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CAPABILITY STATEMENT

Nereda

Worldwide Nereda Variants and Applications

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HASKONINGDHV NEDERLAND B.V.

Laan 1914 no.35
3818 EX AMERSFOORT
Netherlands
Water
Trade register number: 56515154

+31 88 348 20 00 **T**
+31 33 463 36 52 **F**
info@rhdhv.com **E**
royalhaskoningdhv.com **W**

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Author(s): Annemie Otten/Arnold Zilverentant

Drafted by: Annemie Otten

Checked by: Bart de Bruin

Date / initials:

Approved by: Eric Zandbergen

Date / initials:

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1 General description of the Nereda[®] system

The Nereda[®] Aerobic Granular Biomass Technology was developed by Royal HaskoningDHV in close collaboration with the Dutch water sector and the Delft University of Technology. Following the success of the first full-scale implementation in 2006, the Nereda[®] technology is quickly becoming the international standard for aerobic wastewater treatment. More than 20 Nereda[®] plants are currently in operation or under construction in Europe, Africa, Australia and South America, whilst many more plants are currently being planned or designed. Nereda[®] reactors in operation are amongst the world's largest SBR tanks, showing that the Nereda[®] system has matured and is applicable for even the largest municipal and industrial wastewater treatment challenges.



Figure 1. Settling Properties of the Aerobic Granular Biomass (left) compared to Activated Sludge (right).

Main characteristics of the Nereda[®] technology:

- ✎ One-tank solution
- ✎ Greenfield, retrofit and hybrid
- ✎ Cost-effective in CAPEX and OPEX
- ✎ Plant footprint up to a factor 4 smaller
- ✎ Up to 50% energy savings
- ✎ No/minimal waste generating chemicals
- ✎ Excellent effluent quality
- ✎ Easy to operate
- ✎ AquasSuite[®] Nereda[®] Controller inside

Biomass in Nereda[®] develops as fast settling aerobic granular sludge which is a major advancement from the slow settling flocculent bio-sludge used in conventional Biological Nutrient Removal (BNR) systems. Nereda[®] offers the following key advantages over conventional BNR systems:

- Significant plant footprint reductions:
 Due to high design biomass concentrations and high sludge settling velocities the required bioreactor volumes are smaller. In addition, sludge settling and enhanced biological nutrient removal is performed in the same reactor and there is therefore no need for secondary clarifiers and anaerobic/anoxic tanks. This makes the system even more compact and significantly reduces the required footprint. A reduced footprint results in additional savings for land acquisition (see Figure 3).
- Low energy requirements:
 Since all biological and settling processes take place in one reactor, less mechanical equipment is required. For instance, sludge recycle pumps, mixers and moving decanters are redundant and not

required for the Nereda[®] technology. As a result of this reduction in mechanical equipment, the overall energy consumption of a Nereda[®] is substantially reduced when compared to a conventional BNR plant.

- Low investment costs:

As a result of the compact and uncomplicated reactor structures and the reduction of mechanical equipment required, the investment costs for Nereda[®] systems are significantly lower than for conventional BNR systems.

- Low operating costs:

The minimization of required mechanical equipment reduces both operational (energy) and maintenance costs. Because of the high uptake of phosphorous (P) by the Nereda[®] granules, the amount of chemicals required to achieve low P-effluent values is reduced or made redundant completely, thereby further reducing the operational costs for chemicals and sludge processing.

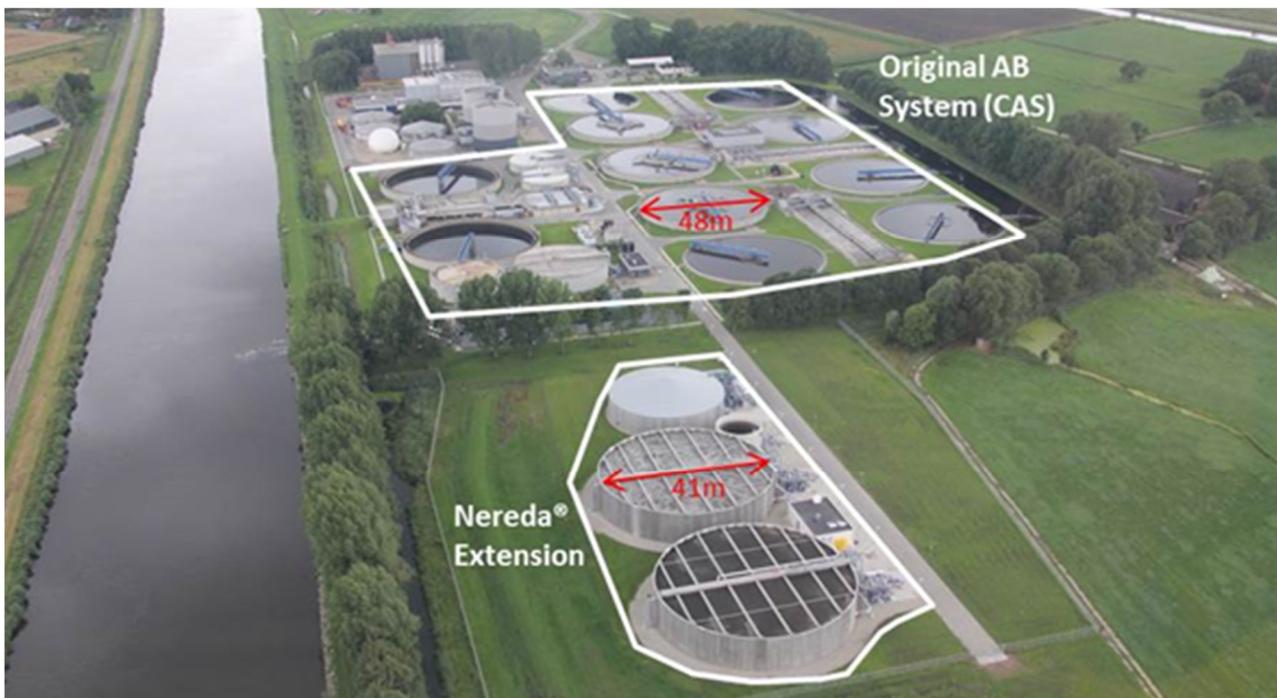


Figure 3. Garmerwolde WWTW with the Nereda[®] extension in the lower part of the picture

Figure 3 of the Garmerwolde WWTW (The Netherlands) illustrates the efficient footprint of the Nereda[®] technology compared to conventional BNR systems. The two \varnothing 41 m Nereda[®] reactors in the bottom of the picture treat 50% of the total flow, whereas the conventional WWTW in the upper part of the picture treats the other half of the flow. Note that the clarifiers of the conventional WWTW (\varnothing 48 m) are bigger than the Nereda[®] reactors. Overall footprint saving for rectangular Nereda reactors is even bigger.

The following sequential steps and processes occur in the Nereda[®] system (see also Figure 4);

1. **Simultaneous fill and draw.** During the fill phase, influent wastewater is fed to the bottom of the reactor and flows under near-plug flow conditions through the settled granular biomass. As a result of the plug flow there is no contact between the purified effluent at the top of the reactor and the raw influent wastewater at the bottom, enabling wastewater treated in the previous cycle to be displaced or “pushed” out of the reactor as well-treated effluent, whilst the reactor is simultaneously being fed.

Therefore, unlike SBR systems, Nereda® does not require a separate time consuming decant phase. More importantly, static fixed overflow weirs (as shown in Figure 8) are used instead of the moving and maintenance intensive decanters typically applied in SBR systems.

