



# Effects of Variable Feeds in Wastewater Plants by Means of Process Simulation

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## Abstract

Extreme weather conditions may cause heavy rain seasons or dry seasons which set new challenges to the wastewater plant operation. These challenges can be prepared for example by simulating the waste water treatment process (WWTP) at different inlet conditions. The feed stream flow rates may be exceeded up to the designed maximum values, and the compositions may vary a lot in extreme climate conditions. The goal of this study is to simplify the multivariate effect analysis of main weather specific variables. The WWTP operation is discussed from water quality viewpoint.

**Keywords:** Process simulation, steady-state, flooding, BOD, COD, extreme weather

## Introduction

The increase of rain in Finland is estimated with different scenarios of RCP 2.6 (Representative Concentration Pathways) and RCP8.0 to be 6-20 % within this century compared to year 2000 rain level (Ruosteenoja et al. 2016). According to Lehtonen (2011) the heavy rain can strengthen 10-25 % from current average rain level within this century. The extreme weather conditions have clear impacts in wastewater treatment plants operations, as WWTP design specifications are exceeded.

Typically, WWTP main units consist of screening, primary clarification, aeration secondary clarification and filtration (Leino 2016). ASM models (IWA, 2000) from the International Water Association for activated sludge processes (ASP), are nowadays extensively used by the scientific community to model dynamic biochemical reactions of ASP reactors (Jeppson, 1996; Roeleveld, P.J., van Loosdrecht, 2002). The models are very complex, and non-linear which makes the use and optimization time-consuming. Additionally several model parameters need to be defined in order to start simulations (Keskitalo et al. 2010). Model parameter establishment is also needed for the use of WWTP specific simulation software (GPS-XTM by Hydromantis). Also multivariate-statistical methods and artificial neural networks modeling techniques

have been studied in addition to white-box models (Gernaye 2004). In addition to activated sludge reactors the clarification section is also matter of modeling the WWTP essential parts (Hreiz et al, 2015).

In this study different feed conditions are simulated by solving steady-state mass balance equations using ASPEN+ (by Aspen-Tech) process simulation tool and simplistic models without cumbersome determination of process parameters for this study. The example is from Kakolanmäki WWTP Year report (Leino 2016) in South-West Finland where the data has been extracted for WWTP model. The minimum and maximum inlet temperature values, and WWTP specific maximum flow rate are used in simulations which were designed to correspond extreme weather conditions. The simulation results are used for describing process sensitivity and thus the process behavior is better understood at limiting conditions. The combined effects of feed stream parameters are studied to the the quality parameters describing process operation.

## Methods

The example wastewater treatment plant is activated sludge treatment with preliminary and secondary clarification, Fig 1. By-pass water circulation is included in the process with Actiflo® (Veolia 2018) purification



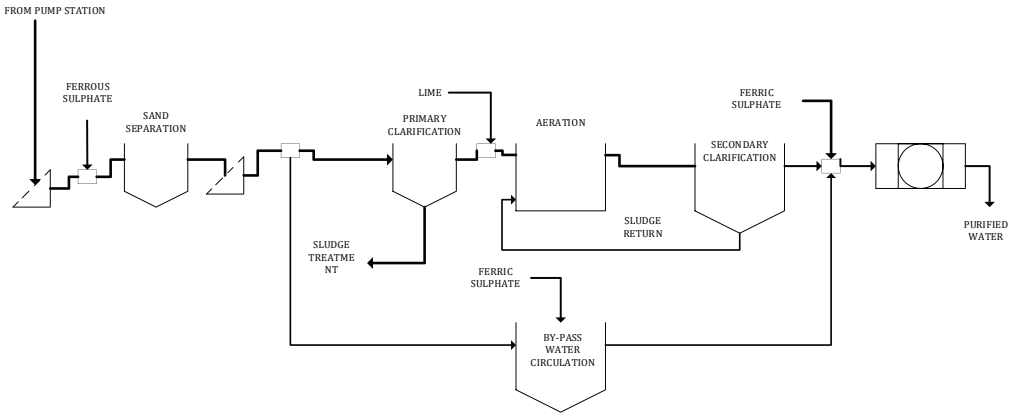


Figure 1 Wastewater treatment plant (Leino, 2016). By-pass water circulation is Actiflo® unit supplied from Veolia.

unit. It is used to equalize flow peaks to treat preclarified wastewater. Maximum allowed flowrate in WWTP is 275000 m<sup>3</sup>/d and 2016 average is 77000 m<sup>3</sup>/d whereas typical range is 74000-85000 m<sup>3</sup>/d. In this study the evaluation of seasonal changes is based on correlating data from Kakolanmäki wastewater treatment plant (Leino, 2016).

WWTP is obliged yearly to report to Finnish environmental authorities the main purified water quality parameters. Acceptable limits are COD<sub>Cr</sub> < 60 mg/L, BOD<sub>7ATU</sub> < 10 mg/L, and total phosphorus P<sub>tot</sub> < 0.3 mg/L, methods according to Leino (2016). In this study the main seasonal parameters affecting the water quality are inflow temperature and inlet flow rate. The report by Leino (2016) consists daily data of inflow and outflow water quality with flow rates and inlet temperature, seasonal variation in Table 1.

