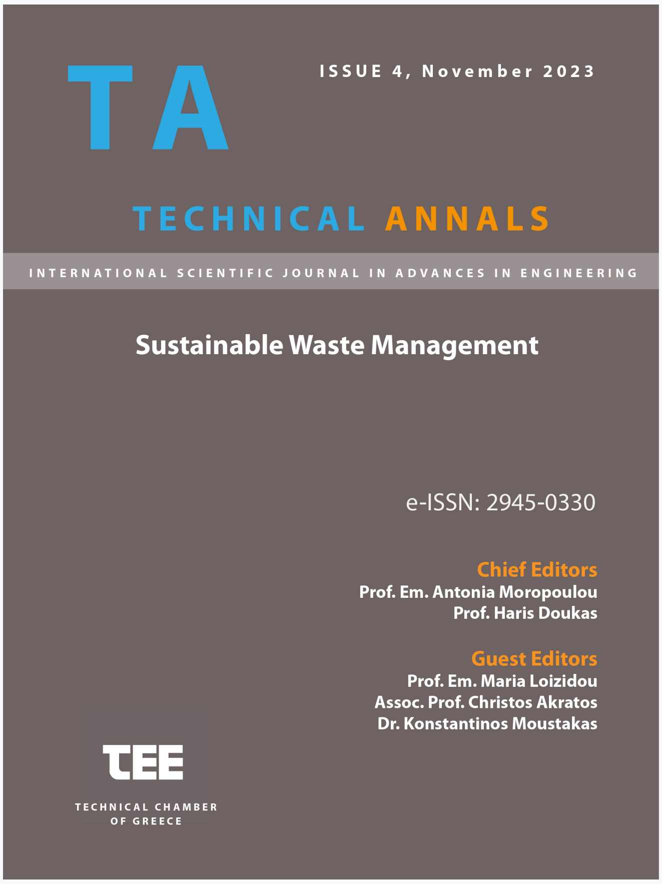
Technical Annals

Vol 1, No 4 (2023)

Technical Annals



Implementation of an activated sludge model to simulate Thriasio Wastewater Treatment Plant operation in West Attica, Greece

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doi: [10.12681/ta.37055](https://doi.org/10.12681/ta.37055)

Implementation of an activated sludge model to simulate Thriasio Wastewater Treatment Plant operation in West Attica, Greece

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Abstract: In the last decades, the use of activated sludge mathematical models has proved to be a useful tool for the simulation both of the design and performance of activated sludge systems in wastewater treatment plants (WWTPs). In this study, Activated Sludge SIMulation Program (ASIM) was used to verify operational performance and effluent characteristics of Thriasio WWTP, in conformity with 91/271 E.E.C, Urban Wastewater Treatment Directive (UWWTD) for discharge in a sensitive water body. Thriasio WWTP is located at a coastal site neighbouring Elefsina Bay in West Attica, Greece, and has a nominal capacity of 117,000 population equivalent (p.e.).

In this context, ASIM was used to simulate operational performance of WWTP for its current operational mode as a case study and its conformity to effluent criteria. Simulation results that were derived for the range of incoming wastewater flows and loads of the last three years indicated that the activated sludge system has a satisfactory performance for carbon oxidation, nitrogen and phosphorus removal, meeting all the effluent criteria. To this respect, ASIM proved to be a useful tool to verify operational performance and predict the effect of influent wastewater flows and loads variation on system behavior. To enhance ASIM applicability on Thriasio WWTP, it would be appropriate as future work to include plant specific data related to wastewater fractionation and biomass kinetics.

Keywords: Activated sludge models, ASIM, Thriasio WWTP

1 Introduction

The region of Attica has a current population of around 3.8 million people, which constitutes almost 40% of the total population of Greece [1]. Most of the population in the Attica region is concentrated at the capital city of Athens. Greater Athens area is currently served according to the Greek National Database that monitors compliance to 91/271 E.E.C, Urban Wastewater Treatment Directive [2], http://astikalimata.ypeka.gr/, with three Biological Nutrient Removal (BNR) activated sludge plants in operation: Psyttalia WWTP (5,630,000 p.e., design capacity), Metamorphosi WWTP in the north (500,000 p.e.) and Thriasio WWTP in the west with a design capacity of around 117,000 p.e. (Figure 1). Future wastewater treatment plants to be developed in East Attica in the next couple of years include Rafina-Artemida and Marathon WWTPs with capacities of 135,000 and 51,400 p.e. respectively. In addition, Koropi-Paiania WWTP which is currently under normal operation has a constructed capacity of about 100,000 p.e. [4].

The area of interest, Thriasio Pedio region, lies to the northwest of Athens and comprises the municipalities of Aspropyrgos, Elefsina, Mandra and Magoula of the Western Attiki Prefecture. The catchment is relatively flat and has an area of about 50 km^2. The domestic population, based on the National Census of 2021, is around 79,000 inhabitants [1]. The Thriasio Pedio region is a heavily polluted area, industrialized and environmentally considered as one of the most sensitive areas in Greece. The receiving water body for the domestic and industrial wastewater produced in the catchment area is the Elefsina Bay, which has been designated by the Greek State as a sensitive area since 1999, in accordance with the requirements of 91/271 EEC, Urban Wastewater Treatment Directive, UWWTD [3].

Since 2012, Thriasio WWTP with a design capacity of 117,000 p.e./21,000 m^3/d as average daily flow, has been under operation by Athens Water Supply and Sewerage Company (EYDAP S.A). Its general layout is given in Figure 2. The current operational mode, includes pretreatment works (coarse screening, fine screening, grit removal) and biological nutrient removal in two plug-flow activated sludge bioreactors having an operational volume of 7,032 m^3 (out of four constructed bioreactors with a total volume of 16,532 m^3) followed by sedimentation of influent wastewater in a settlement tank.

Downstream processes after biological treatment and secondary clarification, include tertiary treatment by chemical coagulation, gravity filtration and ultraviolet (U.V.) disinfection. Treated effluent is discharged into the Elefsina Bay from the outlet pumping station, via a 1.5 km outfall at a depth of around -14m. In case of emergency events (i.e. shock loads, power failure, flooding, etc.), the total raw sewage inflow is bypassed and after receiving coarse screening and chlorine disinfection is discharged into the sea, via a 1 km length second outfall pipe at a depth of around -10m.

As far as sludge treatment processes are concerned, surplus activated sludge is thickened and dewatered to produce a sludge cake of around 15% DS content. This sludge cake is transported to the drying facility of the Psyttalia WWTP for further treatment (i.e. thermal drying, with a final DS content of around 92%).

Constructed works in Thriasio WWTP include primary sedimentation of influent wastewater and anaerobic sludge digestion facilities, according to the detailed design for plant construction [5]. However, due to the low influent wastewater flows and pollutants' loads entering WWTP (about 20-25 % of its design capacity), the above facilities are bypassed. Thus, Thriasio WWTP is being operated as an extended aeration activated sludge system with high solids retention times (in general, SRTs > 10-15 days).

As activated sludge modelling is considered nowadays as a significant tool to simulate WWTPs performance [6-8], Activated Sludge SIMulation Program (ASIM) was used in the present study to simulate Thriasio WWTP operation. ASIM is a user friendly simulation software program that was developed by the Swiss Federal Institute of Aquatic Science and Technology, EAWAG [8, 9]. It is acknowledged as one of the most reliable simulation programs for the activated sludge process with worldwide application [7-8, 10]. Besides, it has been used previously with success to simulate Greek WWTPs either for design purposes (i.e. the newly constructed Koropi-Paiania WWTP) or to validate operational performance such as the Larisa WWTP [11, 12]. The objectives of ASIM application for Thriasio WWTP were to simulate plant operational performance for its current operational mode as a case study and its conformity to effluent criteria. Therefore, the purpose of the simulation was to assess ASIM reliability as a prognostic tool, by comparing simulation results with the plant operational data. On this basis ASIM could be used, at a future step, to assess system behaviour on potential changes in wastewater flows and loads entering WWTP in terms of evaluating alternative operating scenarios.

