Phosphorus

What is it and why do I need to remove it from wastewater?

Author: Paul Barter, Principal Process Engineer
Hydro International

White Paper

Hydro International®

Contents

	Page No.
What is phosphorus?	3
The phosphorus cycle	4
Why do I need to remove it from wastewater?	5
How much phosphorus do I need to remove, and are there any standards I should be meeting?	6
How do I remove phosphorus from wastewater?	7
Hydro International phosphorus removal technology	8
Dosing regimes	16
Verification of technology	17

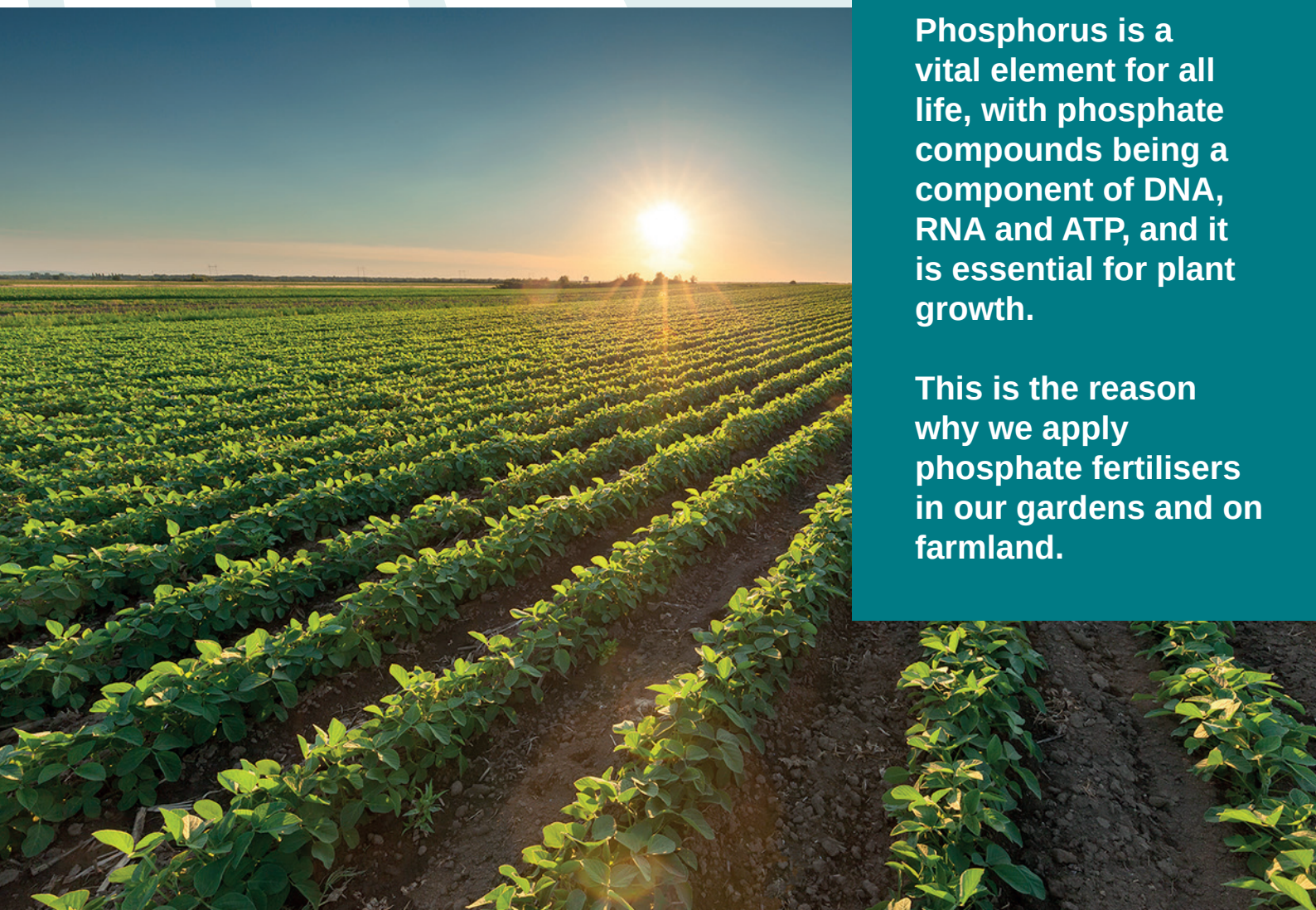
What is phosphorus?

Phosphorus is a chemical element with the symbol P.

It is highly reactive and is therefore never found naturally as a free element, occurring instead as inorganic and organic phosphates (oxidised) in water, soil and sediments.

These phosphates occur in three types:

- Orthophosphates
  The simplest form of phosphate, available for biological metabolism without further breakdown
- Polyphosphates
  Complex molecules which require hydrolysis to revert to orthophosphates
- Organophosphates
  Esters of phosphoric acid; of minor importance in municipal wastewaters, but can be significant in industrial applications.



