FROM SHARED RESOURCES
TO JOINT SOLUTIONS

D 5.2.3 Analysis of phosphorus recovery approach, sludge production and discharge effect mitigation under implemented technologies

(combined D 5.2.3, D 5.2.4 & D 5.2.5 from AF)

FROM SHARED RESOURCES
TO JOINT SOLUTIONS

PROJECT AdSWiM

Work Package:	**5. Technologies and strategies for managing DPs guidelines definition and cross-borders strategies**
Activity:	**5.3 Joint and shared cross-border strategies of WWT plant management and legislative action proposals**
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PART 1: IMPLEMENTATION OF REEF BALLS NEAR WASTEWATER MARINE OUTFALLS

REEF BALL DESCRIPTION

The reefball (Figure 1) is a concrete structure with a belt form and with a lot of holes. These structures are also called “FAD” (Fish Aggregating Devices) due to their function.

Figure 1 Reef ball

The goal of this structure is to become, firstly, a place where algae can grow, secondly a repair for the fishes.

The reef ball are an already known and applied technology and there are many types of it basing on the dimensions of the belt as you can see on Figure 2.

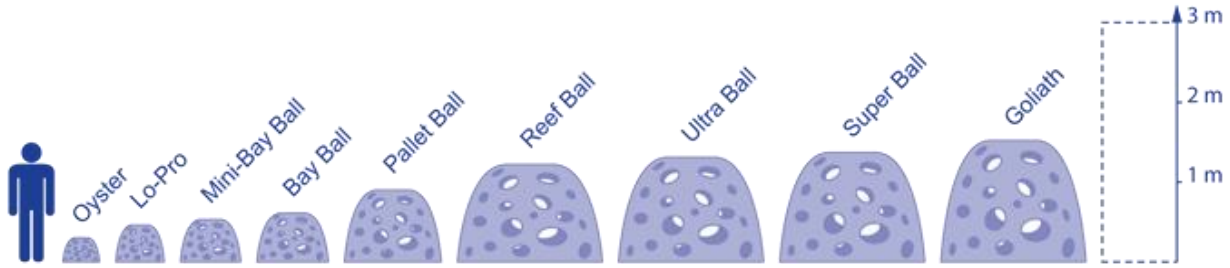


Figure 2 Reef balls types

The dimensions change basing on the place where those structures are going to be installed and basing on the type of fishes that populate that portion of sea.

EXPECTED RESULTS

The Adriatic Sea is poor of nutrients, which is one of the causes of the fish scarcity. The aim of the reef ball placement was to exploit the higher concentration of these nutrients (in particularly of phosphorous) measurable at the exit of the discharge pipe of a wastewater treatment plant, than sea area far away from that pipe.

In fact, the algae can grow quicker and easier in a place where there is a right concentration of phosphorous rather than an area where there do not.

At the beginning, it is expected to see the growth of algae over the entire reef balls surface. Then the small fishes and other small organisms will come, attracted by that concentration of food.

Then the bigger fishes will start to go around the reef balls to eat the just mentioned small organisms and small fishes. And so on until the rebuild of the trophic chain.

THE REEF BALLS PLACEMENT

Cafc decided to place the reef balls along the discharge pipe of the wastewater treatment plant of Lignano. Before of the placement it was necessary to draw up a project.

The project, among the different evaluations, established the following features:

- Number of reef balls: 20;
- Distance between each reef ball: 3 m;
- Distance between reef ball and discharge pipe: 10 m;
- Position of the reef balls: along the last 40 meters of the discharge pipe.

The reef balls placement involved different authorities who gave the approval before of the placement.

The 20th April 2021 it was possible to place the reef balls as reported in the Figure 3.

Figure 3 Reef ball placement

THE SITUATION AFTER THREE MONTHS

In order to check the situation, three months after the reef balls placement, it was decided to make a video of the environment around the reef balls.

On 31.08.2021 a dive was carried out with two divers equipped with reels and photographic equipment to verify the colonization status of the artificial barriers and the presence of fish species.

In Table 1 are reported all the found species.

Fish species found	Number	Dimensions
Dicentrarchus labrax	1	50 cm
Sciaena umbra	3	20 – 30 cm
Conger conger	1	1 m
Diplodus anularis	1	10 cm
Diplodus vulgaris	3	15 cm
Gobius niger	13	10 cm
Parablennius rouxi	9	8 cm
Other marine species found		
Maya verrucosa		
Murex spp		
Cratena peregrina		
Schizobrachiella spp		
Eudendrium spp		

Table 1 List of the found species

The figure 4 a shows the reef ball surface at displacement time.

The figure 4 b shows the reef ball surface after three months.

