FROM SHARED RESOURCES
TO JOINT SOLUTIONS

D 5.1 - Current DP management with SWOT analysis and operating mode cost-benefit

(combined D 5.1.1 & D 5.1.2 from AF)

PROJECT AdSWiM

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CONTENTS

PART 1: INTRODUCTION

The goal of this report is to analyze existing technologies and management of wastewater treatment plants in Italian and Croatian sites. In addition, a general comparison is made between two countries showing the differences and similarities in management strategies, which relates to the monitoring approach, as well as removal rate of wastewater load and sludge management. The strengths and weaknesses are analyzed along with an overview analysis on costs and benefits in current operational mode of each facility.

Figure 1: Location of the analyzed depuration plants on Italian and Croatian test sites

The analyzed test sites are shown in Figure 1. On Italian side analyzed test sites are wastewater treatment plants in City of San Giorgio di Nogaro and City of Lignano on the northern side of the Adriatic Sea, and wastewater treatment plant in municipality Francavilla Al Mare, located in the middle part of the Adriatic Sea. On Croatian side analyzed test sites are wastewater treatment plant in City of Zadar (Centar) and two wastewater treatment plants in City of Split (Stupe and Katalinića brig), which are located on the eastern part of the Adriatic Sea.

PART 2: SURVEY OF ITALIAN AND CROATIAN TEST SITES

San Giorgio di Nogaro plant (Italy)

Wastewater treatment plant in San Giorgio di Nogaro is located within the industrial zone and the main purpose is to treat the wastewater coming from the industrial and production facilities. Average flow rate for year 2018. is shown in Figure 2., and equals to approximately 35.000 m^3/day without large oscillations during the year.

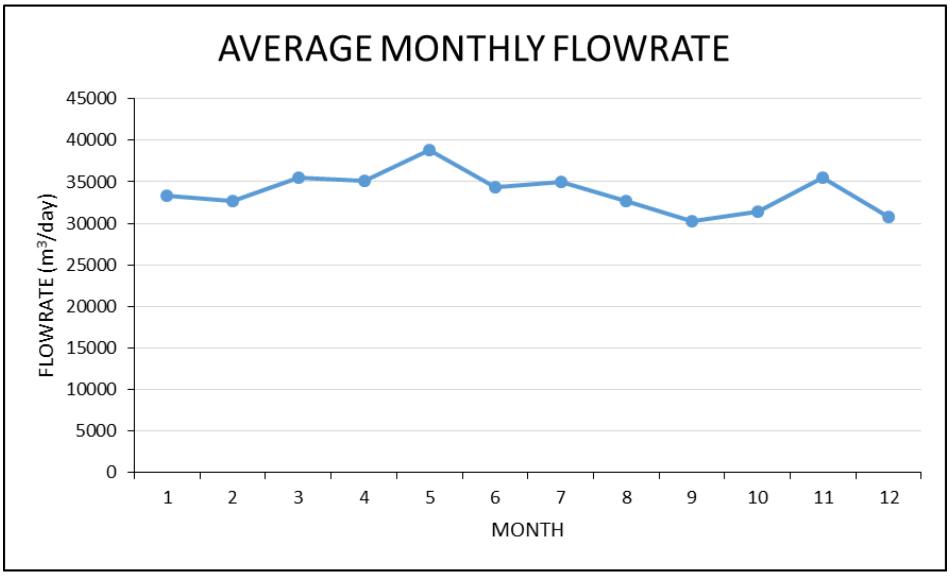

Figure 2: Average monthly flowrate (m^3/day) for year 2018. (San Giorgio di Nogaro)

Technological line is shown in Figure 5., and starts with anaerobic digestion in UASB reactor, where the inflow coming from nearby beer plant is redirected in order to produce biogas. There are two reactors in parallel (one of 1000 m^3 and one of 2000 m^3), which serve as a pre-treatment, where wastewater is homogenized and pre-heated. In case of strongly polluted industrial flowrate, wastewater could be treated using the Fenton process of chemical oxidation. However, both of these lines are currently offline.

Currently, the first step of the treatment is a coarse screen with a size of openings of 100 mm that are cleaned automatically. After that, five electric pumps transfer the wastewater up to the fine screen for a pre-treatment. Opening size of this screen is 6 mm with an automatic cleaning system followed by two lines with the same characteristics (3,25 m x 24 m), which consist of grit and oil removal. The overall treatment capacity is 1250 m^3/h including an aeration system. Chemical and physical treatment starts with two lines for coagulation-flocculation. Each line consists of one unit for coagulation (50 m^3) and one unit for flocculation (875 m^3). The chemicals dosed in the coagulations phase are aluminum polychloride or ferric chloride while in the flocculation phase a polyelectrolyte is added (currently offline).

The flocs formed during the chemical-physical process settle in four rectangular parallel primary settlers (66 m x 15 m), each with a volume of 2970 m^3. Currently, the facility works with just one settler. The flowrate coming out of the primary sedimentation unit passes through activated sludge oxidation unit divided on two parallel treatment lines for a biological treatment. Each line has three sub-units with useful volume of about 5355 m^3 (17 m x 70 m) each. The total oxidation volume is approximately 32130 m^3. Currently there are two working reactors with redox and oxygen probes, and probe measurements are used for managing the aeration process. This system allows the nitrification-denitrification reactions and the organic matter removal. In case of high phosphorous concentration, an electronically controlled dozer adds ferric compounds for a phosphorous removal. Treated water is transferred then to the secondary settlers, with a diameter of 60 m and a volume of about 10000 m^3 each. Currently, the facility works with just one secondary settler. The disinfection is applied by dosing peracetic acid after the secondary settler and providing the required contact time between disinfectant and water.

Collected sludge is transferred to the thickening unit with a maximum flowrate of 220 m^3/h with a dry weight of 0,8-1,5 %, and it is divided between two thickeners. Each one has a diameter of 20 m and a volume of 1100 m^3. The sludge reaches the belt press with a dry concentration of 3%. The polyelectrolyte is added for the chemical conditioning of the sludge. The available filtration surface is 72 m^2. Within a thermal drying process, the sludge is loaded on a rotating disc oven with circulating hot diathermic oil (about 200-250 °C). The total sludge quantity of 25% comes out from the oven consisting of 95% dry fraction. In addition, an incineration plant is installed in the facility, which additionally reduces the sludge mass. However, it has never worked due to authorizations problems and the sludge residual is being handed by an outsourced company.

Table 1 summarizes the recognized strengths and weaknesses on San Giorgio di Nogaro plant. Strengths are related to the flexibility of the plant due to its high capacity that can receive high flowrates, high efficiency of the biological treatment as well as sludge treatment. Main weaknesses are related to high operational and maintenance costs, dependence on the industrial activity of surrounding area, and identified risk coming from high groundwater level.

Table 1. Strengths and weaknesses of San Giorgio di Nogaro plant

WEAKNESS	STRENGHT
High maintenance cost due to the large dimensions of the treatment's units	Oversized plant in relation to current loads, designed for a higher flowrate capacity
Strong dependence on the industrial activity of San Giorgio area	Sludge treatment reduces the sludge to 95% of dry fraction
Large energy consumption	Large flexibility of work due to oversize
High groundwater level	Redox and oxygen probes provide higher efficiency of the biological reactor

Figure 2. shows the influent characteristics of the parameters measured at the San Giorgio di Nogaro plant. The monitoring data relates to Chemical Oxygen demand (COD), Suspended solids, total Phosphorus, total Nitrogen and Nitrite and Nitrate. Highest concentrations in inflow are related to COD (150-250 mg/L) and Suspended Solids (70-120 mg/L). On Figure 3 effluent characteristics are displayed after the wastewater has been treated and before being discharged in submarine outlet. It is shown that the highest concentrations are reduced to approximately 40-60 mg/l for COD and 15-25 mg/L for suspended solids.