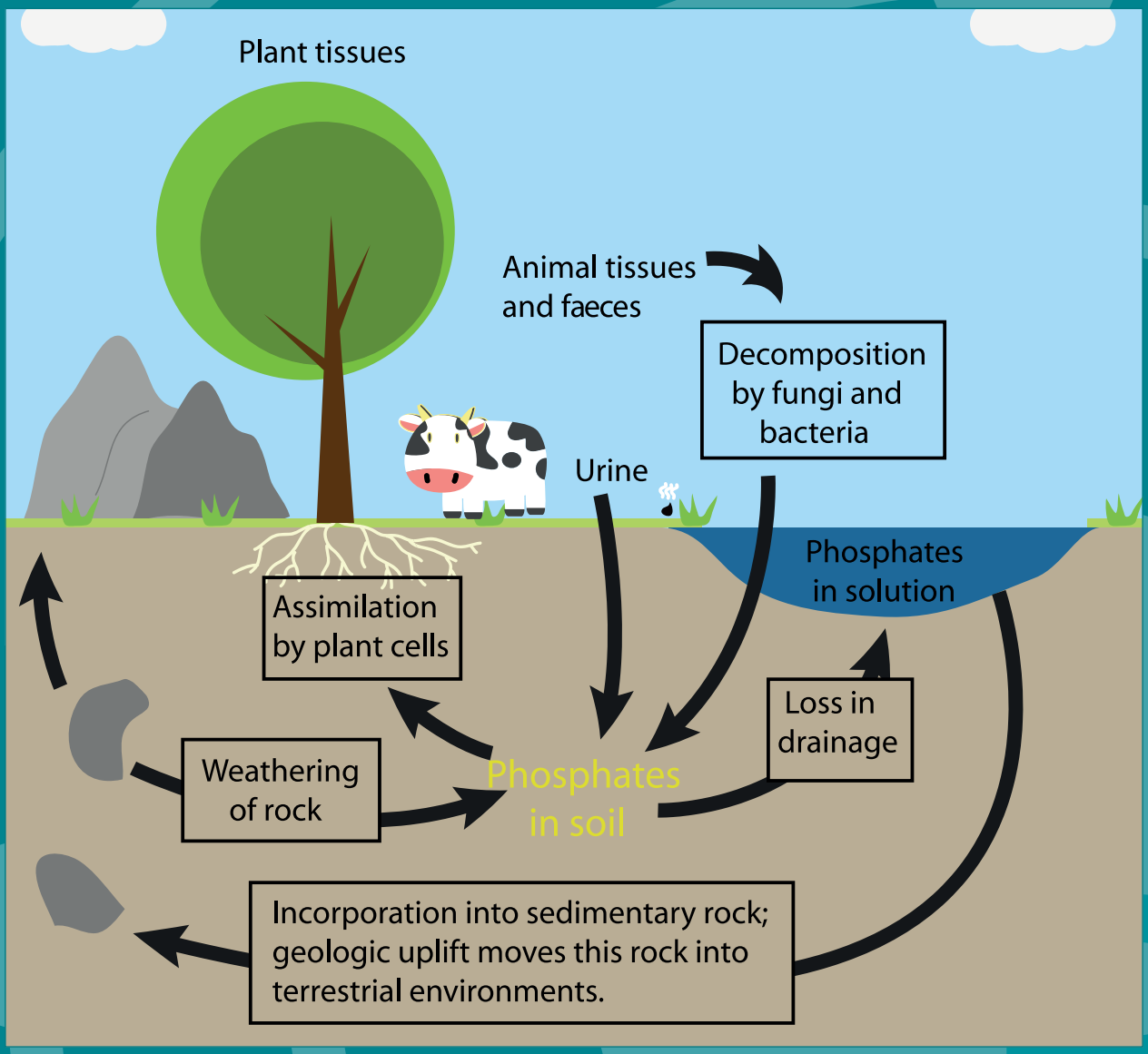
Phosphorus is a vital element for all life, with phosphate compounds being a component of DNA, RNA and ATP, and it is essential for plant growth.

This is the reason why we apply phosphate fertilisers in our gardens and on farmland.

The phosphorus cycle

Phosphates are released from rocks by weathering and the action of plant roots. These phosphates are then assimilated from the soil by plants, with the help of bacteria.

All the phosphorus that the human body needs is obtained by eating the plants or plant-eating animals that have already absorbed and utilised it.



Why do I need to remove it from wastewater?

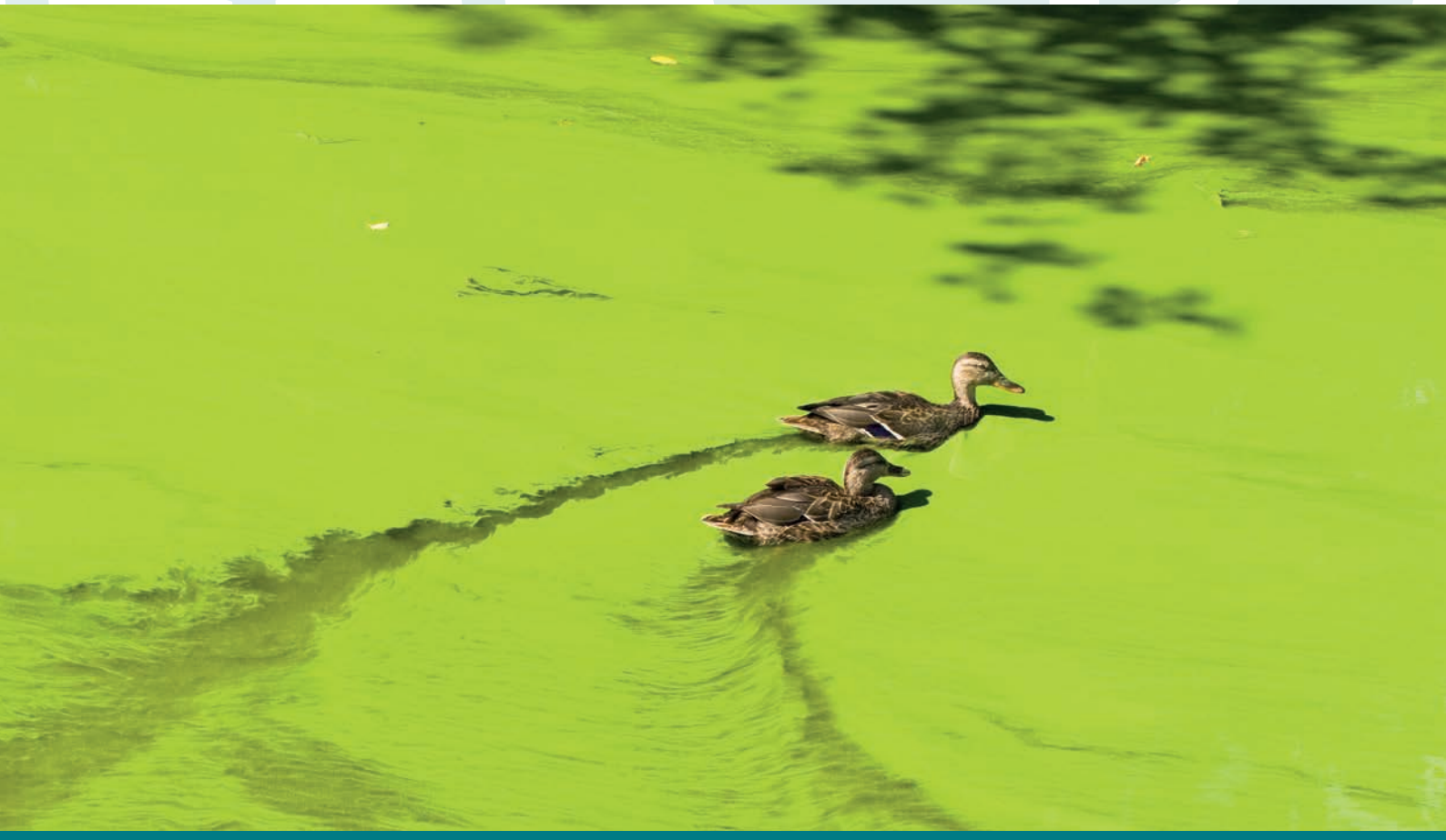
Whilst phosphorus is very useful and effective as a fertiliser to encourage plant growth, it can cause catastrophic problems if too much gets into our streams, rivers, lakes and seas. Phosphorus reaches bodies of water via runoff over land, leaching through soil from fertilisers and discharges from sewage treatment works. In fact, the UK Water Industry Research (UKWIR) cites phosphorus as a major reason that UK rivers are not achieving 'good' status under the Water Framework Directive (WFD).