2. **Aeration.** During the aerated reaction phase all biological processes take place. Fine bubble aeration generates an oxygen gradient in the compact structure of the granular biomass. At the aerobic outer layer of the granule organic pollutants are efficiently oxidized. Nitrifying bacteria also accumulate in the outer layer of the granules and convert ammonium to nitrate. The produced nitrate diffuses into the anoxic core of the granule where it is simultaneously denitrified. In addition enhanced and extensive biological phosphate fixation takes place.
3. **Fast settling.** In this phase the biomass is separated from the treated effluent. As result of the excellent characteristics of the biomass, the required duration for settling is short and this phase is also used to discharge excess biomass formed as a result of growth and accumulation during the aeration phase.

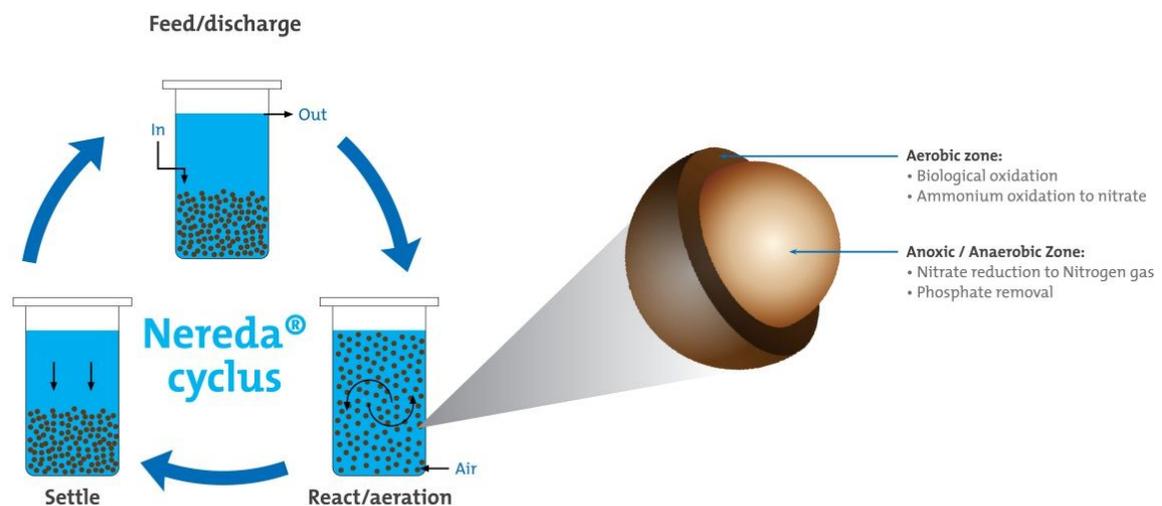


Figure 4. Nereda® Process Cycle.

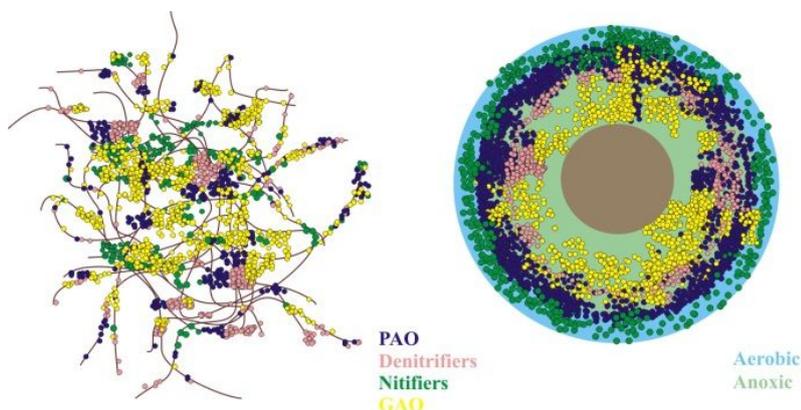


Figure 5. Difference between Activated Sludge (left) and Granular Biomass (right).

2 Nereda[®] Variants and Applications

Since implementing the first full-scale Nereda installations new insights have emerged allowing for further innovation, system development and design optimisation. New system configurations have been developed to suit a variety of scenarios experienced from site to site and from country to country. Two 'greenfield' or parallel extension approaches have been used and are detailed below (see Figure 6):

1. 3+ Nereda[®] reactors
 - At least one Nereda[®] reactor is fed at any given time
 - E.g. applied at Epe WWTP (the Netherlands)
2. Buffer(s) followed by Nereda[®] reactor(s)
 - Typically 1 buffer followed by 2 Nereda[®] reactors.
 - Often results in overall lower tank volumes and capital cost savings (case dependent).
 - E.g. applied at Wemmershoek WWTP (South Africa), Ryki WWTP (Poland), Garmerwolde WWTP (the Netherlands)

In addition two 'brownfield' options have been developed:

3. Nereda[®] and Conventional Activated Sludge (CAS) hybrid
 - Waste sludge from Nereda[®] system is fed into the CAS system.
 - Improves CAS treatment efficiency and / or capacity in addition to the expanded capacity achieved via the Nereda[®] system.
 - E.g. applied at Vroomshoop WWTP (the Netherlands)
4. Nereda[®] retrofit
 - Convert existing tank(s) into a Nereda[®] reactor (SBR, CAS aeration basin or any other suitable tank)
 - Make use of existing infrastructure whilst increasing system capacity and reducing energy, chemical use.
 - E.g. applied at Frielas WWTP (Portugal) (in combination with the hybrid approach)

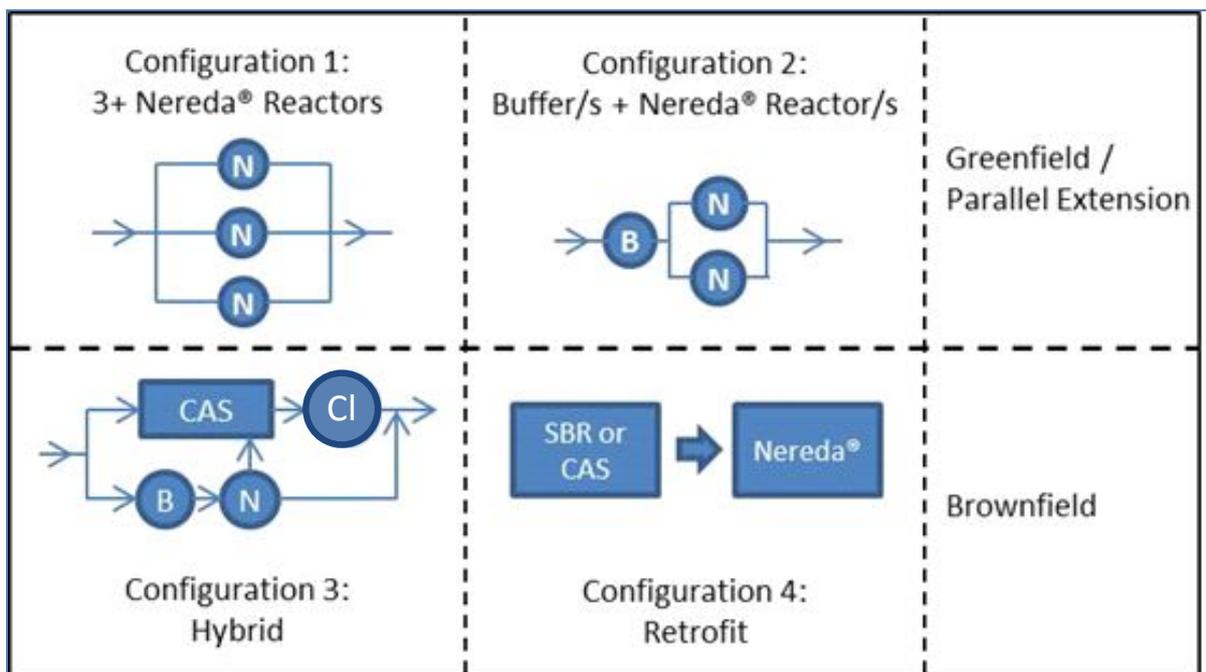


Figure 6. Nereda[®] configurations/approaches.