2 Description of the Activated Sludge System

The treatment standards adopted for the design of the Thriasio WWTP reflect the nature and requirements of the receiving water body (i.e. Elefsina Bay of Saronikos Gulf), which is an enclosed sensitive water body. These standards are summarized in Table 1, according to the approved environmental terms for Thriasio WWTP operation [13]. They are stricter in terms of 5-day Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) effluent concentrations than those required by the 91/271 EEC UWWTD for sensitive receiving water bodies Their attainment requires the adoption of an appropriate biological nutrient removal treatment scheme followed by tertiary treatment to achieve an enhanced removal of suspended solids, nitrogen, phosphorus and coliform bacteria.

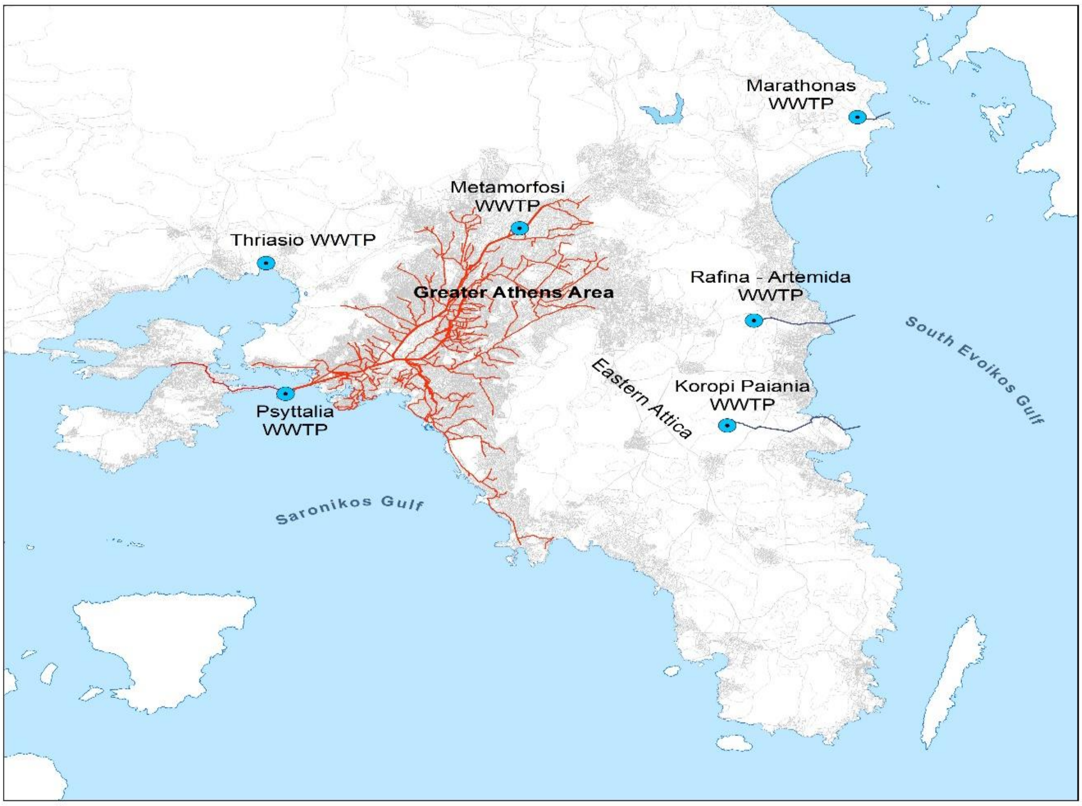

Fig. 1.: Existing WWTPs with sewerage network of the Greater Athens area and future WWTPs in East Attica [4]

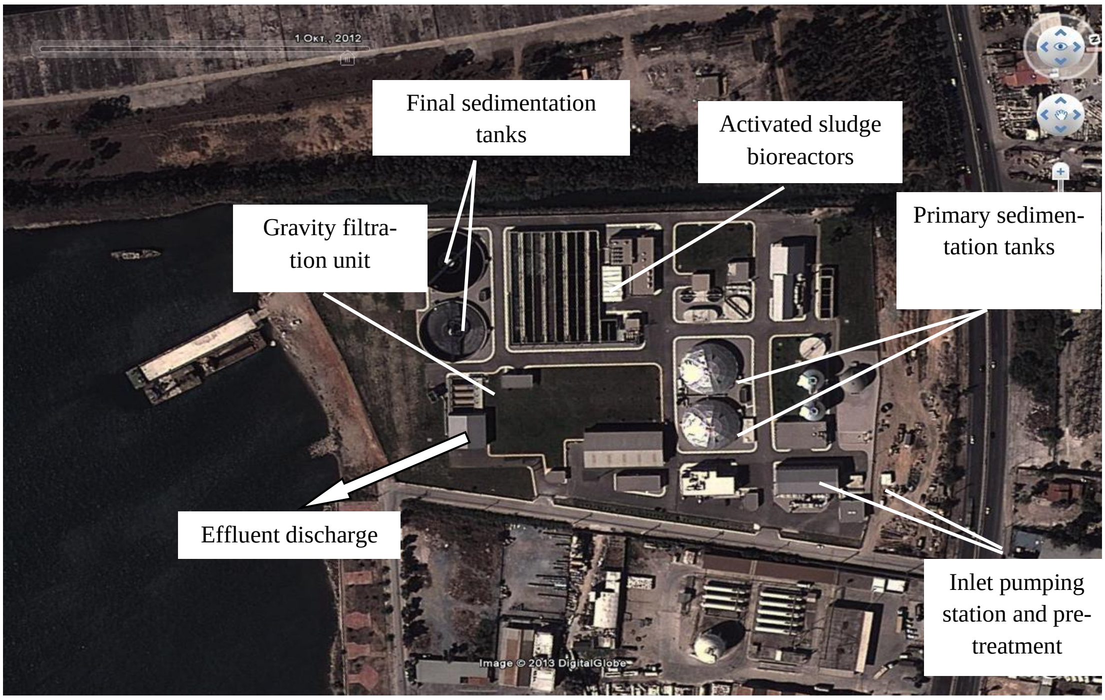

Fig. 2.: General layout of Thriasio WWTP

The activated sludge biological process for N and P removal is a typical A^2O activated sludge system (anaerobic-anoxic-aerobic), modified with the inclusion of a pre-anoxic zone for return activated sludge (RAS) denitrification. The activated sludge flow scheme includes two bioreactors in operation (no 1 and 2) that receive half of the influent wastewater flow and operate in parallel with their compartmentalization given in Figure 3. Besides, the total volumes of bioreactors and of individual compartments are given in Table 3. The process scheme applied is generally known as the Johannesburg configuration developed in South Africa [5, 14, 15].

As can be seen in Figure 3, each bioreactor is a plug-flow system being compartmentalized with an anaerobic-anoxic-aerobic sequence in twelve tanks in series. This activated sludge configuration is capable of achieving almost complete carbonaceous and nitrogen removal via nitrification/denitrification at about 95% removal rates. Besides, biological phosphorus removal is accomplished in the anaerobic/aerobic zones of the bioreactors to achieve total phosphorus (TP) concentrations in the outlet of the activated sludge system well below 3 mg/l. In order to further reduce TP concentrations to lower than 1 mg/l, a supplementary chemical precipitation unit with aluminium sulphate (alum) is involved.