This is the reason why:

Where levels of phosphates in water bodies are too high, it can trigger algal blooms which block sunlight from reaching lower waters, thereby causing plants to die. As the plants and also the algae die and decay they cause depletion of oxygen levels – this is known as eutrophication. Oxygen depletion can lead to fish dying, impaired reproduction of remaining fish and a reduction in biodiversity. The algal blooms themselves can also be toxic to people, plants and animals.

Where does wastewater phosphorus come from?

Fertilisers, human waste and detergents are the main sources of phosphate pollution. One person produces an average of 2 g of phosphorus a day which ends up at municipal treatment works. At the end of the treatment process, municipal wastewaters can contain 2 – 5 mg/l of total phosphorus.



How much phosphorus do I need to remove, and are there any standards I should be meeting?

In 1991 the Urban Wastewater Treatment Directive set a consent level of 2 mg/l of phosphorus for larger wastewater treatment works or those discharging into sensitive waters.

Then, the Water Framework Directive (2000) (WFD), with its aim to improve the status of all water bodies to 'good', cited limits of 0.5 – 1.0 mg/l in the water body itself, though phosphorus is just one of a number of substances listed as detrimental to water bodies. Some of these other substances include: hydrocarbons, metals, industrial chemicals, pharmaceuticals and hormones.

Although there is no actual phosphorus discharge limit for wastewater into general water bodies, it is generally now considered that for a water body to actually achieve 'good' status under the WFD, a limit as low as 0.1 mg/l may be necessary.

To prioritise substances of potential concern and find out what their concentrations were in Wastewater, UKWIR undertook a Chemicals Investigation Programme (CIP).

CIP Phase 1, which ran from 2010 to 2014, identified substances present in sewage and treated wastewater and prioritised them according to Environmental Quality Standard (EQS) compliance risk. Sampling for this phase covered 74 substances at over 600 sewage treatment plants. From this programme 8 substances were identified as posing the greatest risk – phosphorus is one of them.

CIP Phase 2, initiated in 2015 and programmed to run until 2020, is investigating technologies to remove the four priority pollutants. Initial findings can be found on the UKWIR website.

Knowledge gained from CIP1 and CIP2 could be used to set regulatory standards for total phosphorus removal.

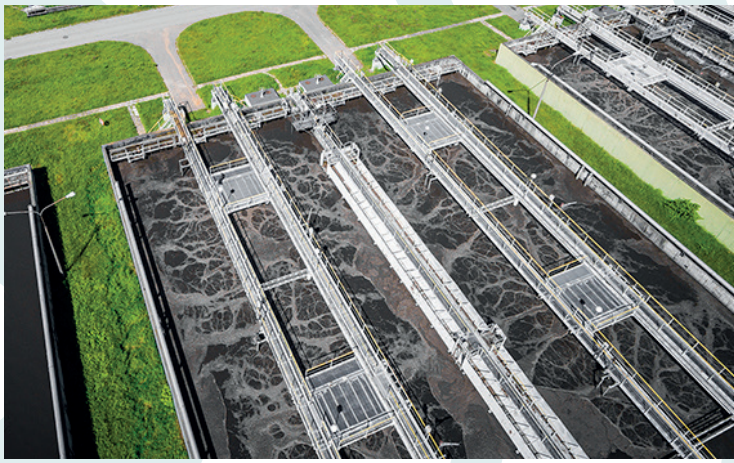
How do I remove phosphorus from wastewater?

To maximise phosphate removal there can be up to three processes applied:

1) Phosphate in solid form can be removed using filtration / solids settlement processes. This generally occurs in the primary treatment stage.

However, much of the phosphate will be dissolved in the wastewater stream. These dissolved phosphates can be removed by the secondary and tertiary processes:

2) A proportion of the dissolved phosphates will be removed by the biological process at the treatment works. This is done by growing microorganisms that can absorb and store phosphorus as polyphosphate. The phosphorus is incorporated into the biomass which is then separated from the treated water at the end of the process. This stage is associated with the secondary treatment processes.