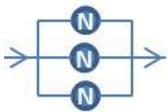
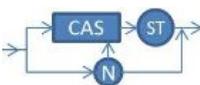
	Nereda Configuration	Typical Layout	Attributes	Advantages	Reference examples	Potential Applications
1	3+ reactors	3 reactors 	At least 1 reactor fed at all times	Scalable for application to the world's largest treatment challenges	Epe WWTP (Netherlands) 	Greenfield sites; extension to existing plants with parallel Nereda line
2	Buffer followed by X reactors	1 buffer + 2 reactors 	Buffer stores between feeds to reactors	Optimized investments (2 reactors vs 3).	Wemmershoek WWTP (South Africa) 	Greenfield sites; extension to existing plants with parallel Nereda line
3	Hybrid	1 or more Nereda reactor – connected to activated sludge system 	Waste Nereda sludge to activated sludge system	Improve activated sludge system performance/ optimise existing infrastructure	Vroomshoop WWTP (Netherlands) 	Brownfield sites Extension / optimisation scenarios with optimal use of existing infrastructure
4	Retrofit	Convert existing SBR/ activated sludge reactor or any suitable existing tank 	Use existing infrastructure	Cost-effective way to increase capacity and improve performance whilst using existing infrastructure	Frielas WWTP (Portugal) 	Brownfield sites. Space or budget constraints / capacity increase or improved performance required

Figure 7. Nereda® configurations

The four basic configurations or approach options outlined above have covered all of the treatment scenarios experienced to date at full-scale.

Further details of the Epe WWTP (configuration 1), Garmerwolde WWTP, Ryki WWTP and Wemmershoek WWTP (configuration 2), Vroomshoop WWTP (configuration 3) and Frielas WWTP (configuration 4) are presented.

 **Epe WWTP (configuration 1)**

Client: Water Board Vallei & Veluwe
Wastewater type: Municipal & Industrial
Location & start-up: Epe, The Netherlands, 2011
Average capacity: 8,000 m³/day | 54,000 p.e. inclusive 13,750 p.e. from industrial discharges
Peak flow: 1,500 m³/h

The first Dutch municipal full-scale plant was constructed at Epe WWTP. The Epe WWTP was designed and constructed by Royal HaskoningDHV in 2010-2011 and is operational since September 2011. Prior to design, a pilot trial was carried out for four years and the data was used to design the full scale plant. The plant consists of the following main processes; inlet works with screens and grit removal, followed by three Nereda® reactors and effluent polishing via gravity sand filters. The Nereda® reactors are designed to take flows with an average daily flow of 8,000 m³/day and a peak flow of 36,000 m³/day. The waste sludge is thickened via a gravity belt thickener and transported off-site.

Since September 2011 the influent to the plant was progressively increased to 100% over a period of four months. The existing plant continued to process the influent along with Nereda® Bioreactors whilst granules were building-up within the bioreactor. It should be noted that part of the “granulation period” was over the winter months when the average wastewater temperature was well below 10°C.

Even though the overall start-up took 4 months, the reactors were able to produce a good quality effluent within just a few days of having been seeded with standard activated sludge. Whilst a 4 month start-up period could be seen to detract from the process, these results show that a good effluent quality can be obtained rapidly.



Figure 8. Epe WWTP

The official process proving period for Epe WWTP was completed between March - May 2012. The effluent quality achieved, based on twenty-four hours/ seven days a week composite samples, is summarised in Table 1. Whilst Dutch effluents standards are typically based on average values, 95 percentile values are also shown for comparison to other plants.

Table 1. Epe WWTP – Performance Results during Process Verification March - May 2012.

Parameter	Influent (mg/l)	Effluent (Average) (mg/l)	Effluent (95%ile) (mg/l)
COD	879	27	32
BOD	333	< 2.0	< 2.0
NKj	77	1.4	1.8
NH4-N	54	0.1	0.1
N-total		< 4.0	5.1
P-total	9.3	0.3	0.34
Suspended Solids	341	< 5.0	< 6.0

Due to industrial discharges, the plant has to cope with large fluctuations in influent characteristics and loads – in particular with pH-values frequently peaking to above pH 10. During the pilot trials, that ran in parallel to the existing CAS, the remarkable process stability of Nereda was noticed: whilst pH peaks caused complete loss of nitrification in the CAS system taking several weeks to recover, the Nereda pilot unit receiving the same influent resumed smooth operation after a few cycles and was back to normal operation in 1-2 days after the occurrence.

A key advantage of Nereda is reduced power consumption. At Epe, the original plant energy consumption was approximately 3,500 kWh/day. With Nereda, the average consumption is now 2,000 kWh/day - 2,500 kWh/day. This is approximately 40% less than all types of similar sized conventional plants in the Netherlands. This was further demonstrated at for instance the demonstration plant at Frielas WWTP, Portugal and Garmerwolde WWTP, the Netherlands as discussed below.

Garmerwolde WWTP (configuration 2)

Client: Construction consortium GMB/Imtech for Water Board Noorderzijlvest

Wastewater type: Municipal

Location & start-up: Garmerwolde, The Netherlands, 2013

Average capacity: 30,000 m³/day | 140,000 p.e.

Peak flow: 4,200 m³/h

The Garmerwolde WWTP was retrofitted into an AB activated sludge system in 2005 and was subsequently not able to meet the required nutrient removal targets, which necessitated a plant upgrade. Nereda[®] was selected as the preferred solution to extend the capacity and improve the biological nutrient removal capabilities of the plant. The solution, which commenced operation in 2013, involved the addition of two 9,500 m³ Nereda[®] reactors – tank sizes similar to the world’s largest SBR-tanks – preceded by a 4,000 m³ buffer in parallel to the existing plant. The extension was designed for 140,000 P.E. of pollution load and hydraulically for 20,000 m³/day (average flow) and 4,200 m³/h (peak flow).

The use of 1 buffer and 2 Nereda[®] reactors (configuration 2) enabled an overall tank volume saving of approximately 35% when compared to the 3 Nereda[®] reactor option (configuration 1, e.g. Epe WWTP) for this specific case.

The Nereda[®] performance requirement for nutrient removal (without any downstream filtration step) is a Total-N of 7 mg/l (yearly average) and Total-P of 1 mg/l (average of ten successive samples). After a year-long monitoring period (2014) the Garmerwolde WWTP was found to fully comply with the overall effluent requirements.

The Garmerwolde WWTP offers the possibility to directly compare the performance of the Nereda[®] and activated sludge technologies. The energy consumption of the Nereda[®] installation (including intermediate pumping) was consistently more than 40% lower than the energy consumption of the parallel AB system in 2014. Furthermore, the AB system requires chemical dosing, including C-source (denitrification), coagulants (sludge properties) and iron salts (phosphorous removal). Apart from the high chemical costs incurred, the dosing also results in a sludge production almost double that of the parallel Nereda[®] extension. Consequently the overall operational costs (energy, chemicals, sludge treatment) of the activated sludge plant are significantly higher than that of the Nereda[®] extension. Table 2 compares the consumptions for both plants.

Table 2. Garmerwolde WWTP – Comparative consumptions Nereda and AB system 2014 / 2015

parameter	unit	Nereda	AB/Sharon
Flow treated	Mm ³ /year	8.6 / 12.4	13.1 / 15.9
power consumed	GWh/year	1.5 / 2.4	4.9 / 5.6
Specific power consumption	kWh/m ³	0.17 / 0.2	0.38 / 0.35
PAC dosage	m ³ /year	0	144 / 140
PE-Coagulant dosage	m ³ /year	0	40 / 30
PE-Flocculant dosage	m ³ /year	0	8.4 / 7
C-source	m ³ /year	0	720 / 600
Ferric dosage	kg Fe/year	26 / 8	120 / 130

Considering that the Nereda[®] installation treats 41% of the daily influent flow and the original installation (AB-system) 59%, Figure 3 (paragraph 2) showed Nereda[®]'s advantage in terms of system footprint.