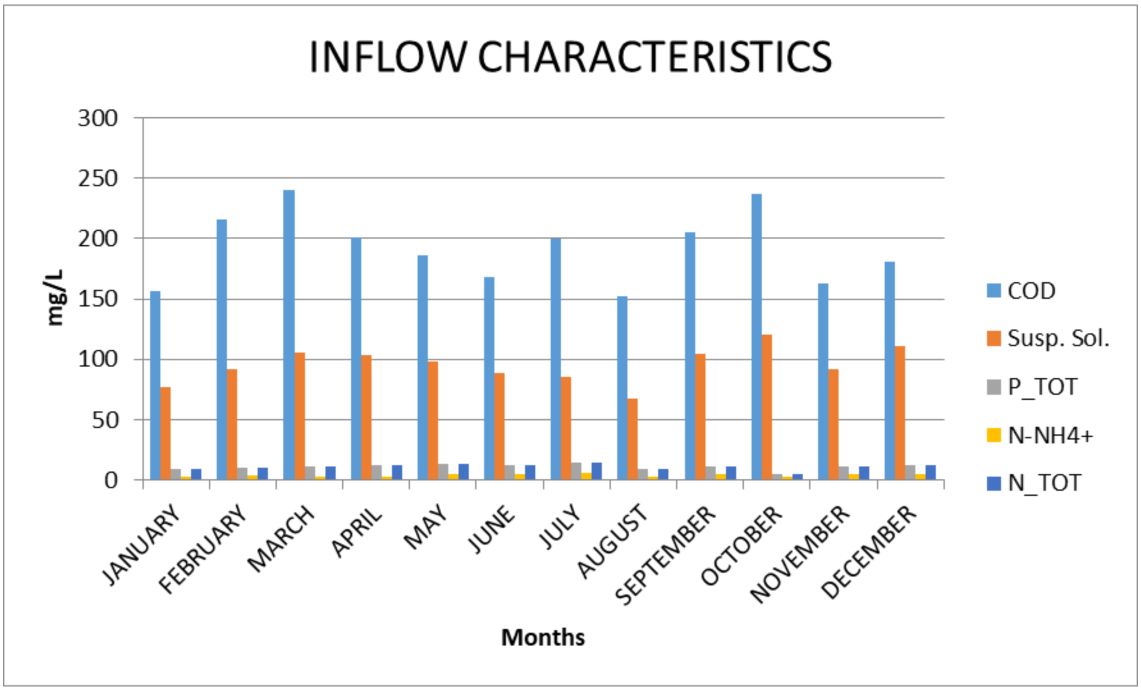

Figure 3: Inflow characteristics at San Giorgio di Nogaro plant

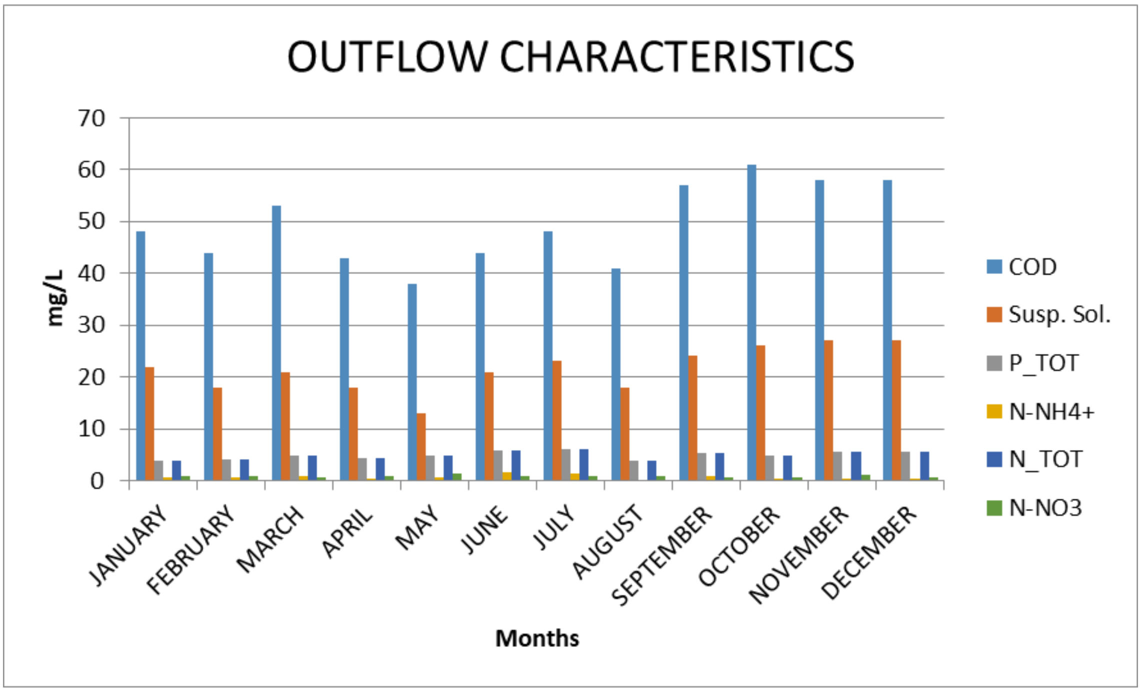

Figure 4: Outflow characteristics at San Giorgio di Nogaro plant

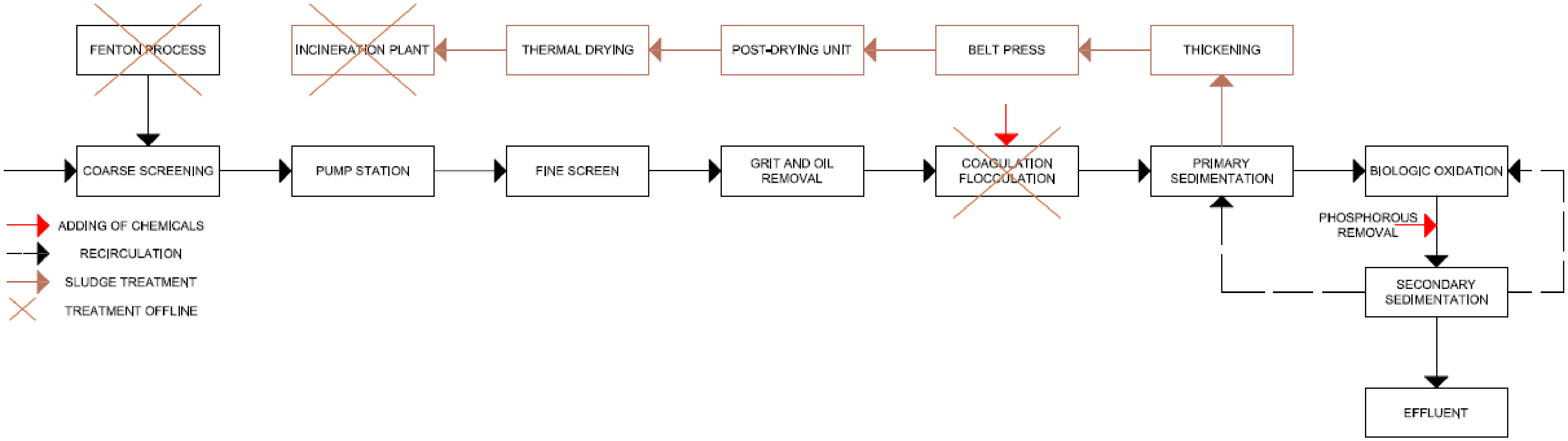

Figure 5: Technological scheme of San Giorgio plant

Lignano plant (Italy)

Wastewater treatment plant in Lignano is located within the urban area and the main purpose is to treat the wastewater coming from housing and tourism. Average flow rate for year 2018. is shown in Figure 6., and equals to average approximately 15.000 m^3/day with a relatively large seasonal oscillations during the year with flowrate range from 7000 m^3/day up to 23.000 m^3/day.

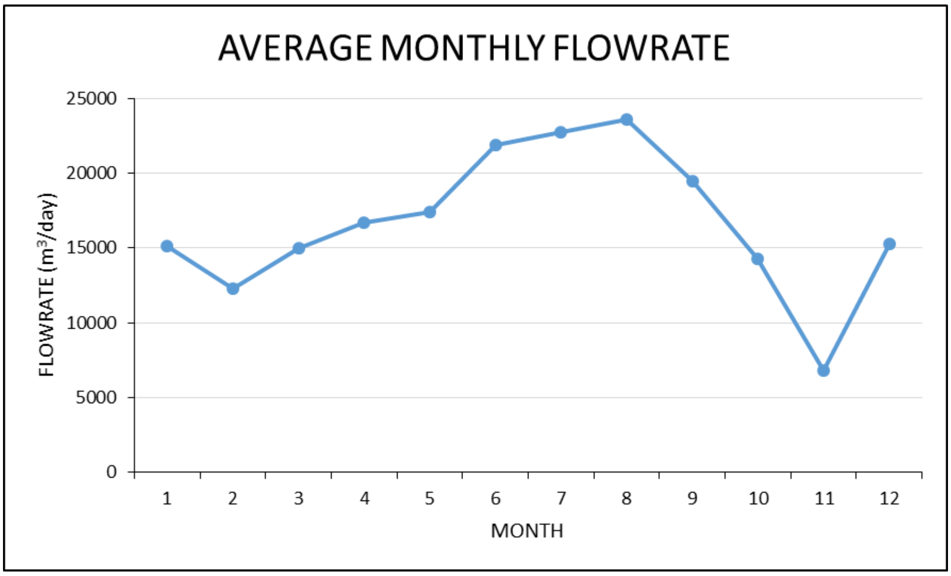

Figure 6: Average monthly flowrate (m^3/day) for year 2018. (Lignano)

Technological line (Figure 9) starts with a pumping station that is composed of two auger pumps (one of 1800 m^3/h and the second for the rain water with a capacity of 720 m^3/h) and three submersible pumps (two of 720 m^3/h and one of 360 m^3/h). The wastewater is pumped up to the screenings for a pre-treatment, which are able to receive a flowrate of 2520 m^3/h. The size of opening between bars is 3 mm and it is automatically cleaned. The settled solids are removed within the two units dedicated to grit removal each one with a volume of 150 m^3, aerated with 200 m^3/h of air.

After the pre-treatment wastewater can be treated on three different lines:

1. Chemical physical treatment
2. Biological treatment (BIO_1)
3. Biological treatment (BIO_2)

The first line is currently not in use while the third line is the most frequently used. The primary settler removes the suspended solids (about 50-70%), floating material and also 25-40% of BOD_5. The total volume is around 1840 m^3 with a surface of 707 m^2. A biological treatment (BIO1) line is served by four square plan reactors with a total volume of 2360 m^3. The maximum water level inside each of them is 3,5 m. Biological treatment (BIO2) line consists of two different lines operating on the sequencing batch reactors principle, with each reactor is operating continuously. However, they are characterized by different phases of aeration and no aeration. The volume of each unit is 2520 m^3 with a rectangular plan (35 x 12 m) and a flowrate capacity of 450 m^3/h. There are three secondary settlers: two are associated to BIO1 and one to BIO2. The rectangular one (volume 1050 m^3; overall dimensions 12 x 35 m) and circular one (volume 2350 m^3; diameter 35 m) are associated to BIO1. The third one, associated to BIO2, was installed as a lamellar packed bed settler. However, the lamellar packs have been removed and now it works as a normal rectangular reactor (volume: 1120 m^3; dimensions: 35 x 8 m). The disinfection line is optional and it consists on UV treatment, with four modules each containing 18 lamps, and capacity to treat 1800 m^3/h. In addition, there is also a possibility for disinfection by adding the peracetic acid and dosing the disinfectant directly on the outgoing channel.