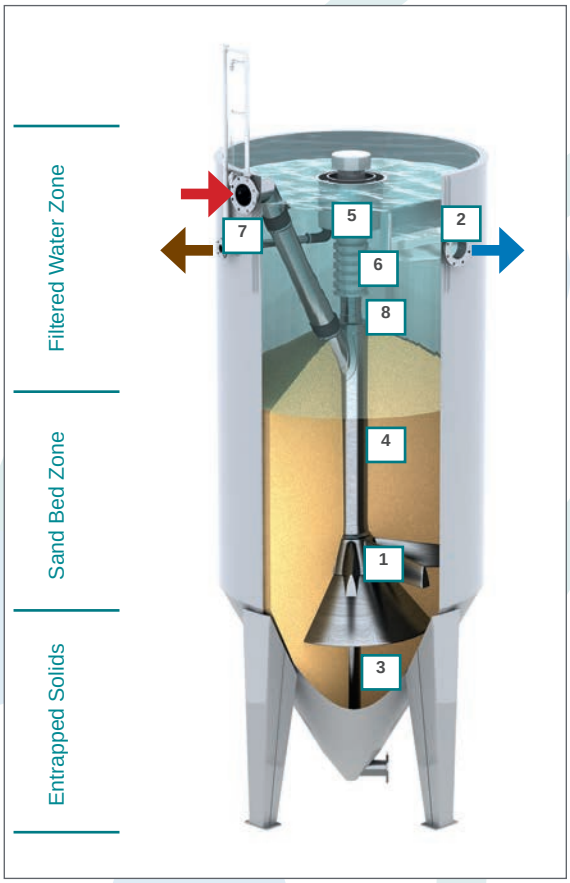


3) The remaining dissolved phosphates can be chemically precipitated to convert into solids that can be removed with filtration processes. This is normally done using addition of metal salts to react with the soluble phosphate to form solid precipitates. This is explicitly applied as a tertiary treatment process. Dosing can be performed at various stages in the wastewater treatment process.

Hydro International phosphorus removal technology

The DynaSand® Range

We have a range of continuous upflow vertical sand filtration technologies available in the UK which, with the addition of a coagulant such as ferric sulfate, can remove phosphates from wastewater at the tertiary treatment stage.



Basic principles of operation

The DynaSand® filter is based on the counter flow principle. The water to be treated (red arrow) is admitted through the **inlet distributor (1)** in the lower section of the unit and is cleaned as it flows upwards through the sand bed, prior to discharge (blue arrow) through the **filtrate outlet (2)** at the top. The sand containing the entrapped solids is conveyed from the tapered bottom section of the unit **(3)**, by means of an **airlift pump (4)**, to the **sand washer (5)** at the top.

Cleaning of the sand commences in the pump itself where impurities are separated from the sand grains by the turbulent mixing action. The contaminated sand spills from the pump outlet into the **washer labyrinth (6)** in which it is washed by a small counter current flow of clean water. The separated solids (brown arrow) are discharged through the **wash water outlet (7)**, while the grains of clean sand (which are heavier) are returned to the sand bed **(8)**. As a result, the bed is in slow, constant downward motion through the unit. Compressed air for the sand pump is provided by via the control panel.

Thus, water purification and sand washing both take place continuously enabling the filter to remain in service without interruption.

Three variants of DynaSand® are available which use different filter media to allow the removal of specific polluants:

Pollutant	DynaSand®	DynaSand® Oxy	DynaSand® Deni
TSS	✓	✓	✓
BOD	✓	✓	✓
Phosphorus	✓	✓	✓
Ammonia	X	✓	X
Nitrogen	X	X	✓

DynaSand®

The DynaSand® system uses sand as the filter media and provides high-quality suspended particle filtration from a small-footprint filter bed with no moving parts or backwash equipment requirements.

DynaSand® can provide removals down to 0.1 mg/l whilst also removing effluent BOD and TSS down to 10 mg/l.

Feature	DynaSand® Performance
Effluent TSS removal	Down to 10 mg/l *
Effluent BOD removal	Down to 10 mg/l *
Effluent Phosphorus removal	Down to 0.1 mg/l **
Effluent Ammonia removal	N/A
Effluent Nitrogen removal	N/A
Maximum flow-rate per filter	29 l/s

* effluent standards quoted to 95%ile
** annual average

DynaSand® delivers high-quality suspended particle filtration from a small footprint filter bed with no moving parts or backwash equipment requirements.

Aluminium or ferric salt may be injected directly into the DynaSand® inlet stream to facilitate precipitation of the phosphates. As the water flows upwards through the filter bed to the filtrate outlet, precipitated particles are deposited on the sand grains. The sand is continuously circulated by an airlift pump and impurities washed from the sand in the separate sand washer, to be discharged for additional treatment or disposal.

DynaSand® handles high concentrations of suspended solids efficiently without requirements for settlement tanks and has a 90% smaller footprint than the equivalent horizontal filter bed.

DynaSand® Oxy

The DynaSand® Oxy system uses sand as the filter media, plus the addition of air and provides small-footprint, continuous sand filtration with air addition to facilitate removal of ammonia from wastewater.

Primarily designed for ammonia removal, for which it delivers removals down to 2 mg/l, the DyanSand® Oxy can also provide removals of effluent phosphorus down to 0.2 mg/l as well as effluent BOD and TSS down to 10 mg/l.

Feature	DynaSand® Performance
Effluent TSS removal	Down to 10 mg/l *
Effluent BOD removal	Down to 10 mg/l *
Effluent Phosphorus removal	Down to 0.2 mg/l**
Effluent Ammonia removal	Down to 2 mg/l *
Effluent Nitrogen removal	N/A
Maximum flow-rate per filter	29 l/s

* effluent standards quoted to 95%ile
** annual average

DynaSand® Oxy is a continuous sand filtration system with air addition to facilitate removal of ammonia from wastewater.

As the water flows upwards through the filter bed, ammonia is converted into nitrate by bacteria - Nitrosomonas and Nitrobacter - which form a layer on the surfaces of the filter grains. The bacteria, which are autotrophic and thus live only on inorganic materials, produce new biomass out of carbon dioxide.

As with the standard DynaSand®, aluminium or ferric salt can be injected directly into the inlet stream to facilitate precipitation of phosphates.

DynaSand® Deni

The DynaSand® Deni uses sand as the filter media with carbon addition to provide small-footprint removal of nitrates from wastewater.