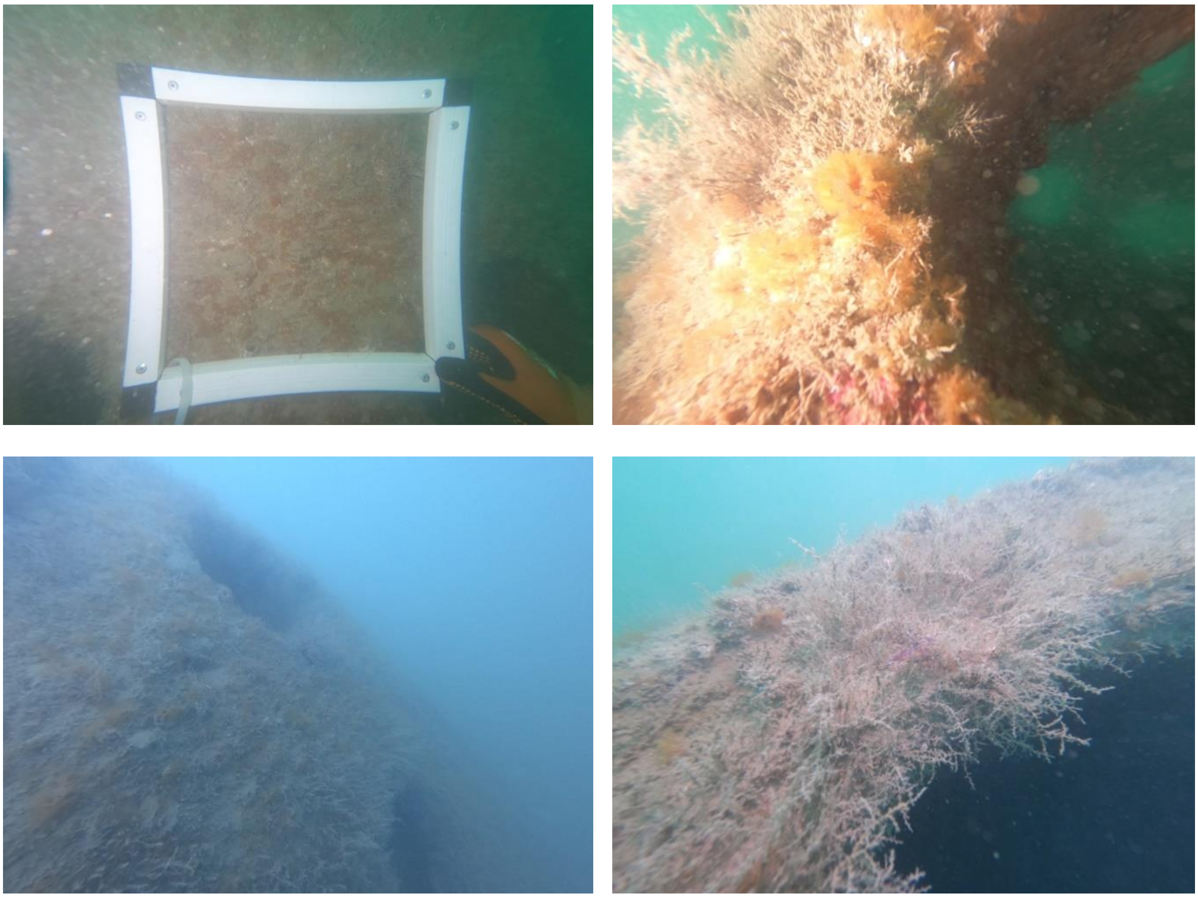


Figure 4 Reef ball surface colonization after three months

As expected, the surface has been colonized by different epiphytic organisms such algae and colonial hydrozoans, bryozoans and have been observed in visual census monitoring, different types of fishes, crustaceans, gastropods and nudibranch mollusks, populating the artificial barriers.

The observed results, exceeds the expectations because the number of species seen around the reef balls was higher than other case study.

CONCLUSIONS

The reef balls were placed successfully, the observed results are better than those expected.

In the deliverable "*Report regarding how are, discharge effect of treated WW, mitigated with the use of artificial submerged structures*" a monitoring campaign of the reef balls was established.

Unfortunately, the reef balls placement authorization procedure took more time than that considered. Due to this fact, it was realized just a monitoring day. Cafc wants to go on with the monitoring campaign also after the end of the Adswim project.

Until now, the only observed positive result is the covering of reef ball surface by the algae and some microorganism and small fishes.

During the winter the water will be clearer and it will be easier the estimation and the evaluation of the results.

There is also another aspect to follow up in the future: in the proximity of the discharge pipeline, there is a conducive environment for the development of the trophic chain. Researchers will follow up this important outcome in the future. The challenge will be the recovery in the sea of all residual substances present in the WWTP outlet (an outlet that already respects the law limits).

PART 2: PHOSPHORUS RECOVERY APPROACH

OBJECTIVE AND METHOD

As is known, the wastewater treatment plants (WWTPs) managed by CAFC on which the experiences of the ADSWIM project were carried out are those of San Giorgio di Nogaro and Lignano Sabbiadoro.

In particular, the experience of the REEFBALLs placement along the discharge pipe of the Lignano Sabbiadoro plant had a considerable value. The first results of this experience, although not measured at the moment, are visible through the films and photos taken and have demonstrated a marine environment suitable for restocking and restoring the marine food chain.

These first positive considerations are giving rise to new research opportunities focused on the theme of the reuse of nutrients (primarily phosphorus) in alternative forms to those already extensively studied and investigated in recent decades. In particular, the questions that will need to be answered in the coming years are whether some marine environments are deficient in phosphorus and whether the recovery of the same in the marine environment can be admissible and favored by the laying of these multifunctional marine reefs (in addition to repopulation, they also act as barriers to protect pipelines against sea currents).

