



OPTIMIZATION OF THE WWTP OF SAN GIOVANNI DI GROSSETO

Exam: Optimization of Chemical Environmental Plants



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Introduction

The Wastewater Treatment Plant of San Giovanni di Grosseto plays a critical role in managing the region's wastewater, ensuring that effluent discharge meets environmental standards and supports the sustainability of local water resources. As urbanization and industrial activities in the area continue to grow, the demand for efficient wastewater treatment has increased, placing additional strain on the existing infrastructure. This project aims to optimize the operational efficiency of the WWTP by evaluating the current processes, identifying bottlenecks, and implementing advanced optimization techniques. The primary goals are to enhance treatment performance, reduce operational costs, and minimize the environmental impact of the plant's operations. Through the application of optimization strategies, this project seeks to ensure that the WWTP can handle future increases in wastewater volumes while maintaining high standards of treatment quality. The project will provide a comprehensive framework for improving the WWTP's efficiency and sustainability. This initiative not only aims to address current challenges but also prepares the facility to meet future regulatory requirements and environmental goals, ensuring long-term resilience and reliability in wastewater management for the Grosseto area.

Legislation, Regulations and Directives

European Directives

European Water Framework

European Parliament and Council Directive 2000/60/EC of 23 Oct. 2000 established a framework for Community action in the field of water policy: WATER FRAMEWORK DIRECTIVE. This framework includes specific sectors such as drinking water, bathing water, urban wastewater (91/271), nitrates (connected to nitrates pollution about groundwater, in a vulnerable zone we need to protect soil from nitrate, that's where lower nitrogen limits are set), IPPC, EID and other industry discharges, chemicals, pesticides, biocides, landfills, sewage, sludge and finally water reuse (741/2020, if the plant discharges in NVZ (Nitrate Vulnerable Zones) the limits will be placed on also on N and P, if it discharges in non NVZ then there are no limits on N and P, the design changes).

Urban Wastewater Treatment Directive

On 26 October 2022, the Commission revised the UWWTP Directive in line with the results of an evaluation and based on an extensive impact assessment, adapting it to the newest standards. The revision aims to reduce pollution, energy use and greenhouse gas emissions, improve water quality by addressing remaining urban wastewater pollution, improve access to sanitation especially for the most vulnerable and marginalised, make industry pay to treat micropollutants, require EU countries to monitor pathogens in wastewater, lead to a more circular sector.

By 2040 the new rules will, save almost EUR 3 billion per year across the EU, reduce greenhouse gas emissions by over 60% compared to 1990, decrease water pollution by more than 365 thousand tonnes, cut microplastics emissions by 9%. Challenges which should be assessed are identified as: improving cost-recovery (water tariffs), better collection and treatment of stormwater overflows and urban runoff (more heavy rainfall events expected in the future increasingly important source of pollution), emerging contaminants (pharmaceuticals, microplastics), more coherent definition of eutrophication of ‘Sensitive Areas’ by Member States, Circular Economy potentials (control at source of pollutants to facilitate agricultural use of sludge and water reuse), improving treatment wastewater from smaller agglomerations and non-connected households (these place significant pressure on over 10% of Europe’s water bodies).

Despite the generally high level of implementation of the UWWTD, a number of challenges remain, such as: improving the quality and recovery of sludge, minimizing the effects of storm water overflows that pollute water bodies with untreated wastewater, by encouraging the use of natural water retention systems, enhancing the management of the networks connected with treatment plants and additional investments; increasing the reuse of treated wastewater (in cases of water scarcity), guaranteeing the proper water quality; enhancing the energy consumption of sanitation systems, producing renewable energy at treatment plant level (biogas).

Italian Regulation

Legislative Decree 152/2006

The Legislative Decree No. 152/2006, which focuses on environmental matters and provides a legislative framework for environmental protection, has its foundation in the Galli Law. The Law No. 36 of January 5, 1994, also known as Galli's Law, focused on water resources in Italy, it had the aims to protect and regulate the use of water resources as well as integrating the management of water services, including water supply, sewage, and purification. The goal was that to reduce fragmented management and move away from purely economic considerations.

Activities under the L. 36/94:

1. Geographic definition of the A.T.O. (territorial limits and modalities of Constitution) according to territorial homogeneity of the water cycle criteria.
2. Establishment of the A.T.O. (agreement between municipalities and provinces or consortia) and the Autorità d'Ambito.
3. Recognition of the works belonging to the S.I.I. that fall within the A.T.O.
4. Drafting and approval of the Piano d'Ambito, which identifying the programmed interventions to ensure the minimum levels of service, water tariff evaluation ("Normalized method" D.M. 1/8/96) to cover costs in a defined time horizon (20-30 years) and identification of the method of concession of the service management.
5. Concession of the S.I.I. management of one of the possible methods (in house, mixed/private company, public tender).

The A.T.O. is public and maintains the role of "decision-maker" of the infrastructure development plan and fee plan. There's a clear separation between control (which belongs to the ATO and is therefore of public competence) and management functions (which can be private), there's an integration of numerous and fragmented administrations before L.36/94, even by safeguarding of those who demonstrate ability to efficiency and economy.

The fee must provide coverage of the service total costs (management, maintenance and investment). The law of March 26, 2010, n°42 of conversion of the Decree-Law January 25, 2010 n°2, about the urgent interventions concerning local authorities and regions has suppressed the A.T.O., even if it is not clear what will be the subject that replaces it. The D.Lgs. 152/2006 (WATER LEGISLATION FRAMEWORK - TESTO UNICO AMBIENTALE) is composed of 6 parts: Common provisions (1st Part), VIA, VAS, IPPC (2nd Part), soil defence (related to hydraulic risks) - water protection from pollution - water resource management (3rd Part), waste management - remediation of contaminated sites (related to waste and landfills) (4th Part), air pollution (5th Part) and environmental damage (crimes) (6th Part). According to this legislation all water becomes public, there's no distinction between public and private water. The 3rd part of the Legislation on the Government of water provides different intervention areas to regulate the use of water or its safeguard: soil protection and hydro geological hazard, water resources and water pollution. The difficulties arise from the interconnection and overlapping of the competences of certain rules, the integration between national, regional and European legislation and the existence of acts and procedures arising from repealed regulation.

The phases through which the improvement activities of the water bodies are developed are:

- definition of quality objectives for specific destination of use (drinking, bathing, etc) and environmental quality, that you want to guarantee for the body water.
- monitoring of water body characteristics and possible pollution sources.
- identification of the quality status of the water bodies and their consequent classification, according to a quantitative criterion based on the results of the monitoring.
- rehabilitation of water bodies, with the identification of measures to achieve the desired quality objective or to maintain that already possessed.

The investment planning depends on the quality of water I want to achieve or need to achieve, if water quality is bad investments are high, if it is already good, they might be low. The water bodies are surface water bodies (lakes, rivers), groundwater bodies, sea water body, the water quality is defined in the base of chemical and biological parameters. Two classes of "quality objectives" are defined that must be guaranteed for the "significant water bodies":

- the quality target for specific destination identifies the state of the water bodies suitable for a particular use.
- the objective of environmental quality is defined according to the capacity of water bodies to maintain the natural processes of self-purification and to support large and well diversified animal and plant communities.

It is important to distinguish between sensitive water body which is related to nutrient pollution of surface water body, N and P, vulnerable water body is related to nitrate pollution for gw and specific uses water body i.e., surface fresh water suitable for drinking water purposes, water suitable for bathing water, for the life of fish or molluscs. No substantial difference in relation to regulations already in force or repealed by the decree. Both surface water bodies (rif. Tab.2 of All.1 of D.Lgs. 152/99) and groundwater (rif. Tab.3 of All.1 of D.Lgs. 152/99) can be defined by environmental quality status, such as high quality, good quality, sufficient quality, poor quality or bad quality. By 2015 it had to be reached the environmental quality status "good" but it wasn't. The measures to achieve these objectives are reported in the "Protection Plan", which constitutes an excerpt of the Basin Plan, provided for by law 183/89.

The significant water bodies are the ones that need to be monitored and classified in order to achieve environmental quality objectives are defined. The criteria for the identification of significant water bodies are given in article 1 of the Decree and concern: shallow waterways, lakes, coastal marine waters. transition waters, artificial water bodies and groundwater. For the monitoring of surface water bodies, parameters are observed in relation to the water, the biota and the sediments. The detected parameters are distinguished between basic parameters (obligatory) and additional parameters. For monitoring of groundwater bodies quantitative measures (piezometric level, courses) and qualitative measures (chemical analysis) are found. The current environmental quality status of water bodies is identified by the value assumed by some indicator parameters, determined following the monitoring phase (ALL. 1 D. Lgs. 152/99):

- in running waters
 - LIM pollution Level macro-categories
 - IBE Extended Biotic Index
 - SECA Environmental Status Running Waters
 - SACA Environmental State Waters
- in lakes
 - SEL Environmental Status Lakes
 - SAL Environmental State Lakes
- in marine waters
 - TRIX Trophic Index
 - SAM Marine Environmental Status
- in groundwater
 - SQAS Groundwater Quantitative Status
 - SCAS Groundwater Chemical Status
 - SAAS Environmental Groundwater Status

The Water Protection Plan must include: the results of characterization activities, the identification of the environmental quality objectives and for specific intended use, the list of water bodies in specific intended use and areas requiring remediation and pollution prevention measures, the protective measures for each river basin, the indication of the chronogram of interventions and priorities, the evaluation of effectiveness of interventions and the remediation of water bodies. All the framework is applied at regional level with the water protection plan (piano di tutela delle acque), at national level we cannot define indicators for the local rivers. The wpp is the link between environment (water resource) and infrastructure (water service).

The sensitive areas are thus identified:

- natural lakes, estuaries and coastal waters already eutrophicated or probably exposed to next eutrophication.
- fresh surface water intended for the abstraction of drinking water which might contain, in the absence of intervention, a concentration of nitrate greater than 50 mg/l;
- areas that need a complementary treatment to secondary treatment in order to comply with the provisions of the Decree.

Are considered "sensitive" those lakes that are placed at an altitude below 1000 m s.l.m. and with a liquid mirror surface of at least 0.3 km² as well as the rivers in their catchment up to 10 km from the coastline. The vulnerable areas are so by nitrates from agricultural sources those territories which discharge directly or indirectly nitrogen compounds of agricultural or zootechnical origins to already polluted water or that may be due to those types of discharges. In Italy the Legislative Decree 152/06 identifies limits depending on the achievement of quality objectives for receiving water bodies in sensitive areas and non-sensitive areas:

Parameter	Concentrations		Limits on effluent			
	Urban Wastewater	Industrial Wastewater	Non sensitive areas	Sensitive areas	Soil	Reuse
Suspended Solid	200 – 400	100 – 250	35	35	25	10
BOD5	150 – 300	40 – 250	25	25	20	10
COD	250 – 450	100 – 500	125	125	100	50
Total N (as N)	25 – 60	-	-	10	15	15
Nitrate N (as N)	1 – 5	1 – 30	20	-	-	-
Ammonia Nitrogen (as N)	25 – 60	5 – 15	11	-	5	2
Total Phosphorus	3 – 8	0 – 10	10	1	2	2
Surfactants	4 – 6	1 – 4	2	2	0.5	0.5
E. Coli (UFC/100mL)	10^6 – 10^8	-	$5 \cdot 10^3$	$5 \cdot 10^3$	$5 \cdot 10^3$	10

Table1. limit concentrations on effluent related to wastewater parameters

Limits are based on water quality; the new limits are discussed on different basis considering the interaction of water with the environment. This is why Ecoregions are being defined, on these regions the proposals to build new plants are done based on environmental interactions. It is not found in legislations but that's the direction towards which we are going.

Local Regulation

PTA – Toscana Region

The Piano di Tutela delle Acque (PTA) for the region of Tuscany is a comprehensive plan established to protect and manage water resources in alignment with both regional and national regulations. Introduced as part of Italy's compliance with the European Union's Water Framework Directive 2000/60/EC, the PTA outlines key strategies and measures aimed at maintaining or achieving a "good status" for all water bodies, including rivers, lakes, coastal waters, and groundwater. The primary objectives of the PTA in Tuscany are to ensure that all water bodies meet the required quality standards, particularly by reducing pollution from agricultural, industrial, and urban sources. The PTA promotes an efficient use of water resources by balancing the demands of various sectors such as agriculture, industry, tourism, and households while safeguarding the ecosystem's health. It allows for continuous monitoring of water quality and quantity in order to assess the health of the region's water bodies, this includes the use of bio-indicators, chemical analyses, and hydrological models.

The PTA also cover for specific measures aimed at reducing the pollution from diffuse sources, such as agriculture, by encouraging the adoption of sustainable farming practices, and from point sources, like wastewater treatment plants and industrial facilities. The planning of the hydrographic district is coordinated by the District Basin Authorities (Art. 63 of Legislative Decree 152/2006). The regional territory is included in three river basin districts; the PTA takes into account the new delimitation of district boundaries provided by Law No. 221/2015. (CIVILE, 2016).

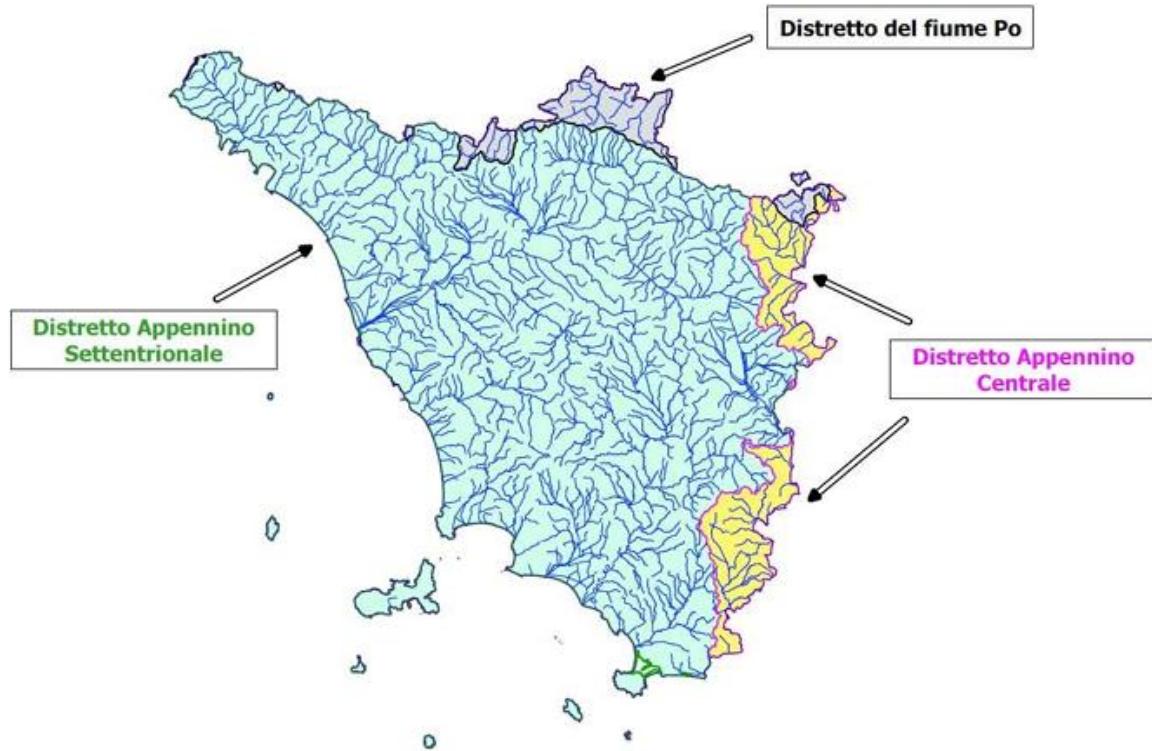
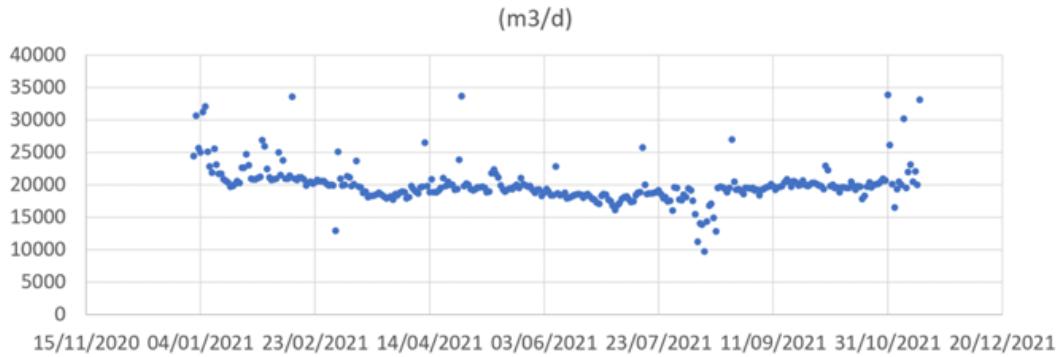


Figure1, Tuscany's District Basin Authorities

San Giovanni Di Grosseto WWTP

The San Giovanni di Grosseto WWTP has a nominal treatment capacity of 100000 PE, the sewerage system afferent to the plant was created as a separate type; however, in the event of rain, there are considerable increases in the flow rate of influent effluent similar to what could be found in the case of a mixed sewerage system. This is mainly due to the presence of parasite water infiltrating the black sewer and the presence of spillways along the white sewer that discharge rainwater into the black sewer. The wastewater that discharges into the plant has a civil origin with minor contributions of some industrial surrounding wastewater. The daily average flow coming to the plant, measured in 2022, is equal to 19800 m³/d, with the following inlet contractions: 425 mg COD/, 19 mg BOD/l, 166 mg TSS/l, 38 mgNH4/l, 42 mg TN/l, 5.4 mg TP/l.



Flow	Average	DEV. STD
m³/d	19206	1570
m³/h	800	65

Peak factor (hourly)= 1.5

Table 2, Daily average flow measured from 01/2021 to 11/2021

The fractioning characterization of the influent wastewater is listed below:

	Influent (mg/l)	%of total COD	Effluent from primary treatment (mg/l)	%of total COD
COD	225.81	100%	245.16	100%
bCOD	106.75	47%	140.41	57%
nbCOD	119.06	53%	104.75	43%
sCOD	47.75	21%	97.30	40%
pCOD	178.06	79%	147.86	60%
rbCOD	45.36	20%	94.86	39%
nbsCOD	2.39	1%	2.44	1%
sbCOD	61.39	27%	45.55	19%
nbpCOD	116.67	52%	102.31	42%

Table n.3, COD fractions characterization

The receiving water body is the Fosso Razzo which is subsequently flowing into the river Ombrone, and there's no discharging into sensitive areas.