3 Mathematical Modelling of Activated Sludge Plants

Many mathematical models for the activated sludge process have been used in the last decades, to simulate seasonal system behaviour under various temperature conditions. These models can simulate different complex activated sludge flow schemes under steady-state or dynamic conditions, performing organic carbon removal and nitrogen/phosphorus removal. These are usually based on the development of a series of process rate equations which describe the fate of various components. These equations are then incorporated into mass balance equations to be solved for the systems being modelled, given that a biokinetic model is defined with its stoichiometry and the kinetic data for the components involved.

In the history of activated sludge modelling, a core model incorporating the above principles was that developed in 1987 by International Association on Water Pollution and Research Control (IAWPRC, currently International Water Association, IWA) [16]. This original model was named Activated Sludge Model No 1 (ASM 1).

ASM 1 is capable of predicting performance of single-sludge systems carrying out carbon oxidation, nitrification and denitrification. The model includes eight fundamental processes of importance in single-sludge systems: aerobic growth of heterotrophic biomass, anoxic growth of heterotrophic biomass, aerobic growth of autotrophic biomass, decay of heterotrophic biomass, decay of autotrophic biomass, ammonification of soluble organic nitrogen and hydrolysis of entrapped particulate organic matter under aerobic and anoxic conditions. Process rate equations for each of these processes are defined by ASM 1 model, and all kinetic expressions and stoichiometry are presented in a matrix format. Since 1987, several modifications of ASM 1 such as ASM 2, ASM 2d and ASM 3 were developed, either to include more processes such as Enhanced Biological Phosphorus Removal (EBPR) or provide greater flexibility [17].

Table 1.: Thriasio WWTP effluent criteria

Parameter	**Maximum permissible concentration**	**Percentage of conformity (%)**
BOD_5	15 mg/l	95%*
COD	100 mg/l	95%*
TSS	10 mg/l	95%*
Total nitrogen (TN)	10 mg/l	UWWTD **
Total phosphorus (TP)	1 mg/l	UWWTD **
Fecal coliforms (FC)	100 FC/100 ml	Arithmetic mean ***

* Percentage of conformity for daily composite samples according to 91/271/EEC
** 91/271/EEC, UWWTD
*** Mean value of 30 consecutive days for grab samples

Table 2.: Design parameters and operational values of the activated sludge system for the period 2021-2023 (mean monthly values)

Parameter	Design values	Operational values (2021-2023)
1) Flows/loads to bioreactors		
Average daily flow, Q (m^3/d)	23,740	5,361-6,858
Average daily BOD_5, kg/d	5,780	904-2,078
Average daily COD, kg/d	11,850	1,962-4,129
Average daily TSS, kg/d	4,455	845-2,044
Average daily TN, kg/d	1,092	296-486
Average daily TP, kg/d	242.5	21-70
2) Operational parameters of the activated sludge system		
Total bioreactors' volume V_{tot} (m^3)	16,532 (4,133 x 4)	7,032 (4,133+2,899)
Number of bioreactors	4	2
Hydraulic retention time, HRT (hrs)	13-16.7	26-39
Temperature (°C)	15-28	18-24
MLSS (mg/l)	3,180-3,900	3,586-7,207
F/M loading (kg BOD_5/kg MLSS.d)	0.09-0.11	0.03-0.06
Solids retention time, SRT (days)	9-10.5	9,5-37
SAS, Q_w (kg SS/d)	4,511-6,350	963-5,121
VSS fraction to TSS (%)	70%	70%
Return sludge flow ratio (Q_r/Q)	0.65-0.92	0,86-1.44
Internal recycle flow ratio (Q_R/Q)	3.70	3.70

As mentioned above, in the context of activated sludge modelling one of the most useful variants is the Activated Sludge Simulation Program (ASIM), [10]. In the case of ASIM unlike other activated sludge simulation programs where the biokinetic model used is fixed, it allows to choose the biokinetic model from a list of IWA models (ASM1, ASM 2, ASM 2d, ASM 3, etc.) or to define a fit-for-purpose new biokinetic model for the simulations.

In the present study, ASIM was implemented to simulate Thriasio WWTP operation under steady-state conditions. The use of ASIM had the objective to simulate current operation of the plant with regard to its operational parameters and conformity to effluent criteria.

4 Simulation of Thriasio WWTP with ASIM

For the purpose of the simulation, input data was required as follows:

i. Definition of the biokinetic model;
ii. Activated sludge flow scheme;
iii. Influent pollutants' concentrations/wastewater composition and;
iv. Definition of kinetic and stoichiometric parameters

4.1 Definition of the biokinetic model

ASM 1 was used as the biokinetic model for the simulation of Thriasio WWTP. Regarding biological phosphorus removal in the anaerobic/aerobic zones of the bioreactors, TP effluent concentrations were derived based on the daily estimated quantities of surplus activated sludge (SAS). It was assumed that the phosphorus percentage in surplus activated sludge (SAS) may vary between 1% to 5% (0.01-0.05 kgP/kgVSS), depending on the COD/TP influent wastewater ratio [19].

4.2 Activated sludge flow scheme

Thriasio WWTP activated sludge flow scheme and bioreactors' compartmentalisation is presented in Figure 3. As can be seen in Figure 3, the influent wastewater flow is split to the bioreactors no 1 and 2 which operate in parallel. Bioreactors total volumes as well as volumes of individual anaerobic/anoxic/aerobic compartments are given in Table 3. Biological stage of WWTP comprises two bioreactors in operation (out of four constructed tanks) with a total operating volume of 7,032 m^3. This includes, one full bioreactor with volume 4,133 m^3 plus another bioreactor with modified its aerobic zones with volume 2,899 m^3 as shown in Table 3. In each bioreactor, the second compartment D1/AN is facultative and may operate either as a second anaerobic compartment or as a first anoxic compartment. Besides, the first compartment in the aerobic zone D4/A1 is also facultative and may operate either as a fourth anoxic compartment or as a first aerobic compartment.

More specifically, as presented in Figure 3 the current operational mode of bioreactor no. 1 includes one anaerobic compartment (AN), three anoxic compartments (D1/AN, D2 and D3) and eight aerobic compartments (D4/A1 to A8).

Regarding bioreactor no. 2, the current operational mode includes one anaerobic compartment (AN), three anoxic compartments (D1/AN, D2 and D3) and five aerobic compartments (A4 to A8). Compartments D4/A1, A2 and A3 are bypassed and the wastewater flow from anoxic compartment D3 passes to aerobic compartment A4.

Return activated sludge from the settlement tank to bioreactors no. 1 and 2 passes through a pre-anoxic tank with a volume of 634 m^3 to provide denitrification of nitrates contained in the sludge. This is essential since a requirement to have an effective biological phosphorus removal is to have nitrate nitrogen (NO_3 – N) concentration in the anaerobic zone below 0.5 mg/l. Mixed liquor internal recycle is carried out from the last aerobic compartment (A8) of bioreactors no. 1 and 2 to the fist anoxic compartment (D1/AN), in order to enhance the nitrification-denitrification process and hence biological nitrogen removal.