The hypothesis on the possibility of recovering phosphorus in the sea is carried out in continuity with the study already carried out by the Polytechnic University of Marche in which it is highlighted that for the two aforementioned plants it is not convenient to recover phosphorus in situ under current conditions. As already mentioned, therefore, following the reefball experiences and considering the positioning of the structures near the discharge point, the hypothesis to increase the outcoming phosphorus in order to benefit the fauna and fish flora has emerged.

But, based on what has just been hypothesized, what could be the consequences:

- on the quality of the waste sludge from the purifier considering the discharge of phosphorus directly into the sea without making it precipitate in the mud totally or partially through dedicated treatments?

- on the management costs of the system as a result of the hypothesis referred to in the previous point?

As is known, in fact, at the moment the phosphorus is removed chemically in both plants and precipitated along the purification process.

In this report it was decided to answer, briefly and with the available data, the questions posed

WASTE WATER TREATMENT PLANTS DESCRIPTION

In this paragraph it will be described the sludge treatment lines of the plants studied for the evaluations on the phosphorous recovery.

The two plants discharge on the Adriatic sea with pipes which go into the sea and release the effluent thanks to some diffusors devices.

San Giorgio Waste water treatment plant

The sludge treatments performed on San Giorgio di Nogaro site, are the following:

1) Thickener;
2) Mechanic dehydration;
3) Post-dehydration;
4) Thermic drying;
5) Incineration plant (not working).

From Table 1 to Table 11 are listed all the characteristics of the sludge treatments devices.

Thickener	n°	2
Diameter	m	22
Surface	m^2	
Depth	m	4,00
Useful volume	m^3	1.200

Crane	n°	1

Table 2 Thickner

Belt press	n°	3
Belt wide	m	3,00
Total filtering surface	m^2	118,00
Filtering active surface	m^2	72,00
Pressing Surface	m^2	60,00
Installed power	kW	4,0
Monho pumps	n°	3+1
Polyelectrolyte maker	n°	3
Conveyor belt reverse	n°	1
Length	m	21
Wide	mm	500
Installed power	kW	1,5
Centrifuge blower	n°	2

Table 3 Belt press

Fiberglass tank	**n°**	**1**
useful volume	**m3**	**1**
Dosing pumps	**n°**	**3**
Flow rate	**l/h**	**100**

Table 4 Fiberglass tank

Post-dehydration tank	n°	4

wide	m	10,00
length	m	80,00
height	m	6,00
useful volume/cad	m^3	4000

Table 5 Post dehydration tank

Sludge Storage tank	n°	1
wide	m	7,40
length	m	4,60
Depth	m	3,50
useful volume	m^3	120
Extraction pumps		3

Table 6 Sludge storage tank

Dosing and weighing system	n°	1
Hopper	n°	1
Geometric capacity	m^3	2
Cochlea mixing		1
Propeller diameter	mm	380
Wide	mm	220
Installed power	kW	0,75
Monho pumps	n°	1
Flow rate	m^3/h	5
Power installed	kW	7,50

Table 7 Dosing and weighing system

Sludge dryer	n°	1
Length	m	6,4
diks diameter	m	1,7
disk number	n°	42
contact surface	m^2	163
installed power	kW	90,00
Evaporative capacity	kg/h	2201,00
Monho pumps	n°	1+1
Flow rate	m^3/h	1-5,50
Inflow pressure	bar	8,00
Velocity	giri/min	variabile
installed power	kW	7,50
Horizontal Cochlea	n°	1
Length	mm	3100
propeller length	mm	250
screw pitch	mm	250
Flow rate	m^3/h	8,50
installed power	kW	11,00
Transferring propeller	n°	1
length	mm	7500

propeller diameter	mm	250
screw pitch	mm	250
flow rate	m^3/h	8,50
Installed flow rate	kW	1,5
Horizontal Cochlea	n°	1
Length	mm	3550
propeller diameter	mm	250
screw pitch	mm	250
Flow rate	m^3/h	8,50
installed power	kW	0,37
Rotary valve	n°	1
Installed power	kW	0,37
Refrigerating propeller	n°	1
Length	mm	6130
propeller diameter	mm	250
screw pitch	mm	250
Flow rate	m^3/h	0,60
Installed power	kW	0,25

Table 8 Drying system

Cyclone for powder separation	n°	1
cylindric part diameter	mm	560

height cylindric part	mm	840
conic part diameter	mm	560-225
height conic part	mm	1100
Transferring Cochlea	n°	1
Rotary valve	n°	1
installed power	kW	0,37

Table 9 Cyclone for powder separation

Storage dry sludge silo	n°	1
cylindric part diameter	m	2,50
height cylindric part	m	11,4
useful volume	m^3	58
Bucket elevator	n°	1
total height	m	22,00
Control system		
Type		level probe
Quantity	n°	1

Table 10 storage dry sludge

Water heater	n°	1
Fire Termic power	kcal/h	2.000.000
Centrifuge fans	n°	1
Installed power	kW	5,50
Oil recirculation pump	n°	1+1

Flow rate	m^3/h	100
Velocity	round/min	2.915
Installed power	kW	22,00
Expansion tank	n°	1
Useful volume	m^3	1
discharge storage tank	n°	1
useful volume	m^3	5
Chimney	n°	1
Diameter	mm	500
thick rock wool insulation	mm	50
Control system		
Type		calibrated flange gauge

Table 11 water heater

Condenser	n°	1
potential power	kcal/h	1.200.000
inlet diameter	mm	800
Cylindric height	mm	3.000
Total height	mm	3.800
Isolating layer	mm	100
Water refrigerating power	n°	1+1
Flow rate	m^3/h	60,00

Installed power	kW	9,00
blower for smoke evacuation	n°	1
Installed power	kW	4,00

Table 12 Condenser

Since many years the incineration plant has not worked and it has not the authorizations needed to work so it has not been considered.