Figure n.2, Top view of San Giovanni di Grosseto WWTP

The block flows below provide a visual representation of the proposed changes and improvements to the Grosseto WWTP. It illustrates the key modifications that will be implemented as part of the optimization project, highlighting the enhanced layout, upgraded infrastructure, and advanced treatment processes that will be introduced.

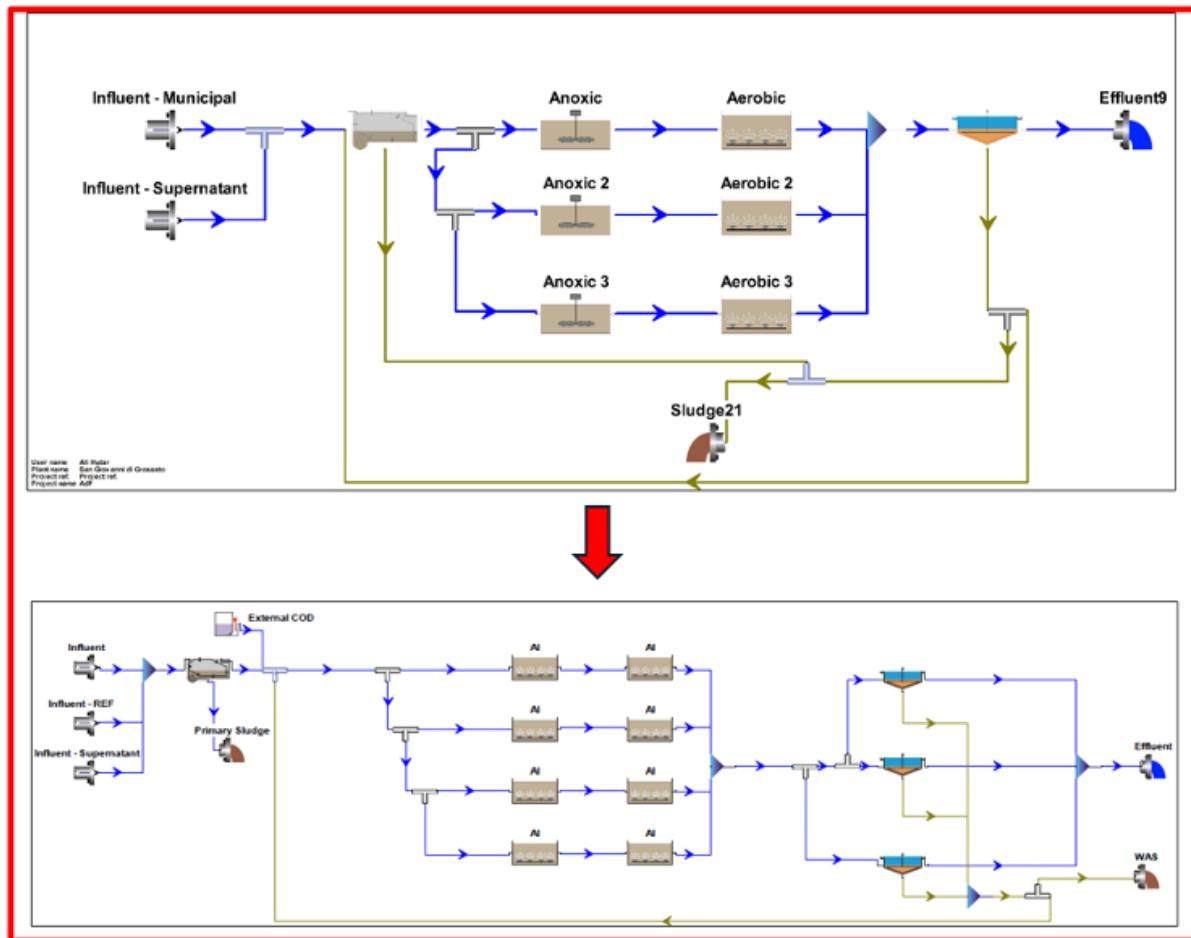


Figure n.3, WWTP upgrade explanation

Actual Status

In this section, a detailed explanation of the key units and processes involved in the water line of our wastewater treatment plant (WWTP) will be provided. Each unit plays a critical role in ensuring the efficient treatment and purification of wastewater. Understanding the function and interaction of these units is essential for optimizing plant performance and maintaining regulatory compliance. Below, each unit will be broken down, describing its purpose, operation, and how it contributes to the overall treatment process. The plant is characterized by a primary sedimentation which occurs in 3 rectangular tanks placed in parallel positions, equipped with a bridge with a bottom scraper blade.

This stage removes the settleable solids, which, once separated, are transferred by gravity to the mixed sludge pumping station. The overflow from the clarifier is collected in a metal gutter for each individual tank; these gutters spill into a channel that leads to the subsequent denitrification tanks. In the main channel upstream of the inlet to the biological compartment, a side overflow weir system is installed for bypassing secondary treatments. Due to their geometric configuration, the biological tanks behave hydrodynamically as CSTR, for which it is assumed that the fluid particles introduced into the reactors undergo instantaneous and uniform mixing throughout the entire volume.

The denitrification phase is conducted in six parallel rectangular tanks, each with a capacity of 697 m³, with two tanks assigned to each treatment line. The denitrification reactors receive effluent from primary sedimentation, recirculated sludge from secondary sedimentation, and internally recirculated aerated mixture from the oxidation compartment. To maintain the sludge in suspension and ensure even distribution of recirculated nitrates, each tank should be equipped with two slow-type submerged mixers (one at the beginning and one at the end). However, it should be noted that the mixers are either missing or not functioning properly: in tank 2, the mixer in the end zone is incorrectly oriented; in tank 3, there is no mixer in the end zone; and in tanks 5 and 6, there are no mixers in the initial part. The nitrification phase takes place in 3 almost squared parallel tanks (1552 m³ each), in which the transfer of oxygen necessary for biological reactions is ensured by a blown-air aeration system with fine bubble disc diffusers. Each oxidation tank is equipped with a probe that measures the level of ammoniacal nitrogen. This setup is part of a cascade control system. In this system, the reading of ammoniacal nitrogen at the tank's output is used to regulate the process.

The control system adjusts the dissolved oxygen (DO) concentration within a specified range to maintain the desired levels of ammoniacal nitrogen. Essentially, the system ensures that the DO concentration is adjusted based on the ammoniacal nitrogen readings to optimize the treatment process. Once the DO setpoint value has been identified, a PID (Proportional-Integral-Derivative) controller evaluates the difference between the DO set-point and the DO concentration measured in the reactor, and according to this value controls the air flow rate to be blown. The objective is to keep the output ammonia nitrogen within a certain set range.

The aerated mixture from the 3 oxidation tanks flows into a common channel, it enters a distributor sump that divides the flow among 6 secondary sedimentation basins. These basins are grouped as 2 basins for each biological process line. It's important to note that the flow rate isn't necessarily evenly distributed across all 6 sedimentation tanks. This can cause variations in the operating conditions of each tank, meaning that some tanks may process more or less water than others. Each sedimentation tank is equipped with an overhead crane, a skimming blade (to remove floating materials) and a bottom scraper (to collect settled solids). The sludge coming from the Sedimentation Tanks 1 and 2 is collected in a separate well where there are two pumps (1+1) that recirculate the sludge back to the denitrification tanks. The sludge from Sedimentation Tanks 1, 2, 3, and 4 is collected in another sump where there are three pumps (2+1) which also recirculate sludge back to the denitrification tanks, along with the recirculated sludge from Sedimentation Tanks 1 and 2. The last unit of the waterline is the disinfection, carried out by dosing peracetic acid, in a contact basin in parallel lanes, obtained by inserting diverter baffles to give the basin an elongated shape with piston flow.

This type of flow is realised in open basins with a high length-to-width ratio, in which the longitudinal dispersion of fluid particles is minimal or completely absent. There are 2 reagent dosing pumps (1+1) and 2 storage tanks. As an alternative to peracetic acid, if this is not available, it is dosed sodium hypochlorite, by means of 4 pumps. The purified effluent is discharged into the receiving water body, the river Fosso Razzo, outside the plant perimeter, via a pipeline. In this section, a comprehensive breakdown of the sludge line in our wastewater treatment plant will be provided. The sludge line is responsible for the management, treatment, and disposal of the solids that are separated from the wastewater during the treatment process. Proper handling of sludge is crucial for both environmental protection and operational efficiency.

Primary, secondary and extra sludge entering the plant are conveyed into 2 pre-thickener parallel tanks, this unit is used to increase the solids content of the sludge by removing some of the water associated with it and thus achieving volumetric reduction. The sludge is allowed to settle and compact and once thickened, is removed from the lower part of the tank, while the supernatant is extracted at the top and recirculated (by gravity) at the head of the water line, after the inlet sampler related to the sewage effluent, thus representing an additional pollutant load. There is an activated charcoal deodorising system for the intake air. Each thickener is equipped with 2 pumps that send the sludge to the aerobic stabilization. The thickened sludge is subsequently sent into 2 parallel biological tanks (2812 m³ each) that hydrodynamically behave like CSTR reactors and in which the aerobic stabilisation phase takes place, aimed at reducing putrescibles and bacterial load, together with the removal of suspended solids.

At present, one and a half tanks are active. Aeration is carried out by means of a submerged mechanical system of the radial jet type, a device consisting of a submersible electric motor directly connected to a hydraulic section with a radial impeller and peripheral diffuser equipped with a suction duct and radial expulsion channels. The air sucked in through a special vertical duct communicating with the atmosphere then mixes with the pumped sludge and is expelled into the tank through the radial channels. There are 4 radial jets in the whole tank, while in the half tank there is currently 1 radial jet, but there are plans to install a second one. The final stage of the sludge line is represented by the mechanical dewatering unit, composed of 2 rotating drum centrifuges. Their performance is improved by the addition of an organic polyelectrolyte with which the sludge is preliminarily additivities, which then undergoes a chemical conditioning process to improve its dehydratable. The high rotational speed of the drum imparts centrifugal acceleration to the sludge, causing the separation of solids that settle against the device wall and are then conveyed towards the outlet end by an internal screw conveyor, while the supernatant is recirculated at the head of the water line, after the inlet sample. The final sludge coming out of the dewatering unit is disposed in 2 silos of about 70 m³ each, where these silos are full, they're emptied into roll-off skips that can then be transported to their final destinations. The following block flow helps visualize the layout of the plant as well as the flowrate direction between the units.

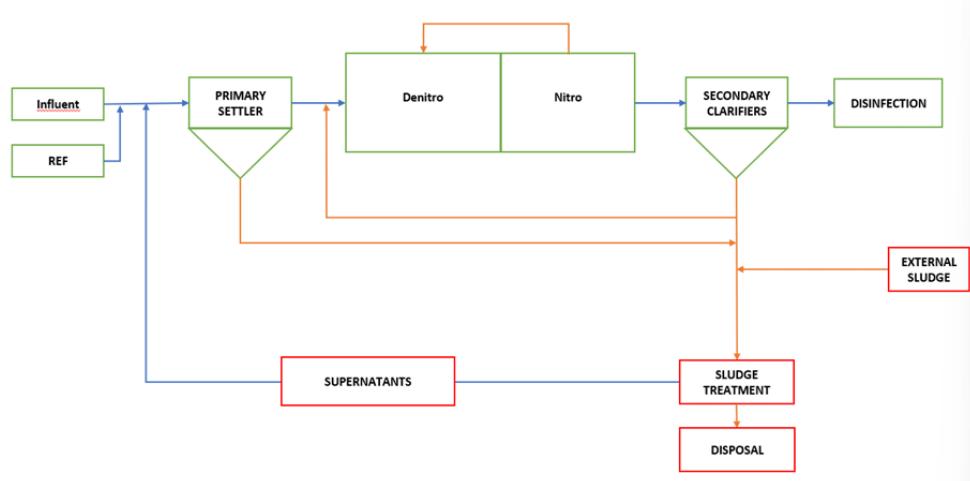


Figure 4, Block-flow diagram

PLANT CONFIGURATION (as it is)

For the calculation of concentrations and mass loads, the pollutant taken as reference for all the formulas will be the TSS, since it is present both in the water and in the sludge line. The influent flowrate is calculated as the sum of the external liquid waste, influent and supernatants flowrates. For the external liquid waste, the flowrate and the concentration of pollutants have been provided by the plant; consequently, it was only necessary to calculate the mass loads as follows:

$$TSS \left[\frac{kg}{d} \right] = TSS \left[\frac{mg}{L} \right] * Q \left[\frac{m^3}{d} \right]$$

For the influent, such as for the previous contribution, flowrates and concentrations were given and the mass loads were calculated. In the supernatants, only some concentrations were known: the flowrate and the TSS concentration had to be derived after the dimensioning of the plant, considering that the sludge line is the last part of it.

Primary Settler

Q (m ³ /d)	19551
COD (mg/L)	334
BOD ₅ (mg/L)	149
TSS (mg/L)	125
N-NH ₄ (mg/L)	28
TN (mg/L)	40
Ptot (mg/L)	5
COD (kg/d)	6736
BOD ₅ (kg/d)	2919
TSS (kg/d)	2453
N-NH ₄ (kg/d)	550
TN (kg/d)	781
Ptot (kg/d)	94

table n.4, influent flowrate, concentrations, and mass loads

The flowrate is given by the sum of the following members

$$Q \left[\frac{m^3}{d} \right] = Q_{ext} + Q_{in} + Q_{super}$$

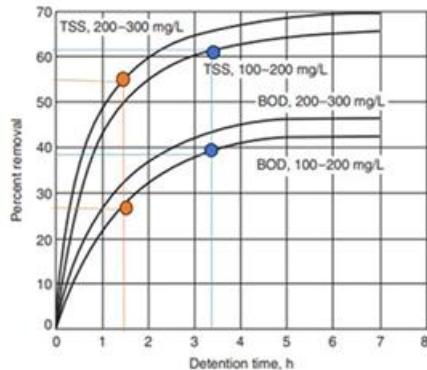
The mass loads follow the same principle of summing the different components entering the plant; so, the concentrations of the pollutants are calculated as follows:

$$TSS \left[\frac{mg}{L} \right] = \frac{TSS \left[\frac{kg}{d} \right]}{Q \left[\frac{m^3}{d} \right]}$$

Also, as the volume of the reactor was given, it was possible to calculate the HRT (Hydraulic Retention Time, time for which water is processed inside a unit):

$$HRT[h] = \frac{V}{Q}$$

The percentages of removal of the contaminants from the primary settler are calculated through a graph which relates the percentages with the HRT:



Sludges from the primary settler

Exiting the settler, the flowrate going in the sludge was given, as for the TS%: the mass load for the TS sent in the sludge line was then found:

$$TS \left[\frac{kg}{d} \right] = \frac{Q_{WI} * TS\% * 10000}{1000}$$

Biological reactor (Denitrification + Nitrification)

The inlet flowrate in the biological reactor was found as the difference between what is entering the primary settler and what is going in the sludge line:

$$Q_{bio} \left[\frac{m^3}{d} \right] = Q_{in} - Q_{WI}$$

The mass loads were then calculated applying the reduction factor for each constituent:

$$TSS \left[\frac{kg}{d} \right] = TSS - TSS * R\%$$

Knowing mass loads and flowrates, concentrations were calculated. Since the plant exists, the volumes of denitrification and nitrification tanks were known. The HRT for each unit was then found, considering that HRT nitro > HRT denitro. Also, the concentration of MLSS was provided, so it was possible to calculate the TS%:

$$TS\% = \frac{MLSS}{10000}$$

In the end, the SRT (Sludge Retention Time, time for which the solid material is kept inside a unit) was calculated, considering both the volumes of the denitrification and nitrification tanks:

$$SRT [h] = \frac{(V_{NITRO} + V_{DENITRO}) * MLSS}{(Q_{WI} * TS\% * 10000) + (Q_{eff} * TSS_{eff})}$$

Secondary Clarifier

The secondary clarifier was composed by 6 units: through mathematical formulas, it was possible to calculate the Area and the Volume for each unit for a given height:

$$A [m^2] = \pi r^2$$

$$V [m^3] = A * h$$

For the calculation of the CIS and CSS the following formulas were applied:

$$Cis \left[\frac{m}{h} \right] = \frac{Q}{A}$$

$$CSS \left[\frac{\frac{kg}{m^2}}{h} \right] = \frac{Q_{bio} * MLSS}{A}$$

After these, the HRT of the secondary clarifier was found.

Sludges from the secondary clarifier

The flowrate coming into the sludge line was already given, so it was possible to calculate the TS% and then the mass load:

$$TS\% = 2 * MLSS$$

$$TS \left[\frac{kg}{d} \right] = \frac{Q_{WII} * TS\% * 10000}{1000}$$

Effluent

The effluent flowrate has been calculated as the difference between the flowrate coming out from the secondary treatments and the secondary sludges flowrate:

$$Q_{eff} \left[\frac{m^3}{d} \right] = Q_{bio} - Q_{WII}$$

Since the concentration of the effluent contaminants were provided, the mass loads were then found through already shown formulas.