4.3 Influent concentrations – wastewater composition

Mean influent wastewater flows and pollutants' loads entering the activated sludge scheme, such as the 5-day Biochemical Oxygen Demand, Chemical Oxygen Demand, Total Suspended Solids, Total Nitrogen and Total Phosphorus (BOD_5, COD, TSS, TN & TP respectively) for the last three years 2021-2023 are given in Table 2. Main operational parameters of the activated sludge system such as sludge loadings (Food to Microorganisms: F/M ratios), mixed liquor suspended solids concentrations (MLSS), solids retention times (SRTs) and surplus activated sludge (SAS) production are also presented. Influent wastewater entering Thriasio WWTP is of domestic origin with COD/BOD_5 ratio in the range of 1.5-2.3. Regarding organic carbon and nitrogen fractionation with respect to the rate and extent of their degradation, this input data was estimated based on typical data obtained previously in Greek WWTPs [20, 21]. This was essential, since there is a lack of such kind of information in Thriasio WWTP. Based on the above assumptions, total influent COD is split to 50% soluble (S) and 50 % particulate matter (X). For inert soluble and particulate COD (S_i and X_i respectively), it was assumed that they constitute 6 % of total COD. Hence, the percentage of readily biodegradable COD, S_s and slowly biodegradable COD, X_s were taken as 44 % of total COD. Input values used for organic carbon and nitrogen fractionation with respect to their biodegradability are summarized in Table 4.

4.4 Definition of kinetic and stoichiometric parameters

Input data for kinetic and stoichiometric parameters for the activated sludge at T = 20 ^oC were default values proposed in ASM 1. These values are given in Table 5. They have been generally verified from relevant observations in Greek WWTPs, where a nitrification inhibition at about 15% is possible [20, 21].

Biological processes of growth and decay for heterotrophic and autotrophic biomass as well as hydrolysis of entrapped particulate organic matter under aerobic and anoxic conditions are temperature dependent. Dependence of the values of kinetic parameters of these processes on temperature variation is modelled based on the well-established Arrhenius equation [18] as given in Table 6. Monthly temperature variation taken in Thriasio WWTP is given in Table 7.

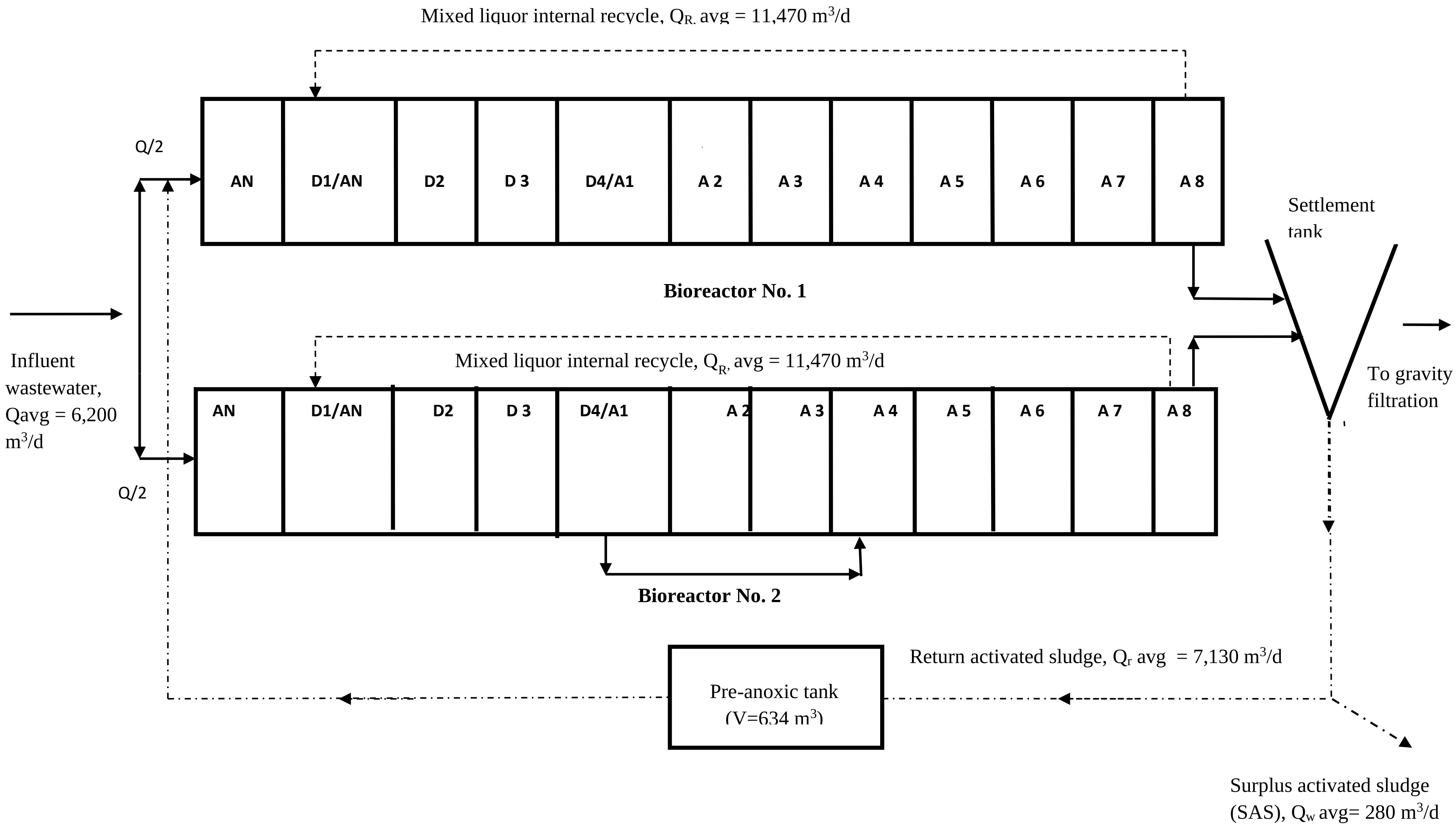

Fig. 3.: Activated sludge flow scheme and bioreactors' compartmentalization

Table 3.: Bioreactors volumes of anaerobic/anoxic/aerobic compartments and total volumes

Compartments	**Volumes (m^3)**	
	1st lane	**2^{nd} lane**
AN (anaerobic)	303	303
D1/AN (currently αnoxic)	303	303
D2 (anoxic)	227	227
D3 (anoxic)	411	411
D4/A1 (currently aerobic)	411	0
A2, A3, A4 & A5 (aerobic)	1,644 (411x4)	822 (411x2)
A6 (aerobic)	227	227
A7 & A8 (aerobic)	606 (303x2)	606 (303x2)
Total	**4,133 m^3**	**2,899 m^3**
Total bioreactors' volume	**7,032 m^3**	

Table 4.: Wastewater fractionation used for the mathematical simulation

Parameter	**Operational values, mg/l (2021-2023)**
Total influent COD in the activated sludge system	331.36 - 666.67
Total influent nitrogen in the activated sludge system	55.22 - 78.36
COD fractions (mg/l)	
Total COD	331.36 – 666.67
Soluble COD, S	165.70 - 333.33
Particulate COD, X	165.70 - 333.33
Soluble readily biodegradable COD, S_s	145.80 - 293.33
Inert soluble COD, S_i	19.90 – 40.0
Particulate slowly biodegradable COD, X_s	145.80 - 293.33
Particulate inert COD, X_i	19.90 – 40.0
Nitrogen fractions (mg/l)	
Total nitrogen, TN	55.22 - 78.36
Ammoniacal nitrogen, S_{NH}	35.84 - 44.30
Soluble organic nitrogen, S_{ND}	9.69 - 17.03
Particulate organic nitrogen, X_{ND}	9.69 - 17.03

Table 5.: Kinetic and stoichiometric parameters used for the mathematical simulation.