Lignano wastewater treatment plant

All produced sludge in the different treatment stages of the wastewater treatment plant (primary sludge from the first rain tanks, biological excess sludge) is collected in a tank with a capacity of 20 m^3. From here, sludge is then re-launched to the pre-thickening tank by means of four pumps having a single capacity of 50 m^3/h.

The pre-thickening of the sludge takes place in a thickener, with a diameter of 11 m and an average height of the sludge equal to 4.3 m. Taking into account that the starting concentrations are on average 0.8% for biological sludge and 1.5% for other sludge, the degree of thickening of the sludge obtained varies on average between 3 and 5% dry. In the summer season, when the quantity of biological sludge prevails, a flocculating product (aluminum polychloride) is injected into the thickener to improve the thickening characteristics.

Parameter	U.m.	Value
Diameter	m	11
average height of the sludge	m	4,3
Capacity	m^3/h	50
Concentration of biologic sludge	%	0,8
Concentration of others sludge	%	1,5
Thickening yield	%	3-5

Thickened sludge flow rate	m^3/d	20-150
Retention time	d	2,7-20,4
Overflow rate	$kgSS/(m^2 \cdot d)$	80,00

Table 13 Lignano Thickener features

Then, the thickened sludge is invited to the anaerobic digester by means of a special lifting system.

The stabilization of the thickened sludge is achieved with a mesophilic anaerobic treatment. The process is regulated on the basis of the data provided by special instrumentation for the continuous measurement of the feed sludge flow rate, the temperature, the pH and the pressure of the biogas.

To heat the sludge, the biogas produced by the digestion process is used as fuel. In summer, this satisfies 70-100% of the heat requirement.

Parameter	U.m.	Value
Digester diameter	m	16
Temperature	°C	30-32
Digester volume	m3	2200
Suspended Volatile Solid (SSV)	%	60
Inflow sludge	m3/d	144
Specific SSV removal rate	%	40
Specific biogas production	$Nm^3/kgSSV_{removed}$	1,1
Total biogas production	Nm^3/d	1140
Heat requirement satisfied by using the produced biogas	%	70-100

Table 14 Lignano anaerobic digester

The anaerobic sludge is discharged into four uncovered tanks of 3500 m^3 used for the static accumulation and post-thickening of the sludge before the subsequent dehydration phase carried out with a mobile centrifuge. Two blowers insufflate air to keep mixed the sludge

Parameter	U.m.	Value
Quadratic uncovered tanks	n°	4
Total tanks volume	m^3	3500
Blowers for the air insufflation	n°	2

Table 15 Lignano post-thickener

AMOUNT OF PHOSPHOROUS IN THE INFLUENTS, IN THE EFFLUENTS AND IN THE SLUDGES

In this paragraph are reported the quantities of phosphorous that coming in with the wastewater and the phosphorous that exits with sludge and effluent.

San Giorgio Waste water treatment plant

Influent and effluent

Every day in San Giorgio wastewater treatment plant phosphorous concentrations are analysed in a 24 hours sample. This permits to have a precise definition of the concentrations of this component in the water.

In the Table 15 are reported the amounts of phosphorous that enters and exits from the plant. Further, there is the calculated amount of removed phosphorous for each month of 2020.

Month	Inlet orthophosphate	Outlet orthophosphate	Removed orthophosphate
	kg	**kg**	**kg**
January	1192	376	816
February	1417	411	1007
March	1451	603	848
April	890	391	499

May	1047	410	637
June	1961	621	1340
July	1717	507	1210
August	2368	666	1702
September	1300	632	668
October	1845	584	1261
November	1403	702	701
December	1493	734	759

Table 16 Amount of entering, exiting and removed orthophosphate in 2020

Sludge

For the estimation of phosphorous concentration in the sludges, there is just one analysis. The concentration is about 2,7 % w/w of phosphorous in dry matter as well as for Lignano. Knowing the sludges features and amounts, the release of phosphorous with the sludge is 50 kg/d.

Lignano Waste water treatment plant

Influent and effluent

Considering the summer conditions, the data of phosphorous in the effluent and influent of Lignano plant are reported in Table 16. In Table 16 phosphorous concentrations are reported as Total phosphorous unlikely from the data of San Giorgio di Nogaro.