Primarily designed for nitrate removal, for which it delivers down to 10 mg/l total N, the DynaSand® Deni can also provide removals of effluent phosphorus down to 0.2 mg/l, effluent BOD and TSS down to 10 mg/l.

Feature	DynaSand® Performance
Effluent TSS removal	Down to 10 mg/l *
Effluent BOD removal	Down to 10 mg/l *
Effluent Phosphorus removal	Down to 0.2 mg/l **
Effluent Ammonia removal	N/A
Effluent Nitrogen removal	Down to 10 mg/l Total N
Maximum flow-rate per filter	29 l/s

* effluent standards quoted to 95%ile
** annual average

DynaSand® Deni denitrification helps reduce the adverse environmental impact of excess nitrate compounds from treatment works into receiving watercourses.

With the addition of aluminium or ferric salt the scope of the DynaSand® Deni can be extended to remove phosphorus at the same time. As with the standard DynaSand®, the metal salts can be injected directly into the inlet stream to facilitate precipitation of phosphates.

Incoming water flows upwards through the DynaSand® Deni filter bed, where nitrite (NO_2) and nitrate (NO_3) are converted into gaseous nitrogen (N_2) by microbial action. Nitrogen is discharged to the atmosphere. The vertical configuration of the DynaSand® Deni means a 90% smaller footprint than the equivalent horizontal sand filtration beds.

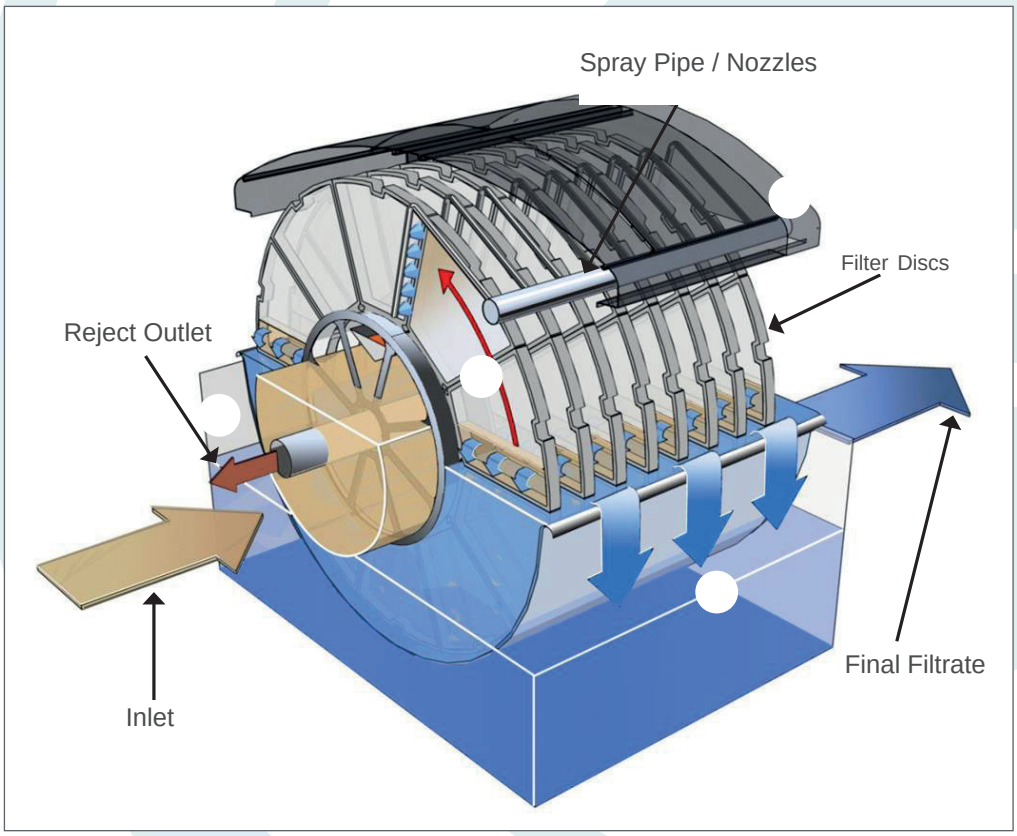
DynaDisc® Filtration

We also supply a high-performance, high-volume, low headloss disc filter for tertiary wastewater applications, the DynaDisc® system.

Basic principles of operation

1. Water to be filtered is guided into the rotor drum and flows by gravity into the filter discs, through openings in the drum, and passes through the filter cloth.
2. Suspended solids are separated and accumulate on the inside of the filter cloth.
3. When the water level inside the filter increases to a preset point, the filter starts rotating and the backwashing of the filter cloth is initiated.
4. The high pressure backwash spray removes the accumulated suspended solids into the reject flume inside the central drum.
5. The suspended solids are then discharged via the reject pipe. 65% of the disc area is submerged in operation, providing a high area through which the flow can pass.

The washwater is harvested from the clean side of the filter and therefore no separate washwater tanks are required, and the process operates on a continuous basis.



DynaDisc® Filtration

Primarily designed for TSS and BOD removal, for which it delivers removals down to 10 mg/l for each, the DynaDisc® can also provide removals of effluent phosphorus down to 1 mg/l in its standard configuration and 0.25 mg/l with the addition of metal salts.

Feature	DynaDisc®	DynaDisc® Floc
Effluent TSS removal	Down to 10 mg/l *	Down to 10 mg/l *
Effluent BOD removal	Down to 10 mg/l *	Down to 10 mg/l *
Effluent Phosphorus removal	Down to 1 mg/l **	Down to 0.25 mg/l **
Effluent Ammonia removal	N/A	N/A
Effluent Nitrogen removal	N/A	N/A
Maximum flow-rate per filter	up to 588 l/s	294 l/s

* effluent standards quoted to 95%ile
** annual average

Providing a large area for filtration in a compact process vessel, the DynaDisc® delivers high-volume, low-headloss disc filtration for tertiary wastewater and industrial process water applications.

The DynaDisc® is a microscreen consisting of multiple filter discs. The reliability of the DynaDisc® seals and durability of the filter fabrics allows the system to be used in a wide range of applications.