Sludge is treated with a sludge thickener, where the sludge is pumped to a circular thickener with a diameter of 11 m where the filling height is about 4,3 m, and flowrate capacity of 50 m^3/h. In this phase the maximum dry fraction is about 5%. After thickening the sludge is transferred to anaerobic digester. The mesophilic anaerobic digester has cylindrical form with a diameter of 16 m. The total volume is 2200 m^3 and the inflow capacity is 144 m^3/d. There are 4 storage tanks that play the role of secondary thickener. The sludge is loaded in a mobile centrifuge before reaching the final disposal. Within a gasometer (volume 367 m^3) the biogas is produced and the flare is installed to burn the biogas in case of emergency.

Table 2. Strengths and weaknesses of Lignano plant

WEAKNESS	STRENGHT
Strong variability between winter and summer	Biogas production
Low organic load during the winter time	Remote control of the plant and alarm system in case of failures
Energy consumption due to heating of the anaerobic digester	Chemical disinfection (peracetic acid) in case of maintenance of UV disinfection system
Poor design of lamellar packed bed settler	Optimization of organic matter and nitrogen removal thanks to discontinuous aeration of biological reactor

Table 2 shows the recognized strengths and weaknesses on Lignano plant. Strengths are related to the possibility of producing biogas, application of chemical disinfection additionally to UV system, good control possibilities in case of emergency, and good optimization of organic matter and nitrogen removal. Main weaknesses are related to seasonal variability of plant operation, low organic load during winter due to small number of users, energy consumption due to heating of anaerobic digestors, and the poor design of lamellar packed bed.

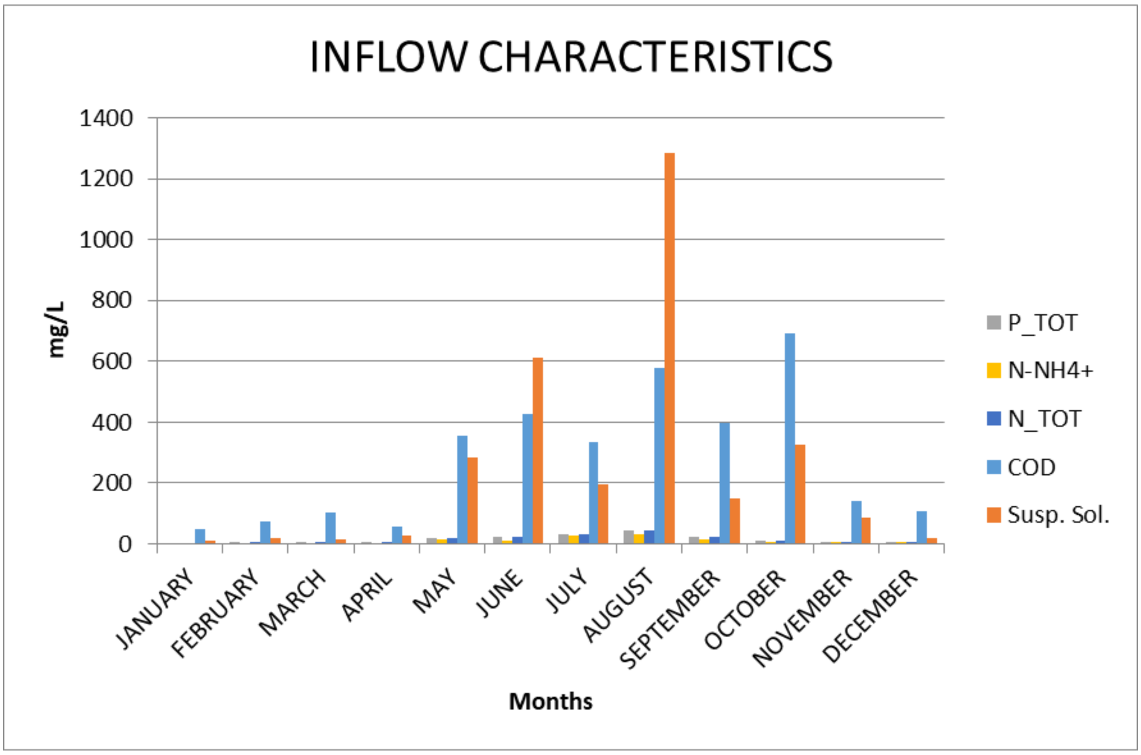

Figure 7: Inflow characteristics at Lignano plan

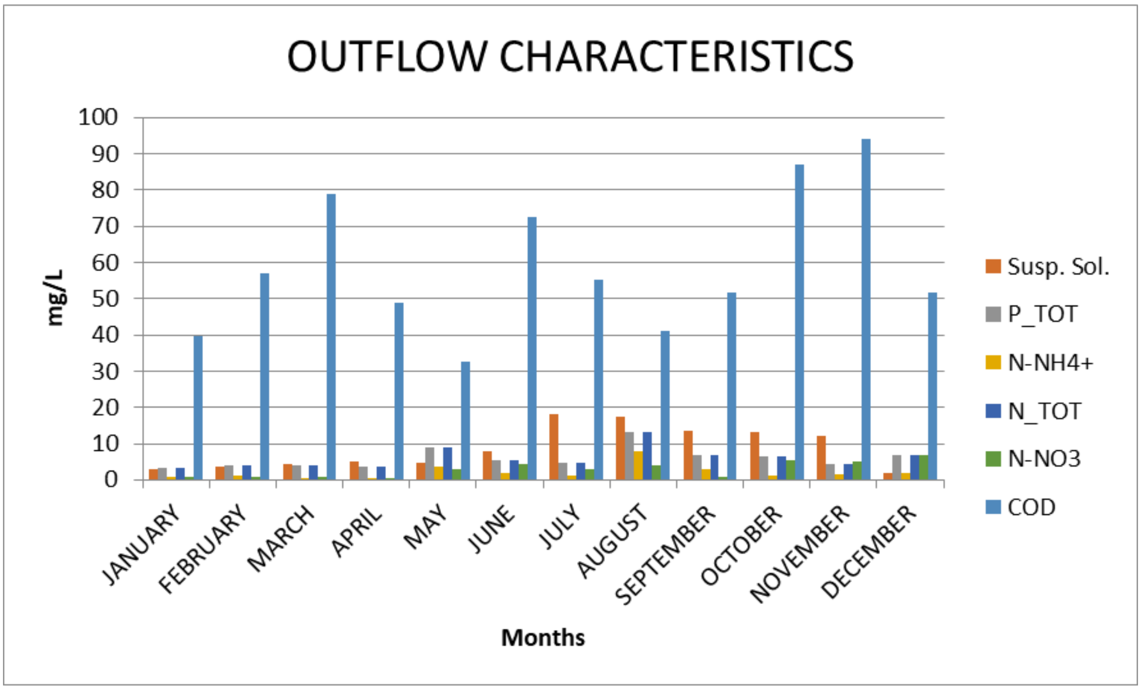

Figure 8: Outflow characteristics at Lignano plan

Figure 7. shows the influent characteristics of the parameters measured at the Lignano plant. The monitoring data relates to Chemical Oxygen demand (COD), Suspended solids, total Phosphorus, total Nitrogen and Ammonium. Highest concentrations in inflow are related to Suspended Solids (up to 1300 mg/L) and COD (up to 700 mg/L) showing the intensive seasonal variability in load. On Figure 3 effluent characteristics are displayed after the wastewater has been treated and before being discharged in submarine outlet. It is shown that the highest concentrations are reduced to approximately 40-80 mg/l for COD, and below 20 mg/L for suspended solids.

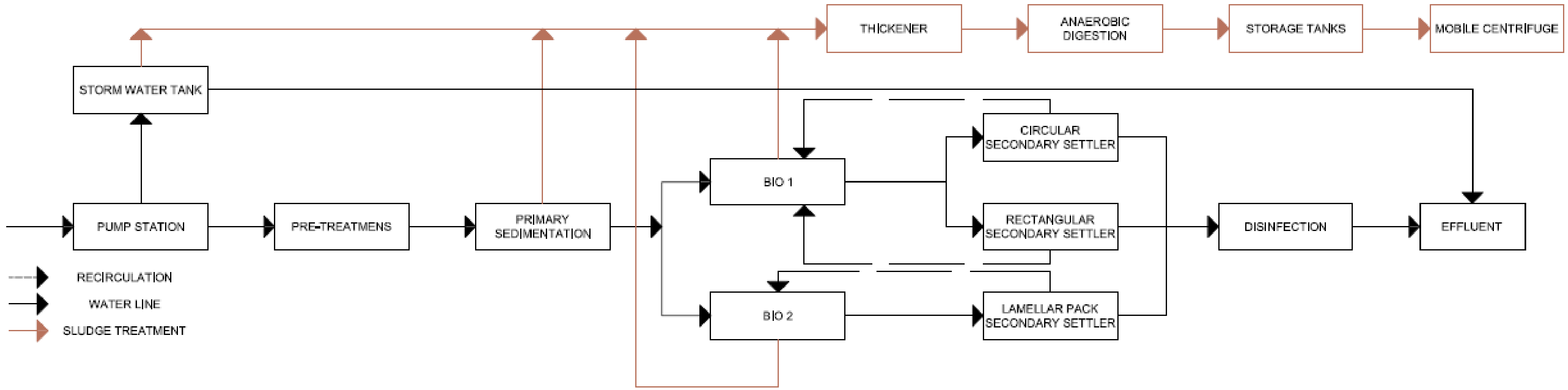

Figure 9: Technological scheme of Lignano plant

Francavilla Al Mare plant (Italy)

Wastewater treatment plant in Francavilla Al Mare is located within the urban area and the main purpose is to treat the wastewater coming from housing. Average flow rate for year 2018. is shown in Figure 6., and equals to average approximately 7.000 m^3/day.