Parameters	**Units**	**Typical values, T=20ºC***
1. Kinetic parameters		
Heterotrophic biomass		
Maximum specific growth rate, μ_H	day^{-1}	6.0
Decay rate constant, b_H	day^{-1}	0.62
Monod saturation constant for substrate S, K_{sh}	gCOD/m^3	20.0
Monod saturation constant for oxygen, K_o	gO_2/m^3	0.20
Monod saturation constant for ammoniacal nitrogen, K_{NH}	gN/m^3	0.001
Monod saturation constant for nitrate nitrogen K_{NO}	gN/m^3	0.50
Correction factor for anoxic growth, n_g	Unitless	0.80
Autotrophic biomass		
Maximum specific growth rate, μ_A	day^{-1}	0.68
Decay rate constant, b_A	day^{-1}	0.12
Monod saturation constant for ammoniacal nitrogen, K_{NH}	n/m^3	1.0
Monod saturation constant for oxygen, K_o	gO_2/m^3	0.4
Maximum specific hydrolysis rate, K_h	gCOD/gCOD/day	3.0
Saturation constant for substrate X, K_X	gCOD/gCOD	0.03
Monod saturation constant for oxygen, K_o	gO_2/m^3	0.2
Ammonification rate, K_a	m^3/gCOD/day	0.08
Correction factor for anoxic hydrolysis. n_h	Unitless	0.25
2. Stoichiometric parameters		
Heterotrophic biomass yield, Y_H	gCOD/gCOD	0.62
Autotrophic biomass yield, Y_A	gCOD/gN	0.20
Mass of nitrogen per mass of COD in biomass, i_{XB}	gN/gCOD	0.086
Mass of nitrogen per mass of inert COD, i_{XI}	gN/gCD	0.01
Fraction of inert COD in biomass, f_P	gCOD/gCOD	0.080

Table 6.: Dependence of kinetic parameters of biological processes on temperature variation

$c(T) = c(20^oC) * e^{[\theta *(T-20)]}$	X_H	X_{Nitr}	Units
θ for μ_{max} (growth)	0,069	0,1	$(^oC)^{-1}$
θ for b (decay)	0,1	0,095	$(^oC)^{-1}$
θ for k_h (hydrolysis)	0,11 (aerobic/anoxic)		
c (T) = biological process rate at T^{o}C, c= μ_{max}, b ή k_h			
c (20^{o}C) = biological process rate at 20^{o}C			
θ = temperature coefficient			

Table 7.: Monthly temperature variation used for the mathematical simulation

Mean monthly temperature of the activated sludge system											
Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
19^{o}C	19^{o}C	19^{o}C	20^{o}C	21^{o}C	22^{o}C	23^{o}C	24^{o}C	24^{o}C	23^{o}C	21^{o}C	18^{o}C

5 Results

Simulation of Thriasio WWTP operation was carried out for the mean monthly daily influent wastewater flows to bioreactors for the last three years 2021-2023. (Figure 4). Besides, the pollutants concentrations in the bioreactors for BOD_5, COD, TSS, TN & TP are given in Figures 5 and 6. Monthly temperature variation used is given in Table 7.

According to the information provided by EYDAP S.A. relevant Department which operates Thriasio WWTP, dissolved oxygen (DO) concentration in the aerobic zones of the bioreactors was taken at 2 mg/l. Also, the average recycled flows percentages (return activated sludge and mixed liquor internal recycle) are given in Table 2.

Simulation results are presented in Figures 7 to 13 and relate to:

- operational parameters of the activated sludge system for various sludge loadings (F/M ratios), SAS production (Figure 7) and MLSS concentrations Figure 8)
- effluent characteristics in terms of organic carbon, suspended solids, nitrogen and phosphorus concentrations (BOD_5, COD, TSS, NH_4-N/NO_3-N, TN & TP), are given in Figures 9 to 13.

6 Discussion

Based on the simulation results, the following key findings are derived:

Estimated values of the operational parameters are close to the obtained data from plant operation. Regarding effluent characteristics, estimated concentrations of main pollutants are in good agreement with measured data from plant operation;

According to the mathematical simulation, all parameters in the effluent satisfy the relevant criteria given in Table 1 for discharging to the sensitive water body of Elefsina Bay. Almost complete removal of organic carbon and suspended solids is achieved as well as very satisfactory nitrogen removal via nitrification-denitrification. Estimated concentrations of total soluble COD in the effluent (inert and readily biodegradable, $S_I + S_S$) vary between 20 – 41 mg/l. These values are quite close with measured data from plant operation (~ 17 – 27 mg/l).

Moreover, estimated values of total suspended solids (TSS) at the outlet of the activated sludge system are in the range of 7 - 11 mg/l, with an average value of 8 mg/l. By taking into account that about 50 % of total suspended solids from the outlet of the activated sludge system are removed via downstream gravity filtration, these values are being decreased to 3.5 – 5.5 mg/l for effluent TSS concentrations, which are very close to measured data.

Regarding, nitrogen removal, estimated effluent concentrations for ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3 – N) and total nitrogen (TN) are in good agreement with the corresponding measured values from plant operation. Estimated NH_4-N concentrations are well below 0.5 mg/l and TN concentrations are close to 10 mg/l. Elevated effluent concentrations for NO_3 – N and TN were estimated in the summer/autumn period (July-August and September to November). In this period, higher temperatures coupled with the maintenance of an adequate concentration of dissolved oxygen in the aerobic zone of the bioreactors (DO = 2 mg/l) leads to an enhanced production of nitrates through nitrification. As a consequence, total nitrogen (TN) concentrations in the effluent may exceed the maximum permissible concentration of 10 mg/l. It is therefore recommended to keep DO concentrations in the aerobic zone during this period in the range of 1.0 – 1.5 mg/l. For the winter/spring period, the maintenance of DO = 2 mg/l could be more appropriate. Estimated concentrations of nitrate nitrogen (NO_3 – N) of recycled sludge in the outlet of the pre-anoxic tank vary between 0.1 – 0.5 mg/l. Therefore, NO_3 – N concentrations in the anaerobic compartment of the bioreactors (AN) are well below 1 mg/l and in many cases near zero. This justifies the adequacy of pre- anoxic zone for removing nitrate in recycled sludge. Estimated concentrations of total phosphorus (TP) in the outlet of the activated sludge system are generally below 3 mg/l, thus meeting the design criteria for the biological phosphorus removal process [5]. Further removal of phosphorus is accomplished via chemical precipitation with the addition of aluminum sulphate (alum) either upstream of the settlement tank or upstream of gravity filters. This is essential to reach the effluent criterion of TP < 1 mg/l as measured data indicates.

In summary, application of ASIM to simulate Thriasio WWTP proved to be a consistent and practical tool, which verified the plant operational performance. In this context, it should be mentioned that although activated sludge modelling is well established worldwide as a significant tool to simulate WWTPs operational performance it has very limited application in Greece. This is attributed to the general lack of plant specific data in Greek WWTPs (wastewater characterization, kinetics data, etc.). An exemption to this is Psyttalia WWTP, which is the main wastewater treatment plant that serves the Greater Athens area – being one of the largest in size WWTPs in Europe and worldwide. In recent years, activated sludge modeling with GPS-X simulation software which is similar to ASIM program was implemented [21]. The objectives were to simulate operational performance of the activated sludge scheme for different operating scenarios related to the variation of flows and loads, mixed liquor temperatures and Solids Retention Times, SRTs. These results obtained verified the operational performance of Psyttalia WWTP and system response to various operating conditions, such as the results obtained in this study.

