decisions



are taken. The time scale varies from seconds to minutes for the first layer of sensors and basic control, from minutes to hours for the advanced process control and from days to weeks for the process management.

The online control, realised at Bleebruck is shown in the scheme below. The analytical online sensors measure the composition of the water at various levels of the treatment process. The measures as well as all control actions of the automates at the basic control level are saved in the central database of the control and regulation system. This information is transferred from the database to the simulation system. After an automatic validation of the data and a substitution in case of erroneous values, the information is

passed on to the mathematical CONTROL model. The CONTROL model defines the control actions to be taken to adapt the treatment process to the pollutant load. Off-line batch simulations are made with the OBSERVER model that is fed with the same data out of an archive. This model is used for a regular control of the calibration and the control strategies. The internal parameters (mathematical and biochemical), derived from these batch simulations allow to update the CONTROL model.



## Environmental impacts

The LIFE project has led to a global reduction of the environmental impacts of wastewater treatment at Bleebruck. The project's achievements contribute at three levels to this reduction:

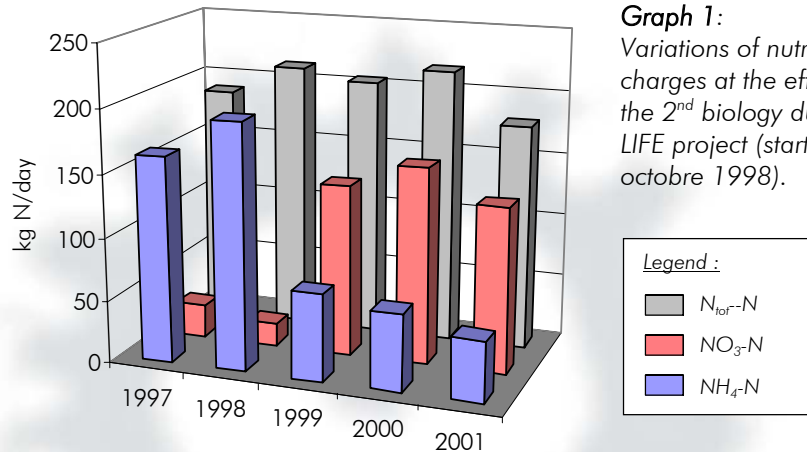
1. Improvements mainly due to the modifications realised after the detailed analysis of the processes (the results are quantified in table 1):
  - ⇒ Reduction of the discharge of non-treated water at the inlet of the WWTP, following the increase in hydraulic capacity of the grit chamber.
  - ⇒ Reduction of the remaining pollution released with the treated wastewater into the receiving water body due to a better treatment and optimised processes in the 2 biological treatment units. (proper functioning of the 1<sup>st</sup> biology with elimination of COD, nitrification in the 2<sup>nd</sup> biology).

**Table 1 :** General improvement of wastewater treatment at Bleebruck during the time period of the LIFE project

	1998	2001
Hydraulic load at the inlet of the WWTP	9'900 m <sup>3</sup> /day	17'500 m <sup>3</sup> /day
Elimination of the organic load (COD)	77 %	95 %
Elimination of the total nitrogen load (N <sub>tot</sub> )	28 %	30%



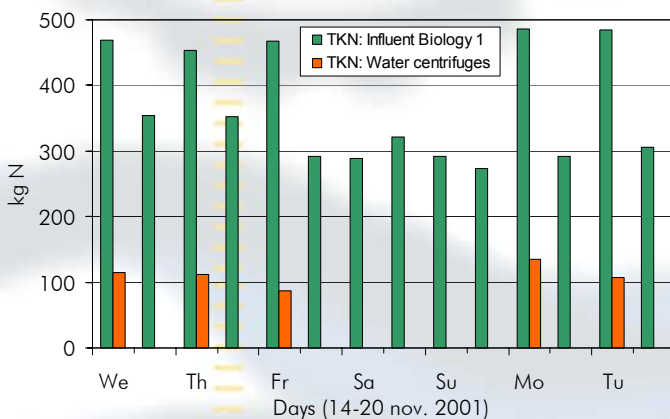
A further reduction of the nitrogen load will only be possible by putting in place a tertiary treatment of nutrients (denitrification). The infrastructure modifications necessary for such a treatment were out of scope for this project. Graph 1 illustrates, however, the net improvement of nitrification during the project.