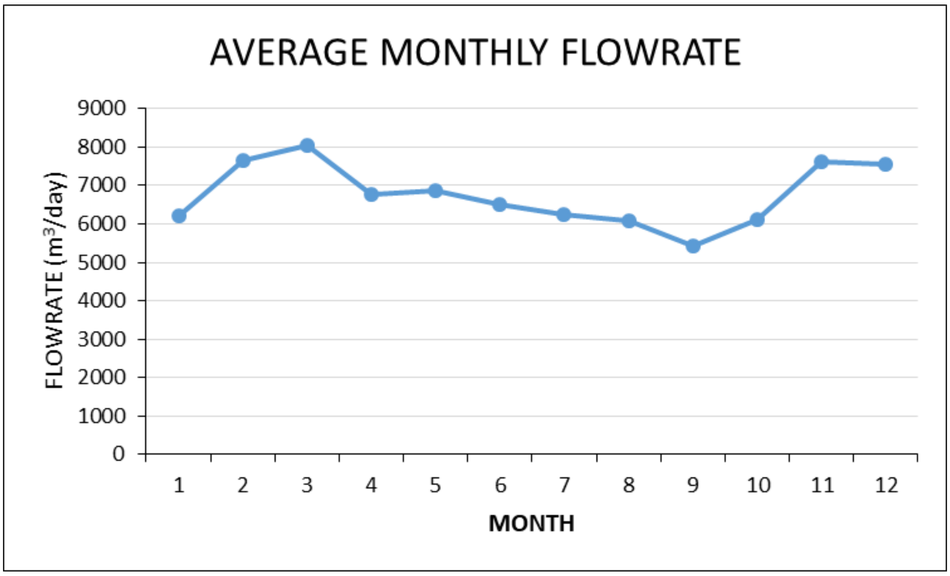

Figure 10: Average monthly flowrate (m^3/day) for year 2018. (Francavilla al Mare)

Technological line is shown in Figure 13, and starts with a pre-treatment where the wastewater passes through a manually cleaned coarse screen. This is followed by an automatically cleaned fine screen, as well as grit and oil removal and equalization tank. The 20% of the flow reaches the biological oxidation reactor called REA1 with a volume of 325 m^3. The associated secondary settler has a volume of 285 m^3. The 15% of the flowrate reaches the Nord Imhoff tank (Sed-I 1) with a volume of 770 m^3. Middle Imhoff tank (Sed-I 2) with a volume of 770 m^3 receives the 15% of the flowrate. Wastewater exiting from two fluidized bed reactors is carried to the secondary settler. The 50% of the flow reaches the biological oxidation reactor called REA2 with a volume of 1380 m^3. The associated secondary settler has a volume of 800 m3. Chemical disinfection is applied in a labyrinth path dosing peracetic acid. The sludge is firstly stored in a silo after which it is carried to the thickener after and transferred to the belt press where the sludge is dried.

Table 3 shows the strengths and weaknesses of Francavilla Al Mare Plant. Main strengths relate to optimized disinfection using peracetic acid, additional filters in biological reactors, microfiltration being partially applied, and remote-control possibilities. Weaknesses are related to the location of the facility in a small village, undersized mechanical dehydration process, lack of filters on all technological lines, and age of the facility.

Table 3. Strengths and weaknesses of Francavilla Al Mare plant

WEAKNESS	STRENGHT
The plant is placed in a village of 1000 inhabitants	Optimised disinfection with dozers of peracetic acid
Filters existing on only two technological lines	Two filters were transformed in biological oxidation (REA 1 and REA 2) that are able to treat 180 m^3/h on an overall flowrate of almost 300 m^3/h
Mechanical dehydration with an undersized belt press	Microfiltration of one third of the total incoming flowrate
Age of the plant equipment (1980)	Remote control of the plant and alarm system

Figure 11. shows the influent characteristics of the parameters measured at the Francavilla al Mare plant. The monitoring data relates to Chemical Oxygen demand (COD), Suspended solids, total Phosphorus, total Nitrogen and Ammonium. Highest concentrations in inflow are related to COD (up to 700 mg/L) showing the excessive variability in January and April. On Figure 12 effluent characteristics are displayed showing that the highest concentrations are reduced to approximately 40-90 mg/l for COD.