➤ Ryki WWTP (configuration 2)

Client: Przedsiębiorstwo Gospodarki Komunalnej i Mieszkaniowej
Wastewater type: Municipal & industrial
Location & year: Ryki, Poland, 2015
Average capacity: 5,300 m³/day | 41,000 p.e., high portion of tanked-in septic and industrial discharges which can go up to 60% of the total COD load
Peak flow: 430 m³/h

Based on the outcome of a public tender process, the municipal-owned utility company selected Nereda® technology-based offer for the design and engineering of their new wastewater treatment. Important criteria in the tender evaluation process were capital expenditure and total costs of operation. The wastewater is a mixture of sewage, tanked-in septic and industrial discharges from primarily vegetable processing. Start-up of this plant was mid-February. The effluent of the two reactors is discharged into a pond which overflows to the surface water. When the pond is overflowing the effluent is measured. Effluent quality is well within standards.

Table 3. Nereda® Ryki data from the end of March 2015.

Parameter	Units	Influent	Effluent R1	Effluent R2	Outlet effluent pond	Effluent standard
COD	mgO ₂ /l	623	39	42	50	125
BOD	mgO ₂ /l	227	5.6	6.3	8.2	15
TN	mgN/l	72	4.8	4.8	6.6	15
TP	mgP/l	7.7	0.5	0.5	1.0	2
TSS	mg/l	238	15	17	10	30



Figure 9. Ryki WWTP: Nereda® testing during cold conditions


Wemmershoek WWTP (configuration 2)

Client: Stellenbosch Municipality
Wastewater type: Municipal
Location & start-up: Wemmershoek, South Africa, 2015
Average capacity: 5,000 m³/day | 39,000 p.e.
Peak flow: 625 m³/h

In 2010 the Stellenbosch Municipality decided to centralise wastewater treatment for the Franschoek area by decommissioning two existing treatment plants (Franschoek and La Motte WWTPs) and treating all wastewater at the Wemmershoek WWTP. To realise a cost-effective centralisation of treatment capacity a new 5,000 m³/day treatment system was required at the Wemmershoek works. The Franschoek area falls within the sensitive Berg River catchment which meant stringent effluent requirements (special limits). Royal HaskoningDHV proposed the Nereda® technology and effluent reuse as a cost-effective and sustainable means to meet the project requirements. By utilising effluent reuse (irrigation) the need for extensive tertiary treatment to meet expected future (even more stringent) standards was not required. Details of the treatment plant are provided in Table 4.

Table 4. Wemmershoek WWTP design details.

Design Component	Unit	Wemmershoek Design
Primary Treatment	-	Screening and grit removal
Secondary treatment	-	1 x 600m ³ Nereda® Influent Buffer; 2 x 1 800m ³ Nereda® reactors
Tertiary treatment	-	Chlorine disinfection, maturation pond
Sludge treatment	-	Mechanical thickening and dewatering
Average Dry Weather Flow	m ³ /day	5,000
Peak Wet Weather Flow	m ³ /h	625
Effluent discharge	-	Discharge to Berg River and re-use for irrigation (pumped to Franschoek)
Influent Characteristics		Design (actual)
COD	mgO ₂ /l	870 (796)
Total Kjeldahl Nitrogen	mgN/l	60
Ammonium	mgN/l	45 (79)
Nitrate	mgN/l	-
Total Phosphorus	mgP/l	12 (11.7)
Ortho-phosphate	mgP/l	- (8.6)
Suspended Solids	mg/l	- (381)

()_The data in parenthesis are averages over the last 4 independently analysed samples (24 March to 1 April 2015)

The new 5,000 m³/day system was commissioned in August 2014 and following the development of granular sludge the treatment plant is producing excellent effluent quality (well below requirements) – see Table 4 with recent effluent results.



Figure 10. Nereda[®] reactor at Wemmershoek discharging effluent.

Table 5. Effluent quality at Wemmershoek WWTP.

Parameter	Unit	Average CSIR Lab Results – Final Effluent	Effluent Requirement (General Limit)
COD	mgO ₂ /l	48	<75
Ammonium	mgN/l	0.3	<6
Nitrate	mgN/l	0.1	<15
Nitrite	mgN/l	0.1	-
Total phosphorus	mgP/l	2.6	-
Ortho-phosphate	mgP/l	2.3	<10

The data presented in Table 5 is based on average effluent results from March to April 2015 independently verified by an external laboratory (CSIR). The Wemmershoek treatment plant has a discharge limit of 10 mgP/l. Although the phosphorus concentrations in the final effluent are well below this limit, the process control has not yet been fully optimised for biological phosphorus removal. If optimal Nereda[®] biological phosphorus removal is implemented, effluent ortho-phosphate concentrations below 0.9 mgP/l could be achieved without chemical dosing (concentrations of 1.5 mg/l, 0.6 mg/l and 1.2 mg/l were achieved during March 2015, giving a clear indication of the potential).

The Berg River Improvement Plan (BRIP) was developed in 2012 by the Western Cape provincial government, the Department of Water Affairs and local stakeholders. The main aims of the BRIP are the sound management of this sensitive catchment and to improve water quality. The Wemmershoek WWTP project is positively contributing to achieving the BRIP's goals by limiting pollution loads from the Franschhoek area. This is an example of how innovative wastewater treatment solutions (Nereda[®]) in conjunction with exceptional municipal operations and management (Stellenbosch Municipality) can fit into broader integrated water resource management as envisaged by South Africa's National Water Act (2008).

👉 Vroomshoop WWTP (configuration 3)

Client: Water Board Vechtstromen
Wastewater type: Municipal
Location & start-up: Vroomshoop, The Netherlands, 2013
Average capacity: 1,500 m³/day | 12,000 p.e.
Peak flow: 400 m³/h

In 2008, the Dutch Waterboard Vechtstromen became interested in participating in the development of the Nereda® technology as a part of their strategic commitment to advancing the wastewater treatment technology field. At the Vroomshoop WWTP an opportunity emerged to use Nereda® for the expansion and replacement of the existing treatment plant, which consisted of an ageing oxidation ditch system that would not be able to meet future effluent requirements, especially with regard to nutrient (nitrogen and phosphorus) removal.

A hybrid configuration (configuration 3) was selected because it was found to be an effective means of making use of an existing settling tank at the site, an optimal way to deal with the high rain weather to dry weather flow ratio at the plant and this option provided an opportunity to meet innovation and sustainability targets such as reducing energy usage. The hybrid arrangement of the treatment plant is schematically shown in Figure 11 below.