Q (m ³ /d)	19567
COD (mg/L)	31.2
BOD5 (mg/L)	6.7
TSS (mg/L)	7.7
N-NH4 (mg/L)	5.7
N-NO3 (mg/L)	4.8
N-NO2 (mg/L)	1.8
TN (kg/d)	14
Ptot (mg/L)	1.9
COD (kg/d)	610
BOD5 (kg/d)	132
TSS (kg/d)	150
N-NH4 (kg/d)	112
N-NO3 (mg/L)	93
N-NO2 (mg/L)	93
TN (kg/d)	275
Ptot (kg/d)	37.0000

Table n.5, effluent flowrate, concentrations, and mass loads

SLUDGE LINE

Mixed sludges

For the mixed sludge, the flowrate and the mass load are given by the sum between what has been found in the primary and secondary sludges. The concentration in % is then calculated:

$$Q_w \left[\frac{m^3}{d} \right] = Q_{wI} + Q_{wII}$$

$$TS \left[\frac{kg}{d} \right] = TS_I + TS_{II}$$

$$TS\% = \frac{TS * 1000}{Q_w * 10000}$$

Pre thickener

In the pre thickener, the flowrate is the same of the mixed sludges ‘one; since the percentage of remotion and the TS% were given, the mass load was calculated as shown before:

$$Q \left[\frac{m^3}{d} \right] = Q_{mixed}$$

Supernatants from prethickener

Considering the percentage of remotion, the mass load was given by the difference between the TS present in the prethickener and the removed ones:

$$TS \left[\frac{kg}{d} \right] = TS - TS * R\%$$

The flowrate was consequently calculated:

$$Q \left[\frac{m^3}{d} \right] = \frac{TS * 1000}{TS\% * 10000}$$

Aerobic stabilization

Only the R%TS was to be inserted manually, while the other parameters of the aerobic stabilization unit were determined considering the previous unit:

$$Q \left[\frac{m^3}{d} \right] = Q_{preth} - Q_{out}$$

$$TS \left[\frac{kg}{d} \right] = TS_{preth} * R\%TS$$

$$TS\% = \frac{TS * 1000}{Q * 10000}$$

Dewatering unit

Since the TS% and the R%TS were already provided, the values for flowrate, mass load and WET were estimated as follows:

$$Q \left[\frac{m^3}{d} \right] = Q_{aer} - Q_{out}$$

$$TS \left[\frac{kg}{d} \right] = TS_{aer} * R\%TS$$

$$WET \left[\frac{kg}{d} \right] = \frac{TS}{TS\%}$$

Supernatants from dewatering unit

Considering the percentage of remotion, the mass load was given by the difference between the TS present in the prethickener and the removed ones:

$$Q \left[\frac{m^3}{d} \right] = Q_{aer}$$

$$TS \left[\frac{kg}{d} \right] = TS - TS * R\%TS$$

Supernatants going to the inlet of the plant

As said before, the concentration of almost all the pollutants were provided. The flowrate and the concentration of TSS were to be determined considering the values of the sludge line: since there were two supernatants' outlets, the total was calculated as the sum of respectively the flowrates and the mass loads:

$$Q_{sup} \left[\frac{m^3}{d} \right] = Q_{supI} + Q_{supII}$$

$$TS_{sup} \left[\frac{kg}{d} \right] = TS_{supI} + TS_{supII}$$

Knowing the flowrate and the mass load, the concentration was estimated as shown before.

OPTIMIZATION PROJECT

The future design scenario after the optimization process will be characterized by an addition of a new biological line, in support of the three already existing lines, a new two-line for the secondary clarification, and an upgrade of the sludge line with the addition the anaerobic digestion, whose supernatant will have the following

characteristics:

NEW SUPERNATANTS	Unit	Value
Q flow	m^3/d	~300
bCOD	mg/L	~500
TSS	mg/L	~2000
N-NH₄	mg/L	~400–600
P	mg/L	~80–150

Table n.6, New supernatants flowrate and concentrations

PLANT CONFIGURATION (optimization)

As in the previous chapter, for the calculation of concentrations and mass loads, the pollutant taken as reference for all the formulas will be the TSS, since it is present both in the water and in the sludge line. The influent flowrate is calculated as the sum of the external liquid waste, influent and supernatants flowrates. For the external liquid waste, the flowrate and the concentration of pollutants have been provided by the plant; consequently, it was only necessary to calculate the mass loads as follows:

$$TSS \left[\frac{kg}{d} \right] = TSS \left[\frac{mg}{L} \right] * Q \left[\frac{m^3}{d} \right]$$

For the influent, such as for the previous contribution, flowrates and concentrations were given and the mass loads were calculated. In the supernatants, only some concentrations were known: the flowrate and the TSS concentration had to be derived after the dimensioning of the plant, considering that the sludge line is the last part of it.

Primary Settler

Q (m ³ /d)	19551
COD (mg/L)	334
BOD5 (mg/L)	149
TSS (mg/L)	125
N-NH4 (mg/L)	28
TN (mg/L)	40
Ptot (mg/L)	5
COD (kg/d)	6736
BOD5 (kg/d)	2919
TSS (kg/d)	2453
N-NH4 (kg/d)	550
TN (kg/d)	781
Ptot (kg/d)	94

table n.4, influent flowrate, concentrations, and mass loads

The flowrate is given by the sum of the following members

$$Q \left[\frac{m^3}{d} \right] = Q_{ext} + Q_{in} + Q_{super}$$

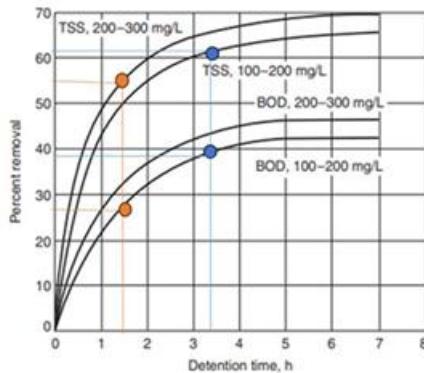
The mass loads follow the same principle of summing the different components entering the plant; so, the concentrations of the pollutants are calculated as follows:

$$TSS \left[\frac{mg}{L} \right] = \frac{TSS \left[\frac{kg}{d} \right]}{Q \left[\frac{m^3}{d} \right]}$$

Also, as the volume of the reactor was given, it was possible to calculate the HRT (Hydraulic Retention Time, time for which water is processed inside a unit):

$$HRT[h] = \frac{V}{Q}$$

The percentages of removal of the contaminants from the primary settler are calculated through a graph which relates the percentages with the HRT:



Sludges from the primary settler

Exiting the settler, the flowrate going in the sludge was given, as for the TS%: the mass load for the TS sent in the sludge line was then found:

$$TS \left[\frac{kg}{d} \right] = \frac{Q_{WI} * TS\% * 10000}{1000}$$

External COD dosage

To calculate how much external chemical oxygen demand (COD) in the form of acetate (CH_3COOH) had to be dosed before the activated sludge process in order to achieve the desired carbon-to-nitrogen (C/N) ratio, the followings steps have been followed.

1. C/N Ratio:
2. Required COD to obtain the desired C/N Ratio.
3. COD to dose: This is the additional COD required to achieve the desired COD level.
4. Acetate (CH_3COOH) dosing: $=770\text{ kg d} \times 8.0 = 6162\text{ kg d}$ $- 4251\text{ kg d} = 1911\text{ kg d}$ Acetate (CH_3COOH) is being used as the external COD source, and its stoichiometric relation with oxygen (O_2) helps to determine the mass of acetate required.
5. Acetate Solution Properties: 64.05 The acetate solution you are using contains 50% by mass of CH_3COOH . To find the total mass of solution to dose.
6. Volume of Solution to dose: Given the density of the acetate solution is 1.0557 kg/L, it was possible to calculate the volume of solution to dose:

Biological reactor (Denitrification + Nitrification)

The inlet flowrate in the biological reactor was found as the difference between what is entering the primary settler and what is going in the sludge line:

$$Q_{bio} \left[\frac{m^3}{d} \right] = Q_{in} - Q_{WI}$$

The mass loads were then calculated applying the reduction factor for each constituent:

$$TSS \left[\frac{kg}{d} \right] = TSS - TSS * R\%$$

Knowing mass loads and flowrates, concentrations were calculated. Since the plant exists, the volumes of denitrification and nitrification tanks were known. The HRT for each unit was then found, considering that $HRT_{nitro} > HRT_{denitro}$. Also, the concentration of MLSS was provided, so it was possible to calculate the TS%:

$$TS\% = \frac{MLSS}{10000}$$

In the end, the SRT (Sludge Retention Time, time for which the solid material is kept inside a unit) was calculated, considering both the volumes of the denitrification and nitrification tanks:

$$SRT [h] = \frac{(V_{NITRO} + V_{DENITRO}) * MLSS}{(Q_{WI} * TS\% * 10000) + (Q_{eff} * TSS_{eff})}$$

Secondary Clarifier

The secondary clarifier was composed by 6 units: through mathematical formulas, it was possible to calculate the Area and the Volume for each unit for a given height:

$$A [m^2] = \pi r^2$$

$$V [m^3] = A * h$$

For the calculation of the CIS and CSS the following formulas were applied:

$$Cis \left[\frac{m}{h} \right] = \frac{Q}{A}$$
$$Css \left[\frac{kg}{m^2} \right] = \frac{Q_{bio} * MLSS}{A}$$

After these, the HRT of the secondary clarifier was found.

Sludges from the secondary clarifier

The flowrate coming into the sludge line was already given, so it was possible to calculate the TS% and then the mass load:

$$TS\% = 2 * MLSS$$
$$TS \left[\frac{kg}{d} \right] = \frac{Q_{WII} * TS\% * 10000}{1000}$$

Effluent

The effluent flowrate has been calculated as the difference between the flowrate coming out from the secondary treatments and the secondary sludges flowrate:

$$Q_{eff} \left[\frac{m^3}{d} \right] = Q_{bio} - Q_{WII}$$

Since the concentration of the effluent contaminants were provided, the mass loads were then found through already shown formulas.

Q (m ³ /d)	19567
COD (mg/L)	31.2
BOD5 (mg/L)	6.7
TSS (mg/L)	7.7
N-NH4 (mg/L)	5.7
N-NO3 (mg/L)	4.8
N-NO2 (mg/L)	1.8
TN (kg/d)	14
Ptot (mg/L)	1.9
COD (kg/d)	610
BOD5 (kg/d)	132
TSS (kg/d)	150
N-NH4 (kg/d)	112
N-NO3 (mg/L)	93
N-NO2 (mg/L)	93
TN (kg/d)	275
Ptot (kg/d)	37.0000

Table n.5, effluent flowrate, concentrations, and mass loads

SLUDGE LINE

Mixed sludges

For the mixed sludge, the flowrate and the mass load are given by the sum between what has been found in the primary and secondary sludges. The concentration in % is then calculated:

$$Q_w \left[\frac{m^3}{d} \right] = Q_{wI} + Q_{wII}$$

$$TS \left[\frac{kg}{d} \right] = TS_I + TS_{II}$$

$$TS\% = \frac{TS * 1000}{Q_w * 10000}$$

Pre thickener

In the pre thickener, the flowrate is the same of the mixed sludges 'one; since the percentage of remotion and the TS% were given, the mass load was calculated as shown before:

$$Q \left[\frac{m^3}{d} \right] = Q_{mixed}$$

Supernatants from prethickener

Considering the percentage of remotion, the mass load was given by the difference between the TS present in the prethickener and the removed ones:

$$TS \left[\frac{kg}{d} \right] = TS - TS * R\%$$

The flowrate was consequently calculated:

$$Q \left[\frac{m^3}{d} \right] = \frac{TS * 1000}{TS\% * 10000}$$

Aerobic stabilization

Only the R%TS was to be inserted manually, while the other parameters of the aerobic stabilization unit were determined considering the previous unit:

$$Q \left[\frac{m^3}{d} \right] = Q_{preth} - Q_{out}$$

$$TS \left[\frac{kg}{d} \right] = TS_{preth} * R\%TS$$

$$TS\% = \frac{TS * 1000}{Q * 10000}$$

Dewatering unit

Since the TS% and the R%TS were already provided, the values for flowrate, mass load and WET were estimated as follows:

$$Q \left[\frac{m^3}{d} \right] = Q_{aer} - Q_{out}$$

$$TS \left[\frac{kg}{d} \right] = TS_{aer} * R\%TS$$

$$WET \left[\frac{kg}{d} \right] = \frac{TS}{TS\%}$$

Supernatants from dewatering unit

Considering the percentage of remotion, the mass load was given by the difference between the TS present in the prethickener and the removed ones:

$$Q \left[\frac{m^3}{d} \right] = Q_{aer}$$

$$TS \left[\frac{kg}{d} \right] = TS - TS * R\%TS$$

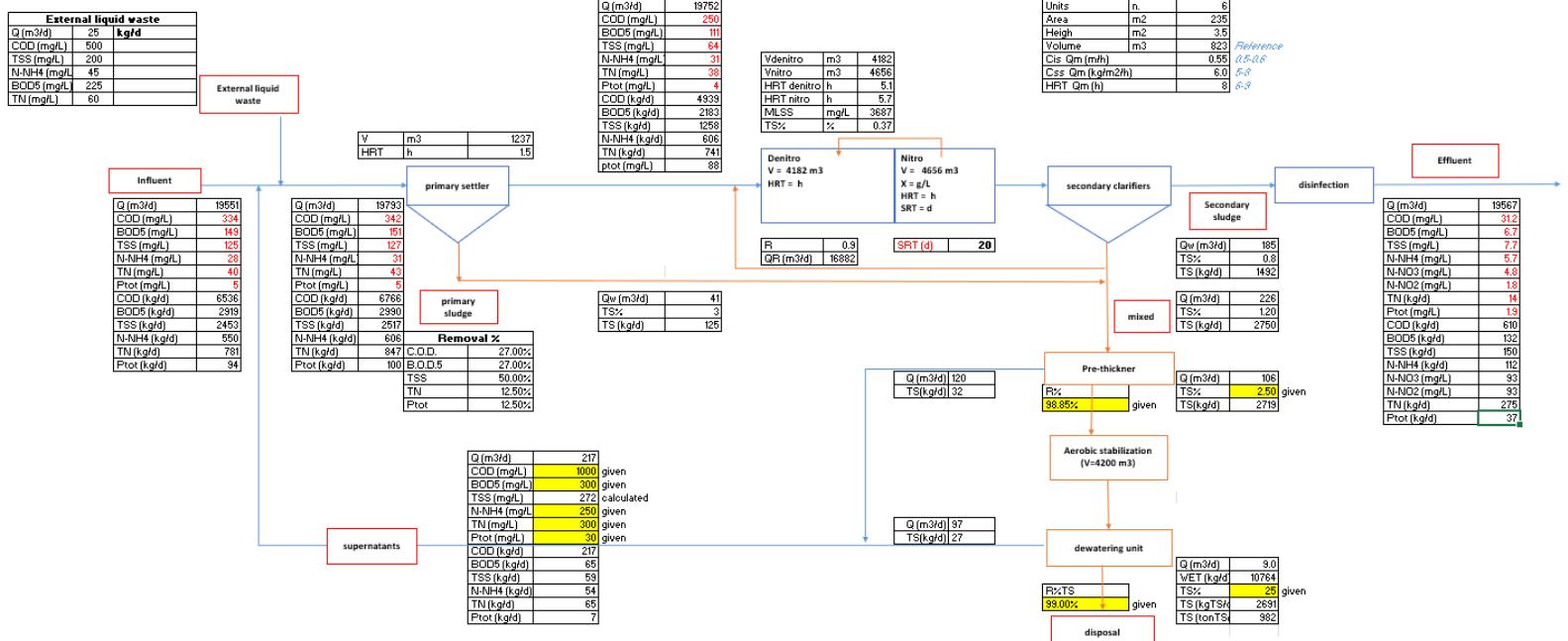
Supernatants going to the inlet of the plant

As said before, the concentration of almost all the pollutants were provided. The flowrate and the concentration of TSS were to be determined considering the values of the sludge line: since there were two supernatants' outlets, the total was calculated as the sum of respectively the flowrates and the mass loads:

$$Q_{sup} \left[\frac{m^3}{d} \right] = Q_{supI} + Q_{supII}$$

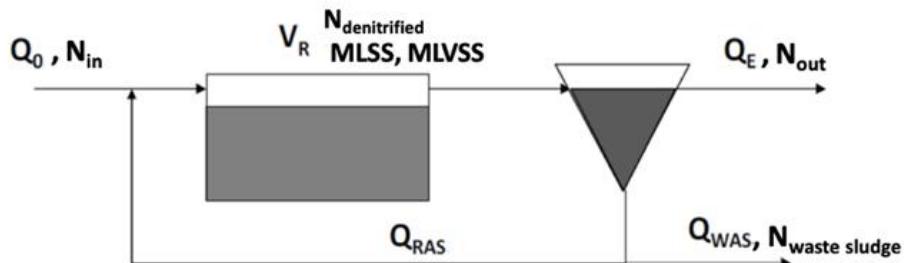
$$TS_{sup} \left[\frac{kg}{d} \right] = TS_{supI} + TS_{supII}$$

Knowing the flowrate and the mass load, the concentration was estimated as shown before.