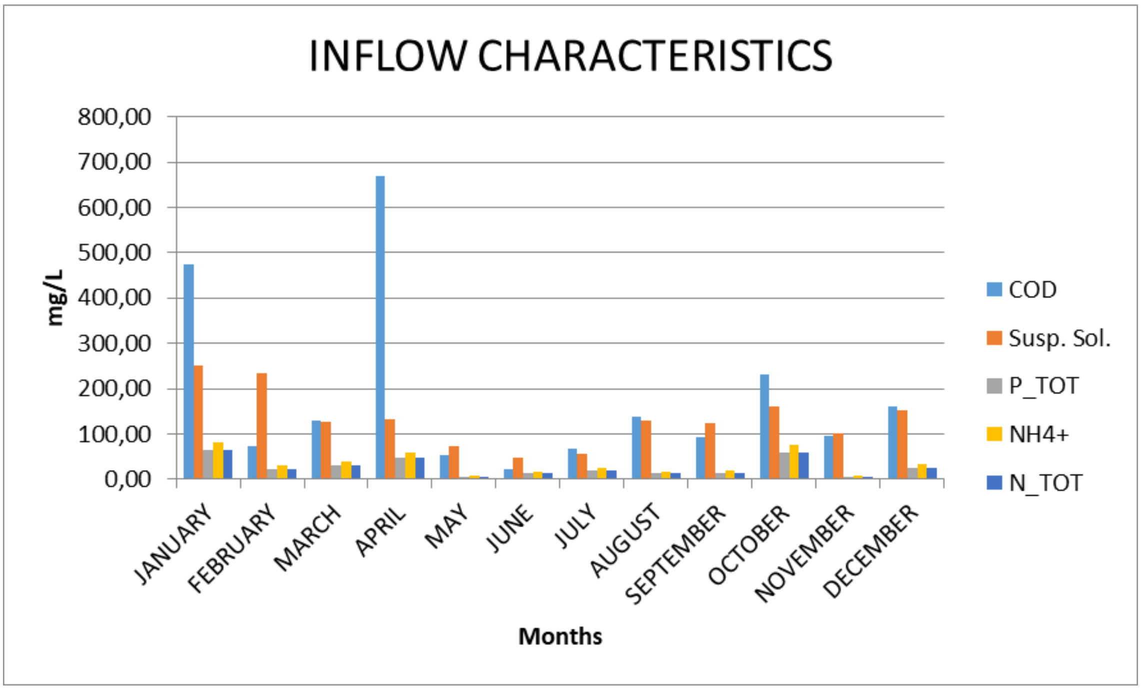

Figure 11: Inflow characteristics at Francavilla Al Mare plant

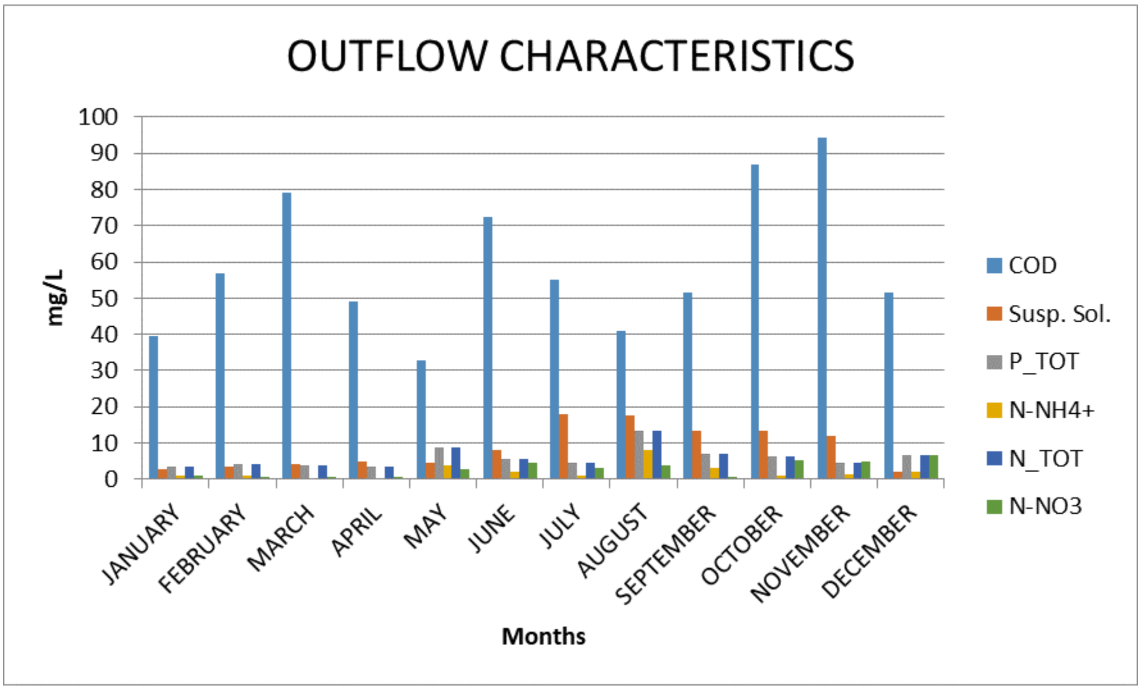

Figure 12: Outflow characteristics at Francavilla Al Mare plant

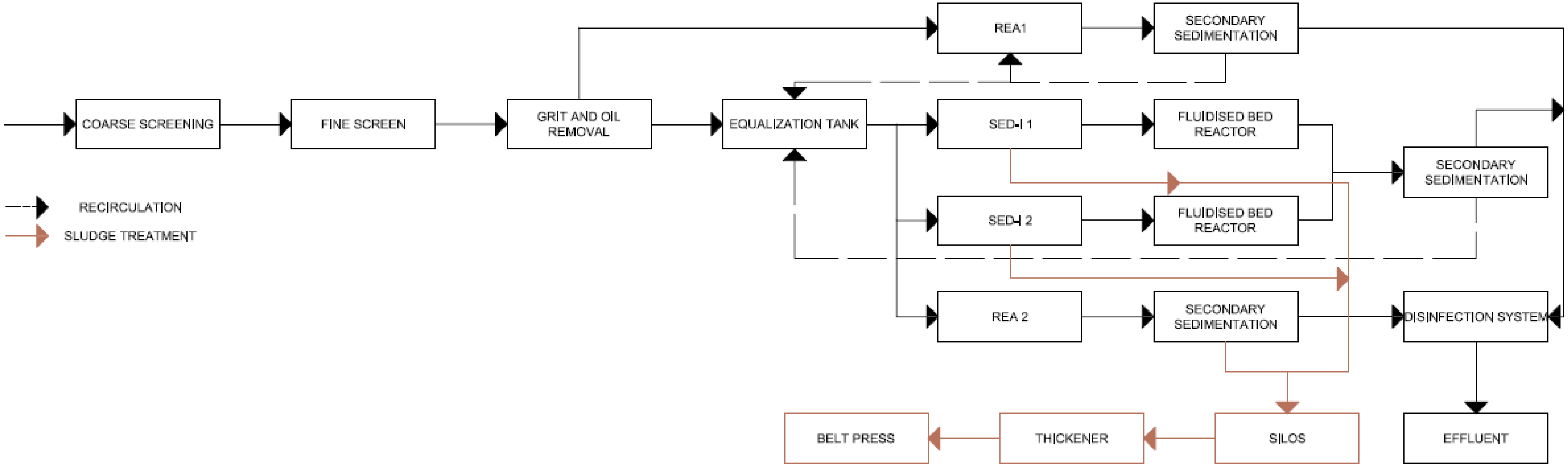

Figure 13: Technological scheme of Francavilla al Mare plant

Zadar Centar Plant (Croatia)

Wastewater treatment plant in Zadar is located within the urban area and the main purpose is to treat the wastewater coming from housing and tourism. Average flow rate for year 2018. is shown in Figure 6., and equals to average approximately 16.000 m^3/day with some oscillations during the year.

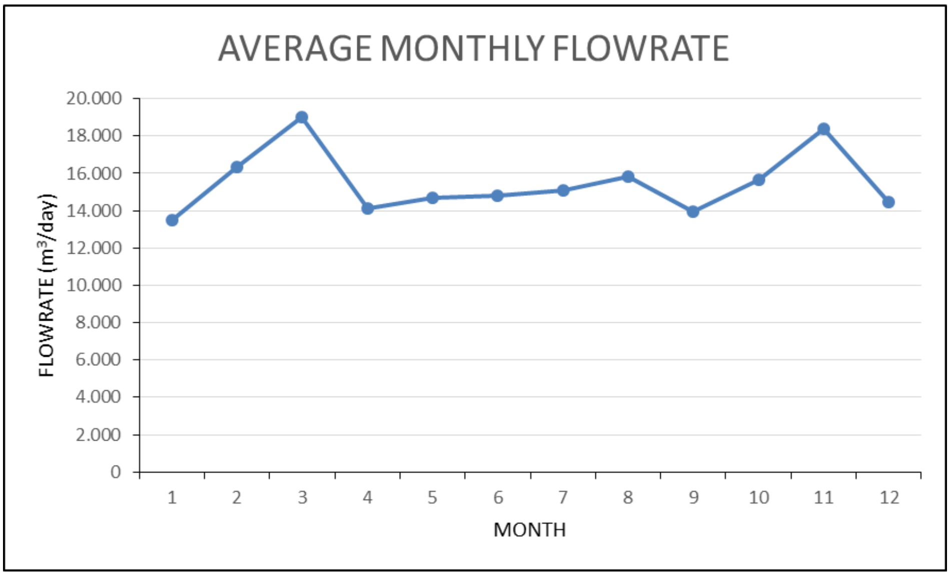

Figure 14: Average monthly flowrate (m^3/day) for year 2018. (Zadar - Centar)

The plant is designed for 100.000 population equivalents (PE) for the first phase. It is designed for the treatment of urban wastewater. Waterline starts with a pre-treatment where wastewater comes to a coarse grid with opening size between bars of 4 cm and flow capacity of 1000 l/s.

Technological scheme is shown in Figure 17. The grid is operated automatically and the separated waste is transferred to a container. Fine grid has an opening size of 3 mm between the bars with flow capacity of 1000 l/s. This process is followed by a sand and oil removal. In the primary settlers more than 50% of suspended solid are removed. Biological treatment is based on the principle of organic matter dissolvement using bacteria in the active sludge. The oxidation process is based on the diffusing the air in the wastewater which enhances the biological metabolism of bacteria. In bio-aeration tanks the partial absorption of organic matter leads to flocculation of active sludge on the surface. In the secondary settler absorption is completed that leads to final separation of clear wastewater and sludge. The sludge is recirculated to bio-aeration tank while the sludge excess is removed to the thickener. The secondary sludge, after the recirculation process, is transferred to the thickener as well, after which the total sludge is transferred to dehydration process where the dry matter is increased from 5% to 25%. Daily production of dehydrated sludge is 14.000 to 18.000 kg/day.

Table 4. Strengths and weaknesses of Zadar Centar plant

WEAKNESS	STRENGHT
Sludge management after removal	New facility
No biogas production	High rate of COD, BOD and SS removal
Oversized facility - currently only one (of total 2) technological line in operation	Good biological treatment

Table 4 shows main strengths and weaknesses of Zadar Centar plant. Main strengths are related to good performance of the facility with high rate of COD, BOD and suspended solids removal. Additionally, biological treatment is satisfying. Main weaknesses are related to sludge management after removal and treatment (sludge is disposed to a landfill), and there is no biogas production. Facility currently works on partial capacity.

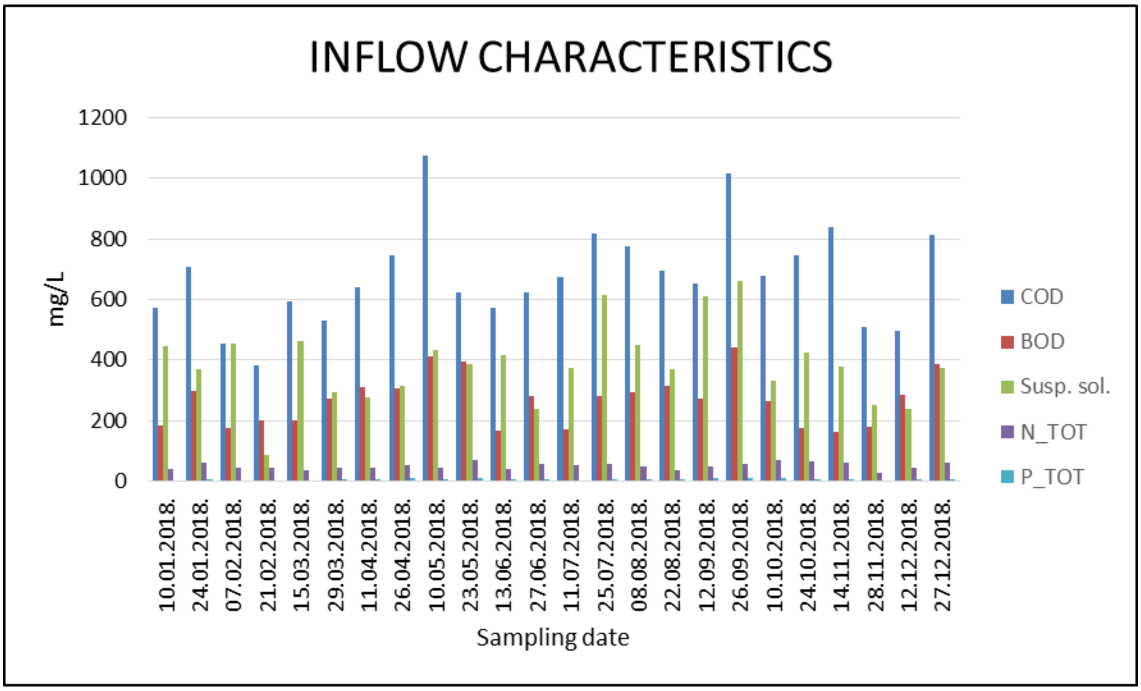

Figure 15: Inflow characteristics at Zadar Centar plant

Figure 15. shows the influent characteristics of the parameters measured at the Zadar Centar plant. The monitoring data relates to Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) Suspended solids, total Phosphorus, and total Nitrogen. Highest concentrations in inflow are related to COD (up to 1000 mg/L) showing the excessive variability during summer. On Figure 16 effluent

characteristics are displayed showing that the highest concentrations are reduced to approximately 30-70 mg/l for COD.