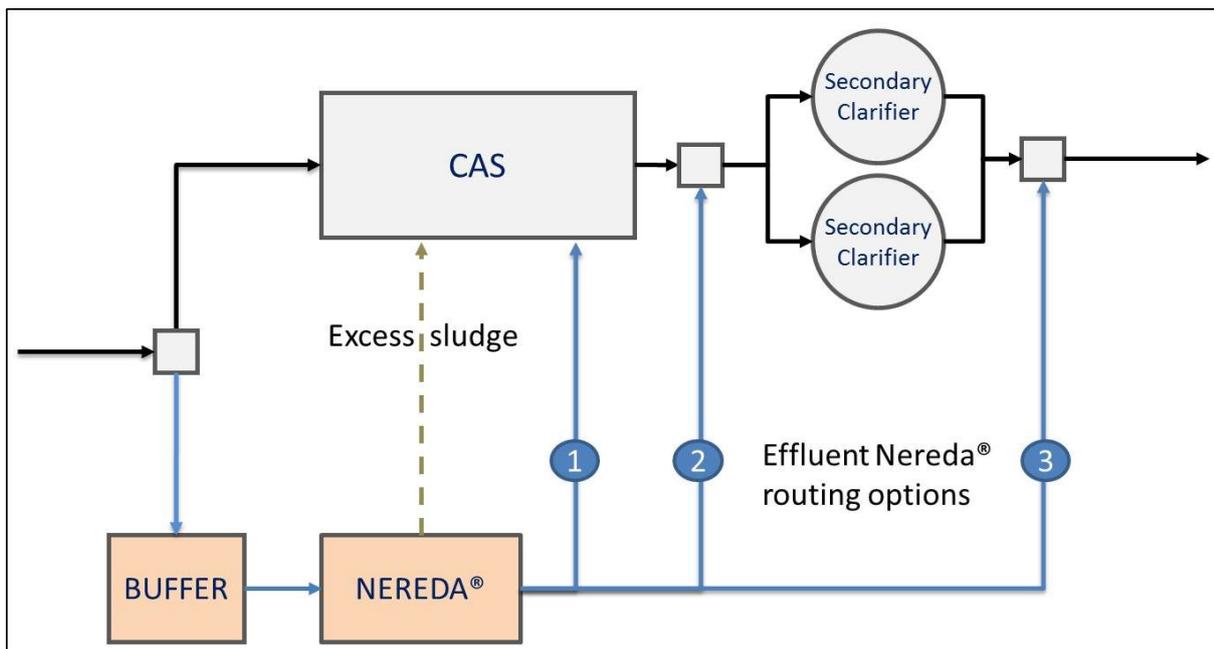


Figure 11. Flow scheme at Vroomshoop WWTP with full hydraulic routing options (1, 2 and 3)

The new Vroomshoop WWTP entered operation in mid-2013. The plant is designed for a pollution load of 22,600 P.E. (150 gTOD) and hydraulically to receive 156 m³/h of wastewater during dry weather conditions and 1,000 m³/h during rain weather conditions. The introduction of Nereda® excess/waste sludge into the CAS system has proven to be an effective way to improve the performance of the CAS system. The settle ability of the CAS sludge showed a marked improvement (lower SVI) as can be seen in Figure 12.

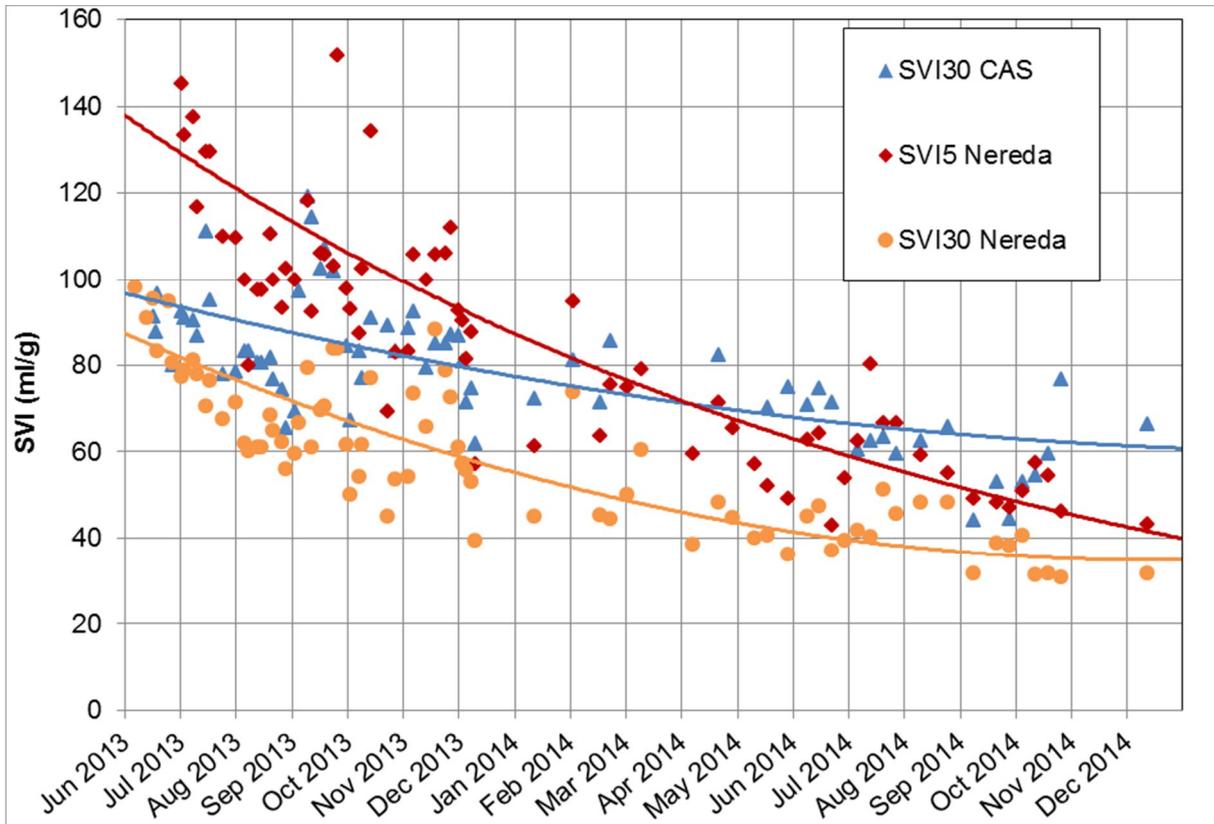


Figure 12. SVI comparison of the Nereda[®] and CAS systems at Vroomshoop from start-up in June 2013 until the end of 2014.

Using Nereda[®] waste sludge to improve settleability in CAS systems (hybrid – configuration 3) offers numerous advantageous possibilities, such as:

- the potential to increase biomass concentrations in the CAS system, thereby increasing biological treatment capacity and;
- enabling higher hydraulic loading through the CAS system.

Furthermore, Nereda[®] waste sludge contains a high fraction of Phosphate Accumulating Organisms (PAOs) (which drive bio-P removal) and therefore improvement in biological phosphorus removal in the CAS side of a hybrid system is possible. With the plant at full loading, the performance in terms of effluent quality has met all requirements (see Table 6). Furthermore, energy consumption monitoring at Vroomshoop (June-November 2014) showed the Nereda[®] side of the treatment plant used approximately 35% less energy than the CAS side.

Table 6. Vroomshoop WWTP - overall treatment performance in 2014/2015.

Parameter	Unit	Influent	Effluent	Requirement	Compliance Conditions
COD	mg/l	720	75	125	Limit (3 x per year up to 250)
BOD5	mg/l	263	<10	10	Limit (3 x per year up to 20)
TN	mg/l	-	6	10	Yearly Average
TKN	mg/l	66	-	-	-
NH ₄ -N	mg/l	-	2.2	Summer = 2 Winter = 4	Average (1 May - 1 Nov.) Average (1 Nov. - 1 May)
NO _x -N	mg/l	-	2.0	-	-
TP	mg/l	8.9	1.2	2	Moving average of 10 successive samples
PO ₄ -P	mg/l	-	0.5	-	-
TSS	mg/l	317	20	-	Limit (3 x per year up to 30)

👉 Frielas WWTP (configuration 4)

Client: Agua de Portugal – Simtejo
Wastewater type: Municipal & Industrial
Place & year: Lisbon, Portugal, 2012 + 2014
Average capacity demo: 3,000 m³/day | 10,000 p.e.
Average capacity full scale retrofit: 12,000 m³/day | 40,000 p.e.

The Frielas WWTP is a 70,000 m³/day plant currently at 70% of its biological design capacity and receives, mainly, domestic wastewater from 250,000 inhabitants, in the Greater Lisbon area. Regarding effluent quality, the WWTP has carbon removal and disinfection requirements (i.e., COD < 125 mg/l and TSS < 35 mg/l) and no specific discharge limits for nitrogen and phosphorous. Since start-up in 1997, the Frielas WWTP suffered from several operational constraints related to some technological decisions made at the design phase but also because the wastewater characteristics became quite different from those used for the original plant design. To validate if Nereda could improve the plant performance under realistic field conditions, one of the six continuous activated sludge reactors was retrofitted into a Nereda[®] reactor (Figure 13) with a volume of approximately 1,000 m³, which was then run in parallel to the remaining five activated sludge reactors. This was the first continuous Activated Sludge Nereda[®] retrofit application.