Month	Inlet total phosphorous	Outlet total phosphorous	Removed total phosphorous
	kg	**kg**	**kg**
June	1593	759	834

July	1932	1049	884
August	4104	936	3168

Table 17 Amount of entering, exiting and removed total phosphorous of summer 2020

Sludge

Also for Lignano waste water treatment plant, concentrations of phosphorous in the sludge are studied in Marche University study. The concentration is about 2,7 % w/w of phosphorous in dry matter. Considering a sludge flowrate of 1200 ton/y (with 24% of dry matter) the mean amount of phosphorous is 20 kg/d.

THE COSTS FOR PHOSPHOROUS REMOVAL

The phosphorous removal is performed by the use of chemicals, so, simplifying the estimation, the costs of phosphorous removal will be associated to the cost of chemicals added for this reason.

Costs for phosphorous removal

The chemicals added for the phosphorous removal are:

- Ferric chloride in San Giorgio waste water treatment plant;
- Aluminum polychloride for Lignano wastewater treatment plant.

It will be considered just the cost of the chemicals and not all the others minor costs (dosing pumps electricity, transport of the chemicals and equipment maintenance) associated to this treatment.

San Giorgio wastewater treatment plant

In San Giorgio di Nogaro plant, ferric chloride is added in the final settlers. In Table 19 are reported the consumptions of this chemical in 2020.

Month	$FeCl_3$

	kg/month	€/month
January	19371	3487
February	4808	865
March	24179	4352
April	14575	2624
May	19520	3514
June	24.389	4390
July	24.333	4380
August	19.317	3477
September	19.381	3489
October	14.557	2620
November	14.616	2631
December	19.664	3540
TOTAL	**218.710**	**39368**

Table 18 Ferric chloride consumptions of 2020

The considered cost for ferric chloride is 0,18 €/kg.

Lignano wastewater treatment plant

The aluminum polychloride is added to the sludge recirculation station. The major part of aluminum polychloride is consumed during the summer period. So, there is not a monthly consumption as well as for San Giorgio, but just a value for the 2020 consumption. The annual consumption is 54940 kg while the cost is 0,2 €/kg. So the annual cost is 10.988 €/y.

SLUDGE COMPOSITION WITHOUT PHOSPHOROUS REMOVAL

In this paragraph, the concentration of phosphorous inside the produced sludge is studied in the hypothesis that phosphorous removal is not performed.

As the phosphorous concentration in the sludges is not regularly measured, the following considerations are based on few analysis made for Lignano and San Giorgio sludges. Those analysis show the same mean value for both the plants and equal to 2,65 % w/w of dry matter.

San Giorgio di Nogaro wastewater treatment plant

The removed orthophosphate reported in Table 15 is assumed to be transferred to the sludges. Now, it is necessary to verify which would be the concentration of phosphorous in the sludge with no add of ferric chloride.

In Table 18 the monthly quantity of produced sludge in 2020 is reported. The sludges are produced on the different forms:

Palable (18,6 % d.m.);

Crust (40% d.m.);

Dried (95% d.m.).

Month	Palable sludge (kg)	Crust sludge (kg)	Dried sludge (kg)	Total dry matter (kg)
January	0	4600	0	1840
February	29180	0	0	5427
March	0	0	26780	25441
April	0	0	74140	70433
May	0	0	117580	111701
June	0	0	111260	105697

July	0	0	87140	82783
August	0	0	86800	82460
September	0	0	67300	63935
October	92680	0	45500	84056
November	0	0	1445980	19589
December	0	0	0	0
TOTAL	121860	4600	637120	653362

Table 19 Produced sludge in 2020

In Table 19 the amount of orthophosphate is transformed into total phosphorous due to the fact that the sludge analysis refer to concentration of total phosphorous.

Month	Removed orthophosphate	Removed Total phosphorous
	kg	**kg**
January	816	269
February	1007	332
March	848	280
April	499	165
May	637	210
June	1340	442
July	1210	399
August	1702	562
September	668	220
October	1261	416

November	701	231
December	759	251
TOTAL		**3778**

Table 20 Removed total phosphorous with ferric chloride

The measured concentration of phosphorous in dry matter is 2,65 % w/w.

In Table 20, the hypothetical concentration of phosphorous in the sludge is calculated

Month	Total dry matter (kg)	Amount of phosphorous (with chemical add) (kg)
January	1840	48,76
February	5427	143,82
March	25441	674,19
April	70433	1866,47
May	111701	2960,08
June	105697	2800,97
July	82783	2193,75
August	82460	2185,19
September	63935	1694,28
October	84056	2227,48
November	19589	519,11
December	0	0
TOTAL	653362	**17314,09**

Table 21 Amount of phosphorous in the sludge

The amount with no chemical phosphorous removal should be:

$$\dot{P}_{tot} = 17314 - 3778 = 13536 \frac{kg_{Ptot}}{y}$$

So, the concentration in the sludge would be:

$$P_{tot} = \frac{\dot{P}_{tot}}{Total\ dry\ matter} = \frac{13536}{653362} \cdot 100 = 2{,}07\ \%\ w/w$$

Nowadays the sludge is destinated to an incinerator to produce energy so it not so important the percentage of P within the sludge. Despite this fact, it is important to highlight that the sludge has the properties to be recovered in agriculture as a fertilizer. For this reason it is important to investigate the amount of the variation of P in the sludge due to switching off the phosphorous removal section.