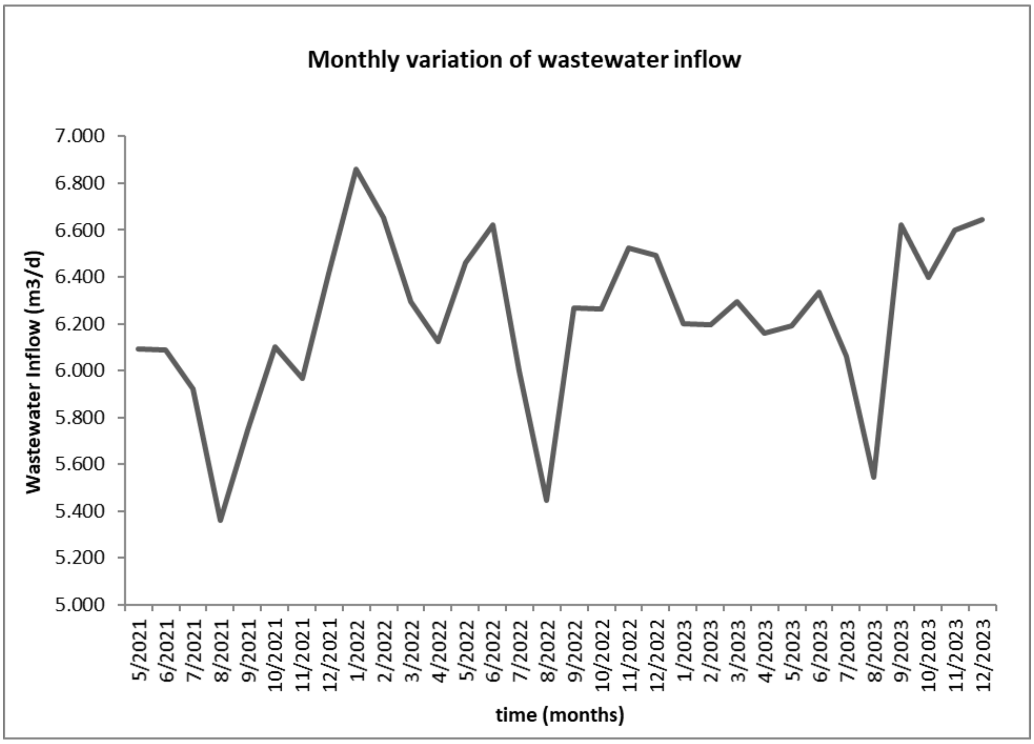

Fig. 4.: Monthly variation of wastewater inflow (m^3/d), 2021-2023

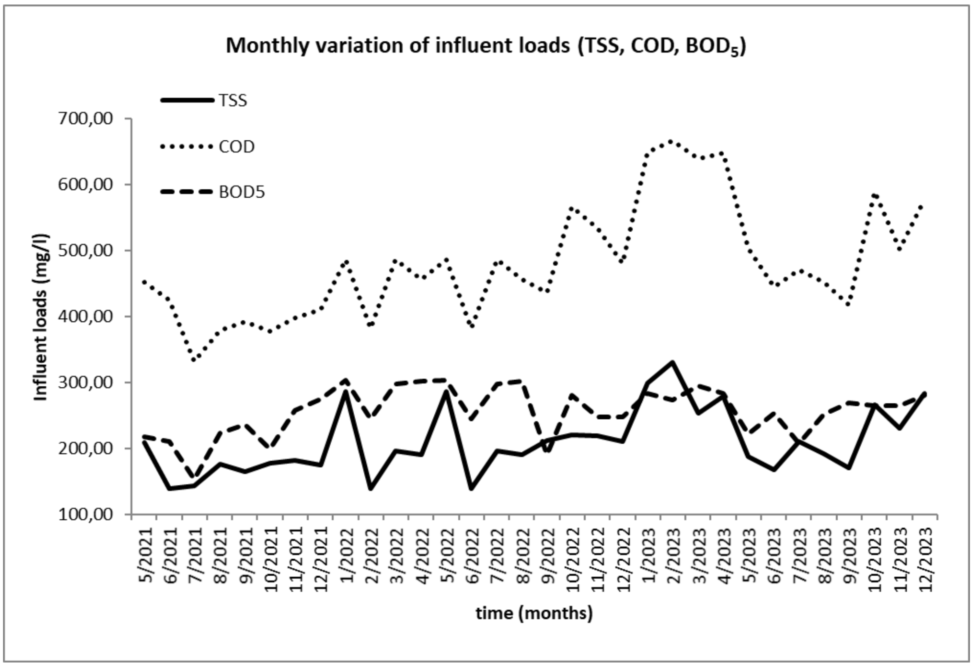

Fig. 5.: Monthly variation of influent loads (TSS, COD, BOD_5), 2021-2023

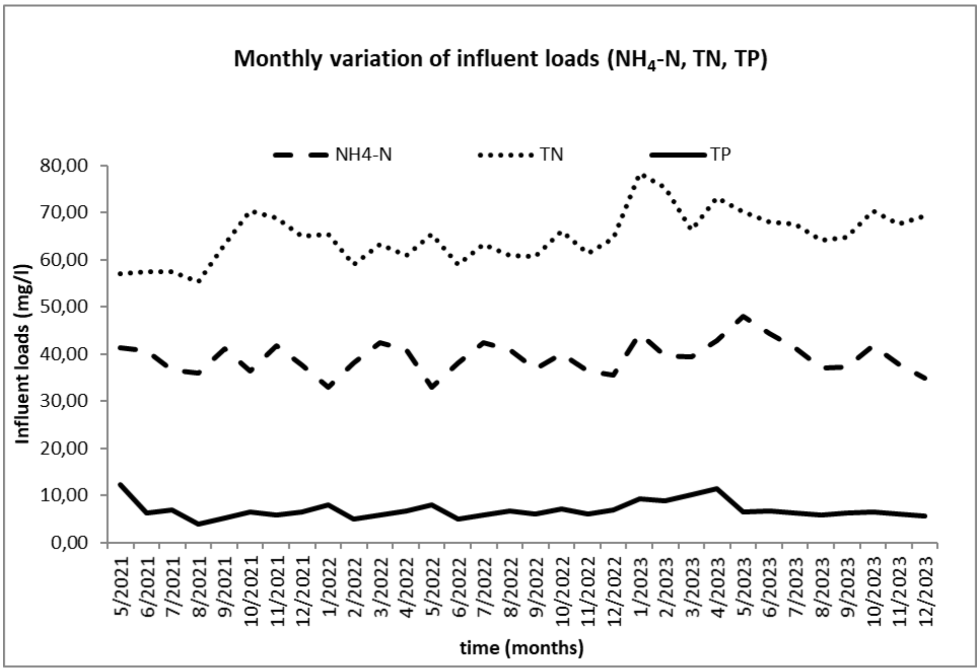

Fig. 6.: Monthly variation of influent loads (NH_4-N, TN, TP). 2021-2023

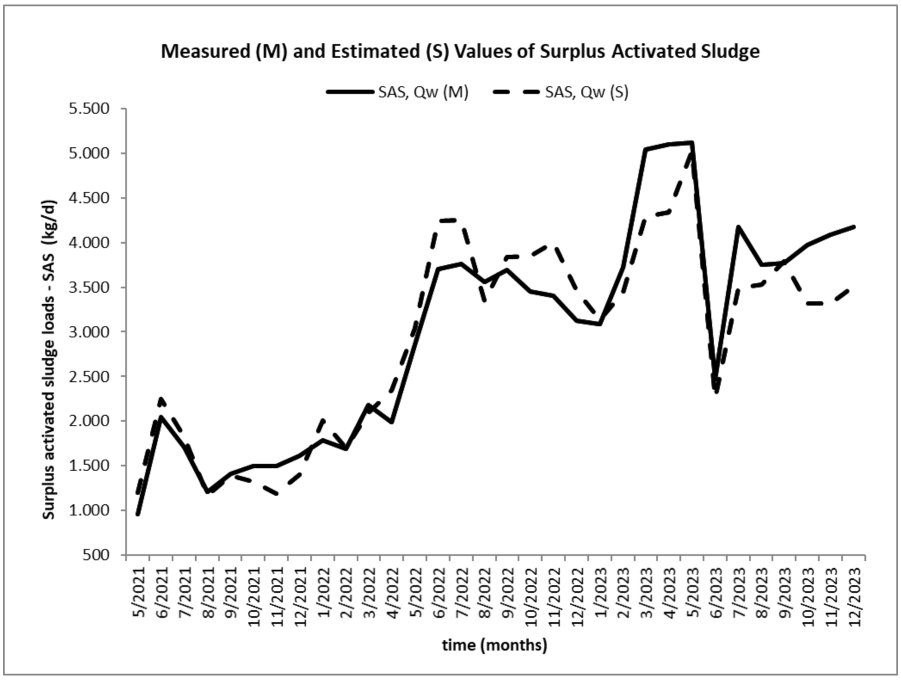