Figure 13. Conversion of reactor n°6 of Frielas WWTP to Nereda[®] technology.

Besides providing a robust and efficient operation during all influent conditions, a driver for the retrofit was to evaluate the possibility to substantially lower the electricity demand of a conventional WWTP. Another important motivation for the implementation of Nereda[®] was the possibility of working at higher hydraulic loads and achieving nutrient removal without the (eventual) future need for increasing reactor volume. The demonstration reactor start-up was made with normal activated sludge from one of the other aeration streams. Operation reached a steady state SVI₃₀ around 40 ml/g, a SVI₁₅ as low as 60 ml/g, a granulation fraction above 80% and an increasing biomass concentration in the range of 6 to 8 g/l. It is important to note that the start-up was made partially during winter time with diluted wastewater (i.e. COD levels below 300 mg/l) contributing to a slower biomass growth and transformation rate.

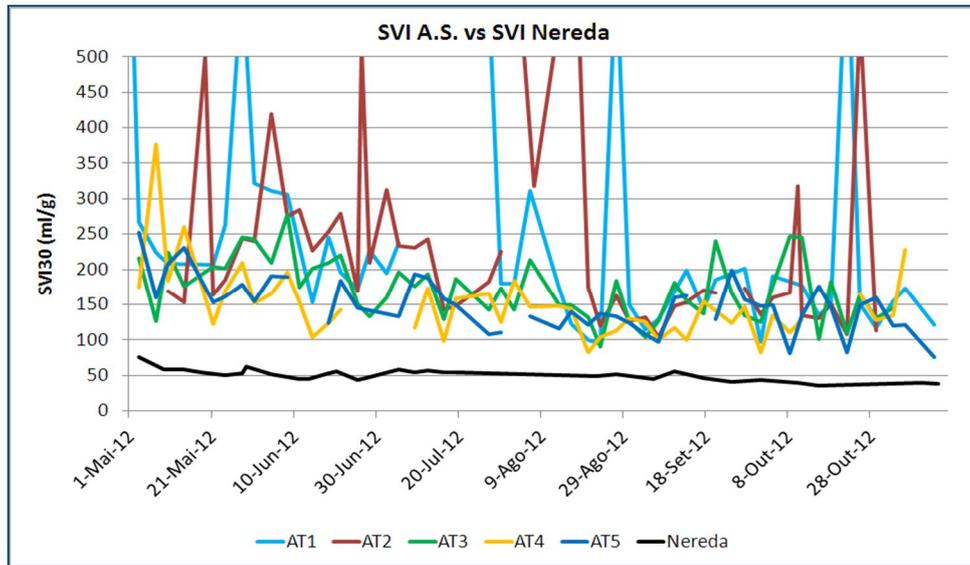


Figure 14. Comparison between the settleability of the biomasses from the Nereda reactor and the activated sludge (AS) from the other five biological reactors (AT) in the Frielas WWTP.

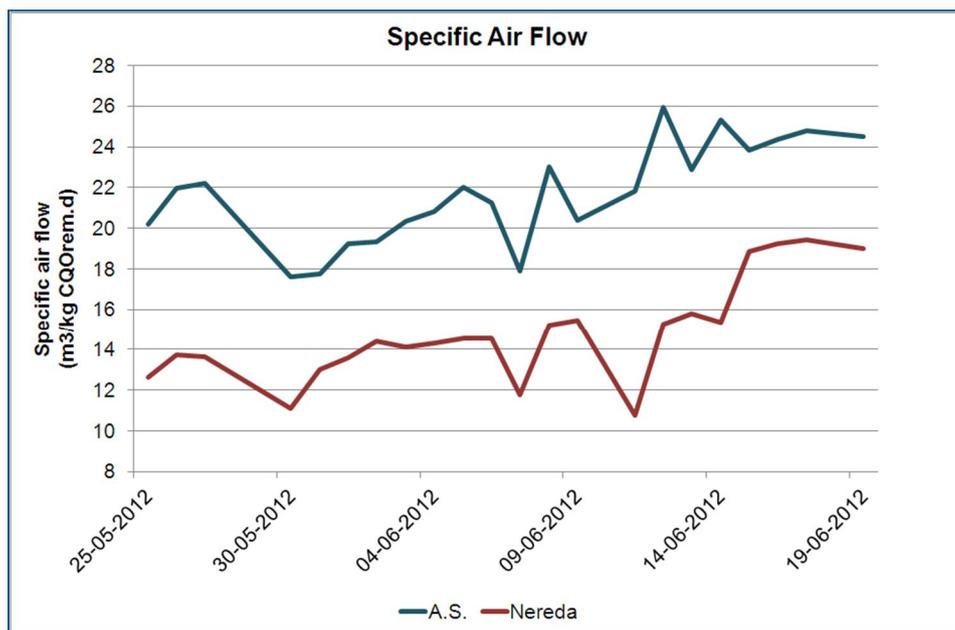


Figure 15. Comparison between the airflow rates to activated sludge and Nereda plants.

After more than one year of plant operation the effluent quality was shown to be significantly better and far more consistent than the quality obtained in the original CAS. This plant also gave a unique opportunity to observe the power consumption of Nereda® in parallel to a CAS. Airflow rates are shown in Figure 15. A significant decrease in energy consumption was observed. Since Nereda® is operated in parallel with the conventional aeration tanks using the same water depth, existing and common air supply equipment, the comparison between the two technologies is reliable and representative. During a two month monitoring period the air consumption of both systems was measured with the dissolved oxygen (DO) levels similar and nitrification in Nereda® fully suppressed to mimic the biological performance of the CAS reactors.

Taking into account the efficiency of the air blowers, the measured air flow consumed in each system per mass of chemical oxygen demand (COD) removed was translated into the specific electricity consumption. It was observed that the average specific consumption for the Nereda amounts to 0.35 kWh/kg COD removed, representing approximately 30% electricity savings compared to aeration for the AS system. Combining this with the energy saving that granules bring by not using settling tanks, sludge recirculation pumps and post-filtration units, the overall electricity saving potential for the plant was computed to 50%.

Following the positive results obtained with the Nereda® demonstration reactor, Simtejo has implemented an extension of the demo to a full-scale reactor (4,000 m³) operated parallel to the existing continuous activated sludge reactors. The reactor has a treatment capacity of 12,000 m³/day and 40,000 inhabitants with a start-up in the summer of 2014. Although using only 9% of the total biological volume of the plant, the Nereda® technology will treat 25% of the total flow and will produce an effluent with a better quality.

During two months the air flows were compared. Taking into account the efficiency of the air blowers, specific electricity requirements were computed and savings of about 30% were calculated, with a specific average consumption of 0,35 kWh/kgCOD. Combined with savings regarding the fact that Nereda® does not need separate settlers, sludge recirculation and post-filtration, the potential savings on the plant are 50%.