Nitrogen Mass Balance

Figure for nitrogen mass balance



Nitrogen mass balance

At steady state conditions

$$NL_{in} = NL_{waste\ sludge} + NL_{out} + NL_{den}$$

NL_{in} = Total influent nitrogen load (kg/d)

$NL_{waste\ sludge}$ = Nitrogen load removed with sludge (kg/d)

NL_{out} = Nitrogen load exiting with the treated effluent (kg/d)

NL_{den} = Total nitrogen load that is denitrified (kg/d)

- If we know the influent and treated effluent and waste sludge nitrogen concentration and the respective flows we can find NL_{in} , $NL_{waste\ sludge}$ and NL_{out} . Then we can solve the above equation for NL_{den}

Nitrification efficiency

It is the nitrogen load that is nitrified compared to the total nitrogen load that enters the system

$$E_n = (NL_{\text{nitrified}} / NL_{\text{in}}) * 100$$

E_n = Nitrification efficiency (%)

- $NL_{\text{nitrified}}$ = Nitrogen load that is nitrified (kg/d)

Where $NL_{\text{nitrified}} = NL_{\text{den}} + (NOx-N)L_{\text{out}} + (TN)L_{\text{sewage sludge}} - (NOx-N)L_{\text{in}}$

- NL_{den} = Total nitrogen load that is denitrified (kg/d)

- $(NOx-N)L_{\text{out}}$ is the nitrate and nitrite load that exits with the treated effluent (kg/d)

- $(NOx-N)L_{\text{sewage sludge}}$ is the nitrate and nitrite load of excess (waste) activated sludge (kg/d)

- $(NOx-N)L_{\text{in}}$ is the nitrite and nitrate load that enters with wastewater (kg/d). This is zero in almost all cases

Nitrification efficiency of the nitrifiable nitrogen load entering

$$E_{nn} = [NL_{\text{nitrified}} / (NL_{\text{in}} - NL_{\text{waste sludge}} - NL_{\text{nb org}}_{\text{out}} - (NOx-N)L_{\text{in}})] * 100$$

- E_{nn} = Nitrification efficiency based on the nitrifiable nitrogen load (%)
- $NL_{\text{nb org}}_{\text{out}}$ = Non biodegradable organic nitrogen leaving with the treated effluent (kg/d)
- $(NOx-N)L_{\text{in}}$ is the nitrate and nitrite load that enters with wastewater. This is in almost all case zero (kg/d)

Denitrification efficiency

Nitrogen denitrified compared to the total nitrogen load entering the system

$$E_d = (NL_{\text{den}} / NL_{\text{in}}) * 100$$

❖ E_d = Denitrification efficiency (%)

❖ NL_{den} = Total nitrogen load that is denitrified (kg/d)

❖ NL_{in} = Total influent nitrogen load (kg/d)

Nitrogen denitrified compared to the total nitrogen

entering the system that can denitrify

$$E_{dd} = [NL_{\text{den}} / (NL_{\text{nitrified}} + (NOx-N)L_{\text{in}})] * 100$$

❖ E_{dd} = Denitrification efficiency based on the nitrogen load that is denitrifiable (%)

❖ $NL_{\text{nitrified}}$ = Nitrogen load that is nitrified (kg/d)

❖ NL_{den} = Total nitrogen load that is denitrified (kg/d)

Ntot ing kg/d	Nout effl kg/d	Solids in Sludge Kgtot	Days d	Solids in Sludge Kg/d	TS% %	N%TS %
6538	610	80730	30	2691	25	4

N in the sludge Kg/d	Nden.to kg/d	N-NOx ing kg/d	N-NOx out kg/d	N nitr.to kg/d	N den.bile kg/d	N nitr.bile kg/d
108	358	111	129	598	598	722

E den sul tot	E nitr sul tot	E den sul den.bile	E nitr sul nit.bile
%	%	%	%
48.4	80	95	70.4

The above parameters were calculated thank to the following formulas:

$$Solids \text{ in sludge } [kg \text{ tot}] = \frac{kg \text{ of sludge} * \%TS}{100}$$

$$Solids \text{ in sludge } [\frac{kg}{d}] = \frac{Solids \text{ in sludge } [kg \text{ tot}]}{days}$$

$$N \text{ in the sludge } [\frac{kg}{d}] = \frac{N\%TS}{100} * Solids \text{ in the sludge } [\frac{kg}{d}]$$

$$N_{denitrified} = N_{tot \text{ ing}} \left[\frac{kg}{d} \right] - N \text{ in the sludge } \left[\frac{kg}{d} \right] - N_{out} \left[\frac{kg}{d} \right]$$

$$N \text{ nitr. to } \left[\frac{kg}{d} \right] = N_{den} \left[\frac{kg}{d} \right] + NNOx \text{ in } \left[\frac{kg}{d} \right] + NNOx \text{ out } \left[\frac{kg}{d} \right]$$

$$N_{den. bile} \left[\frac{kg}{d} \right] = NNOx \text{ in } \left[\frac{kg}{d} \right] + N \text{ nitr. to } \left[\frac{kg}{d} \right]$$

$$N_{nitr. bile} = N_{tot \text{ in}} \left[\frac{kg}{d} \right] - N \text{ in the sludge } \left[\frac{kg}{d} \right] - NNOx \text{ in } \left[\frac{kg}{d} \right]$$

$$E \text{ den } [\%] \text{ on the total} = \frac{N_{den. to} [\frac{kg}{d}]}{N_{tot \text{ in}} [\frac{kg}{d}]}$$

$$E \text{ den } [\%] \text{ on den. bile} = \frac{N_{den. to} [\frac{kg}{d}]}{N_{den. bile} [\frac{kg}{d}]}$$

$$E \text{ nitr } [\%] \text{ on the total} = \frac{N_{nitr. to} [\frac{kg}{d}]}{N_{tot \text{ in}} [\frac{kg}{d}]}$$

$$E \text{ nitr } [\%] \text{ on nitr. bile} = \frac{N_{nitr. to} [\frac{kg}{d}]}{N_{nitr. bile} [\frac{kg}{d}]}$$

P mass balance

Phosphorus mass balance

At steady state conditions

$$\begin{aligned} LTP_{in} &= LTP_{out} + LTP_{WAS} = \\ &= PO_4-P + TSS_{out} * P\%TS + MLSS_{WAS} * P\%TS_{WAS} \end{aligned}$$

Ptot ing kg/d	Pout effl kg/d	P in Sludge		Days d	Solids in Sludge Kg/d	TS% %	P%TS ave %
100	37	63	1890	30	2691	25	4

$$Premoved \text{ in the sludge } \left[\frac{kg}{d} \right] = Ptot \text{ ing } \left[\frac{kg}{d} \right] - Pout \text{ effl } \left[\frac{kg}{d} \right]$$

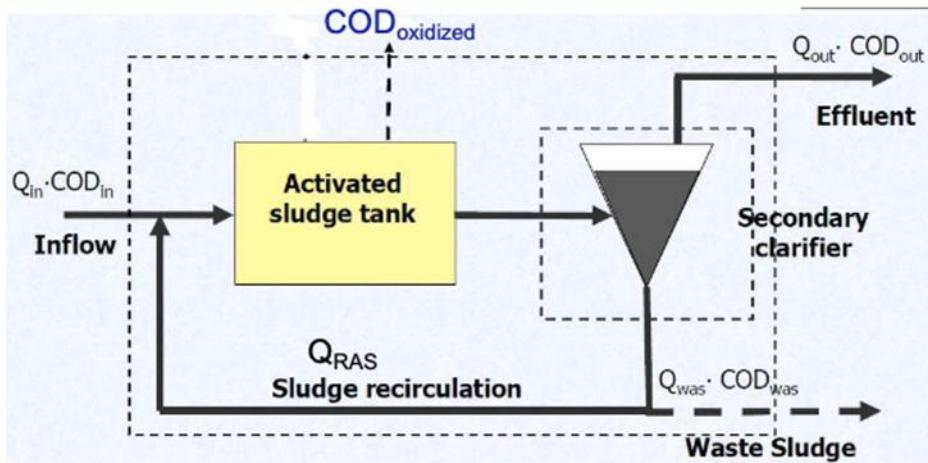
$$Solids \text{ in the sludge } \left[\frac{kgTStot}{month} \right] = kg \text{ of sludge } * \frac{TS\% \text{ average}}{100}$$

$$Solids \text{ in the sludge } \left[kg \frac{TS}{d} \right] = \frac{solids \text{ in the sludge } \left[\frac{kgTStot}{month} \right]}{days}$$

$$P\%TS \text{ Average} = \frac{Premoved \text{ in the sludge } \left[\frac{kg}{month} \right]}{Solids \text{ in sludge } \left[\frac{kgTStot}{month} \right]} * 100$$

COD Mass Balance

Mass balances for COD in AS process



- ❖ At steady state conditions $dC/dt = 0$ and thus no further accumulation takes place

$$\text{Mass balance } COD_{in} = COD_{out} + COD_{consumed}$$

- ❖ Influent COD load = $Q_{in} \cdot COD_{in}$ (kg/d)
- ❖ Treated effluent COD load = $Q_{out} \cdot COD_{out}$ (kg/d)
- ❖ COD that is wasted with sludge = $Q_{WAS} COD_{WAS}$ (kg/d)
- ❖ COD that is oxidized and thus lost = $COD_{oxidized}$ (kg/d)

L_COD in	Kg COD/d	493
L_COD_out	Kg COD/d	610
L_COD_sludge	Kg COD/d	2119
L_COD_denitr	Kg COD/d	1161
L_COD_respiraz	Kg COD/d	1049

$$L COD_{in} \left[kg \frac{COD}{d} \right] = Q_{in} \left[\frac{m^3}{d} \right] * COD_{in} \left[\frac{mg}{L} \right]$$

$$L CODout \left[kg \frac{COD}{d} \right] = Qin \left[\frac{m^3}{d} \right] * CODout \left[\frac{mg}{L} \right]$$

$$LCOD sludge \left[\frac{kg COD}{d} \right] = 1,42 * Px, tss \left[\frac{kg}{d} \right]$$

$$L COD denitrified \left[kg \frac{COD}{d} \right] = 2,86 * L Ndenitrified \left[\frac{kg}{d} \right]$$

$$L COD respiraz \left[\frac{kg COD}{d} \right] = L COD in - L COD out - L COD sludge - L COD denitrif$$

ASM – Activated Sludge Model series

In this section all the ASI model will be described in detail, although only the ASM2d was used to simulate the optimization of our plant. The detailed application of the ASM2d model to our WWTP will be added under the section “ASIM2d application for the simulation of the plant optimization”. The following table resumes the main difference between the three models:

Model	Year	Focus	Process modelled	P removal
ASIM1	1987	Carbon and N removal	Heterotrophic growth, nitrification and denitrification	No
ASIM2	1995	Carbon, N and P removal	Removal of P, heterotrophic growth, nitrification and denitrification	Yes
ASIM3	2000	Improved carbon, N and P removal	More realistic carbon storage, heterotrophic growth, nitrification and denitrification	No

ASM1

The ASM1 was the first model of the ASMs series and the basis of all the following implementations. It is composed by several differential equations describing different processes:

This model is very used by researchers and technicians because of its simplicity, although not very precise, it requires for a relatively small amount of information. Moreover, the huge part of WWTPs around the world just operate the biological removal of C and N and not P removal.

The ASM1 model was developed to simulate the biological processes responsible for carbon and nitrogen removal in activated sludge systems. The model includes processes such as the heterotrophic biomass growth (for organic carbon removal), the autotrophic nitrification (conversion of ammonia to nitrate) and the anoxic denitrification (conversion of nitrate to nitrogen gas in the absence of oxygen).

The model considers variables like organic substrates (readily biodegradable and slowly biodegradable), nitrogen compounds (ammonia, nitrate, etc.), oxygen, and microbial biomass (heterotrophs and autotrophs). It assumes no biological phosphorus removal and does not explicitly model some of the more complex biochemical reactions present in real systems.

ASM1 takes into account 13 different components:

1. Soluble COD, S_s
2. Particulate COD, X_s
3. Heterotrophic biomass, as COS, X_{HB}
4. Autotrophic biomass, as COD, X_{BA}
5. Not-biodegradable soluble COD, S_I
6. Not-biodegradable particulate COD, X_I & X_P
7. Ammonia nitrogen, SNH

8. Oxidized nitrogen ($\text{NO}_2 + \text{NO}_3$), SNO
9. Soluble organic nitrogen, SND
10. Particulate organic nitrogen, XND
11. Inert organic nitrogen, XNI & XNP
12. Dissolved oxygen, SO
13. Alkalinity, SAL

It includes 8 different processes linked to 8 different kinetic equations:

1. Aerobic growth of heterotrophs: $S_s + S_{nh} + S_o \rightarrow X_{BH}$
2. Anoxic growth of heterotrophs: $S_s + S_{NO} + S_{NH} \rightarrow X_{BH}$
3. Aerobic growth of autotrophs: $S_{NH} + S_o \rightarrow X_{BA} + S_{NO}$
4. Decay of heterotrophs: $X_{BH} \rightarrow X_p + X_s + X_{ND}$
5. Decay of autotrophs: $X_{BA} \rightarrow X_p + X_s + X_{ND}$
6. Ammonification $S_{ND} \rightarrow S_{NH}$
7. Hydrolisis of Xs: $X_s \rightarrow S_s$
8. Hydrolisis of XND: $X_{ND} \rightarrow S_{ND}$

ASM2

ASM2 is an extension of ASM1, starting from the same set of processes, it includes then also biological and chemical removal of phosphorous. As a consequence, a number of anaerobic processes were added in the model matrix. The model includes processes as the uptake of P thanks to the Phosphorus Accumulating Organisms (PAOs), these organisms uptake phosphate under aerobic conditions and release it under anaerobic conditions, in addition there's also the storage and release of the P. In addition to carbon and nitrogen-related components, ASM2 adds phosphorus-related variables, including Polyphosphate (storage form of phosphorus) and Phosphorus accumulating organisms (PAOs).

Both ASM2 and ASM2d also consider the chemical precipitation of phosphate within the activated sludge process.

ASM2 takes into account 19 different components:

1. Dissolved Oxygen, SO₂
2. Readily biodegradable substrate, SF
3. Fermentation products (Acetate), SA
4. Ammonium, SNH₄
5. Nitrate and Nitrite, SNO
6. Phosphate, SPO₄
7. Inert non-biodegradable organics, Si
8. Bicarbonate alkalinity, Salk,

9. Dinitrogen at 0.78 atm and 20 degrees, SN2,
10. Particulate inert non-biodegradable organics, Xi
11. Particulate slowly biodegradable substrate, Xs
12. Particulate heterotrophic biomass, XH
13. Particulate P accumulating organisms, XPAO
14. Particulate stored poly-P of PAO, XPP
15. Particulate organic storage products of PAO, XPHA
16. Particulate autotrophic biomass, XA
17. Ferric hydroxide, XMeOH
18. Ferric phosphate, XMeP
19. Particulate material, XTSS

It includes 21 different processes linked to 8 different kinetic equations:

Hydrolysis processes:

- 1 Aerobic hydrolysis $K_h \cdot \frac{S_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{X_S/X_H}{K_X+X_S/X_H} \cdot X_H$
- 2 Anoxic hydrolysis $K_h \cdot \eta_{NO_3} \cdot \frac{K_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{S_{NO_3}}{K_{NO_3}+S_{NO_3}} \cdot \frac{X_S/X_H}{K_X+X_S/X_H} \cdot X_H$
- 3 Anaerobic hydrolysis $K_h \cdot \eta_{fe} \cdot \frac{K_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{K_{NO_3}}{K_{NO_3}+S_{NO_3}} \cdot \frac{X_S/X_H}{K_X+X_S/X_H} \cdot X_H$

Heterotrophic organisms: X_H

- 4 Growth on fermentable substrates, S_F $\mu_H \cdot \frac{S_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{S_F}{K_F+S_F} \cdot \frac{S_F}{S_F+S_A} \cdot \frac{S_{NH_4}}{K_{NH_4}+S_{NH_4}} \cdot \frac{S_{PO_4}}{K_P+S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK}+S_{ALK}} \cdot X_H$
- 5 Growth on fermentation products, S_A $\mu_H \cdot \frac{S_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{S_A}{K_A+S_A} \cdot \frac{S_A}{S_F+S_A} \cdot \frac{S_{NH_4}}{K_{NH_4}+S_{NH_4}} \cdot \frac{S_{PO_4}}{K_P+S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK}+S_{ALK}} \cdot X_H$
- 6 Denitrification on fermentable substrates, S_F $\mu_H \cdot \eta_{NO_3} \cdot \frac{K_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{S_F}{K_F+S_F} \cdot \frac{S_F}{S_F+S_A} \cdot \frac{S_{NH_4}}{K_{NH_4}+S_{NH_4}} \cdot \frac{S_{NO_3}}{K_{NO_3}+S_{NO_3}} \cdot \frac{S_{ALK}}{K_{ALK}+S_{ALK}} \cdot \frac{S_{PO_4}}{K_P+S_{PO_4}} \cdot X_H$
- 7 Denitrification on fermentation products, S_A $\mu_H \cdot \eta_{NO_3} \cdot \frac{K_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{S_A}{K_A+S_A} \cdot \frac{S_A}{S_F+S_A} \cdot \frac{S_{NH_4}}{K_{NH_4}+S_{NH_4}} \cdot \frac{S_{NO_3}}{K_{NO_3}+S_{NO_3}} \cdot \frac{S_{ALK}}{K_{ALK}+S_{ALK}} \cdot \frac{S_{PO_4}}{K_P+S_{PO_4}} \cdot X_H$
- 8 Fermentation $q_{fe} \cdot \frac{K_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{K_{NO_3}}{K_{NO_3}+S_{NO_3}} \cdot \frac{S_F}{K_{fe}+S_F} \cdot \frac{S_{ALK}}{K_{ALK}+S_{ALK}} \cdot X_H$
- 9 Lysis $b_H \cdot X_H$

Phosphorus-accumulating organisms (PAO): X_{PAO}

- 10 Storage of X_{PHA} $q_{PHA} \cdot \frac{S_A}{K_A+S_A} \cdot \frac{S_{ALK}}{K_{ALK}+S_{ALK}} \cdot \frac{X_{PP}/X_{PAO}}{K_{PP}+X_{PP}/X_{PAO}} \cdot X_{PAO}$
- 11 Storage of X_{PP} $q_{PP} \cdot \frac{S_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{S_{PO_4}}{K_{PS}+S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK}+S_{ALK}} \cdot \frac{X_{PHA}/X_{PAO}}{K_{PHA}+X_{PHA}/X_{PAO}} \cdot \frac{K_{MAX}-X_{PP}/X_{PAO}}{K_{IPP}+K_{MAX}-X_{PP}/X_{PAO}} \cdot X_{PAO}$
- 12 Aerobic growth on X_{PHA} $\mu_{PAO} \cdot \frac{S_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{S_{NH_4}}{K_{NH_4}+S_{NH_4}} \cdot \frac{S_{ALK}}{K_{ALK}+S_{ALK}} \cdot \frac{S_{PO_4}}{K_P+S_{PO_4}} \cdot \frac{X_{PHA}/X_{PAO}}{K_{PHA}+X_{PHA}/X_{PAO}} \cdot X_{PAO}$
- 13 Lysis of X_{PAO} $b_{PAO} \cdot X_{PAO} \cdot S_{ALK} / (K_{ALK}+S_{ALK})$
- 14 Lysis of X_{PP} $b_{PP} \cdot X_{PP} \cdot S_{ALK} / (K_{ALK}+S_{ALK})$
- 15 Lysis of X_{PHA} $b_{PHA} \cdot X_{PHA} \cdot S_{ALK} / (K_{ALK}+S_{ALK})$

Nitrifying organisms (autotrophic organisms): X_{AUT}

- 16 Growth $\mu_{AUT} \cdot \frac{S_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{S_{NH_4}}{K_{NH_4}+S_{NH_4}} \cdot \frac{S_{PO_4}}{K_P+S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK}+S_{ALK}} \cdot X_{AUT}$

- 17 Lysis $b_{AUT} \cdot X_{AUT}$

Simultaneous precipitation of phosphorus with ferric hydroxide $Fe(OH)_3$

- 18 Precipitation $k_{PRE} \cdot S_{PO_4} \cdot X_{MeOH}$
- 19 Redissolution $k_{RED} \cdot X_{MeP} \cdot S_{ALK} / (K_{ALK} + S_{ALK})$

As per the ASM1 also the ASM2 and ASM2d have some limitation, such as the fact that they're only valid for municipal wastewater, the fact that they cannot model processes with an overflow of Sa to the aeration tanks. The wastewater must contain both Mg⁺⁺ and K+, it must have a nearly neutral pH, and the T shall be contained between 10 and 25 degrees.