The purification efficiencies have been correlated to inlet flow rates and to inlet flow

temperatures according to 2016 Kakolanmäki WWTP data by excluding outliers, such as reported process malfunctions.

$$1 - \frac{P_{TOT,out}}{P_{TOT,in}} = 0.9449 \left( \frac{T}{F} \right)^{0.0136} \quad (1)$$

where  $F$  is inlet flow (m<sup>3</sup>/s),  $P_{TOT,in}$  and  $P_{TOT,out}$  are total phosphorus in feed and purified streams,  $T$  is inlet temperature (°C). R<sup>2</sup> fit is 0.83.

$$1 - \frac{COD_{out}}{COD_{in}} = 0.9561 - 1.9977F/T^2 \quad (2)$$

where  $COD_{in}$  and  $COD_{out}$  are Chemical oxygen demand using K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> method in feed and purified streams, R<sup>2</sup> fit is 0.82

$$1 - \frac{BOD_{out}}{BOD_{in}} = 0.9977 - 0.0001F^3T \quad (3)$$

where  $BOD_{in}$  and  $BOD_{out}$  are biological oxygen demand after 7 days using allyl thiourea method in feed and purified streams, R<sup>2</sup> fit is 0.98.

Table 1 Minimum and maximum water quality during 2016 with inflow and temperature data.

Parameter	Minimum	Maximum
COD <sub>Cr</sub> , mg/L (inflow)	290	1300
BOD <sub>7ATU</sub> (inflow)	120	610
P <sub>TOT</sub> (inflow)	3.4	20
COD <sub>Cr</sub> , mg/L (outflow)	20	54
BOD <sub>7ATU</sub> (outflow)	1.2	15
P <sub>TOT</sub> (outflow)	0.08	0.75
Temperature, °C	8.1	18.8
Inflow, m3/d	47200	247000



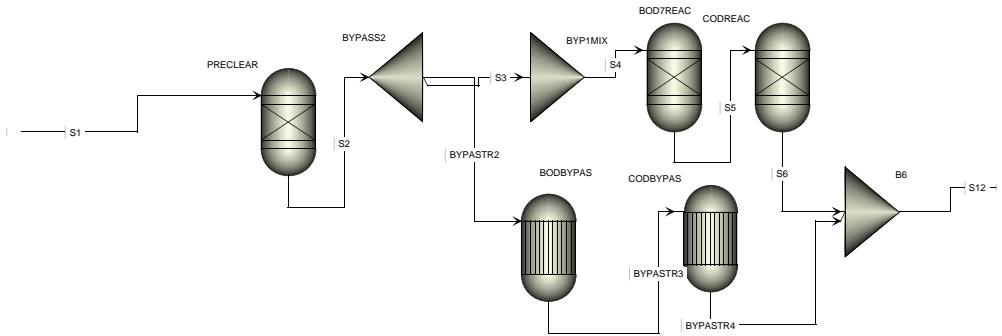


Figure 2 ASPEN+ flow diagram from wastewater treatment process.

The WWTP flow diagram used in ASPEN+ (v8.6) is presented in Figure 2. The preliminary clarification, aeration, Actiflo® (Veolia 2018) and secondary clarification have been simulated with RYIELD reactor models based on yields of remaining COD, BOD and total phosphorus values. These simplistic models have been selected to describe the complex wastewater treatment processes in the estimation of seasonal extreme conditions. Chemical dosings are assumed to be based on plant control systems and dosing system operation does not depend on external seasonal process parameters like temperature or inlet flow rates. Also solid separation, screening and sand separation are neglected in this process model. BODREAC and CODREAC are considered to model clarification

and aeration units, CODBYPASS and BOD-BYPASS model Actiflo® unit in bypass water circulation.

### Results

The simulation model can be adjusted to correspond correct actual outlet values by setting correct yield parameters for reactor units. The interesting part is the extreme conditions where correlation based yields are set in simulations. The WWTP year report did not include daily information about by-pass water treatment efficiencies. The Actiflo® unit purification efficiencies were simulated with ASPEN+ to match the reported overall efficiencies (Table 2), and the difference between efficiencies at main stream and by-pass stream is minimal.