3 Nereda® References Overview

Operational plants	Average flow (m ³ /day)	Peak flow (m ³ /h)	Population Equivalent (PE)		Start-up	Greenfield or Retrofit
			Design	PE Basis		
Vika, Ede (NL)	50-250	20	5,000	54 gram BOD	2005	Retrofit
Cargill, Rotterdam (NL)	700	100	30,000	54 gram BOD	2006	Retrofit
Smilde, Oosterwolde (NL)	500	80	5,000	54 gram BOD	2009	Retrofit
STP Gansbaai (RSA)	5,000	400	63,000	60 gram BOD	2009	Greenfield
STP Epe (NL)	8,000	1,500	41,000	54 gram BOD	2011	Greenfield
STP Garmerwolde (NL)	30,000	4,200	140,000	54 gram BOD	2013	Greenfield
STP Vroomshoop (NL)	1,500	200	12,000	54 gram BOD	2013	Greenfield
STP Dinxperlo (NL)	3,100	570	11,000	54 gram BOD	2013	Greenfield
STP Wemmershoek (RSA)	5,000	468	39,000	60 gram BOD	2013	Greenfield
STP Frielas, Lisbon (PT)	12,000	1,850	40,000	60 gram BOD	2015	Retrofit
STP Ryki (PL)	5,300	430	41,000	60 gram BOD	2015	Greenfield
Westfort Meatproducts, IJsselstein (NL)	1,250	330	43,000	54 gram BOD	2015	Greenfield
STP Clonakilty (IRL)	4,900	622	20,500	60 gram BOD	2015	Greenfield
STP Carrigtwohill (IRL)	6,700	844	30,000	60 gram BOD	2015	Greenfield
STP Deodoro, Rio de Janeiro (BR) Phase I	64,800	4,590	360,000	60 gram BOD	2016	Greenfield
STP Kingaroy (AUS)	2,630	450	16,000	60 gram BOD	2016	Greenfield
STP Simpelveld (NL)	3,700	945	10,000	54 gram BOD	2016	Greenfield
STP Cork Lower Harbour (IRL)	18,300	1,830	65,000	60 gram BOD	2017	Greenfield
STP Highworth (UK)	1,720	197	9,000	60 gram BOD	2017	Greenfield
STP Ringsend, Dublin (IRL) Phase I (PPS2)	21,000	1,700	83,000	60 gram BOD	2017	Retrofit
STP Jardim Novo, Rio Claro (BR)	24,200	1,806	152,000	60 gram BOD	2017	Greenfield
Plants under construction						
STP Hartebeestfontein (RSA)	5,000	208	44,000	60 gram BOD	2018	Greenfield
STP Alpnach (CH)	14,000	1,872	65,000	60 gram BOD	2018	Greenfield
STP Zutphen (NL)	10,100	550	237,000	54 gram BOD	2018	Greenfield
STP Utrecht (NL)	55,000	13,200	343,000	54 gram BOD	2018	Greenfield
STP Inverurie (UK)	10,900	544	47,200	60 gram BOD	2018	Retrofit
STP Kendal (UK)	16,000	1,749	92,900	60 gram BOD	2018	Greenfield
STP Österröd, Strömstad (S)	3,730	360	12,000	60 gram BOD	2018	Greenfield
STP Faro – Olhão (PT)	20,600	1,908	134,000	60 gram BOD	2018	Greenfield
STP Ringsend, Dublin (IRL) Phase II (CUC)	117,000	10,800	400,000	60 gram BOD	2020	Greenfield
Plants under design/planning consent						
STP Morecambe (UK)	17,000	2,088	30,000	60 gram BOD	2018	Greenfield
STP Barston (UK)	21,800	1,424	77,400	60 gram BOD	2018	Greenfield
STP Walsall Wood (UK)	7,200	646	26,300	60 gram BOD	2018	Greenfield
STP Radcliffe (UK)	5,320	463	22,300	60 gram BOD	2018	Greenfield
STP Blackburn (UK)	68,200	11,756	430,000	60 gram BOD	2018	Greenfield
STP Tatu, Limeira (BR)	57,000	3,492	322,000	60 gram BOD	2019	Greenfield
STP Tijuco Preto, Sumaré (BR)	19,900	1,492	100,000	60 gram BOD	2019	Greenfield
STP Breskens (NL)	3,500	1,000	31,300	54 gram BOD	2019	Greenfield
STP Lontra, Araguaína (BR)	34,100	2,196	228,000	60 gram BOD	2019	Greenfield
STP Dungannon (UK)	7,900	720	26,100	60 gram BOD	2020	Greenfield
STP Newham (UK)	1,760	260	9,700	60 gram BOD	2020	Greenfield
STP Ringsend, Dublin (IRL) Final capacity	600,000	49,600	2,400,000	60 gram BOD	2023	Combined
STP Kloten (CH)	26,000	2,850	95,000	60 gram BOD	2023	Retrofit
STP Deodoro, Rio de Janeiro (BR) Phase II	86,400	6,120	480,000	60 gram BOD	2025	Greenfield
STP Jardim São Paulo, Recife (BR)	22,800	1,871	109,000	60 gram BOD	2019	Greenfield
Phase II	67,800	5,577	325,000	60 gram BOD	2025	Greenfield
STP São Lourenço, Recife (BR)	18,800	1,287	105,000	60 gram BOD	2020	Greenfield
Phase II	25,100	1,715	140,000	60 gram BOD	2024	Greenfield
STP Jaboatão, Recife (BR)	109,700	8,536	609,000	60 gram BOD	2020	Greenfield
Phase II	154,500	12,037	858,000	60 gram BOD	2025	Greenfield

4 Irish Nereda[®] Projects

➤ Nereda[®] Clonakilty

Client: EPS / Irish Water
Wastewater type: Municipal
Place & start-up: Clonakilty, Ireland, 2015
Average capacity: 4,896 m³/day | 21,000 p.e.
Peak flow: 626 m³/h

Based on the outcome of a public tender process, EPS was awarded a 20 year DBO Contract which provided for the design, construction, commissioning and operation of an upgrade to the municipal Waste Water Treatment Plant at Clonakilty. EPS selected the Nereda[®] technology in agreement with the state water authority in Ireland, Irish Water (established in 2014). The plant in Clonakilty (Figure 16) became operational end of 2015. Despite being heavily overloaded, the plant is capable of meeting the effluent demands (table 8).

Pre-treatment: Combined screening, grit and FOG removal

Table 7. Waste water characteristics Nereda[®] Clonakilty.

Parameter	Unit	Raw sewage	Return flow	Feed
Dry weather flow	m ³ /day			4,896
Peak flow	l/s	170	4	174
Population Equivalent	–	20,500	1,500	22,000
BOD ₅	kg/day	1,151	79	1,230
COD	kg/day	2,648	182	2,830
Oil and grease	mg/l	<80	ns	<80
Total Suspended Solids	kg/day	1,438	100	1,538
Total Nitrogen	kg N/day	230	26	256
Total Phosphate	kg P/day	48	13.5	61.5
pH	–	5 – 9	6 – 8	5 – 9
Temperature	°C	10 – 20	10 – 20	10 – 20

Table 8. Effluent Requirements Nereda[®] Clonakilty

Parameter		Discharge limit	Type of Standard
BOD	mg/l	25	95 th percentile
COD	mg/l	125	95 th percentile
Suspended Solids	mg/l	35	95 th percentile
Total N	mg/l	15	Annual Mean
NH ₄ -N	mg/l	10	Not specified
Total P	mg/l	2	Annual Mean
Ortho-phosphate	mg/l	1	Not specified



Figure 16. Nereda® Clonakilty


Nereda® Carrigtohill

Client: EPS / Irish Water
Wastewater type: Municipal
Place & start-up: Carrigtohill, Ireland, 2015
Average capacity: 6,570 m³/day | 30,000 p.e.
Peak flow: 844 m³/h

Carrigtohill has been identified in the Cork Development Plan and the Cork Area Strategic Plan as an area of potential high growth. A substantial increase in the capacity of the foul and surface water networks as well as the treatment plant is required to cater for the increased hydraulic and biological loads. This in combination with more stringent discharge standards necessitates the construction of a new wastewater treatment facility at Carrigtohill. The construction of the wastewater treatment facilities at Carrigtohill is being procured under a design/build/operate (DBO) form of contract.

Pre-treatment: screenings and FOG removal.

Table 9. Waste water characteristics Nereda® Carrigtohill.