ASM3

The discrepancy with the previous models (ASM1, ASM2 and ASM2d) is related to the assumption that the storage of the organic substrate is fundamental for the metabolism of heterotrophs. therefore, the S_s fraction, is stored as a cell component (X_{STO}) and is then used for bacterial growth. In the ASM3, there is no process of direct growth of heterotrophs on S_s, it only allows to deal with industrial wastewaters rich in S_s, where storing mechanisms are fundamental, and anaerobic conditions are often longer than expected.

Since several processes and equations are un-coupled in comparison to the ASM1, hence the obtained results are generally of higher quality.

ASM2 takes into account 21 different components:

1. Hydrolysis rate constant, K_h
2. Hydrolysis saturation constant, K_x
3. Storage rate constant, k_{STO}
4. Anoxic reduction factor, η_{NO}
5. S_o saturation constant, K_o
6. SND saturation constant, k_{ND}
7. S_s saturation constant, k_S
8. X_{STO} saturation constant, k_{STO}
9. Heterotrophic max growth rate, μ_h
10. SNH saturation constant, k_{NH}
11. X_h bicarbonate saturation constant, k_{HCO}
12. X_h aerobic endogenous respiration rate, b_{H,O2}
13. X_h anoxic endogenous respiration rate, b_{H,NO}
14. X_a aerobic endogenous respiration rate, b_{A,O2}
15. X_a anoxic endogenous respiration rate, b_{A,NO}
16. X_{STO} aerobic respiration rate, b_{STO,O2}
17. X_{STO} anoxic respiration rate, b_{STO,NO}
18. Autotrophic max growth rate, μ_a
19. SNH saturation constant for X_a, k_{a,NH}
20. Oxygen saturation for nitrifiers, k_{a,O}

21. Bicarbonate saturation for nitrifiers, Ka,HC

It includes 12 different processes:

Hydrolysis processes:

- 1 Aerobic hydrolysis $K_h \cdot \frac{S_{O_2}}{K_{O_2} + S_{O_2}} \cdot \frac{X_S/X_H}{K_X + X_S/X_H} \cdot X_H$
- 2 Anoxic hydrolysis $K_h \cdot \eta_{NO_3} \cdot \frac{K_{O_2}}{K_{O_2} + S_{O_2}} \cdot \frac{S_{NO_3}}{K_{NO_3} + S_{NO_3}} \cdot \frac{X_S/X_H}{K_X + X_S/X_H} \cdot X_H$
- 3 Anaerobic hydrolysis $K_h \cdot \eta_{fe} \cdot \frac{K_{O_2}}{K_{O_2} + S_{O_2}} \cdot \frac{K_{NO_3}}{K_{NO_3} + S_{NO_3}} \cdot \frac{X_S/X_H}{K_X + X_S/X_H} \cdot X_H$

Heterotrophic organisms: X_H

- 4 Growth on fermentable substrates, S_F $\mu_H \cdot \frac{S_{O_2}}{K_{O_2} + S_{O_2}} \cdot \frac{S_F}{K_F + S_F} \cdot \frac{S_F}{S_F + S_A} \cdot \frac{S_{NH_4}}{K_{NH_4} + S_{NH_4}} \cdot \frac{S_{PO_4}}{K_P + S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK} + S_{ALK}} \cdot X_H$
- 5 Growth on fermentation products, S_A $\mu_H \cdot \frac{S_{O_2}}{K_{O_2} + S_{O_2}} \cdot \frac{S_A}{K_A + S_A} \cdot \frac{S_A}{S_F + S_A} \cdot \frac{S_{NH_4}}{K_{NH_4} + S_{NH_4}} \cdot \frac{S_{PO_4}}{K_P + S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK} + S_{ALK}} \cdot X_H$
- 6 Denitrification with fermentable substrates, S_F $\mu_H \cdot \eta_{NO_3} \cdot \frac{K_{O_2}}{K_{O_2} + S_{O_2}} \cdot \frac{K_{NO_3}}{K_{NO_3} + S_{NO_3}} \cdot \frac{S_F}{K_F + S_F} \cdot \frac{S_F}{S_F + S_A} \cdot \frac{S_{NH_4}}{K_{NH_4} + S_{NH_4}} \cdot \frac{S_{PO_4}}{K_P + S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK} + S_{ALK}} \cdot X_H$
- 7 Denitrification with fermentation products, S_A $\mu_H \cdot \eta_{NO_3} \cdot \frac{K_{O_2}}{K_{O_2} + S_{O_2}} \cdot \frac{K_{NO_3}}{K_{NO_3} + S_{NO_3}} \cdot \frac{S_A}{K_A + S_A} \cdot \frac{S_A}{S_F + S_A} \cdot \frac{S_{NH_4}}{K_{NH_4} + S_{NH_4}} \cdot \frac{S_{PO_4}}{K_P + S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK} + S_{ALK}} \cdot X_H$
- 8 Fermentation $q_{fe} \cdot \frac{K_{O_2}}{K_{O_2} + S_{O_2}} \cdot \frac{K_{NO_3}}{K_{NO_3} + S_{NO_3}} \cdot \frac{S_F}{K_F + S_F} \cdot \frac{S_{ALK}}{K_{ALK} + S_{ALK}} \cdot X_H$
- 9 Lysis $b_H \cdot X_H$

Phosphorus-accumulating organisms (PAO): X_{PAO}

- 10 Storage of X_{PHIA} $q_{PHIA} \cdot \frac{S_A}{K_A + S_A} \cdot \frac{S_{ALK}}{K_{ALK} + S_{ALK}} \cdot \frac{X_{PP}/X_{PAO}}{K_{PP} + X_{PP}/X_{PAO}} \cdot X_{PAO}$
 - 11 Aerobic storage of X_{PP} $q_{PP} \cdot \frac{S_{O_2}}{K_{O_2} + S_{O_2}} \cdot \frac{S_{PO_4}}{K_{PS} + S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK} + S_{ALK}} \cdot \frac{X_{PHIA}/X_{PAO}}{K_{PHIA} + X_{PHIA}/X_{PAO}} \cdot \frac{K_{MAX} - X_{PP}/X_{PAO}}{K_{PP} + K_{MAX} - X_{PP}/X_{PAO}} \cdot X_{PAO}$
 - 12 Anoxic storage of X_{PP} $\rho_{12} = \rho_{11} \cdot \eta_{NO_3} \cdot \frac{K_{O_2}}{S_{O_2}} \cdot \frac{S_{NO_3}}{K_{NO_3} + S_{NO_3}}$
 - 13 Aerobic growth on X_{PHIA} $\mu_{PAO} \cdot \frac{S_{O_2}}{K_{O_2} + S_{O_2}} \cdot \frac{S_{NH_4}}{K_{NH_4} + S_{NH_4}} \cdot \frac{S_{PO_4}}{K_P + S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK} + S_{ALK}} \cdot \frac{X_{PHIA}/X_{PAO}}{K_{PHIA} + X_{PHIA}/X_{PAO}} \cdot X_{PAO}$
 - 14 Anoxic growth on X_{PP} $\rho_{14} = \rho_{13} \cdot \eta_{NO_3} \cdot \frac{K_{O_2}}{S_{O_2}} \cdot \frac{S_{NO_3}}{K_{NO_3} + S_{NO_3}}$
 - 15 Lysis of X_{PAO} $b_{PAO} \cdot X_{PAO} \cdot S_{ALK}/(K_{ALK} + S_{ALK})$
 - 16 Lysis of X_{PP} $b_{PP} \cdot X_{PP} \cdot S_{ALK}/(K_{ALK} + S_{ALK})$
 - 17 Lysis of X_{PHIA} $b_{PHIA} \cdot X_{PHIA} \cdot S_{ALK}/(K_{ALK} + S_{ALK})$
 - 18 Nitrifying organisms (autotrophic organisms): X_{AUT} $\mu_{AUT} \cdot \frac{S_{O_2}}{K_{O_2} + S_{O_2}} \cdot \frac{S_{NH_4}}{K_{NH_4} + S_{NH_4}} \cdot \frac{S_{PO_4}}{K_P + S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK} + S_{ALK}} \cdot X_{AUT}$
 - 19 Lysis of X_{AUT} $b_{AUT} \cdot X_{AUT}$
- Simultaneous precipitation of phosphorus with ferric hydroxide $Fe(OH)_3$*
- 20 Precipitation $k_{PRE} \cdot S_{PO_4} \cdot X_{MeOH}$
 - 21 Redissolution $k_{BED} \cdot X_{MeP} \cdot S_{ALK}/(K_{ALK} + S_{ALK})$

ASM3 recognizes that heterotrophic organisms store biodegradable organic matter before using it for growth, whereas ASM1 assumes immediate growth upon substrate availability. The autotrophic nitrification process is similar to ASM1, but denitrification is modelled more realistically, including some simplifications for better calibration and application. Unlike ASM2, ASM3 does not model biological phosphorus removal, focusing solely on carbon and nitrogen dynamics. Therefore, it is similar to ASM1 but includes additional compartments for the storage of organic matter and improved kinetics for biomass behaviour.

ASIM2d APPLICATION FOR THE SIMULATION OF THE PLANT AS IT IS

The Model File contains an Activated Sludge Model as biokinetic model, all kinetic and stoichiometric parameters, including temperature dependency, initial conditions for integration and the concentrations of the first influent.

The activated sludge reactor is modelled with three separate tanks in order to reproduce the hydraulic behaviour of the plant. The influent and return-sludge are fed into the first reactor, and there is an internal recirculation going from the third reactor to the first one. The sludge age amounts to 18 days. The secondary clarifier is represented with two reactors (in Asim the secondary clarifiers are ideally separating solids from the liquid, therefore the solids retention time is 0).

Figure n.6, Definition of flowrates parameters

The O₂-setpoint is the Oxygen concentration which needs to be kept at a certain level, the kLa-value is the aeration capacity. O₂-setpoint remains has the following values:

Reactors	Volume	O2 Setpoint	kLa Value
Reactor 1	697.000	0.000	30.000
Reactor 2	697.000	0.000	40.000
Reactor 3	1593.000	1.800	0.000
Clarifier 1	1583.000		

Figure n.7, Setting of reactor's volumes

The concentrations of the first was added to the model. This following first Table illustrates how the COD tot-concentration is divided into various COD-fractions.

Table 2: Standard Values for the Various Fractions of the Total COD in ASM3 (Koch et al., 2000)

Fraction Share	Dissolved		Particulate					Total: 100%
	Inert 6%	Substrate 10%	Inert 20%	Substrate 55%	Heterotroph 9%	Storage p 0%	Nitrifier 0%	

Table n.10, Fractionation of the COD inside the model

These are the inlet concentrations that were implemented inside the model:

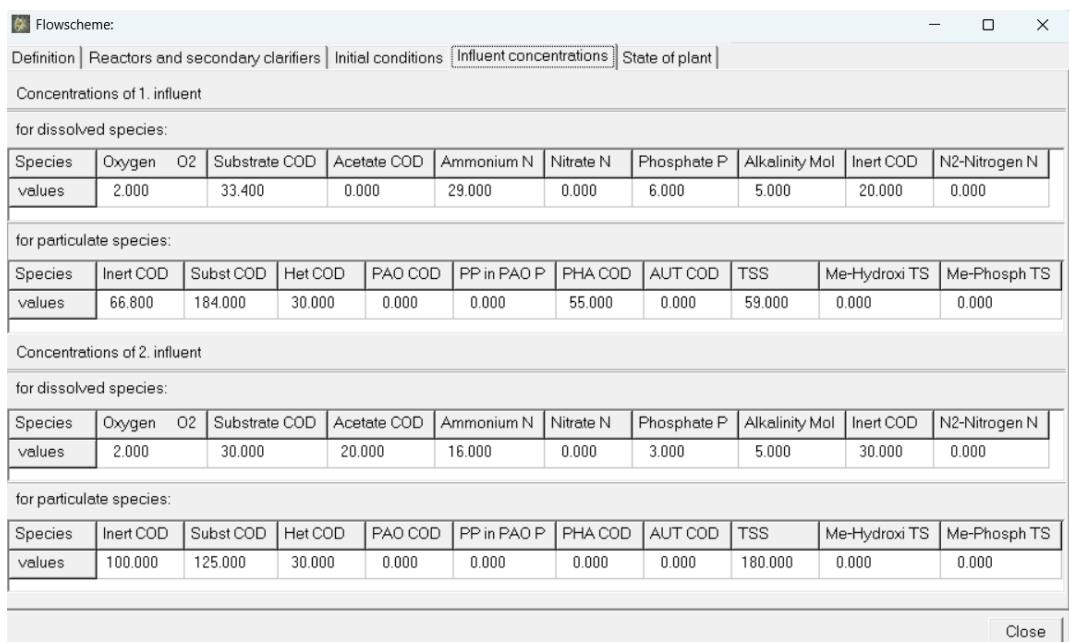


Figure n.8, Influent concentrations

Flowscheme: Activated Sludge Reactor

	1.influent	Reactor 1	Reactor 2	Reactor 3	Clarifier 1	State of plant
Flowrate/Volumes	6792.400	697.000	697.000	1593.000	1583.000	
Oxygen O ₂	2.000	0.185	0.254	1.800		
Substrate COD	20.300	0.562	0.396	0.332	0.332	
Acetate COD	0.000	0.034	0.027	0.012	0.012	
Ammonium N	29.000	6.227	5.160	1.321	1.321	
Nitrate N	0.000	17.050	17.651	21.593	21.593	
Phosphate P	6.000	6.599	6.636	6.723	6.723	
Alkalinity Mol	5.000	2.265	2.152	1.609	1.609	
Inert COD	12.200	12.200	12.200	12.200	12.200	
N ₂ -Nitrogen N	0.000	8.384	9.023	9.302	9.302	
Inert COD	40.000	2312.010	2312.828	2314.696		
Subst COD	111.600	48.159	42.362	31.433		
Het COD	18.300	1486.360	1486.970	1486.717		
PAO COD	0.000	1.92E-3	1.92E-3	1.92E-3		
PP in PAO P	0.000	6.41E-4	6.42E-4	6.44E-4		
PHA COD	0.000	1.00E-5	1.00E-5	1.00E-5		
AUT COD	0.000	139.561	139.663	140.229		
TSS	59.000	281.887	278.739	272.102		
Me-Hydroxi TS	0.000	1.00E-5	1.00E-5	1.00E-5		
Me-Phosph TS	0.000	1.38E-4	1.38E-4	1.39E-4		
Oxygen consumption		371.261	386.683	557.206		

Close

Figure n.9, State of the plant after the Integration analysis

In ASIM2d, when creating a Plant File, there are two important registers:

The Initial Conditions, which holds the starting values needed for differential equations. These values set the initial state for the simulation, it's a sort of baseline setup before any processes begin. The State of Plant contains the current values for various parameters in the influent (incoming flow), reactors, and secondary clarifiers. These values represent the ongoing state of the plant during the simulation. So, both registers use the same set of parameters, after the computations, the values in the "Initial Conditions" are updated with the new values from the "State of Plant". This allows the simulation to continue dynamically, using the most recent data. A Variation File contains information that is necessary for dynamic simulations, such as changes in influent, excess sludge draw-off (DX), concentrations, etc. over a certain stretch of time. The first register requires individual cycle periods and their change intervals to be defined. As illustrated in the next Table, the first influent has a 24-hour-cycle with 2-hour resolution.