It respects the law limits (> 0,4 %) for the use of the sludge in agriculture. This is an important result because it means that nonetheless the decrease of phosphorous in the sludge, it could be used as a fertilizer.

Lignano waste water treatment plant

In Lignano waste water treatment plant, phosphorous is removed by the addiction of alluminum polychloride. In Table 17 the removed phosphorous is report for all the summer months.

In Table 21 are reported different working periods of Lignano WWTP with the corresponding last of it.

Period	Days
WINTER PERIOD	151
LOW CHARGE PERIOD	122
MEAN CHARGE PERIOD	61
HIGH CHARGE PERIOD	31

Table 22 Duration of the different working periods

In Table 22 are reported the flowrate for the different working period.

	Flow rate 2015 (m^3/h)		Flow rate 2016 (m^3/h)		Flow rate 2017 (m^3/h)	
	Average	50th perc.	Average	50th perc.	Average	50th perc.
WINTER PERIOD	453	415	577	567	490	450
LOW CHARGE PERIOD	619	575	577	605	602	601
MEAN CHARGE PERIOD	837	840	940	947	819	804
HIGH CHARGE PERIOD	1010	1005	1034	1028	888	890

Table 23 Mean flow rate of the different working periods

YEAR	PERIOD	kgP_{tot}/d
2015	WINTER PERIOD	10
	LOW CHARGE PERIOD	40
	MEAN CHARGE PERIOD	110
	HIGH CHARGE PERIOD	190
2016	WINTER PERIOD	14
	LOW CHARGE PERIOD	27
	MEAN CHARGE PERIOD	52
	HIGH CHARGE PERIOD	92

2017	WINTER PERIOD	18
	LOW CHARGE PERIOD	36
	MEAN CHARGE PERIOD	81
	HIGH CHARGE PERIOD	153

Table 24 Inlet phosphorous between 2015-2017

Considering Table 23 the mean values for the different working periods are reported in Table 24.

PERIOD	kgP_{tot}/d
WINTER PERIOD	14
LOW CHARGE PERIOD	34
MEAN CHARGE PERIOD	81
HIGH CHARGE PERIOD	145

Table 25 Mean values of incoming phosphorous for working period

Then, it is possible to estimate the average amount of phosphorous that comes in the Lignano plant each year.

From the values of Table 21 and those of table 24, the yearly amount of phosphorous is 15.698 kg/y.

It is necessary to estimate an annual percentage of phosphorous removal as there are not many effluent phosphorous analysis out of the high charge period.

In the Table 25 the inlet concentrations are reported.

YEAR	PERIOD	mgP_{tot}/L
2015	WINTER PERIOD	1,2
	LOW CHARGE PERIOD	2,6
	MEAN CHARGE PERIOD	5,8

	HIGH CHARGE PERIOD	8,1
2016	WINTER PERIOD	1,2
	LOW CHARGE PERIOD	2,1
	MEAN CHARGE PERIOD	2,4
	HIGH CHARGE PERIOD	4,5
2017	WINTER PERIOD	1,6
	LOW CHARGE PERIOD	2,3
	MEAN CHARGE PERIOD	4,1
	HIGH CHARGE PERIOD	7,6

Table 26 Inlet concentrations for Lignano Plant

So, during the winter period phosphorous is not removed as the inlet concentration is lower than that of the legislation limit (equal to 2 mg/L). In the low charge period, addiction of alluminum polychloride is minimum, while in the mean charge and high charge period the chemical dosing is relevant. Starting from these considerations, the calculated phosphorous removal rate is of 35%. Knowing the mean phosphorous removal rate the estimated removed phosphorus is 5494 kg/y.

The total sludge production for Lignano plant is on average 1200 ton/y.

Then, the amount of dry matter is 24% w/w so 288 ton/y. Considering the measured concentration of phosphorous (2,65 % w/w of dry matter) the total amount of phosphorous in the sludge is 7632 kg/y of total phosphorous.

Then, the amount of phosphorous in the sludge without adding alluminum polychloride would be:

$$\dot{P}_{tot} = 7632 - 5494 = 2138 \frac{kg_{Ptot}}{y}$$

So, the concentration in the sludge would be:

$$P_{tot} = \frac{\dot{P}_{tot}}{Total\ dry\ matter} = \frac{2138}{288000} \cdot 100 = 0{,}7\ \%\ w/w$$

Nevertheless the value of 0,7% is just a little bit higher than the request value (> 0,4%), it would permit to continue to use the Lignano sludge in agriculture.

SPECIFIC EXPENSES WITHOUT PHOSPHOROUS REMOVAL

In this paragraph specific costs for phosphorous removal are calculated. The calculation is quite easy due to the fact that the costs for phosphorous removal are associated to chemicals expenses.

San Giorgio waste water treatment plant

The costs for phosphorous removal are defined in Table 19. The specific costs, for mg of removed phosphorous, are listed in Table 26.

Month	Costs of Ferric chloride	Amount of removed orthophosphate	Specific remotion costs
	€/month	kg/month	€/kg
January	3487	816	4,27
February	865	1007	0,86
March	4352	848	5,13
April	2624	499	5,26
May	3514	637	5,52
June	4390	1340	3,28

July	4380	1210	3,62
August	3477	1702	2,04
September	3489	668	5,22
October	2620	1261	2,08
November	2631	701	3,75
December	3540	759	4,66
		Average	**3,81**

Table 27 Specific removal costs

Lignano waste water treatment plant

From chapter 4.1.1. the costs for phosphorous removal is 10.988 €/y. As the removed phosphorous is 6279 kg/y the consequent specific costs for kg of removed phosphorous is 1,74 €/kg of removed total phosphorous.