Fig.7.: Measured (M) and Estimated (S) values of Surplus Activated Sludge

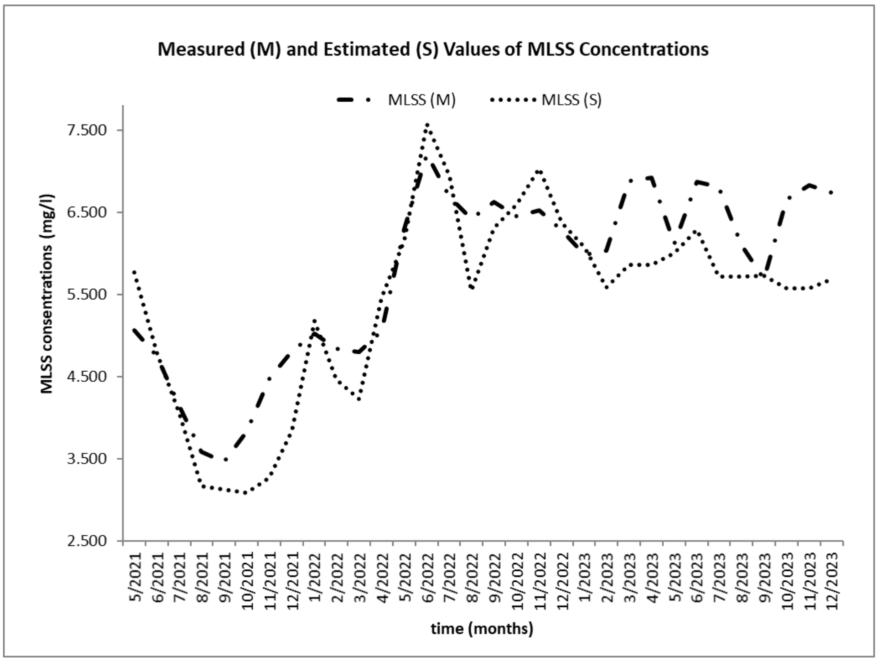

Fig. 8.: Measured (M) and Estimated (S) values of MLSS concentrations

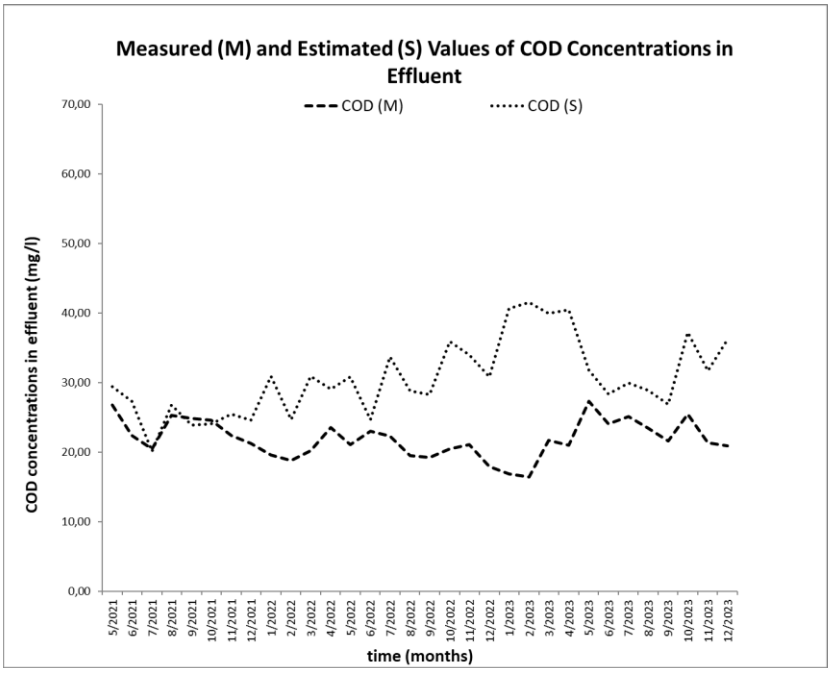

Fig. 9.: Measured (M) and Estimated (S) values of COD concentrations in effluent

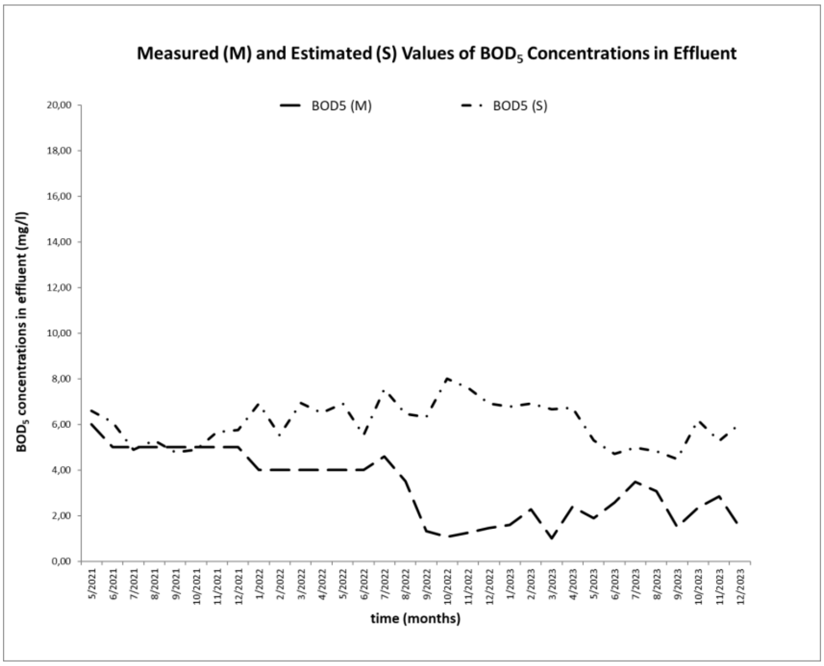

Fig. 10.: Measured (M) and Estimated (S) values of BOD_5 concentrations in effluent