Hydro International phosphorus removal technology performance comparison

Feature	DynaSand® Performance	DynaSand® Oxy Performance	DynaSand® Deni Performance	DynaDisc®	DynaDisc® Floc
Effluent TSS Removal	Down to 10 mg/l *	Down to 10 mg/l *	Down to 10 mg/l *	Down to 10 mg/l *	Down to 10 mg/l *
Effluent BOD Removal	Down to 10 mg/l *	Down to 10 mg/l *	Down to 10 mg/l *	Down to 10 mg/l *	Down to 10 mg/l *
Effluent Phosphorus Removal	Down to 0.1 mg/l **	Down to 0.2 mg/l**	Down to 0.2 mg/l **	Down to 1 mg/l **	Down to 0.25 mg/l **
Effluent Ammonia Removal	N/A	Down to 2 mg/l *	N/A	N/A	N/A
Effluent Nitrogen Removal	N/A	N/A	Down to 10 mg/l Total N	N/A	N/A
Maximum flow-rate per filter	29 l/s	29 l/s	29 l/s	Up to 588 l/s	294 l/s
Headloss	Static + 500 mm + 600 mm/m media depth	Static + 500 mm + 600 mm/m media depth	Static + 500 mm + 600 mm/m media depth	Approx. 500 mm	Approx. 500 mm

* effluent standards quoted to 95%ile
** annual average

Hydro International phosphorus removal technology performance comparison

Feature	DynaSand® Performance	DynaSand® Oxy Performance	DynaSand® Deni Performance	DynaDisc®	DynaDisc® Floc
Media	Graded quartz sand 1.2 to 2 mm	Graded quartz sand 1.2 to 2 mm or DynaAktiv 1.4 to 2.7 mm	DynaAktiv 1.4 to 2.7 mm	10 micron cloth	10 micron cloth
Bed depth	1 - 2m normally 2m	2 to 6 m depending on ammonia load	2 to 6 m depending on nitrogen load	N/A	N/A
Return flow	5% of Full Flow to Treatment	5% of Full Flow to Treatment	5% of Full Flow to Treatment	3% of Full Flow to Treatment	3% of Full Flow to Treatment
Energy consumption per filter	Approx 1.2 kW (for air)	Approx 1.2 to 3 kW (for air)	Approx 1.2 kW (for air)	Up to 25 kW	Up to 25 kW
Media cycle rate	6 to 8 mm/m	6 to 8 mm/m	6 to 8 mm/m	N/A	N/A
Maximum solids load	N/A	N/A	N/A	60 mg/l *	60 mg/l *
Odour control	Yes	Yes	Yes	Yes	Yes

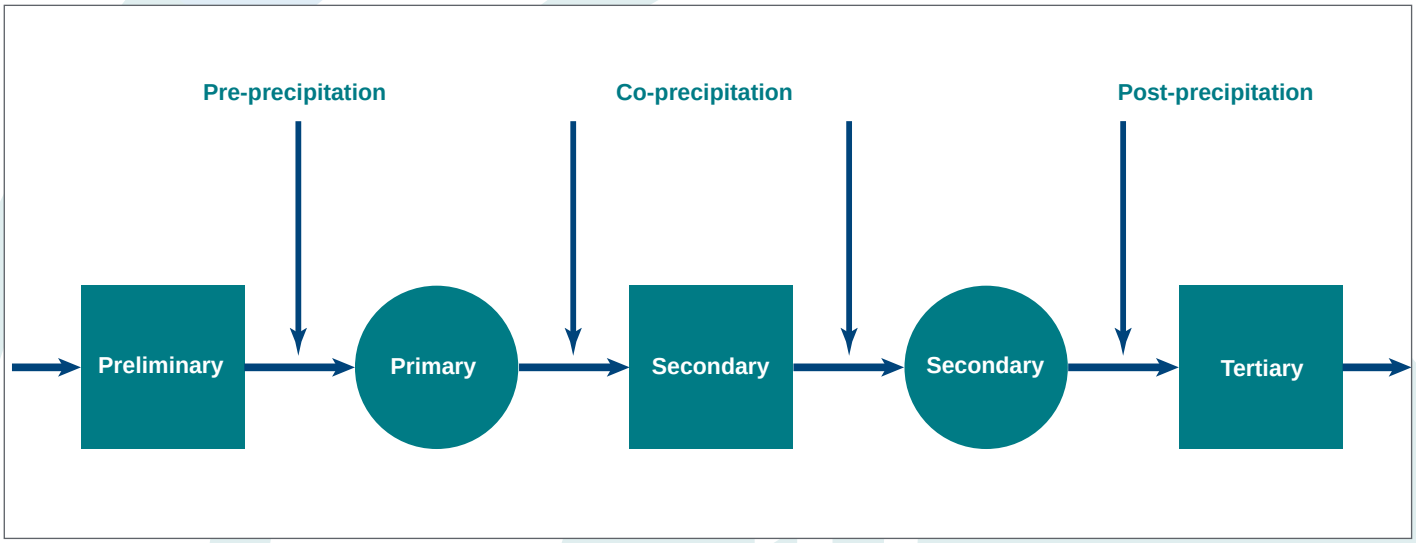
* effluent standards quoted to 95%ile

Dosing regimes

When it comes to chemical dosing a combination of dosing points is recommended, either a pre- or co-precipitation dosing point into the primary or secondary stage treatment, as well as a post precipitation stage onto the DynaSand® filter. Normally ferric sulfate is used, but ferric chloride or aluminium sulfate work just as well or better in some cases, with selection being based on site chemistry and economics.

It is important to dose the correct amount of chemical for the phosphate which is normally in the ratio of 3 to 5 mg/l of ferric per mg/l phosphorus. However the concentration varies throughout the day and with the weather, so it is therefore advisable to perform load-based dosing so there is always sufficient chemical to precipitate the phosphorus, but not too much that the filters become overloaded with solids.