**Graph 1:**  
Variations of nutrient charges at the effluent of the 2<sup>nd</sup> biology during the LIFE project (start in octobre 1998).

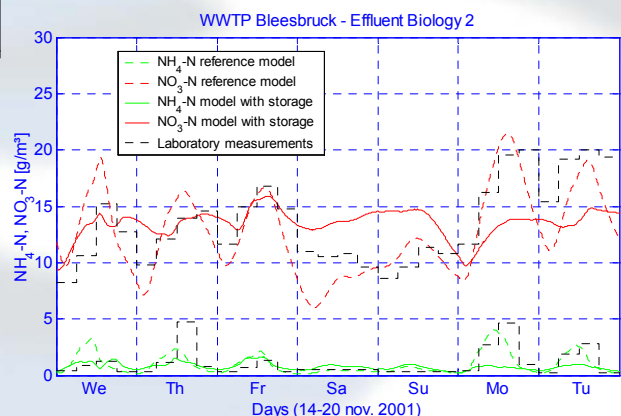
2. Results of the advanced analysis of the treatment processes using the simulation model. The model is a very useful tool to quantify the impact of scenarios for a modernisation or upgrading of the processes. The simulations contribute in a substantial manner to the validation of the following modernisation schemes:

- ⇒ The mathematical model allows to analyse the efficiency of the aeration system and more specifically of the installed air diffusers. Simulations show that energy savings of 40 to 45 % are possible by modernising the aeration system in the biological reactors.
- ⇒ Better management of the internal fluxes. Chemical analyses have shown that process water from the sludge centrifuges that is injected at the influent of the 1<sup>st</sup> biology during daytime carries a considerable nitrogen load (graph 2) and leads to ammonium peaks at the effluent of the 2<sup>nd</sup> biology (graph 3). Simulations show, how storage of the process water and an addition during low load situations (night & weekend) allows to eliminate these peaks.



**Graph 2:**  
Loads of Kjeldhal nitrogen (TKN), shown as 12 hour fractions at the influent of the 1<sup>st</sup> biology, compared to the loads in the process water from sludge treatment

**Graph 3:**  
Simulations showing the reduction of the ammonium peaks at the effluent of the WWTP by an equalisation of the loads at the influent (storage and addition of process water during low load periods)





3. *Improvements due to the installation of the online control tools (advanced model based control and control based on online nutrient sensors). These measures contribute to the reduction of the overall impact on the environment of wastewater treatment at Blesbruck.*

- ⇒ Control of the aeration in the 2<sup>nd</sup> biology, based on online simulations. The concept used for this control adapts the nitrification capacity to the ammonium loads in the influent by variation of the oxygen concentration in the biological reactors (concept adapted from Krause et al. [3]). Reduction in energy consumption of 20 to 30% are expected at the long range as compared to a traditional control of the aeration by fixed setpoints for the oxygen concentration.
- ⇒ Reduction of the consumption of chemicals used for the chemical precipitation of phosphorous in the 1<sup>st</sup> biology due to a control based on the analytical online sensor. The quantity of precipitation agent used (alumine) has been reduced by 50% after the implementation of the control, which corresponds to savings of 60 to of product per year.

## \_ Cost-benefit analysis

The costs for the implementation of the model-based online simulation at Blesbruck are estimated for a "standard" WWTP (modern infrastructures, sufficient control and automation equipment), based on the experiences of the project (table 2). Costs for support and maintenance as well as benefits are calculated over a 10 years period.

**Table 2 :** *Cost-benefit analysis for a 10 years period*

Budget	Costs (€)	Benefits (€)
Equipment (analytical online sensors, container, hardware/software for simulation)	320'000	
Services (measurement campaigns, calibration of the model, setting up of the system, civil engineering and electrical installations)	190'000	
Maintenance of the system (control of sensors, maintenance of the mathematical model)	300'000 € / 10 years	
Economy of energy (aeration) and of chemicals (precipitation of phosphorous)		130'000 € / 10 years
Economies expected from implementation of other project results (modernisation of aeration, without investment costs)		300'000 € / 10 years

These figures show that the actual system is not viable from a pure economic point of view for the WWTP Blesbruck. A favourable cost-benefit ratio over a period of 10 years and based on the figures in table 2 could be realised for a WWTP two or three times bigger than WWTP Blesbruck.