Figure n.10, Results after the dynamic simulation – 5 cycles – Flowrates

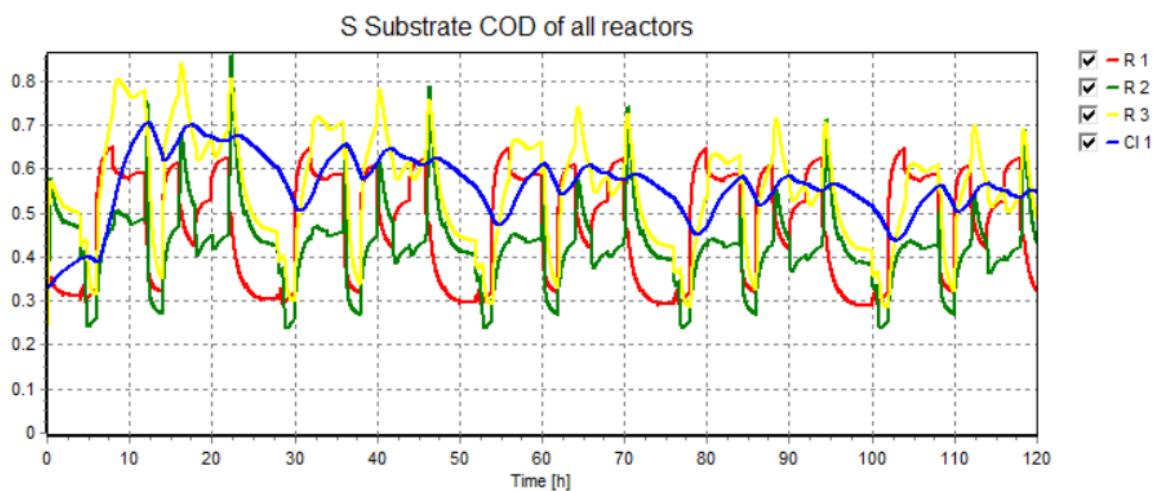


Figure n.11, Results after the dynamic simulation – 5 cycles – Soluble Substrate COD

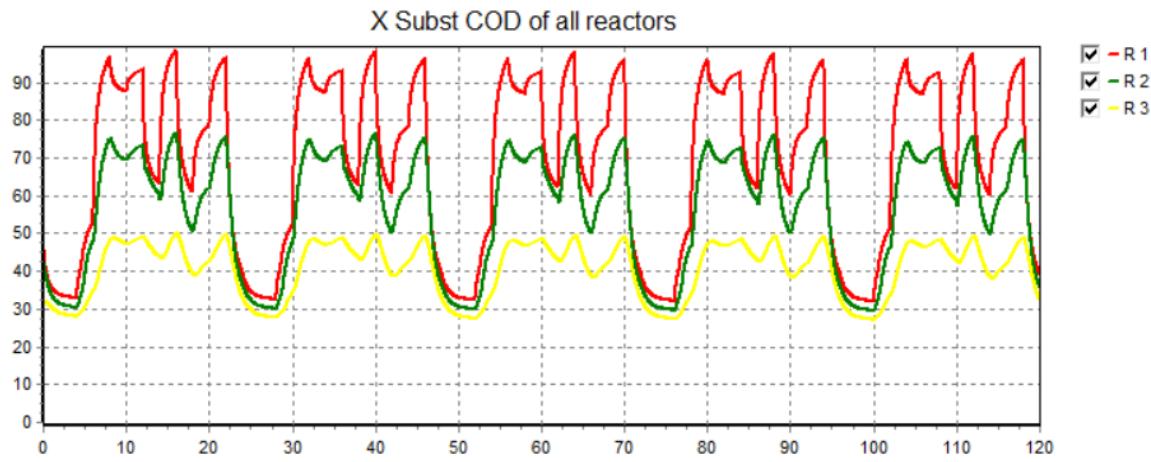


Figure n.12, Results after the dynamic simulation – 5 cycles – Particulate Substrate COD

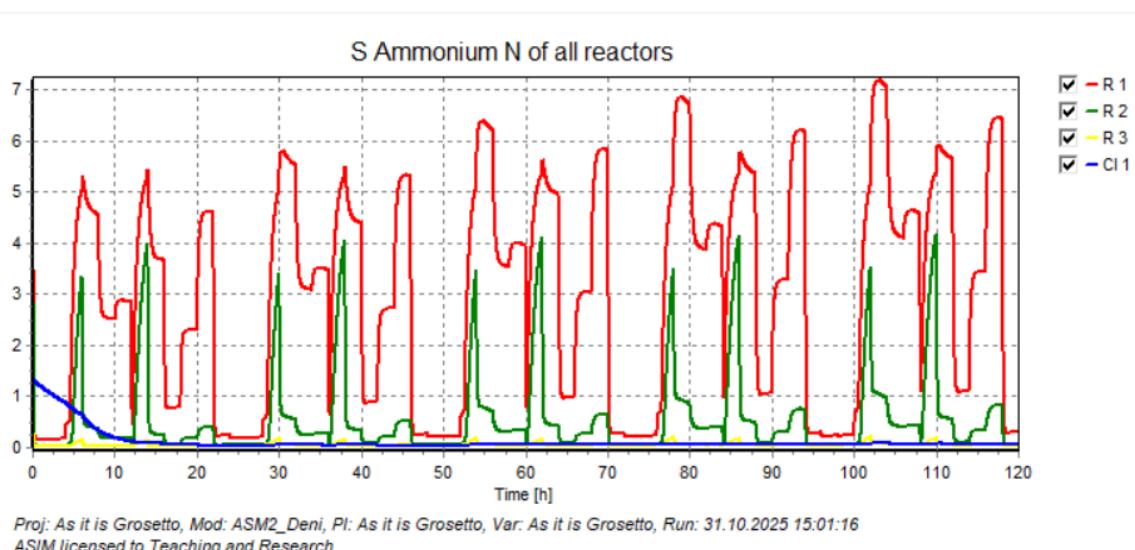


Figure n.13, Results after the dynamic simulation – 5 cycles – Soluble Ammonium N

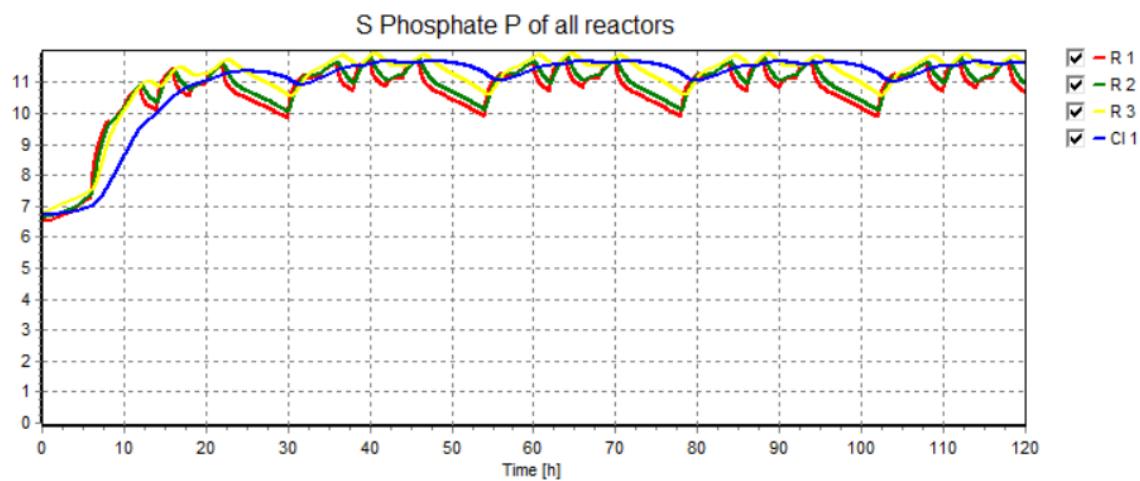


Figure n.14, Results after the dynamic simulation – 5 cycles – Soluble Phosphate P

ASIM2d APPLICATION FOR THE SIMULATION OF THE PLANT OPTIMIZATION

The Model File contains an Activated Sludge Model as biokinetic model, all kinetic and stoichiometric parameters, including temperature dependency, initial conditions for integration and the concentrations of the first influent.

Flowscheme of the plant

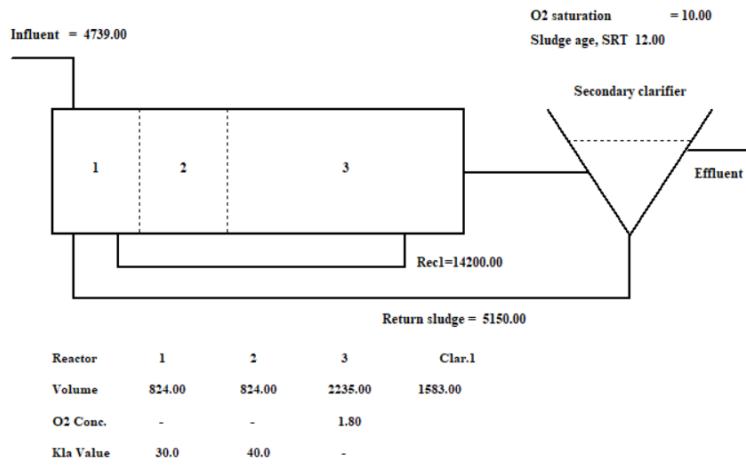


Figure n.15, Flow scheme of the plant OPTIMIZATION

The activated sludge reactor is modelled with three separate tanks in order to reproduce the hydraulic behaviour of the plant. The influent and return-sludge are fed into the first reactor, and there is an internal recirculation going from the third reactor to the first one. The sludge age amounts to 12 days. The secondary clarifier is represented with two reactors (in Asim the secondary clarifiers are ideally separating solids from the liquid, therefore the solids retention time is 0).

Flowscheme:

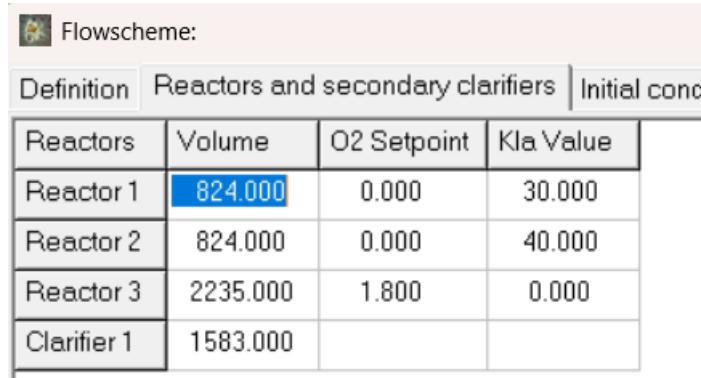
Definition | Reactors and secondary clarifiers | Initial conditions | Influent concentrations | State of plant

Number of reactors: Number of secondary clarifier compartments:

1. influent flowrate:	<input type="text" value="4739.000"/>	directed to reactor Nr.:	<input type="text" value="1"/>
2. influent flowrate:	<input type="text" value="0.000"/>	directed to reactor Nr.:	<input type="text" value="1"/>
Return sludge flowrate:	<input type="text" value="5150.000"/>	directed to reactor Nr.:	<input type="text" value="1"/>
1. internal recirculation flowrate:	<input type="text" value="1.42E+4"/>	taken from reactor Nr.:	<input type="text" value="3"/>
		directed to reactor Nr.:	<input type="text" value="1"/>
2. internal recirculation flowrate:	<input type="text" value="0.000"/>	taken from reactor Nr.:	<input type="text" value="2"/>
		directed to reactor Nr.:	<input type="text" value="1"/>
Sludge age (SRT) (>0.819)	<input type="text" value="12.000"/>		
Saturation concentration for oxygen:	<input type="text" value="10.000"/>	Operating temperature:	<input type="text" value="12.0 °C"/>

Figure n.16, Definition of flowrates parameters

The O₂-setpoint is the Oxygen concentration which needs to be kept at a certain level, the kLa value is the aeration capacity. O₂-setpoint remains has the following values:



A screenshot of a software interface titled "Flowscheme:" showing reactor parameters. The tabs at the top are "Definition", "Reactors and secondary clarifiers", and "Initial conc". The "Reactors and secondary clarifiers" tab is selected. A table below lists four reactors and one clarifier with their volumes, O₂ setpoints, and kLa values.

Reactors	Volume	O ₂ Setpoint	kLa Value
Reactor 1	824.000	0.000	30.000
Reactor 2	824.000	0.000	40.000
Reactor 3	2235.000	1.800	0.000
Clarifier 1	1583.000		

Figure n.17, Reactors and secondary clarifiers parameters

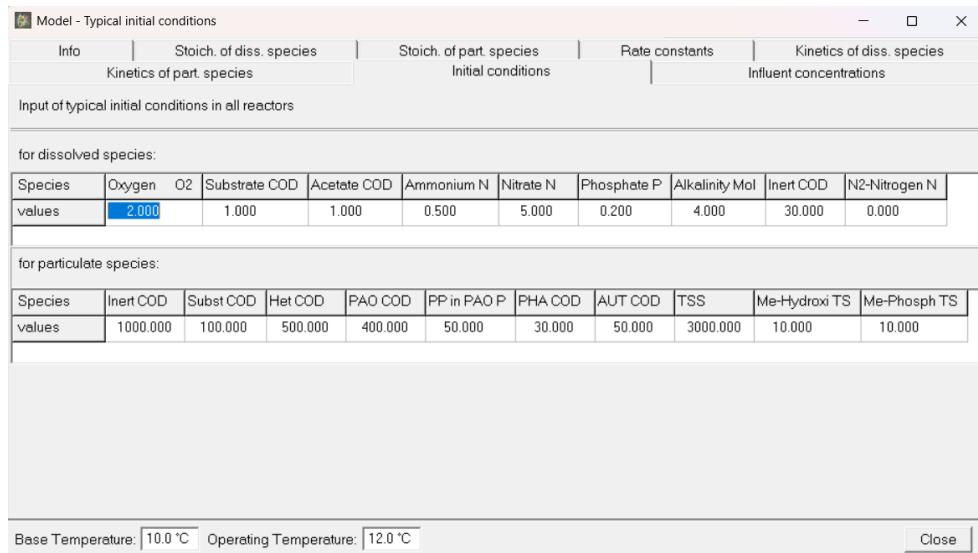
The concentrations of the first and the second influent were added to the model. This following first Table illustrates how the COD tot-concentration is divided into various COD fractions.

Table 2: Standard Values for the Various Fractions of the Total COD in ASM3 (Koch et al., 2000)

Fraction Share	Dissolved		Particulate						Total: 100%
	Inert 6%	Substrate 10%	Inert 20%	Substrate 55%	Heterotroph 9%	Storage p 0%	Nitrifier 0%		

Table n.11, Fractionation of COD for the ASIM model

These are the inlet concentrations that were implemented inside the model:



A screenshot of a software dialog box titled "Model - Typical initial conditions". It contains tabs for "Info", "Stoich. of diss. species", "Kinetics of part. species", "Stoich. of part. species", "Initial conditions", "Rate constants", and "Kinetics of diss. species". The "Initial conditions" tab is active. It shows input fields for typical initial conditions in all reactors. Below this, there are two tables: one for dissolved species and one for particulate species, both with columns for species names and their corresponding values.

Species	Oxygen	O ₂	Substrate COD	Acetate COD	Ammonium N	Nitrate N	Phosphate P	Alkalinity Mol	Inert COD	N ₂ -Nitrogen N
values	2.000	1.000	1.000	0.500	5.000	0.200	4.000	30.000	0.000	

Species	Inert COD	Subst COD	Het COD	PAO COD	PP in PAO P	PHA COD	AUT COD	TSS	Me-Hydroxi TS	Me-Phosph TS
values	1000.000	100.000	500.000	400.000	50.000	30.000	50.000	3000.000	10.000	10.000

Base Temperature: 10.0 °C Operating Temperature: 12.0 °C Close

Figure n.18, Initial conditions

Flowscheme:

Concentrations of 1. influent										
for dissolved species:										
Species	Oxygen O ₂	Substrate COD	Acetate COD	Ammonium N	Nitrate N	Phosphate P	Alkalinity Mol	Inert COD	N ₂ -Nitrogen l	
values	2.000	33.400	10.000	29.000	0.000	6.000	5.000	20.000	0.000	
—	—	—	—	—	—	—	—	—	—	
for particulate species:										
Species	Inert COD	Subst COD	Het COD	PAO COD	PP in PAO P	PHA COD	AUT COD	TSS	Me-Hydroxi TS	Me-Phosph
values	66.800	184.000	30.000	0.000	0.000	55.000	0.000	59.000	0.000	0.000
—	—	—	—	—	—	—	—	—	—	
Concentrations of 2. influent										
for dissolved species:										
Species	Oxygen O ₂	Substrate COD	Acetate COD	Ammonium N	Nitrate N	Phosphate P	Alkalinity Mol	Inert COD	N ₂ -Nitrogen l	
values	2.000	30.000	20.000	16.000	0.000	3.000	5.000	30.000	0.000	
—	—	—	—	—	—	—	—	—	—	
for particulate species:										
Species	Inert COD	Subst COD	Het COD	PAO COD	PP in PAO P	PHA COD	AUT COD	TSS	Me-Hydroxi TS	Me-Phosph
values	100.000	125.000	30.000	0.000	0.000	0.000	0.000	180.000	0.000	0.000
—	—	—	—	—	—	—	—	—	—	

Close

Figure n.19, Influent concentrations

In ASIM2d, when creating a Plant File, there are two important registers:

The Initial Conditions, which holds the starting values needed for differential equations. These values set the initial state for the simulation, it's a sort of baseline setup before any processes begin. The State of Plant contains the current values for various parameters in the influent (incoming flow), reactors, and secondary clarifiers. These values represent the ongoing state of the plant during the simulation.

So, both registers use the same set of parameters, after the computations, the values in the “Initial Conditions” are updated with the new values from the “State of Plant”. This allows the simulation to continue dynamically, using the most recent data. A Variation File contains information that is necessary for dynamic simulations, such as changes in influent, excess sludge draw-off (DX), concentrations, etc. over a certain stretch of time.

The first register requires individual cycle periods and their change intervals to be defined. As illustrated in the next Table, the first influent has a 24-hour-cycle with 2-hour resolution.