With the DynaSand® Deni additional dosing is required to provide a carbon source for the biomass. This normally takes the form of a well-regulated easily digestible compound such as methanol or ethanol. Again, correct dosing is vital: too little and there isn't enough carbon for the biomass to denitrify the nitrates, too much and there is a risk of BOD effluent failure.



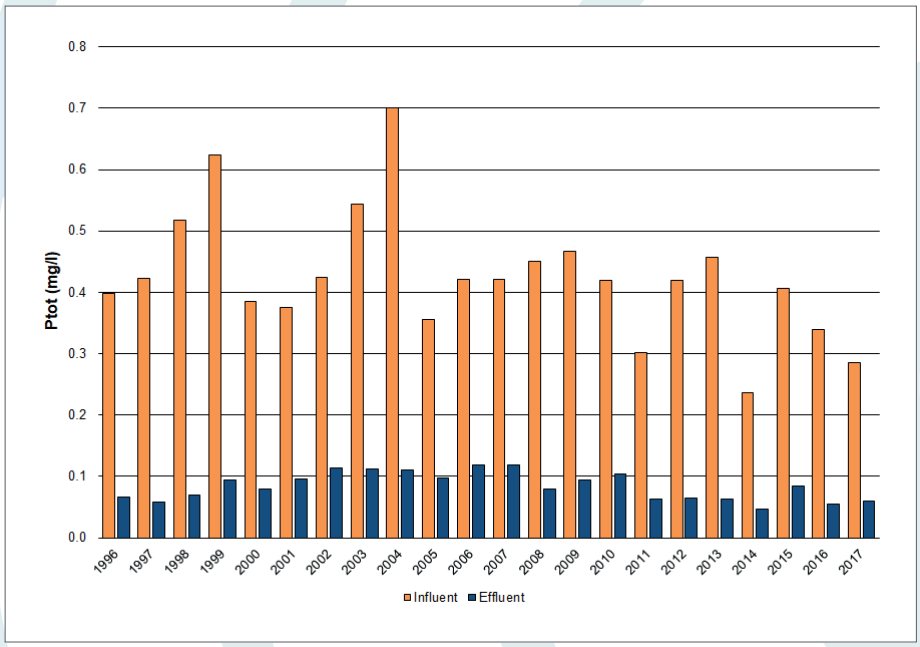
Verification of technology

DynaSand® 20 Year Track Record in Växjö, Sweden Proves Ability for Phosphorus Removal

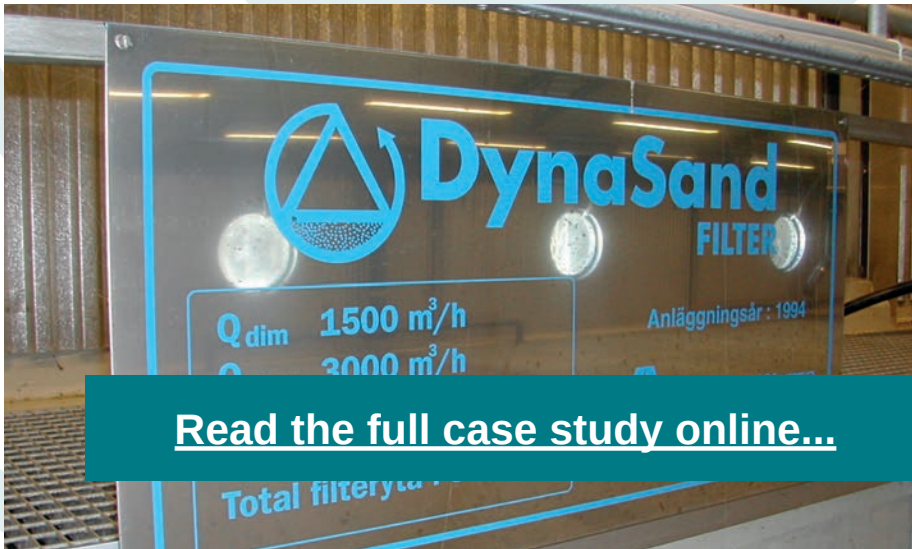
The Växjö Sundet sewage treatment plant was built just outside Växjö, Sweden in 1994. Phosphorus removal at Växjö Sundet is achieved in two stages to meet the plants outlet requirement of 0.2 mg/l of total phosphorus. The first stage is located after the initial mechanical treatment and before the biological stage. Chemicals, generally iron sulfate, are added to precipitate phosphorus into flocs which are then removed by sedimentation.

The second phosphorus removal stage is filtration through continuous sand filters. The filter stage is the last element in the treatment process chain and consists of 60 DynaSand® filters. The 60 DynaSand® filters are divided into six separate treatment lines, each equipped with 10 DynaSand® units housed in concrete structures. The total filter area is 300 m^2. The filtration rate in Växjö Sundet is 5 to 10 m per hour.

The DynaSand® filters consistently deliver substantially lower phosphorus content than the 0.2 mg/l consent, with effluent concentrations regularly below 0.1 mg/l.



Graph showing annual average of P_{tot} in the inlet to/outlet from the tertiary DynaSand® filters over the years 1996-2017.

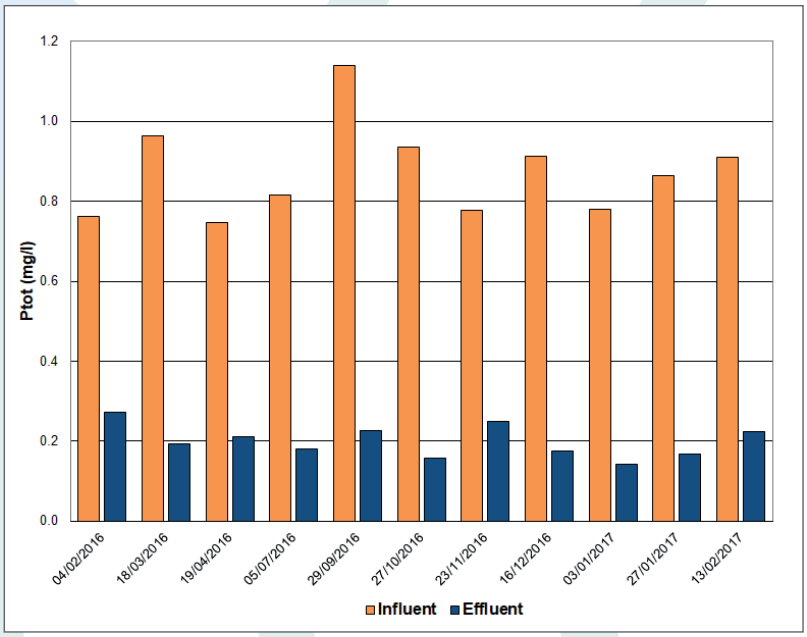


Read the full case study online...