CONCLUSIONS

The sludge lines of Lignano and San Giorgio WWTPs were presented and described.

Starting from 2020 analysis, the concentration and quantities of phosphorous were reported and the removed quantities were calculated.

Also the costs associated to the removal processes were studied.

Since the amount of produced sludge and phosphorous concentration inside the sludge, sludge composition with no phosphorous removal was calculated. It reveals that in both the WWTPs, sludge could be used in agriculture also if there is no phosphorus removal.

The phosphorous, if not removed during depuration process, it would reach the sea. Anyway, the estimated amount of phosphorous that would reach the final effluent should be precisely evaluated to exclude possible eutrophication effects in case of an increase on phosphorus release.

The possibility to increase the released amount of phosphorous is valorised if linked with the reefballs placement. A higher concentration of phosphorous in the sea would probably help to get better the growth of fish fauna on the reefballs and so to restore the sea life. This point will follow up in further studies.

PART 3: SLUDGE VARIATION DUE TO THE INTERVENTIONS AT WATER LINE OF DP

Aerobic Granular Sludge Technology

One of the innovative methods of treatment proposed by the project for the treatment of treated wastewater for the protection of marine and coastal surface waters is the method of aerobic granular biomass (Aerobic Granular Sludge Technology (AGS Technology)).

The method is based on the binding of selected microorganisms or activated sludge into a solid flake form associated with naturally produced biopolymers (exopolysaccharides). Polysaccharides, in addition to importing microorganisms, also contribute to the stability of granular biomass.

Although the concept of aerobic granulation is not new, the application of aerobic granules in wastewater treatment on an industrial scale is relatively small. Granulation of microorganisms, which ensures the strength and stability of the system, occurs under specific process conditions, which facilitates the excretion of microbial biopolymers used for microgranulation of selected microorganisms (Figure 1). Microgranulation ensures that all selected microorganisms, which should be present in the granules, are held together, e.g. nitrification and denitrification of microorganisms and microorganisms for biodegradation or detoxification of certain industrial wastewaters. In the next stage, the microgranules are translated into granules. Different granule sizes can be expected, depending on the quality of the wastewater, but a size range between 1-2.5 mm in diameter can be achieved.

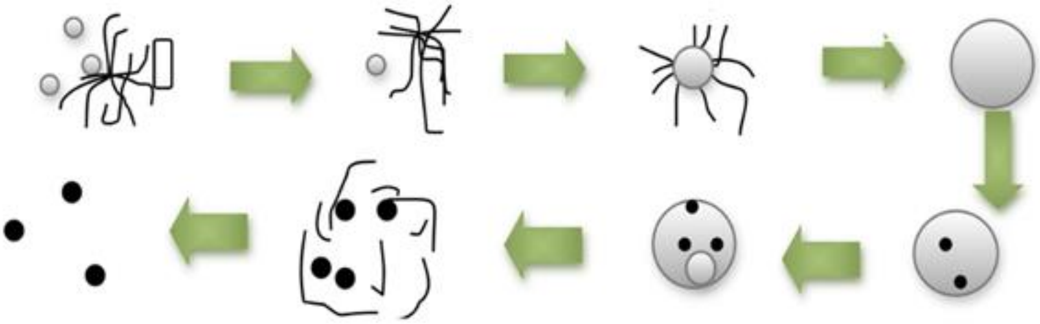
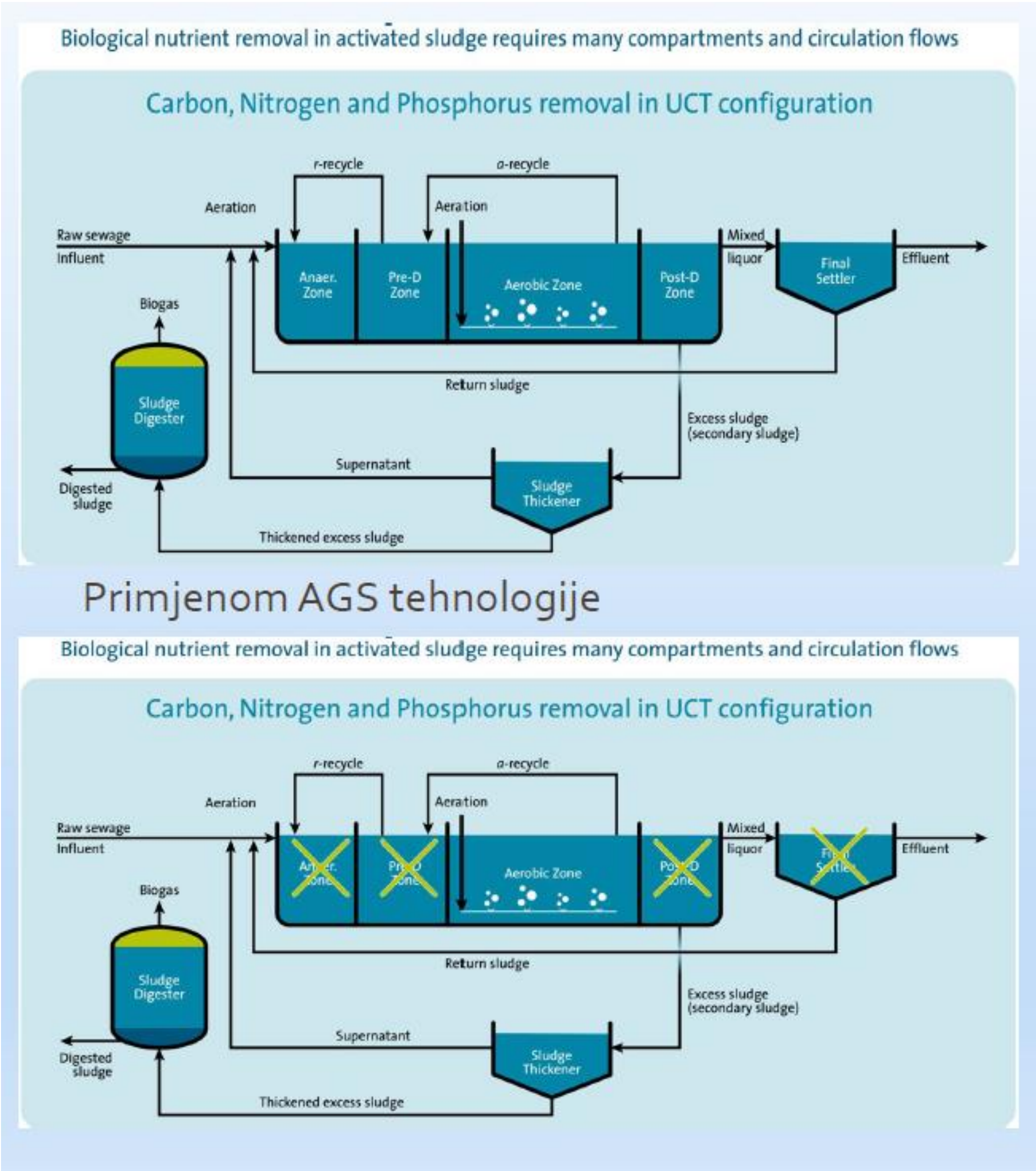