Variation

Options	Inflows	dissolved species	particulate species	kla's or O ₂ setpoi
Duration of a cycle (hours):	24.000			
Number of points in a cycle:	12			
Variable concentrations in 2. influent	<input checked="" type="checkbox"/>			

Figure n.20, Variation file inputs

Variation

Options | Inflows | dissolved species | particulate species | kia's or O2 setpoints | temperature |

time step	Oxygen	O2	Substrate COD	Acetate COD	Ammonium N	Nitrate N	Phosphate P	Alkalinity Mol	Inert COD	N2-Nitrogen N
0- 2 hrs	2.000	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600
2- 4 hrs	1.000	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600
4- 6 hrs	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
6- 8 hrs	1.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
8-10 hrs	2.000	1.800	1.800	1.800	1.800	1.800	1.800	1.800	1.800	1.800
10-12 hrs	1.000	1.900	1.900	1.900	1.900	1.900	1.900	1.900	1.900	1.900
12-14 hrs	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
14-16 hrs	1.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
16-18 hrs	2.000	1.300	1.300	1.300	1.300	1.300	1.300	1.300	1.300	1.300
18-20 hrs	1.000	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700
20-22 hrs	2.000	1.950	1.950	1.950	1.950	1.950	1.950	1.950	1.950	1.950

	Oxygen	O2	Substrate COD	Acetate COD	Ammonium N	Nitrate N	Phosphate P	Alkalinity Mol	Inert COD	N2-Nitrogen N
Factor	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Average=A	1.333	1.379	1.379	1.379	1.379	1.379	1.379	1.379	1.379	1.379
AFactor	1.333	1.379	1.379	1.379	1.379	1.379	1.379	1.379	1.379	1.379
Load	1.850	2.204	2.204	2.204	2.204	2.204	2.204	2.204	2.204	2.204

Figure n.21, Variation file inputs – Dissolved species

Variation

Options | Inflows | dissolved species | particulate species | kia's or O2 setpoints | temperature |

time step	1.influent	return sludge	1.recirculation	excess sludge	2.influent	
0- 2 hrs	0.600	1.000	1.000	1.000	1.000	
2- 4 hrs	0.600	1.000	1.000	1.000	1.000	
4- 6 hrs	1.000	1.000	1.000	1.000	1.000	
6- 8 hrs	2.000	1.000	1.000	1.000	1.000	
8-10 hrs	1.800	1.000	1.000	1.000	1.000	
10-12 hrs	1.900	1.000	1.000	1.000	1.000	
12-14 hrs	1.000	1.000	1.000	1.000	1.000	
14-16 hrs	2.000	1.000	1.000	1.000	1.000	
16-18 hrs	1.300	1.000	1.000	1.000	1.000	
18-20 hrs	1.700	1.000	1.000	1.000	1.000	
20-22 hrs	1.950	1.000	1.000	1.000	1.000	
22-24 hrs	0.700	1.000	1.000	1.000	1.000	

	1.influent	return sludge	1.recirculation	excess sludge	2.influent	
Factor	1.000	1.000	1.000	1.000	1.000	
Average=A	1.379	1.000	1.000	1.000	1.000	
AFactor	1.379	1.000	1.000	1.000	1.000	

Figure n.22, Variation file inputs – Inflows

Variation

Options | Inflows | dissolved species | particulate species | **kla's or O2 setpoints** | temperature

time step	kla of R1	kla of R2	O2 setp. R3
0- 2 hrs	1.000	60.000	1.10E+2
2- 4 hrs	1.000	60.000	1.10E+2
4- 6 hrs	1.000	60.000	1.10E+2
6- 8 hrs	1.000	60.000	1.10E+2
8-10 hrs	1.000	60.000	1.10E+2
10-12 hrs	1.000	60.000	1.10E+2
12-14 hrs	1.000	60.000	1.10E+2
14-16 hrs	1.000	60.000	1.10E+2
16-18 hrs	1.000	60.000	1.10E+2
18-20 hrs	1.000	60.000	1.10E+2
20-22 hrs	1.000	60.000	1.10E+2
22-24 hrs	1.000	60.000	1.10E+2

	kla of R1	kla of R2	O2 setp. R3
Factor	1.000	1.000	1.000
Average=A	1.000	60.000	1.10E+2
A-Factor	1.000	60.000	1.10E+2

Figure n.23, Variation file inputs – Kla's or O2 setpoints

Variation

Options | Inflows | dissolved species | particulate species | **temperature**

time step	Temp difference
0- 2 hrs	15.000
2- 4 hrs	15.500
4- 6 hrs	16.000
6- 8 hrs	16.500
8-10 hrs	17.000
10-12 hrs	17.500
12-14 hrs	18.000
14-16 hrs	17.500
16-18 hrs	17.000
18-20 hrs	16.500
20-22 hrs	16.000
22-24 hrs	15.000

	Temp difference
Average	16.458

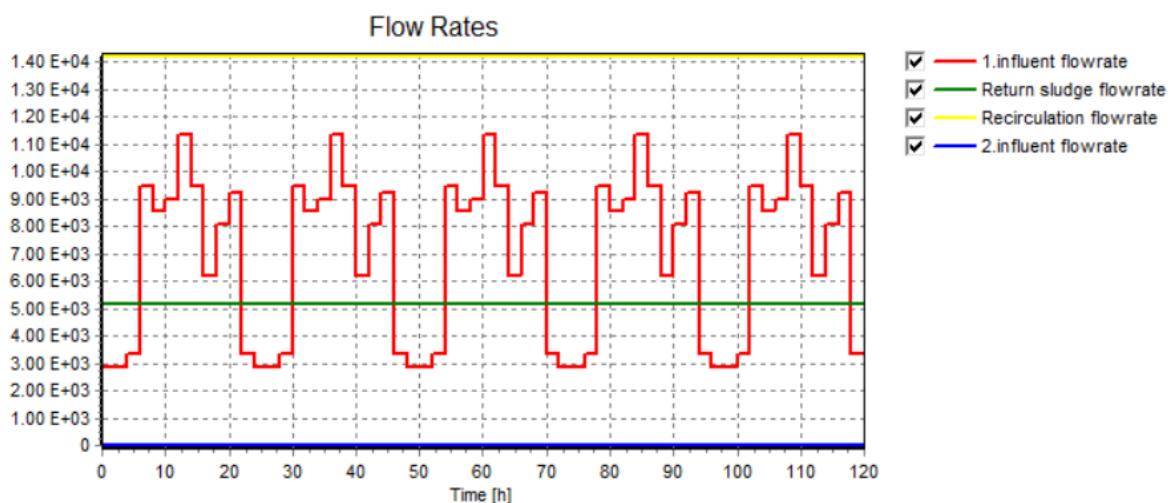
Figure n.24, Variation file inputs – Temperature

Flowscheme:

	1.influent	Reactor 1	Reactor 2	Reactor 3	Clarifier 1	
Flowrate/Volumes	4739.000	824.000	824.000	2235.000	1583.000	
Oxygen O ₂	2.000	0.316	0.673	1.800		
Substrate COD	20.600	0.658	0.329	0.291	0.290	
Acetate COD	10.000	0.210	0.034	3.91E-3	3.89E-3	
Ammonium N	35.000	5.439	3.282	0.537	0.545	
Nitrate N	0.000	24.363	26.213	29.086	29.071	
Phosphate P	8.000	4.761	4.229	4.906	4.942	
Alkalinity Mol	5.000	1.440	1.170	0.766	0.767	
Inert COD	12.360	12.360	12.360	12.360	12.360	
N ₂ -Nitrogen N	0.000	5.212	5.464	5.651	5.679	
Inert COD	41.200	1309.950	1311.985	1317.512		
Subst COD	13.300	8.026	7.305	6.241		
Het COD	18.540	275.642	275.340	273.281		
PAO COD	0.000	152.409	153.822	152.032		
PP in PAO P	0.000	50.857	51.385	50.830		
PHA COD	55.000	5.802	1.746	0.137		
AUT COD	0.000	38.451	38.718	38.807		
TSS	395.000	6048.362	6049.898	6047.210		
Me-Hydroxi TS	0.000	2.33E-5	2.46E-5	2.22E-5		
Me-Phosph TS	0.000	2.74E-4	2.73E-4	2.79E-4		
Oxygen consumption		335.124	362.456	204.460		

Close

Figure n.25, State of plant after the Integration simulation



Proj: Scenario 1, Mod: ASM2_Deni, Pl: scenario 1, Var: Scenario 1, Run: 31.10.2025 18:53:16
ASIM licensed to Teaching and Research

Figure n.26, Results after the dynamic simulation – 5 cycles – Flowrates

The graph of flow rates from the ASIM result during the optimization project simulation.

- X-axis (Time [h]): Represents the simulation time, which runs for 120 hours (5 days).
- Y-axis (Flow Rate [m^3/h]): The flow rates are shown on a logarithmic scale, ranging from 1,000 m^3/h to 14,000 m^3/h .

The red line represents the influent flowrate, the primary influent flow into the system, which shows a cyclical pattern with significant fluctuations over time. The influent flow peaks at around 12,000 m^3/h and drops down to around 5,000 m^3/h during the troughs.

The cyclical nature indicates the influent flow follows a predictable daily pattern, possibly reflecting diurnal variations in wastewater inflow (higher flows during the day due to human activities, lower flows at night).

The return sludge flow typically refers to the flow of settled sludge from the clarifier back into the aeration basin to maintain adequate biomass concentration. The steady value suggests a consistent return sludge rate, which helps maintain stable biological treatment.

The blue line represents the recirculation flow, which is relatively low and constant, around 1,000 m^3/h . This could indicate the rate at which effluent is recirculated within the treatment process, such as in denitrification or nutrient removal zones. The low and stable flow suggests a specific recirculation strategy, possibly for maintaining biological activity or controlling nutrient levels.

The second external influent flowrate is indicated by the purple line, but it is constant at a very low value of 1,000 m^3/h . This represents a secondary or additional influent stream. Summarizing, the simulation shows cyclical variations in the influent flow, which are being managed with stable return sludge and recirculation rates. The peaks in influent flow are likely due to human activity, leading to higher wastewater generation during specific times of the day. The constant return sludge flow suggests a stable biological process aimed at maintaining proper treatment efficiency.

The simulation indicates that the system is handling daily fluctuations in influent flow efficiently, and the return sludge and recirculation systems are optimized to ensure consistent performance. If the goal of the optimization was to manage fluctuating loads while maintaining stability in the biological process, this result suggests success.

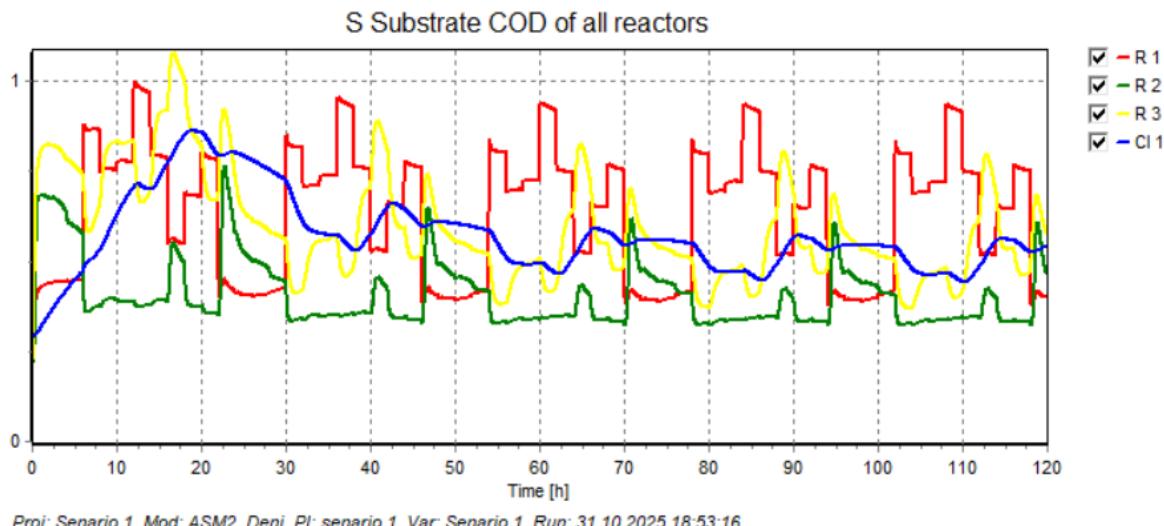


Figure n.27, Results after the dynamic simulation – 5 cycles – Soluble Substrate COD

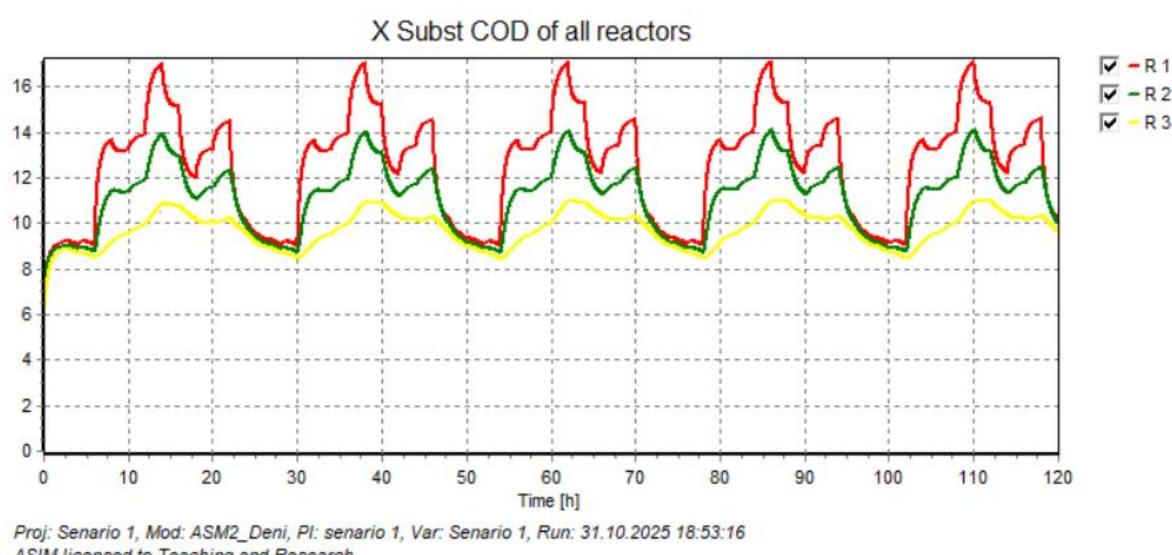


Figure n.28, Results after the dynamic simulation – 5 cycles – Particulate Substrate COD

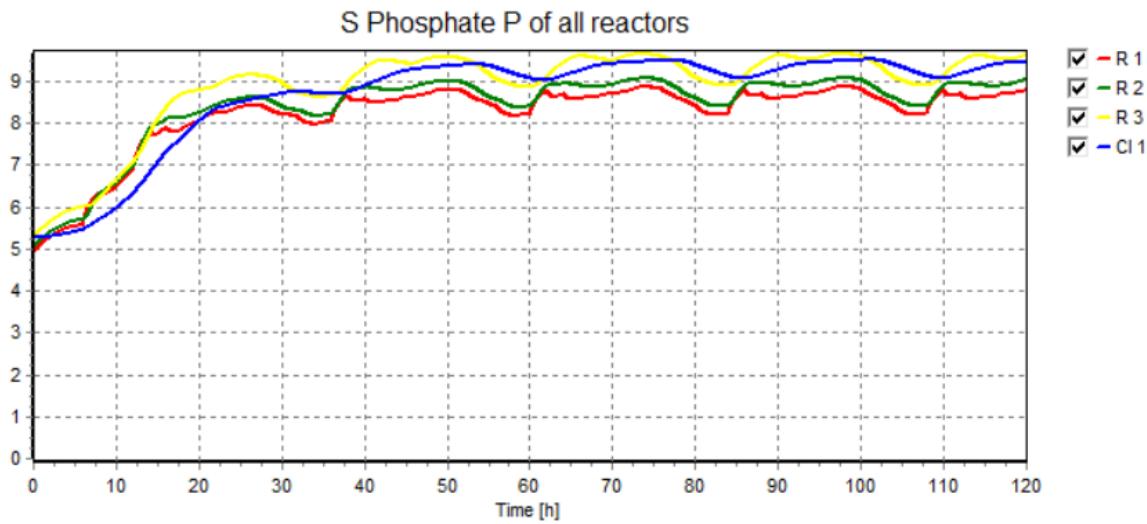


Figure n.29, Results after the dynamic simulation – 5 cycles – Soluble Phosphate P

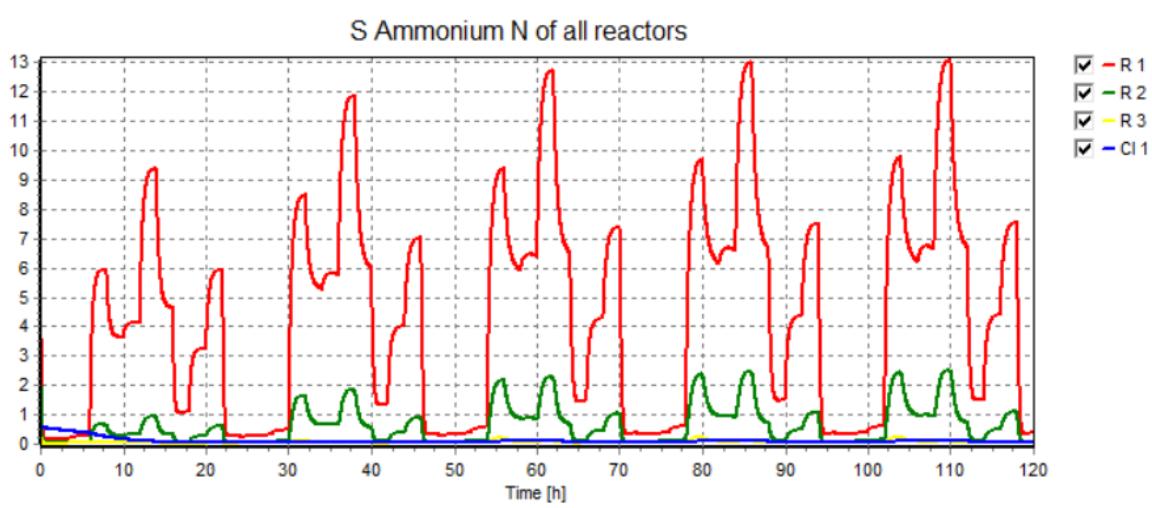


Figure n.30, Results after the dynamic simulation – 5 cycles – Ammonium N

DISCUSSION

In this section, I compared the performance of the wastewater treatment plant under two conditions: the current ‘as-is’ operational scenario and the optimized configuration. The goal of this comparison is to evaluate the impacts of the optimization on system stability, flow regulation, and process efficiency. By analysing flowrate patterns, shown in the following two graphs, and operational parameters in both cases, I aim to highlight the improvements made and potential areas of further enhancement. The influent flowrate in the pre optimization graph is generally higher, with peaks reaching 18,000 m³/h, and troughs around 4,000 m³/h. In the optimized graph, the influent peaks are slightly lower, around 12,000 m³/h, and the troughs are around 5,000 m³/h. This suggests that the optimization process might have helped to better regulate or smooth the influent flow, reducing peak loads on the system, which can enhance treatment efficiency and prevent overloading.

The return sludge flowrate is constant at 6,000 m³/h before optimization. In the optimized graph, the return sludge flowrate is slightly reduced to around 5,000 m³/h. This could indicate improved process efficiency in the activated sludge system, requiring less sludge recirculation to maintain stable treatment conditions.

The recirculation flowrate is again stable at 1,000 m³/h, similar to the optimized scenario, suggesting that this flowrate was already stable and did not require adjustment during the optimization process.

The cyclical pattern of the influent flowrate has higher peaks and deeper troughs, indicating a less controlled influent load. The optimized flowrate shows a smoother cyclical pattern with smaller peaks and more stable flows, which suggests the system has been adjusted to better handle the variable loads over time. In conclusion, the optimization process seems to have led to better management of influent flowrates, ensuring more consistent performance and possibly reducing operational strain on the system. This can result in improved treatment efficiency, energy savings, and a more balanced load for the biological processes.