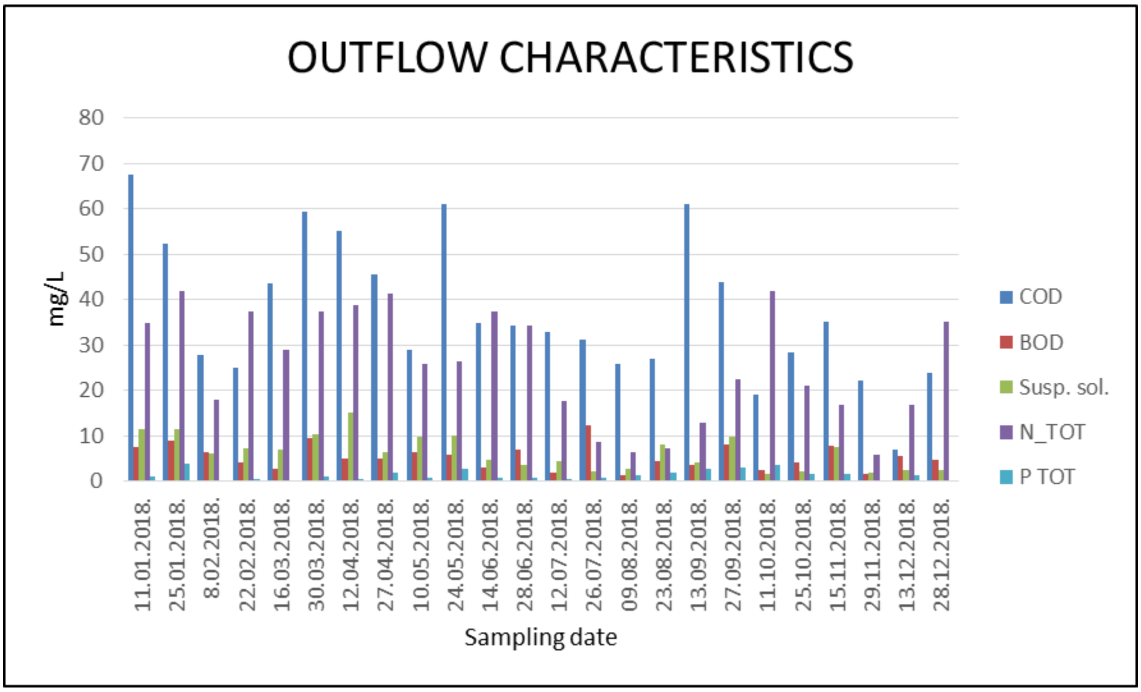

Figure 16: Outflow characteristics at Zadar Centar plant

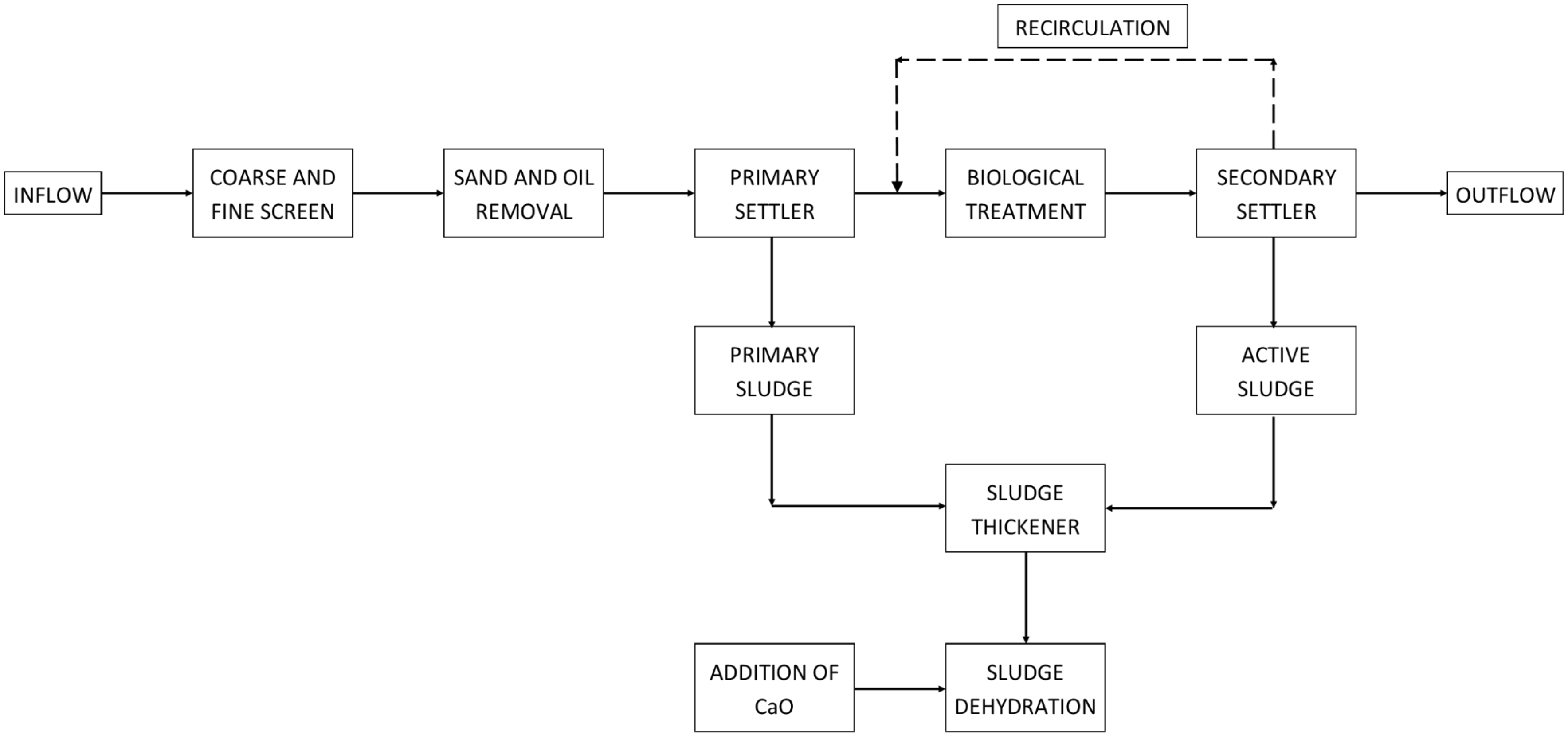

Figure 17: Technological scheme of Zadar Centar plant

Split Katalinića brig plant (Croatia)

Wastewater treatment plant Katalinića brig is located near Bačvice beach in Split, and it is designed to receive and treat the wastewater from southern basin of Split, with a capacity for 122.000 population equivalents. The average flowrate around 35.000 m^3/day (Figure 18) with some oscillations during the year.

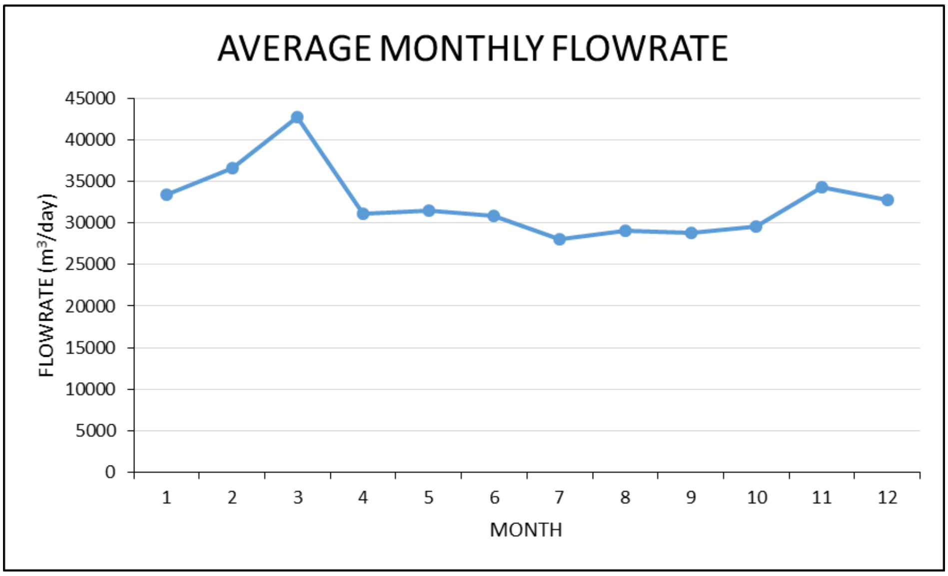

Figure 18: Average monthly flowrate (m^3/day) for year 2018. (Katalinića brig)

Wastewater coming on the plant is a mixed type – combined urban wastewater and rainfall runoff. Treatment consist only of automatically cleaned coarse grid with a screen hatch of 50 mm, and a fine grid with screen hatch of 7 mm (Figure 19).

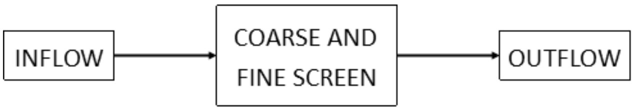

Figure 19: Technological scheme of Split Katalinića brig plant

The treated wastewater is discharged by a pumping station through submarine outfall with a diffuser. The total length is 1570 m (100 m on land, 1470 m underwater), with a discharge depth of 43 m. Submarine discharge pipe has diameter of 800 mm. Maximum allowed discharge quantities according to water permit are 17.005.400 m^3 per year.