DynaSand® Oxy Filters in Year-Long Trial at Watton Water Recycling Centre, UK

The DynaSand® Oxy trial at the Watton plant consisted of six DynaSand® DS7000 (2m) Oxy filters, commissioned over the winter of 2015. A full 13-month trial was performed from the beginning of February 2016 to the end of February 2017. The trial was commissioned by Steve Riley of Anglian Water. Ferric sulfate was dosed at the inlet to the filters via a static mixer at 5 mg/l Fe to precipitate phosphorus salts for removal. Changes to plant operation were minimised.

When the plant is operating optimally without other external factors causing an increase in the phosphorus load to the filters, the results demonstrate that an effluent total P concentration of 0.20 mg/l can be achieved.



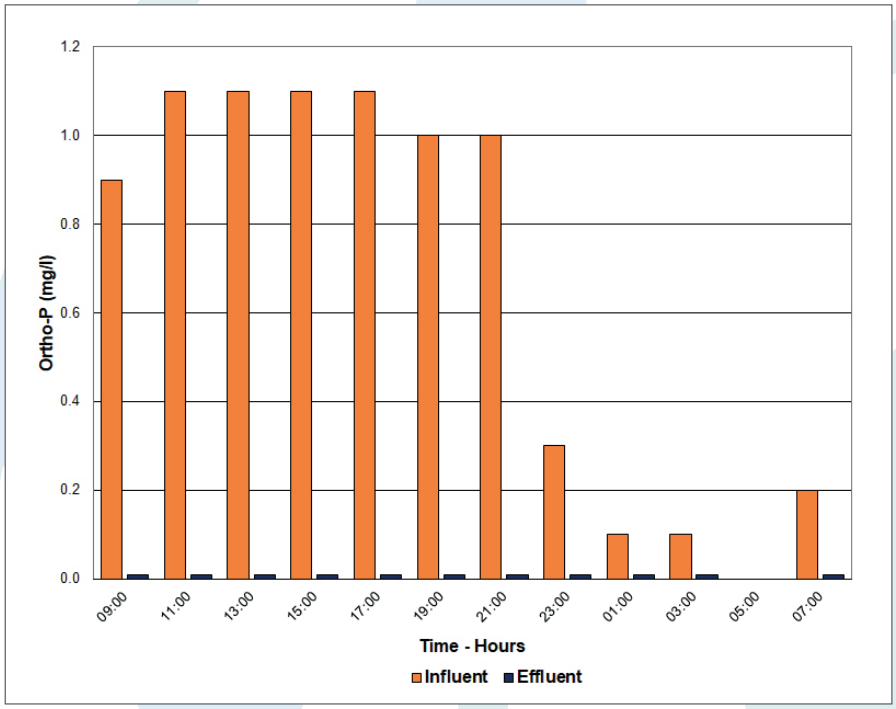
The trials demonstrated effective reductions of both phosphorus and ammonia to 0.2 mg/l and 0.7 mg/l respectively.

Read the full case study online...

DynaSand® Deni Filters Provide Phosphorus Removal at a Wastewater Treatment Plant in Ratzeburg, Germany

In 2005 a new wastewater treatment plant was opened in Ratzeburg, in the Lauenburgischer National Park, Germany.

To help meet specific outlet restrictions for discharge a filtration stage undertaken by four DynaSand® Oxy filters and six DynaSand® Deni vertical continuous sand filters was installed to provide removals of TSS, BOD, ammonia, nitrate and phosphorus.



One day's example test data from January 1999.

EU reporting in 2012 and 2014 has shown effluent N levels at 7.47 mg/l and 7.57 mg/l (93.6% and 92.4% reductions) respectively.[1]

EU reporting in 2012 and 2014 has shown effluent P levels at 0.24 mg/l and 0.17 mg/l respectively, corresponding with >98% reductions. [1]

This shows that the units are still operating well below the originally stipulated consent levels

(1)

http://uwwtd.oieau.fr/Germany/treatment-plant/detpsh53100/2014

Read the full case study online...

DynaDisc® delivers phosphorus removals for Pietersaari WWTP, Finland

Two CDC2435/35 DynaDisc® filters were installed at the Pietersaari WWTP in Finland. As well as removing TSS the filters are also removing phosphates.

The design flow to the DynaDisc® filters is 2200 m^3/h and contains a maximum phosphorus content of 0.75 mg/l. The target for total phosphorus removal is to 0.25 mg/l or less. Sampling to date has shown phosphorus levels of less than 0.1 mg/l.

Typical Flow and Discharge Limits	
Design Flow	2200 m^3/h
P Discharge Limit	0.25 mg/l or less
TSS Discharge Limit	5 mg/l

Results of Sampling	
TSS at inlet	15-25 mg/l
Total P at inlet	0.75 mg/l
TSS at outlet	6-7 mg/l
Total P at outlet	0.06 - 0.08 m/gl

The DynaDisc® filters demonstrated effective reductions of Total phosphorus down to 0.063 mg/l and TSS down to 6 mg/l.

Read the full case study online...

Visit hydro-int.com/hydro-p-removal to learn more about how the DynaSand® range of sand filters can help you meet your phosphorus removal objectives.

Contact:

+44 (0)1353 645700
wastewater@hydro-int.com

We are a global company who provide advanced products, services and expertise to help municipal and industrial customers to improve the way they process, treat and manage water.