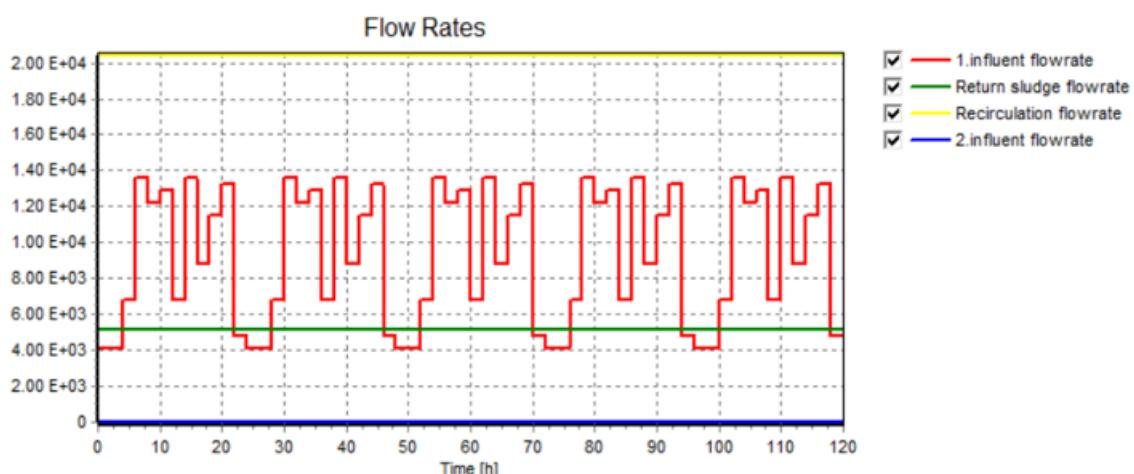


Figure 1. As it is

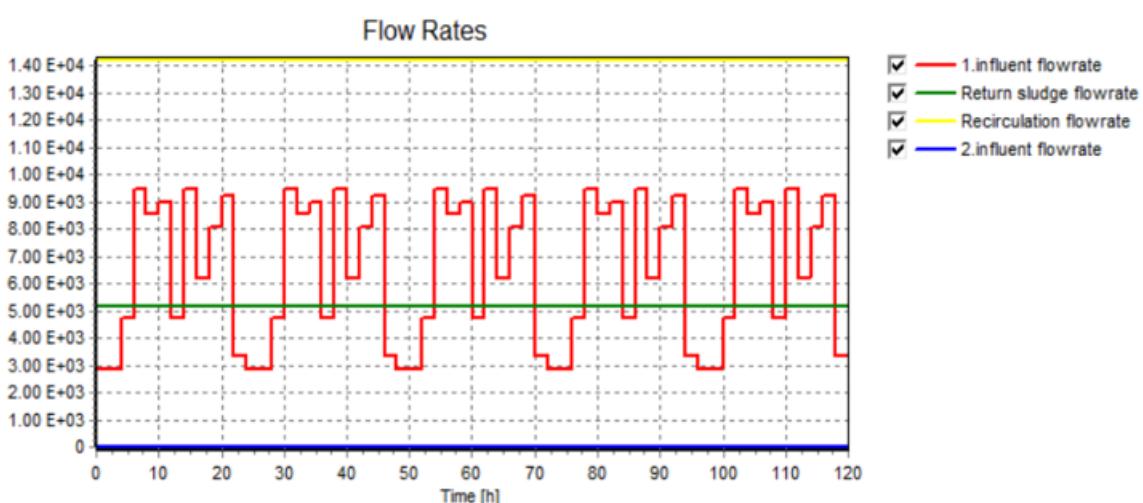


Figure 2. Optimized

Figure 31: Flow rate comparison as it is and optimization

The optimization process has successfully reduced the variability and COD peaks across all reactors, with R1 showing the most improvement in peak height and R2 and R3 demonstrating enhanced stability. The overall system now performs more consistently, indicating that the optimization likely improved the overall efficiency of the COD removal process in the plant. Further adjustments to R1 may help bring it more in line with the other reactors, but the current results show clear progress.

The first graph related to the initial state shows significant fluctuations and larger peaks in COD, the optimized conditions display reduced fluctuations and generally smoother curves across all reactors. The reduction in peak height implies that the optimization has improved the COD management or removal efficiency, though some fluctuation remains.

The optimization has led to more consistent COD levels, especially in R2 and R3, which exhibit much less variability compared to the initial state. Although R1 still shows the highest fluctuations, its peaks are lower and more controlled than in the initial analysis.

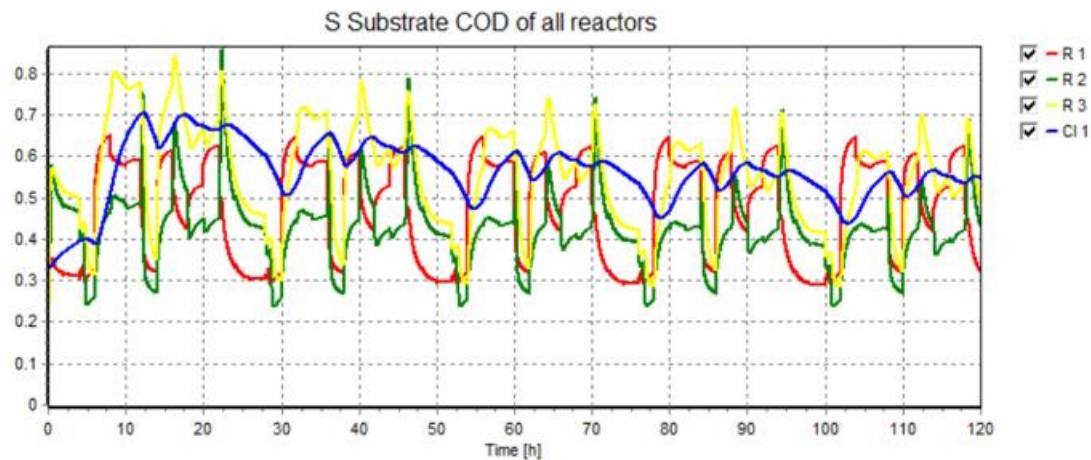


Figure 1. As it is

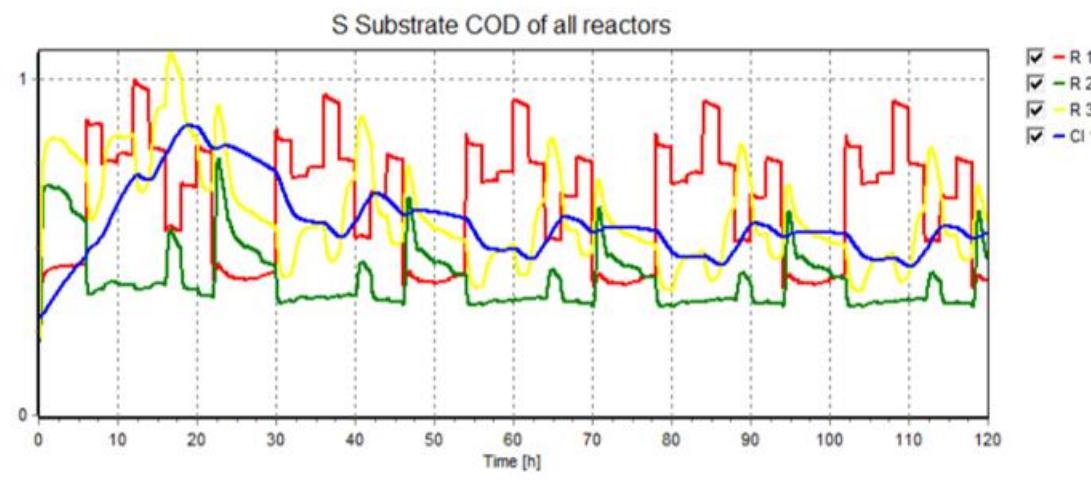


Figure 2. Optimized

Figure 32: COD comparison

The optimized condition also shows an improved performance in terms of ammonium nitrogen removal, which is shown in the next two graphs, with lower peaks and more stable operation across the reactors. In the "as it is" condition there are higher and more frequent peaks, indicating less efficient removal processes and fluctuations in nitrogen levels within the system.

In the initial conditions the peaks, especially in R1 (red line) and R2 (green line), are larger and more pronounced. R1 shows ammonium concentration spikes reaching about 25 mg/L at several points. The optimization project simulation shows that the peaks are reduced significantly in all reactors. For R1, the concentration of ammonium N still rises but not as high, maxing around 18 mg/L.

The clarifier peaks, C1 (yellow line), remains mostly flat and low in both cases, indicating minimal ammonium nitrogen levels in the clarifier across both conditions. In conclusion, the optimization results in a more stable and efficient process, with lower peaks and better ammonium nitrogen removal, especially in R1 and R2.

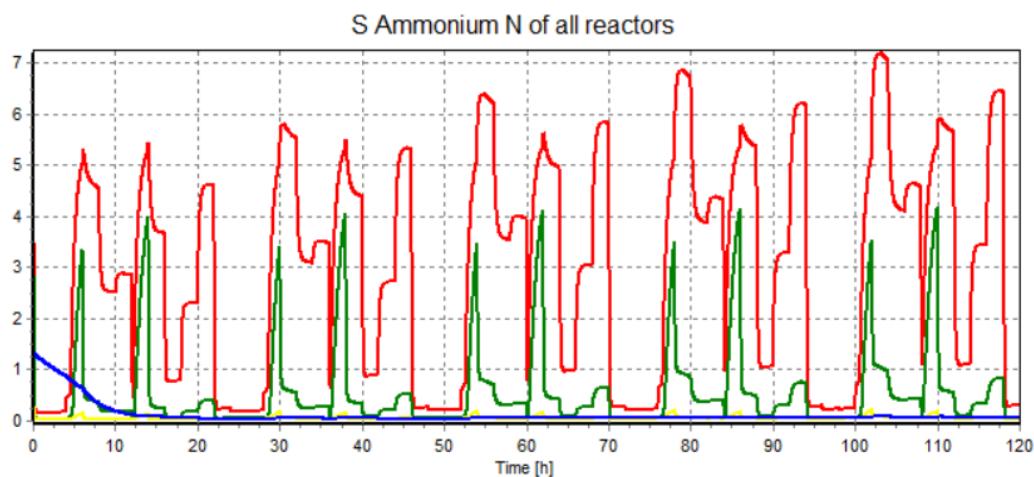


Figure 1. As it is

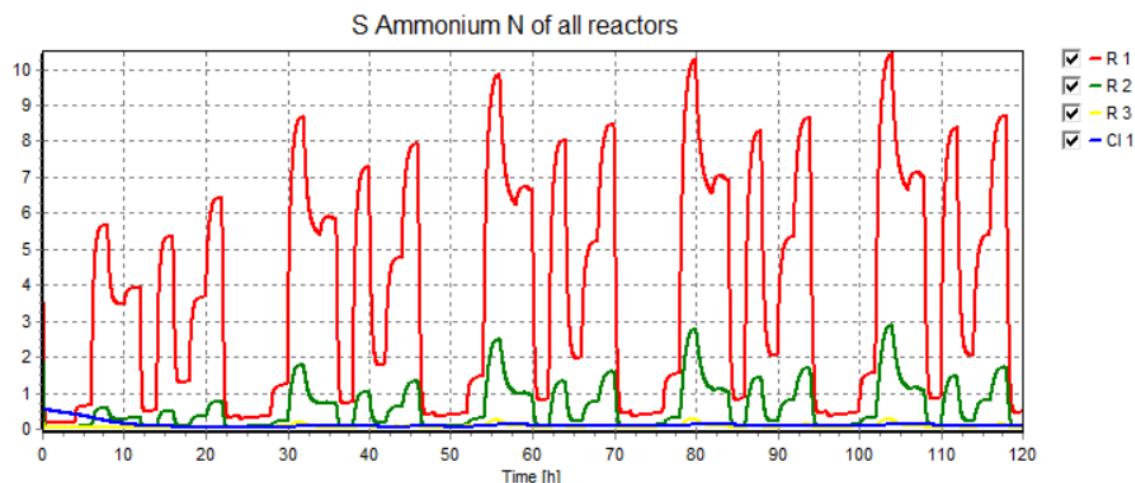


Figure 33. Optimized and as it is comparison

The last comparison analysis was done referring to the P removal, shown in the last two graphs. It is visible that the "as it is" condition displays steady but relatively high phosphate , indicating a less dynamic system. In contrast, the optimized condition shows more frequent and substantial fluctuations in phosphate levels, particularly in R1 and R2, indicating a more responsive system with improved phosphate removal. Overall, the optimization leads to lower average phosphate concentrations and a system better able to handle variability in phosphate loads.

Under the optimized condition, R1 shows more pronounced peaks and troughs, indicating more active phosphate removal processes. R2 also shows notable fluctuations but lags slightly behind R1. R3, while more stable, exhibits a lower overall concentration and smaller fluctuations.

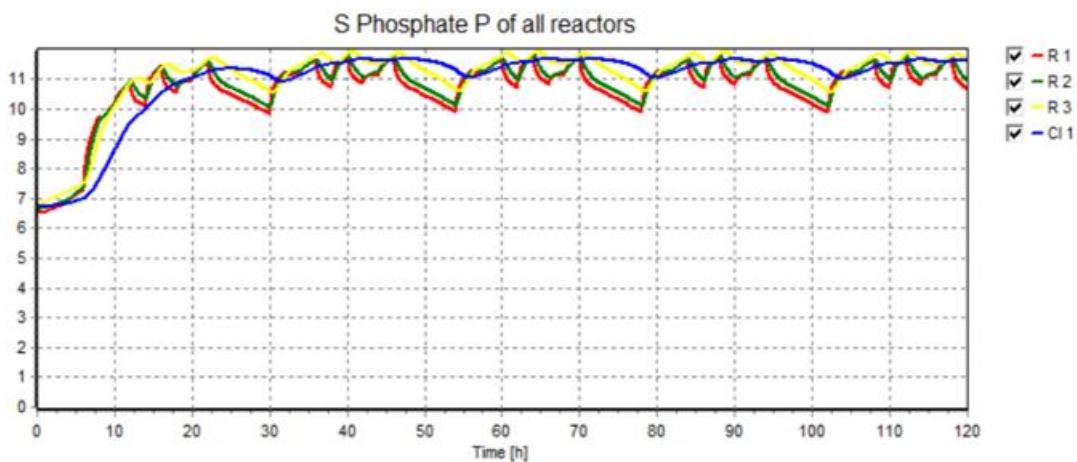


Figure 1. As it is

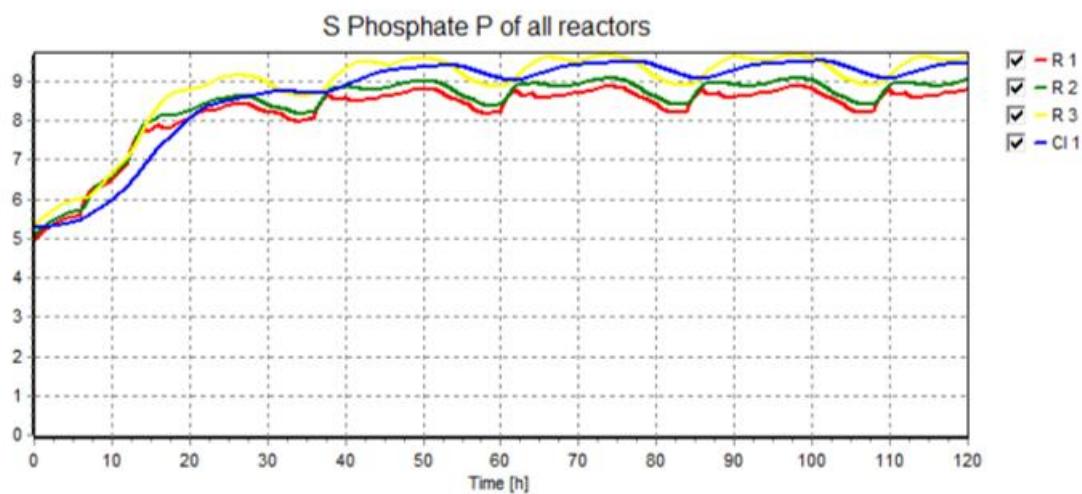


Figure 2. Optimized

Figure 34. optimized and as it is comparizon

CONCLUSION

The optimization project for the Grosseto wastewater treatment plant has laid the foundation for significant improvements in both capacity and operational efficiency. After careful analysis and implementation of optimization strategies, the future design scenario for the plant will be enhanced by several upgrades. These include the addition of a new biological treatment line, which will support the existing three lines, thereby increasing the plant's ability to handle higher inflow rates and ensuring better pollutant removal.

Additionally, a new two-line secondary clarification system will be introduced, improving the efficiency of solids separation and ensuring better effluent quality. The sludge line will undergo a major transformation with the integration of anaerobic digestion. This addition will not only stabilize the sludge but also produce biogas, contributing to the plant's sustainability goals by generating renewable energy. The supernatant from the anaerobic digestion process will have specific characteristics that are designed to minimize the impact on the overall treatment process, ensuring a smooth reintegration into the water line.

To guide the optimization process and ensure its accuracy, the simulation was carried out using the ASM2d model. This advanced model provided a reliable framework for simulating the biological and chemical processes within the plant, allowing us to evaluate different design scenarios and predict the performance of the upgraded system with precision. These upgrades, validated by the ASM2d simulation, will optimize the energy use and will reduce the operational costs. The optimization process represents a sustainable, forward-thinking approach that will provide long-term benefits to the plant and the surrounding community.

In conclusion, the optimization process implemented in the wastewater treatment plant has demonstrated notable improvements in several areas of performance. By regulating and smoothing the influent flow, the optimization reduced peak loads on the system, contributing to enhanced overall treatment efficiency and preventing overloading. The system now operates more consistently, which is reflected in the improved efficiency of the COD removal process. Additionally, the optimized conditions led to better ammonium nitrogen removal, with lower peaks and more stable operation observed across the reactors. This suggests that the adjustments made to the system have fostered a more balanced and controlled operational environment. Furthermore, the comparative analysis of phosphorus removal revealed contrasting behaviours between the "as-is" and optimized conditions. While the original system maintained relatively steady but high phosphate levels, the optimized system exhibited more dynamic fluctuations. These fluctuations indicate a more responsive system, capable of enhanced phosphate removal.

Overall, the optimization has significantly improved the plant's ability to handle variable loads, resulting in a more effective and reliable treatment process for COD, ammonium nitrogen, and phosphorus.