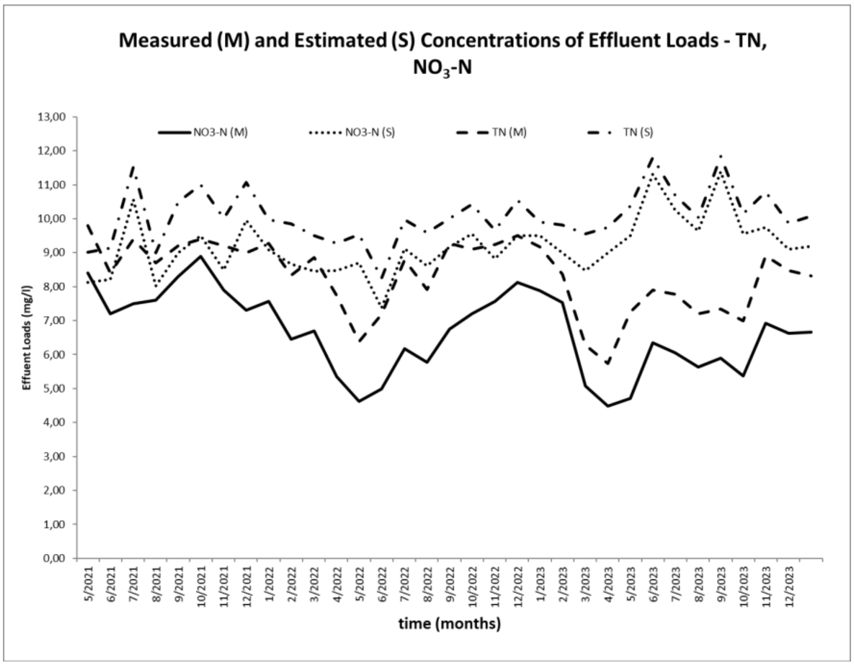

Fig. 11.: Measured (M) and Estimated (S) values of TSS concentrations in effluent

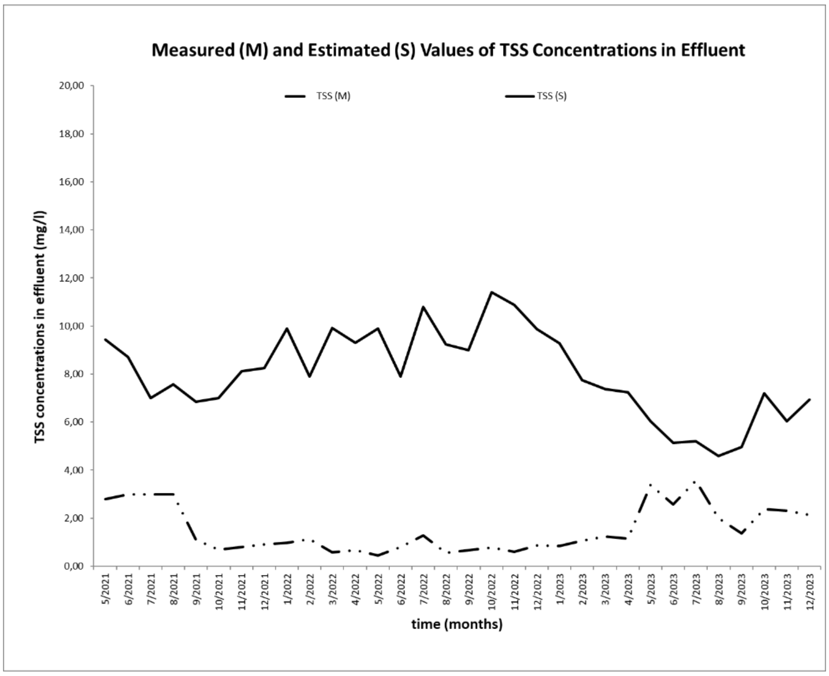

Fig. 12.: Measured (M) and Estimated (S) values of effluent loads – TN, NO_3-N

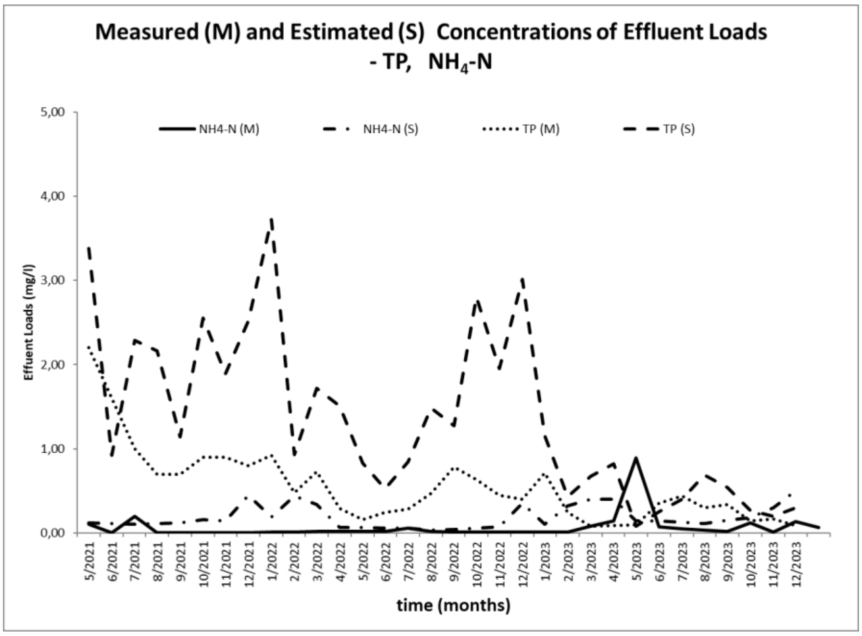

Fig. 13.: Measured (M) and Estimated (S) values of effluent loads –NH4-N & TP

7 Conclusions

Activated Sludge SIMulation Program (ASIM) was used to simulate the operation of Thriasio WWTP which is a biological nutrient removal activated sludge plant. Estimated values from mathematical modelling for the operational parameters are in good agreement with the observed operational data. Estimated values of the concentrations of effluent parameters are also close with observed operational data. Overall, the activated sludge system has a satisfactory performance for carbon oxidation, nitrogen and phosphorus removal meeting all the effluent criteria. Regarding biological nitrogen removal, the activated sludge system achieves total nitrogen concentrations (TN) generally less than 10 mg/l, thus fulfilling the effluent criterion for nitrogen removal. Besides, biological phosphorus removal achieves total phosphorus (TP) concentrations in the outlet of the activated sludge system less than 3 mg/l and with chemical removal less than 1 mg/l, thus fulfilling the effluent criterion for phosphorus additional removal.

The simulation of the activated sludge system had the purpose to simulate plant performance for the hydraulic flows and loads of the last three years 2021-2023, in terms of meeting effluent criteria for carbon oxidation, nitrogen and phosphorus removal. Input data for the simulation, related to wastewater fractionation and the values of kinetic/stoichiometric parameters for the biomass are based on relevant information obtained from other Greek WWTPs. Besides, default values were used as they are defined in Activated Sludge Model No 1 (ASM 1).

In summary, simulation with ASIM proved to be a useful tool to predict and verify the operational performance of Thriasio WWTP. Therefore, future work may focus on optimizing the operational performance of the activated sludge scheme by evaluating different operating scenarios. These could investigate for instance system behaviour on the variation of flows and loads, mixed liquor temperatures and different SRTs. To this respect, it is expected that ASIM applicability to Thriasio WWTP could be enhanced with the provision of plant specific data for the needs of the simulation, related to wastewater fractionation and biomass kinetics which are not currently available.

Acknowledgements

The authors wish to express their special thanks to Mr. Athanasios Marangos, Chemical Engineer, Head of Thriasio WWTP Department, General Division of Sewerage, Athens Water Supply & Sewerage Company (EYDAP S.A) for the provision of plant operational data.

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