It is, however, important to notice that the calculations are made without putting into figures the *environmental benefits achieved* (reduction of emissions). With an environmental tax system, imposing financial penalties if the required emission limits are not respected by the WWTP or imposing taxes on the emitted pollutant loads, thereby inciting the plant managers to reduce the emissions, the project could be profitable in its present shape. Such tax systems are in place in various countries of the EC but do not exist in Luxembourg.

One can also argue that the LIFE project has led to the creation of additional treatment capacities of 8'000 m<sup>3</sup> wastewater per day in Blesbruck (table 1). The costs of the LIFE project can therefore be related to the investment costs necessary for the construction of treatment infrastructure with an equivalent capacity (~37'000 population equivalents). These investments are estimated to approximately 11.1 Mio € based on usual



calculation rules applied in Luxembourg and exceed thus by far the costs of the LIFE project.



The methodology of model-based online simulation implemented at Blesbruck can be applied to modernise other WWTP's, with the following restrictions:

## \_ Application of the results

- The economic feasibility depends largely on the size of the WWTP, the state of infrastructures and the technical equipment of the WWTP. An implementation of an advanced control system only makes sense, if the basic controls of the WWTP are efficient and flexible and if the capacity of the treatment processes is not already at its limits (sufficient control authority).
- The realisation of a detailed analysis of the infrastructure and the processes and an off-line modelling of the WWTP can already yield very useful information about the performance of the WWTP. Minor modifications then allow to increase the efficiency of the treatment processes significantly. Better treatment results can also be obtained with simple and robust controls that makes use of analytical online sensors for nutrients (e.g. control of chemical phosphorous precipitation). These measures are usually profitable on a short timescale due to savings in energy and chemicals.
- One has to be aware that the implementation and maintenance of such a system requires specific skills and knowledge in the fields of modelling and process control. A rigorous follow-up of the analytical online sensors by a laboratory is necessary. The higher maintenance costs are, however, compensated by savings for the wastewater treatment.

At a national level the LIFE project had a positive impact on applied research activities in the field of wastewater treatment. A number of follow-up projects aim at applying the methodology in similar fields (see [www.fnr.lu](http://www.fnr.lu) for more information).

## \_ Project partners



The LIFE project has been realised within the framework of the following partnership:

- The "Syndicat Intercommunal de Dépollution des Eaux Résiduaire du Nord" (SIDEN), manager of the WWTP Blesbruck ([www.siden.lu](http://www.siden.lu))
- "Environnement, Fluide et Gaz S.A." (EFG), a firm specialised in measurement and regulation equipment for WWTP's ([www.elco.lu](http://www.elco.lu))
- Dahlem, Schroeder & Associés. (D&S), consulting engineers, specialised in wastewater treatment ([www.schroeder.lu](http://www.schroeder.lu))
- Public Research Centre Henri Tudor (CRPHT), with its structures "Centre de Ressources des Technologies pour l'Environnement" (CRPHT / CRTE) and "Laboratoire de Technologies Industrielles" (CRPHT / LTI), specialised in applied research for the implementation of innovative environmental technology, modelling and control of processes, data analysis and data processing. ([www.crte.lu](http://www.crte.lu), [www.lti.lu](http://www.lti.lu))

The consulting engineers OtterWasser have contributed in a substantial way with their experience in the field of modelling of wastewater treatment facilities. ([www.otterwasser.de](http://www.otterwasser.de)).

- [1] Ifak system GmbH (1999). SIMBA 3.4+– Simulation of Biological Wastewater Treatment, User Guide, Magdeburg-Barleben, D (see also [www.ifak-system.com](http://www.ifak-system.com)).
- [2] Olsson G. and Newell B. (1999) Wastewater Treatment Systems - Modelling, Diagnosis and Control. IWA Publishing, London, UK.
- [3] Krause K., Böcker K. and Londong J. (2001) Simulation of a nitrification control concept considering influent ammonium load. 1<sup>st</sup> IWA Conference on Instrumentation, Control and Automation. Malmö, Sweden. June 3-7, 2001. pp. 555-562.