Parameter	Unit	Average	Maximum
Dry weather flow	m ³ /day	6,750	
Rain weather flow	m ³ /day m ³ /h	–	20,256 844
Design wastewater temperature	°C	>12	
pH	–	5 – 9	9
BOD5	kg/day	1,854	2,225
COD	kg/day	4,635	5,562
TSS	kg/day	2,317.5	2,782
TKN	kg N/day	354.3	426
TP	kg P/day	92.7	112
Oil and grease	mg/l	<80	<80

Table 10. Effluent Requirements Nereda® Carrigtohill.

Parameter		Discharge limit	Type of Standard
BOD	mg/l	25	95th percentile
COD	mg/l	125	95th percentile
Suspended Solids	mg/l	35	95th percentile
Total N	mg/l	20	Annual Mean
Total P	mg/l	1	Annual Mean

The Test on completion in April 2016 showed the plant meeting all the demands easily (figure 17)

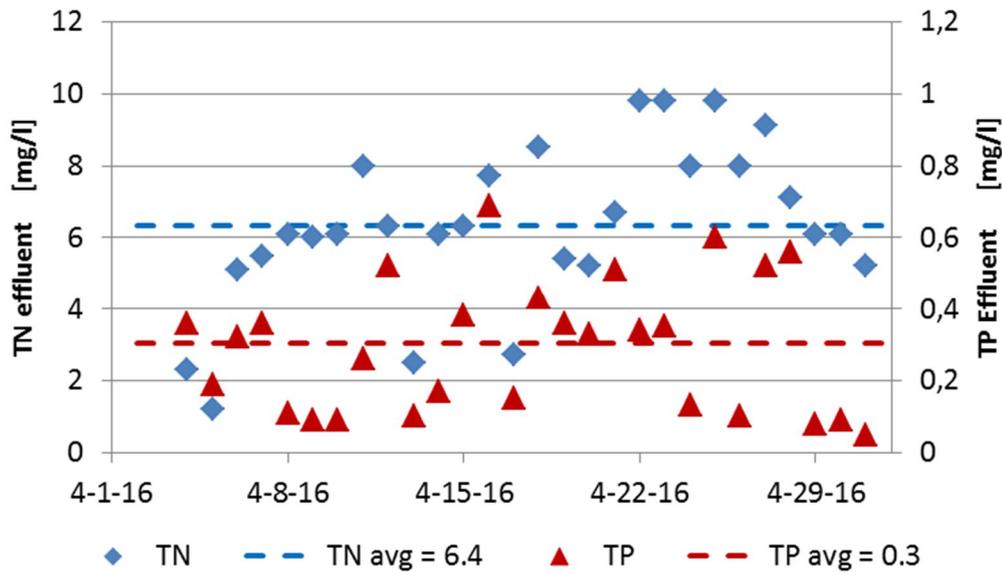


Figure 17. Effluent TN and TP Nereda[®] Carrigtohill



Figure 18. Nereda[®] Carrigtohill


Nereda® Cork Lower Harbour

<p>Client: EPS / Irish Water</p> <p>Wastewater type: Municipal</p> <p>Place & start-up: Cork Lower Harbour, Ireland, 2016</p> <p>Average capacity: 18,500 m³/day 65,000 p.e.</p> <p>Peak flow: 1,830 m³/h</p>
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This Nereda® installation is a part of the “Cork Lower Harbour Main Drainage (CLHMD) Project” and is required to significantly enhance the water quality in Cork Harbour.

The CLHMD Scheme includes the population/industrial centres of Cobh, Carrigaline, Crosshaven, Passage West, Monkstown, Glenbrook, Ringaskiddy Shanbally and Coolmore. Wastewater from these areas is currently discharged into the harbour following preliminary screening or untreated.

Shanbally (North West of Carrigaline) has been selected as the location for the centralised waste water treatment works utilising the existing IDA outfall discharging to the Harbour at Dognose Bank.

The need for a wastewater treatment plant for Cork Lower Harbour is a requirement under both European and National legislation in order to improve health, integrity of the environment and improve water quality in compliance with the European Union’s Urban Wastewater Treatment Directive. The Cork Lower Harbour Main Drainage Project will ensure that these water quality standards set down by regulatory bodies will be achieved, which will help Ireland.

From 1st January 2014 Irish Water has taken over responsibility for water and wastewater services in Ireland, in partnership with the Local Authorities under a Service Level Agreement (SLA). Irish Water recognises the vital importance of the Cork Lower Harbour Main Drainage Project to Cork and to Ireland in order to protect the environment, facilitate economic development and for a growing population. Cork County Council will support Irish Water in the continued development of the Project.

The Cork Lower Harbour Main Drainage Project will consist of:

- A new Wastewater Treatment Plant
- 14 new pumping stations
- Approximately 30km of new sewers
- A drilled crossing under the estuary



Figure 19. Nereda® Cork lower harbour

Nereda® Ringsend

Irish Water is planning the Ringsend Wastewater Treatment Plant - Upgrade Project. This includes:

- In plant improvements – ongoing;
- Plant Capacity Upgrade of 400,000 PE (with N and P removal) on a 0.8 ha site within the works;
- Retro-fit existing works to achieve N and P removal.

Following the upgrade and retrofit works, the plant will have a projected capacity of 2.4 MPE (basis 60 gBOD). Given the specific characteristics of the project the aerobic granular activated sludge technology (AGS) Nereda® provides a potential and promising solution.

To confirm the application of the AGS / Nereda® process specific in the Ringsend WwTW and allowing for optimisation of the application in the existing reactors a “process proving program” is being implemented. This program has a two-step approach, presented in Table 11 following.

Table 11. Process Proving and Design Optimisation Ringsend

PPS1: Semi-technical scale; Nereda® unit

Capacity up to 5 m³/day, 2 reactors: height 6 m - diameter 600 mm

Process proving - Process optimization - Salinity & Spiking tests

PPS2: Single existing SBR cell scale

Retrofit of one of the existing SBR cells with Nereda® internals & Nereda® Control

Process optimization – validate retrofit design / procedure

On 23 April 2015 PPS1 was installed and was in operation until July 2016. This first step successfully demonstrated the suitability of the Activated Granular Sludge technology, based on the Nereda® concept, for application in the Ringsend WwTW Upgrade and retrofit project.

PPS2 involves the complete retrofit of one SBR cell (13,500 m³ volume) to a Nereda® AGS reactor. The primary purpose of PPS2 was to demonstrate the scalability of the technology towards the retrofit of the existing SBR cells. Table 12 lists the phases within PPS2.

Table 11. Phasing PPS2 Ringsend

Phase 1:	Scoping (Feasibility Design Phase) of PPS2 and preparation of 30% design and target costs
Phase 2:	Detailed Engineering Design & Procurement
Phase 3:	Retrofit of 1 cell, testing, commissioning
Phase 4a:	Process Start Up
Phase 4b:	Conduct Process Proving Test
Phase 5:	Re-instatement / Implement final retrofit

As signed off in December 2017, the PPS2 tests conclusively demonstrated the suitability of the Nereda® technology. The retrofitted cell remains in use as a permanent Nereda® reactor, greatly outperforming the SBR cells at a much higher loading rate.

The findings of the Process proving are presented in a separate AGS Process Proving Summary Report.



Ringsend PPS2 Retrofit

5 Conclusions

The experience over the last decade has proven the Nereda® process to be:

- Robust and proven on large and small scale, showing stable operation with proper granular biomass having superior settling characteristics
- Capable of extended N&P removal to 10/1 limits (or even lower depending on design) even at temperatures below 10 °C
- Very energy and consumable efficient, typically showing an energy consumption 40 – 60% lower compared to conventional plants running under similar conditions
- Efficient in footprint, typically only 20 – 30% of conventional plants
- Versatile in design. Number of tanks and shape (rectangular, circular, water depth) can easily be made fit for purpose
- Suitable for retrofits
- Capex and Opex efficient

Overall the Nereda can be considered a game changer in terms of wastewater treatment.



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