Table 2 Simulated by-pass water treatment efficiencies, comparison to main stream efficiencies

Inlet, t/d	Bypass t/d	Temperature °C	COD (Inlet)	COD (outlet)	Efficiency in COD removal (main process)	Efficiency in COD removal (by-pass)
73700	3395	15.3	750	39	0.948	0.948
89500	7841	17.7	660	47	0.929	0.925
165000	65037	14	550	54	0.902	0.9015
247000	100804	8.2	300	36	0.875	0.88
Inlet, t/d	Bypass t/d	Temperature °C	BOD (Inlet)	BOD (outlet)	Efficiency in BOD removal (main process)	Efficiency in BOD removal (by-pass)
73700	3395	15.3	390	5.9	0.985	0.982
89500	7841	17.7	260	4.3	0.983	0.989
165000	65037	14	220	13	0.941	0.941
247000	100804	8.2	120	15	0.875	0.875



The first simulations were performed for maximum flow rate 275000 m<sup>3</sup>/d. In simulations the maximum allowed BOD, COD and total phosphorus (P<sub>tot</sub>) at outlet were set to estimate maximum loadings in inlet flow. The effect of temperature to BOD, COD and P<sub>tot</sub> is presented in Fig. 3. P<sub>tot</sub> yearly variation is 3.4-20 ppm, and maximum allowed amount is 6-8.5 ppm. Minimum COD was 290 ppm in 2016, which is exceeded at max. inflow even above 6.5 °C inflow temperatures. The calculated BOD and COD process efficiencies were 0.62-0.9 and 0.70-0.93 at 275000 m<sup>3</sup>/d, respectively. At average 77000 m<sup>3</sup>/d the BOD and COD efficiencies are 0.99-1.00 and 0.89-0.95. Minimum BOD was 120 ppm in 2016, which is not possible to achieve with 275000 m<sup>3</sup>/d inflow.

In the next set of simulations the effect of flow rate was estimated based on 15 °C temperature in inlet flow, Fig. 4. It can be found

that at 120 ppm BOD inlet values BOD limit 10 ppm will be exceeded above 230000 m<sup>3</sup>/d inflows.

### Conclusions

A wastewater treatment plant performance to seasonal effects has been studied, namely temperature and inflow loading. The actual plant data in this study has been used. The simulation set-up instead of complex reaction modeling was done using correlating the whole year daily data to determine purification efficiencies. The extreme seasonal changes at heavy rain seasons will be difficult to keep the BOD and COD quality within allowed limits while P<sub>tot</sub> quality is possible to satisfy the limits by authorities. Also, simulations revealed BOD quality as most sensitive to inlet flow variations. Interestingly, at high flow rate loadings the wastewater temperature has a clear effect in purification.results.

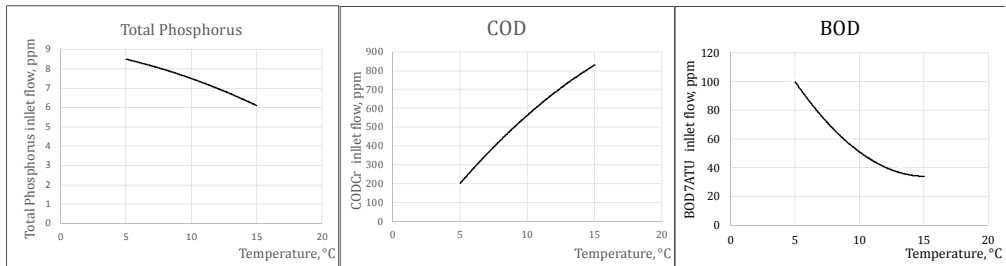


Figure 3 Effect of temperature to maximum phosphorus, COD and BOD loadings in inlet at 275000 m<sup>3</sup>/d.

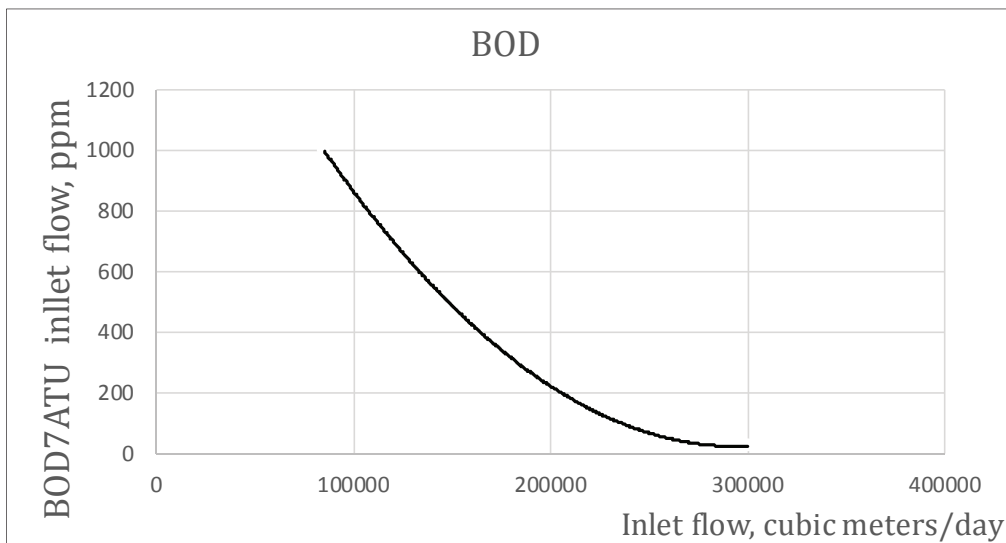


Figure 4 Effect of inlet flow to maximum BOD loading in inlet at 15 °C inlet flow temperature.



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