In Table 5., main strengths and weaknesses are shown for wastewater treatment plant Katalinića brig. Strengths are related to good recipient characteristics, large depth of submarine outfall and the fact that there is no industrial or agricultural load coming on the facility. The weaknesses are related to poor treatment technology with no biological treatment, no nutrient or sludge removal. In addition, the system is combined rainfall runoff and sewage wastewater. There is no monitoring on the entrance, which makes impossible to determine the inflow parameters of wastewater.

Table 5. Strengths and weaknesses of Split - Katalinića brig plant

WEAKNESS	STRENGHT
Combined system – rainfall runoff and sewage wastewater	Good recipient characteristics
Poor depuration technology, no biological treatment or nutrient removal	Submarine outfall at large depth (44 m)
No sludge removal	No industrial or agricultural load
Lack of monitoring on depuration plant entry	

On Figure 20, measured parameters of outflow are displayed that are measured on the exit. Parameter COD has highest concentration especially during summer (900 mg/L) showing the exceedance compared to allowed concentrations before entering the sea. Unfortunately, wastewater is not analyzed at the entry of the plant so it is impossible to determine the removal rate.

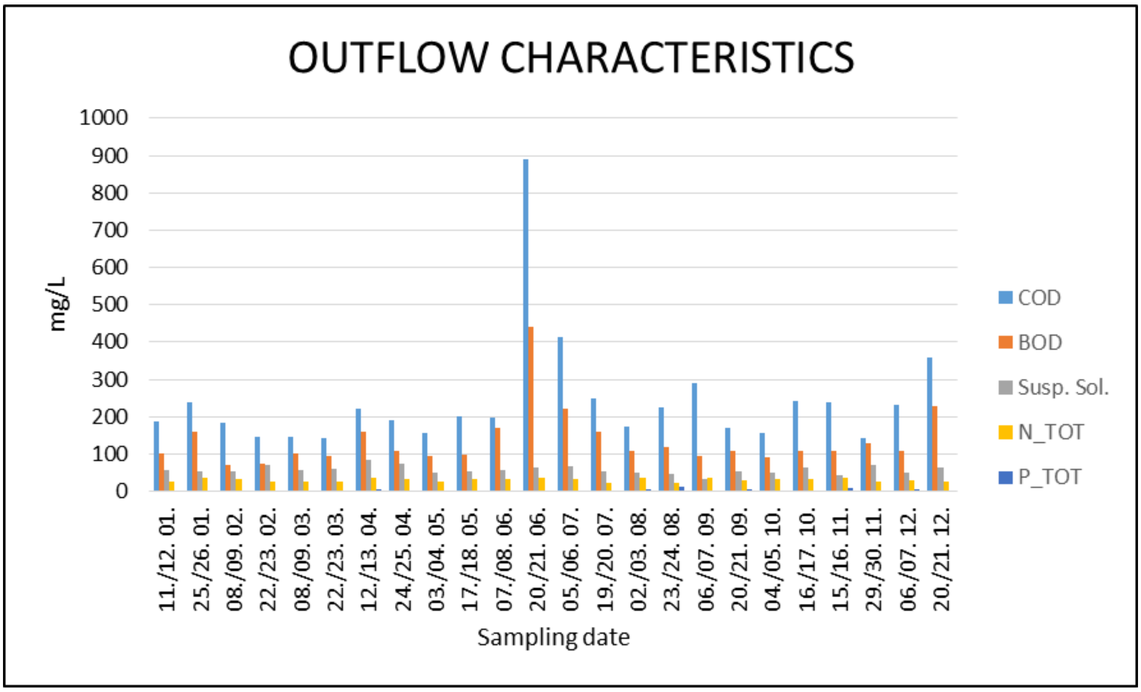

Figure 20: Effluent characteristics at Split Katalinića brig plant

Split Stupe plant (Croatia)

Wastewater treatment plant Stupe is located in the eastern part of Split, and it is designed to receive and treat the wastewater coming from north-eastern part of Split as well surrounding municipalities (Solin, Podstrana, Klis, Dugopolje). Design capacity is equal to 138.000 population equivalents. Average inflow is equal to approximately 30.000 m^3/day with significant oscillations (Figure 21.).

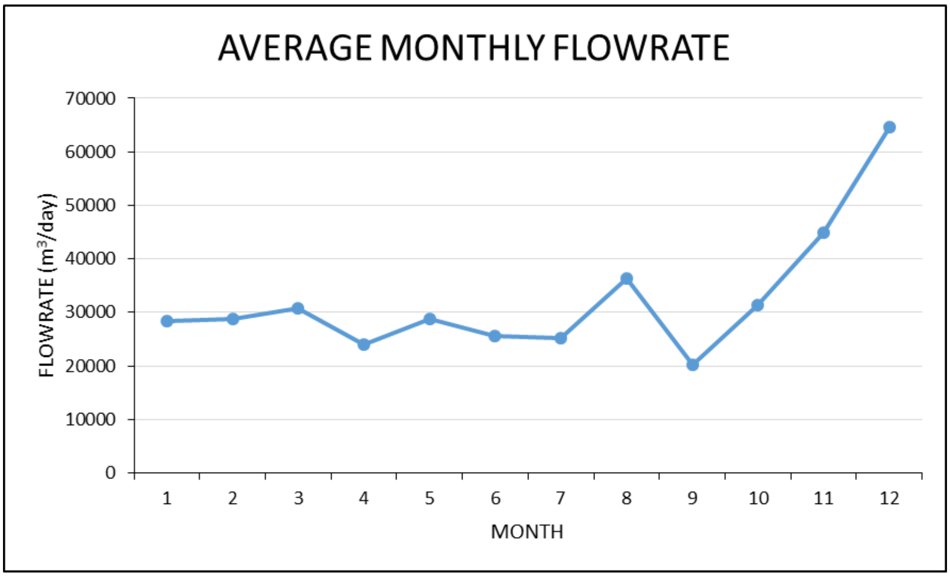

Figure 21: Average monthly flowrate (m^3/day) for year 2018. (Stupe)

Wastewater is treated with two automatically cleaned coarse grids (screen hatch of 10 mm), two fine grids (screen hatch of 2 mm), aerated sand and grease filter, with sand classifier as well as oil and grease separator (Figure 22). In addition, within this wastewater treatment plant exist a facility for septic tanks wastewater collection. Maximum discharge according to water permit is 11.000.000 m^3 per year. The treated wastewater is discharged through submarine outfall with diffuser, total length is 2750 m (1850 m on land, 900 m underwater), discharge depth 37 m.

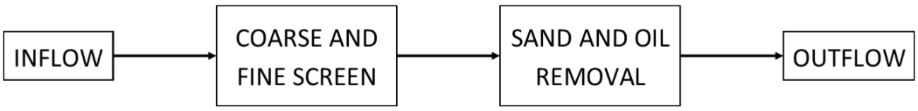

Figure 22: Technological scheme of Split Stupe plant

In Table 6., main strengths and weaknesses are shown for wastewater treatment plant Stupe. Similarly to Katalinića brig, main strengths are related to good recipient characteristics, large depth of submarine outfall and the fact that there is no industrial or agricultural load coming on the facility. The weaknesses are related to poor treatment technology with no biological treatment, no nutrient or sludge removal. There is no monitoring on the entrance, which makes impossible to determine the inflow parameters of wastewater. In addition, wastewater from septic tanks with unknown content is received at the facility.

Table 6. Strengths and weaknesses of Split - Stupe plant

WEAKNESS	STRENGHT
Poor depuration technology, no biological treatment or nutrient removal	Good recipient characteristics – auto purification capacity
No sludge removal	Submarine outfall at large depth
Lack of wastewater monitoring on DP entry	No industrial or agricultural load
Septic tanks sewage reception	

On Figure 23, measured parameters of outflow are displayed that are measured on the exit. Parameter COD has highest concentration (900 mg/L) showing the exceedance compared to allowed concentrations before entering the sea. Unfortunately, wastewater is not analyzed at the entry so it is impossible to determine the removal rate.