Figure 1. Representation of aerobic granule formation

Compared to conventional biological flakes, granular biomass has a strong structure and excellent deposition properties. Granulated sludge was first described for strictly anaerobic systems in 1984 by Letting et al., And only later did other groups adapt and use this principle to form and apply aerobic granules. Granulated sludge improved the deposition characteristics of microbial biomass, facilitating highly efficient separation of biomass from liquid.

Some of the most important features of granulated biomass are:

- Uses optimized batch cycle structure
- Three main specifics of cycle phases: filling, reaction, precipitation
- The duration of the phases is defined by the sludge characteristic, flow and effluent requirement
- Robust granule structure withstands fluctuations in chemical jumps, loads, salts, pH and toxic shocks
- No secondary sedimentation tanks, selectors, separate basins or pumping stations for sludge recovery
- Sedimentation properties at SVI values of 30 50 ml / g allow an MLSS concentration of 8000 mg / l or higher
- Proven enhanced removal of biological nutrients (BNR)
- Simplified operation with fully automated process controls



In granular biomass there are 3 process zones in different layers within granular particles, with diffusion connecting the reaction zones, allowing the simultaneous existence of anaerobic, aerobic and anoxic conditions in the granules resulting in excellent biological nutrient removal capabilities (Figure 2).

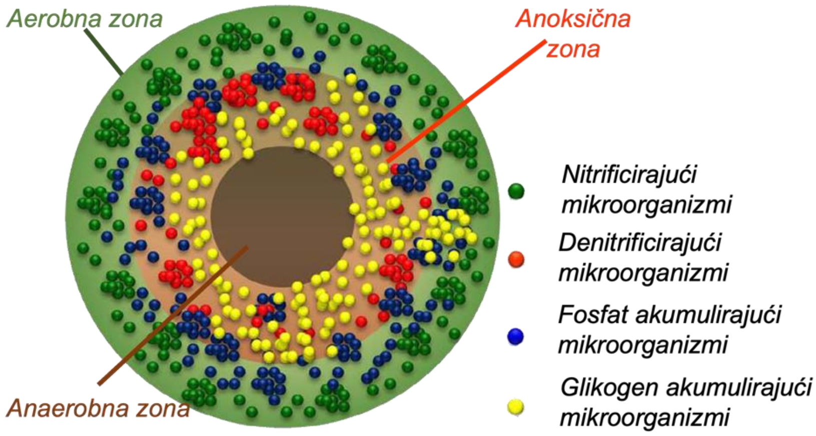


Figure 2. Graphic representation of the distribution of microorganisms in granular biomass

The process operates intermittently, with the filling and pouring phase occurring at the same time, and therefore no mobile decanters are required to ensure low solids in the effluent. Wastewater treatment systems with aerobic granular sludge simultaneously remove organic matter and nutrients in a single reactor.