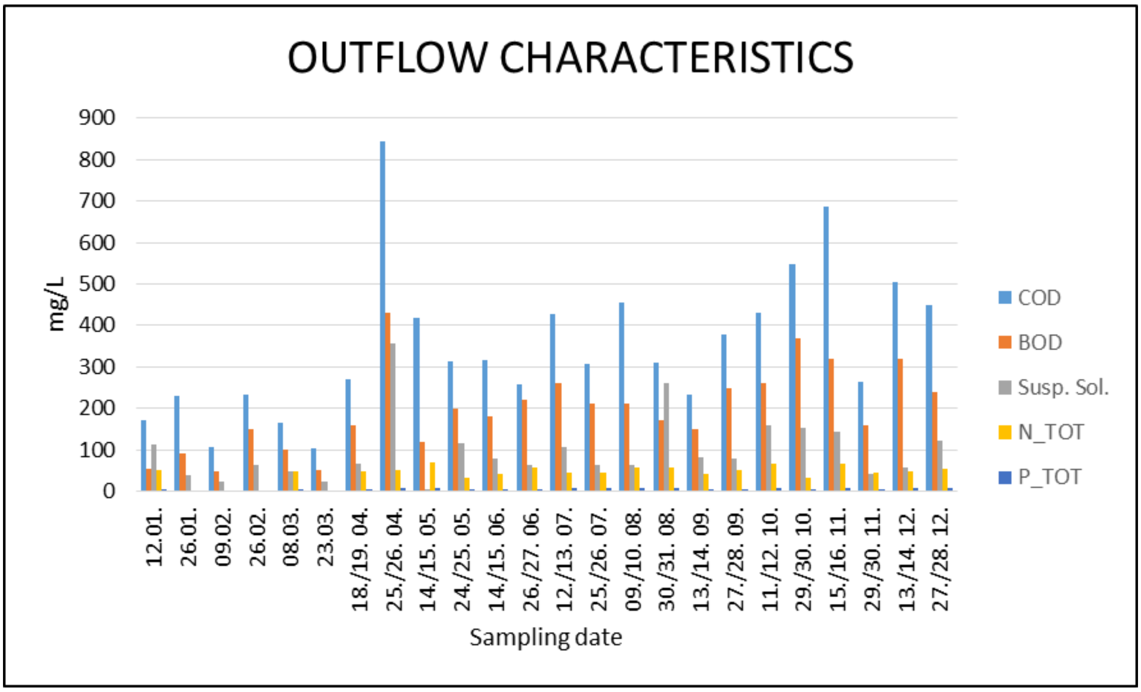

Figure 23: Outflow characteristics at Split Stupe plant

PART 3: COST BENEFIT ANALYSIS OF CURRENT OPERATION MODE

Cost-benefit analysis of current operational mode of pilot depuration plants is performed from a perspective where costs consider operational expenses such as labor cost, electricity, maintenance etc. On the other hand, benefits from current operational mode are quantified through percentage of removed substances from wastewater before being releasing into environment. To quantify these benefits, the benefit transfer method was applied. In this method, benefit estimates from existing case studies are spatially and/or temporally transferred to new studies. Benefits are quantified according to UNEP Guidelines, where approach from Hernandez-Sancho et al., 2010. is adopted in estimating monetary benefits from wastewater treatment process. This approach defines shadow prices for wastewater parameters (Table 7.) in case of wastewater discharge into environment. This approach is used here inversely in estimating what are the benefits from removal of each parameter in kg/year.

Table 7. Shadow prices for each parameter removal in case of sea as a recipient (Hernandez-Sancho et al., 2010.)

Shadow prices for undesirable effects (€/kg)				
COD	**BOD**	**Susp. Sol.**	**P_TOT**	**N_TOT**
0,010	0,005	0,001	7,533	4,612

The prices of parameters in 2010 have been adjusted to 2018 using harmonized index of consumer prices Italy and Croatia from Eurostat.

Table 8. Adjustment of shadow prices, Italy, 2018

Shadow prices for undesirable effects (€/kg)				
COD	**BOD**	**Susp. Sol.**	**P_TOT**	**N_TOT**
0,011	0,006	0,001	8,338	5,105

Table 9. Adjustment of shadow prices, Croatia, 2018

Shadow prices for undesirable effects (€/kg)				
COD	**BOD**	**Susp. Sol.**	**P_TOT**	**N_TOT**
0,011	0,006	0,001	8,321	5,094

San Giorgio di Nogaro plant

Analysis of the depuration performance is summarized in Table 10., showing the removal rate of wastewater parameter concentrations. Highest removal rate is for $N\text{-}NH_4^+$ while phosphorus and nitrogen are at bit lower removal rate. Using the shadow prices from Table 8., benefits from the depuration process are calculated using available prices and particular measured parameters without BOD (shown in Table 11). Benefit calculation for BOD is missing since the stated parameter is not measured at the facility as well as parameter $N\text{-}NH_4^+$ for which a shadow price is not estimated at first place. Total estimated monetary benefit equals to *530.420 €* for year 2018, while operational costs are *993.252 €.*

Table 10. Overview on depuration efficiency of San Giorgio di Nogaro plant (year 2018.)

PARAMETER	COD	Susp. Sol.	P_TOT	N_TOT	$N\text{-}NH_4^+$
Inflow load (kg/year)	2.365.530	1.176.560	24.802	138.766	49.337
Outflow load (kg/year)	606.322	263.334	11.430	60.719	8.529
Removal rate (%)	**74,37**	**77,6**	**53,9**	**56,2**	**82,7**

Table 11. Summarized costs and benefits for current operational mode of San Giorgio di Nogaro plant (year 2018.)

PARAMETER	COD	Susp. Sol.	P_TOT	N_TOT	$N\text{-}NH_4^+$
Removed load (kg/year)	1.759.207	913.226	13.371	78.047	40.808
Benefits (€/year)	19.473	1.011	111.501	398.436	N/A
Total benefits (€/year)	**530.420**				
Total operational costs (€/year)	**993.252**				

Lignano plant

Depuration efficiency for Lignano plant is shown in Table 12, where it can be seen that the highest removal rate is for suspended solids concentration, and COD as well as $N\text{-}NH_4^+$ are at high level as well. Using shadow prices for Table 8., an overall benefit is estimated using proposed available prices (Table 13.). Total estimated monetary benefit for Lignano plant equals to *493.898 €* for year 2018., while operational costs are *682.535 €.*

Table 12. Overview on depuration efficiency of Lignano plant (year 2018.)

PARAMETER	COD	Susp. Sol.	P_TOT	N_TOT	$N\text{-}NH_4^+$
Inflow load (kg/year)	1.871.193	1.923.599	20.125	113.093	73.408
Outflow load (kg/year)	345.496	57.467	8.533	38.993	14.650
Removal rate (%)	**81,5**	**97,0**	**57,6**	**65,5**	**80,0**

Table 13. Summarized costs and benefits for current operational mode of Lignano plant (year 2018.)

PARAMETER	COD	Susp. Sol.	P_TOT	N_TOT	$N\text{-}NH_4^+$
Removed load (kg/year)	1.525.697	1.866.131	11.592	74.100	58.759
Benefits (€/year)	16.888	2.066	96.658	378.286	N/A
Total benefits (€/year)	**493.898**				
Total operational costs (€/year)	**682.535**				

Francavilla al Mare plant

Depuration efficiency for Francavilla al Mare plant is shown in Table 14, where it can be seen that the highest removal rate is for $N\text{-}NH_4^+$ concentration, and COD as well as suspended solids are at high level as well. Total estimated monetary benefit for Francavilla al Mare plant equals to *310.075 €* for year 2018.

Table 14. Overview on depuration efficiency of Francavilla al Mare plant (year 2018.)

PARAMETER	COD	Susp. Sol.	P_TOT	N_TOT	$N\text{-}NH_4^+$
Inflow load (kg/year)	447.935	326.294	10.516	65.494	84.206
Outflow load (kg/year)	76.209	45.493	3.386	17.268	5.455
Removal rate (%)	**83,0**	**86,1**	**67,8**	**73,6**	**93,5**

Table 15. Summarized costs and benefits for current operational mode of Francavilla al Mare plant (year 2018.)

PARAMETER	COD	Susp. Sol.	P_TOT	N_TOT	$N\text{-}NH_4^+$
Removed load (kg/year)	371.726	280.802	7.129	48.226	78.751
Benefits (€/year)	4.115	311	59.453	246.197	N/A
Total benefits (€/year)	**310.075**				
Total operational costs (€/year)	**N/A**				

Zadar Centar plant

Depuration efficiency for Zadar Centar plant is shown in Table 16., where it can be seen that the highest removal rate is for suspended solids concentration, and COD as well as BOD are at high level as well. Using shadow prices from Table 9., an overall benefit is estimated using proposed available prices (Table 157). Total estimated monetary benefit for Zadar Centar plant equals to *1.011.285 €* for year 2018., while operational costs are *1.655.300 €.*

Table 16. Overview on depuration efficiency of Zadar - centar plant (year 2018.)

PARAMETER	COD	BOD	Susp. Sol.	P_TOT	N_TOT
Inflow load (kg/year)	3.806.726	1.498.095	2.169.001	35.925	286.121
Outflow load (kg/year)	208.962	30.640	35.830	7.802	143.400
Removal rate (%)	**94,5**	**98,0**	**98,3**	**78,3**	**49,9**

Table 17. Summarized costs and benefits for current operational mode of Zadar Centar plant (year 2018.)

PARAMETER	COD	BOD	Susp. Sol.	P_TOT	N_TOT
Removed load (kg/year)	3.597.763	1.467.455	2.133.171	28.122	142.722
Benefits (€/year)	39.741	8.105	2.356	234.008	727.075
Total benefits (€/year)	**1.011.285**				

Total operational costs (€/year)	**1.655.300**

Split Stupe and Katalinića brig plants

For plants in Split there is no data available about inflow characteristics so it is impossible to determine the removal rate and estimate environmental as well as monetary benefits from wastewater treatment. The total operational costs for Stupe and Katalinića brig are shown in Table 18. and Table 19.

Table 18. Summarized costs and benefits for current operational mode of Split Stupe plant (year 2018.)

PARAMETER	COD	BOD	Susp. Sol.	P_TOT	N_TOT
Outflow load (kg/year)	3.702.004	2.075.512	1.021.500	59.888	531.993
Total operational costs (€/year)	**492.200**				

Table 19. Summarized costs and benefits for current operational mode of Split Katalinića brig plant (year 2018.)

PARAMETER	COD	BOD	Susp. Sol.	P_TOT	N_TOT
Outflow load (kg/year)	2.894.692	1.647.319	689.330	49.549	365.905
Total operational costs (€/year)	**250.480**				

LITERATURE

- *Economic Valuation of Wastewater, The Cost of Action and The Cost of No Action*, The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA), through the Global Wastewater Initiative (GW2I), UNEP (2015)
- Hernández-Sancho, F., Molinos-Senante, M. and Sala- Garrido, R. (2010); *Economic valuation of environmental benefits from wastewater treatment processes: An empirical approach for Spain*; Science of Total Environment, 408, pp. 953-57.